INL/EXT-09-16417

Preliminary Review of Models, Assumptions, and Key Data Used in Performance Assessments and Composite Analysis at the Idaho National Laboratory

Arthur S. Rood
Swen O. Magnuson

July 2009

The INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance

INL/EXT-09-16417

Preliminary Review of Models, Assumptions, and Key Data Used in Performance Assessments and Composite Analysis at the Idaho National Laboratory

Arthur S. Rood
Swen O. Magnuson

July 2009

Idaho National Laboratory
Idaho Falls, Idaho 83415

http://www.inl.gov

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
Contract DE-AC07-05ID14517

Preliminary Review of Models, Assumptions, and Key Data used in Performance Assessments and Composite Analysis at the Idaho National Laboratory

Arthur S. Rood and Swen O. Magnuson
Idaho National Laboratory
July 1, 2009

Introduction

This document is in response to a request by Ming Zhu, DOE-EM to provide a preliminary review of existing models and data used in completed or soon to be completed Performance Assessments and Composite Analyses (PA/CA) documents, to identify codes, methodologies, main assumptions, and key data sets used. The PA/CAs that are completed at the Idaho National Laboratory (INL) are listed in Table 1. Facilities for which PA/CAs were performed are located in the southwestern corner of the INL (Figure 1) and all major sources of groundwater contamination are located in this area. For the Radioactive Waste Management Complex (RWMC), the original PA was published in 1994 and has undergone two revisions. The CA for the RWMC was originally published in 2000 and was last revised in 2008. For this report, only the latest revision of the PA/CA will be discussed.

Table 1. Completed Performance Assessments and Composite Analyses at the Idaho National Laboratory.

Facility	Performance Assessment (document number, publication date)	Composite Analysis (document number, publication date)
Radioactive Waste Management Complex (RWMC)	(1) EGG-WM-8773, May 1994	(1) INEEL/EXT-97-01113, September 2000
	(2) INEEL/EXT-2000-01089, September 2000	(2) DOE/NE-ID-11244, September, 2008
	(3) DOE/NE-ID-11243 September 2007	
Idaho CERCLA Disposal Facility (ICDF)	DOE/ID-10978, August, 2003	DOE/ID-10979, August, 2003
Tank Farm Facility (TFF)	DOE/ID-10966-Rev 1, April, 2003	DOE/ID-10974 (rev 1), May, 2006

