Contaminant Migration Modeling of Lead and Heavy Water within C-Reactor (105-C) (U)

Tetra Tech, Inc. Atlanta, GA

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EXECUTIVE SUMMARY

In-Situ Decommissioning (ISD) alternatives are under consideration for deactivation and decommissioning (D&D) of the C-Reactor building. To evaluate ISD alternatives, a GoldSim® contaminant fate and transport model was developed that allowed for stochastic analysis of each source and ISD alternative under consideration. GoldSim® is a general-purpose simulator that allows the evaluation of complex processes in a deterministic or stochastic environment. In the context of this modeling effort, the GoldSim® model was used to evaluate ISD alternatives to help decision makers evaluate the preferred path forward based on the estimated impact to groundwater and surface water for each source. The model takes into account site specific data, events (e.g., building collapse), processes (e.g., solubility-limited release of radionuclides), and flow paths.

The specific sources within the C-Reactor building simulated in this study are:

- 20-ton Process Area lead source;
- 230-ton Crane Maintenance Area lead source;
- Deionizer trailer lead source; and
- Heavy water Tank 204 and Tank 205.

Multiple ISD alternatives are considered for each of these sources that involve adding an engineered roof or cap, relocating source materials, adding grout layers within buildings, and grouting materials in place.

Vadose-zone modeling was not conducted as part of this work. Rather, infiltration rates developed based on modeling conducted for the F Area using the UNSAT-H simulator were used for the various ISD alternatives and performance time periods. Other inputs and assumptions are taken from prior studies at the Savannah River Site (SRS) as well.

The GoldSim® model produces predictions of groundwater concentrations at various points of assessment (POAs) downgradient from the source areas: 1-meter (m) from each source area, at the C-Area fence-line, and at the location where groundwater discharges to surface water at Castor Creek. Model-generated predictions are then compared against performance objectives (POs) as applied during relevant compliance periods (CPs) that extend to 10,000 years. Simulations were extended up to 1,000,000 years to estimate peak concentrations of certain constituents. GoldSim® includes calculation of radioactive decay and ingrowth of radionuclide species. The list of contaminants modeled includes radionuclides (with half-lives longer than three years), lead, and other non-radioactive inorganics identified in prior inventory analyses (plus long-lived progeny).

In summary, POs will be met for all radionuclides present at C-Reactor source areas for every combination of ISD alternatives and POAs. This outcome is due to the low inventory (i.e., current activity/mass) of radionuclides currently present within C-Reactor building and time to failure of the moderator water containment combined with short half-lives for radionuclides, such as tritium, Co-60, and Cs-137.The start of the predictions within the GoldSim® model is January 1, 2044 based on the proposed closure date, but the start of the radionuclide decay is based on the sample dates associated with the inventory estimates. Decaying the existing activity of radionuclides to the closure date reduces the inventory estimates even further.

Lead is the only simulated constituent that exceeds POs for the four ISD alternatives that are proposed for the 230-ton Crane Maintenance Area lead source at the 1-m and C-Area boundary POAs. Lead concentrations exceed the PO of 15 micrograms per liter (µg/L) (USEPA Maximum Contaminant Level [MCL]) between approximately 100,000 to 600,000 years for the No Action, Grout and Cap Source, and Engineered Roof scenarios where the source is located in the Crane Maintenance Area. The peak concentration at the 1-m POA occurs between 311,000 and 312,500 years at a concentration of approximately 301 µg/L for the No Action, Grout and Cap Source, and Engineered Roof ISD scenarios. Lead concentrations also exceeds the PO between approximately 100,000 to 600,000 years, but the peak concentration occurred at an earlier time (301,500 years) and at a higher concentration (350 µg/L) for the Moved Source, and Grout Subgrade and Engineered Roof scenario at the 1-m POA. Lead concentrations also exceeded the PO at the C-Area boundary POA for all four 230-ton Crane Maintenance Area lead source scenarios from approximately 33 to 37 µg/L, where the highest lead peak concentration of 37 µg/L also occurred with the Moved Source, Grout Subgrade, and Engineered Roof scenario. This higher peak lead concentration and faster travel time of lead for the Moved Source, Grout Subgrade, and Engineered Roof scenario is due to the source being moved from the Crane Maintenance Area to a location area where the 20-foot and 40-foot floor are present within the reactor building below the moved source. The moved source is left on the ground level, and the area below ground surface is grouted. In the other three 230-ton Crane Maintenance Area lead source ISD scenarios, the lead source resides in the Crane Maintenance Area that is underlain by multiple layers of sand and clay in the vadose zone. The lead K_d values for sand and clay are large. When the lead is moved, the area under the source consists mostly of grout and concrete; these materials have much smaller lead K_d values. Thus, there is less sorption of lead in the vadose zone for the Moved Source, Grout Subgrade, and Engineered Roof scenario compared to the other 230-ton Crane Maintenance Area lead source scenarios where the source still resides in the Crane Maintenance Area. Based on the GoldSim® modeling, it is recommended that the lead source remain in the Crane Maintenance Area.

For the 20-ton Process Area lead source, the maximum concentration of lead occurs at the end of the simulation (approximately 4 µg/L at the 1-m POA at 100,000 years), which is below the PO of 15 µg/L (MCL). For the deionizer trailer lead source and the heavy water Tank 204 and 205 sources, all of the simulated concentrations are significantly less than the POs or are zero.

The model presented in this report is a good framework for evaluating groundwater concentrations resulting from discharge at the C-Reactor building and can be a useful tool for SRS. Even though the modeling effort presented in this report contains many simplifying assumptions, they are conservative, and the model results show no exceedances of POs at the Castor Creek POA.

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LIST OF ACRONYMS AND ABBREVIATIONS

μg/L	micrograms/liter
ACP	Area Completion Projects
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	centimeter
CM	crane maintenance
COC	contaminants of concern
CP	compliance period
d	day
D&D	deactivation and decommissioning
DI	deionizer
DIT	deionizer tank
DOE	Department of Energy
EPA	Environmental Protection Agency
ft	feet
g	gram
g/cm^3	grams per cubic centimeter
HW	heavy water
in	inches
ISD	in-situ decommissioning
K_d	soil-water distribution coefficient
kg	kilogram
L	liter
LS	lead source
m	meter
MCL	maximum contaminant level
mg	milligrams
mL/g	milliliter per gram
mol/L	mole per liter
mm	millimeter
NRC	Nuclear Regulatory Commission
NSL	no solubility limit
PA	process area
pCi/L	picocuries per liter
PNNL	Pacific Northwest National Laboratory
PO	performance objectives
POA	point of assessment
POTM	peak of the means
PV	pore volume

RCRA	Resource Conservation and Recovery Act
SME	subject matter expert
sq	square
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
SZ	saturated zone
USEPA	United States Environmental Protection Agency
UTRA	Upper Three Runs Aquifer
VZ	vadose zone
yr	year

1.0 BACKGROUND INFORMATION AND OVERVIEW

The historical Savannah River Site (SRS) mission was to reprocess reactor core material to produce plutonium and tritium for nuclear weapons, enriched uranium for weapons and military and commercial use, and numerous specialty isotopes such as plutonium-238 (Pu-238) for thermoelectric generators. The 105-C Reactor, located in C Area (Figure 1.1), achieved criticality in 1955 and was shut down for maintenance in 1985. The reactor was then placed on cold standby in 1987 and shut down permanently (SRNS 2011).

The C-Reactor building (Figure 1.2) is currently used to store tritiated-moderator water, or heavy water, in tanks. Lead shielding material was also stored at the C-Reactor building to support cask car refurbishment. Both the heavy water and lead remain in the C-Reactor building.

Heavy water in the C-Reactor building is contained within two steel tanks: Tank 204 and Tank 205. These tanks are located within the Storage Tank Room below and between the C-Reactor Personnel and Disassembly Areas. The volume of heavy water within Tank 204 and Tank 205 is approximately 60,567 liters (L) and 102,206 L (16,000 and 27,000 gallons), respectively. A portion of the Tank 204 heavy water will be transferred to Tank 205 at closure, resulting in a final volume of approximately 8,500 gallons in Tank 204 and 34,500 gallons in Tank 205.

Lead is assumed to remain within the C-Reactor building at closure. The total lead inventory is approximately 250 tons, with 20 tons of shielding located throughout the Process Area, which will remain in place. The remaining 230 tons is currently located in the Crane Maintenance Area and in the Stack Area of the C-Reactor building. Finally, there is a 20-ton lead shielded tank from a de-ionizing trailer that is assumed to be relocated within the C-Reactor building adjacent to the Crane Maintenance Area for closure.

This report documents the evaluation of potential future releases from the C-Reactor building based on In-Situ Decommissioning (ISD) alternatives under consideration for final closure. The emphasis for this analysis is on groundwater protection.

1.1 GoldSim® Modeling Approach Overview

To evaluate ISD alternatives, a GoldSim® contaminant fate and transport model for each source location was developed that allowed for stochastic analysis of each ISD alternative. GoldSim® is a general-purpose simulator that allows the evaluation of complex processes in a deterministic or stochastic environment. In the context of this modeling effort, the GoldSim® model was used to evaluate ISD alternatives to help decision makers evaluate the preferred path forward based on the estimated impact to groundwater and surface water for each source. The model considers site specific data, events (e.g., building collapse), processes (e.g., solubility-limited release of radionuclides), and flow paths. The strength of GoldSim® is that it allows a complex system to be evaluated, sensitive parameters to be identified, and uncertainty to be quantified. The GoldSim® process model is generally one-dimensional and requires important simplifying assumptions. As such, detailed heterogeneity in the flow system, variations in boundary conditions, and changes along a flow path are not necessarily captured. However, most detailed process models cannot include all potential pathways in a single model and include uncertainty in a manner that allows reasonable computational effort for the purposes of evaluating decommissioning.

The modeling effort focused on developing a reasonable model of the ISD alternatives to evaluate the fate and transport of contaminants of concern (COC) for each of the C-Reactor building source locations with respect to regulatory requirements. When additional source concentration information is available, the inventory can be updated within the model.

The general approach used for modeling at C-Area was developed for each proposed ISD alternative and was based on the F-Area modeling approach (Tetra Tech 2020, 2021). Those reports established an approach to perform contaminant fate and transport modeling for the selected constituents and alternatives that produce meaningful results. The approach is based on a review of available documentation pertaining to the inventory, layout, expected contaminant transport from the C-Reactor building, and previous modeling efforts of ISD alternatives at other areas [i.e., P/R-Reactors (Council 2008, 2009); Building 235-F (Taylor and Phifer 2012, Hamm et al. 2019); F-Area Hardened Facilities (Tetra Tech 2021)].

The water flow into the C-Reactor building is defined as the infiltration rate, which was determined by modeling infiltration through concrete, grout, and other material properties that are included in the ISD scenarios. The infiltration modeling was conducted using the UNSAT-H model (Fayer 2000) for the F-Area Hardened Facilities (Tetra Tech 2021). The infiltration rates developed were assumed to be the same for C-Area and then are incorporated into GoldSim® via switches that indicate whether the infiltration is based on the intact, partial, or collapsed conditions of the building, depending on elapsed time and the ISD scenario.

The ISD scenarios for each source area were constructed as slice models through the contaminant source(s), that were aligned with the principal flow direction in the saturated zone, based on particle traces using the groundwater flow model for the C-Area Groundwater Operable Unit (WSRC 2000). Vertically stacked cells in the GoldSim® slice models were used to simulate concrete slabs, clayey soil horizons, and sandy soil horizons of the unsaturated zone, or vadose zone, where present. After vertical transport through the vadose zone, the COCs originating from the C-Reactor building enter the saturated zone, travel horizontally in the direction of groundwater flow, and ultimately discharge to the perennial surface-water interface points of assessment (POAs) along Castor Creek (Figure 1.3). These pathways are simulated using GoldSim® aquifer pathway elements.

1.2 Objectives and Performance Criteria

The ISD alternatives were developed by Savannah River Nuclear Solutions (SRNS) Area Completion Projects (ACP) Engineering for deactivation and decommissioning (D&D) of the C-Reactor building, considering groundwater protection, public/industrial worker protection, and cost. The analyses presented within this report are limited to the ISD scenarios developed and the data currently available. Groundwater protection is assessed by comparing predicted groundwater concentrations. The comparison of the results among ISD alternatives allows evaluation of the ability of each ISD to reduce and/or delay the release of COCs to groundwater, such as radionuclides and metals from the C-Reactor building.

This report presents the model-predicted groundwater concentrations at different locations and over different evaluation time periods. The definitions of Performance Objectives (POs) are based on information in EPA guidance documents, United States Department of Energy (DOE) guidance, and personal communication with Savannah River Nuclear Solutions (SRNS) staff (personal communication, Willey 2023).

- Points of Assessment (POAs): 1 meter beyond the outside perimeter of the C-Reactor building in the direction of groundwater flow (USEPA 2009, 2014), C-Area boundary, which is the distance from the outside perimeter of the C-Reactor building to the C-Area boundary (i.e., fence) in the direction of groundwater flow (personal communication, Willey 2023, (DOE 1999, DOE 2017), and perennial surface water interface where there is a groundwater-surface water interface (i.e., Castor Creek). (USEPA 2009, 2014). These three POAs are shown in Figure 1.3.
- Compliance Periods (CPs): 1,000-year, 100,000-year, and 1,000,000-year time windows beyond the start of predictions, which is assumed to be January 1, 2044 (personal communication, Willey 2023, NRC 2000). The 100,000-year and 1,000,000-year CP options are included to determine the peak concentrations of lead; and
- Concentrations: lead, gross alpha, beta-gamma, total uranium, and radium-226 plus radium-228. The Peak of the Means (POTM) at the designated POA is used to summarize results.

Table 1.1 lists the POs used for this project.

Table 1.1 Performance Objectives for C-Reactor Building Analyses

Media	Pathway	Performance Criteria	Points of Assessment	Stochastic Assessment
Groundwater	Lead	15 µg/L	1 meter, C-Area Boundary, Seepage Boundary	POTM
Groundwater	Gross alpha	15 pCi/L	1 meter, C-Area Boundary, Seepage Boundary	POTM
	Radium (Ra-226 + Ra-228)	5 pCi/L	1 meter, C-Area Boundary, Seepage Boundary	POTM
	Uranium	30 µg/L	1 meter, C-Area Boundary, Seepage Boundary	POTM

POTM – Peak of the Means is computed for each point of assessment for 1,000 realizations

The performance criteria for the POAs selected for drinking water MCLs are listed in Table 1.1 and the location of the POAs are shown on Figure 1.3. The locations for the groundwater POAs were defined based on a particle-tracking based groundwater flow model simulation that computed the advective flow path from C-Reactor building to its discharge point on Castor Creek (WSRC 2000).

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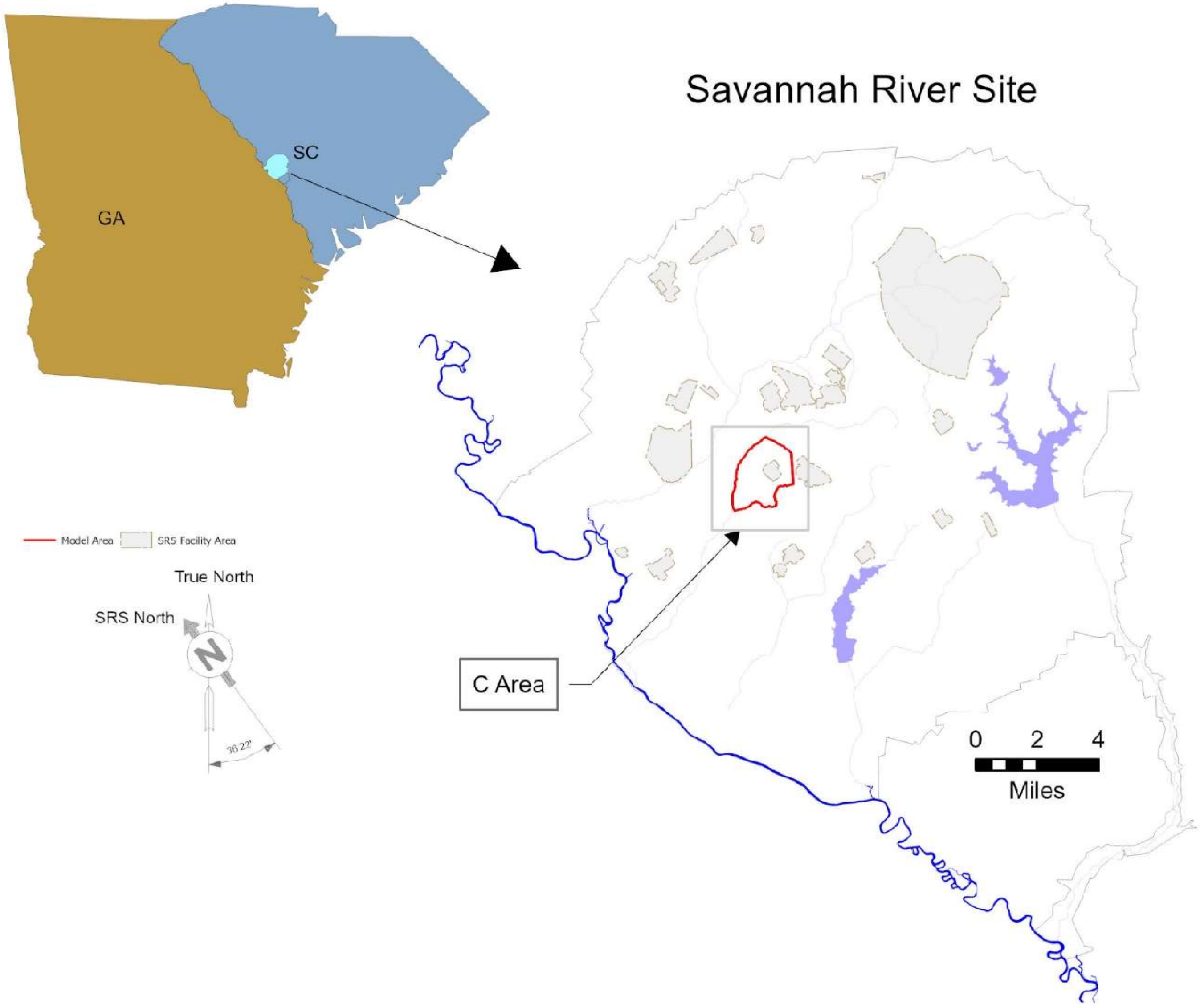

Figure 1.1 Location of C Area within SRS.

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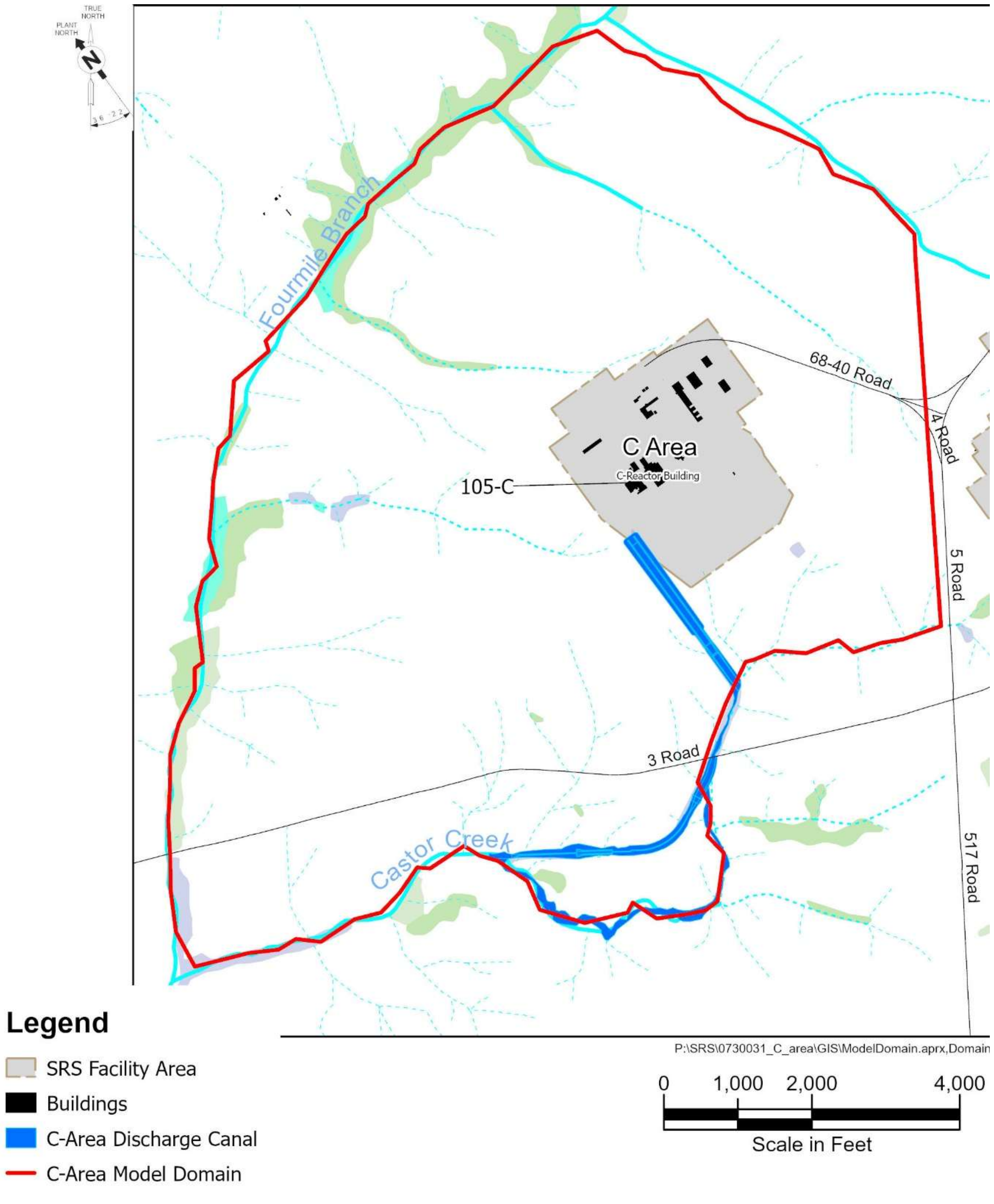

Figure 1.2 Location Map of Major Streams and C-Reactor building (105-C).

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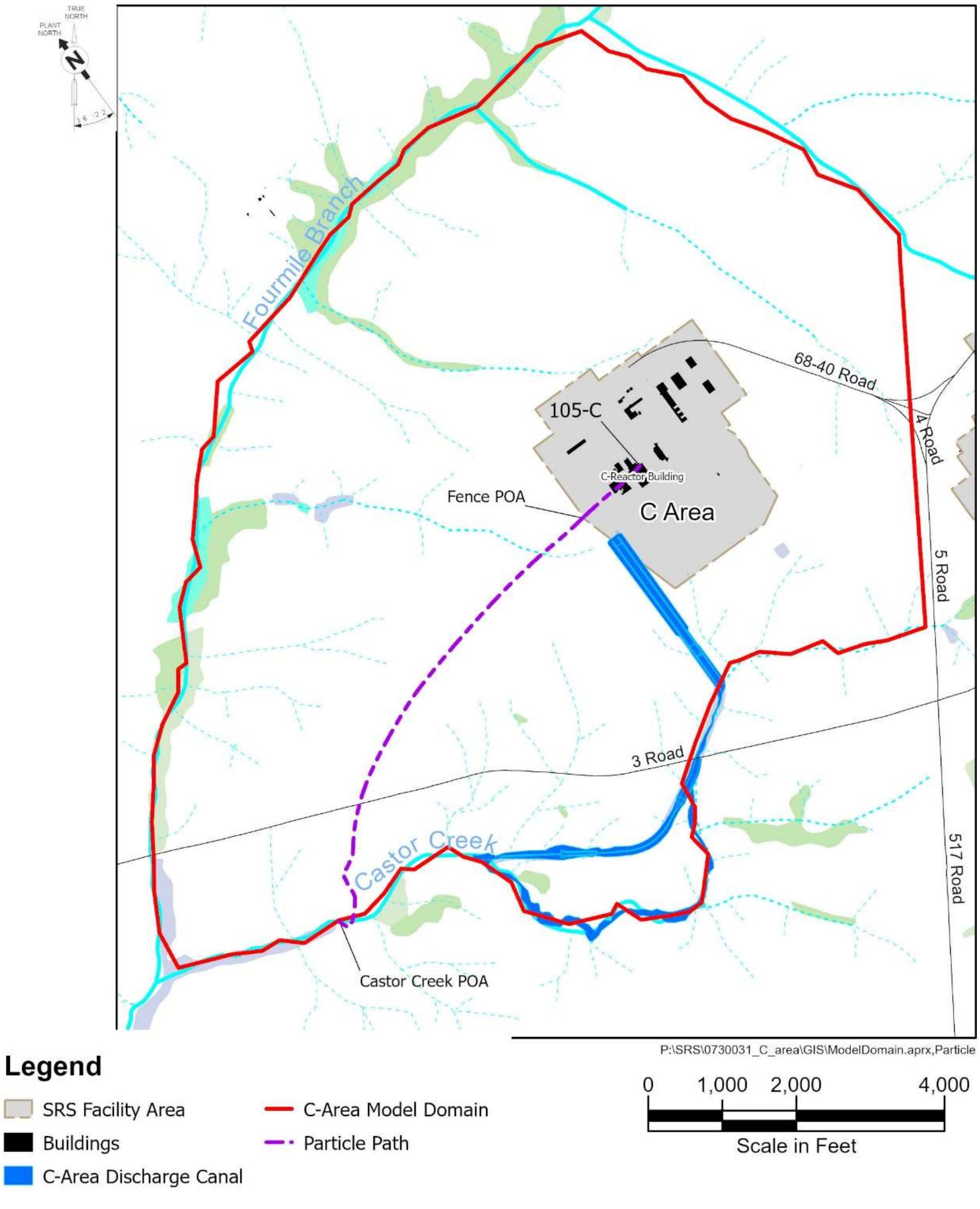

Figure 1.3 Locations of Groundwater POAs for Buildings in the C Area and particle track from C-Reactor building.

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2.0 MODELING APPROACH

This section discusses overall model approach, the material properties of the concrete, grout, and engineered roof in the model, and the ISD scenarios that were considered for each source area being evaluated. Overall, the approach is conservative. In some cases, the analysis maybe overly conservative and alternative approaches to represent the inventory based on the results are discussed in the results and/or summary sections.

The fate and transport modeling of the ISD scenarios was conducted in GoldSim® to evaluate radionuclide and lead transport from the various source areas within the C-Reactor building. The GoldSim® model utilized the radioactive transport module that includes the ability to simulate decay chains, ingrowth, and engineered barriers. Inputs to the model were based on the best estimates of the inventory (personal communication, Willey 2023), inputs from the C-Area groundwater model (WSRC 2000), SRS Geochemical Database (Kaplan 2021), the Hydraulic Property Data Package (Phifer et al. 2006), previous flow and transport models developed by and for SRS (Council 2008, 2009; and Hamm et al. 2019), and infiltration rates (Tetra Tech 2021) to estimate recharge fluxes for different ISD alternatives. The best estimate for the inventory is the value determined based on actual measurements, estimated material inventories, differences in material inventories, and/or information available from site operations. These inventory values can be updated in the GoldSim® model in the future, as they are refined. The modeling analysis assumes that closure occurs in 2044, but the start of the radionuclide decay is based on the date associated with the inventory estimates (e.g., as provided in personal communication, Willey 2023).

Infiltration rates were calculated using a vadose zone model developed with UNSAT-H (Fayer, 2000). UNSAT-H was developed at Pacific Northwest National Laboratory (PNNL) to estimate recharge fluxes for scenarios pertinent to waste disposal facilities. The flow model in UNSAT-H is a one-dimensional analysis based on the Richards equation for water flow in vadose zone soil. The model developed considered infiltration, evaporation, and vapor transport. Plant transpiration and soil heat flow were not simulated as part of the present analysis. The infiltration evaluation focused on the infiltration into intact buildings with and without ponded conditions on flat roofs, and ponding after roof failure. This evaluation considered two different types of ordinary concrete for existing structures and a high performance concrete to be used in the design of a sloped engineered roof that would allow water to drain off of the roof, prevent vegetative growth and extend the time before the roof is anticipated to collapse. The infiltration modeling details and results are presented in Tetra Tech (2021) for the F-Area Hardened Facilities. An assumption is made that the infiltration rates developed for F Area are applicable to C Area. The infiltration modeling analysis provides the infiltration rates incorporated into the GoldSim® probabilistic evaluation of contaminant migration from the C-Reactor building.

2.1 GoldSim® Modeling Overview

The GoldSim® models for the fate and transport modeling are one-dimensional (1-D) representations of flow and contaminant transport through each of the source areas in the C-Reactor building, the vadose zone below each source area, and within the aquifer(s) in the saturated zone to discharge locations at the surface water interface. GoldSim® does not numerically solve equations for flow through porous media. Instead, it utilizes a user prescribed flow (i.e., infiltration rate) or advective flux to move the mass along the defined path, which in the simulations would be defined by UNSAT-H, PORFLOW, and/or MODFLOW modeling. GoldSim® solves transport equations for the COCs, and models radioactive decay and ingrowth explicitly. Contaminant transport through the building and vadose zone are controlled by infiltration rates, material properties, soil-water distribution coefficients (K_d), and solubility limits. The mass flux is then distributed into the saturated zone. The flow within the saturated zone is controlled by the Darcy velocity, aquifer length, area, dispersivity, and material properties. In GoldSim®, the aquifer element simulates the average concentration at the downgradient end of an aquifer segment due to advection and longitudinal dispersion since it does not include three-dimensional variability. The plume function in GoldSim® applies a multiplier to the aquifer element that accounts for spatial variation through eleven input arguments, such as transverse and vertical dispersivity. The parameter inputs can be represented deterministically or stochastically. The strength of GoldSim® is to evaluate the uncertainty associated with transport of radionuclides and metals to help determine the range of potential outcomes that can be used to help evaluate the best approach for decommissioning.

2.2 Material Properties

2.2.1 Concrete and Grout

An evaluation of hydraulic properties for cementitious materials for E-Area and Z-Area classified the material into low quality, ordinary, and high-quality concrete (Phifer et al. 2006) and included a review of literature at the time of the report. For the F-area GoldSim® model analysis, it was determined that the quality of the extant concrete for the F-Area buildings being evaluated would be considered "ordinary" concrete (Jolin 2020). The same assumption was made for the C-Reactor building model. The best-fit properties from Schneider et al. (2012) and the data from Rockhold et. al. (1993) were used for ordinary concrete to bracket the saturated hydraulic conductivities selected by Phifer et al. (2006). The hydrologic material properties selected for the concrete are described in the infiltration memo in Tetra Tech (2021).

The dry bulk density and porosity properties for concrete used in the model was represented as truncated normal distribution with a mean of 2.11 g/cm^3 and 0.184, respectively. The water content of the concrete was represented by a triangular distribution with a most likely value of 0.164.

For ISD scenarios that included grout, ordinary concrete properties were used in the model. Data previously reviewed on grout properties (Schneider et. al. 2012 and Rockhold 1993) indicate the range of potential properties could vary up to six orders of magnitude, and that the concrete properties fell within the range reviewed. Use of the concrete properties to represent grout was discussed and agreed upon with SRS as a conservative approach (personal communication, Willey 2023).

2.2.2 Engineered Roof

The proposed C-Reactor building engineered roof would be similar to what has been suggested for Building 235-F (Hamm et al. 2019) and the R- and P-Reactor ISD evaluations (Council 2009, 2008). The engineered roof design would utilize a high-performance concrete that has a hydraulic conductivity approximately three orders of magnitude lower than the concrete used during construction of the building, which results in a lower infiltration rate. For the C-Reactor model, ordinary concrete was also used for the engineered roof as a conservative assumption. In addition, the engineered roof is sloped to allow drainage, prevents vegetative growth, and contains a crystalline waterproofing to help heal concrete cracks and extend the time before the roof is anticipated to collapse. The time for the collapse of the existing Building 235-F roof was determined by a subject matter expert (SME) to be 100 to 200 years without the engineered roof, and greater than 1,000 years with the engineered roof (Carey 2020; see Tetra Tech 2021). The time for collapse of the C-Reactor building was also assumed to be 100 to 200 years without the engineered roof and between 1,000 years and 1,400 years (mean of 1,200 years) with the engineered roof.

2.3 Simulations of ISD Alternatives

The ISD alternatives vary for each source area. This section discusses the information and data that were included in modeling each of the scenarios. Also, each ISD alternative has an abbreviated name (XX-YY-S#), where *XX* describes the source type (LS = lead source, DIT = deionizer tank, HW = heavy water), *YY* describes the source location (PA = process area or CM = crane maintenance) and *S#* describes the scenario number (S1, S2, etc.). An example would be LS-PA-S1 for 20-ton lead source in process area for scenario S1. Source location is not specified for the deionizer tank and Tanks 204 & 205 scenario names since these sources do not have scenarios where the source is moved. After preliminary modeling was conducted and reviewed, a decision was made to remove a subset of the ISD alternatives that were originally being considered (personal communication, Willey 2023). This decision resulted in non-consecutive numbering of the ISD alternatives below.

2.3.1 20-ton Process Area Lead Source

Figure 2.1 illustrates the ISD alternatives simulated for the 20-ton Process Area lead source in the process area of the C-Reactor building. The 20 tons of lead that remains in the process area is shielding from the reactor assembly.

The two ISD scenarios for the 20-ton Process Area lead source as shown in Figure 2.1 are:

- No action (LS-PA-S1) and
- Grout all space below ground surface and add an engineered roof (LS-PA-S3).

The 20 tons of lead in the process area are comprised of miscellaneous lead shielding, such as bricks, sheets (coated and uncoated), and blankets (personal communication, Willey 2023). Lead inventory (mass) in the process area was estimated by inspection of pictures taken during vessel maintenance in March 2007 (Figure 2.2) and by visual observation from the doorway to the process area by engineers with process knowledge of the lead shielding forms used. Conservative estimates for the various forms of lead shielding were used to calculate a lead mass in the process room. Although the lead inventory for the process area is estimated, it is based on the best available information at the time of this effort, and was conservative in approach.

An accurate account of all lead location and layout in the process area was not available at the time of this modeling effort; therefore, a conservative approach was used, assuming the lead sources form an annulus around the former reactor assembly. This is consistent with a majority of the lead inventory in the process area, which was left in place surrounding the reactor vessel assembly (Figure 2.2). Using dimensions from the process area drawings (Sheet W134619 and W134620), the area of annulus was estimated to be 27.9 m^2 (300 ft^2). Using this source area, the source width was estimated to be approximately 6 m (19.5 ft) in the GoldSim® model.

Since the thickness of lead shielding can vary due to it being in the form of a brick, sheet, or blanket, an estimate for lead thickness was developed for use in GoldSim® to determine lead corrosion rates in air or water. An approximate lead thickness of 5.74 cm (2.26 inches) was estimated from using the mass of lead (20 tons), estimated source area (27.9 m^2), and the density of lead (11.34 g/cm^3).

For the different scenarios, infiltration is applied at the top of the C-Reactor building, and it infiltrates through either the concrete roof or engineered roof. As water infiltrates, the concrete will degrade over time. After the water passes through the concrete roof there is an air space in the facility. Although it is shown on Figure 2.1 to represent the building structure, the air space is not modeled. The infiltration from the bottom of the roof was applied to the top of the source area, which assumes the infiltration rate has reached equilibrium. Ponding on the roof is not modeled directly in GoldSim®, however ponding is accounted for in the infiltration rate evaluation (Tetra Tech 2021).

The 20-ton Process Area lead source rests on a 4-foot thick concrete floor. The timing for concrete degradation of the slabs is dependent on the volume of water that passes through all of the slabs, even after the roof collapse. Below the 20-ton source area, it was assumed the -20 foot and -40 foot levels of the C-Reactor building extend beneath the process area room (personal communication, Willey 2023). The -20 and -40 foot level voids are grouted in Scenario LS-PA-S3 (Figure 2.1).

There are assumed to be no radionuclides present in the 20-ton Process Area lead source scenarios. Only elemental lead is simulated. The simulations were conducted for a period of 100,000 years.

2.3.2 230-ton Crane Maintenance Area Lead Source

Figure 2.3 illustrates the three ISD alternatives being considered for the 230-ton lead source in the Crane Maintenance Area of the C-Reactor building. The 230 tons of lead that remain in the Crane Maintenance Area included approximately seventy B-12 containers totaling 230,800 pounds (115 tons), 15 defense program casks totaling 68,500 pounds (34.3 tons), and approximately 17,000 pounds (8.5 tons) of miscellaneous reactor lead shielding (totaling 316,300 pounds [158 tons]). Each B-12 container was weighed and the known tare weight subtracted to determine the lead weight. The defense program cask lead weight was determined by reviewing the design specifications and engineering drawings. Miscellaneous lead shielding weight was estimated based on observations, records, and process knowledge. This lead inventory was assumed to be consolidated within the Crane Maintenance Area for the modeling effort.

At the time modeling inputs were being determined, it was unclear what the path forward was for the Cask Car CD-5 located in the C-Reactor Transfer Bay. In a conservative effort, initial source estimates assumed lead shielding from CD-5 (140,400 pounds [70.2 tons]) would also be consolidated within C-Reactor's Crane Maintenance Area, although this would not be practical considering size and configuration of CD-5. The additional lead mass (total for all inventory of

230 tons) did not result in groundwater impacts within the compliance period based on the model results and therefore the conservative assumption was retained.

The four ISD scenarios for the 230-ton Crane Maintenance Area lead source as shown in Figure 2.3 are:

- No action (LS-CM-S1),
- Grout and cap the source in place (LS-CM-S2A),
- Add an engineered roof (LS-CM-S3A), and
- Move B-12 boxes, defense caskets and T-pin caskets adjacent to the crane maintenance area, grout all space below ground surface and add an engineered roof (LS-CM-S3B).

The No Action Scenario (LS-CM-S1, as shown in Figure 2.3) represents the current location of the B-12 boxes, defense caskets, and T-pin caskets as shown in cross section on Sheet W134592 and plan view on Sheet W134714. The dimensions of the B12 boxes, defense caskets, and T-pin caskets are shown on Container Technology Industries Reference Sheet 970-342-01, Sheet W134583 and Sheet W154034, respectively. Based on the dimensions of various containers and assuming that on average the B-12 boxes are stacked two high; a footprint of approximately 83.6 m^2 (900 ft^2) was used for the source area.

The Grout and Cap the Source in Place Scenario (LS-CM-S2A, as shown in Figure 2.3) assumes that 1.6 meters (6 ft) of grout is added above the various containers. The B-12 boxes are supported on three risers to allow lifting (<10 cm), but the space below the boxes was considered insignificant for modeling and the model represented the source directly on the floor. The total height of the B-12 boxes is 78.1 cm (30.75 in), so two boxes would be 1.56 m (5.125 ft) tall, and an additional 6 feet of grout was placed over the source.

The Engineered Roof Scenario (LS-CM-S3A, as shown in Figure 2.3) is the same as the no action scenario but has an engineered roof added, which will delay the length of time before infiltration enters the building based on the time to collapse of the engineered roof.

In the final 230-ton Crane Maintenance Area lead source Scenario (LS-CM-S3B, as shown in Figure 2.3), the source is moved from the Crane Maintenance Area to an adjacent area where the 20-foot and 40-foot floor are present within the reactor building. In this scenario, the source is left on the ground level, and the area below ground surface is grouted and an engineered roof is used.

For the different 230-ton Crane Maintenance Area lead source scenarios, infiltration is applied at the top of the C-Reactor building, and it infiltrates through either the 5-ft thick concrete roof or engineered roof. As water infiltrates, the concrete will degrade over time. After the water passes through the existing concrete roof or engineered roof, there is an air space in the facility for all four ISD alternatives. Although it is shown on Figure 2.3 to represent the building structure, the air space is not modeled. The infiltration from the bottom of the roof was applied to the top of the sources or grout, which assumes the infiltration rate has reached equilibrium. Ponding on the roof or sources was not modeled directly in GoldSim®, however is accounted for in the infiltration evaluation (Tetra Tech 2021).

The 230-ton Crane Maintenance Area lead source rests on a 4-foot thick concrete floor. The timing for concrete degradation of the slab is dependent on the volume of water that passes through the slab, even after the roof collapse. Below the 230-ton lead source area is approximately 21 m (69 ft) of vadose zone soils consisting of sands and clays in all scenarios except LS-CM-S3B when the source is moved to an area of the building where the -20 foot and -40 foot levels of the C-Reactor building are present. In that scenario the void space between the 4-foot concrete floors is filled with grout and the base of the building has a 10-foot concrete slab, which is above approximately 7 m (23 ft) of sandy and clayey vadose zone soils.

The radionuclide inventory associated with the 230-ton Crane Maintenance Area lead source was divided into two sources: one that originated from the canyon and one that came from non-canyon sources; the inventories for these two sources were provided by SRS (personal communication, Willey 2023). The radionuclide inventory provided includes the relative abundance and activity for americium (Am)-241, barium (B)-137, carbon (C)-14, curium (Cm)-244, cesium (Cs)-137, cobalt (Co)-60, tritium (H-3), iodine (I)-129, nickel (Ni)-59, neptunium (Np)-237, plutonium (Pu)-238, Pu-239, Pu-240, Pu-241, Pu-242, technetium (Tc)-99, uranium (U)-233, U-234, and U-235.

