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Summary of Conceptual Models and Data Needs to Support the INL Remote-Handled Low-Level Waste Disposal Facility Performance Assessment and Composite Analysis

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Idaho National Laboratory

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ABSTRACT

An overview of the technical approach and data required to support development of the performance assessment and composite analysis is presented for the remote-handled low-level waste onsite disposal alternative being considered for the Idaho National Laboratory. The onsite disposal alternative is being evaluated in anticipation of the closure of the Radioactive Waste Management Complex at the Idaho National Laboratory.

An assessment of the proposed facility performance and of the composite performance are required to meet radioactive waste management requirements in Department of Energy (DOE) Order 435.1 (DOE O 435.1 2001), which stipulate that operation and closure of the disposal facility will be managed in a manner that is protective of worker and public health and safety, and the environment. Corresponding established procedures for ensuring these protections are contained in DOE Manual 435.1-1, "Radioactive Waste Management Manual" (DOE M 435.1-1 2001). Requirements include assessment of (1) all-exposure pathways, (2) air pathway, (3) radon, and (4) groundwater pathway doses. Doses are computed from radionuclide concentrations in the environment. The performance assessment and composite analysis are being prepared to assess compliance with performance objectives, to establish limits on concentrations and inventories of radionuclides at the facility, and to support specification of design, construction, operation, and closure requirements.

Technical objectives of the performance assessment and composite analysis are primarily accomplished through development of an established inventory and use of predictive environmental transport models implementing an overarching conceptual framework. This document reviews the conceptual model, inherent assumptions, and data required to implement the conceptual model in a numerical framework. Available site-specific data and data sources are identified, and differences in required analyses and data are captured as outstanding needs.

CONTENTS

FIGURES

ACRONYMS

ATR	Advanced Test Reactor
bls	below land surface
CA	composite analysis
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CFR	Code of Federal Regulations
DOE	Department of Energy
EDE	effective dose equivalent
ICDF	INL CERCLA Disposal Facility
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
LLW	low-level waste
Kd	distribution coefficient
NESHAP	National Emission Standards for Hazardous Air Pollutants
NRC	Nuclear Regulatory Commission
OU	operable unit
PA	performance assessment
RH	remote-handled
RI/BRA	Remedial Investigation/Baseline Risk Assessment
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SRPA	Snake River Plain Aquifer

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1. BACKGROUND

Since 1952, all remote-handled low-level waste (RH-LLW) generated at the Idaho National Laboratory (INL) has been disposed of at the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC). In anticipation of closure of RWMC, INL is proposing to establish a new RH-LLW disposal facility. The new facility must comply with requirements set forth in Department of Energy (DOE) Order 435.1, "Radioactive Waste Management," (DOE O 435.1 2001), which stipulate that operation and closure of the disposal facility will be managed in a manner that is protective of worker and public health and safety and the environment. Established procedures for ensuring these protections are contained in DOE Manual 435.1-1, "Radioactive Waste Management Manual" (DOE M 435.1-1 2001). The manual further describes requirements and establishes specific responsibilities for implementing DOE Order 435.1. Specifically, Chapter IV of DOE Guide 435.1-1, "Implementation Guide for Use with DOE M 435.1-1, Radioactive Waste Management Manual," (DOE G 435.1-1 1999) addresses LLW disposal. Section IV-P(1) addresses performance objectives, which are summarized as follows:

- Dose to a representative member of the public shall not exceed 25 mrem/year effective dose equivalent (EDE) from all exposure pathways
- Dose to a representative member of the public via the air pathway shall not exceed 10 mrem/year EDE, excluding radon and its progeny
- Release of radon is limited to 20 pCi/m^2-s
- Groundwater impacts do not exceed federal or State of Idaho drinking water standards (40 CFR 141 [40 CFR 141 2007] and IDAPA 58.01.08 [IDAPA 2009]).

To assess compliance with the above performance objectives, a radiological performance assessment (PA) and composite analysis (CA) are being prepared to establish limits on concentrations and inventories of radionuclides at the facility. The results of the PA and CA also are used to support specification of design, construction, operation, and closure requirements.