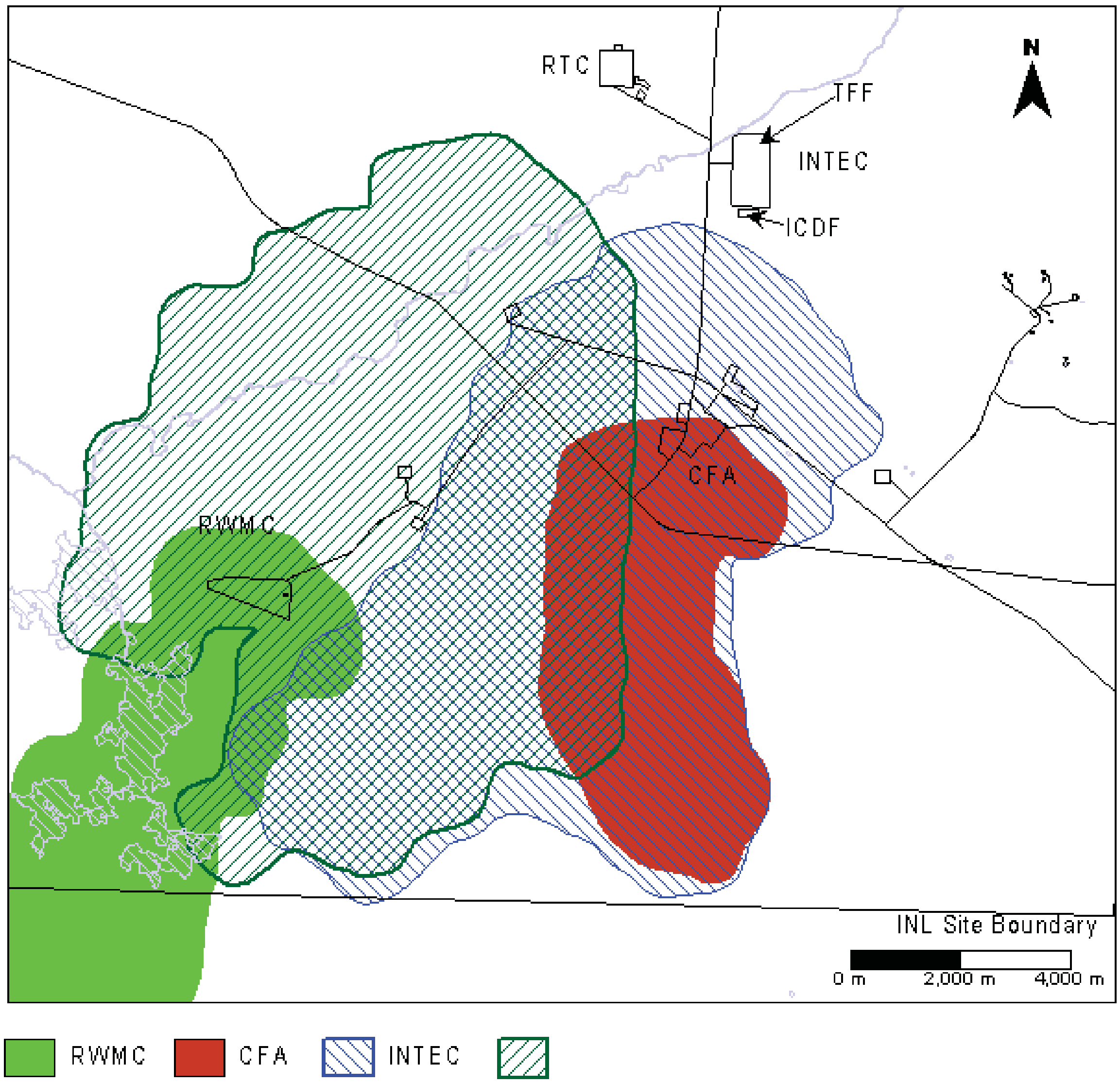

Figure 1. Map of the southwestern corner of the INL showing major facilities that have contributed or may potentially contribute to groundwater contamination. The figure was developed using the Response Surface Model (Rood 2005b) where a hypothetical tracer is injected at each facility for 40 years from the start of the simulation. Contours represent the tracer plume at 40 yeas for CFA and RWMC, and 55 years for INTEC and RTC. The hypothetical tracer plumes originating from each facility illustrate the possible interaction between the various sources.

The assessment objective in a PA/CA is to demonstrate compliance with dose limits for a 1,000 year period after closure for a future member of the public. In general, a graded approach is used to fulfill this objective. That is, if compliance can be demonstrated using simple conservative models, then the PA/CA meets its objectives. In most cases however, more detailed modeling is needed. Detailed modeling is targeted to significant transport processes and important radionuclides that are major dose contributors. Furthermore, it must be recognized that availability of characterization data limits the complexity of PA/CA models. Models should incorporate what is known about the system and use simplifying assumptions for processes that are not well understood or cannot be characterized in a meaningful way.

Review of INL PA/CA Methodologies and Key Assumptions

In general, developing an INL facility PA/CA involves analysis of the following components:

- Source term
- Unsaturated zone transport
- Saturated zone transport
- Exposure scenario and dose assessment
- Uncertainty/Sensitivity analysis
- Intruder/radon dose analysis.

The general methodology employed for each of these topics is discussed for each PA/CA.

Source Term

The source term is defined here as the flux of radionuclides from the disposal facility to the environment (unsaturated/saturated zone) over time. Key factors that need to be considered in the source term include:

- Inventory of radionuclides disposed
- Infiltration
- Radionuclide release rates from waste forms
- Waste packaging or other containment
- Engineered cover.

RWMC

For the RWMC PA, inventory estimates from 1984 onwards up to 2010 were obtained from an onsite database. For the CA, the source term included all inventory disposed since the facility began operation in 1952. The inventory was screened for the groundwater pathway based on half-life, National Council on Radiation Protection (NCRP) Report 123 screening factors, and simplified leaching and transport modeling. The screened list of radionuclides for the PA consisted of seven fission and activation products (C-14, Ca-41, Cl-36, H-3, I-129, Ni-59, Tc-99) and ten actinides (Np-237, Pa-231, Pu-239, Th-230, Th-232, U-233, U-234, U-235, U-236, and U-238). The CA screened list of radionuclides included those of the PA plus Am-241, Pu-238, and Pu-241. For mobile fission and activation products, consideration was given to waste form, waste emplacement rates, and waste containment. For actinides, no credit was given to waste form, emplacement rate, or containment. Chemical solubility was considered for both fission and activation products and actinides. The DUST code was used to calculate release rates from fission/activation product waste forms to the backfilled soil. A compartmental model of the backfilled soil was used to estimate the flux from the backfilled soil, out of the waste pit and into the unsaturated zone.