Based on the relative abundance present, SRS reduced the list of radionuclides to be simulated to only include Cs-137, H-3, I-129, Pu-239, Pu-241, Tc-99, U-234, and U-238. The start of the decay was February 1, 2001 for the canyon source and October 1, 2000 for the non-canyon source in GoldSim®. The two sources were combined at the 1-m POA. The scenario also included elemental lead (Pb), aluminum (Al), iron (Fe), chromium (Cr), silver (Ag), and cadmium (Cd). The initial inventory was provided in an excel spreadsheet by SRS (personal communication, Willey 2023). The 230-ton Crane Maintenance Area lead source simulations were run for 1,000,000 years.

2.3.3 Deionizer Trailer Lead Tank Source

Figure 2.4 illustrates the ISD alternatives simulated for the deionizer (DI) trailer lead tank that is currently stored in N Area of SRS but is being included in the C-area ISD alternatives. If moved, the deionizer tank and lead shielding would be moved to a location near the Crane Maintenance Area in the C-Reactor building (Sheet W134592), but different from the 230-ton Crane Maintenance Area lead source ISD scenario where the source moves. The DI tank contains approximately 8,517 L (2,250 gallons) of resin with radionuclides and 20 tons of lead shielding. The model assumes that the tank would be placed in an upright position because the DI tank sheet (D Sheet, Cream City Boiler Company, BPF21140-1 Rev 4) indicates there are no ports on the side that would allow the second ISD to be considered.

The two ISD scenarios for the deionizer trailer lead tank source as shown in Figure 2.4 are:

- No action (DIT-S1) and
- Grout space within tank and add an engineered roof (DIT-S3).

The No Action Scenario (DIT-S1), as shown in Figure 2.4 represents the proposed location for the deionizer trailer and lead shielding. The tank would sit on a 1.2-m (4-foot) concrete floor. Below the floor is a 1.1-m (3.5-foot) gap filled with sand, a 2.1-m (7-foot) concrete slab, and then approximately 17.7 m (58 ft) of alternating layers of sand and clay in the vadose zone. The other scenario (DIT-S3) considers both adding grout inside the tank and adding an engineered roof. The subsurface geometry remains the same for both scenarios.

A resin sample was collected from the tank on September 19, 2022 and was used as the basis for the DI Tank inventory. Constituents present in the resin include Al, Am-241, antimony (Sb), barium (Ba), C-14, Cd, calcium (Ca), Cr, Co-60, Cs-137, Fe, magnesium (Mg), manganese (Mn), mercury (Hg), nickel (Ni), potassium (K), Pu-238, Pu-239, Pu-240, Ag, sodium (Na), strontium (Sr)-90, Tc-99, H-3 and zinc (Zn). SRS reduced the list of constituents to be simulated to only include Al, Cd, Cr, Cs-137, Fe, Sr-90, H-3, Pu-238, Ag, and Tc-99. The start of the radionuclide decay was September 19, 2022 in GoldSim®. The 20-ton lead shielding was also modeled. The resin in the tank was modeled using clay sorption/desorption properties as an analog. The simulations were run for 100,000 years.

2.3.4 Heavy Water Tank 204 and Tank 205

Figure 2.5 illustrates the ISD alternatives simulated for the heavy water Tank 204 and Tank 205 for the Storage Tank Area.

The two scenarios for the heavy water tanks are:

- No action (HW-S1),
- Solidify source in the tank and grout around the tanks (HW-S4),

The No Action Scenario (HW-S1, as shown in Figure 2.5) represents the current location of the heavy water source. The tanks sit on a 3.3-m (10.75-foot) thick concrete floor, which is 7.3 m (24 feet) below the 1.2-m (4-foot) concrete floor at grade. Below this 3.3-m (10.75-foot) thick concrete floor is 6.4 m (21 ft) of vadose zone.

Tank 204 has a source volume of approximately 60, 567 L (16,000 gallons) and Tank 205 has a source volume of approximately 102,206 L (27,000 gallons). The radionuclide concentration in the tanks represent the result from either Tank 204 or Tank 205 that had the highest decay corrected result, which represents the most conservative inventory at this time. The total activity is calculated for H-3, Co-60, and Cs-137, which is then used to calculate the inventory mass for use in GoldSim®.

The second scenario evaluated (HW-S4, as shown in Figure 2.5) assumes that the distribution between the two tanks changes, and Tank 204 has approximately a source volume of 32,176 L (8,500 gallons) and Tank 205 has approximately a source volume of 130596.7 L (34,500 gallons). This scenario also assumed the 7.3-m (24 ft) of air space around the tanks are grouted and the water sources inside the two tanks are solidified using AQUASET (Fluid Tech, LLC). The properties of AQUASET were assumed to behave like clay (personal communication, Willey 2023).

The heavy water Tank 204 and 205 source inventories provided by SRS were decay corrected to February 2, 2023, which was used in GoldSim® as the start date for radioactive decay. The simulations were run for 1,000 years starting from the decommission date of January 1, 2044.

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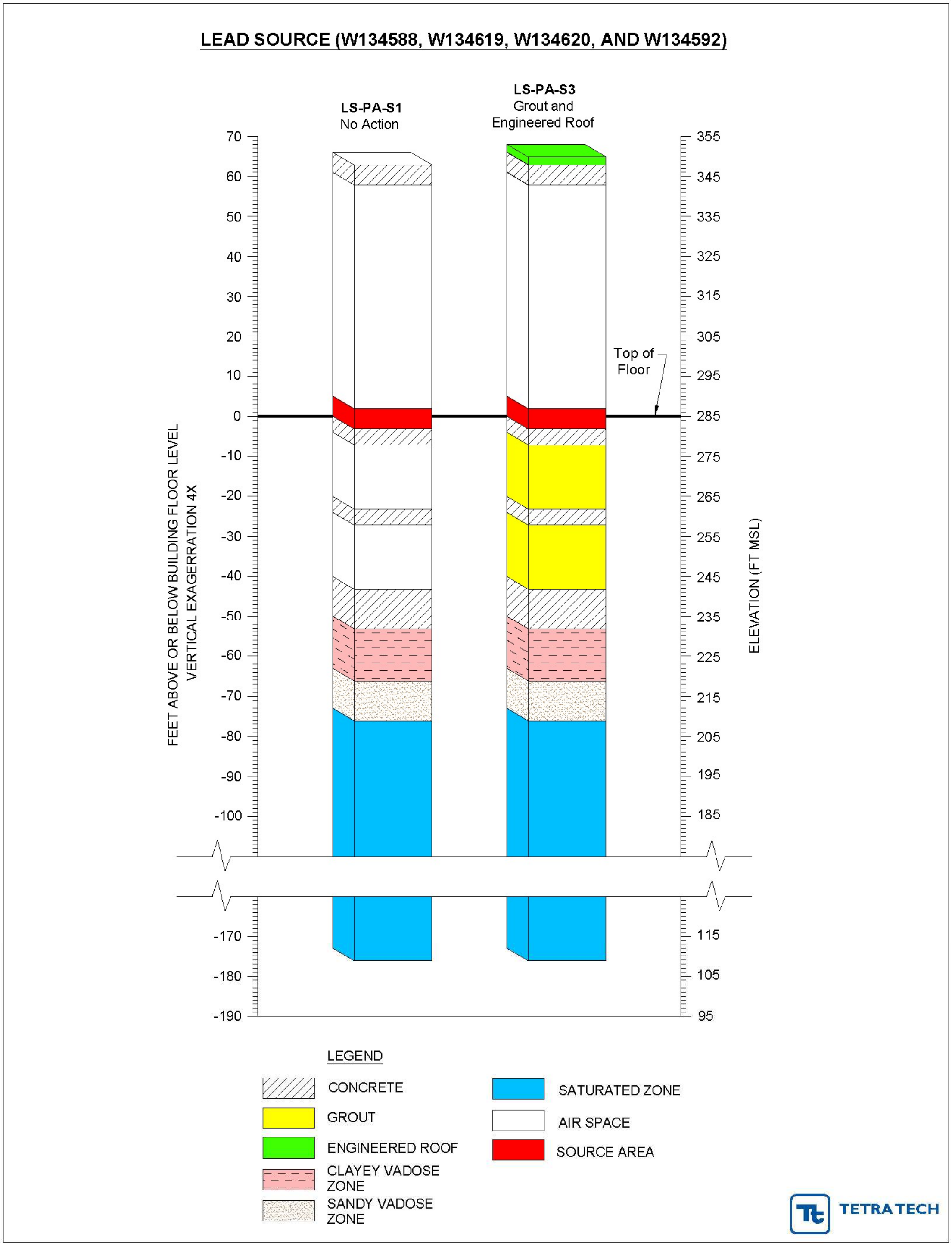

Figure 2.1 20-ton Process Area Lead Source Conceptual Model

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Figure 2.2 Process Area Lead in Photo Taken During Maintenance Activities in March 2007

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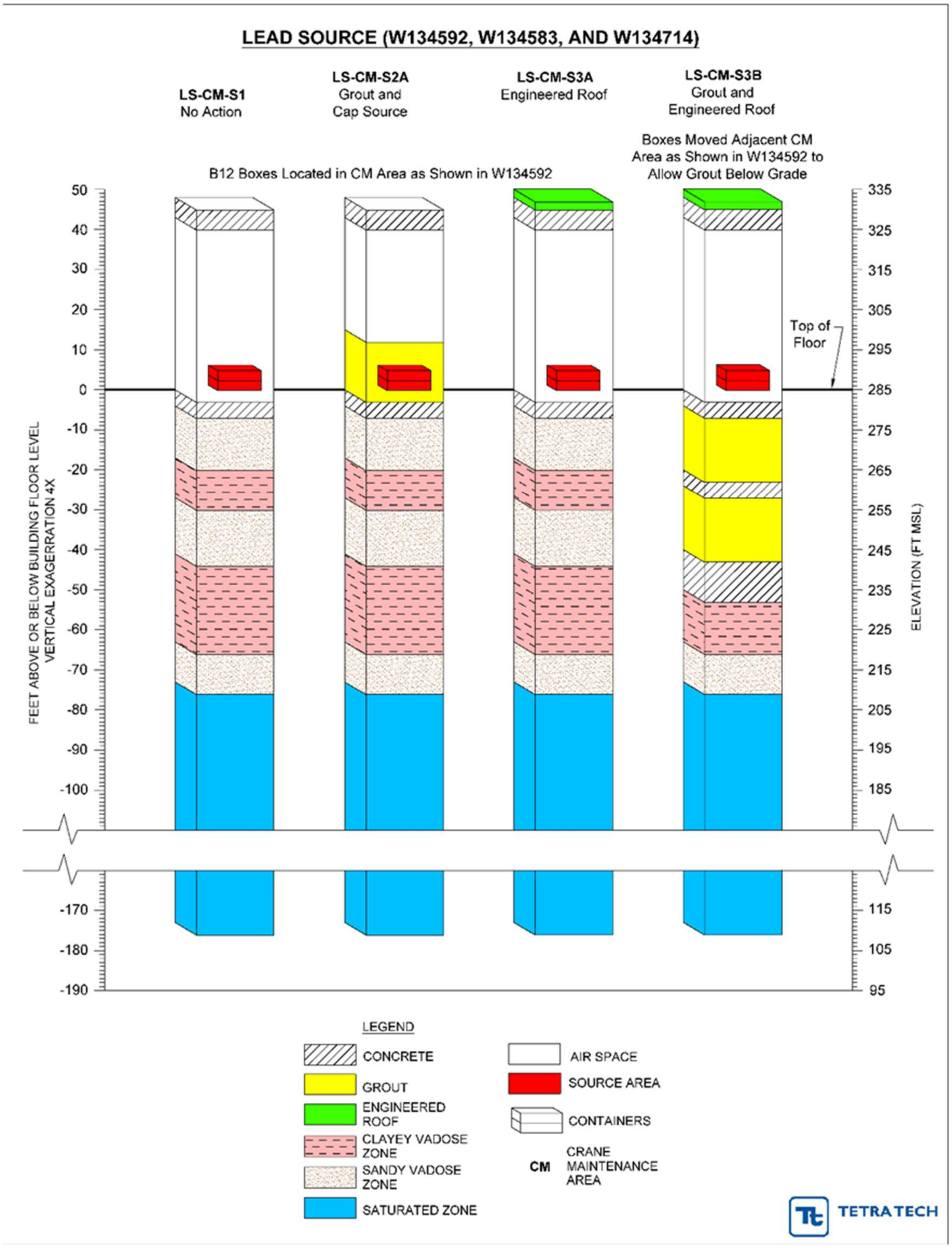

Figure 2.3 230-ton Crane Maintenance Area Lead Source Conceptual Model.

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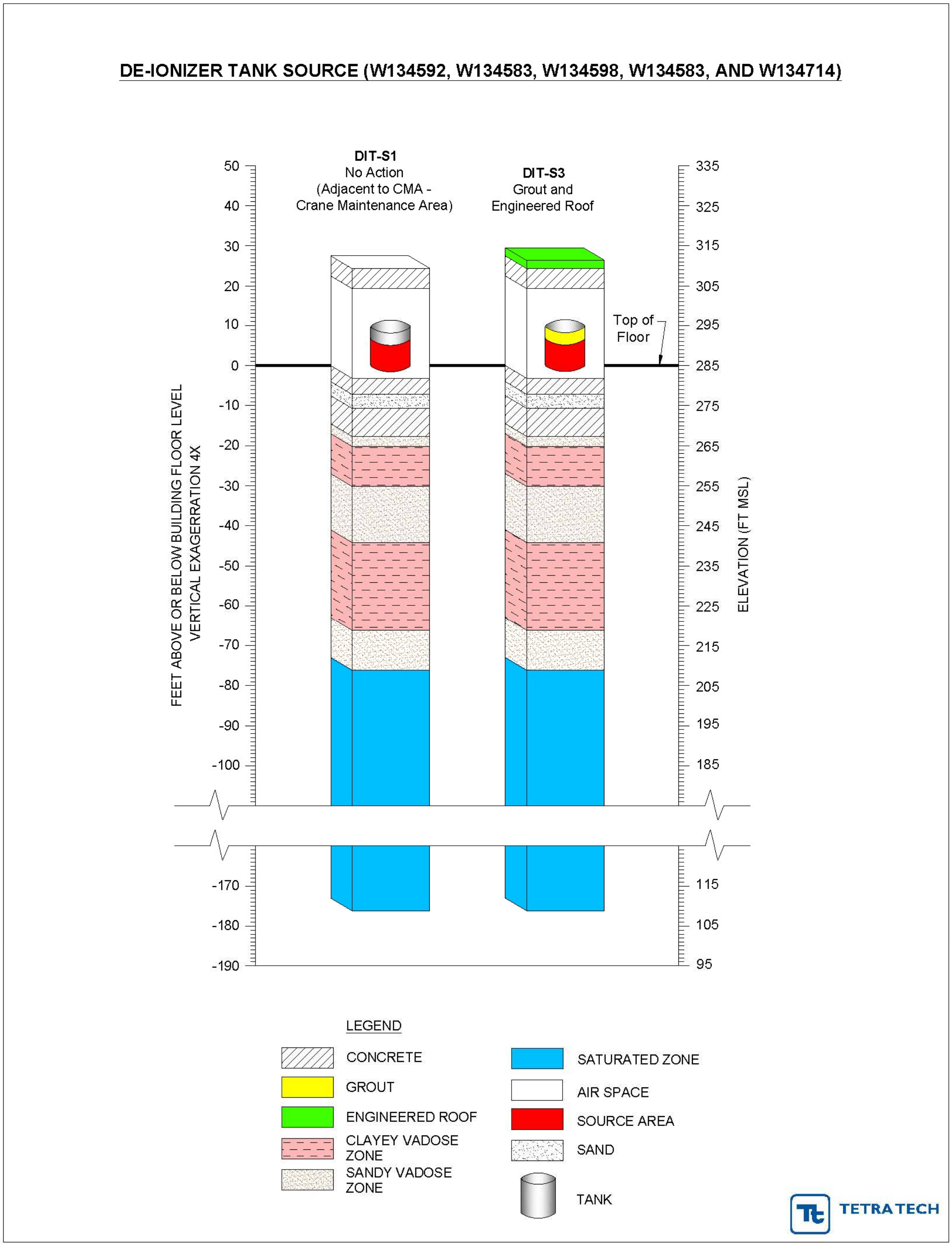

Figure 2.4 Deionizer Tank Conceptual Model

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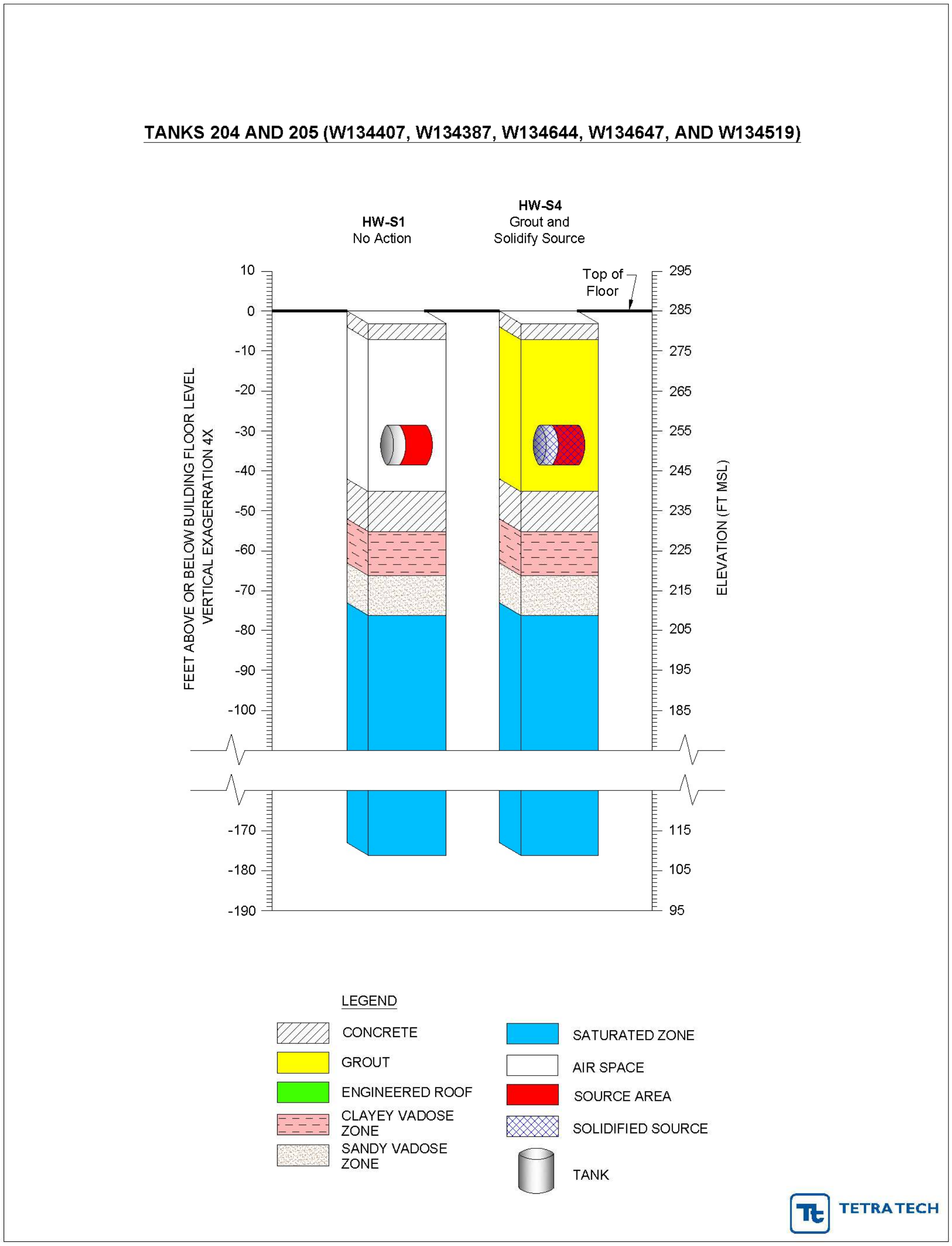

Figure 2.5 Tanks 204 & 205 Conceptual Model

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3.0 MODEL INPUTS

3.1 Infiltration

Infiltration was based on an analysis performed with the UNSAT-H simulator for ISD scenarios for F-Area Hardened Facilities (Tetra Tech 2021). The modeling analysis showed that for the scenarios considered, the basal flux is dependent on the type of concrete, whether there are ponded conditions, and the thickness of the layers. The scenarios evaluated show a range of basal flux values through building materials with an average of 0.00046 cm/yr (0.00018 in/yr; Tetra Tech 2021). This value is less than the 0.0013 cm/yr (0.0005 in/yr) estimated by Jones and Phifer (2006). For the C-Reactor building, the assumption was made to use the same infiltration rates that were used for the F-Area Hardened Facilities. Table 3.1 shows the infiltration rate used for the C-Reactor building ISD scenarios based on whether the existing roof or an engineered roof is used in the scenario. For the partially degraded scenario, it is assumed that water ponds on the floor below the roof. In the GoldSim® model, the *Pore Volume* selector is used to determine the ISD scenario, which defines the thickness of the concrete and grout and the infiltration rate based on the time period. This information is then used internally within GoldSim® to determine the number of pore volumes that pass through the concrete that determines the age of the concrete as discussed in Section 3.7.1.

Table 3.1 Infiltration Rate Used to Calculate the Number of Pore Volume Flushes

ISD	Time Period (years)	Degradation Stage	Infiltration Rate (cm/yr)	Infiltration Rate (inches/year)
Existing Roof	0 – 150	Intact	4.6×10^{-4}	1.8×10^{-4}
	150 – 750	Partial	6.1×10^{-3}	2.41×10^{-3}
	>750	Full	38	15
Engineered Roof	0 - 1200	Intact	4.6×10^{-4}	1.8×10^{-4}
	1200 – 1700	Partial	6.1×10^{-3}	2.41×10^{-3}
	>1700	Full	38	15

3.2 Vadose Zone

The GoldSim® model of each C-Reactor source simulates transport through 1-D streamtubes from the source term layer (i.e., waste layer or contaminant zone) downward through grout (if present), concrete floor slabs, and then through the vadose zone. The regions above the source term were accounted for implicitly in pore volume calculations, which modify the infiltration rate through concrete roofs, steel containers and/or grout. The pore volume calculations control several model variables in the vadose zone including porosities, dry bulk densities, and distribution coefficients (K_d) that are sensitive to the concrete degradation stage based on variations in pH and physical degradation.

Water flow through the C-Reactor building is caused by precipitation entering the building, which is modified through switches in GoldSim® that trigger intact, partial, or collapsed roof infiltration rates depending on elapsed time and ISD scenario. The lead and steel sources experience different rates of corrosion based on the infiltration rate. The presence of grout encasing the source term influences radionuclide transport by altering the chemical environment, which alters the K_d values for radionuclide transport within the grout and concrete while these materials are intact. Degradation of grout and concrete are modeled by calculating the number of pore volume flushes of water that go through these materials. This includes modifications of K_d, porosity, and infiltration rate as the grout/concrete is degraded.

Cell pathway elements were used to simulate each facility's source term(s) in GoldSim®. One-dimensional groundwater-transport "slice models" were constructed in each facility through the source term(s) and align with the principal flow direction in the saturated zone based on MODFLOW-MODPATH based modeling (WSRC 2000). Aquifer pathway elements were used in GoldSim® to simulate vertical transport through concrete slabs and clayey/sandy soil horizons of the vadose zone. Each GoldSim® aquifer pathway element represents a material where K_d and solubility limits are applied for governing COC transport.

Based on the lithology encountered at boring CRG-5 (Figure 3.1) (personal communication, Willey 2023), the thicknesses of the sand and clays horizons of the vadose zone near the C-Reactor building are as follows:

- Sand 1: 5.2 m (17 ft) thick
- Clay 1: 3.0 m (10 ft) thick
- Sand 2: 4.3 m (14 ft) thick
- Clay 2: 6.7 m (22 ft) thick
- Sand 3: 3.0 m (10 ft) thick

The total vadose zone thickness is approximately 22 m (73 feet) from land surface to the water table. However, this total thickness was reduced at each source area where the C-Reactor building has subgrade levels (Table 3.2).

Table 3.2 Vadose-zone Layer Thicknesses in Feet by Source Area for No Action Alternatives

Source	Sand 1	Clay 1	Sand 2	Clay 2	Sand 3	Total Thickness
230-ton Crane Maintenance Area lead source	13	10	14	22	10	69
20-ton Process Area lead source	NP[1]	NP	NP	13	10	23
Deionizer tank	2.5	10	14	22	10	58.5
Tank 204 & Tank 205	NP	NP	NP	11	10	21

Notes:
1. NP: Not Present

Longitudinal dispersivity in the concrete slabs and in the clayey and sandy vadose zone horizons was assumed to be 0.1 meters (Hamm et al. 2019). Transverse dispersivity was assumed to be negligible in the vadose zone.

3.3 Saturated Zone

After transport through the vadose zone, the contaminants originating from the C-Reactor building enter the saturated zone and travel horizontally in the Upper Three Runs Aquifer (UTRA). The transport pathway ends at the Castor Creek seepage interface POA from the UTRA. Since there are differences in the number of cells where the inventory is placed (e.g., Canyon and Non-Canyon waste streams), and the number of source terms (230-ton Crane Maintenance Area lead, 20-ton Process Area lead, DI Tank, and heavy water Tanks 204 and 205), multiple consistent aquifer models were simulated using GoldSim®. The same modeling elements were utilized in these separate aquifer models.

The number of aquifer segments that were used in GoldSim® to transport contaminants through the saturated zone to the POAs were determined from MODFLOW model results. Each aquifer pathway element in GoldSim® is defined by the following inputs: aquifer length (along direction of flow), aquifer cross-sectional area, longitudinal dispersivity, number of cells, infill medium, and fluid saturation.

The saturated-zone thickness was assumed to be 100-feet thick which is the approximate thickness of the UTRA beneath the C-Reactor building. The aquifer width was assumed to equal to the width of the source area. Saturated-zone sand Darcy flow velocities were assumed to be 50 ft/year based on the Building 235-F GoldSim® model (Hamm et al. 2019). Longitudinal dispersivity in the saturated zone was assumed to be 0.1 meters for the 1-m POA and 10 meters for the C-Area boundary and Castor Creek POAs, which were the values used in the Building 235-F model (Tetra Tech 2021). Transverse dispersivity was assumed to be 5 feet or 1.5 meters in the saturated zone (Hamm et al. 2019).

Groundwater concentrations at aquifer element endpoints representing POAs were compared to regulatory standards (Table 3.9) through graphs and tables.

3.4 Source Terms and Inventories

The primary source terms for the modeling effort are derived from the radionuclides that are present at the source areas and lead from shielding, metals as appropriate, resin within the deionizer trailer, and the use of AQUASET to solidify the water within Tanks 204 and 205. Clay was used as an analog for the resin. Properties for the solidification of the heavy water in the tanks were based on properties provided by the AQUASET manufacturer.

The radionuclide, lead, and resin inventories for the C-Area Reactor building sources are best estimates provided by SRS using inventory tracking, process knowledge, sample data, and radiological screening (personal communication, Willey 2023). Radioactivity concentrations for the de-ionizer tank resin and the moderator water in Tanks 204 and 205 were based on actual measurements performed previously by SRS. The source term for modeling was placed into a conceptual representation of the possible ISD scenarios in a conservative manner based on an evaluation of the presumed location of the inventories. The representation of the source terms is discussed in detail in Section 2.3, which includes the assumptions made and potential impact on modeling.

Tables 3.3 through 3.7 show the radionuclide, lead, and other inorganics inventories in each of the C-Reactor building source areas. Table 3.8 contains radionuclide half-lives, long half-life radionuclide or stable daughter-products, specific activity, and gross alpha contributors. Table 3.9 lists modeled inorganics, gross alpha, radium-226 plus radium-228 and uranium isotopes, and their respective USEPA Primary Drinking Water Standard.

GoldSim® simulates truncated decay chains for radionuclides input to the model and evaluates the transport of parent and daughter products assuming secular equilibrium. For parent/daughter products such as Np-237/U-233, Th-230/Ra-226, U-233/Th-229, and U-234/Th-230, where some of these daughters do not attain secular equilibrium within the 100,000-year model duration, the daughter product was modeled explicitly in GoldSim®.

Table 3.3 Canyon 230-Ton Radionuclide and Lead Inventories

Constituent	Inventory (g)
Cs-137	2.19E-04
H-3	3.55E-06
I-129	4.77E-05
Pu-241	1.77E-02
Tc-99	2.47E-02
U-234	3.61E-01
Lead	1.034E+08

Notes:
Inventory located in Crane Maintenance Area. Sample date was 2/1/2001.

Table 3.4 Non-Canyon 230-Ton Radionuclide and Lead Inventories

Constituent	Inventory (g)
Cs-137	2.48E-06
H-3	7.02E-12
I-129	2.35E-09
Pu-241	8.17E-06
Tc-99	7.70E-06
U-234	5.59E-02
Lead	1.038E+08

Notes:
Inventory located in Crane Maintenance Area. Sample date was 10/1/2000.

Table 3.5 20-Ton Lead Inventory

Constituent	Inventory (g)
Lead	1.814E+07

Notes:
Inventory located in Process Area.

Table 3.6 Deionizer Tank Radionuclide and Lead Inventories

Constituent	Inventory (g)
Ag	0.186
Al	1251
Cd	0.145
Cr	15.58
Cs-137	5.03E-09
Fe	804.57
H-3	5.39E-11
Pu-238	4.60E-08
Sr-90	6.03E-08
Tc-99	2.02E-06
Lead	1.814E+07

Notes:
Inventory located in Crane Maintenance Area. Sample date was 9/19/2022.

Table 3.7 Tank 204 & 205 Radionuclide Inventories

Constituent	Inventory (g)
Co-60	2.47E-07
Cs-137	2.72E-06
H-3	3.24E+01

Notes:
Inventory located in Storage Tank Room. Sample date was 3/21/1996 and decay corrected to 2/2/2023 by SRS.

Table 3.8 Modeled Radioactive Isotopes, Properties, and Gross Alpha Contributors

Species	Half-Life (years)	Daughter Product[1]	Specific Activity (Ci/g)[2]	Gross Alpha Contributor[3]
Ac-227	2.18E+01	Pb (stable)	7.24E+01	Yes
Am-241	4.32E+02	Np-237	3.43E+00	Yes
Co-60	5.27E+00	Ni (stable)	1.13E+03	No
Cs-137	3.02E+01	Ba (stable)	8.66E+01	No
H-3	1.23E+01	He (stable)	9.62E+03	No
I-129	1.57E+07	Xe (stable)	1.77E-04	No
Np-237	2.14E+06	Pa-233[1]	7.05E-04	Yes
Pa-231	3.28E+04	Ac-227	4.73E-02	Yes
Pb-210	2.22E+01	Pb (stable)	7.67E+01	No
Pu-238	8.77E+01	U-234	1.71E+01	Yes
Pu-239	2.41E+04	U-235	6.23E-02	Yes
Pu-241	1.44E+01	Am-241	1.06E+02	No
Ra-226	1.60E+03	Pb-210	9.89E-01	No
Sr-90	2.88E+01	Y-90[1]	1.38E+02	No
Tc-99	2.11E+05	Ru (stable)	1.71E-02	No
Th-229	7.34E+03	Bi (stable)	2.13E-01	Yes
Th-230	7.54E+04	Ra-226	2.06E-02	Yes
U-233	1.59E+05	Th-229	9.65E-03	Yes
U-234	2.46E+05	Th-230	6.21E-03	Yes
U-235	7.04E+08	Pa-231	2.16E-06	Yes
U-238	4.47E+09	U-234	3.34E-07	No

Notes:
1. Pa-233 and Y-90 are not modeled since their half-lives are less than 3 years
2. Specific Activity automatically calculated by GoldSim®
3. Included in the calculation of gross alpha concentration; MCL is 15 pCi/L.

Table 3.9 Environmental Standards for Modeled Inorganics, Gross Alpha, and Radioactive Isotopes

Species or Inorganic	MCL[1]	Units
Ag	0.1[2]	mg/L
Al	0.05 to 0.2[2]	mg/L
Cd	5	µg/L
Cr	0.1	mg/L
Fe	0.3[2]	mg/L
Pb	15	µg/L
H-3	20,000[3]	pCi/L
Co-60	100[3]	pCi/L
Sr-90	8[3]	pCi/L
Tc-99	900[3]	pCi/L
I-129	1[3]	pCi/L
Cs-137	200[3]	pCi/L
Ra-226 + Ra-228	5[4]	pCi/L
Gross alpha	15	pCi/L
U-233	30[5]	µg/L
U-234	30[5]	µg/L
U-235	30[5]	µg/L
U-238	30[5]	µg/L

Notes:
1. MCL: USEPA primary drinking water Maximum Containment Level
2. No primary MCL for silver – USEPA secondary MCL listed
3. Radionuclide concentrations calculated using the 4 mrem/yr beta particles and photon emitters USEPA MCL standard
4. Sum of radium-226 and radium-228 concentration should not exceed USEPA MCL of 5 pCi/L
5. Sum of mass concentrations of uranium isotopes should not exceed the USEPA MCL of 30 µg/L

3.5 Transport Parameters

Tables 3.10 and 3.11 provide a list of the deterministic and stochastic model parameters, respectively, required to simulate transport from the C-Reactor building to the POAs. These tables are divided into subsections for building dimensions and sources, common parameters used in modeling flow and transport from each source, time dependent events, and radionuclide specific parameters. Also, each parameter in these tables has its SI and English units shown.

Most parameters related to the C-Reactor building were simulated deterministically since their dimensions are measurable or known. An exception is the stainless-steel corrosion rate of vessels or tanks, which was modeled stochastically due to its uncertainty and sensitivity. Several SRNL studies have been performed that quantify the stainless-steel corrosion rate in air, water, and grout (Mickalonis et al. 2012; Gdowski and Bullen 1998; CRWMS M&O 2000).

The common model parameters, such as porosity, bulk density, water content, tortuosity, solubility, and K_ds are used to simulate flow and transport in the vadose zone and saturated zone or infiltration through the building roof, cap, and slabs, as appropriate. The infiltration rates were simulated stochastically. Some of the material properties of the vadose and saturated zones are also modeled stochastically, such as porosity and dry bulk density. Deterministic parameters include known values such as lithologic unit thicknesses or values derived from groundwater flow modeling, such as flow velocities and dispersivities. The stochastic parameters use minimum, maximum, standard deviation, and mean values from the probability distributions developed for the F-Area Hardened Facilities modeling effort (Tetra Tech 2021).

Time-dependent events were simulated for transport modeling. The number of pore volumes through concrete layers were calculated for each building and scenario to set physical and chemical inputs that depend on the age of the concrete. The timing of the roof collapse, partial building collapse, and engineered roof collapse for each building are assumed to be (on average) 150 years, 750 years, and 1,200 years, respectively based on previous estimates by an SME for Building 235-F (Hamm et al. 2019).

Element-specific parameters include vadose zone cementitious leachate factors (element-specific values used to modify K_d values in the vadose zone to account for the influence of leachate from cement structures on groundwater chemistry that may alter radionuclide partitioning to subsurface sediment), sorption coefficients (K_d), and solubility. These parameters were simulated stochastically due to their uncertainties and their probability distributions were derived from the 2021 Geochemical Data Package (Kaplan 2021).