1.1 Purpose and Scope

The purpose of this report is to present an overview of the assessment approach and data required to support development of the PA and CA for the proposed RH-LLW disposal facility. Previous analyses and available data that meet requirements are identified and discussed. Outstanding data and analysis needs also are identified and summarized.

2. PERFORMANCE ASSESSMENT OVERVIEW

Several elements of the PA must be defined and understood in order to identify the data necessary to conduct the PA. The most important elements are exposure pathways and scenarios and the release and transport model processes, which are summarized in this section. It should be noted that these elements will be the same or similar to those used for the RWMC PA (DOE-ID 2007) due to similarities in waste stream, disposal methods, location, etc. Justification for these elements will not be provided here, but will be provided in the PA.

2.1 Exposure Pathways and Scenarios

The PA is a comprehensive, systematic analysis of potential long-term impacts due to LLW disposal. It requires calculation of potential radiation doses from all exposure pathways to members of the public and evaluation of impacts to water resources. Exposure pathways (shown in Figure 1) include radionuclide exposures via inhalation and ingestion and external exposure through air, soil, water, and biota. These exposure pathways were determined to be inclusive and appropriate based on the site geology, hydrology, demography, facility design, and other disposal site characteristics. This PA will not include analysis of the surface water exposure pathway because surface water on the INL Site is very limited and there are no surface water uses. This is consistent with the RWMC PA (DOE-ID 2007), the INL Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Disposal Facility (ICDF) PA (DOE-ID 2003a), and other INL investigations.