Infiltration through the disposal pit was modeled for operations and after installation of an engineered cover. Measurements during current operations indicated infiltration through the disposal pits (~5 cm/yr) is higher than natural recharge (~1 cm/yr). After cover emplacement, infiltration was decreased to 1 mm/yr and the cover was assumed to last indefinitely

Other upgradient sources considered in the CA included percolation ponds from the Reactor Test Area, and injection well, tank leaks, percolation ponds, and the ICDF disposal facility from the Idaho Nuclear Technology Complex. Contaminant plumes from other INL facilities excluding those just mentioned were shown not to interact with contaminant plumes originating from the RWMC.

ICDF

The source term for the ICDF was based on the amount of radionuclides that could be disposed in the facility such that regulatory limits would not be exceeded and termed the design inventory. The design inventory was based on preliminary modeling and administrative decisions. Preliminary modeling used a one-dimensional simulation implemented in the PNNL code STOMP. Administrative decisions also played a role in determining the design inventory, and as such, the design inventory was not entirely based on modeling. Releases were modeled assuming all waste was homogenously mixed with soil. A simple, two-compartment first order leaching model was implemented that accounted for variable infiltration through the engineered cap, and radioactive decay and ingrowth. Infiltration through the cap was specified as 0.1 mm/yr from 0-500 years, and linearly increased to 1 cm/yr from 500 to 1000 years.

TFF

The TFF PA/CA source term was based on the residual waste left in the tank, and prior contamination from piping leaks contained in the surrounding soil and the sand pad underlying the tank. The source term addressed corrosion failure of the tank, and degradation of concrete grout in the tanks and underlying sand pad. No engineered cover was assumed to be placed over the facility because the design of the cover had not been completed at the time the PA was conducted. Custom models were developed to estimate the inventory of radionuclides in the sand pad and piping. Release mechanisms included diffusion and solute leaching and were computed using the DUST-MS code.

The CA considered all other potential sources of contamination that could interact with TFF. These additional sources were not modeled explicitly within the CA. Instead, the flux from the unsaturated zone to the aquifer for each facility was obtained from previous studies and used in the TFF CA model.

Unsaturated Zone Transport

The unsaturated zone is defined here as the region from the base of the disposal facilities or the TFF to the top of the regional aquifer surface (i.e., the Snake River Plain Aquifer). The unsaturated zone varies in thickness from about 75 m near the RWMC to 145 m near the ICDF and TFF and is composed primarily of fractured basalt with horizontal-laying sedimentary interbeds of various thickness and depth dispersed within the region. Flow through the fractured basalt is rapid, often occurring in terms of days or weeks, whereas flow through the sedimentary interbeds relatively slow. Therefore, unsaturated water travel times are largely controlled by the presence of sedimentary interbeds. Perched water can form on top of sedimentary interbeds.

RWMC

The unsaturated zone at the RWMC was originally modeled using the three-dimensional multiphase flow and transport model, TETRAD (Vinsome and Shook, 1993, Martian 2006 V&V). The RWMC TETRAD application was primarily conducted for the CERCLA assessment of the RWMC (Holdren et al 2005; Magnuson and Sondrup, 2005). The model was based on an equivalent porous medium approach with transient surface infiltration conditions to account for historical flooding events at the RWMC. The model included spatially varying surface topography and infiltration, variable basalt and interbed lithology based on stratigraphic interpretations, and spatially variable hydraulic conductivity for the sedimentary interbeds based on core analyses. The hydraulic properties of the fractured basalt were based on inverse modeling of a large-scale infiltration test conducted near the RWMC. The model used a deformable structured integrated finite-difference grid with concentric local refinement to reflect available data density. Transport was simulated for both contaminants that existed purely in aqueous-phase and for contaminants that also partitioned into the gaseous-phase. The available monitoring data for hydrologic and contaminant transport showed general trends but were severely impacted by the extreme heterogeneity expected in a fractured basalt setting. This made definition of reasonable calibration targets problematic. Instead the general trends in hydrologic data, such as conditions in the interbeds beneath the SDA compared to outside the SDA were compared. For transport, the model results were compared to observed results to ensure that the model results were conservative, meaning the concentrations were overpredicted compared to observed concentrations.