Table 3.10 C-Reactor Building Deterministic Model Parameters

Parameter Description	Value	
230-ton Crane Maintenance Area lead source	**SI**	**English**
230-ton lead source width	9.14 m	30 ft
230-ton lead source length	9.14 m	30 ft
230-ton lead source concrete building roof thickness	1.52 m	5 ft
230-ton lead source slab (floor) thickness	1.22 m	4 ft
ISD2 grout thickness	3.35 m	11 ft
ISD4 grout thickness	4.88 m	16 ft
ISD4 concrete slab #3 thickness	3.05 m	10 ft
Aquifer width beneath 230-ton lead source	9.14 m	30 ft
VZ Sand 1 thickness below 230-ton lead source	3.96 m	13 ft
VZ Clay 1 thickness below 230-ton lead source	3.05 m	10 ft
VZ Sand 2 thickness below 230-ton lead source	4.27 m	14 ft
VZ Clay 2 thickness below 230-ton lead source	6.71 m	22 ft
VZ Sand 3 thickness below 230-ton lead source	3.05 m	10 ft
Area of boxes for canyon waste	23.23 m^2	250 ft^2
Area of boxes for noncanyon waste	60.39 m^2	650 ft^2
20-ton Process Area lead source		
20-ton lead source width	5.94 m	19.5 ft
Thickness of lead source	5.74 cm	2.26 in
20-ton lead source concrete building roof thickness	1.52 m	5 ft
Aquifer width beneath 20-ton lead source	5.94 m	19.5 ft
20-ton lead source total slab thickness	5.49 m	18 ft
VZ Clay 2 thickness below 20-ton lead source	3.96 m	13 ft
VZ Sand 3 thickness below 20-ton lead source	3.05 m	10 ft
Deionizer Tank		
DI tank source width	1.96 m	6.42 ft
DI tank source slab (floor) thickness	1.22 m	4 ft
DI tank source second concrete slab thickness	2.13 m	7 ft
Total thickness of concrete below DI tank source	3.35 m	11 ft
ISD2 grout thickness	4.69 m	15.4 ft
Aquifer width beneath DI tank source	1.96 m	6.42 ft
Sand layer below floor and above the lower concrete slab thickness for DI tank source	1.07 m	3.5 ft
VZ Sand 1 thickness below DI tank source	0.76 m	2.5 ft
VZ Clay 1 thickness below DI tank source	3.05 m	10 ft
VZ Sand 2 thickness below DI tank source	4.27 m	14 ft
VZ Clay 2 thickness below DI tank source	6.71 m	22 ft

Parameter Description	Value	
VZ Sand 3 thickness below DI tank source	3.05 m	10 ft
Tank 204 & 205 rooms		
Tank 204 & 205 rooms source width	14.38 m	47.17 ft
Tank 204 & 205 rooms source length	14.38 m	47.17 ft
Thickness of slab (floor) above Tanks 204 & 205 source	1.22 m	4 ft
Thickness of concrete floor below Tank 204 & 205	3.28 m	10.75 ft
Total thickness of concrete below Tank 204 & 205 source	4.50 m	14.75 ft
Aquifer width beneath Tank 204 & 205 source	14.38 m	47.17 ft
VZ Clay 2 thickness below Tank 204 & 205 source	3.35 m	11 ft
VZ Sand 3 thickness below Tank 204 & 205 source	3.05 m	10 ft
Common Parameters		
Distance from C-Reactor building to surface water POA (Castor Creek)	2415 m	7923 ft
Distance from C-Reactor building to C-Area fence line	313 m	1027 ft
Initial tank steel thickness	0.79 cm	0.31 in
Steel density	7889 kg/m^3	492.5 lb/ft^3
Longitudinal dispersivity	10 m	32.81 ft
Longitudinal dispersivity (for small aquifer segments)	1 m	3.28 ft
Longitudinal dispersivity (slab and VZ)	0.1 m	0.33 ft
Thickness of saturated zone (SZ)	30.48 m	100 ft
Sandy soil (SZ) Darcy velocity	15.2 m/yr	50 ft/yr
Young cementitious solids; pore volume exchange cycles	50	
Moderately-aged cementitious solids; pore volume exchange cycles	500	
Aged cementitious solids; pore volume exchange cycles	4000	
Plume Function		
Length of aquifer	109.42 m	359 ft
Pathway length	varies	
Cross-sectional area	varies	
Length of source parallel to flow direction	0 m	0 ft
Vertical position of observation point	1.52 m	5 ft
Transverse position of observation point	0 m	0 ft
Vertical depth to the top of the source from the top of the aquifer	0.76 m	2.5 ft
Width of source, transverse to aquifer flow	varies	
Thickness of source	varies	
Thickness of aquifer	30.48 m	100 ft
Dispersivity in transverse direction	1.52 m	5 ft
Dispersivity in the vertical direction	1.54 m	5.05 ft

Table 3.11 C-Reactor Building Stochastic Model Parameters

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Cementitious Leachate Factor (both Clayey and Sandy)					Truncated Normal	unitless
Ac	1.5	0.22	1.0	2.0		
Ag	3.2	0.47	2.1	4.3		
Al	1.5	0.22	1.0	2.0		
Am	1.5	0.22	1.0	2.0		
Cd	3	0.44	2.0	4.0		
Co	3.2	0.47	2.1	4.3		
Cr	1.5	0.22	1	2		
Cs	1.1	0.05	1.0	1.3		
Fe	1.5	0.22	1.0	2.0		
H	1	0.05	1	1.33		
I	0.1	0.005	0.1	0.13		
Np	1.5	0.22	1.0	2.0		
Pa	1.5	0.22	1.0	2.0		
Pb	3.2	0.47	2.1	4.3		
Pu	2	0.29	1.3	2.7		
Ra	3	0.44	2.0	4.0		
Sr	3	0.44	2.0	4.0		
Tc	0.1	0.005	0.1	0.13		
Th	2	0.29	1.3	2.7		
U	3	0.44	2.0	4.0		
Kd in young aged cementitious solids environment					Truncated normal	mL/g
Ac	6000	1200	1500	10500		
Ag	4000	800	1000	7000		
Al	6000	1200	1500	10500		
Am	6000	1200	1500	10500		
Cd	4000	800	1000	7000		
Co	4000	800	1000	7000		
Cr	10	2	2.5	17.5		
Cs	2	0.4	0.5	3.5		
Fe	6000	1200	1500	10500		
H	1E-05	2E-06	1E-06	1E-04		
I	8	1.6	2	14		

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Np	10000	2000	2500	17500		
Pa	10000	2000	2500	17500		
Pb	300	60	75	525		
Pu	10000	2000	2500	17500		
Ra	200	40	50	350		
Sr	90	18	22.5	157.5		
Tc	0.8	0.16	0.2	1.4		
Th	10000	2000	2500	17500		
U	1000	200	250	1750		
Kd in middle aged cementitious solids environment					Truncated normal	mL/g
Ac	6000	1200	1500	10500		
Ag	4000	800	1000	7000		
Al	6000	1200	1500	10500		
Am	6000	1200	1500	10500		
Cd	4000	800	1000	7000		
Co	4000	800	1000	7000		
Cr	10	2	2.5	17.5		
Cs	20	4	5	35		
Fe	6000	1200	1500	10500		
H	1E-05	2E-06	1E-06	1E-04		
I	10	2	2.5	17.5		
Np	10000	2000	2500	17500		
Pa	10000	2000	2500	17500		
Pb	300	60	75	525		
Pu	10000	2000	2500	17500		
Ra	100	20	25	175		
Sr	20	4	5	35		
Tc	0.8	0.16	0.2	1.4		
Th	10000	2000	2500	17500		
U	5000	1000	1250	8750		
Kd in old aged cementitious solids environment					Truncated normal	mL/g
Ac	600	120	150	1050		
Ag	400	80	100	700		
Al	600	120	150	1050		
Am	600	120	150	1050		

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Cd	400	80	100	700		
Co	400	80	100	700		
Cr	1	0.2	0.25	1.75		
Cs	10	2	2.5	17.5		
Fe	600	120	150	1050		
H	1E-05	2E-06	1E-06	1E-04		
I	4	0.8	1	7		
Np	5000	1000	1250	8750		
Pa	5000	1000	1250	8750		
Pb	100	20	25	175		
Pu	2000	400	500	3500		
Ra	200	40	50	350		
Sr	90	18	22.5	157.5		
Tc	0.5	0.1	0.125	0.875		
Th	2000	400	500	3500		
U	5000	1000	1250	8750		
Kd in clayey soil environment					Truncated normal	mL/g
Ac	9000	1700	4500	13500		
Ag	30	6	15	45		
Al	1000	190	500	1500		
Am	9000	1700	4500	13500		
Cd	30	6	15	45		
Co	100	20	50	150		
Cr	1000	190	500	1500		
Cs	300	60	150	450		
Fe	400	76	200	600		
H	1E-05	2E-06	1E-06	1E-04		
I	3	0.6	1.5	4.5		
Np	20	3.8	10	30		
Pa	20	3.8	10	30		
Pb	5000	1000	2500	7500		
Pu	6000	1100	3000	9000		
Ra	200	38	100	300		
Sr	20	4	10	30		
Tc	1.8	0.3	0.9	2.7		
Th	2000	380	1000	3000		
U	400	80	200	600		

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Kd in sandy soil environment					Truncated normal	mL/g
Ac	1000	200	250	1750		
Ag	10	2	2.5	17.5		
Al	1000	200	250	1750		
Am	1000	200	250	1750		
Cd	20	4	5	35		
Co	40	8	10	70		
Cr	400	80	100	700		
Cs	20	4	5	35		
Fe	200	40	50	350		
H	1E-05	2E-06	1E-06	1E-04		
I	1	0.2	0.25	1.75		
Np	4	0.8	1	7		
Pa	4	0.8	1	7		
Pb	2000	400	500	3500		
Pu	1000	200	250	1750		
Ra	30	6	7.5	52.5		
Sr	5	1	1.25	8.75		
Tc	0.6	0.12	0.15	1.05		
Th	900	180	225	1575		
U	300	60	75	525		
Solubility in young aged cementitious solids environment					Truncated log-normal	mol/L
Ac	1E-11	5E-12	1E-12	1E-10		
Ag	1E-07	5E-08	1E-08	1E-06		
Al	1E-11	5E-12	1E-12	1E-10		
Am	1E-11	5E-12	1E-12	1E-10		
Cd	1E-07	5E-08	1E-08	1E-06		
Co	1E-07	5E-08	1E-08	1E-06		
Cr	NSL[1]	NSL	NSL	NSL		
Cs	NSL	NSL	NSL	NSL		
Fe	1E-11	5E-12	1E-12	1E-10		
H	NSL	NSL	NSL	NSL		
I	NSL	NSL	NSL	NSL		
Np	1E-13	2E-14	1E-14	1E-12		

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[1] NSL = No Solubility Limit

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Pa	1E-13	5E-14	1E-14	1E-12		
Pb	1E-07	5E-08	1E-08	1E-06		
Pu	1E-12	5E-13	1E-13	1E-11		
Ra	1E-06	5E-07	1E-07	1E-05		
Sr	1E-05	5E-06	1E-06	1E-04		
Tc	NSL	NSL	NSL	NSL		
Th	1E-12	5E-13	1E-13	1E-11		
U	1E-06	3E-07	1E-07	1E-05		
Solubility in middle-aged cementitious solids environment					Truncated log-normal	mol/L
Ac	1E-08	5E-09	1E-09	1E-07		
Ag	1E-07	5E-08	1E-08	1E-06		
Al	1E-08	5E-08	1E-09	1E-07		
Am	1E-08	5E-09	1E-09	1E-07		
Cd	1E-07	5E-08	1E-08	1E-06		
Co	1E-07	5E-08	1E-08	1E-06		
Cr	NSL	NSL	NSL	NSL		
Cs	NSL	NSL	NSL	NSL		
Fe	1E-08	5E-09	1E-09	1E-07		
H	NSL	NSL	NSL	NSL		
I	NSL	NSL	NSL	NSL		
Np	1E-13	2E-14	1E-14	1E-12		
Pa	1E-13	5E-14	1E-14	1E-12		
Pb	1E-07	5E-08	1E-08	1E-06		
Pu	1E-12	5E-13	1E-13	1E-11		
Ra	1E-06	5E-07	1E-07	1E-05		
Sr	1E-05	5E-06	1E-06	1E-04		
Tc	NSL	NSL	NSL	NSL		
Th	1E-12	5E-13	1E-13	1E-11		
U	1E-05	3E-06	1E-06	1E-04		
Solubility in old-aged cementitious solids environment					Truncated log-normal	mol/L
Ac	1E-07	5E-08	1E-08	1E-06		
Ag	1E-06	5E-07	1E-07	1E-05		
Al	1E-07	5E-08	1E-08	1E-06		
Am	1E-07	5E-08	1E-08	1E-06		
Cd	1E-06	5E-07	1E-07	1E-05		

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Co	1E-06	5E-07	1E-07	1E-05		
Cr	NSL	NSL	NSL	NSL		
Cs	NSL	NSL	NSL	NSL		
Fe	1E-07	5E-08	1E-08	1E-06		
H	NSL	NSL	NSL	NSL		
I	NSL	NSL	NSL	NSL		
Np	1E-07	2E-08	1E-08	1E-06		
Pa	1E-07	5E-08	1E-08	1E-06		
Pb	1E-06	5E-07	1E-08	1E-05		
Pu	1E-07	5E-08	1E-08	1E-06		
Ra	1E-06	5E-07	1E-07	1E-05		
Tc	NSL	NSL	NSL	NSL		
Th	1E-07	5E-08	1E-08	1E-06		
U	1E-06	3E-07	1E-07	1E-05		
Roof collapse	150		100	200	uniform	yr
Partial Building collapse	750		500	1000	uniform	yr
Engineered roof collapse	1200		1000	1400	uniform	yr
Intact roof infiltration	4.47E-04	7.34E-04	5.46E-06	2.67E-03	truncated log-normal	cm/yr
Background infiltration	3.81E+01	4.32E-01			normal	cm/yr
Engineered roof infiltration	2.32E-03	1.82E-03	4.27E-07	3.89E-03	truncated log-normal	cm/yr
Ponded roof infiltration	6.12E-03	5.05E-03	4.67E-04	1.18E-02	truncated log-normal	cm/yr
Lead corrosion rate in water	0.68333	0.46562	0	2	triangular	mm/yr
Lead corrosion rate in air	0.142	0.08336	0	0.376	triangular	mm/yr
Steel corrosion rate in water	61.66	87.066			cumulative	μm/yr
Steel corrosion rate in air	0.1104	0.073641			cumulative	μm/yr
Steel corrosion rate in grout	2.93E-03	14.16			log-normal	kg$_m$/yr/m^2
Dry bulk density of sandy soil	1.62	0.022	1.554	1.686	truncated normal	g/cm^3
Porosity of sandy soil	0.39	0.008	0.366	0.414	truncated normal	unitless

Parameter Description	Mean	Std. Dev.	Min.	Max.	Distribution Type	Units
Water content of sandy soil	0.259		0.252	0.268	triangular	unitless
Dry bulk density of clayey soil	1.65	0.028	1.556	1.734	truncated normal	g/cm^3
Porosity of clayey soil	0.39	0.011	0.357	0.423	truncated normal	unitless
Water content of clayey soil	0.317		0.312	0.323	triangular	unitless
Dry bulk density of grout	2.06	0.029	1.973	2.147	truncated normal	g/cm^3
Porosity of grout	0.211	0.09	0.184	0.238	truncated normal	unitless
Water content of grout	0.281		0.276	0.286	triangular	unitless
Dry bulk density of concrete	2.11	0.1	1.81	2.41	truncated normal	g/cm^3
Porosity of concrete	0.184	0.013	0.145	0.223	truncated normal	unitless
Water content of concrete	0.164		0.113	0.207	triangular	unitless

3.6 Hydraulic Property Data Package

The Hydraulic Property Data Package (Phifer et al. 2006) was used for the analysis of C-Reactor building contaminant migration and the C-Area groundwater MODFLOW model (WSRC 2000) was used to determine the flow paths for the flow and transport modeling. The hydrologic parameters for the thickness of the hydrogeologic units, saturated zone Darcy velocity, and aquifer path lengths were the same as the MODFLOW-MODPATH model. The approach for C-Reactor building analysis was to use the particle tracking conducted with MODPATH to provide the length of the aquifer pathways (see Figure 1.3). In terms of the representation in GoldSim®, the number of aquifer elements were evaluated within the UTRA. Dispersion in the saturated zone was accounted for by using the GoldSim® Plume Function with the parameters described earlier.

3.7 Geochemical Data

The SRS Geochemical Database was developed to support performance assessment at the SRS for low-level and high-level radioactive waste (Kaplan 2021). This database includes the justification and assumptions for the values assigned. Specifically, this database contains cementitious leachate factors, solubility values, and distribution coefficient values. The geochemical database was based on specific data when available and supplemented with literature data and professional judgment where data gaps existed.

3.7.1 Aging of Cement

The fate and transport model considered concrete and grout materials to be engineered barriers that modify the infiltration rate, sorption of radionuclides, and release of the holdup inventory. The integrity of the concrete and grout degrades over time, and the transport model includes the temporal variation in the analysis. The hydraulic and chemical degradation of concrete and grout are based on changes in pH as various amounts of water infiltrate through the material as they age, which has been widely accepted in transport models (Taylor and Phifer 2012; Hamm et al. 2019; Tetra Tech 2021). As the cement ages, the porosity increases, which allows for an increase in the infiltration rate. The SRS Geochemical Database (Kaplan 2021) divides the degradation of concrete into four stages:

- Stage I: Young Cementitious Materials Conceptual Environment. During this stage, the pH (>12.5), ionic strength, and concentrations of potassium and sodium are elevated. For SRS, if a project specific value is not available, it is assumed that Stage I lasts until the cumulative amount of water flowing through the cementitious material exceeds 50 pore volumes (PV).

- Stage II: Moderately aged Cementitious Materials Conceptual Environment. During this stage, the pH is stable (~12.5), and the soluble salts of the alkali metals are all dissolved and washed out of the cement solids. For SRS, it is assumed that Stage II last 450 PV beyond the transition from Stage I to Stage II, although ranges in the literature vary between 100 to 1,000 PVs.

- Stage III: Aged Cementitious Materials Conceptual Environment. During this stage, the infiltrating water controls the pH and the material degrades. Duration ranges in the literature vary between 1,000 to 10,000 PVs. At SRS, precipitation and groundwater have low carbonate concentrations which affects the longevity calculation for cementitious material; a value of 3,500 PVs beyond the transition from Stage II to Stage III was selected for flow and transport calculations as recommended in the geochemical database (Kaplan 2021).

- Stage IV: During this stage the cement is assumed to behave as sandy soil.

The SRS Geochemical Database (Kaplan 2021) assumes that the concrete structures are based on generic oxidizing cement. During the flow and transport modeling, each stage was given an associated porosity due to concrete degradation.

Another component of concrete degradation includes the collapse of building components (i.e., roof and floor slabs) over time. For the C-Reactor building, the assumption that the roof collapse of a building without an engineered roof would occur at 150 years is based on input from an SME, Shawn Carey (Appendix G of Hamm et al. 2019) and confirmed for this modeling effort (personal communication, Willey 2023).

3.7.2 Solubility

The Geochemical Database (Kaplan 2021) contains ranges of apparent solubility for cementitious environments for the three stages of concrete and grout degradation. These database values were used for the release of the hold-up material from the C-Reactor building. The database contains liquid-phase solubility values for both oxidizing and reducing cementitious leachate. Currently there are no data to indicate that anything besides the generic oxidizing condition should be used, but for other disposal areas, the reducing cementitious values are more appropriate.

In GoldSim®, a mean value for solubility is provided by element and by stage (i.e., young, middle, or old) for the elements that have a solubility limitation specified in Kaplan (2021). A stochastic element is utilized to select the solubility value for each realization via a log-normal distribution, where the minimum value of the distribution is one tenth of the mean value, the maximum value is ten times the mean value, and the standard deviation is 50% of the mean value (see Table 3.11).

3.7.3 Sorption Coefficients

Ranges of sorption coefficients (K_d) that are based on either a low- or high-pH environment are also included in the SRS Geochemical Database (Kaplan 2021). Once the leachate that represents the source term leaves the building, the flow and transport simulations use K_d values for the sandy and clayey sediment present in the vadose and/or saturated zone (see Table 3.11). During Stage I and II of the cementitious degradation, simulations use high-pH K_d values for the plume as it enters the vadose zone below the buildings. For the modeling of the C-Reactor building, it was assumed that high-pH conditions exist in the vadose zone during these stages. Once the plume enters the saturated zone it is assumed to be neutralized and the low-pH K_d values are more appropriate. During Stages III and IV, the low pH K_d values were used for the vadose zone and saturated zone.

Cementitious leachate factors are element-specific values used to modify Kd values in the vadose zone to account for the influence of leachate from cement structures on groundwater chemistry that may alter radionuclide partitioning to subsurface sediment. Leachates have higher pH and ionic strength, which can increase sorption by promoting precipitation or decrease sorption by promoting competition for sorption sites (Kaplan 2021).

3.7.4 Steel Degradation Rates

The steel degradation rates used for the modeling varied stochastically based on whether the steel was within an air, water, or grout environment (see Table 3.11). The steel degradation rates used in the C-Reactor building GoldSim® model are the same rates as developed for the F-Area Hardened Facilities (Tetra Tech 2021) and the R- and P-Reactor GoldSim® models (Council 2009, 2008, respectively).

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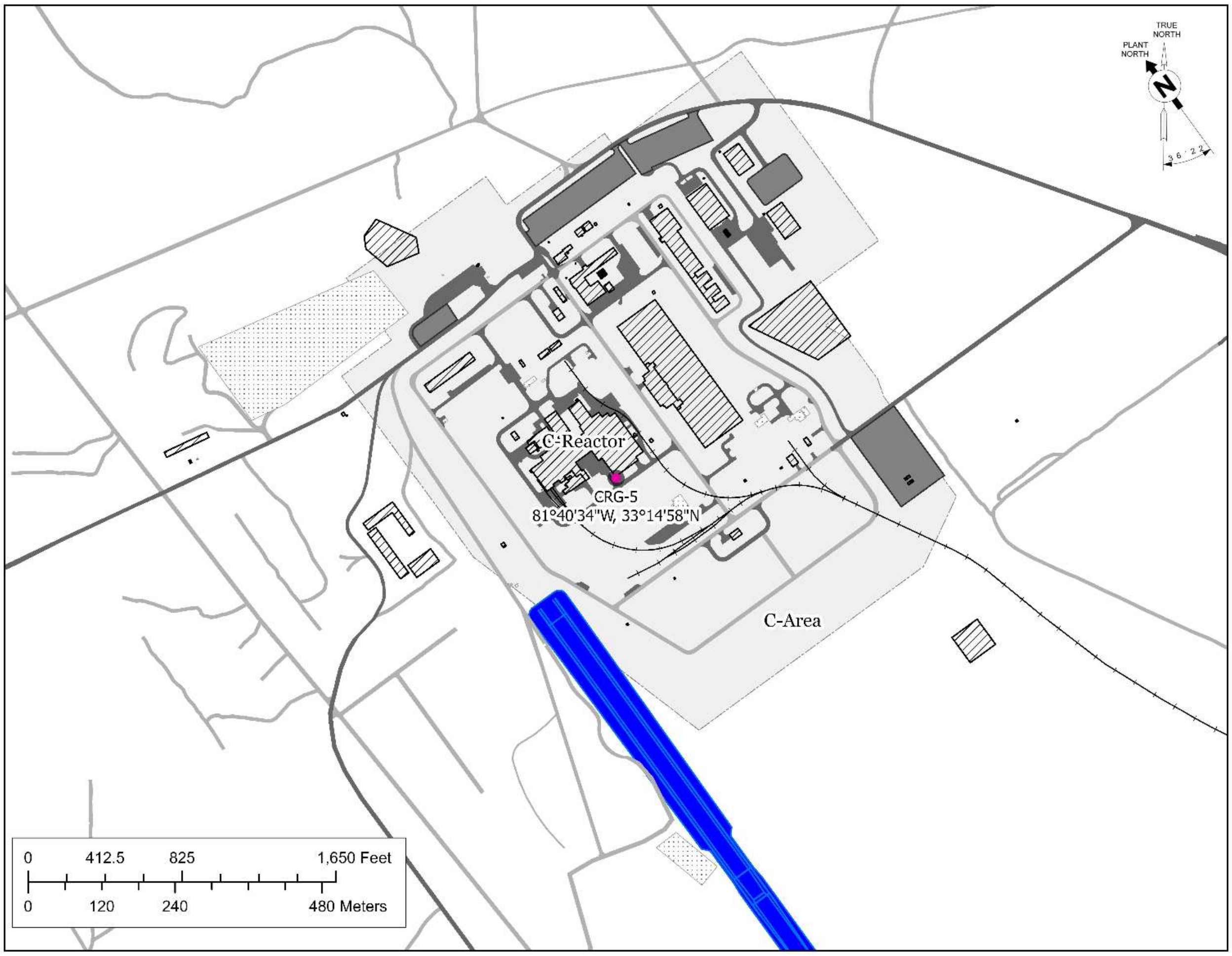

Figure 3.1 Location Map for Boring CRG-5

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4.0 MODEL STRUCTURE AND CALCULATIONS

This section describes the fate and transport model used to evaluate the ISD alternatives for D&D of the C-Reactor building. The C-Reactor building GoldSim® model simulates contaminant release from the 20-Ton Process Area Lead, 230-Ton Crane Maintenance Area Lead, De-ionizer tank, and Tank 204 and 205 source areas. The model simulates fate and transport through the source areas, the vadose zone, and the saturated zone to the surface water interface. The model includes the fate and transport of radioisotopes, lead, and metals, as appropriate, based on the source being modeled.

The model was developed using GoldSim® (release 14.0 #344). GoldSim® provides the ability to simulate both deterministic (a single realization at specified conditions) and stochastic (input parameters being varied by specified probability distributions) model runs. The final model for each ISD alternative is designed as a stochastic simulation with 1,000 realizations being simulated for each scenario evaluated.

The following sections provide a description of the GoldSim® C-Reactor building fate and transport model. GoldSim® elements are indicated by *italics*.

4.1 Model Overview

At the top level, the GoldSim® model consists of six containers. These containers, which will be described in more detail in the following sections, are as follows:

- *Simulation Controls* – determines which ISD to run for each source.
- *Material* – specifies the contaminants/species, material properties and transport parameters.
- *Inventory* – contains inventory for each building/source.
- *Sources* – contains the flow and transport elements specific to each source.
- *Miscellaneous* – contains various useful parameters (e.g., data elements for dose conversion factors; data elements to indicate which species are alpha, beta, gamma emitters)
- *Results* – contains results elements (e.g., time-series) for constituents of interest for each source.

4.2 Container Descriptions

This section contains descriptions for each of the top-level containers shown in Appendix A (Figure A.1).

4.2.1 Simulation_Controls Container

The content of the *Simulation_Controls* container for the 230-Ton Crane Maintenance Area lead source is shown in Appendix A (Figure A.2). There are data elements for each source in this container (e.g., *Lead_230Ton_Alternative, Lead_20Ton_Alternative, DI_Tank_Alternative, Tanks204_205_Alternative*). The value of each data element corresponds to the ISD being simulated for that source area. The data element *Retardation_Switch* allows the user to turn off retardation in the model. The container *ISD* contains the conceptual model figure of each ISD alternative for each source as reference.

4.2.2 Material Container

The content of the *Material* container is shown in Appendix A (Figure A.3). This container defines the transport species being modeled and the liquid and solid material transport properties for those species. This container also defines the material properties for the porous media and fluid. In this model the only fluid is water. The contents of the *Material* container are:

- *Species* – defines the radionuclide and stable species used in the transport calculations.
- *Water* – reference fluid element that defines the properties of the flowing medium, water.
- *HalfLives* – data element that provides the half-lives for the radionuclides being simulated.
- Solid elements and associated containers – Containers *SandySoilProperties, SatSandySoilProperties, ClayeySoilProperties, SatClayeySoilProperties*, *ConcreteProperties, GroutProperties,* and solid elements *SandySoil, SatSandySoil, ClayeySoil, SatClayeySoil, Steel* define the properties (e.g., density, porosity, or partition coefficients) of the porous media and material properties used in the model. Note that concrete and grout solid elements are separately defined within localized source containers to allow the properties of these solids to vary at different times in accordance with the number of pore volumes that pass through these materials.

- Containers – *SandySoilKds, ClayeySoilKds, OxidizingConcreteKds* define the partition coefficients for each species being modeled. Partition coefficients are defined for each elemental species with each isotope of an element having the same K_d. Appendix A (Figure A.4) shows the elements in the *SandySoilKds* container, and Appendix A (Figure A.5) shows the stochastic element *Kd_Dist_Sandy* that calculates the distribution for each species. The other partition coefficient containers are structured similarly.
- Containers – *CemLeachSandySoilKds* and *CemLeachClayeySoilKds* define the cement leaching factor for each species being modeled and adjusts the K_ds based on the cement leaching factor in clayey or sandy soils. Appendix A (Figure A.6) shows the elements in the *CemLeachSandySoilKds* container, and Appendix A (Figure A.7) shows the stochastic element *ChemLeach_Sandy_Dist* that calculates the distribution for each species. The other cement leaching factor container is structured similarly.
- *Water_Solubility_Concrete* – This container defines the solubilities of each element for cementitious environments for the three stages of concrete degradation (i.e., Stage I, II, and III (young, middle, and old)). The solubilities for each element are defined by a log-normal distribution through stochastic elements for each element modeled. Appendix A (Figure A.8) shows the stochastic element used to define the distribution for Pu (Stage I, young). All other stochastic elements in this container are defined similarly.

4.2.3 Inventory Container

The contents of the *Inventory* container are shown in Appendix A (Figure A.9). This container specifies the starting inventory for each source. There are separate containers within the *Inventory* container for each source area. The data element *Simulation_Start_Date* specifies the start date of the simulation (January 1, 2044). Appendix A (Figure A.10) shows the *Lead230Ton* container that defines the initial inventory for the 230 Ton source (Canyon and Non-Canyon streams). The data elements in this container contain the initial inventory, inventory (sample) date, and the calculation of the decay term to decay the inventory to the *Simulation_Start_Date.* The other containers are structured similarly.

4.2.4 Sources Container

The contents of the *Sources* container are shown in Appendix A (Figure A.11, 230-Ton Crane Maintenance Area lead source shown). The fate and transport elements of the model are located in the *Sources* container for each source. As shown in Appendix A (Figure A.11), each source is represented by a localized container within GoldSim®. A localized container (i.e., "Treat as Subsystem" within GoldSim®) can be thought of as a stand-alone model in that it can function independently from any other localized containers. The other container not treated as a localized container, *CommonInput*, provides common model parameters used by the localized container.

Appendix A (Figure A.12) shows the *CommonInput* container. As mentioned above, this container provides parameters that are used by the localized fate and transport containers (for each source). Appendix A (Figure A.13) shows the *Infiltration* container. This container contains stochastic elements for each type of infiltration rate that can be modeled (intact, background, engineered, and ponded). Appendix A (Figure A.14) shows the stochastic element *Stochastic_Intact_Infiltration*. The other stochastic elements are structured similarly. Appendix A (Figure A.15) shows the *DegradationRates* container. This container provides the degradation rates for the steel tanks when in contact with air, water, and grout. The structure and data for this container is taken from the R- and P-Reactor GoldSim® models (Council 2009, 2008, respectively). The other data elements in *CommonInput* provide values for various elements that are used throughout the model (i.e., saturated zone thickness, sand and clay Darcy velocity, longitudinal dispersivity values).

Appendix A (Figure A.16) shows the *Lead_230Ton* localized container. The structure shown in this localized container is identical for the other sources. Appendix A (Figure A.17) shows the *Source_Geom_Prop* container for the 230-ton Crane Maintenance Area lead source. This container provides specifications for the geometric properties of each source (e.g., source area length, width, etc.). In this example, the containers for these parameters are *Building_Geometry_230Ton* (Appendix A, Figure A.18). Subsurface dimensions (e.g., aquifer width, distance to downgradient POAs) in this example are in the container *Subsurface_Geometry_230Ton* (Appendix A, Figure A.19). Solubilities based on the stage of cement aging are in the *Water_Solubility* container and the degradation rate (selector element) for the steel containers and lead based on the ISD being simulated are in the *Degradation_Rate* container (Appendix A, Figure A.20). In this example, there are four selector elements to specify the type of steel and lead degradation rate based on the ISD scenario being simulated (i.e.., there are four ISD alternatives for the 230-ton Crane Maintenance Area lead source; Appendix A, Figure A.21 shows the selector element properties for steel degradation rate through time for the No Action ISD scenario). The other selector element (*Degradation_Rate_Steel*) in Figure A.20 selects the appropriate degradation rate based upon the ISD scenario being simulated. This selector element's properties are shown in Appendix A) (Figure A.22). The *Water_Solubility* container provides the solubility values for each element based on the age of the cement. The age of the cement is based on the number of pore volume flushes for each source. Appendix A (Figure A.23) shows the *Solubility* selector element's properties.

Local solid elements for concrete are needed for the aging of the concrete and grout, if applicable; for example, the age is dependent on the number of pore volume flushes (in this example, the solid elements are *Concrete_230Ton* and *Grout_230Ton*). The number of pore volume flushes will be different for each source based on the structure/geometry of each source being simulated. The same methodology applies for the local solid elements for the sandy and clayey soil (in this example, the solid elements are *SandySoil_230Ton* and *ClayeySoil_230Ton*). These solid elements are used to specify the K_ds for the sandy and clayey vadose zone beneath each source. The K_ds are based on the cementitious environments for the three stages of concrete degradation (Stages I-III: young, middle, old). Under these stages, the K_ds will be based on *CemLeachSandySoilKds* and *CemLeachClayeySoilKds.* When the stage is greater than Stage III, the K_ds for sandy or clayey soil are used (i.e., *Kd_Sandy* and *Kd_Clayey*).

The other selector elements in this container are described below:

- *Concrete_Kd_Input_230Ton* – selector element to specify the K_d based on the age of the concrete (young, middle, and old) which is based on the number of pore volume flushes for the 230-ton Crane Maintenance Area lead source (Appendix A, Figure A.24).
- *Phys_Degrade_Concrete_230Ton* – selector element to specify the porosity of the concrete based on the age of the concrete (young, middle, and old) which is based on the number of

pore volume flushes for 230-ton Crane Maintenance Area lead source (Appendix A, Figure A.25).

These selector elements are repeated for each source and the name of the element reflects the source (e.g., *Concrete_Kd_Input_20Ton* for the 20-ton Process Area lead source).

Appendix A (Figure A.26) shows the *Pore_Volume* localized container. The structure shown in the localized container for 230-ton Crane Maintenance Area lead source is similar for the other sources based on the geometry of the buildings. This container determines the stage of the simulation (Stage I – IV) based on the number of pore volume flushes. In this example, the elements *Integrated_Flow_230Ton*, *Por_Vol*, and *No_Por_Vol_Concrete* are used to determine the stage for each source (*Stage_PVol_230Ton*). Also, in this example, for the 230-ton Crane Maintenance Area lead source ISD2 (LS-CM-S2A), there are additional elements to calculate the number of pore volume flushes and stage of the grout that would be put in place around and above the steel containers (the additional thickness of grout affects the number of pore volume flushes and thus affects the steel degradation rate based on whether the grout is present).

Appendix A (Figure A.27) shows the *Flow* localized container. The structure shown in the localized container for 230-ton Crane Maintenance Area lead source is similar for the other sources. This container has function and selector elements used to determine the water flow (L^3/T) used in the transport container. These elements are:

- *Lead_230Ton_Infiltration_Selector* – selector element that specifies the infiltration rate, based on the ISD being simulated.
- *Q_Slab, Q_Slab_Canyon, Q_Slab_Non-Canyon* – functions to calculate the flow through the concrete slab for the 230 Ton source based upon the infiltration rate and the area of the source. For 230 Ton, the source is divided into two waste streams: Canyon and Non-Canyon. Each waste stream has a different area, hence different flow rates. The other three sources (20 Ton, De-ionizer tank, and Tank 204 and 205) have a single waste stream and only have the *Q_Slab* function element in their respective localized *Flow* container.

- *Q_SZ_230Ton* - function to calculate the flow through the saturated zone. The flow rate is based on the saturated zone thickness, aquifer width, and saturated zone.

Appendix A (Figure A.28) shows the *InfilRate_230Ton* localized container. The structure shown in the localized container for the 230 Ton source and is similar for the other sources. This container has selector elements for the infiltration rates based on the ISD being simulated. An example of one of these selector element's properties is shown in Appendix A (Figure A.29) (selector element *Lead_230Ton_ISD1_InfilRates).*

Appendix A (Figure A.30) shows the *Transport* localized container. The structure shown is the localized *Transport* container for the 230-ton Crane Maintenance Area lead source. The transport pathway is divided into two waste streams: Canyon and Non-Canyon. Each waste stream has a separate inventory (Figure A.10). The transport waste stream contains the source elements, concrete slab and vadose zone aquifer elements based on the conceptual model for that source. There are two source elements (*Source_230Ton_Canyon and Source_230Ton_NonCanyon*) for the 230 Ton source. Aquifer elements representing the concrete slab (*Slab_230Ton_Canyon and Slab_230Ton_NonCanyon*), the first sandy vadose zone (*VZ_Sand1_230Ton_Canyon and VZ_Sand1_230Ton_NonCanyon*), the first clayey vadose zone (*VZ_Clay1_230Ton_Canyon and VZ_Clay1_230Ton_NonCanyon*), the second sandy vadose zone (*VZ_Sand2_230Ton_Canyon and VZ_Sand2_230Ton_NonCanyon*), the second clayey vadose zone (*VZ_Clay2_230Ton_Canyon and VZ_Clay2_230Ton_NonCanyon*), the third sandy vadose zone (*VZ_Sand3_230Ton_Canyon and VZ_Sand3_230Ton_NonCanyon*), and the saturated zone beneath the source representing the various POAs (*POA_1m_230Ton, POA_Fence_230Ton, and POA_Creek_230Ton*). While the Canyon and Non-Canyon waste streams are modeled separately from source through the vadose zone, they are combined in the saturated zone at the 1-m POA, and thereafter.

Appendix A (Figures A.31 and A.32) shows the properties of the source elements for *Source_230Ton_Canyon* and *Source_230Ton_NonCanyon*, respectively. Appendix A (Figure A.33) shows the aquifer pathway element representing the concrete slab (*Slab_230Ton_Canyon*) for the Canyon waste stream (the Non-Canyon concrete slab element is structured similarly). Appendix A (Figure A.34) shows the aquifer pathway element representing the first sandy vadose zone (*VZ_Sand1_230Ton_Canyon*) for the Canyon waste stream (the Non-Canyon aquifer element is structured similarly). Appendix A (Figure A.35) shows the aquifer pathway element representing the first clayey vadose zone (*VZ_Clay1_230Ton_Canyon*) for the Canyon waste stream (the Non-Canyon aquifer pathway element is structured similarly). The other aquifer pathway elements for the remaining vadose zone layers are structured similarly for both Canyon and Non-Canyon waste streams.

Appendix A (Figure A.36) shows the aquifer pathway element representing the saturated zone at the 1m POA (*POA_1m_230Ton*). *POA_1m_230Ton* is used as the 1m compliance point for fate and transport analysis. The separate Canyon and Non-Canyon waste streams are combined at this POA. Appendix A (Figure A.37) shows the aquifer pathway element representing the saturated zone at the C-Reactor boundary (i.e., fence) POA (*POA_Fence_230Ton*). Appendix A (Figure A.38) shows the aquifer pathway element representing the saturated zone at the perennial surface-water interface POA at Castor Creek (POA_Creek_230Ton).

Appendix A (Figure A.39) shows the *Plume_Mod* container. The plume function has eleven input arguments that account for spatial variation in concentration. These eleven data elements include specifying the size of the source, the dispersive properties, and the exact location of the observation point. These eleven arguments are described further in Table 3.10. The result of the plume function is a multiplier that varies between zero and one and is multiplied by the Aquifer Pathway element's average concentration at each POA to obtain the actual concentration. If the plume function returns a multiplier value greater than one, which can occur at near-source POAs, such as the 1-m POA, then the multiplier value is capped at one.

Appendix A (Figure A.40) shows the *Results* container for the 230-ton Crane Maintenance Area lead source. This container contains function elements to calculate mass and activity concentrations for constituents of interest for each source. The function *MassConc_x* (where *x* is the point of assessment of interest, i.e., 1-m, fence, and creek) collects the concentration output for each species from the aquifer element for each corresponding POA. From this function, other functions are used to calculate the activity concentrations, concentrations of species of interest, and gross alpha, beta, and gamma concentrations, where appropriate.

The functions in the *Results* container located in each source local container are used as input to time history and final value result elements in the main *Results* container found at the top level of the model (Figure A.41). The time history element for each species of interest is exported to Microsoft Excel (Excel); within Excel, the POTM is calculated using the *max* function (i.e., =max(cell1:cell2) in Excel) for each POA for each scenario.

Appendix A (Figure A.42) shows the *Transport* localized container for the 20-ton Process Area lead source. The vadose zone elements (e.g., sand and clayey layers) are based on the conceptual model for each source. Appendix A (Figure A.43) shows the *Transport* localized container for the Deionizer tank source. Appendix A (Figure A.44) shows the *Transport* localized container for the Tank 204 and 205 source. For each of these examples, as well as in Figure A.30 for the 230-ton Crane Maintenance Area lead source, the *Transpor*t localized container is for the base case (i.e., no action) ISD.

5.0 SIMULATION RESULTS

Ten GoldSim® models were developed to simulate the ISD scenarios discussed in Chapter 4. Table 5.1 shows these ten model simulations and which ISD scenarios were modeled in each simulation. The results from each ISD scenario by facility are described in the following sections. The stochastic simulations result in a predicted range of concentrations vs. time for each contaminant, source, and ISD alternative. Performance objectives are evaluated by calculating the POTM concentrations and the time the POTM occurs for each of the pathways at each of the POAs shown in Table 1.1. The POTM is the maximum value (in time) of the mean concentration vs. time curve generated in the stochastic simulation. Figures of concentration versus time are also presented in Appendices B and C for each ISD scenario for the 20-ton lead and 230-ton Crane Maintenance Area lead sources. Figures of the DI Tank and Tank 204 and 205 are not provided since all of the simulated concentrations are well below regulatory standards and are essentially zero or below laboratory detection limits.

Table 5.1 Summary of ISD Scenarios by Model Simulation

Source	ISD Name	ISD #	Description
20-ton Lead	LS-PA-S1	1	No action
20-ton Lead	LS-PA-S3	2	Grout and engineered roof; grout below grade
230-ton Lead	LS-CM-S1	1	No action
230-ton Lead	LS-CM-S2A	2	Grout and cap source
230-ton Lead	LS-CM-S3A	3	Engineered roof
230-ton Lead	LS-CM-S3B	4	Grout and engineered roof; boxes move adjacent CM area to allow grout below grade
Deionizer Tank	DIT-S1	1	No action
Deionizer Tank	DIT-S3	2	Grout and engineered roof
Tank 204 and 205	HW-S1	1	No action
Tank 204 and 205	HW-S4	2	Grout and solidify source

5.1 20-ton Process Area Lead source

Two ISD scenarios are modeled for the 20-ton Process Area lead source (Table 5.1). The simulation time for the 20-ton Process Area lead source ISD alternatives was 100,000 years. This time period is included for seeking peak concentrations in this analysis. The results from these two scenarios are provided in the following sections and in Appendix B.

5.1.1 No Action (LS-PA-S1)

The No Action (LS-PA-S1) scenario for the 20-ton Process Area lead source for C-Reactor building was modeled as ISD1. Table 5.2 shows the POTM lead concentrations and the time of occurrence from GoldSim®. Bolded values in this table and subsequent tables in Section 5 indicate exceedances of POs or groundwater standards.

Probability plots for lead concentrations as a function of time with 1,000 realizations at the 1-m, C-area boundary, and Castor Creek POAs are shown in Appendix B for the No Action (LS-PA-S1) scenario (see Figures B.1 through B.3). Percentiles from 25% to 75% are shown by the dark bands around the median, percentiles from 5% to 95% are shown by the red bands. The light red bands in each plot show absolute minimum and maximum bounding values for the concentrations obtained by drawing an envelope around extreme values from all 1,000 realizations. When each realization curve is plotted together in the probability plots, the overall shape appears to be flattened. Each peak from each realization occurs at a different time and has a different peak concentration. Typically, the later the arrival of the peak, the lower the peak concentration due to more sorption (i.e., higher K_d values) being simulated.

Lead POTM mean concentrations do not exceed the PO of 15 µg/L at any POA (see Figure B.4). Very low concentrations of lead (i.e., >0.1 µg/L) occur at approximately 70,000 years at the 1m POA. The maximum concentration of lead occurs at the end of the simulation (4.21 µg/L at the 1m POA at 100,000 years). The fate and transport of lead is dependent primarily on sorption in the vadose and saturated zones (i.e., large K_d values).

Table 5.2. Peak of the Mean Concentration and Time of Occurrence at each POA for LS-PA-S1 Scenario (20-ton Lead ISD1).

ISD Alternative	CP (years)	POA	Lead	
			µg/L	Time (years)
		MCL	15 µg/L	
LS-PA-S1	0-100,000	1 m	4.210E+00	100,000
		C-Area Fence	2.979E-02	100,000
		Castor Creek	1.042E-07	100,000

5.1.2 Engineered Roof and Grout Subgrade (LS-PA-S3)

The Engineered Roof and Grout Subgrade (LS-PA-S3) scenario for the 20-ton Process Area lead source for C-Reactor building was modeled as ISD2. Table 5.3 shows the POTM lead concentrations and the time of occurrence from GoldSim®. Bolded values in cells indicate exceedances of POs or groundwater standards.

Probability plots for lead concentrations as a function of time with 1,000 realizations at the 1-m, C-area boundary, and Castor Creek POAs are shown in Appendix B for the Engineered Roof and Grout Subgrade (LS-PA-S3) scenario (see Figures B.5 through B.7).

Lead POTM mean concentrations do not exceed the PO of 15 µg/L at any POA (see Figure B.8). The maximum concentration of lead occurs at the end of the simulation (0.08778 µg/L at the 1-m POA at 100,000 years).

Table 5.3 Peak of the Mean Concentration and Time of Occurrence at each POA for LS-PA-S3 Scenario (20-ton Source Lead ISD2).