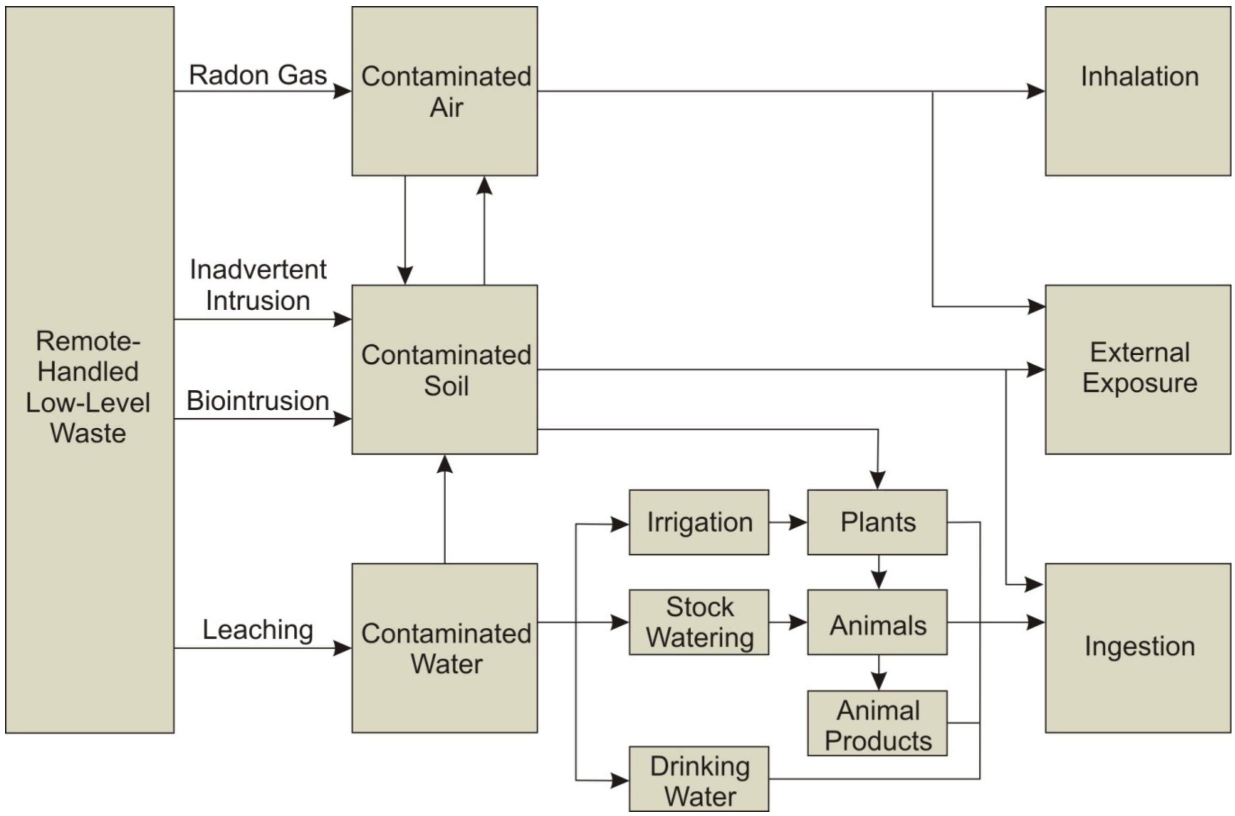

Figure 1. Exposure pathways for the proposed remote-handled low-level waste disposal facility performance assessment.

For the purpose of assessing the performance of the proposed RH-LLW disposal facility, the following four distinct time periods are considered:

1. **Operational Period** – The operational period is anticipated to last 50 years (2016 to 2065). During this time, waste containers are loaded into the concrete vaults. Subsidence and erosion are not of significant concern because the RH-LLW disposal facility will be under continuous maintenance during this period. Vaults and other engineering controls effectively eliminate biotic and human intrusion. At the end of the operational period, an infiltration-reducing and intrusion-limiting cover will be installed and the facility will be effectively closed.

2. **Institutional Control Period** – The institutional control period follows site closure and lasts for 100 years. During this time, the facility is still part of the INL Site and is fenced and patrolled. Periodic maintenance and monitoring activities also will be conducted to ensure erosion and subsidence are controlled so that the hydrologic and biointrusion integrity of the cover remains intact. This assumption is consistent with Nuclear Regulatory Commission (NRC) guidance (NRC 1982: NRC 2000) and the RWMC and ICDF PAs. The vaults also are assumed to remain intact.

3. **Compliance Period** – The compliance period follows the institutional control period and lasts for 900 years. The total time of the institutional control period and compliance period is 1,000 years, the maximum time of compliance for DOE LLW PAs according to DOE Order 435.1. During this time, the facility is assumed to not be maintained and may be accessible to the public. Both the hydrologic and biointrusion integrity of the cover is assumed to be reduced through erosion and subsidence.

4. **Post-Compliance Period** – The post-compliance period follows the compliance period and begins 1,000 years post closure. Although this is beyond the 1,000-year time of compliance (according to DOE Order 435.1), some analyses will be carried out to the time of maximum potential impact to provide perspective on the magnitude of predicted doses beyond the compliance timeframe. During this period, the cover is assumed to have failed and infiltration is assumed to return to the background rate.

Both residential and intruder scenarios will be evaluated in the PA. For the residential scenario, a hypothetical individual is assumed to reside at the downgradient INL site boundary during the operational and institutional control periods. During the compliance and post-compliance periods, the hypothetical receptor is assumed to reside 100 m from the downgradient edge of the disposal facility. In both cases, the residential receptors are assumed to be exposed to contaminants delivered through the groundwater all-pathways scenario, which assumes the receptor consumes (1) contaminated groundwater, (2) leafy vegetables and produce that were irrigated with contaminated groundwater, and (3) milk and meat from animals that consume contaminated water and pasture grass irrigated with contaminated groundwater. Additionally, these individuals are assumed to be exposed through the atmospheric and biotic pathways, which include radon exposures (see Figure 1).

The intruder scenario assumes that a hypothetical receptor inadvertently intrudes into the waste at the start of the compliance period. Both acute and chronic inadvertent intruder well-drilling scenarios will be evaluated. The acute exposure scenario will account for doses from inhalation of contaminated air, direct external exposure, and soil ingestion. The chronic exposure scenario will account for doses from dust inhalation, direct external exposure, soil ingestion, and ingestion of contaminated food (e.g., beef, milk, and plants).

2.2 Release and Transport Model Overview

All dose calculations rely on estimates of radionuclide concentrations in environmental media (i.e., air, soil, and water). This requires knowledge and understanding of the (1) radionuclide inventory and release rates from the facility and (2) migration rates of released constituents through the environment. The link between the initial release inventory and dose is accomplished through release and environmental transport models, which are used to predict concentrations. A simplified representation of this process is shown in Figure 2. The models are described as follows.