Excessive computer run times precluded application of TETRAD to numerous radionuclides, 100,000 year simulations, and Monte-Carlo sensitivity-uncertainty analysis. To address these problems, the TETRAD model was abstracted into a simpler one-dimensional flow and transport model (Mixing Cell Model, [MCM]) that gave essentially the same area-integrated radionuclide flux to the aquifer as the full three-dimensional TETRAD model. One exception was that TETRAD was used to model C-14 since this radionuclide exhibits two-phase flow (vapor and aqueous phase). The MCM model included heterogeneous lithology, transient infiltration, and effects of pre-existing perched zones in the unsaturated zone. Being one-dimensional, MCM was not capable of addressing lateral flow along the sedimentary interbeds. TETRAD modeling indicated that lateral flow from infiltration spreading areas southwest of the facility can contribute to perched water and near-saturated levels in sedimentary interbeds underlying the RWMC. Incorporation of this process in the one-dimensional MCM model was accomplished by assigning a 1 cm/yr infiltration rate (the natural background infiltration) to the unsaturated zone after the cover was emplaced. MCM radionuclide fluxes from the unsaturated zone to the aquifer showed the same temporal trends and magnitude as TETRAD.

ICDF

The GWSCREEN transport code was used to model transport from the base of the disposal facility to the aquifer, and subsequent transport in the aquifer. GWSCREEN includes an unsaturated transport model assumes a homogeneous unsaturated zone with constant infiltration. In this model, the fractured basalt layers were ignored, which essentially assumes instantaneous transport with no sorption. Vadose zone transit times were governed by the presence of 22.7 m of sedimentary interbed. Infiltration in the unsaturated zone was assumed to be 1 cm/yr (the background recharge rate) for all time. The GWSCREEN model accounts for dispersion, sorption, and radioactive decay and ingrowth.

TFF

The PORFLOW (ACRI 2000) numerical model was used to compute water flow and contaminant transport in the unsaturated zone and aquifer underlying the TFF. The model domain consisted of a two-dimensional cross section of the tank farm facility and underlying unsaturated zone and aquifer. Source fluxes predicted by the DUST code were input as external sources near the top of the domain. The domain included sedimentary interbeds and perched water bodies, background infiltration, and seepage infiltration from the Big Lost River. Heads were specified for the aquifer portion of the domain. The model was run until steady-state flow conditions were achieved based on background infiltration and recharge from the Big Lost River. The steady-state flow field was then used in al the contaminant transport runs.

Saturated Zone Transport

The saturated zone at the INL represents the Snake River Plain Aquifer (SRPA) which flows generally from north-northeast to south-southwest. The SRPA is composed mainly of fractured basalt and flow velocities range from 1.5 to 6.1 m/day. Recharge is through irrigation water, valley underflow, and the recharge area in the surrounding mountains to the north.

During the 100-year period of institutional control, the point of compliance in the aquifer is located at the southern INL site boundary. After institutional control, the point of compliance was located 100 m downgradient from the facility. Groundwater quality was evalued anywhere in the aquifer for all times. Therefore, saturated zone modeling required consideration of both local conditions beneath the facility and regional flow to the southern site boundary.

RWMC

The TETRAD model used for the unsaturated zone included a saturated zone that extended slightly beyond the downgradient compliance point. Beneath the RWMC lies a region of low permeability in the aquifer. The 100-m compliance point lies within this region of low permeability which has Darcy velocities around 1.0 m/yr compared to Darcy velocities ranging from about 10 to 80 m/yr that surround the region. This region has major impact on the predicted concentration because at the compliance point, very little dilution occurs in this region.

For the reasons stated earlier, TETRAD was not used directly in the PA/CA. The one-dimensional flow, three-dimensional semi-analytical groundwater assessment code GWSCREEN was used to model transport in the aquifer from the facility to the 100m point of compliance. GWSCREEN-predicted concentrations were compared to the TETRAD concentrations at 100 m and showed the same temporal trends and magnitude as TETRAD.