ISD Alternative	CP (years)	POA	Lead	
			μg/L	Time (years)
		MCL	15 μg/L	
LS-PA-S1	0-100,000	1 m	8.778E-02	100,000
		C-Area Fence	2.664E-04	100,000
		Castor Creek	2.479E-10	100,000

5.2 230-ton Crane Maintenance Area Lead Source

Four ISD scenarios were simulated for the 230-ton Crane Maintenance Area lead source in the Crane Maintenance Area of the C-Reactor building (Table 5.1). The simulation time for the 230-ton Crane Maintenance Area lead source ISD alternatives was 1,000,000 years. This time period is included for seeking peak concentrations in this analysis. The results from these four scenarios are provided in the following sections and in Appendix C.

5.2.1 No Action (LS-CM-S1)

The No Action (LS-CM-S1) scenario for the 230-ton Crane Maintenance Area lead source was modeled as ISD1. Table 5.4 shows the POTM gross alpha, Tc-99, total uranium, radium-226 plus radium-228 and lead concentrations and the time of occurrence from GoldSim®. Bolded values in cells indicate exceedances of POs or groundwater standards.

Probability plots for gross alpha concentrations as a function of time with 1,000 realizations at the 1-m, C-area boundary, and Castor Creek POAs are shown in Appendix C for the No Action (LS-CM-S1) scenario (see Figures C.1 through C.3). A plot of the mean gross alpha concentrations at each POA are shown in Figure C.4. A similar set of plots are shown for lead concentrations in Figures C.5 through C.7.

Lead POTM mean concentrations exceed the PO of 15 µg/L at the 1-m and fence POA (see Figure C.8). The maximum concentration of lead at the 1-m POA occurs at 311,000 years, at a concentration of 301 µg/L. The maximum concentration of lead at the fence POA occurs at 354,000 years, at a concentration of 33.4 µg/L. There are no exceedances for gross alpha or the other constituents.

Table 5.4 Peak of the Mean Concentration and Time of Occurrence at each POA for LS-CM-S1 Scenario (No Action ISD1).

ISD Alternative	CP (years)	POA	Gross Alpha		Tc-99		Ra-226	
			pCi/L	Time (years)	pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	15 pCi/L		900 pCi/L		5 pCi/L	
LS-SM-S1	0-1,000,000	1 m	3.005E-02	35,500	2.089E-01	1,000	1.505E-02	44,500
		C-Area Fence	3.071E-03	42,000	2.477E-02	1,000	2.576E-03	49,000
		Castor Creek	4.172E-04	81,000	7.723E-03	1,000	1.403E-03	97,000
ISD Alternative	**CP (years)**	**POA**	**U-234**		**Total Uranium**		**Lead**	
			µg/L	**Time (years)**	**µg/L**	**Time (years)**	**µg/L**	**Time (years)**
		Regulatory Limit	30 µg/L		30 µg/L		15 µg/L	
LS-SM-S1	0-1,000,000	1 m	4.698E-06	35,500	5.481E-06	35,500	**3.01E+02**	311,000
		C-Area Fence	4.762E-07	41,500	5.570E-07	41,500	**3.34E+01**	354,000
		Castor Creek	6.218E-08	79,500	7.393E-08	79,500	6.18E+00	617,000

5.2.2 Grout and Cap Source (LS-CM-S2A)

The Grout and Cap Source (LS-CM-S2A) scenario for the 230-ton Crane Maintenance Area lead source was modeled as ISD2. Table 5.5 shows the POTM gross alpha, Tc-99, uranium-234, total uranium, radium-226 plus radium-228 and lead concentrations and the time of occurrence from GoldSim®. Bolded values in cells indicate exceedances of POs or groundwater standards.

Probability plots for gross alpha concentrations as a function of time with 1,000 realizations at the 1-m, C-area boundary, and Castor Creek POAs are shown in Appendix C for the Grout and Cap Source (LS-CM-S2A) scenario (see Figures C.9 through C.11). A plot of the mean gross alpha concentrations at each POA are shown in Figure C.12. A similar set of plots are shown for lead concentrations in Figures C.13 through C.16.

The addition of grout and capping the source reduces POTM gross alpha, Tc-99, total uranium, and radium-226 plus radium-228 concentrations at each POA and delays the peak occurrence time for gross alpha, total uranium, and radium-226 plus radium-228. There is no change in the concentrations of lead at the POAs nor in the timing of the peak for this scenario.

Table 5.5 Peak of the Mean Concentration and Time of Occurrence at each POA for LS-CM-S2A Scenario (Grout and Cap Source ISD2).

ISD Alternative	CP (years)	POA	Gross Alpha		Tc-99		Ra-226	
			pCi/L	Time (years)	pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	15 pCi/L		900 pCi/L		5 pCi/L	
LS-SM-S2A	0-1,000,000	1 m	2.721E-02	38,000	4.559E-02	1,000	1.467E-02	48,500
		C-Area Fence	2.835E-03	44,500	5.387E-03	1,000	2.491E-03	52,000
		Castor Creek	4.025E-04	83,500	1.428E-03	1,000	1.366E-03	99,500

ISD Alternative	CP (years)	POA	U-234		Total Uranium		Lead	
			µg/L	Time (years)	µg/L	Time (years)	µg/L	Time (years)
		Regulatory Limit	30 µg/L		30 µg/L		15 µg/L	
LS-SM-S2A	0-1,000,000	1 m	4.246E-06	38,000	4.978E-06	38,000	**3.01E+02**	311,000
		C-Area Fence	4.384E-07	44,000	5.153E-07	44,000	**3.34E+01**	354,000
		Castor Creek	5.990E-08	82,000	7.159E-08	82,000	6.184E+00	617,000

5.2.3 Engineered Roof (LS-CM-S3A)

The Engineered Roof (LS-CM-S3A) scenario for the 230-ton Crane Maintenance Area lead source was modeled as ISD3. Table 5.6 shows the POTM gross alpha, Tc-99, total uranium, radium-226 plus radium-228, and lead concentrations and the time of occurrence from GoldSim®. Bolded values in cells indicate exceedances of POs or groundwater standards.

Probability plots for gross alpha concentrations as a function of time with 1,000 realizations at the 1-m, C-area boundary, and Castor Creek POAs are shown in Appendix C for the Engineered Roof (LS-CM-S3A) scenario (see Figures C.17 through C.19). A plot of the mean gross alpha concentrations at each POA are shown in Figure C.20. A similar set of plots are shown for lead concentrations in Figures C.21 through C.24.

The addition of the engineered roof reduces POTM gross alpha, Tc-99, total uranium, and radium-226 plus radium-228 concentrations at each POA and delays the peak occurrence time for gross alpha, Tc-99, total uranium, and radium-226 plus radium-228. The addition of the engineered roof has a slight effect on the POTM lead concentrations and delays the peak by approximately 1,000 years. Given the long time needed for peak lead concentrations to occur, the addition of an engineered roof that will remain in place for approximately 1,200 years has little effect on lead fate and transport.

Table 5.6 Peak of the Mean Concentration and Time of Occurrence at each POA for LS-CM-S3A Scenario (Engineered Roof ISD3).

ISD Alternative	CP (years)	POA	Gross Alpha		Tc-99		Ra-226	
			pCi/L	Time (years)	pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	15 pCi/L		900 pCi/L		5 pCi/L	
LS-SM-S3A	0-1,000,000	1 m	2.913E-02	36,500	1.801E-01	2,000	1.470E-02	46,000
		C-Area Fence	2.979E-03	43,000	2.129E-02	2,000	2.509E-03	50,500
		Castor Creek	4.052E-04	82,000	5.545E-03	2,000	1.365E-03	98,000

ISD Alternative	CP (years)	POA	U-234		Total Uranium		Lead	
			µg/L	Time (years)	µg/L	Time (years)	µg/L	Time (years)
		Regulatory Limit	30 µg/L		30 µg/L		15 µg/L	
LS-SM-S3A	0-1,000,000	1 m	4.555E-06	36,500	5.352E-06	36,500	**3.013E+02**	312,500
		C-Area Fence	4.619E-07	42,500	5.441E-07	42,500	**3.346E+01**	355,000
		Castor Creek	6.037E-08	80,500	7.234E-08	80,500	6.191E+00	618,000

5.2.4 Move Source, Grout Subgrade and Engineered Roof (LS-CM-S3B)

The Move Source, Grout Subgrade and Engineered Roof (LS-CM-S3B) scenario for the 230-ton Crane Maintenance Area lead source was modeled as ISD4. Table 5.7 shows the POTM gross alpha, Tc-99, total uranium, and radium-226 plus radium-228 and lead concentrations and the time of occurrence from GoldSim®. Bolded values in cells indicate exceedances of POs or groundwater standards.

Probability plots for gross alpha concentrations as a function of time with 1,000 realizations at the 1-m, C-area boundary, and Castor Creek POAs are shown in Appendix C for the Move Source, Grout Subgrade and Engineered Roof (LS-CM-S3B) scenario (see Figures C.25 through C.27). A plot of the mean gross alpha concentrations at each POA are shown in Figure C.28. A similar set of plots are shown for lead concentrations in Figures C.29 through C.32.

Moving the source and grouting the subgrade reduces POTM gross alpha, Tc-99, and total uranium concentrations at each POA and delays the peak occurrence time. POTM concentrations for radium at the 1m and fence POA increase, but their peak occurrence time is much later compared to No Action. Radium POTM concentrations at the creek POA are reduced in this scenario compared to No Action.

Moving the source and grouting the subgrade results in higher lead POTM concentrations as well as earlier time of occurrence. This is due to the source being moved adjacent to the Crane Maintenance Area to an area where the 20-foot and 40-foot floor are present within the reactor building. The source is left on the ground level, and the area below ground surface is grouted. In the No Action scenario, the source resides in the Crane Maintenance Area that is underlain by multiple layers of sand and clay in the vadose zone. The lead K_d values for sand and clay are large (2000 and 5000 mL/g, respectively). When the lead is moved, the area under the source consists mostly of grout and concrete. The lead K_d value for concrete and grout are much smaller compared to the values for sand and clay in the vadose zone (300, 300, and 100 mL/g for young, middle, and old concrete, respectively); it is assumed that the lead K_d value for grout is the same as the value for concrete. Thus, there is much less sorption of lead in the vadose zone for this scenario compared to the other scenarios where the source still resides in the Crane Maintenance Area. Lead mobilizes sooner in this scenario and at higher concentrations compared to the other scenarios.

Table 5.7 Peak of the Mean Concentration and Time of Occurrence at each POA for LS-CM-S3B Scenario (Move Source, Grout Subgrade and Engineered Roof ISD4).

ISD Alternative	CP (years)	POA	Gross Alpha		Tc-99		Ra-226	
			pCi/L	Time (years)	pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	15 pCi/L		900 pCi/L		5 pCi/L	
LS-SM-S3B	0-1,000,000	1 m	2.339E-02	66,500	1.611E-01	2,000	2.338E-02	99,000
		C-Area Fence	2.390E-03	73,000	1.902E-02	2,000	3.164E-03	83,500
		Castor Creek	3.495E-04	112,000	4.587E-03	2,000	1.371E-03	131,000

ISD Alternative	CP (years)	POA	U-234		Total Uranium		Lead	
			µg/L	Time (years)	µg/L	Time (years)	µg/L	Time (years)
		Regulatory Limit	30 µg/L		30 µg/L		15 µg/L	
LS-SM-S3B	0-1,000,000	1 m	3.646E-06	66,500	4.341E-06	66,500	**3.500E+02**	301,500
		C-Area Fence	3.695E-07	72,500	4.412E-07	72,500	**3.670E+01**	343,500
		Castor Creek	5.189E-08	110,500	6.309E-08	110,500	6.048E+00	602,500

5.3 Deionizer Trailer Lead Tank Source

Two ISD scenarios were conducted for the Deionizer trailer lead tank source (Table 5.1). The simulation time for the Deionizer tank source ISD alternatives was 100,000 years. This time period is included for seeking peaks in this analysis. The simulated concentration results from both scenarios were essentially zero and are provided in the following sections.

5.3.1 No Action (DIT-S1)

The No Action (DIT-S1) scenario for the Deionizer trailer lead tank source was modeled as ISD1. Table 5.8 shows the POTM silver, aluminum, cadmium, chromium, iron, lead, Tc-99, and gross alpha concentrations and the time of occurrence from GoldSim®. There are no exceedances for the modeled constituents. All of the simulated concentrations are significantly less than the regulatory limits.

Table 5.8 Peak of the Mean Concentration and Time of Occurrence at each POA for DIT-S1 Scenario (Deionizer Trailer No Action ISD 1).

ISD Alternative	CP (years)	POA	Silver		Aluminum		Cadmium	
			mg/L	Time (years)	mg/L	Time (years)	mg/L	Time (years)
		Regulatory Limit	0.1 mg/L		0.05 to 0.2 mg/L		5 mg/L	
DIT-S1	0-100,000	1 m	1.308E-07	9,000	2.792E-05	100,000	8.994E-08	9,500
		C-Area Fence	3.151E-09	9,000	3.171E-07	100,000	2.136E-09	9,500
		Castor Creek	8.096E-10	10,500	3.591E-10	100,000	3.912E-10	12,500

ISD Alternative	CP (years)	POA	Chromium		Iron		Lead	
			mg/L	Time (years)	mg/L	Time (years)	µg/L	Time (years)
		Regulatory Limit	0.1 mg/L		0.3 mg/L		15 µg/L	
DIT-S1	0-100,000	1 m	5.414E-07	58,500	6.168E-05	35,000	1.082E-03	100,000
		C-Area Fence	1.296E-08	67,000	1.439E-06	39,000	4.883E-07	100,000
		Castor Creek	1.702E-09	100,000	2.437E-07	65,000	3.396E-15	100,000

ISD Alternative	CP (years)	POA	Tc-99		Gross Alpha	
			pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	900 pCi/L		15 pCi/L	
DIT-S1	0-100,000	1 m	7.871E-05	1,000	1.415E-08	40,500
		C-Area Fence	2.005E-06	1,000	3.104E-10	46,500
		Castor Creek	6.202E-07	1,000	4.226E-11	46,500

5.3.2 Grout Subgrade and Engineered Roof (DIT-S3)

The Grout Subgrade and Engineered Roof (DIT-S3) scenario for the Deionizer trailer lead tank source was modeled as ISD2. Table 5.9 shows the POTM silver, aluminum, cadmium, chromium, iron, lead, Tc-99, and gross alpha and the time of occurrence from GoldSim®. There are no exceedances for the modeled constituents. All of the simulated concentrations are significantly less than the regulatory limits.

Table 5.9 Peak of the Mean Concentration and Time of Occurrence at each POA for DIT-S3 Scenario (Deionizer Trailer No Action ISD 2).

ISD Alternative	CP (years)	POA	Silver		Aluminum		Cadmium	
			mg/L	Time (years)	mg/L	Time (years)	mg/L	Time (years)
		Regulatory Limit	0.1 mg/L		0.05 to 0.2 mg/L		5 mg/L	
DIT-S3	0-100,000	1 m	2.863E-08	18,500	2.029E-05	100,000	2.684E-08	18,500
		C-Area Fence	7.306E-10	18,500	1.411E-07	100,000	6.634E-10	18,500
		Castor Creek	2.559E-10	19,000	1.071E-10	100,000	2.060E-10	21,000

ISD Alternative	CP (years)	POA	Chromium		Iron		Lead	
			mg/L	Time (years)	mg/L	Time (years)	µg/L	Time (years)
		Regulatory Limit	0.1 mg/L		0.3 mg/L		15 µg/L	
DIT-S3	0-100,000	1 m	5.452E-07	62,500	6.007E-05	46,000	4.435E-05	100,000
		C-Area Fence	1.306E-08	71,000	1.407E-06	50,000	7.048E-09	100,000
		Castor Creek	1.430E-09	100,000	2.426E-07	76,000	3.099E-17	100,000

ISD Alternative	CP (years)	POA	Tc-99		Gross Alpha	
			pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	900 pCi/L		15 pCi/L	
DIT-S3	0-100,000	1 m	6.750E-05	2,000	1.374E-08	51,000
		C-Area Fence	1.712E-06	2,000	3.025E-10	57,000
		Castor Creek	4.394E-07	2,000	4.118E-11	96,000

5.4 Heavy Water Tank 204 and 205

Two ISD scenarios were conducted for the heavy water Tank 204 and 205 (Table 5.1). The simulation time for the Tank 204 and 205 source ISD alternatives was 1,000 years. This simulation time is sufficient considering the radionuclide inventory included in the heavy water tanks have short-live constituents only. The simulated concentration results from both scenarios were essentially zero and are provided in the following sections.

5.4.1 No Action (HW-S1)

The No Action (HW-S1) scenario for the heavy water Tank 204 and 205 source was modeled as ISD1. Table 5.10 shows the POTM tritium, cobalt-60, and cesium-137 concentrations and the time of occurrence from GoldSim®. There are no exceedances for the modeled constituents since the half-lives of these three radionuclides range from approximately 5 to 30 years. All of the simulated concentrations are significantly less than the regulatory limits or are zero.

Table 5.10 Peak of the Mean Concentration and Time of Occurrence at each POA for Heavy Water Scenario (No Action HW-S1).

ISD Alternative	CP (years)	POA	Tritium		Co-60		Cs-137	
			pCi/L	Time (years)	pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	20,000 pCi/L		100 pCi/L		200 pCi/L	
HW-S1	0-1,000	1 m	4.635E-07	700	0.00E+00	N/A	0.00E+00	N/A
		C-Area Fence	6.496E-08	700	0.00E+00	N/A	0.00E+00	N/A
		Castor Creek	2.836E-09	700	0.00E+00	N/A	0.00E+00	N/A

5.4.2 Grout and Solidify Source (HW-S4)

The Grout and Solidify Source (HW-S4) scenario for the heavy water Tank 204 and 205 source was modeled as ISD2. Table 5.11 shows the POTM tritium, Co-60, and Cs-137 concentrations and the time of occurrence from GoldSim®. There are no exceedances for the modeled constituents. All of the simulated concentrations are significantly less than the regulatory limits or are zero.

Table 5.11 Peak of the Mean Concentration and Time of Occurrence at each POA for HW-S4 Scenario (Grout and Solidify Source ISD 2).

ISD Alternative	CP (years)	POA	Tritium		Co-60		Cs-137	
			pCi/L	Time (years)	pCi/L	Time (years)	pCi/L	Time (years)
		Regulatory Limit	20,000 pCi/L		100 pCi/L		200 pCi/L	
HW-S4	0-100,000	1 m	3.894E-22	850	0.00E+00	N/A	0.00E+00	N/A
		C-Area Fence	7.360E-16	900	0.00E+00	N/A	0.00E+00	N/A
		Castor Creek	9.694E-16	950	0.00E+00	N/A	0.00E+00	N/A

6.0 SENSITIVITY ANALYSIS

Sensitivity analyses were performed in order to determine which parameters had the most effect on a result of interest and for the 20-Ton Process Area and 230-Ton Crane Maintenance Area lead sources at the C-Reactor building. Sensitivity analyses were not performed for DI Tank and Tank 204 & 205 since their groundwater concentrations at the 1-m POAs were several orders of magnitude lower than regulatory standards or zero.

6.1 Parameter Sensitivity - Tornado Plots

Tornado charts were used to assess parameter sensitivity for stochastic inputs. A tornado chart is a type of sensitivity analysis that provides a graphical representation of the degree to which a result of interest (dependent variable) is sensitive to a set of model input parameters (independent variables). For the tornado plot analysis, the result of interest (dependent variable) is the lead concentration at the 1-m POA for each source, which is the constituent with groundwater concentrations above MCLs. The independent variables used in this analysis were the stochastic (scalar) parameters in the C-Reactor building model. GoldSim® uses the lower bound, central value, and upper bound values for each of the independent variables assessed (see Table 3.10).

Figure 6.1 and Figure 6.2 show the tornado plots at the 1-m POA for 20-ton Process Area Lead and 230-ton Crane Maintenance Area Lead Sources, respectively. When evaluating tornado plots, each bar represents the range of values produced when each independent variable is set to the lower bound, central value, and upper bound (with the other variables being held constant). A light blue bar indicates that the value was produced by the lower bound (low), and a dark blue bar indicates that the value was produced by the upper bound (high). The No Action Scenario for each source was used for the tornado plot analysis.

The K_d of the clayey soil and the K_d of the sandy soil are the most sensitive stochastic parameters for each of the sources based on the stochastic range of values used in the model. As expected, using lower values of K_d (light blue bar) increases the lead concentration at the 1-m POA. Although the model results are sensitive to these parameters, both data sets are well established from Kaplan (2021) and have a high confidence interval that indicates that the mean reflects site conditions. For the 230-Ton Crane Maintenance Area Lead Source, the bulk density of the clayey soil, background infiltration rate, and corrosion rate of lead in water appear as parameters contributing to sensitivity, but with smaller ranges than the K_d of the clayey soil and the K_d of sandy soil. With respect to the K_d, a change in the presence or absence of clay or sand and the thickness of the sandy and clayey soil horizons would make the most significant difference in modeled lead concentrations.

6.2 Time to Peak Sensitivity Assessment

Additional sensitivity analyses were performed for the 230-ton Crane Maintenance Area Lead Source to assess the time to peak and the concentration for lead based on the K_d values for sandy and clayey soil, which were shown to be the most sensitive parameters from the tornado plots. For these analyses, the No Action scenario (LS-CM-S1) was simulated for 1,000 realizations. Four simulations were performed where each end member value of the sandy and clayey soil K_d values used in the tornado plot analysis described above were specified explicitly in GoldSim®. The results are shown in Table 6.1. Bolded values in this table indicate exceedances of the lead PO of 15 µg/L. The results indicate that using lower values of K_d increases lead concentration but decreases the time to peak compared to the base case no action ISD. Similarly, using higher values of K_d decreases lead concentration but increases the time to peak compared to the base case no action ISD.

Table 6.1 Sensitivity Analyses Results for Time to Peak and Lead Concentration Based on Sandy and Clayey Soil K_d Values for LS-CM-S1 Scenario (No Action ISD 1).

CP (years)	Simulation	1-m POA		C-Area Fence POA		Castor Creek POA	
		µg/L	Time (years)	µg/L	Time (years)	µg/L	Time (years)
0-1,000,000	No Action (K_d Sand = 2,000 mL/g and K_d Clay = 5,000 mL/g)	**3.01E+02**	311,000	**3.34E+01**	354,000	6.18E+00	617,000
	K_d Sand = 500 mL/g	**3.41E+02**	227,000	**4.06E+01**	237,500	1.36E+01	310,500
	K_d Sand = 3,500 mL/g	**2.90E+02**	393,000	**3.26E+01**	469,000	5.03E+00	941,000
	K_d Clay = 1,250 mL/g	**6.20E+02**	160,000	**5.81E+01**	202,000	6.91E+00	455,500
	K_d Clay = 8,750 mL/g	**2.50E+02**	468,500	**2.84E+01**	512,000	5.89E+00	778,500

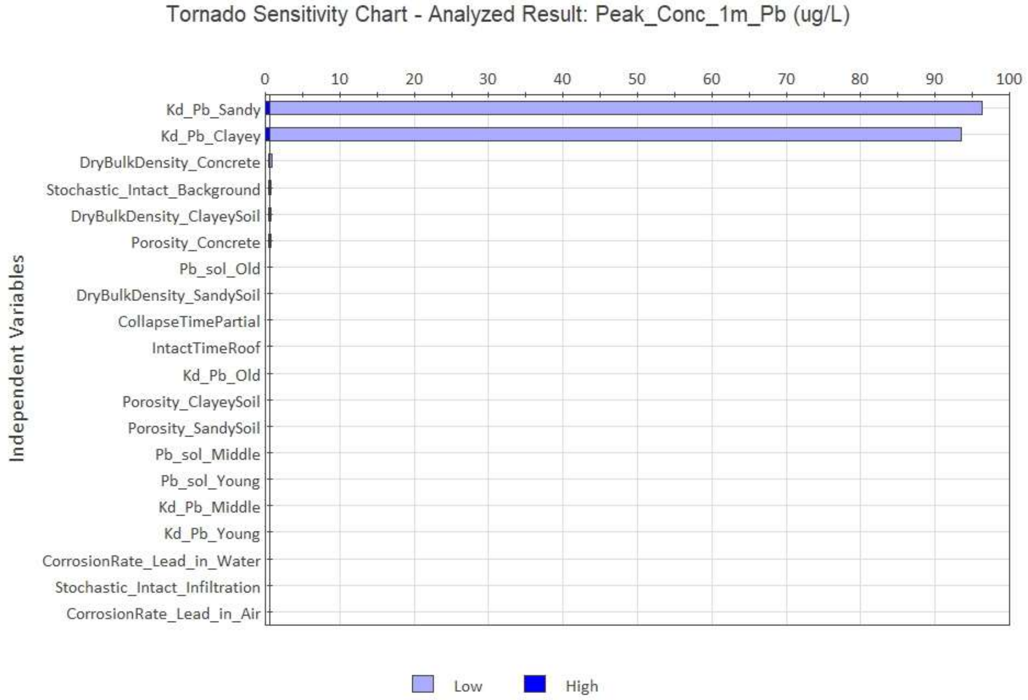

Figure 6.1 Tornado plot for lead concentration (µg/L) at the 1-m POA for the 20-ton Process Area Lead Source No Action Scenario (LS-PA-S1).

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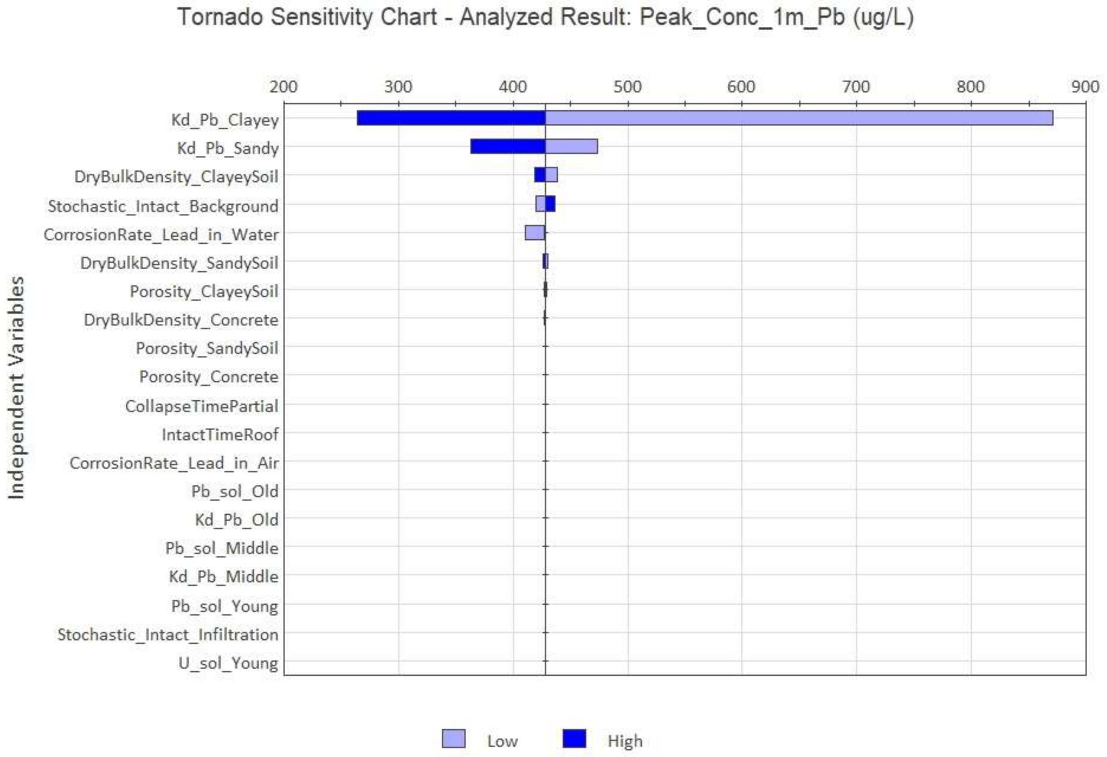

Figure 6.2 Tornado plot for lead concentration (µg/L) at the 1-m POA for the 230-ton Crane Maintenance Area Lead Source No Action Scenario (LS-CM-S1).

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7.0 SUMMARY

ISD alternatives under consideration for D&D of the C-Reactor building have been assessed using a GoldSim® contaminant fate and transport model that has allowed for stochastic analysis of each source area of interest within C-Reactor. Inventory source terms for each of the known C-Reactor source have been provided by the SRNS project team (lead and radionuclides). Building geometry, structural integrity and material properties with respect to time, vadose and saturated zone properties, groundwater flow directions, and POAs were established. The POAs are: 1 meter outside facility footprint, the C-Area boundary, and the perennial surface water interface (i.e., Castor Creek). A model for simulation of the source terms, building degradation over time, contaminant migration through the modeled building, and vadose and saturated zone transport to POAs for each source was developed using GoldSim® (release 14.0 #344).

In summary, the model predicts POs will be met for all radionuclides present at C-Reactor source areas for every combination of ISD alternatives and POAs within the guidance driven CPs (1,000 and 10,000 years [DOE 1999, DOE 2017, NRC 2000]). This is due to the low inventory (i.e., activity/mass) of radionuclides currently present within C-Reactor building and time to failure of the moderator water containment combined with short half-lives for radionuclides, such as tritium, Co-60, and Cs-137. The start of the predictions within GoldSim® is assumed to be January 1, 2044 (the date of closure), but the start of the radionuclide decay is based on the sample date associated with the inventory estimates. Decaying the existing mass of radionuclides to the closure date reduces the inventory estimates even further.

Lead is the only simulated constituent that exceeds POs for the four ISD alternatives that are proposed for the 230-ton Crane Maintenance Area lead source at the 1-m and C-Area boundary POAs. Lead concentrations exceed the PO of 15 µg/L between approximately 100,000 to 600,000 years for the No Action (LS-CM-S1), Grout and Cap Source (LS-CM-S2A), and Engineered Roof (LS-CM-S3A) scenarios where the source is located in the Crane Maintenance Area. The peak concentration at the 1-m POA occurs between 311,000 and 312,500 years at a concentration of approximately 301 µg/L for the No Action (LS-CM-S1), Grout and Cap Source (LS-CM-S2A), and Engineered Roof (LS-CM-S3A) ISD scenarios. Lead concentrations also exceeds the PO between approximately 100,000 to 600,000 years for the Moved Source, and Grout Subgrade and Engineered Roof (LS-CM-S3B) scenario at the 1-m POA, but the peak concentration occurred at an earlier time (301,500 years) and at a higher concentration (350 µg/L). Lead concentrations also exceeded the PO at the C-Area boundary POA for all four 230-ton Crane Maintenance Area lead source scenarios, where the highest lead peak concentration of 37 µg/L also occurred with the Moved Source, Grout Subgrade, and Engineered Roof scenario (LS-CM-S3B). This higher peak concentration and faster travel time of lead for the Moved Source, Grout Subgrade, and Engineered Roof scenario (LS-CM-S3B) is due to the source being moved from the Crane Maintenance Area to a location area where the 20-foot and 40-foot floor are present within the reactor building below the moved source. The moved source is left on the ground level, and the area below ground surface is grouted. In the other three 230-ton Crane Maintenance Area lead source ISD scenarios, the lead source resides in the Crane Maintenance Area that is underlain by multiple layers of sand and clay in the vadose zone. The lead K_d values for sand and clay are large. When the lead is moved, the area under the source consists mostly of grout and concrete; these materials have much smaller lead K_d values. Thus, there is less sorption of lead in the vadose zone for the Moved Source, Grout Subgrade, and Engineered Roof scenario compared to the other 230-ton Crane Maintenance Area lead source scenarios where the source still resides in the Crane Maintenance Area. Based on the GoldSim® modeling, it is recommended that the lead source remain in the Crane Maintenance Area.

For the 20-ton Process Area lead source, the maximum concentration of lead occurs at the end of the simulation (approximately 4 µg/L at the 1m POA at 100,000 years), which is below the PO of 15 µg/L. The simulation time of 100,000 years did not allow for observation of lead peaks for the Process Area lead source. There were no long-lived radionuclides in the source, and the lead inventory was an order of magnitude lower than the nearby Crane Maintenance Area inventory, which was simulated to 1,000,000 years. It is expected the Process Area lead source would result in a lower peak than the Crane Maintenance Area lead source. Therefore, simulations were not rerun for the Process Area lead source with a longer time period. This effort considered only lead shielding within the Process Area, and future modeling will be required before the final ISD end-state is determined for the Process Area. Longer time periods may be necessary at that time for simulating lead peaks and for potential radionuclide sources identified in the reactor vessel inventory. For the deionizer trailer lead and the heavy water tanks 204 and 205 sources, all of the simulated concentrations are significantly less than the regulatory limits or are zero.

7.1 Uncertainty and Limitations

Models necessarily simplify real-world processes and require a variety of simplifying assumptions. Inaccuracies in the simplifying assumptions can lead to substantial uncertainty in the model-predicted results. Conservative assumptions were used throughout in the model inputs to account for the uncertainty in these inputs. The modeling presented in this report includes many important assumptions, some of which are refined through sensitivity analyses. Imprecise knowledge of current and future conditions affecting inventory, travel time, infiltration rates, release of contaminants from solid matrices (making the contaminants available for transport), sorption, and dispersion leads to lower confidence in the numeric concentration results that are compared to regulatory criteria. However, the comparison of ISD alternatives with similar simplifying assumptions generally provides an indication of what types of measures may be effective in meeting POs.

7.2 Recommendations

The model presented in this report provides SRS with a good framework for evaluating groundwater concentrations resulting from discharge at the C-Reactor building. One potential activity that would improve the modeling analysis would be to incorporate radionuclide inventory assays at the source areas after they are conducted and analyzed.

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Appendix A:GoldSim® Model Structure

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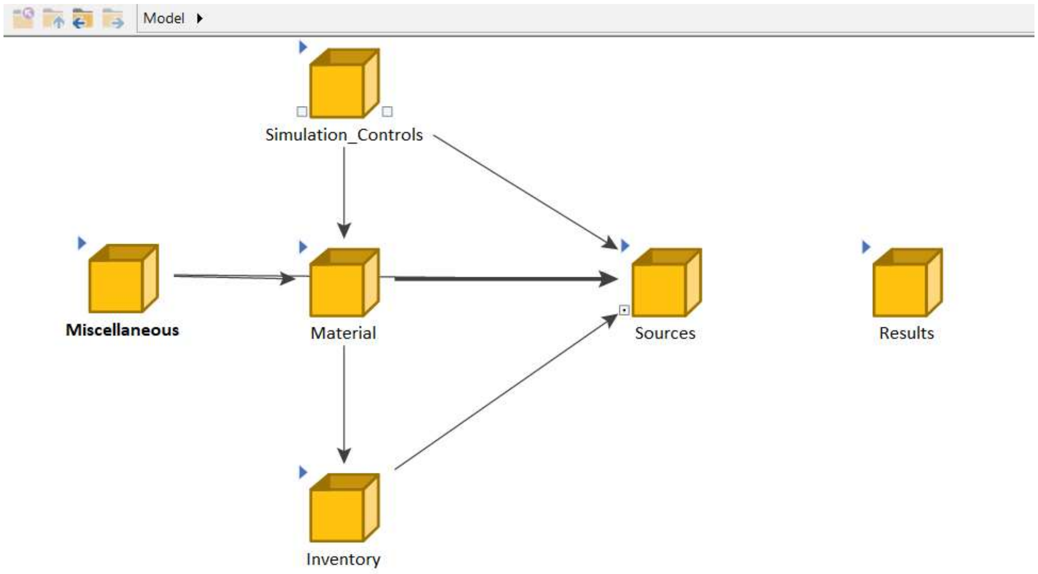


Figure A.1. Top level of C-Reactor GoldSim® model.

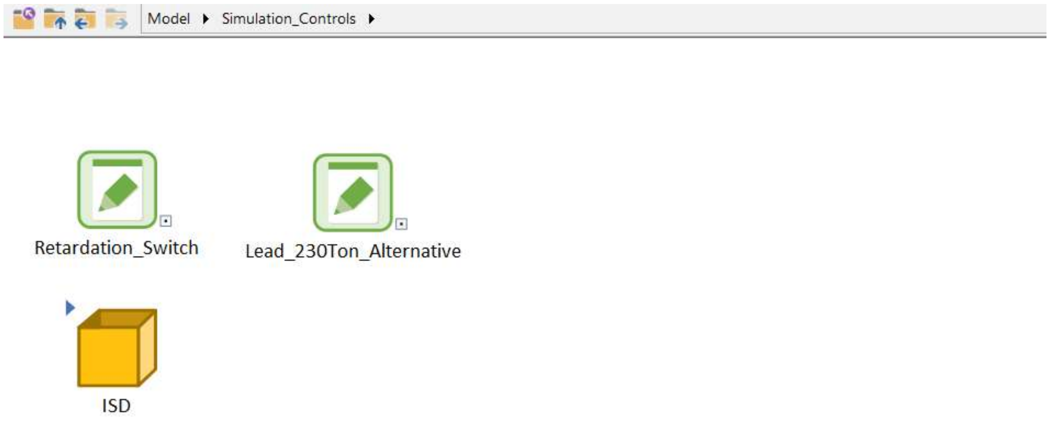


Figure A.2. *Simulation_Controls* container (230-ton lead source alternative shown).

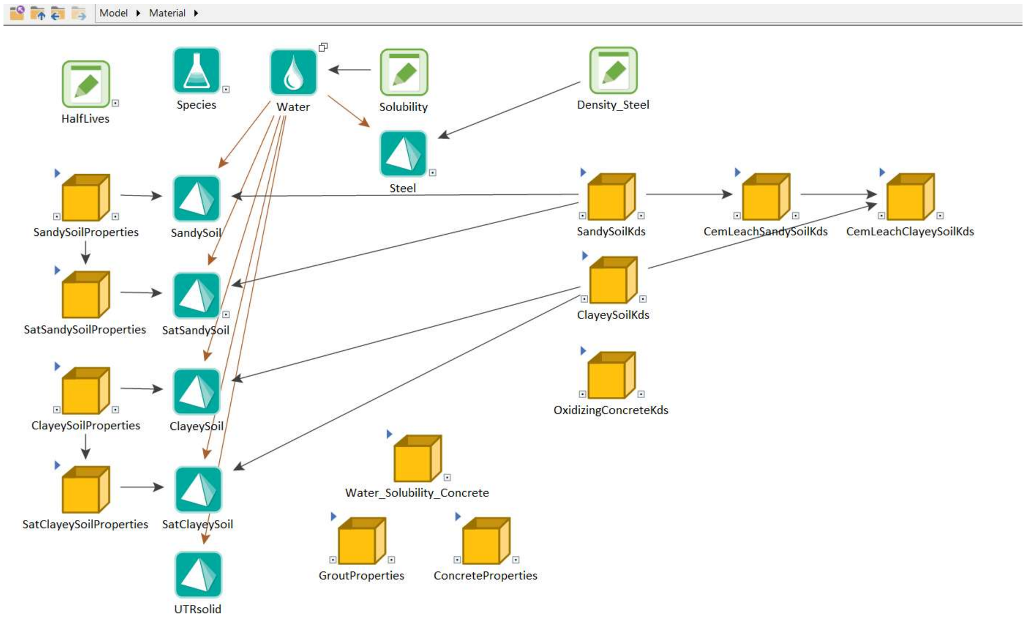
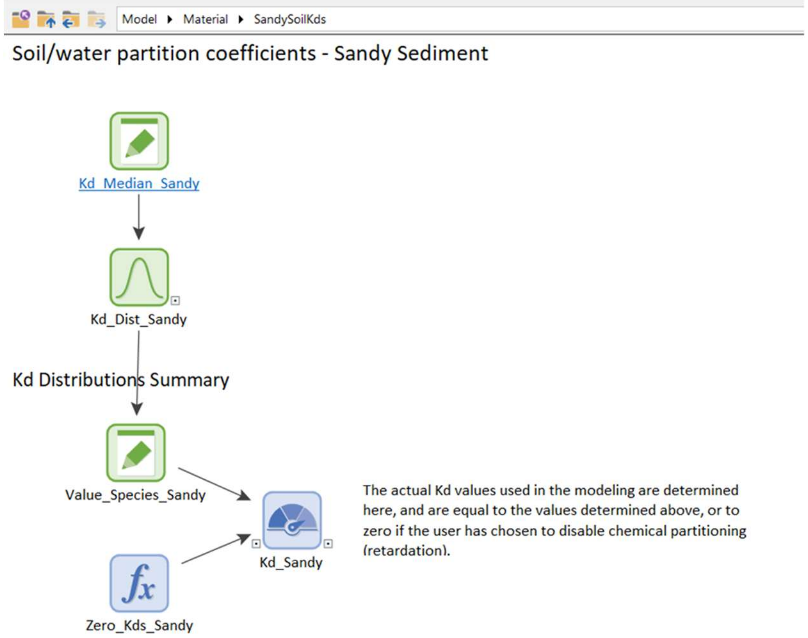


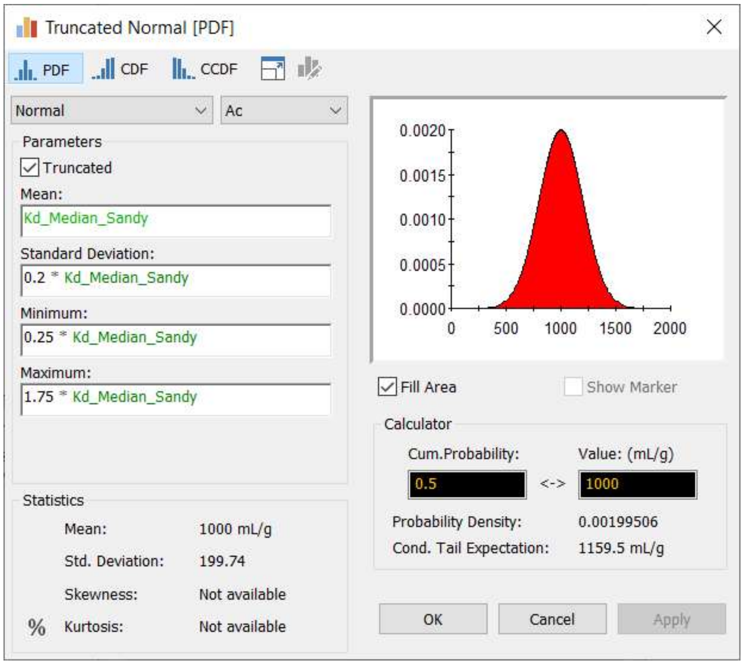
Figure A.3. *Material* container.