- **Source Release Model** – The source release model estimates the release of radionuclides from waste forms and containers into backfill material and ultimately into the environment surrounding the facility. Output from the source release model becomes input to environmental transport models.

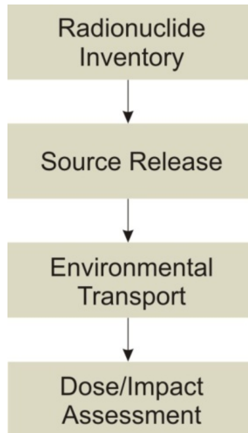

Figure 2. Simplified representation of model elements and linkages for the performance assessment.

- **Groundwater Pathway Transport Model** – The groundwater pathway transport model accepts dissolved phase radionuclide releases from the source release model and transports them through the vadose zone and through the aquifer to potential receptor locations.
- **Atmospheric Pathway Transport Model –** The atmospheric pathway transport model accepts gaseous phase radionuclide releases (excluding radon) from the source release model and transports them through the air to potential receptor locations.
- **Biotic Pathway Transport Model –** The biotic pathway model accepts soil and dissolved phase radionuclide releases from the source release model. The contamination is brought to the surface by burrowing rodents/ants or by plant uptake. Then it is available for resuspension, atmospheric transport, and deposition followed by direct exposure through external contact, inhalation, soil ingestion, and ingestion of contaminated food stuff.

The remainder of this report discusses important elements of these models in further detail.

3. SOURCE RELEASE

The source release model is used to predict the time-history of contaminant releases from the waste form into the facility and ultimately into the surrounding environment. Output from the source release model becomes input to other fate and transport models. Releases are controlled primarily by the movement of water into and out of the facility, which is largely controlled by disposal facility characteristics. Additionally, releases may be controlled by waste form, such as the corrosion and subsequent release of activation products in metal components.

3.1 Source Release Processes and Assumptions

The source release model requires an understanding or assessment of waste types, radionuclide inventory, waste containers, infiltration (inside the facility), and release mechanisms.

- **Waste type –** The disposal facility will accept two primary types of RH-LLW: activated metals and ion-exchange resins. The activated metals are generated by Advanced Test Reactor (ATR) Complex operations, Naval Reactors Facility operations, and from processing waste stored in the Radioactive Scrap and Waste Facility at the Materials and Fuels Complex. The activated metals are typically reactor core components replaced during core internal changeouts and are made from stainless steel , inconel (nickel-based alloy), zircaloy or aluminum. The ion-exchange resins are ceramic beads used to purify reactor cooling water as part of routine operations at the Naval Reactors Facility and the ATR Complex. In addition to the metals and resins, a relatively small amount of miscellaneous debris will be included. The debris consists of cuttings and grindings, polishing discs, tools, cable, wiring, glassware, rags, teri-towels, plastic bags, and gaskets.

- **Radionuclide Inventory** – The total projected quantities of waste from each of the facilities for the 20-year period (i.e., 2016 through 2035) are presented in Figure 3. Waste projections are currently being extended to the year 2065 in anticipation of a potential 50-year operating life for the facility. The projected waste inventory includes the list of each radionuclide and amount (activity) expected in each waste form when shipped to the facility. Any decay time before shipment to the facility will be factored in. The list is anticipated to comprise upwards of 50 to 100 different nuclides. It is anticipated that screening, based on half-life and conservative dose models, will reduce the number of nuclides that are carried through the PA analysis.