Predicted concentrations at the site boundary were also estimated with GWSCREEN, using a Darcy velocity that represented the regional flow instead of flow within the low-permeability zone (57 m/yr). For the CA, another approach was also employed. A MODFLOW model of the SRPA was constructed as part of the RCRA/CERCLA process to provide a comprehensive risk assessment for the entire site. This model was abstracted into a Response Surface Model (RSM) that could rapidly simulate contaminant plumes from numerous facilities and sources. The RSM was used to compute concentrations at the RWMC and the INL site boundary from all upgradient sources. Because the grid resolution of the MODFLOW model was less than TETRAD, the low permeability zone was not fully represented in the RSM. Consequently, the RSM-predicted concentrations from RWMC sources were less than TETRAD/GWSCREEN in that region. Nevertheless, the RSM-predicted concentrations from sources at INTEC and RTC could be captured reasonably well at RWMC 100-m point of compliance. The RSM was primarily used to compute radionuclide concentrations at the site boundary during the 100-year institutional control period.

ICDF

The ICDF PA/CA used the 1-D flow and 3-D transport GWSCREEN model for all saturated zone calculations. For the CA, radionuclide fluxes to the aquifer from other facilities relied on other RCRA/CERCLA modeling activities or modeled independently. Because transit time in the unsaturated zone exceeded the time of institutional control, radionuclide concentrations and doses were only evaluated at the 100-m point of compliance. A Darcy velocity of 21.9 m/yr was based on other modeling studies in the INTEC area.

TFF

The TFF PA used a two-dimensional cross section of the aquifer to compute concentrations in the SRPA. The PORFLOW model was used for computations. The model was incorporated into the unsaturated zone model previously described. The model was aligned along the principal flow path in the SNRA so that concentrations at the 100-m downgradient compliance point could easily be evaluated.

For the CA, a three-dimensional model of the SRPA was constructed in PORFLOW. The model incorporated the extensive hydrologic data set accumulated by the U.S. Geological Survey and other hydrologic investigations. The model domain encompassed the southwestern corner of the INL including the southern site boundary where compliance during the institutional control period is evaluated. Transport simulations were confirmed by comparing the predicted and measured tritium plume from the INTEC injection well.

Exposure Scenario/Dose Assessment

The exposure scenario defines the ingestion rates and activities of a hypothetical person who obtains water from a well located at the compliance point. The RWMC and ICDF used the same exposure scenario where the well water is used by the individual for direct consumption, irrigation of locally-grown vegetables and animal feed, and livestock watering. Analytical food-chain transfer models were used to compute the transfer of radionuclides from well water to vegetables and animal products. Annual ingestion dose (Effective Dose Equivalent) was then calculated by assuming specified rates of water, vegetable, and animal products coupled with EPA Federal Guidance Report No. 11 dose coefficients.

The TFF PA/CA used essentially the same all pathways exposure dose model as the ICDF and RWMC. Slightly different inputs were used for some of the parameters.

Uncertainty/Sensitivity Analysis

Both the RWMC PA and ICDF PA included a Monte Carlo uncertainty/sensitivity analysis where distributions were constructed for each of the transport parameters. A Perl shell script was written to 1) sample from the distributions, 2) write model input files, 3) execute the model, and 4) extract and post process results. Output consisted of distributions of radionuclide concentrations and all pathway doses at specified output times. Sensitivity analysis used the Monte Carlo results combined with rank correlation to establish sensitivity of the output variable (all pathway dose) to the various input parameters. In addition to the Monte Carlo analysis, some single-parameter perturbation cases were run.

For the TFF, the long run times for PORFLOW precluded a Monte Carlo Analysis. Instead, four scenarios were established that would provide an upper and lower bounds of the estimated doses. This method was recommended by NRC as a surrogate to Monte Carlo analysis. The four scenarios were identified as worst case, conservative case, realistic case, and best cases. Each case was defined in terms of parameter values that would result in either an increase or a decrease in the all pathway dose from the base case.

Intruder/Radon Analysis

The RWMC and ICDF PA used RESRAD code to model the intruder scenario and radon analysis. Two acute scenarios and five chronic scenarios were considered. However, calculations were only performed for the acute intruder drilling scenario and the chronic post-drilling scenario because the depth to the waste was sufficient to preclude intrusion by other means. A radon scenario was only evaluated for the RWMC.

The TFF considered four intruder scenarios; acute drilling, acute construction, chronic post-drilling and chronic post-construction. The inclusion of the acute and chronic construction scenario is presumably because not cover was assumed to be placed over the waste and therefore, the waste would be accessible near the surface. Intruder calculations were performed on spreadsheets. A radon analysis was also performed using a custom model to estimate radon concentrations within a structure.