Soil/water partition coefficients - Sandy Sediment

The actual Kd values used in the modeling are determined here, and are equal to the values determined above, or to zero if the user has chosen to disable chemical partitioning (retardation).

Figure A.4. *SandySoilKds* container.



Normal
Ac

Parameters

☑ Truncated

Mean: Kd_Median_Sandy

Standard Deviation: 0.2 * Kd_Median_Sandy

Minimum: 0.25 * Kd_Median_Sandy

Maximum: 1.75 * Kd_Median_Sandy

Statistics

Mean:	1000 mL/g
Std. Deviation:	199.74
Skewness:	Not available
Kurtosis:	Not available

☑ Fill Area ☐ Show Marker

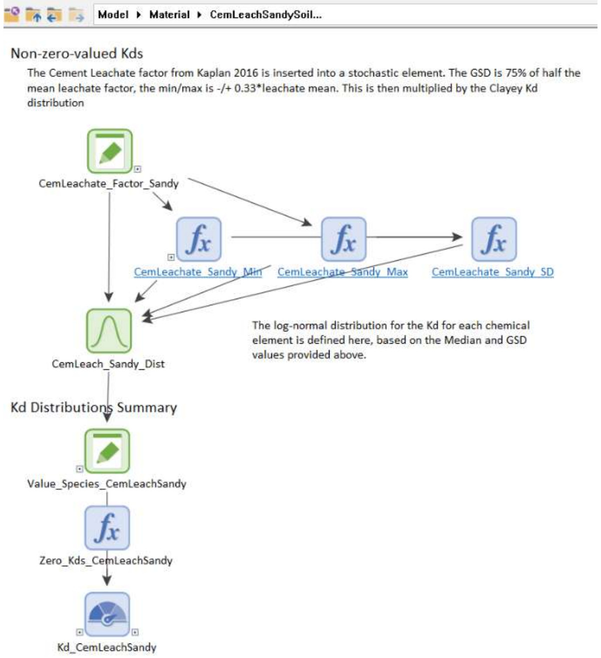
Calculator

Cum.Probability: 0.5 <-> Value: (mL/g) 1000

Probability Density: 0.00199506

Cond. Tail Expectation: 1159.5 mL/g

Figure A.5. ***Kd_Dist_Sandy*** **stochastic element, applied for each species being modeled.**



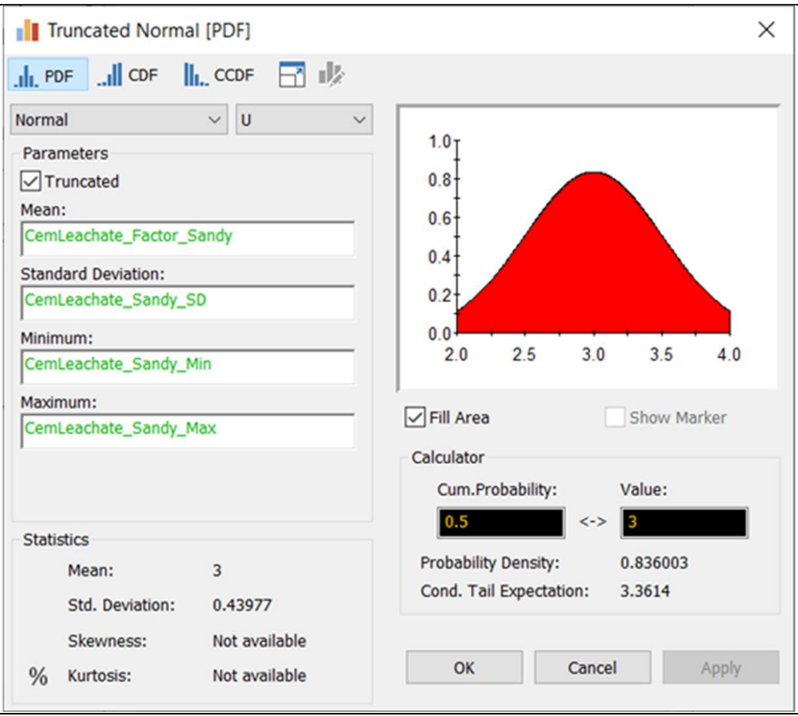
Non-zero-valued Kds

The Cement Leachate factor from Kaplan 2016 is inserted into a stochastic element. The GSD is 75% of half the mean leachate factor, the min/max is -/+ 0.33*leachate mean. This is then multiplied by the Clayey Kd distribution

The log-normal distribution for the Kd for each chemical element is defined here, based on the Median and GSD values provided above.

Kd Distributions Summary

Figure A.6. ***CemLeachSandySoilKds*** **container.**



Normal
U

Parameters

☑ Truncated

Mean: CemLeachate_Factor_Sandy

Standard Deviation: CemLeachate_Sandy_SD

Minimum: CemLeachate_Sandy_Min

Maximum: CemLeachate_Sandy_Max

Statistics

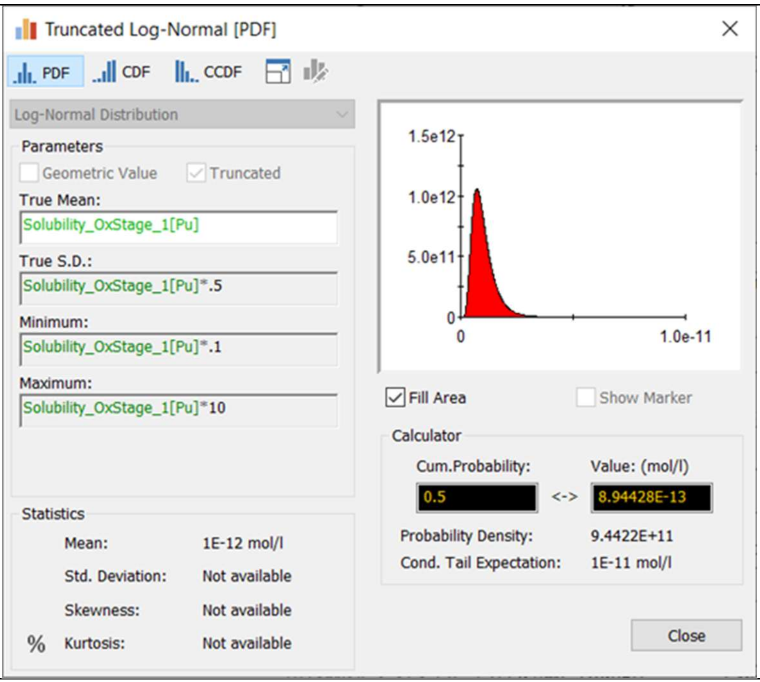
Mean:	3
Std. Deviation:	0.43977
Skewness:	Not available
Kurtosis:	Not available

Calculator

Cum.Probability: 0.5 <-> Value: 3

Probability Density:	0.836003
Cond. Tail Expectation:	3.3614

Figure A.7. ***CemLeach_Sandy_Dist*** **stochastic element, applied for each element being modeled.**



Log-Normal Distribution

Parameters

☐ Geometric Value ☑ Truncated

True Mean: Solubility_OxStage_1[Pu]

True S.D.: Solubility_OxStage_1[Pu]*.5

Minimum: Solubility_OxStage_1[Pu]*.1

Maximum: Solubility_OxStage_1[Pu]*10

Statistics

Mean:	1E-12 mol/l
Std. Deviation:	Not available
Skewness:	Not available
Kurtosis:	Not available

Calculator

Cum.Probability: 0.5 <-> Value: (mol/l) 8.94428E-13

Probability Density:	9.4422E+11
Cond. Tail Expectation:	1E-11 mol/l

Figure A.8. ***Pu_sol_young*** **stochastic element used in** ***Water_Solubility_Concrete*** **container.**

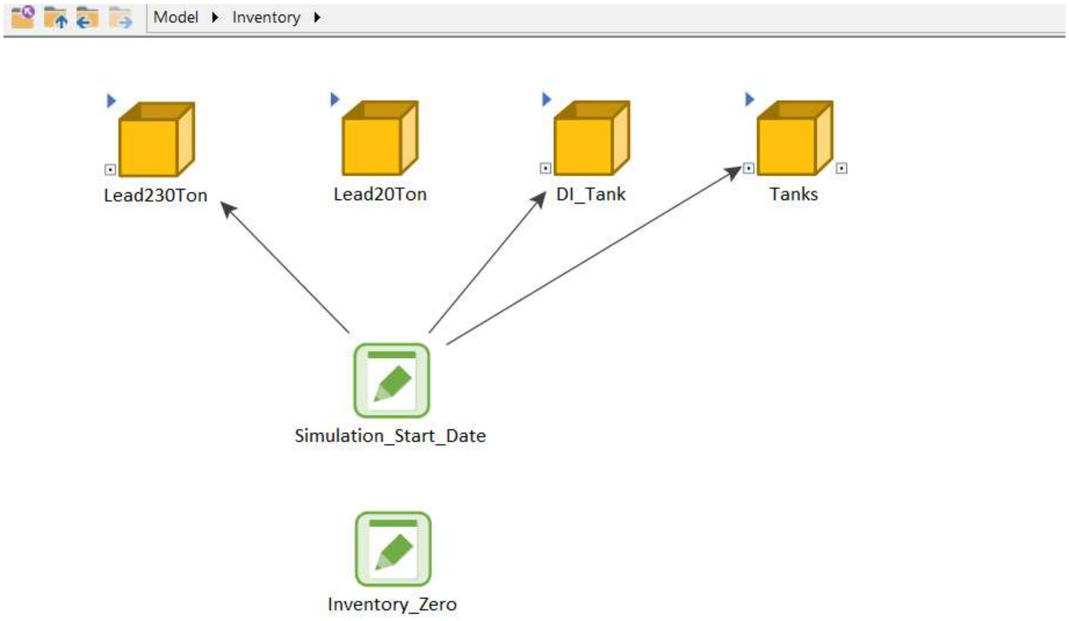


Figure A.9. ***Inventory*** **container.**

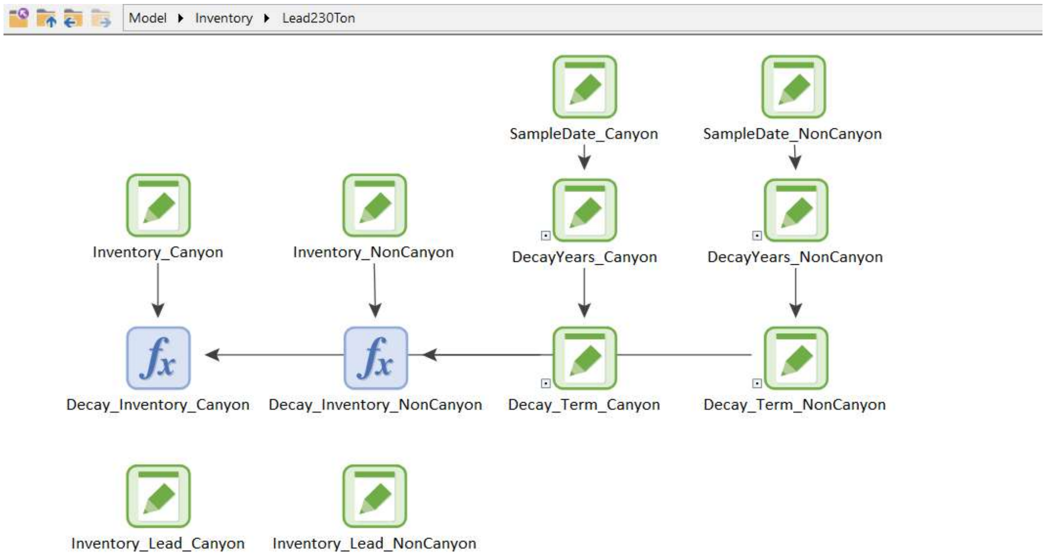


Figure A.10. ***Lead230Ton*** **container that specifies the initial and decayed inventory for canyon and noncanyon radionuclides and lead.**

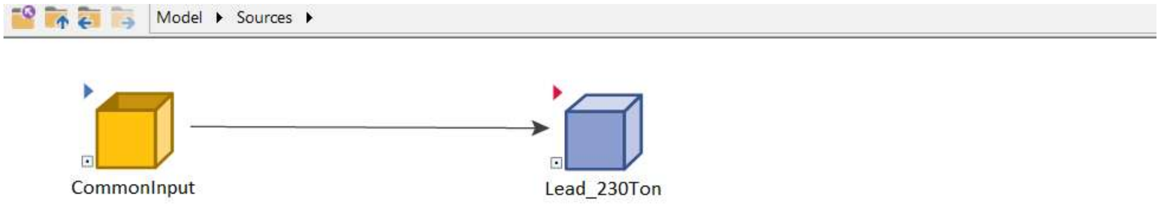


Figure A.11. *Sources* container (230-ton lead source example shown).

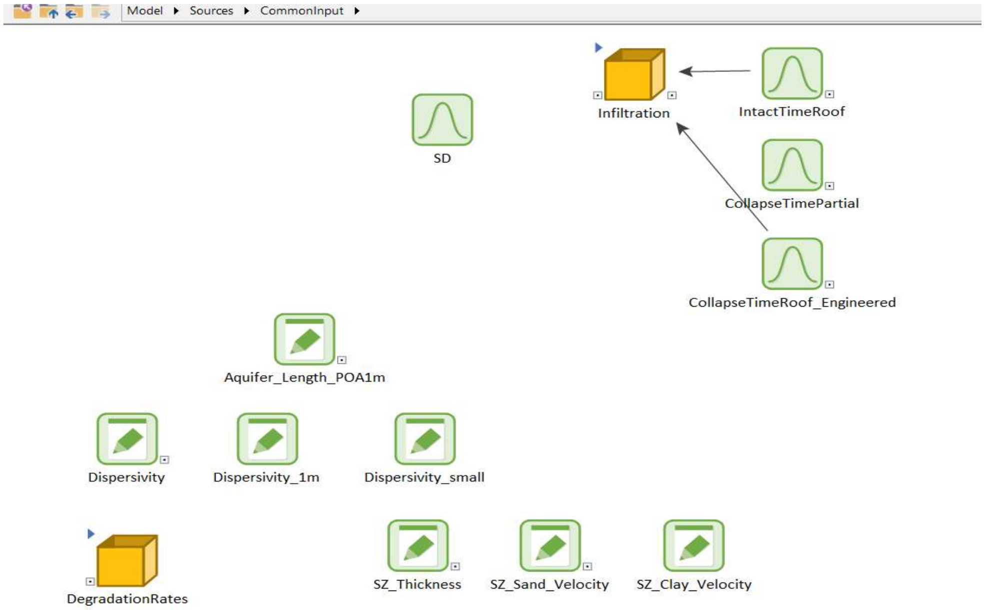


Figure A.12. *CommonInput* container.

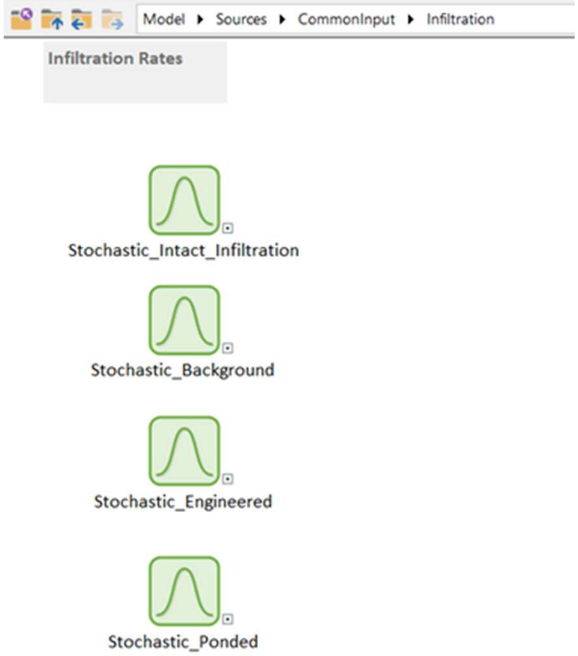
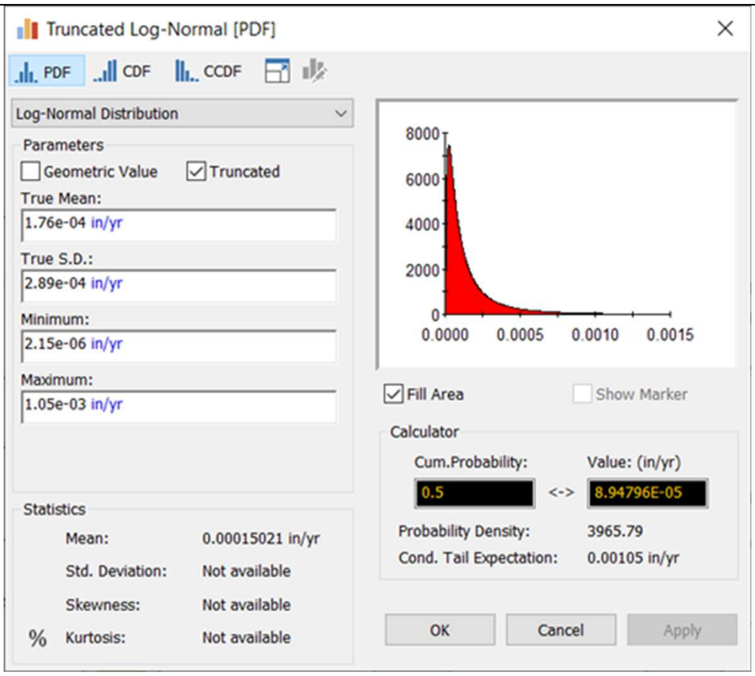


Figure A.13. ***Infiltration*** **container.**



Log-Normal Distribution

Parameters

☐ Geometric Value ☑ Truncated

True Mean: 1.76e-04 in/yr

True S.D.: 2.89e-04 in/yr

Minimum: 2.15e-06 in/yr

Maximum: 1.05e-03 in/yr

Statistics

Mean:	0.00015021 in/yr
Std. Deviation:	Not available
Skewness:	Not available
Kurtosis:	Not available

☑ Fill Area ☐ Show Marker

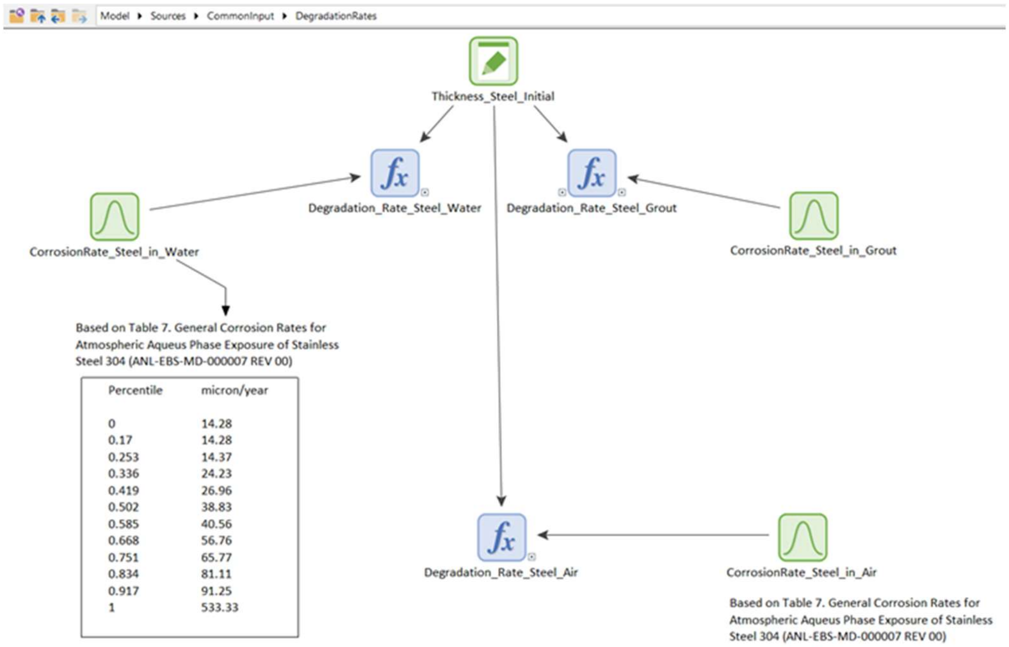
Calculator

Cum.Probability: 0.5 <-> Value: (in/yr) 8.94796E-05

Probability Density: 3965.79

Cond. Tail Expectation: 0.00105 in/yr

Figure A.14. ***Stochastic_Intact_Infiltration*** **stochastic element used in** ***Infiltration*** **container.**



Based on Table 7. General Corrosion Rates for Atmospheric Aqueus Phase Exposure of Stainless Steel 304 (ANL-EBS-MD-000007 REV 00)

Percentile	micron/year
0	14.28
0.17	14.28
0.253	14.37
0.336	24.23
0.419	26.96
0.502	38.83
0.585	40.56
0.668	56.76
0.751	65.77
0.834	81.11
0.917	91.25
1	533.33

Based on Table 7. General Corrosion Rates for Atmospheric Aqueus Phase Exposure of Stainless Steel 304 (ANL-EBS-MD-000007 REV 00)

Figure A.15. ***DegradationRates*** **container.**

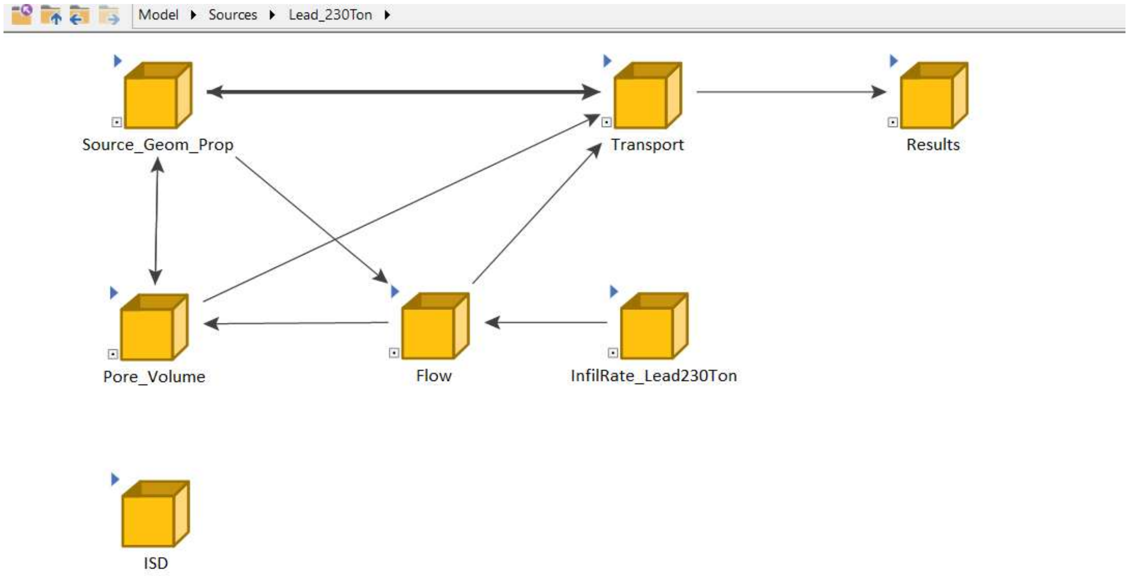


Figure A.16. ***Lead_230Ton*** **localized container. The structure of this container is the same for each source.**

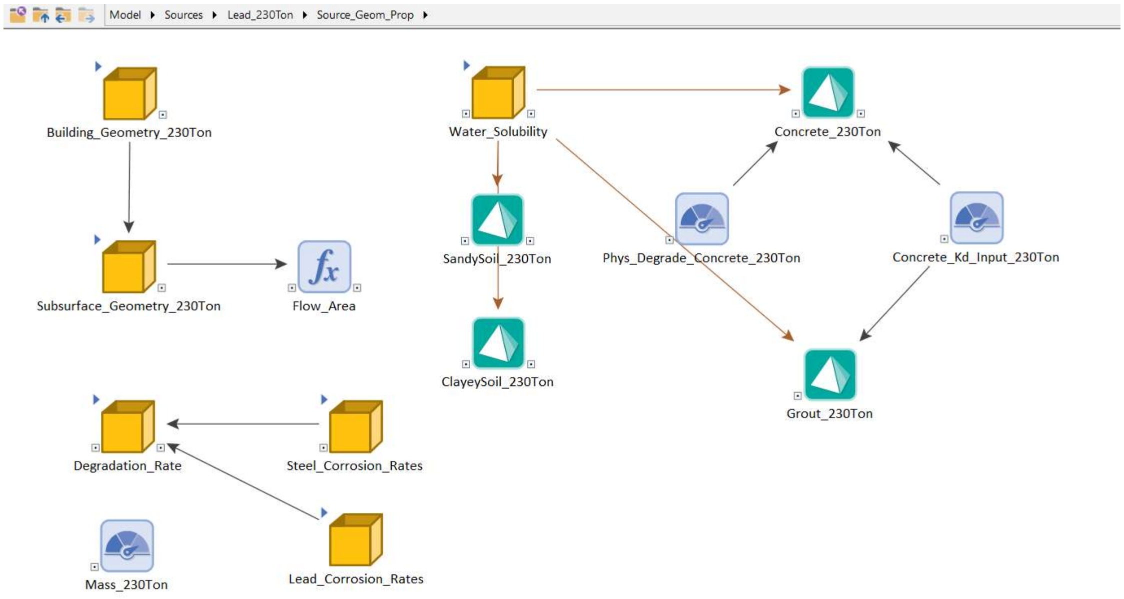


Figure A.17. ***Source_Geom_Prop*** **container for 230-ton lead source.**

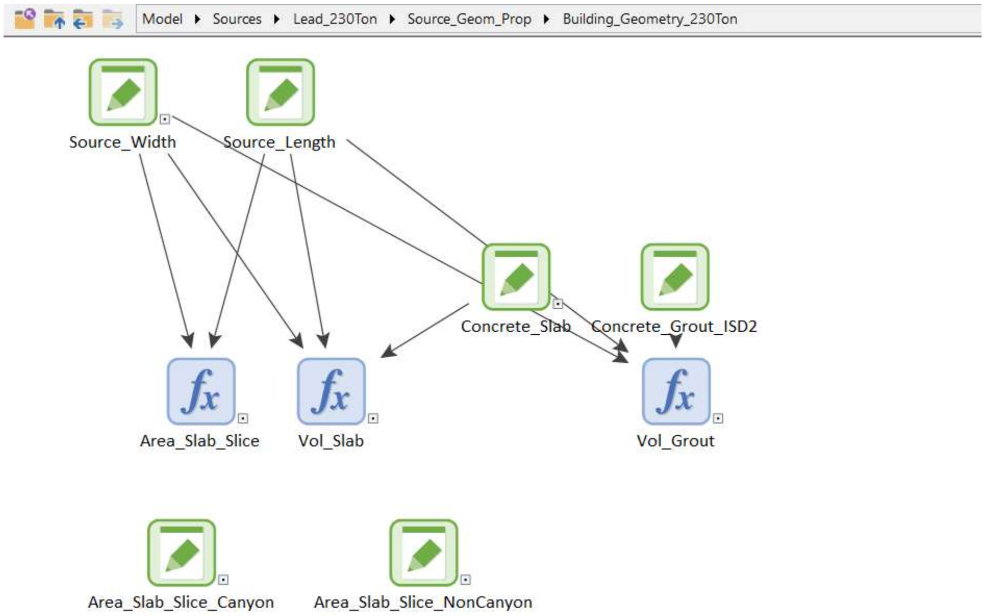


Figure A.18. ***Building_Geometry_230Ton*** **container within** ***Source_Geom_Prop*** **container.**

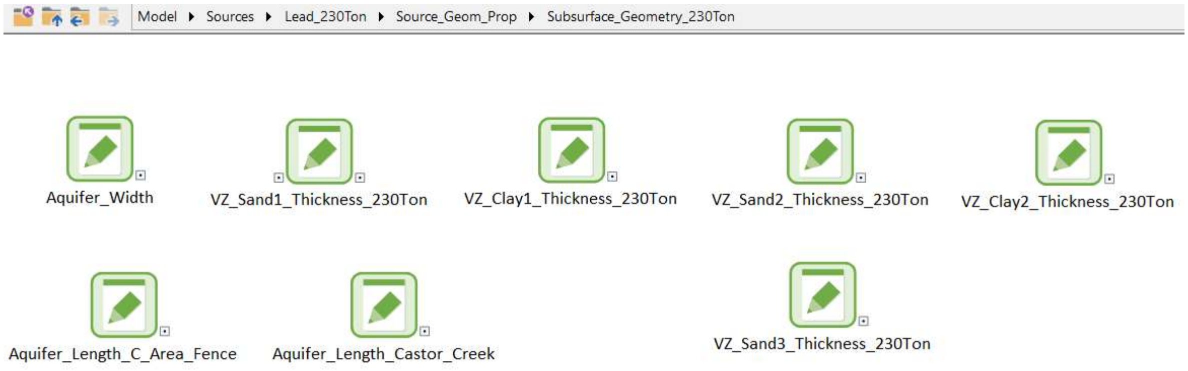


Figure A.19. ***Subsurface_Geometry_230Ton*** **container within** ***Source_Geom_Prop*** **container.**

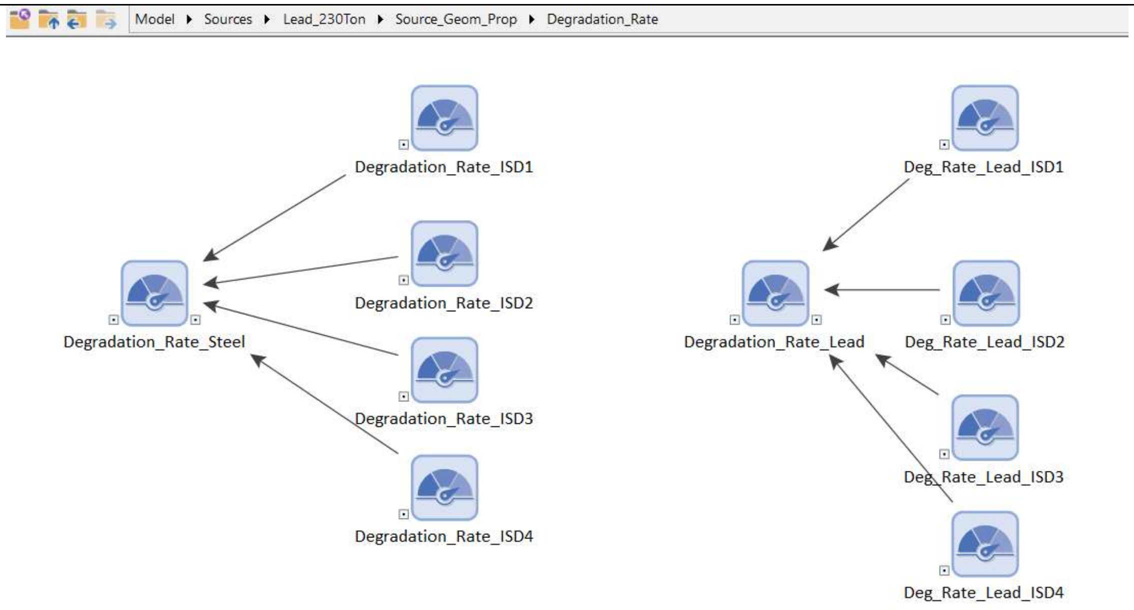
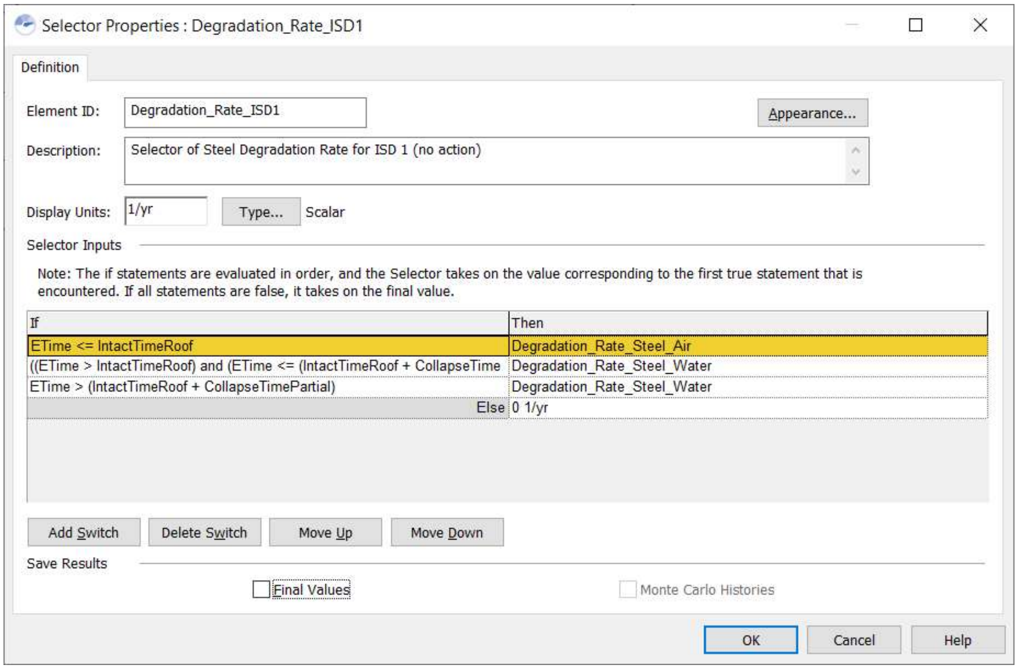


Figure A.20. ***Degradation_Rate*** **container within** ***Source_Geom_Prop*** **container.**



Selector Properties : Degradation_Rate_ISD1

Element ID: Degradation_Rate_ISD1

Description: Selector of Steel Degradation Rate for ISD 1 (no action)

Display Units: 1/yr Scalar

Selector Inputs

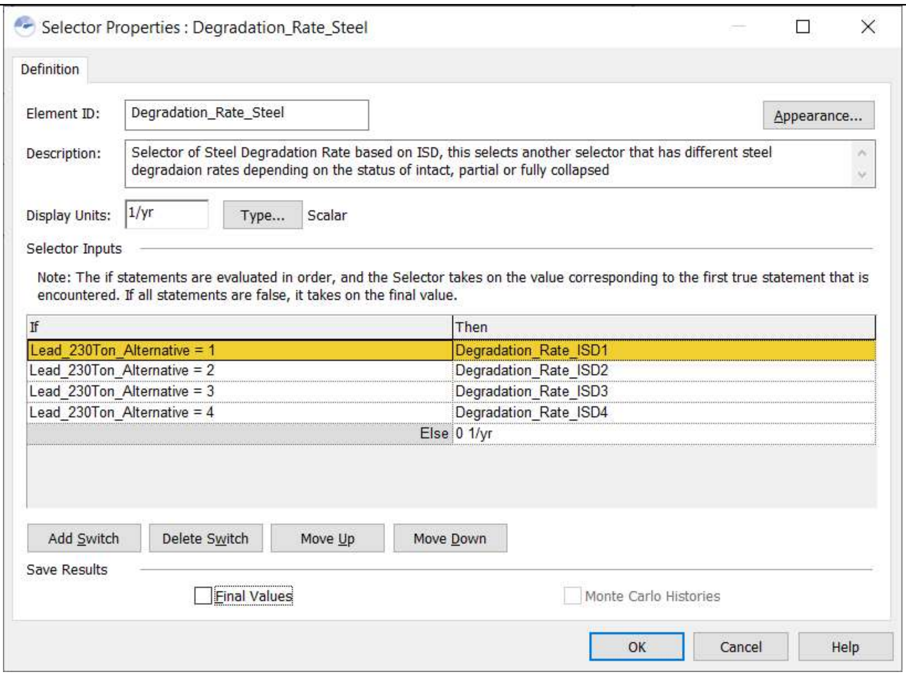
Note: The if statements are evaluated in order, and the Selector takes on the value corresponding to the first true statement that is encountered. If all statements are false, it takes on the final value.

If	Then
ETime <= IntactTimeRoof	Degradation_Rate_Steel_Air
((ETime > IntactTimeRoof) and (ETime <= (IntactTimeRoof + CollapseTime	Degradation_Rate_Steel_Water
ETime > (IntactTimeRoof + CollapseTimePartial)	Degradation_Rate_Steel_Water
Else	0 1/yr

Save Results

☐ Final Values ☐ Monte Carlo Histories

Figure A.21. *Degradation_Rate_ISD1* selector element in Lead_230Ton\Source_Geom_Prop\Degradation_Rate.



Selector Properties : Degradation_Rate_Steel

Element ID: Degradation_Rate_Steel

Description: Selector of Steel Degradation Rate based on ISD, this selects another selector that has different steel degradaion rates depending on the status of intact, partial or fully collapsed

Display Units: 1/yr Scalar

Selector Inputs

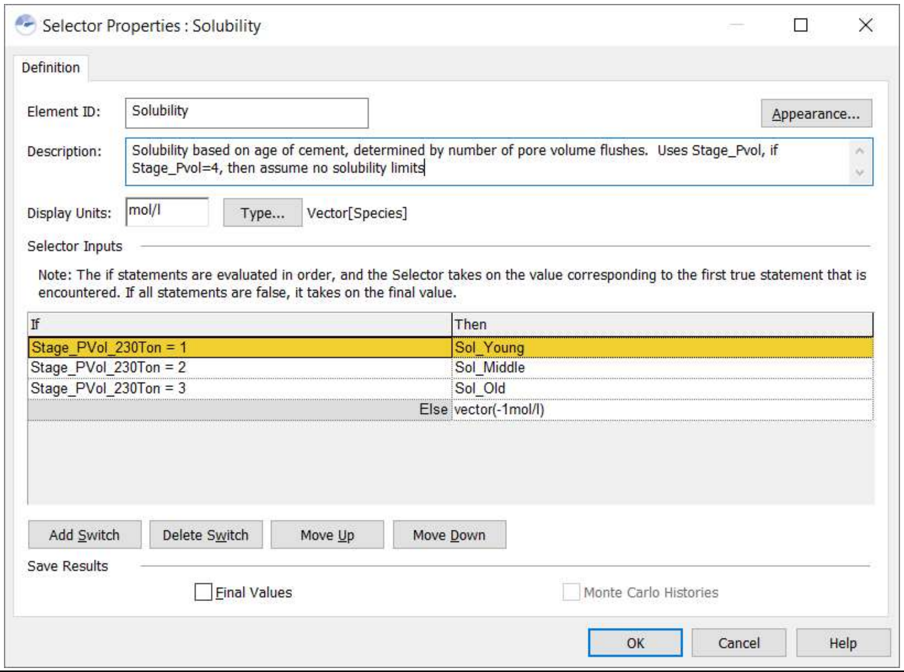
Note: The if statements are evaluated in order, and the Selector takes on the value corresponding to the first true statement that is encountered. If all statements are false, it takes on the final value.

If	Then
Lead_230Ton_Alternative = 1	Degradation_Rate_ISD1
Lead_230Ton_Alternative = 2	Degradation_Rate_ISD2
Lead_230Ton_Alternative = 3	Degradation_Rate_ISD3
Lead_230Ton_Alternative = 4	Degradation_Rate_ISD4
Else	0 1/yr

Save Results

☐ Final Values ☐ Monte Carlo Histories

Figure A.22. *Degradation_Rate_Steel* selector element in Lead_230Ton\Source_Geom_Prop\Degradation_Rate.