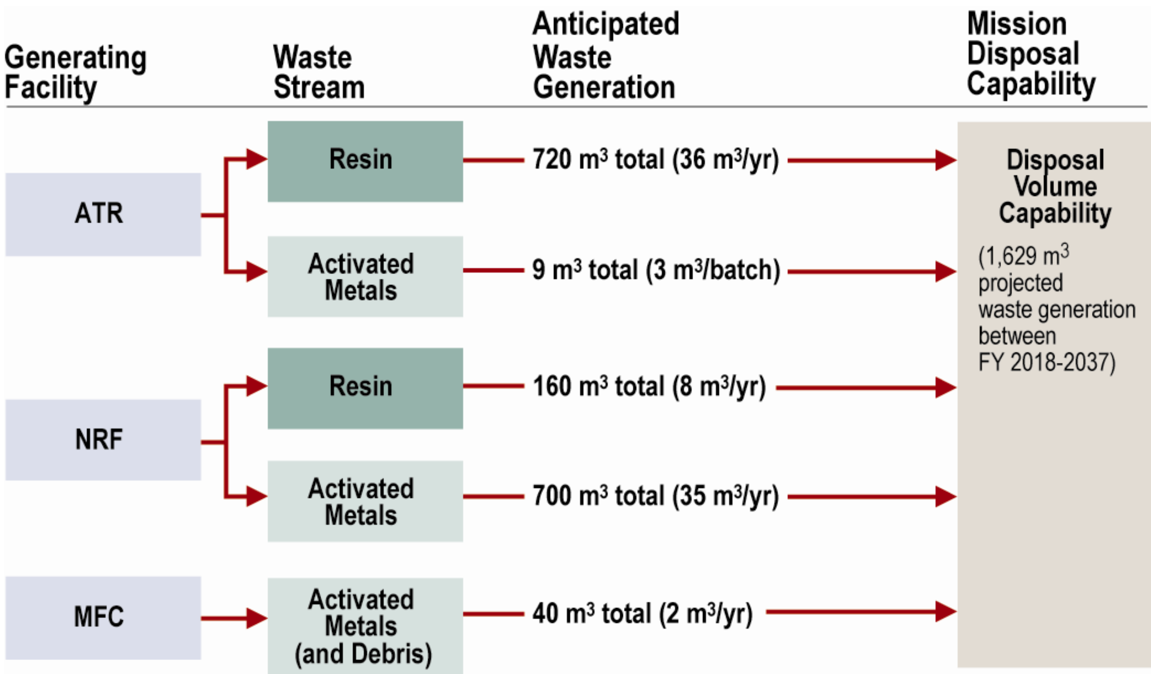

Figure 3. Projected remote-handled low-level waste generation for the 20-yr period 2016 to 2035.

- **Waste Containers** – The metal, resin and debris waste is contained in sealed liners made of steel. The liners are shipped in casks and transferred from the casks into concrete disposal vaults at the disposal facility. The disposal vaults will be similar to those currently in use at RWMC and will be constructed as precast concrete cylinders (i.e., pipe sections) stacked on end and placed in an array as shown in Figure 4. All vaults will be supported by hexagonal reinforced concrete base sections atop a gravel layer and covered with removable hexagonal precast concrete plugs. The plugs serve as a radiation shield for emplaced waste and should also help prevent water from entering the vaults. The area around the vaults will be backfilled with sand or other materials for stability and to promote drainage. During the operational period, the containers and vaults are assumed to provide sufficient barriers from water and air such that negligible transport of contaminants into the environment will occur.

- **Release Mechanisms** – The primary release mechanisms from the waste forms are surface wash (leaching) for the ion-exchange resins and debris, and dissolution or corrosion for activated metals. Release rates via surface wash from the resins will be determined using linear equilibrium partitioning between pore water and resin characterized by a distribution coefficient (Kd). For the RWMC PA, a range of Kds for anions in resins was estimated by Hull (2004), but Hull did not consider the presence of concrete or steel corrosion on pore-water chemistry. Because of the changing water chemistry in the concrete vaults, the Kd values could be time-evolving, and will require an assessment of temporal changes in anticipated pore-water chemistry. If credit is to be taken for sorption onto the backfill material, the material must have a Kd greater than the resin Kd value.

Dissolution releases of radionuclides from activated metals are modeled using a fractional corrosion rate appropriate for the metal type (e.g. stainless steel, inconel, aluminum). The fractional corrosion rate is the fraction of metal corroded per unit time and is determined by the absolute corrosion rate (in mm/year) multiplied by the surface-to volume ratio (in mm^{-1}). Several studies have been performed to estimate absolute corrosion rates of metals buried at the SDA (Nagata and Banaee 1996; Adler-Flitton et al. 2001; Adler-Flitton et al. 2004). Data from these studies, combined with the representative surface-to-volume ratios of the disposed activated metal components, will be used to determine appropriate fractional corrosion rates.