Review of PA/CA Model Codes used at the INL

Table 2 contains a summary of the model codes used in each of the PA/CA reports.

Table 2. Codes used in PA/CAs at the Idaho National Laboratory.

Code	PA/CAs code was used in	Reference to code	Comments
DUST-MS	RWMC, TFF	Sullivan 1992, 2006	Provides flux from waste form to the backfilled soil
GWSCREEN	RWMC, ICDF	Rood, 2003	Semi-analytical screening model for leaching and unsaturated, saturated transport
MCM	RWMC	Rood 2005a	Mixing Cell Model for 1-D transport in unsaturated zone under transient flow conditions
MODFLOW	RWMC	Harbaugh et al. 2000	Most recent INL regional flow model
PORFLOW	TFF	ACRI, 2000	3-D numerical model for unsaturated and saturated flow and transport
RESRAD	RWMC, ICDF	Yu et al. 2001	Used to calculate intruder and radon doses
RSM	RWMC	Rood, 2005b	Response Surface Model abstracted from MODFLOW results for transport in the SRPA
TETRAD	RWMC	Shook et al. 2003	3-D numerical model for multiphase unsaturated and saturated flow and transport
CAP88	RWMC/ICDF	EPA 1988	Atmospheric dispersion and dose assessment

Key Data Sets Used in the PA/CA Modeling at the INL

Key parameters used in a PA/CA analysis include waste inventory data, hydrologic characterization data, and geochemical data for radionuclides. These datasets are discussed for each PA/CA in the following sections.

Waste Inventories

RWMC

Waste inventories for past disposals in the RWMC were obtained from the Integrated Waste Tracking System (IWTS) and Waste Information and Location Database (WILD). The WILD data base provides the amounts and locations of waste buried in the RWMC through June of 1997. The IWTS data base provides container-level information of waste disposed at the RWMC from June 1997 to the present. A combination of both data bases were used to determine the best estimate of actual disposals at the RWMC. The projected inventory disposed from 2000 to 2009 was estimated based on previous trends from disposal practices and information from waste generators about current and planned activities at the INL.

ICDF

The ICDF was in construction at the time the PC/CA modeling was being performed consequently, the inventory was estimated. Two iterations were made in development of what was termed the Design Inventory (DI). The first iteration was called the Initial Design Inventory (IDI) and was based on analytical measurements to the extent available for radionuclides in waste that were anticipated to be disposed in the facility. The IDI included only waste from the CERCLA remediation sites that were identified in the CERCLA Waste Inventory Database (CWID). When data were not available, conservative estimates were made. The IDI provided a conservative estimate of the contaminant concentrations and waste mass to be disposed in the ICDF during the first 10-years of operation. The primary waste form was contaminated soils.

The second iteration was termed the Adjusted Design Inventory (ADI). The ADI increased the total mass of excavated soil by 23% and the radionuclide inventory by 60.2%. Therefore, the ADI provided an additional level of conservatism in the projected waste inventory that was to be disposed in the ICDF.

TFF

The TFF inventory included remaining waste in the tank heels, spills and past leaks, and inventory remaining in piping and other infrastructure. Tank inventories were based on the most recent analytical results from sampling of several tanks, and historical data regarding the contents of the eleven 300,000 gal tanks. Concentrations of radionuclides that lacked current analytical data were estimated using the ORIGEN2 code. Radionuclides were also present in the sand pads beneath the tanks due to past spills. Inventories for the sand pads included only those radionuclides with high sorption coefficients because radionuclide with low sorption coefficients would have been removed through leaching. The inventory in the contaminated piping and other infrastructure was estimated based on radionuclide concentrations in the effluent carried by the piping, and the residuals remaining after washing and decontamination steps.

Hydrologic Characterization Data

Borehole data and site-specific moisture retention curves formed the basis for all hydrological characterization data. Numerous boreholes have been drilled and logged at the INL. Sufficient data existed to develop a three-dimensional geological model of the unsaturated zone beneath the RWMC. This model was used in the TETRAD modeling for the RWMC. The ICDF and TFF used a one- and two-dimensional geologic model respectively. A one-dimensional representation for the ICDF was justified because at the time of closure, most anthropogenic water sources will have ceased and water flow in this case would generally be downward. The TFF chose a two-dimensional model as a logical balance between incorporating known perched water bodies and lateral flow, with the computational demands of a three-dimensional model.