Selector Properties : Solubility

Element ID: Solubility

Description: Solubility based on age of cement, determined by number of pore volume flushes. Uses Stage_Pvol, if Stage_Pvol=4, then assume no solubility limits

Display Units: mol/l Vector[Species]

Selector Inputs

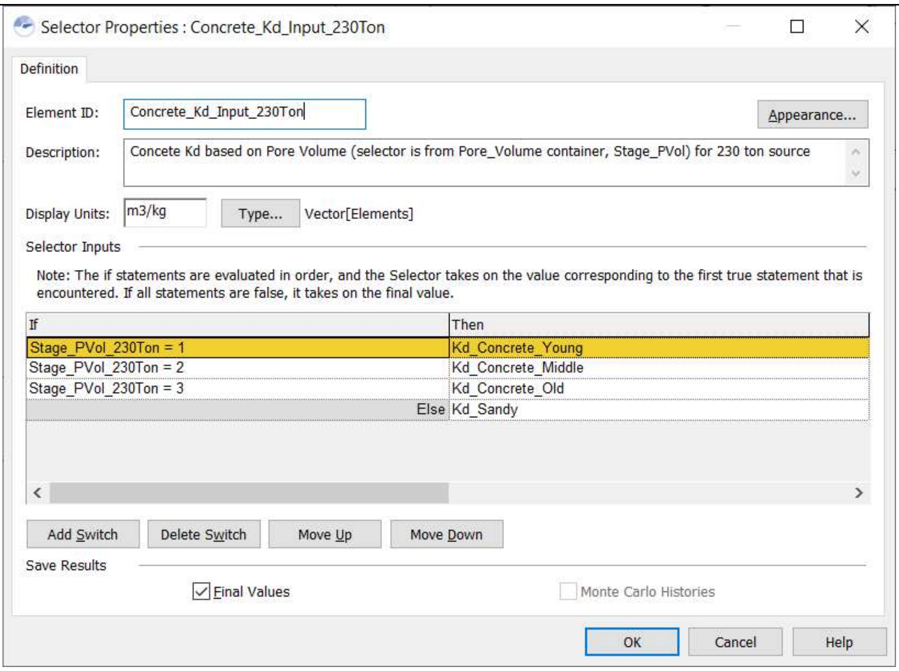
Note: The if statements are evaluated in order, and the Selector takes on the value corresponding to the first true statement that is encountered. If all statements are false, it takes on the final value.

If	Then
Stage_PVol_230Ton = 1	Sol_Young
Stage_PVol_230Ton = 2	Sol_Middle
Stage_PVol_230Ton = 3	Sol_Old
Else	vector(-1mol/l)

Save Results

☐ Final Values ☐ Monte Carlo Histories

Figure A.23. *Solubility* selector element (solubility based on the age of cement that is dependent on the number of pore volumes).



Selector Properties : Concrete_Kd_Input_230Ton

Element ID: Concrete_Kd_Input_230Ton

Description: Concete Kd based on Pore Volume (selector is from Pore_Volume container, Stage_PVol) for 230 ton source

Display Units: m3/kg Vector[Elements]

Selector Inputs

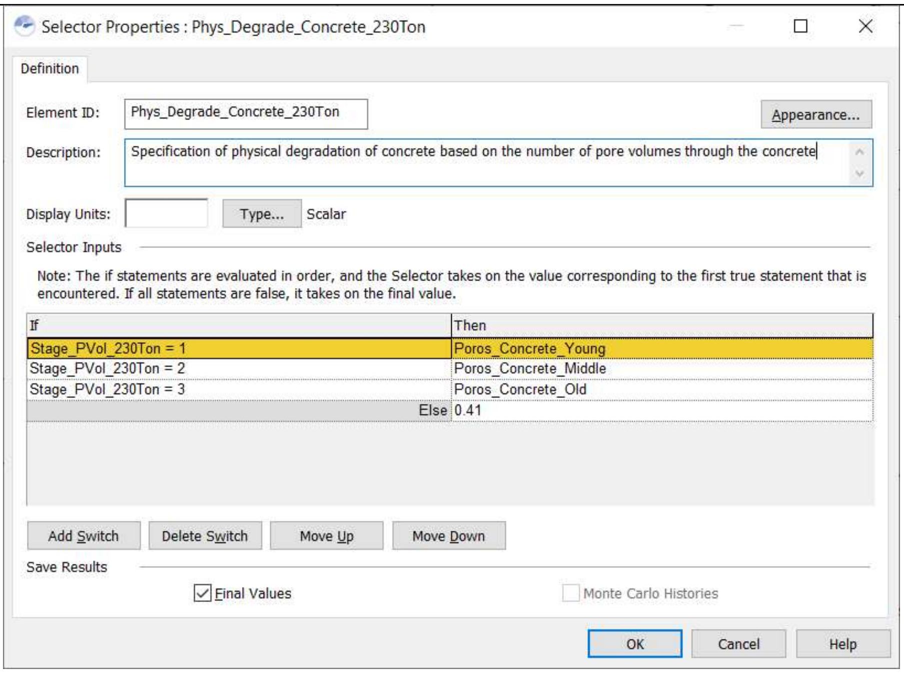
Note: The if statements are evaluated in order, and the Selector takes on the value corresponding to the first true statement that is encountered. If all statements are false, it takes on the final value.

If	Then
Stage_PVol_230Ton = 1	Kd_Concrete_Young
Stage_PVol_230Ton = 2	Kd_Concrete_Middle
Stage_PVol_230Ton = 3	Kd_Concrete_Old
Else	Kd_Sandy

Save Results

☑ Final Values ☐ Monte Carlo Histories

Figure A.24. *Concrete_Kd_Input_230Ton* selector element (K_d based on the age of the cement that is dependent on the number of pore volumes).


Selector Properties : Phys_Degrade_Concrete_230Ton

Element ID: Phys_Degrade_Concrete_230Ton

Description: Specification of physical degradation of concrete based on the number of pore volumes through the concrete

Display Units:

Scalar

Selector Inputs

Note: The if statements are evaluated in order, and the Selector takes on the value corresponding to the first true statement that is encountered. If all statements are false, it takes on the final value.

If	Then
Stage_PVol_230Ton = 1	Poros_Concrete_Young
Stage_PVol_230Ton = 2	Poros_Concrete_Middle
Stage_PVol_230Ton = 3	Poros_Concrete_Old
Else	0.41

Save Results

☑ Final Values ☐ Monte Carlo Histories

Figure A.25. *Phys_Degrade_Concrete_230Ton* selector element (porosity of concrete based on the number of pore volumes).

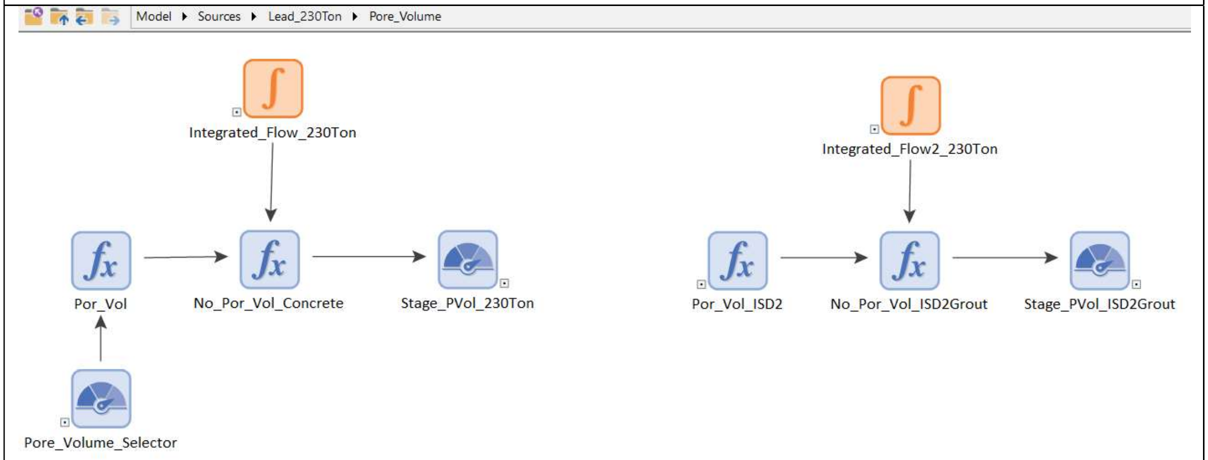


Figure A.26. *Pore_Volume* container for 230-ton lead source.

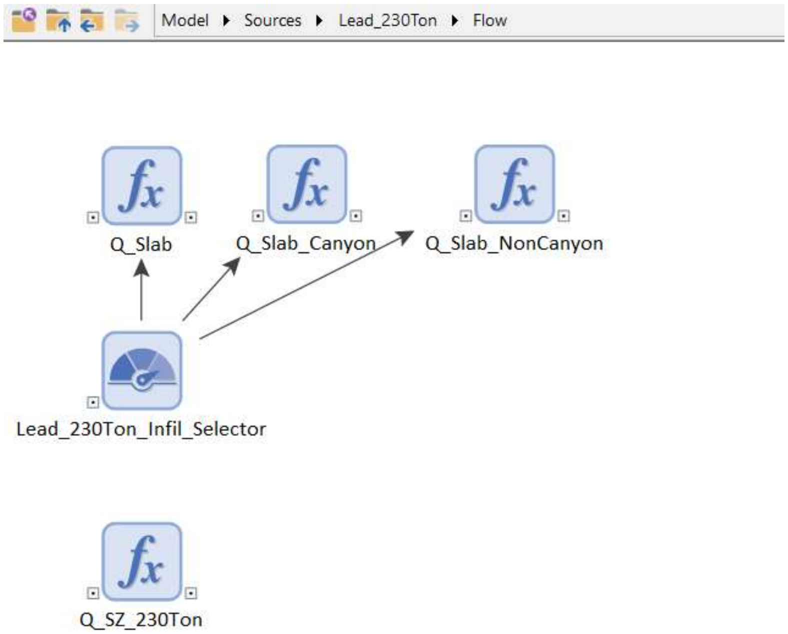
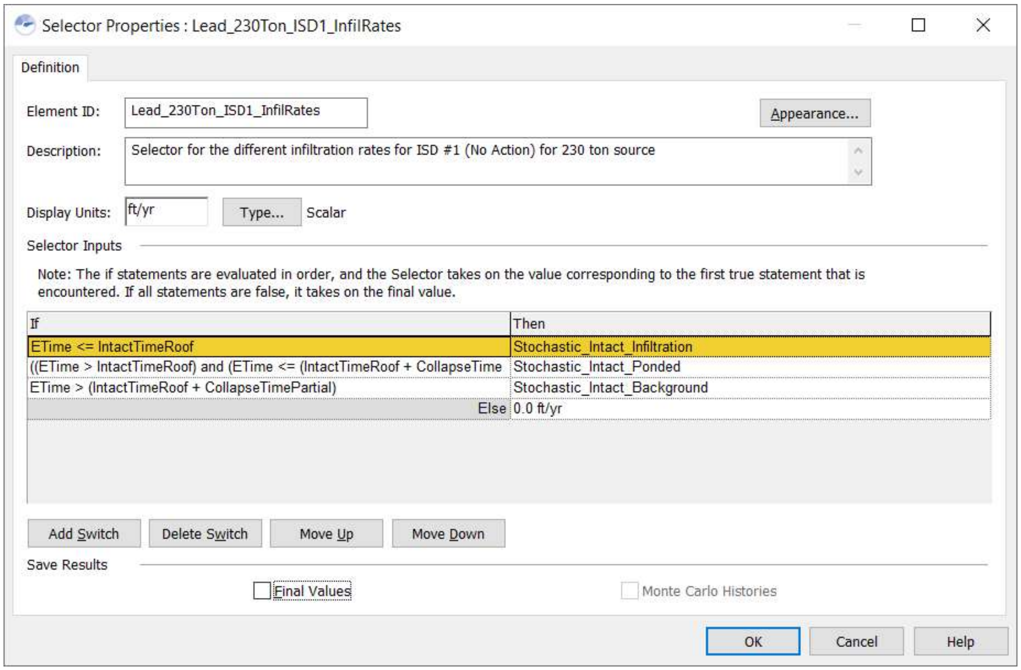


Figure A.27. ***Flow*** **container for 230-ton lead source.**

Figure A.28. ***InfilRate_Lead230Ton*** **container for 230 ton source (infiltration rates based on ISD scenario being simulated).**



Element ID: Lead_230Ton_ISD1_InfilRates

Description: Selector for the different infiltration rates for ISD #1 (No Action) for 230 ton source

Display Units: ft/yr Scalar

Selector Inputs

Note: The if statements are evaluated in order, and the Selector takes on the value corresponding to the first true statement that is encountered. If all statements are false, it takes on the final value.

If	Then
ETime <= IntactTimeRoof	Stochastic_Intact_Infiltration
((ETime > IntactTimeRoof) and (ETime <= (IntactTimeRoof + CollapseTime	Stochastic_Intact_Ponded
ETime > (IntactTimeRoof + CollapseTimePartial)	Stochastic_Intact_Background
Else	0.0 ft/yr

Save Results

☐ Final Values ☐ Monte Carlo Histories

Figure A.29. ***Lead_230Ton_ISD1_InfilRates*** **selector element (infiltration rates for ISD 1 for 230 ton source).**

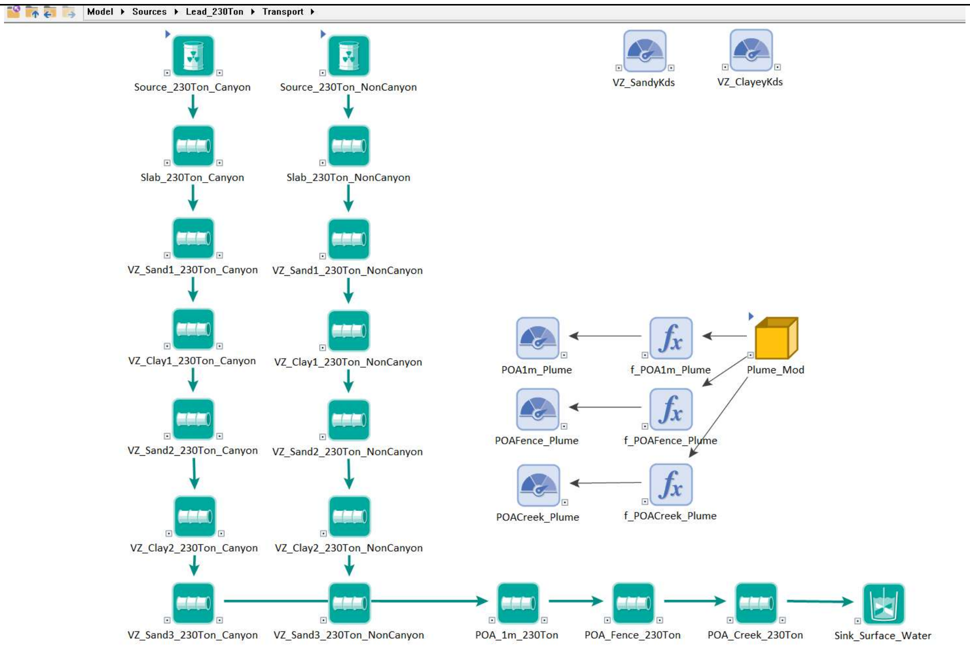
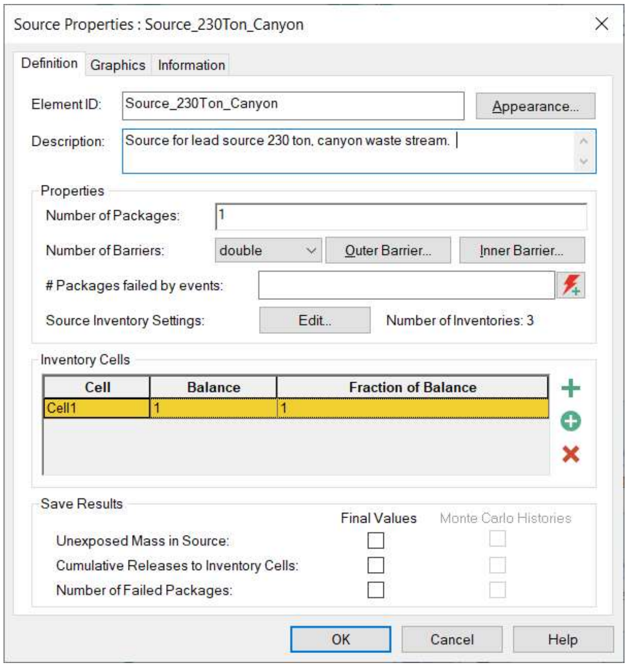


Figure A.30. ***Transport*** **container for 230-ton lead source.**


Source Properties : Source_230Ton_Canyon

Definition | Graphics | Information

Element ID: Source_230Ton_Canyon

Description: Source for lead source 230 ton, canyon waste stream.

Properties

Number of Packages: 1

Number of Barriers: double

Packages failed by events:

Source Inventory Settings: Number of Inventories: 3

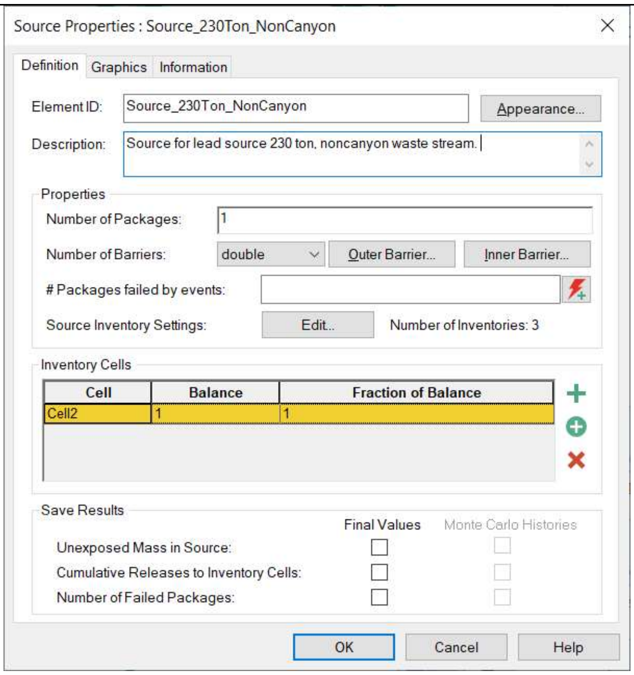
Inventory Cells

Cell	Balance	Fraction of Balance
Cell1	1	1

Save Results

	Final Values	Monte Carlo Histories
Unexposed Mass in Source:	☐	☐
Cumulative Releases to Inventory Cells:	☐	☐
Number of Failed Packages:	☐	☐

Figure A.31. ***Source_230Ton_Canyon*** **element for 230-ton lead source.**


Source Properties : Source_230Ton_NonCanyon

Definition | Graphics | Information

Element ID: Source_230Ton_NonCanyon

Description: Source for lead source 230 ton, noncanyon waste stream.

Properties

Number of Packages: 1

Number of Barriers: double

Packages failed by events:

Source Inventory Settings: Number of Inventories: 3

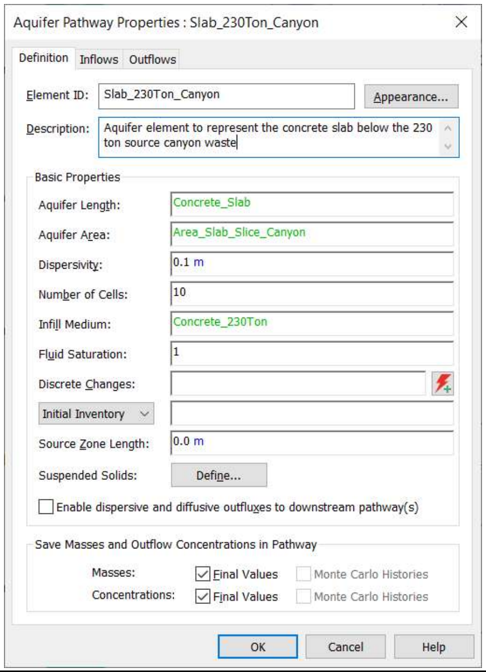
Inventory Cells

Cell	Balance	Fraction of Balance
Cell2	1	1

Save Results

	Final Values	Monte Carlo Histories
Unexposed Mass in Source:	☐	☐
Cumulative Releases to Inventory Cells:	☐	☐
Number of Failed Packages:	☐	☐

Figure A.32. ***Source_230Ton_NonCanyon*** **element for 230-ton lead source.**



Aquifer Pathway Properties : Slab_230Ton_Canyon

Definition | Inflows | Outflows

Element ID: Slab_230Ton_Canyon

Description: Aquifer element to represent the concrete slab below the 230 ton source canyon waste

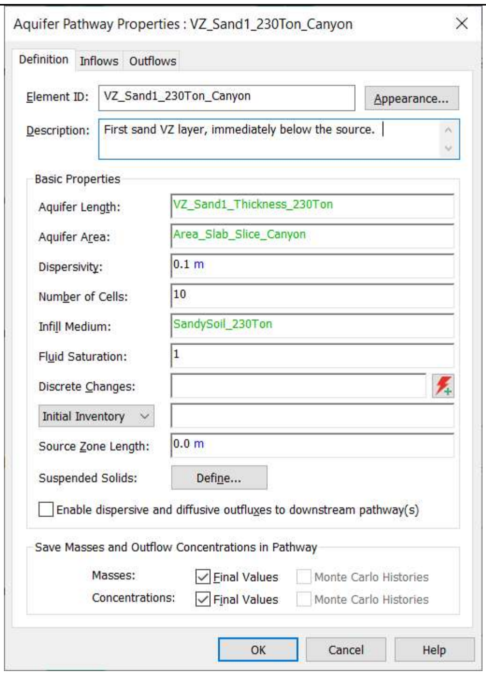
Basic Properties

Aquifer Length: Concrete_Slab
Aquifer Area: Area_Slab_Slice_Canyon
Dispersivity: 0.1 m
Number of Cells: 10
Infill Medium: Concrete_230Ton
Fluid Saturation: 1
Discrete Changes:
Initial Inventory:
Source Zone Length: 0.0 m
Suspended Solids: Define...
☐ Enable dispersive and diffusive outfluxes to downstream pathway(s)

Save Masses and Outflow Concentrations in Pathway

Masses: ☑ Final Values ☐ Monte Carlo Histories
Concentrations: ☑ Final Values ☐ Monte Carlo Histories

Figure A.33. ***Slab_230Ton_Canyon*** **aquifer element for 230-ton lead source.**



Aquifer Pathway Properties : VZ_Sand1_230Ton_Canyon

Definition | Inflows | Outflows

Element ID: VZ_Sand1_230Ton_Canyon

Description: First sand VZ layer, immediately below the source.

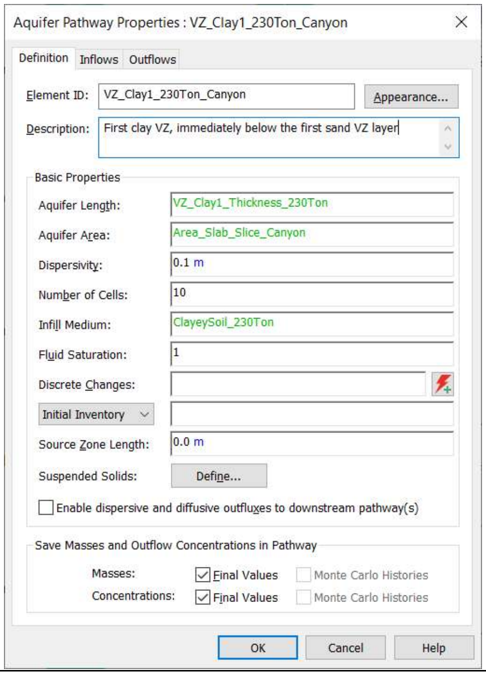
Basic Properties

Aquifer Length: VZ_Sand1_Thickness_230Ton
Aquifer Area: Area_Slab_Slice_Canyon
Dispersivity: 0.1 m
Number of Cells: 10
Infill Medium: SandySoil_230Ton
Fluid Saturation: 1
Discrete Changes:
Initial Inventory:
Source Zone Length: 0.0 m
Suspended Solids: Define...
☐ Enable dispersive and diffusive outfluxes to downstream pathway(s)

Save Masses and Outflow Concentrations in Pathway

Masses: ☑ Final Values ☐ Monte Carlo Histories
Concentrations: ☑ Final Values ☐ Monte Carlo Histories

Figure A.34. ***VZ_Sand1_230Ton*** **aquifer element for 230-ton lead source.**



Aquifer Pathway Properties : VZ_Clay1_230Ton_Canyon

Element ID: VZ_Clay1_230Ton_Canyon

Description: First clay VZ, immediately below the first sand VZ layer

Basic Properties

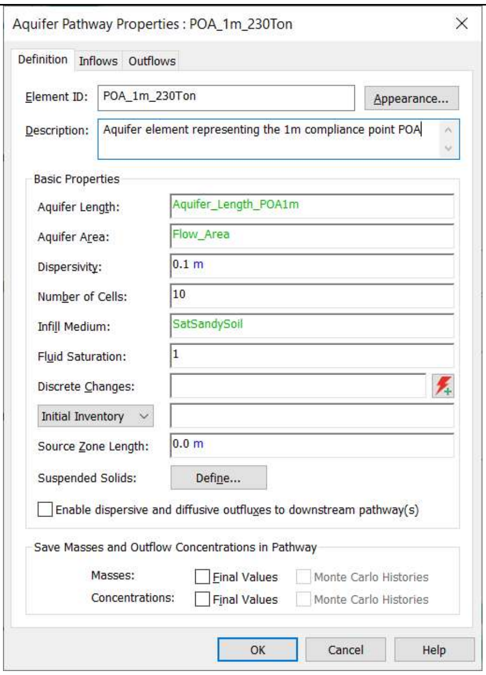
Aquifer Length: VZ_Clay1_Thickness_230Ton
Aquifer Area: Area_Slab_Slice_Canyon
Dispersivity: 0.1 m
Number of Cells: 10
Infill Medium: ClayeySoil_230Ton
Fluid Saturation: 1
Discrete Changes:
Initial Inventory:
Source Zone Length: 0.0 m
Suspended Solids:

☐ Enable dispersive and diffusive outfluxes to downstream pathway(s)

Save Masses and Outflow Concentrations in Pathway

Masses: ☑ Final Values ☐ Monte Carlo Histories
Concentrations: ☑ Final Values ☐ Monte Carlo Histories

Figure A.35. *VZ_Clay1_230Ton_Canyon* aquifer element for 230-ton lead source.



Aquifer Pathway Properties : POA_1m_230Ton

Element ID: POA_1m_230Ton

Description: Aquifer element representing the 1m compliance point POA

Basic Properties

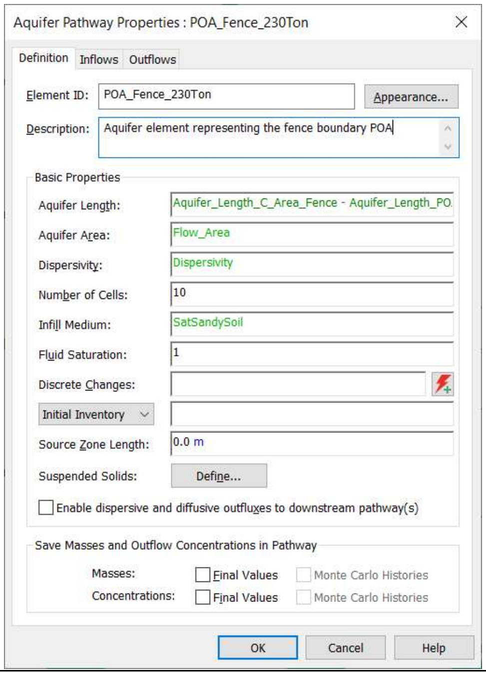
Aquifer Length: Aquifer_Length_POA1m
Aquifer Area: Flow_Area
Dispersivity: 0.1 m
Number of Cells: 10
Infill Medium: SatSandySoil
Fluid Saturation: 1
Discrete Changes:
Initial Inventory:
Source Zone Length: 0.0 m
Suspended Solids:

☐ Enable dispersive and diffusive outfluxes to downstream pathway(s)

Save Masses and Outflow Concentrations in Pathway

Masses: ☐ Final Values ☐ Monte Carlo Histories
Concentrations: ☐ Final Values ☐ Monte Carlo Histories

Figure A.36. *POA_1m_230Ton* aquifer element for 230-ton lead source.



Element ID: POA_Fence_230Ton

Description: Aquifer element representing the fence boundary POA

Aquifer Length: Aquifer_Length_C_Area_Fence - Aquifer_Length_PO

Aquifer Area: Flow_Area

Dispersivity: Dispersivity

Number of Cells: 10

Infill Medium: SatSandySoil

Fluid Saturation: 1

Discrete Changes:

Initial Inventory:

Source Zone Length: 0.0 m

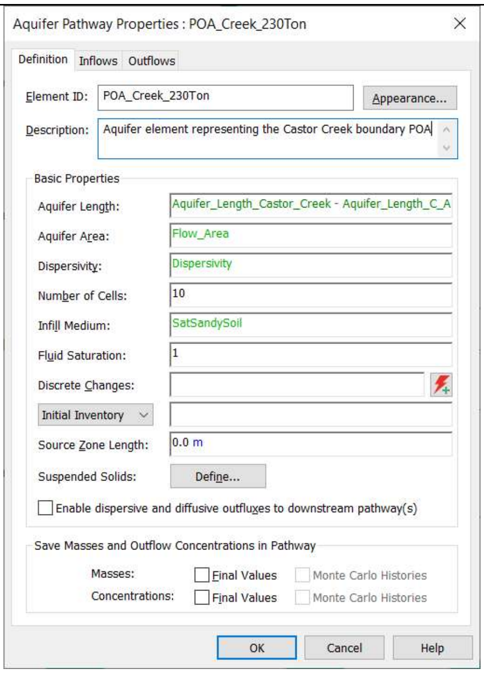
Suspended Solids: Define...

☐ Enable dispersive and diffusive outfluxes to downstream pathway(s)

Masses: ☐ Final Values ☐ Monte Carlo Histories

Concentrations: ☐ Final Values ☐ Monte Carlo Histories

Figure A.37. ***POA_Fence_230Ton*** **aquifer element for 230-ton lead source.**



Element ID: POA_Creek_230Ton

Description: Aquifer element representing the Castor Creek boundary POA

Aquifer Length: Aquifer_Length_Castor_Creek - Aquifer_Length_C_A

Aquifer Area: Flow_Area

Dispersivity: Dispersivity

Number of Cells: 10

Infill Medium: SatSandySoil

Fluid Saturation: 1

Discrete Changes:

Initial Inventory:

Source Zone Length: 0.0 m

Suspended Solids: Define...

☐ Enable dispersive and diffusive outfluxes to downstream pathway(s)

Masses: ☐ Final Values ☐ Monte Carlo Histories

Concentrations: ☐ Final Values ☐ Monte Carlo Histories

Figure A.38. ***POA_Creek_230Ton*** **aquifer element for 230-ton lead source.**

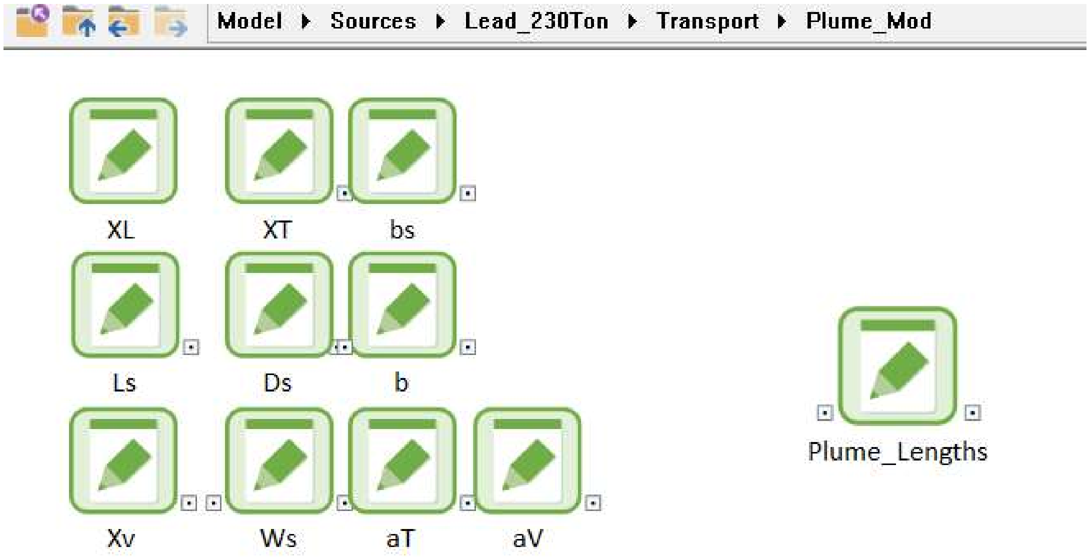


Figure A.39. ***Plume_Mod*** **container for 230-ton lead source.**

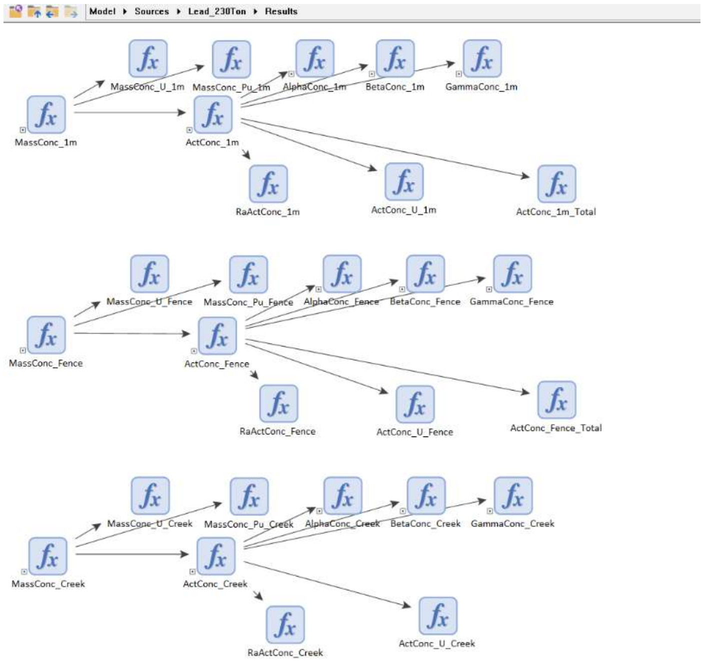


Figure A.40. ***Results*** **container for 230-ton lead source.**

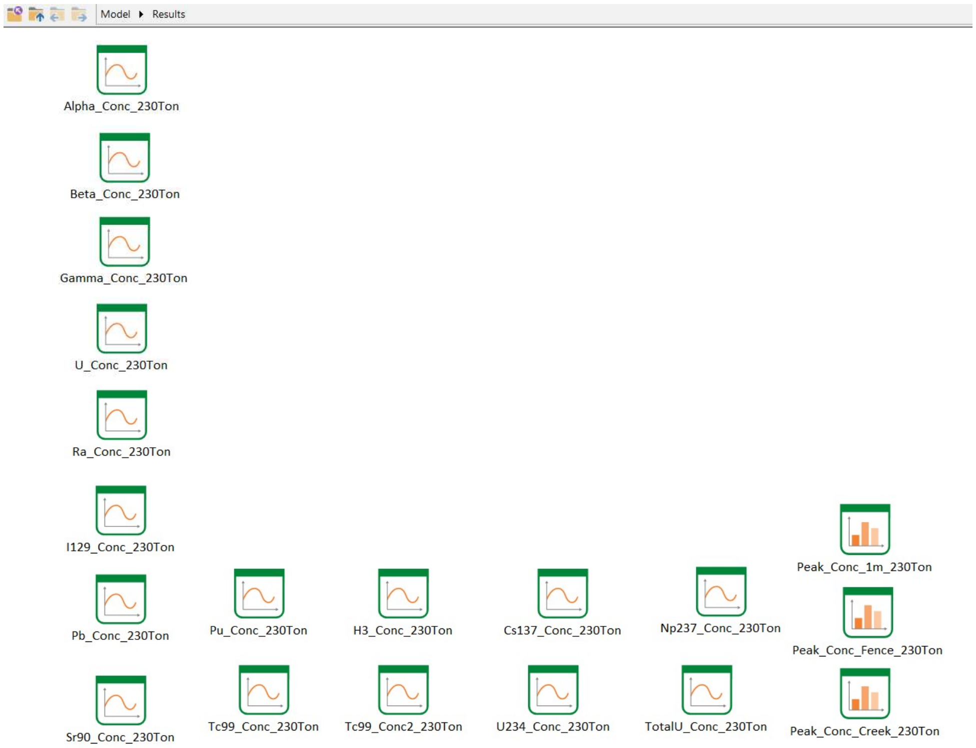


Figure A.41. ***Results*** **container at top level of model (230-ton lead source shown).**

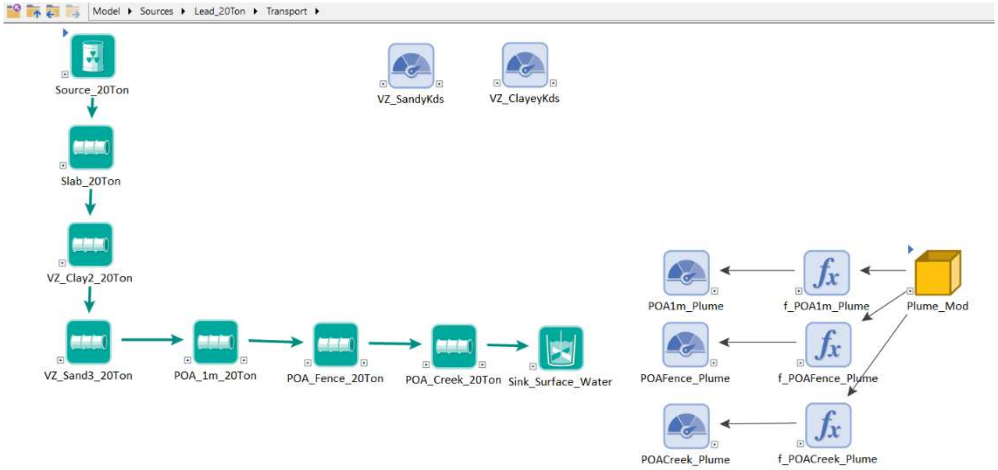


Figure A.42. ***Transport*** **container for 20-ton lead source.**

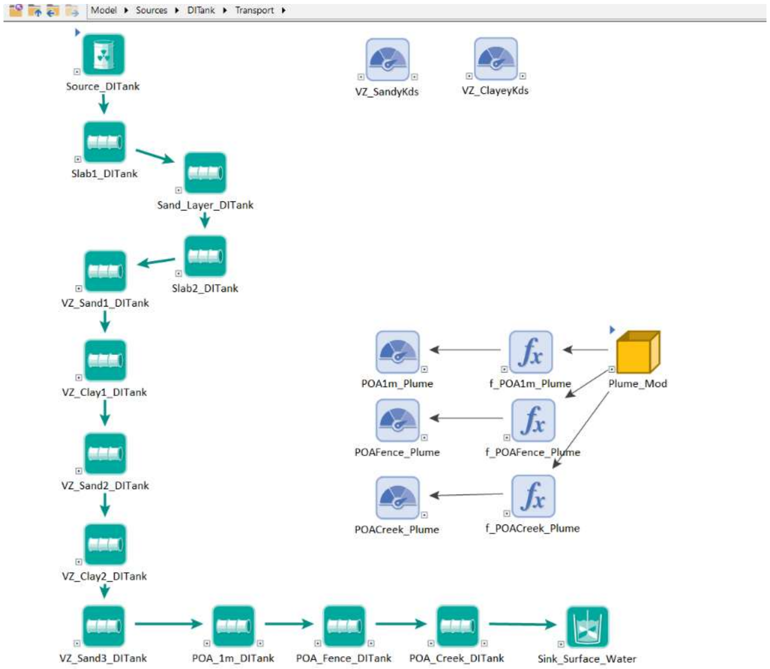


Figure A.43. ***Transport*** **container for deionizer tank source.**

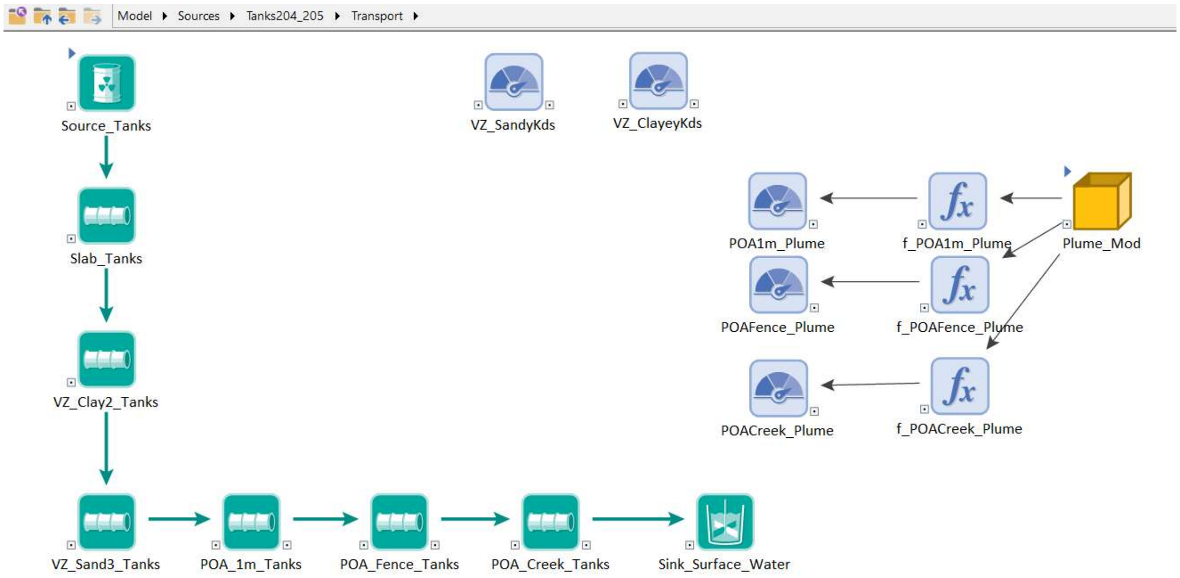


Figure A.44. ***Transport*** **container for Tank 204 & 205 source.**

Appendix B: 20-Ton Source GoldSim® Model Figures

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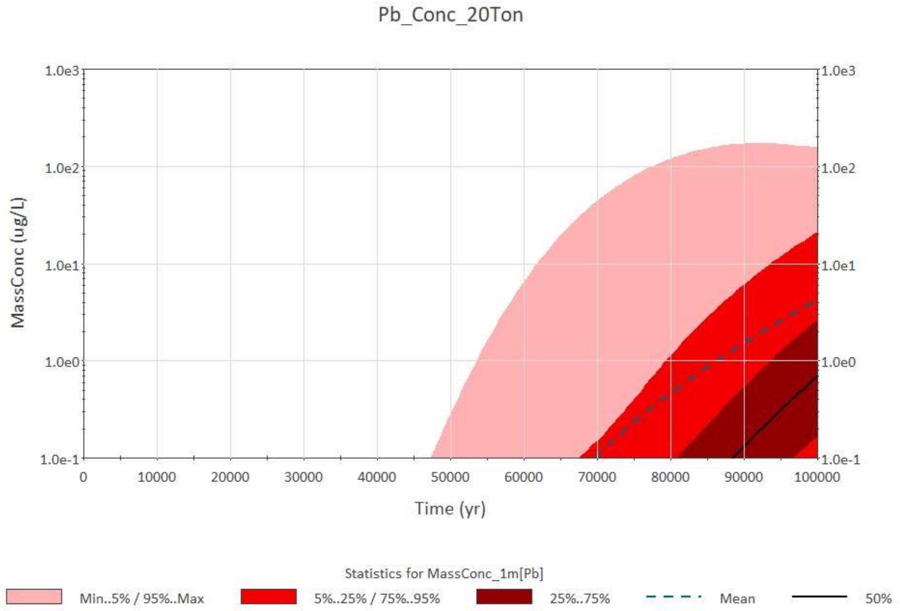

Figure B.1. GoldSim lead concentration statistics at the 1-m POA [1,000 realizations for the No Action Scenario (LS-PA-S1)].