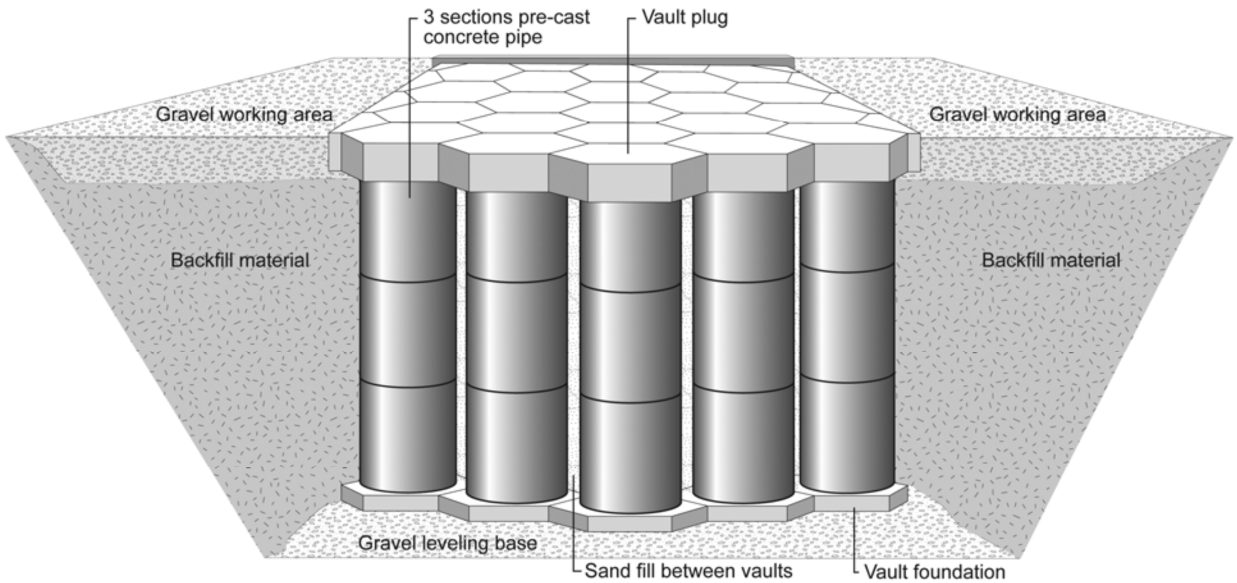

Figure 4. Example of concrete vault layout.

- **Infiltration** – Upon closure, the disposal facility will be covered with an engineered barrier (cover). The primary purposes of the cover are to (1) reduce infiltration into the disposal facility after facility closure, thus reducing leachate generation and contaminant transport and (2) provide a barrier against intrusion. The cover will likely be of similar construction as those planned for the RWMC SDA and ICDF. Those covers were based on the work of Mattson et al. (2004) and the same design infiltration rate will be assumed. Upon closure, the infiltrating water is assumed to pass through the containers and waste at the rate allowed by the cover. The hydrologic integrity of the cover is assumed to remain intact for the first 500 years following closure (NRC 1982; NRC 2000). Beyond 500 years, the cover integrity is reduced and the infiltration rate is increased linearly until it is equal to the background infiltration rate at the end of the compliance period.

  A subsurface liner and leachate collection system is not considered to be necessary in the arid environment at INL. There are currently no plans to incorporate a liner or leachate collection system at the base of the vault excavation (Harvego et al. 2009).

4. SUBSURFACE FATE AND TRANSPORT

According to Harvego et al. (2010), the two highest ranked candidate locations for the proposed disposal facility are (1) southwest of the ATR Complex (Site 5) and (2) southwest of the Idaho Nuclear Technology and Engineering Center (INTEC) at INL (Site 34) (see Figure 5). These sites are similar demographically and climatographically. They are both located near the ephemeral Big Lost River and are roughly equidistant (about 450 ft) above the underlying Snake River Plain Aquifer (SRPA). Contaminants released from either of these facilities could be transported downward through the stratigraphic layers comprising the vadose zone and into the aquifer. Once in the aquifer, there is the potential for mingling with existing contaminates or future predicted contaminants. The purpose of the subsurface fate and transport evaluation is to assess the aquifer concentrations that will be used to determine the time-varying dose to potential receptors located downstream from the proposed facilities as a result of potential releases and in combination with other dose sources.