Moisture retention curves for fractured basalt were obtained from fitting curves to monitoring data from a large scale infiltration test. The curve results in very low moisture contents under typical infiltration conditions, and consequently very rapid pore velocities were calculated. In the ICDF PA, it was shown that the unsaturated zone could be modeled adequately in one-dimension by assuming instantaneous travel through the unsaturated basalt. The overall water travel time was controlled by the presence and thickness of sedimentary interbeds

Geochemical Data

Geochemical data includes element-specific sorption coefficients (Kd) and solubility. Table 3 and 4 summarizes the sorption coefficients used in each of the PA/CAs for all key radionuclides. In general, there is an inconsistency in the sorption coefficients between each PA/CA, and the choice of a Kd value was made independently for each site. Generalized compilations of Kd values for use in INL RCRA/CERCLA site assessments were developed in the early 90s' (DOE 1994) and were intended for screening assessments. These Kd values were used for radionuclide screening for the ICDF and RWMC, but generally were not used in the base case analysis. The Kd value used for unsaturated basalt was zero in all cases. Aquifer Kds were set at $1/25^{th}$ the interbed Kd values because of the larger water-rock contact area compared to the unsaturated zone.

The RWMC PA/CA used sorption coefficients that were consistent with those used in the CERCLA RI/BRA analysis because much of the PA/CA modeling was based on this effort. In general, site-specific information was used if available. If site-specific information was lacking, then literature values were used. Compilations of Kd values reported in Sheppard and Thibault (1990) were used extensively.

The ICDF selected Kd values from a compilation of Kd values from the literature, and some site-specific values. The selection of a value was made in consultation and agreement with the State of Idaho and EPA, since this facility was intended for disposal of CERCLA wastes. For consistency, the PA/CA used the Kd values agreed to by the State and EPA.

The TFF used site-specific Kd values when available, otherwise, Kd values were selected from the literature. The literature values reviewed included Sheppard and Thibault (1990), and the NEA database (Ticknor and Ruegger, 1989).Grout Kd values were selected from Bradbury and Sarott (1995).

Table 3. Sorption coefficients (Kd) for key radionuclides in waste, sedimentary interbeds, and grout that were used in the INL PA/CAs (mL/g).

Element	RWMC PA/CA[a]	ICDF PA[b]	TFF[c]
Ac	225	450 (2400)	---
Am	225	---	---
C	0 (0.4)	---	5 (10,000)
Ca	5	---	---
Cl	0	---	---
H	0	---	---
I	0	0.1 (1)	0.1 (30)
Ni	100	---	---
Np	23	8 (55)	---
Pa	8	550 (2700)	---
Pb	270	100 (710)	---
Pu	2500	140 (1700)	---
Ra	575	100 (1900)	---
Sr	---	---	18 (6)
Tc	0	0.2 (1)	0.01 (5000)
Th	500	100 (1700)	---
U	15.4	6 (63)	---

a. Alluvium (backfilled soil) Kd and interbed Kd in parentheses. If only one value is presented then the alluvium and interbed Kd were the same.
b. Interbed/waste Kd and clay Kd in parentheses.
c. Interbed Kd and grout Kd in parentheses. The Kds listed are based on the conservative scenario which was used to demonstrate compliance

Table 4. Sorption coefficients (Kd) for key radionuclides in waste and aquifer basalt that were used in the INL PA/CAs (mL/g). Sorption coefficients in unsaturated basalt were all assumed to be zero because of rapid transit time through the fractures allowed less time for sorption reactions.

Element	RWMC PA/CA	ICDF PA	TFF
Ac	9	18	---
Am	---	---	---
C	0	---	0
Ca	0.2	---	---
Cl	0	---	---
H	0	---	---
I	0	0.004	0
Ni	4	---	---
Np	0.92	0.32	---
Pa	0.32	22	---
Pb	10.8	4	---
Pu	100	5.6	---
Ra	23	4	---
Sr	---	---	6
Tc	0	0.008	0
Th	20	4	---
U	0.62	0.24	---

Radionuclide solubility was really only important for isotopes of uranium and plutonium at the RWMC, where sufficient quantities of these radionuclide existed so that the potential for the solubility limit to be exceeded existed. The uranium total solubility limit was 0.91 mg/L. Because uranium will exist in several isotopes, isotope-specific solubility limits were calculated for each uranium isotope. The isotope-specific solubility limit was based on the ratio of the mass-fraction of each isotope to the total uranium mass in the disposal facility. In general, U-238 dominates accounting for 99.4% of the total uranium mass.