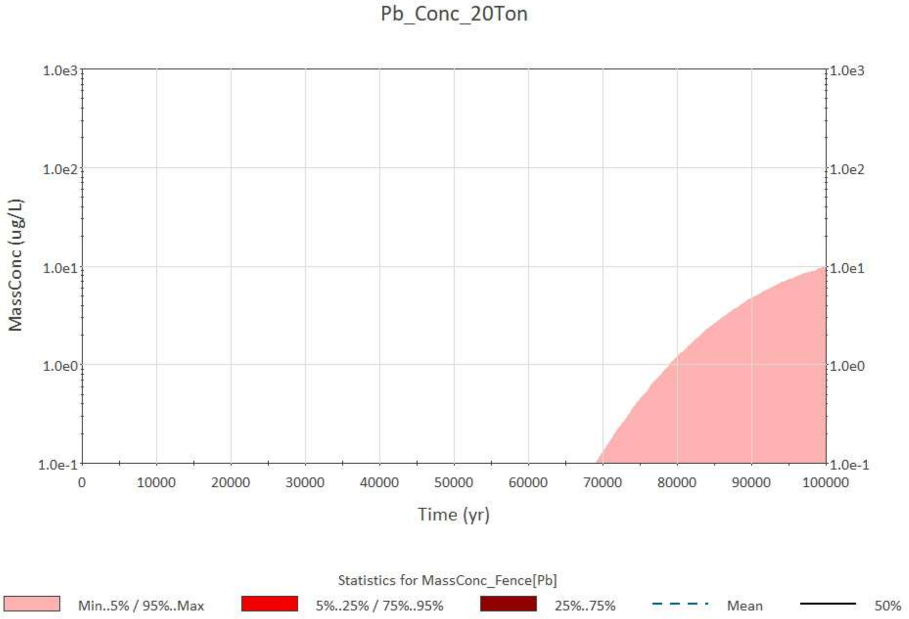

Figure B.2. GoldSim mean lead concentration statistics at the C-area boundary POA [1,000 realizations for the No Action Scenario (LS-PA-S1)].

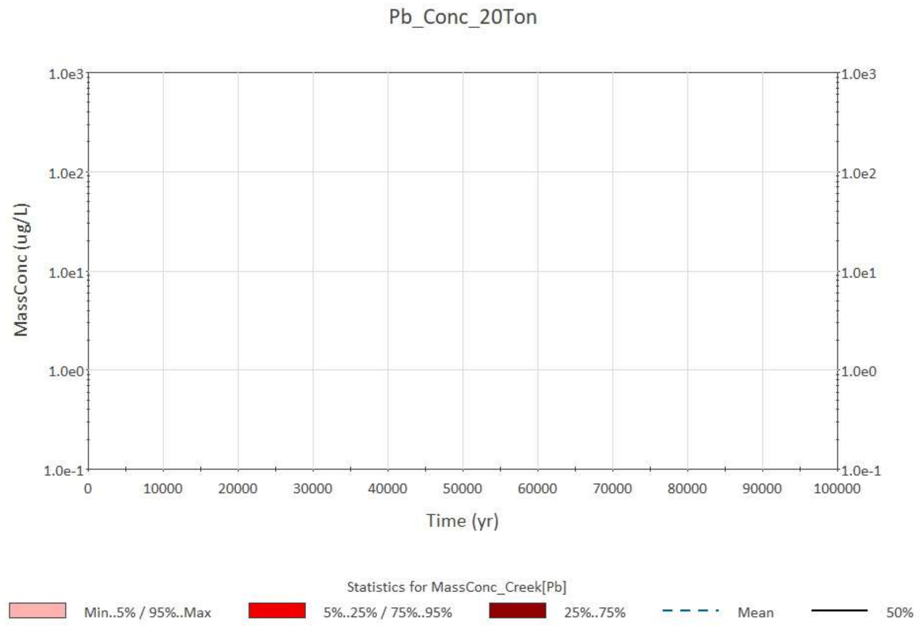

Figure B.3. GoldSim mean lead concentration statistics at the Castor Creek POA [1,000 realizations for the No Action Scenario (LS-PA-S1)].

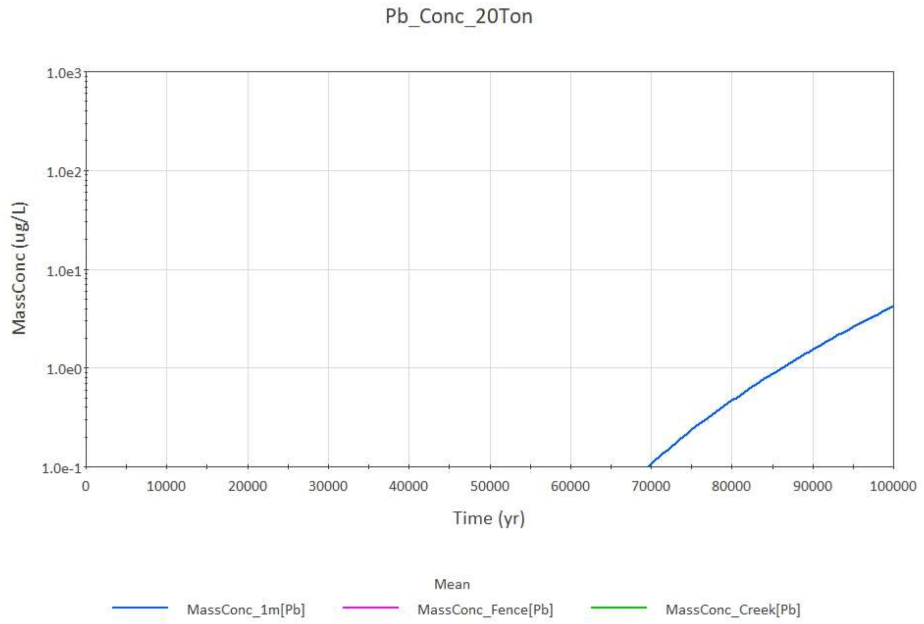

Figure B.4. GoldSim mean lead concentration statistics at the three POAs [1,000 realizations for the No Action Scenario (LS-PA-S1)].

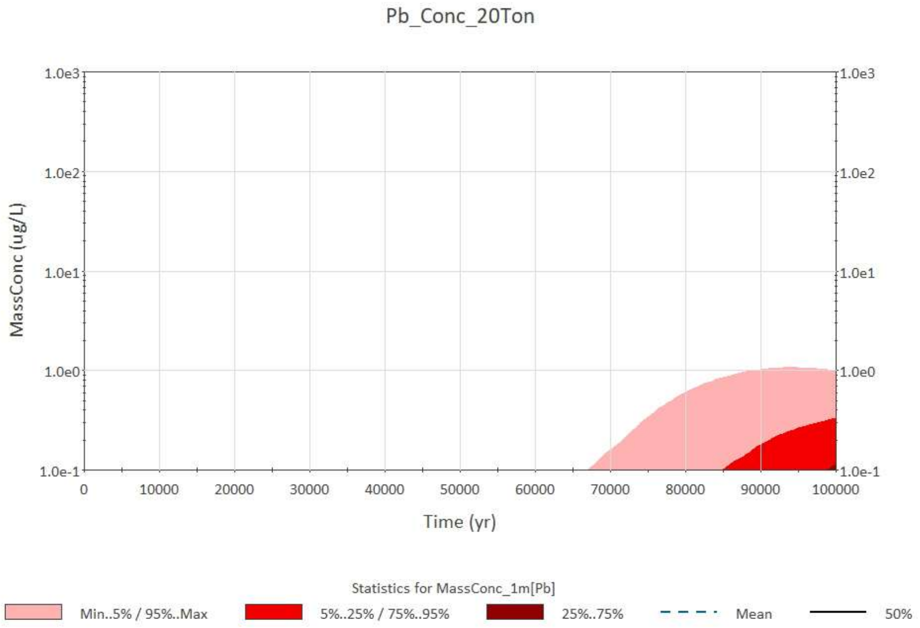

Figure B.5. GoldSim lead concentration statistics at the 1-m POA [1,000 realizations for the Grout and Engineered Roof Scenario (LS-PA-S3)].

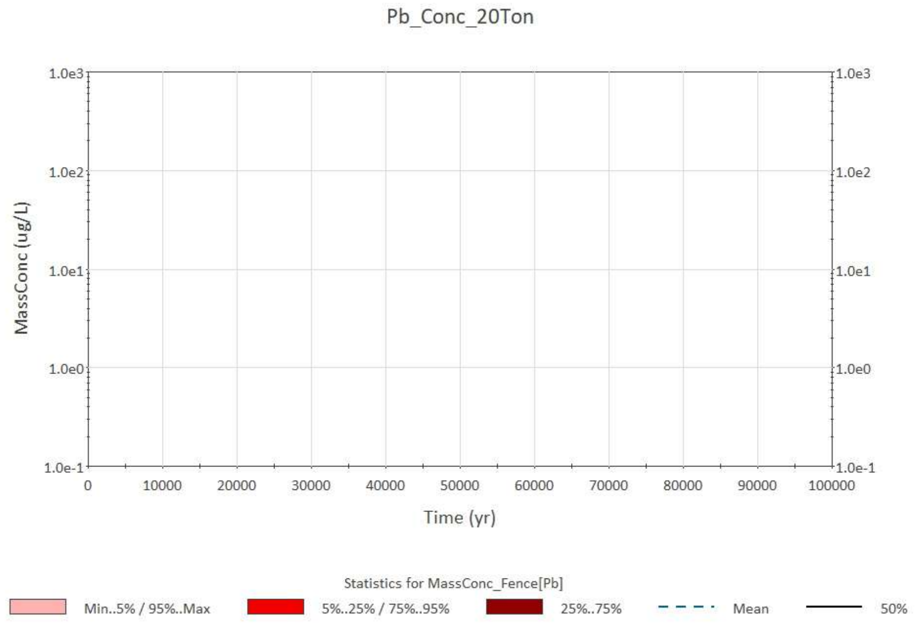

Figure B.6. GoldSim lead concentration statistics at the C-Area Boundary POA [1,000 realizations for the Grout and Engineered Roof Scenario (LS-PA-S3)].

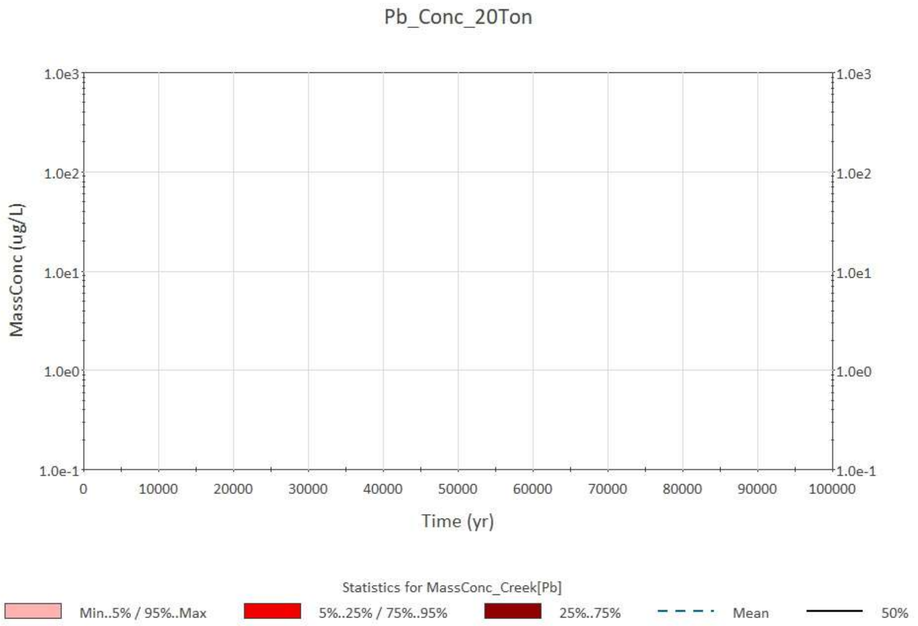

Figure B.7. GoldSim lead concentration statistics at the Castor Creek POA [1,000 realizations for the Grout and Engineered Roof Scenario (LS-PA-S3)].

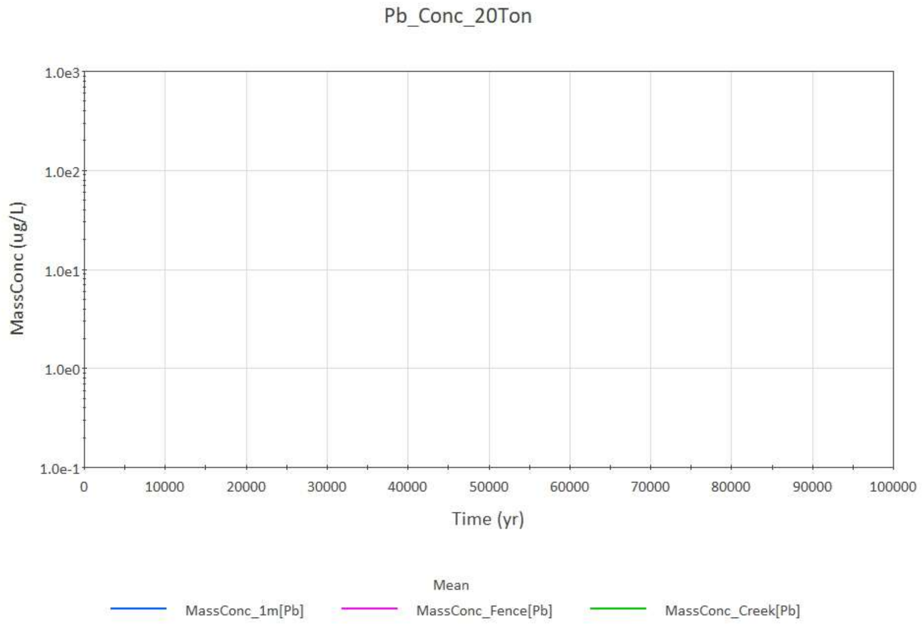

Figure B.8. GoldSim mean lead concentration statistics at the three POAs [1,000 realizations for the Grout and Engineered Roof Scenario (LS-PA-S3)].

Appendix C: 230-Ton Source GoldSim® Model Figures

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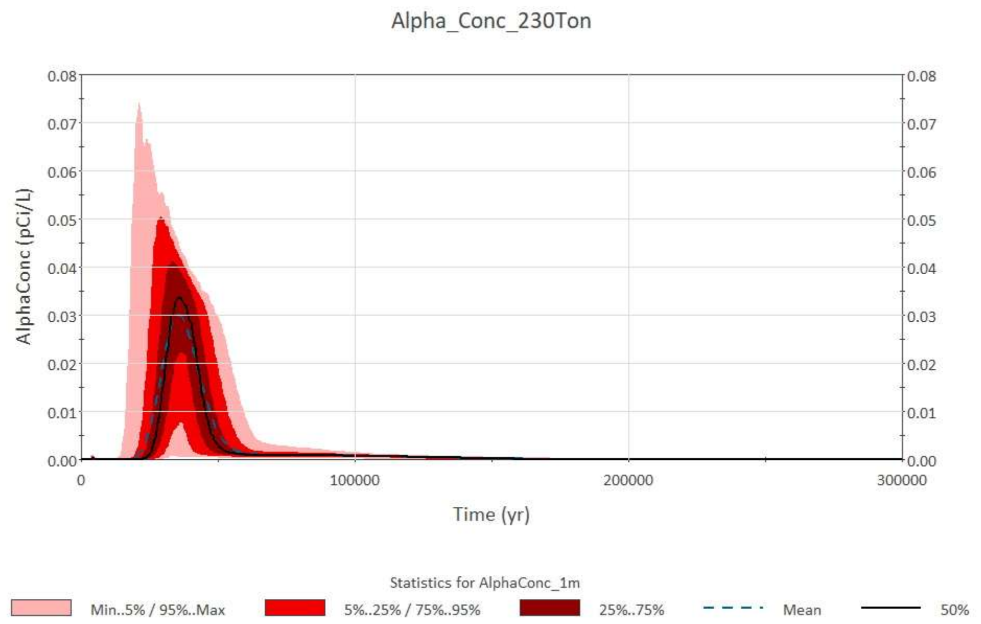

Figure C.1. GoldSim gross alpha concentration statistics at the 1-m POA [1,000 realizations for the No Action Scenario (LS-CM-S1)].

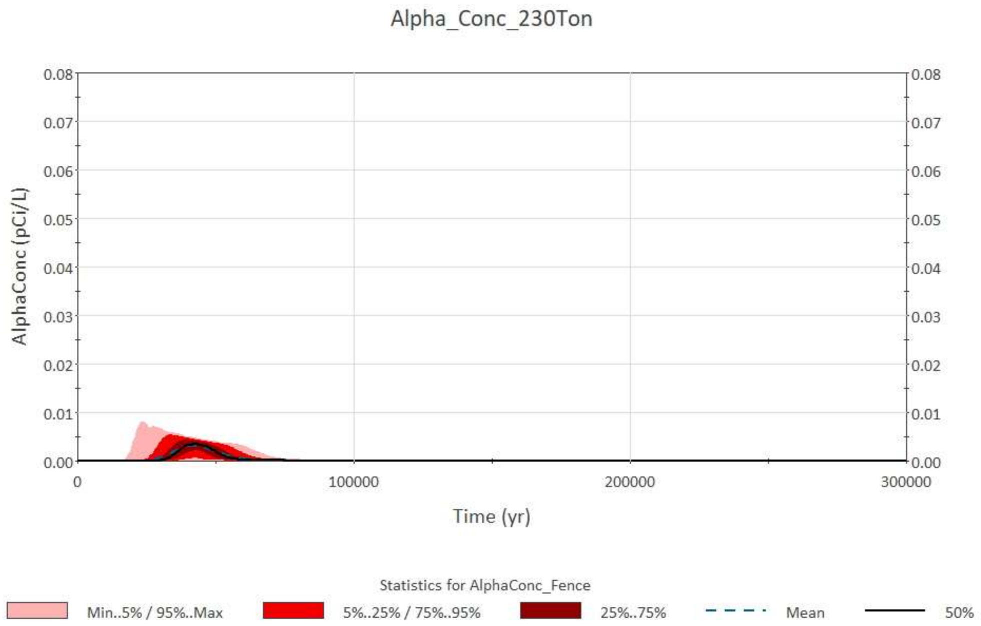

Figure C.2. GoldSim gross alpha concentration statistics at the C-area boundary POA [1,000 realizations for the No Action Scenario (LS-CM-S1)].

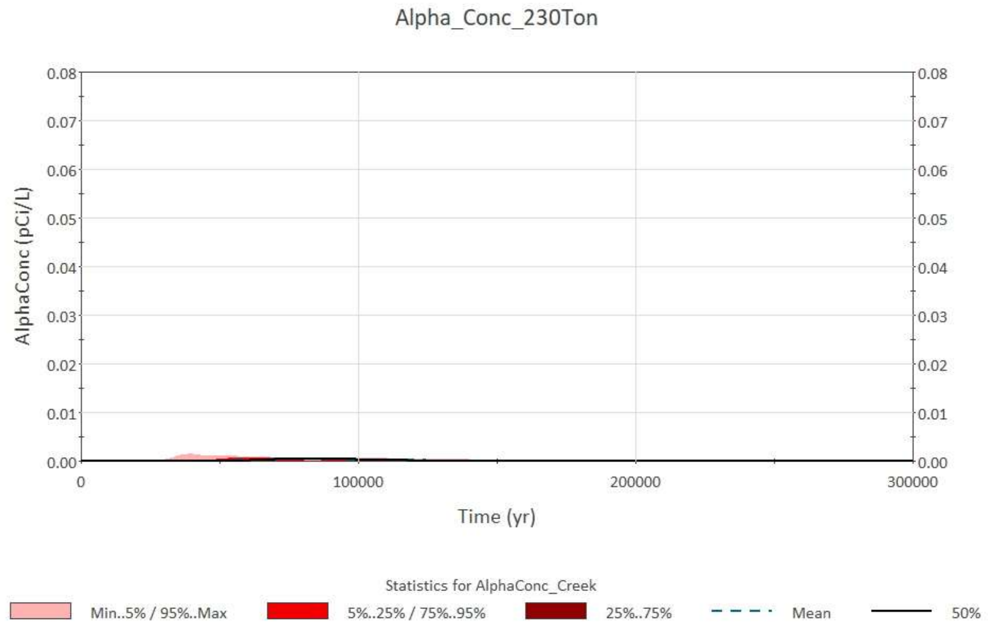

Figure C.3. GoldSim gross alpha concentration statistics at the Castor Creek POA [1,000 realizations for the No Action Scenario (LS-CM-S1)].

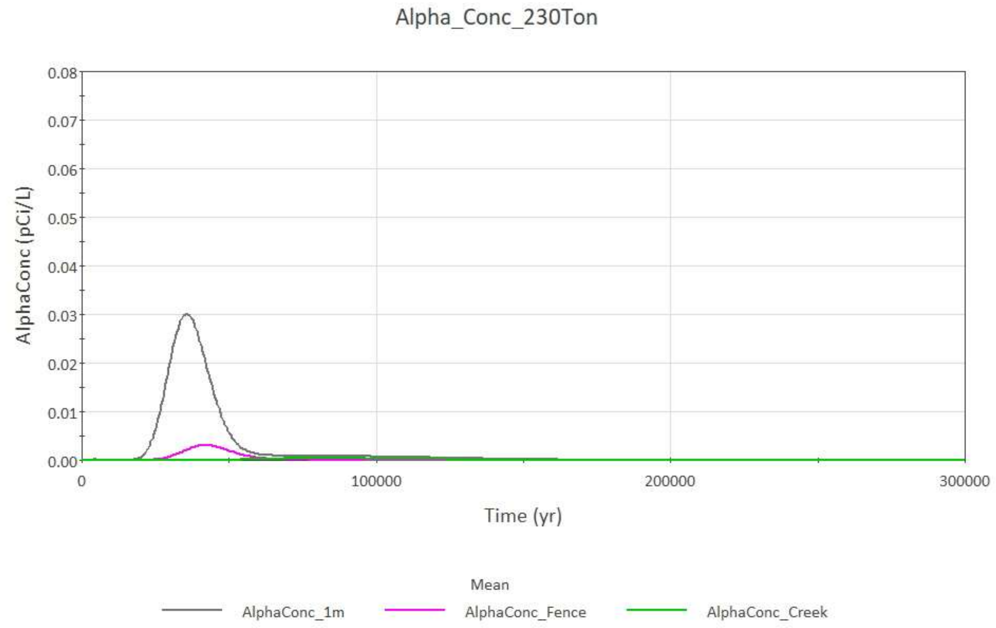

Figure C.4. GoldSim mean gross alpha concentration statistics at the three POAs [1,000 realizations for the No Action Scenario (LS-CM-S1)].

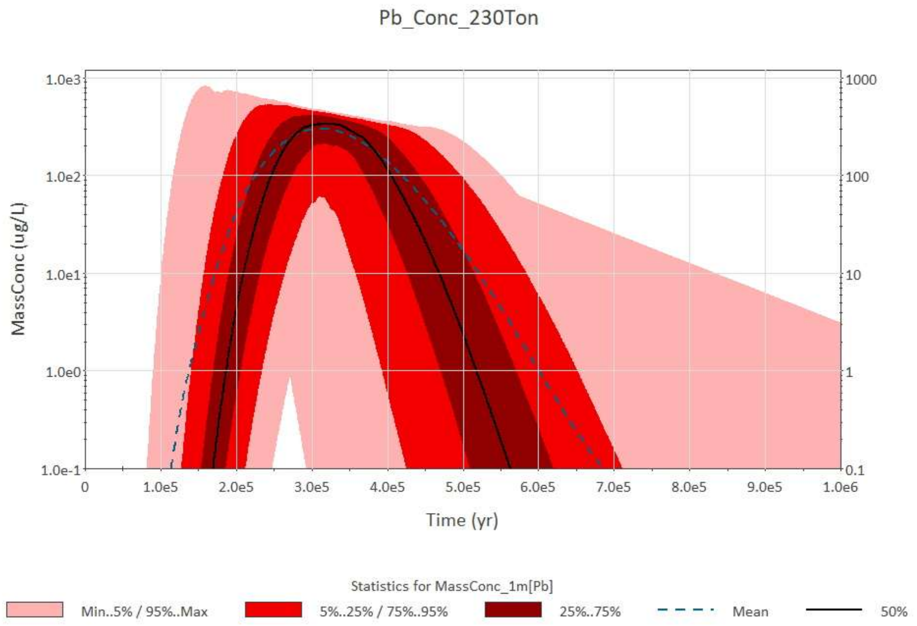

Figure C.5. GoldSim lead concentration statistics at the 1-m POA [1,000 realizations for the No Action Scenario (LS-CM-S1)].

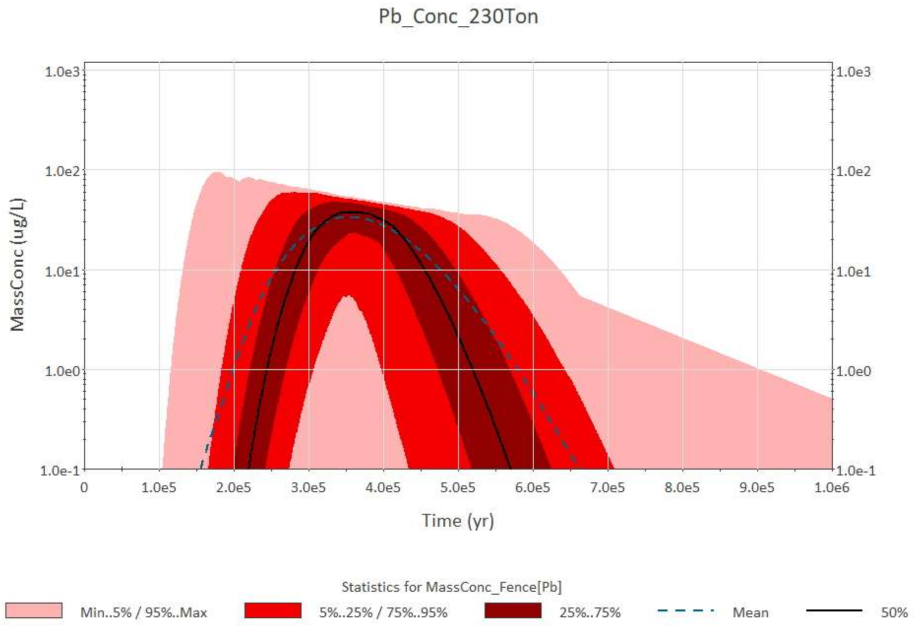

Figure C.6. GoldSim lead concentration statistics at the C-area boundary POA [1,000 realizations for the No Action Scenario (LS-CM-S1)].

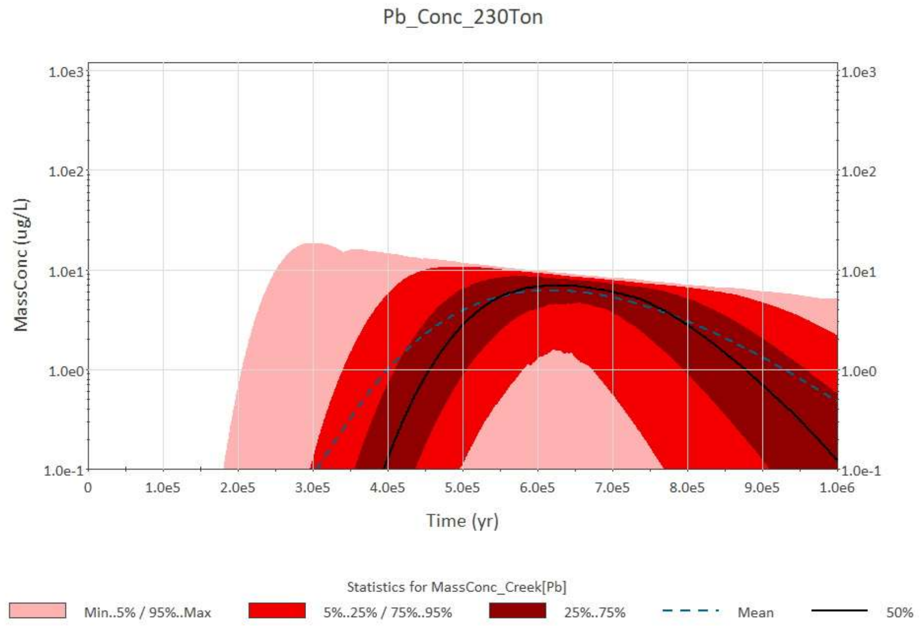

Figure C.7. GoldSim lead concentration statistics at the Castor Creek POA [1,000 realizations for the No Action Scenario (LS-CM-S1)].

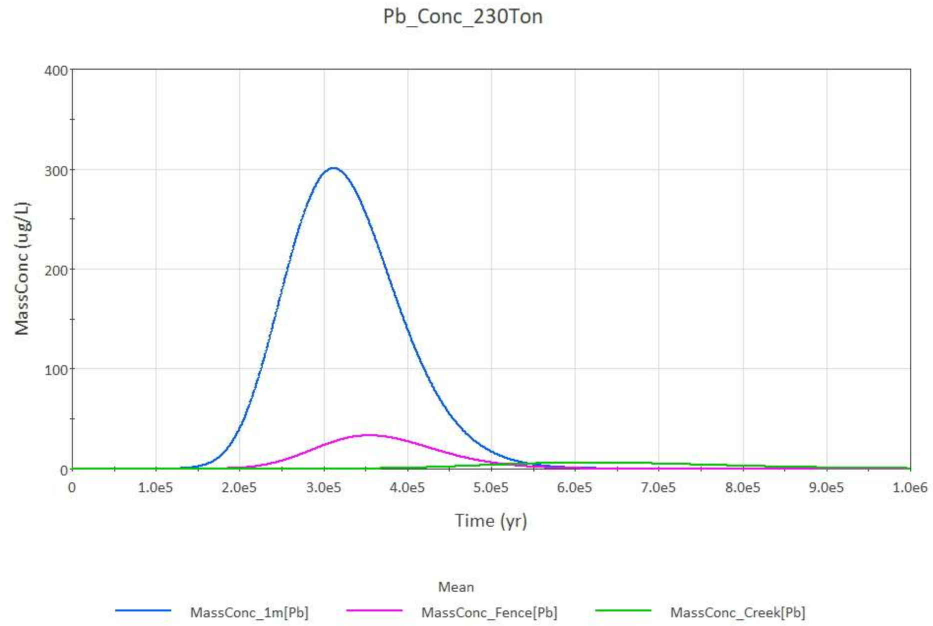

Figure C.8. GoldSim mean lead concentration statistics at the three POAs [1,000 realizations for the No Action Scenario (LS-CM-S1)]..

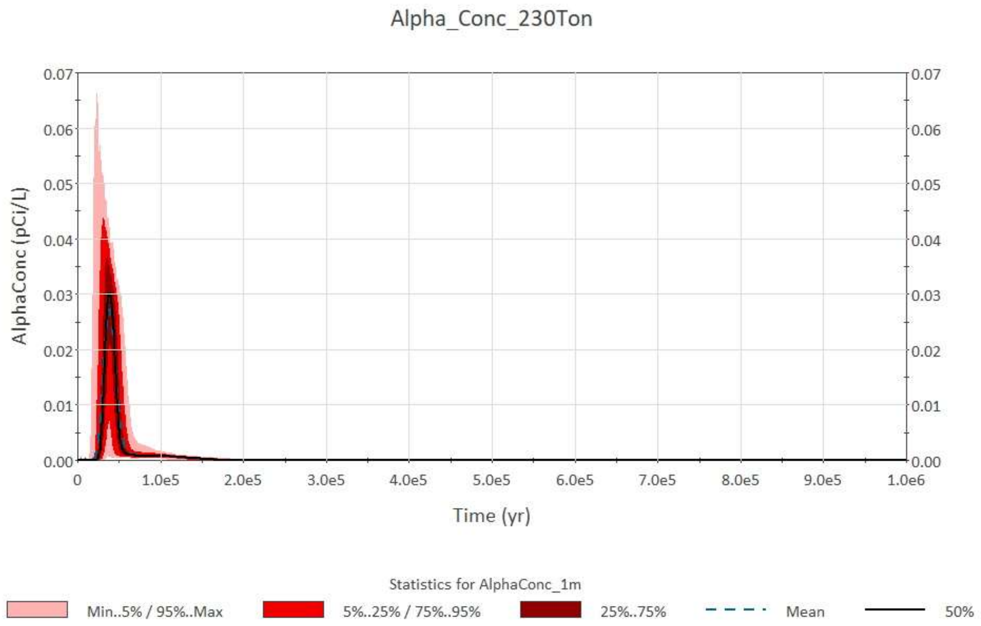

Figure C.9. GoldSim gross alpha concentration statistics at the 1-m POA [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

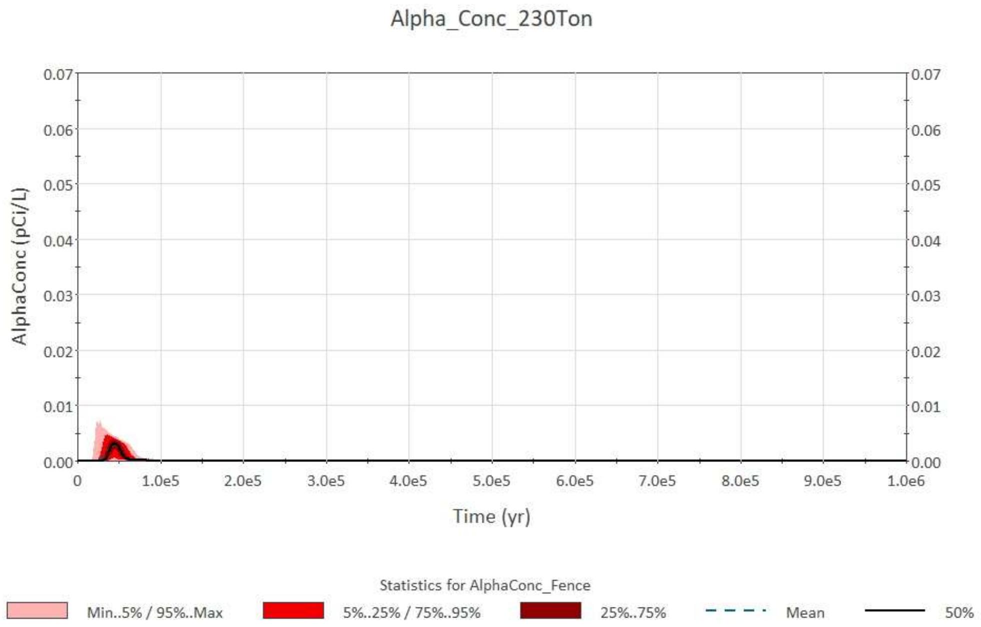

Figure C.10. GoldSim gross alpha concentration statistics at the C-area boundary POA [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

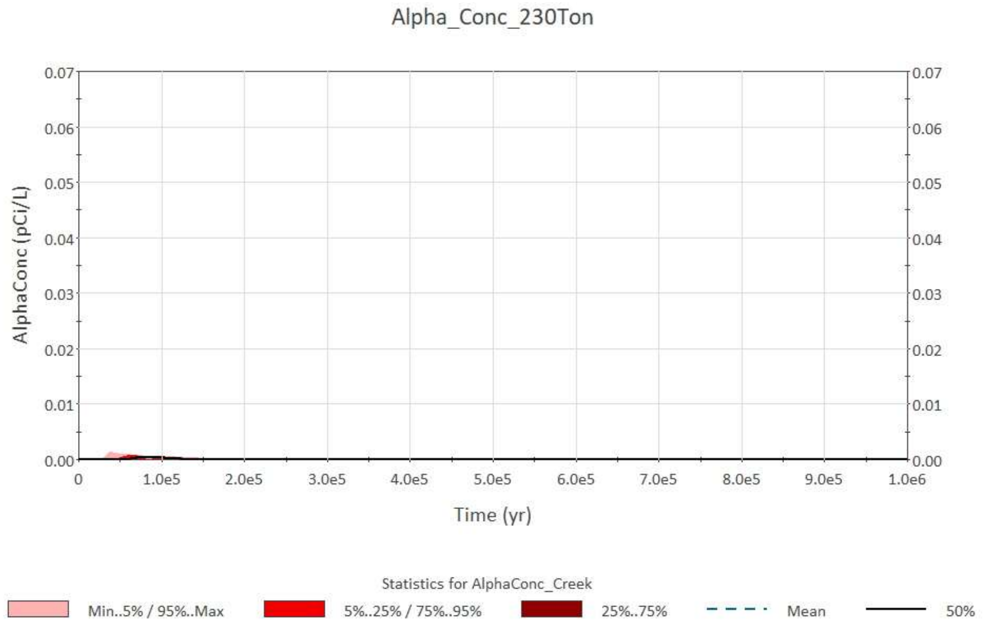

Figure C.11. GoldSim gross alpha concentration statistics at the Castor Creek POA [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

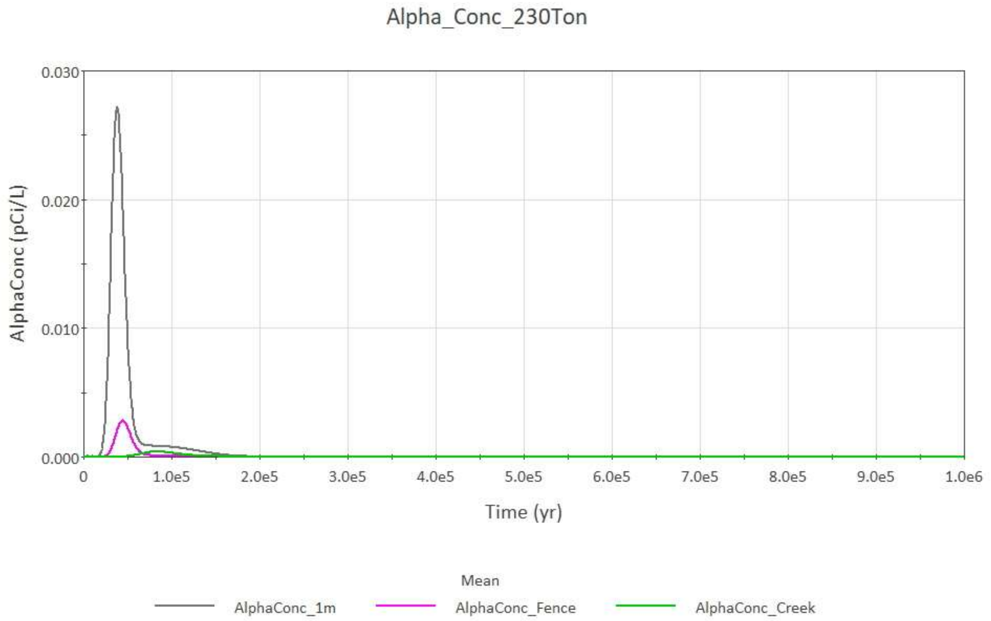

Figure C.12. GoldSim mean gross alpha concentration statistics at the three POAs [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

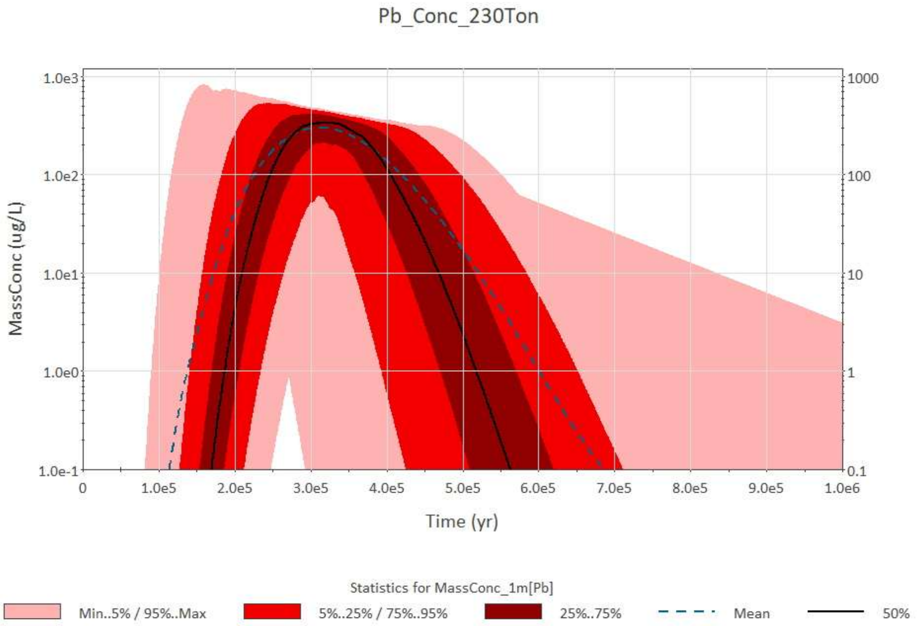

Figure C.13. GoldSim lead concentration statistics at the 1-m POA [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

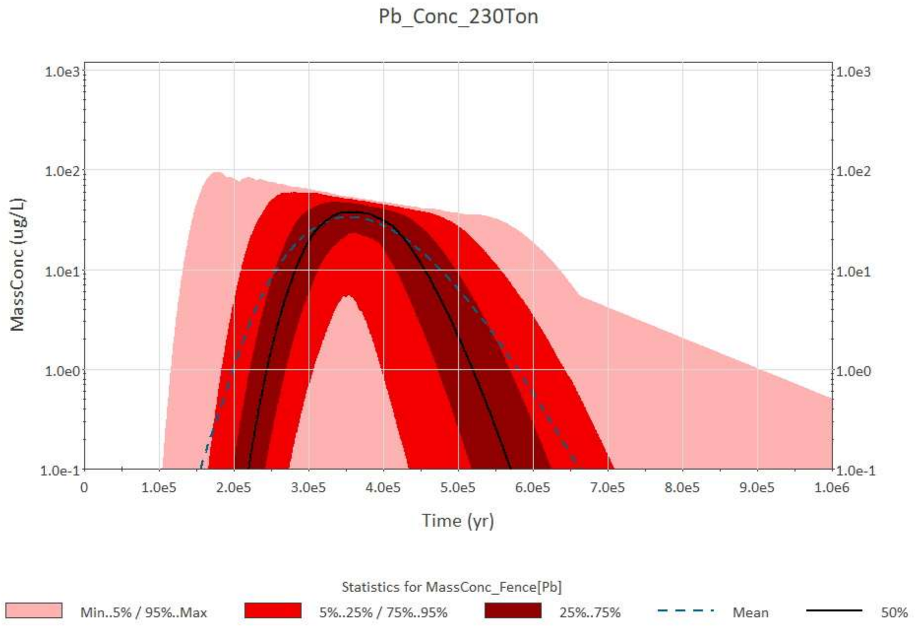

Figure C.14. GoldSim lead concentration statistics at the C-area boundary POA [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

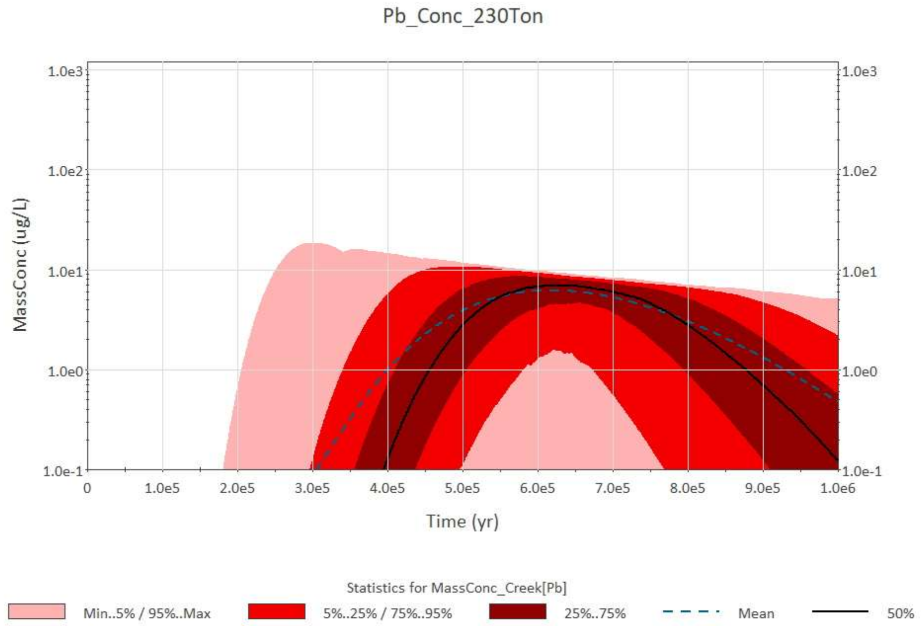

Figure C.15. GoldSim lead concentration statistics at the Castor Creek POA [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

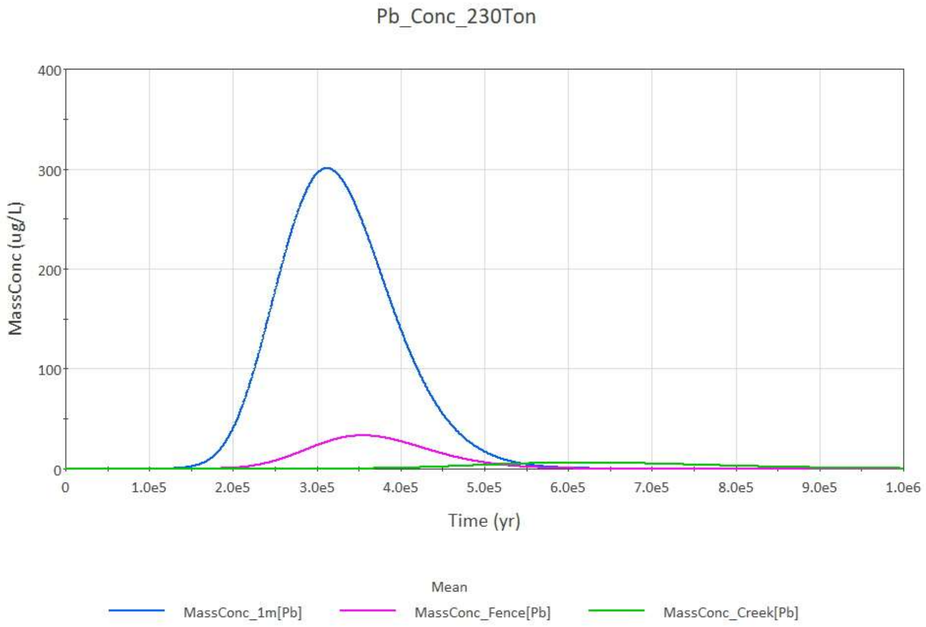

Figure C.16. GoldSim mean lead concentration statistics at the three POAs [1,000 realizations for the Grout and Cap Source Scenario (LS-CM-S2A)].

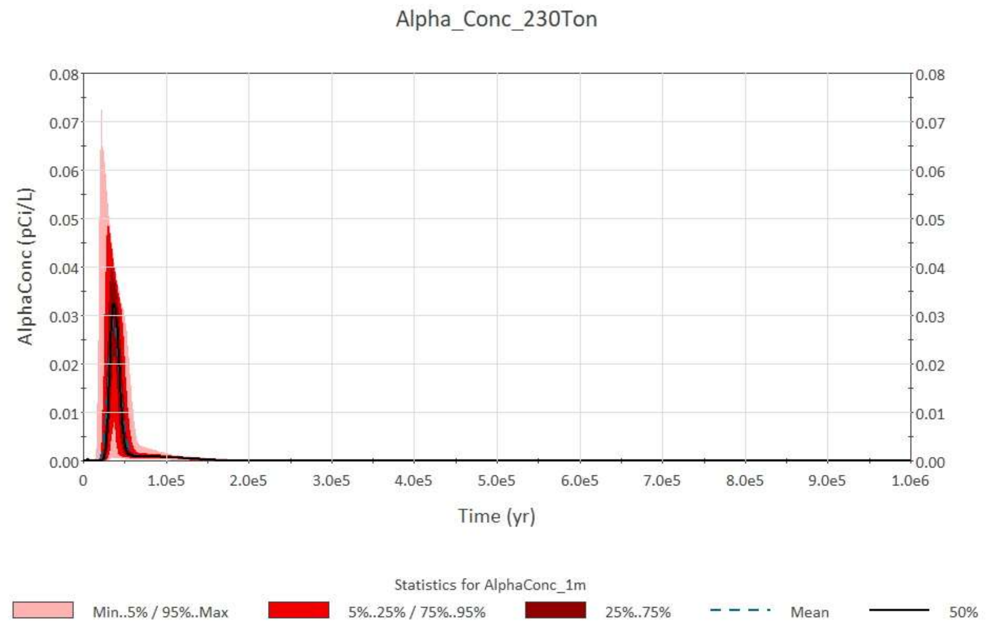

Figure C.17. GoldSim gross alpha concentration statistics at the 1-m POA [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

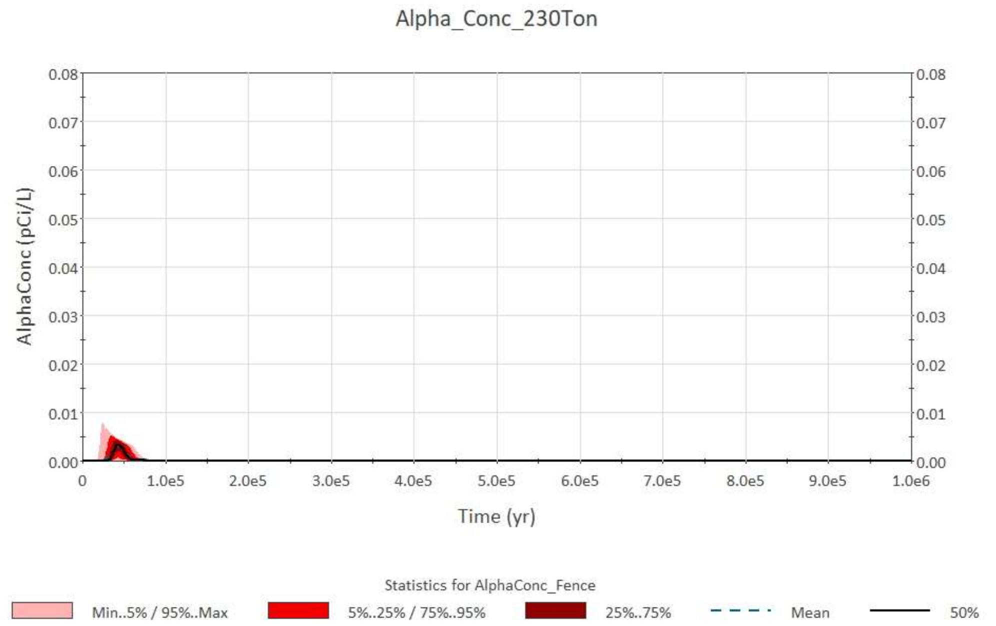

Figure C.18. GoldSim gross alpha concentration statistics at the C-area boundary POA [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

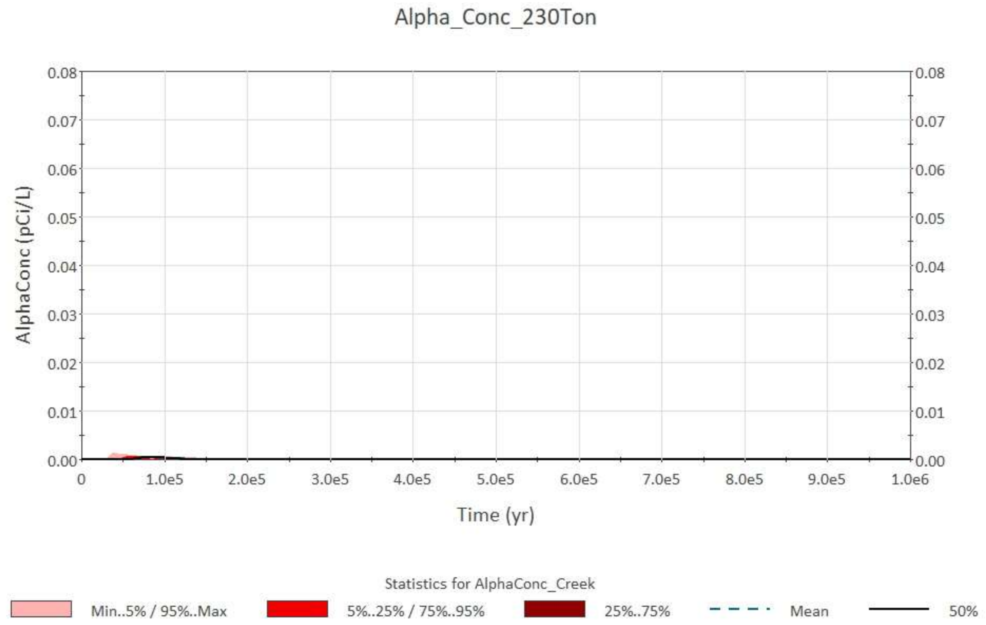

Figure C.19. GoldSim gross alpha concentration statistics at the Castor Creek POA [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

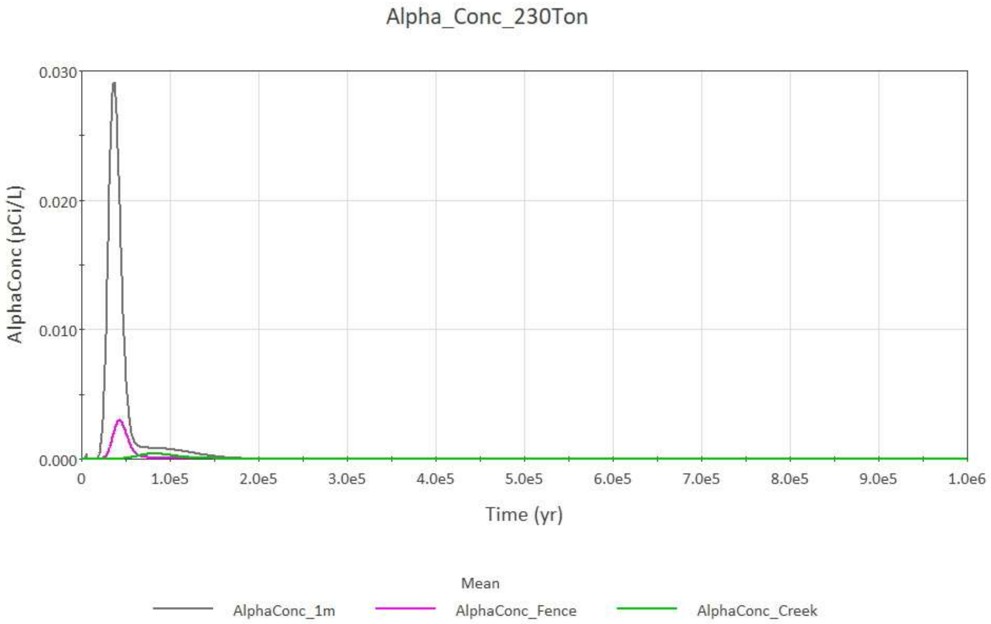

Figure C.20. GoldSim mean gross alpha concentration statistics at the three POAs [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

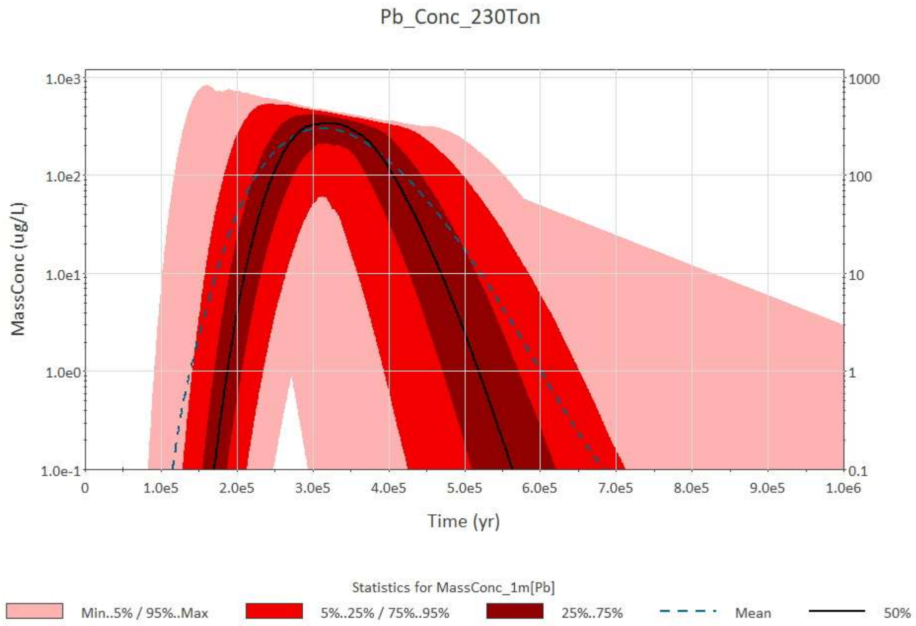

Figure C.21. GoldSim lead concentration statistics at the 1-m POA [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

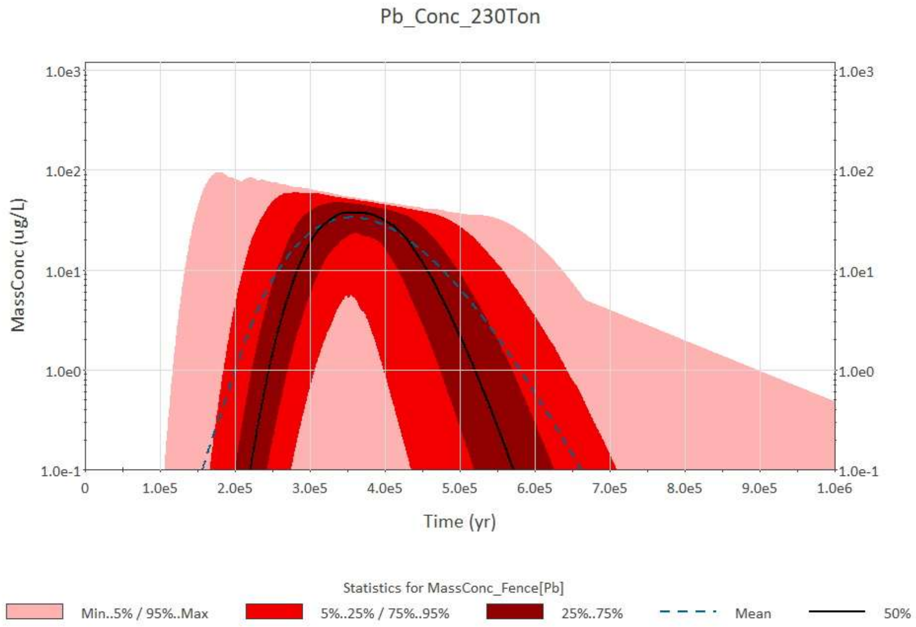

Figure C.22. GoldSim lead concentration statistics at the C-area boundary POA [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

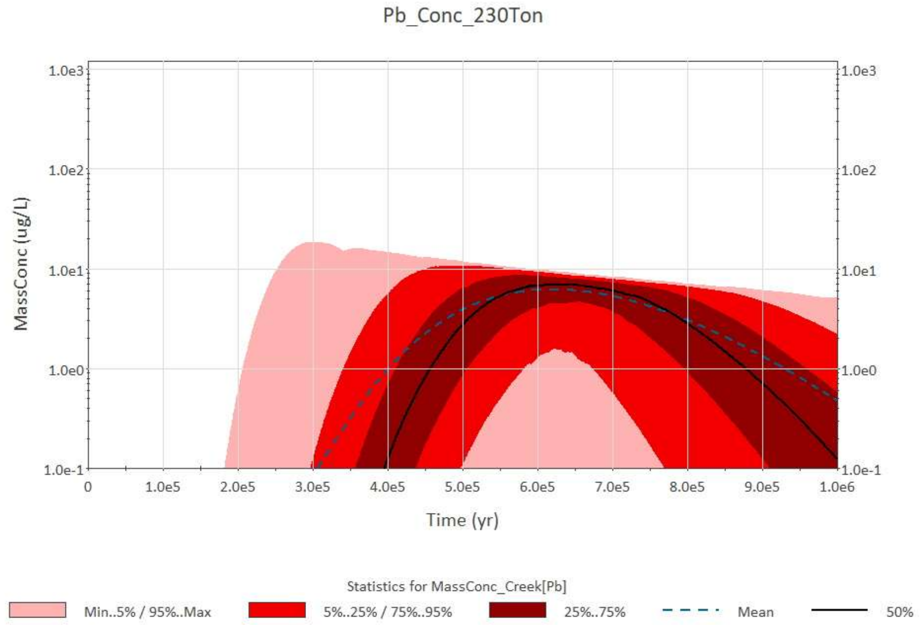

Figure C.23. GoldSim lead concentration statistics at the Castor Creek POA [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

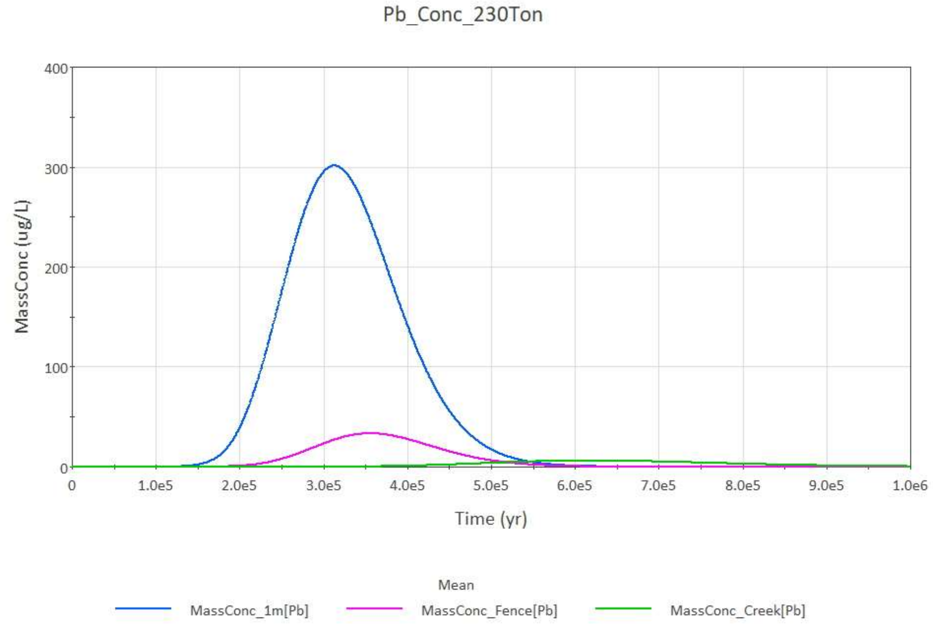

Figure C.24. GoldSim mean lead concentration statistics at the three POAs [1,000 realizations for the Engineered Roof Scenario (LS-CM-S3A)].

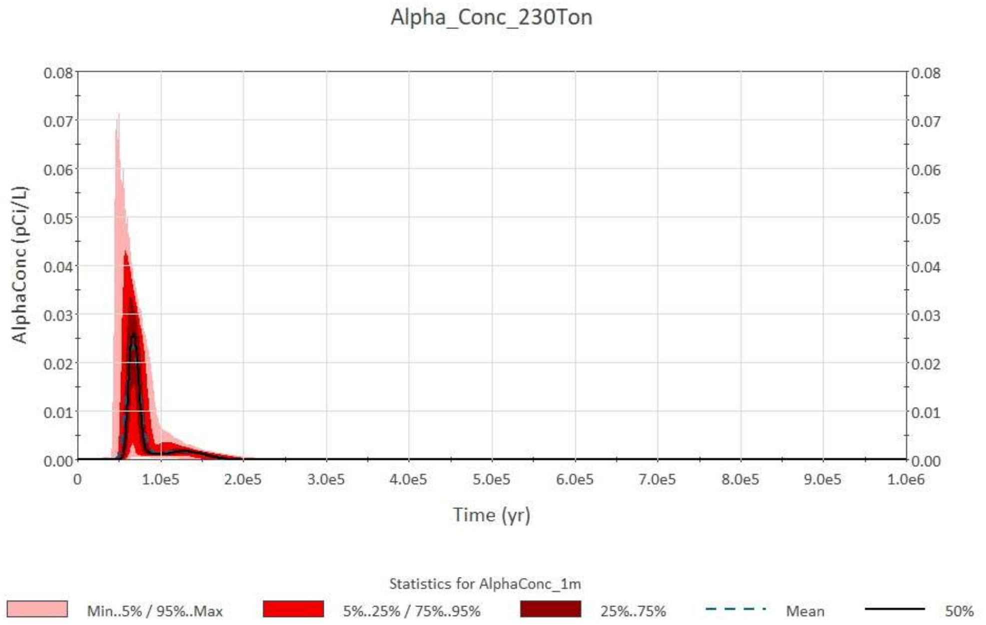

Figure C.25. GoldSim gross alpha concentration statistics at the 1-m POA [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

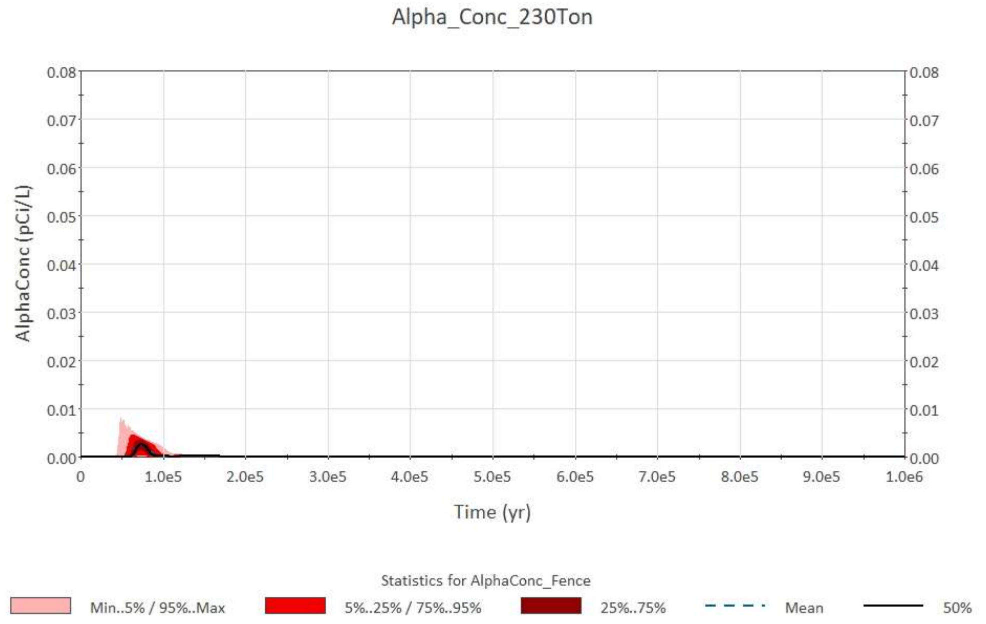

Figure C.26. GoldSim gross alpha concentration statistics at the C-area boundary POA [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

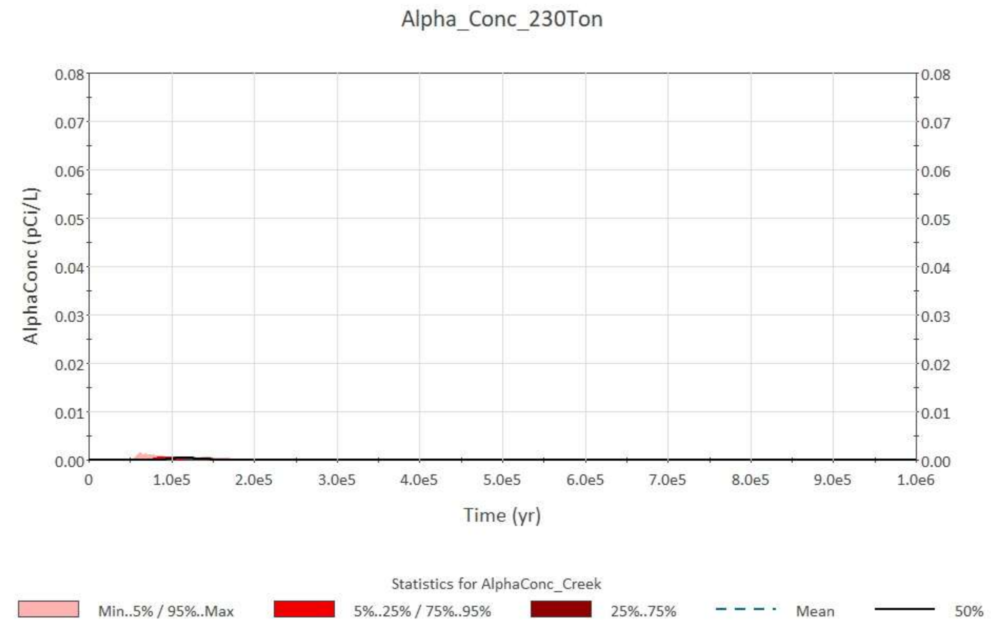

Figure C.27. GoldSim gross alpha concentration statistics at the Castor Creek POA [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

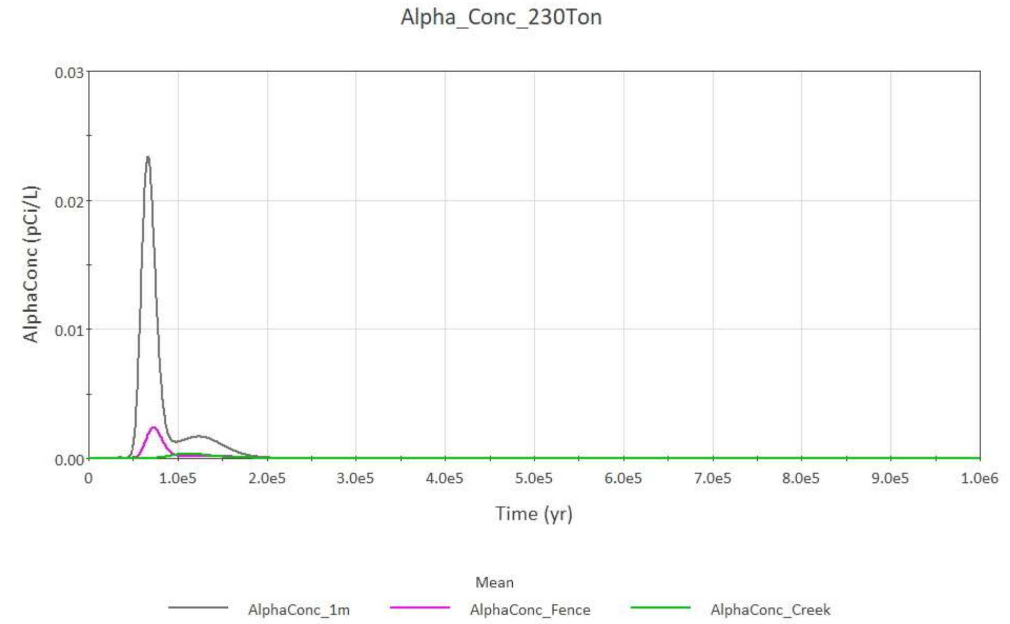

Figure C.28. GoldSim mean gross alpha concentration statistics at the three POAs [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

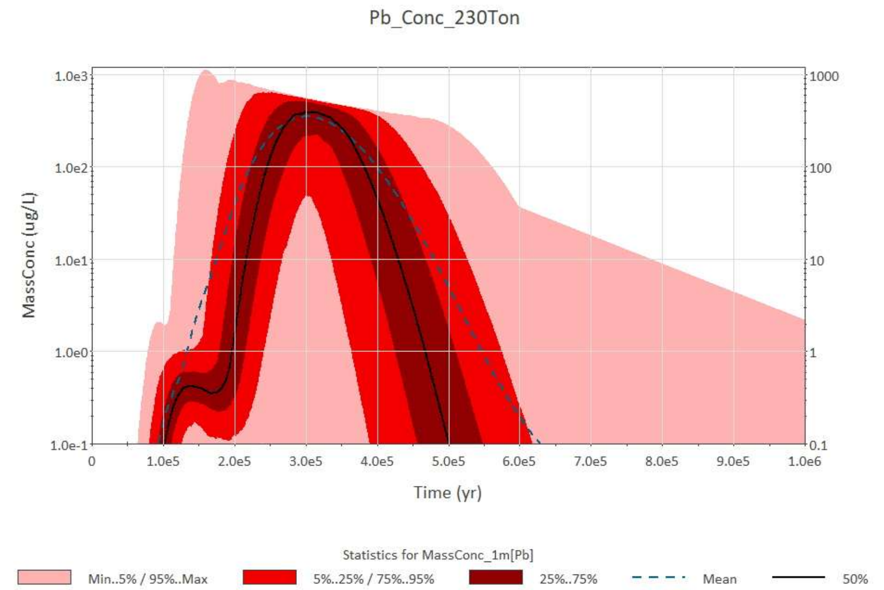

Figure C.29. GoldSim lead concentration statistics at the 1-m POA [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

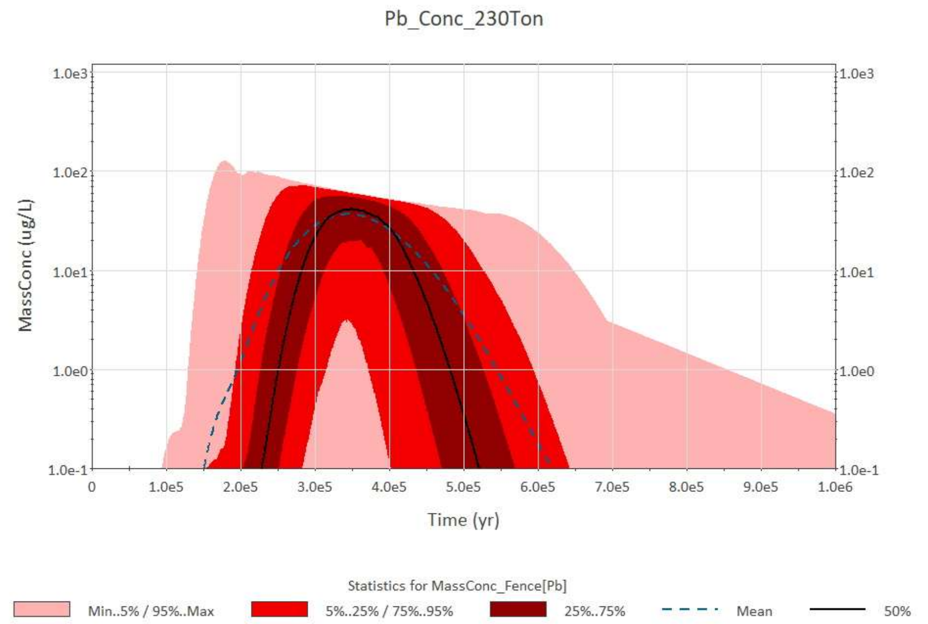

Figure C.30. GoldSim lead concentration statistics at the C-area boundary POA [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

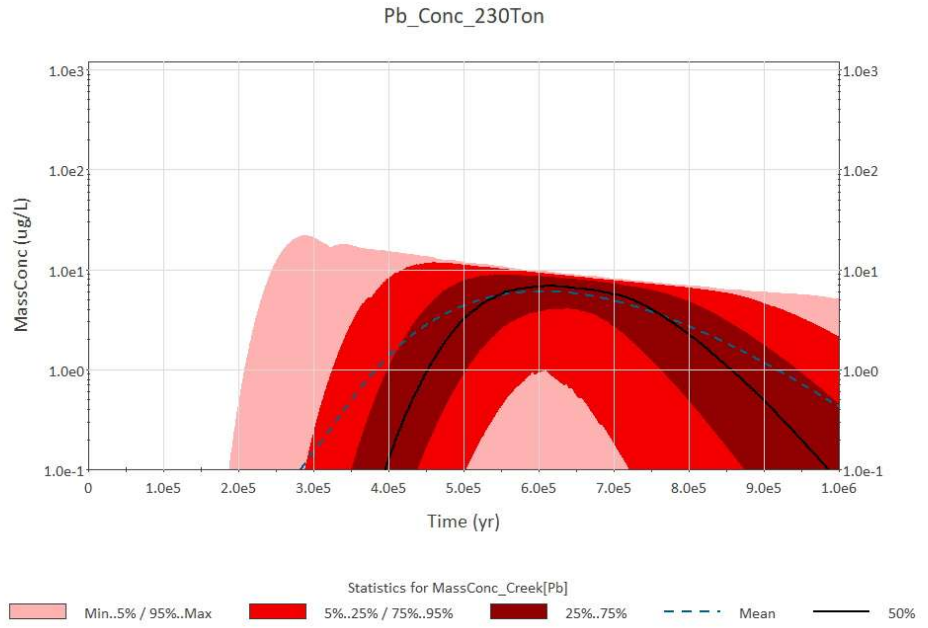

Figure C.31. GoldSim mean concentration statistics at the Castor Creek POA [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].

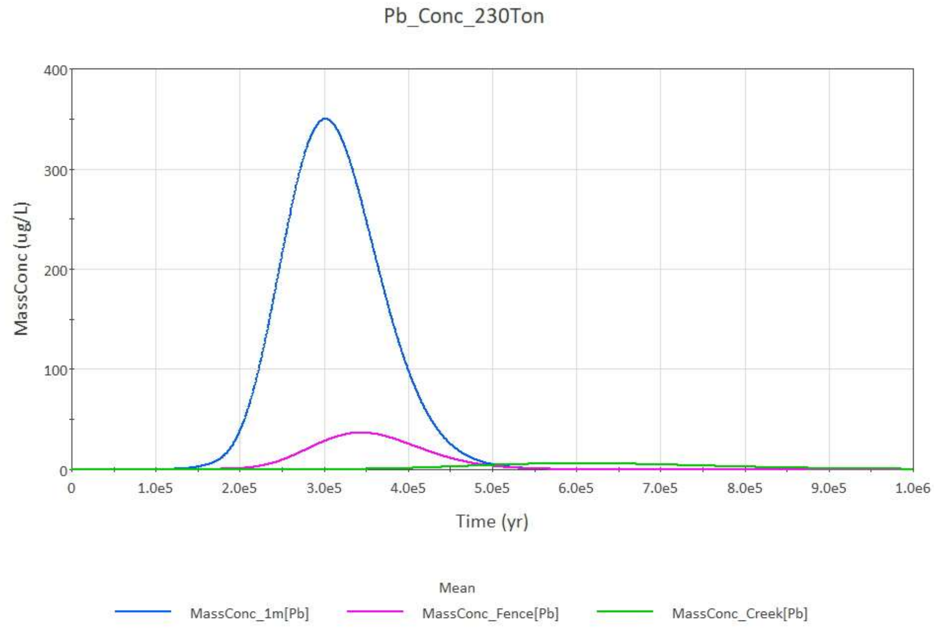

Figure C.32. GoldSim mean lead concentration statistics at the three POAs [1,000 realizations for the Grout, Engineered Roof, and Move Boxes Scenario (LS-CM-S3B)].