References

ACRI (Analytical and Computational Research Incorpoated), 2000. *PORFLOW Users Manual*. ACRI, Bel Air, California.

Bradbury, M.H., and F.A. Sarott, 1995. *Sorption Databases for the Cementitions Near Field of a LLW Repository for Performance Assessment*. Paul Scherrer Institute, 95-12 March.

DOE 1994. Track 2 Sites: Guidance for Assessing Low Probabaility Hazard Sites at the INEL. DOE/ID-10440, U.S. Department of Energy Idaho Operations Office.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000. *MODFLOW-2000, The US Geological Survey Modular Ground-Water Model-User Guide to Modularization Concepts and Groundwater Flow Process*. Open File Report 00-92, U.S. Geological Survey, 2000.

Holdren, K. Jean, Danny L. Anderson, Bruce H. Becker, Nancy L. Hampton, L. Don Koeppen, Swen O. Magnuson, and A. Jeffrey Sondrup, 2006, *Remedial Investigation and Baseline Risk Assessment for Operable Unit 7-13/14*, DOE/ID-11241, U.S. Department of Energy Idaho Operations Office.

Magnuson, Swen O. and A. Jeffrey Sondrup, 2006, *Subsurface Flow and Transport Model Development for the Operable Unit 7-13/14 Remedial Investigation and Feasibility Study,* ICP/EXT-05-01016, Rev. 1, Idaho National Laboratory, Idaho Cleanup Project.

Martian, P., 2007, *Verification and Benchmark Testing of the TETRAD Simulator, Version 12.7ms,* RPT-335, Idaho National Laboratory, Idaho Cleanup Project.

Rood, 2005a. *Mixing Cell Model: A One-Dimensional Numerical Model for Assessment of Water Flow and Contaminant Transport in the Unsaturated Zone*. ICP/EXT-05-00748, Idaho National Laboratory, Idaho Completion Project.

Rood, A.S., 2005b. *Groundwater Transport Modeling Using Response Surface Modeling: Proof of Principle*. ICP/EXT-05-00952, Idaho National Laboratory, Idaho Completion Project.

Rood, A.S., 2003. *GWSCREEN: A Semi-Analytical Model for Assessment of the Groundwater Pathway from Surface or Buried Contamination, Theory and User's Manual, Version 2.5*. INEEL/EXT-98-00750 Rev 1b. Idaho National Laboratory

Sheppard, M.I., and D.H. Thibault, 1990. "Default Soil Solid/Liquid Partition Coefficients Kds, for Four Major Soil Types: A Compendium". *Health Physics*, 59(4), pp 471-482.

Shook, G. M., J. Hope Forsman, M. Elena Velasquez, and S.O. Magnuson, 2003. “Improving Numerical Model Efficiency of an Existing, In-House Simulation Model,” *Laboratory-Directed Research and Development, FY-2003 Annual Report*. INEEL/EXT-04-01772, Idaho National Laboratory, pp. 197-199.

Sullivan, T.M., 1992. *Development of DUST: A Computer Code that Calculates Release Rates from LLW Disposal Unit*. BNL-NUREG-47118, Brookhaven National Laboratory, U.S. Nuclear Regulatory Commission.

Sullivan, T.M., 2006. *DUSTMS-D: Disposal Unit Source Term – Multiple Species- Distributed Failure Data Input Guide*. BNL-75554-2006 Brookhaven National Laboratory.

Ticknor, K.V., and B Ruegger, 1989. *A Guide to the NEA’s Sorption Data Base Version 2.0*, September.

Vinsome, P. K. W., and G. M. Shook, 1993, “Multi-Purpose Simulation,” *Journal of Petroleum Science and Engineering*, Vol. 9, pp. 29-38.

Yu, C., A. J. Zielen, J.-J. Cheng, D. J. LePoire, E. Gnanapragasam, S. Kamboj, J. Arnish, A. Wallo III, W. A. Williams, and H. Peterson, 2001, *User’s Manual for RESRAD Version 6*, ANL/EAD-4, Environmental Assessment Division Argonne National Laboratory.