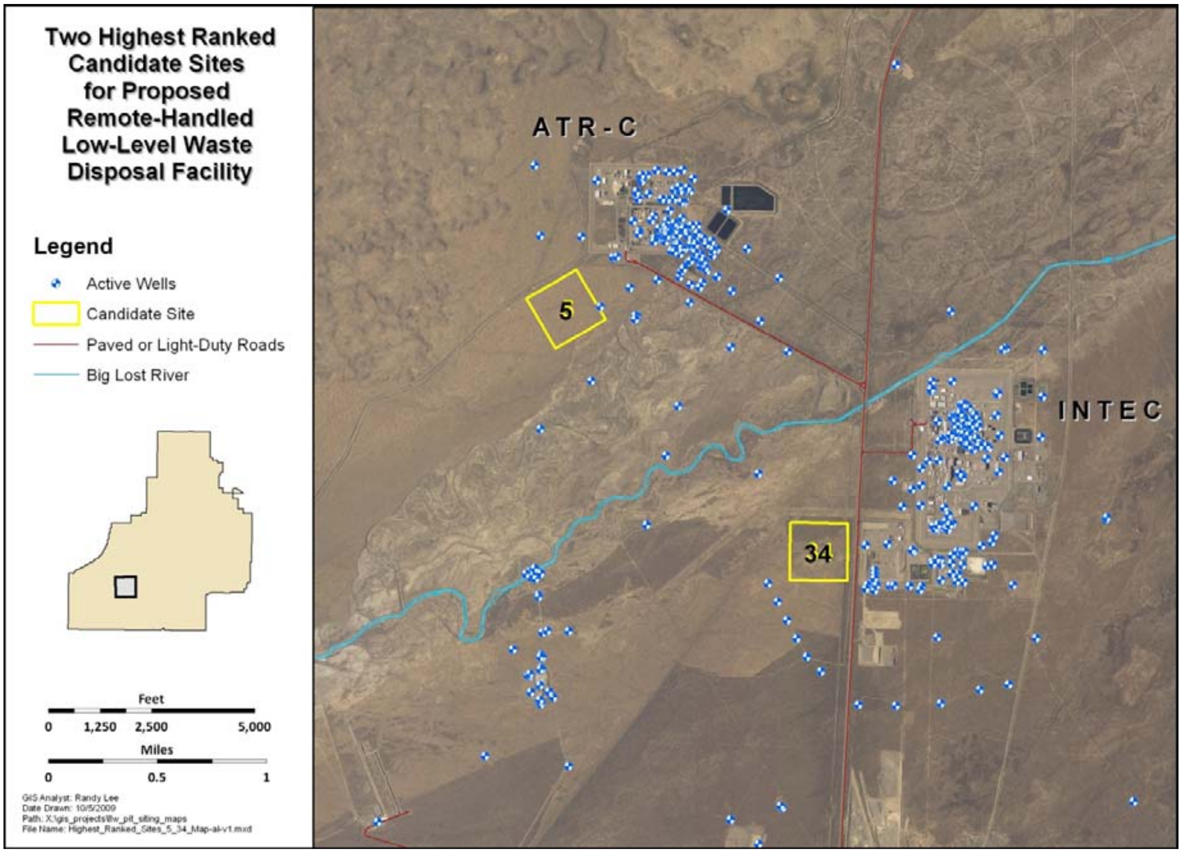

Figure 5. Highest ranked candidate sites for the proposed remote-handled low-level waste disposal facility.

Assessing data availability necessary to evaluate the potential impact to groundwater requires an understanding of key hydrogeochemical processes and development of a conceptual transport model. For the purposes of preparing the PA/CA, we will rely primarily on the knowledge that has been gained as a result of INL-specific large and small-scale experiments, and from extensive modeling and field investigations performed in support of CERCLA evaluations for the ATR and INTEC sites. Data and analyses necessary to support this project are presented in subsequent sections. This presentation begins with an elucidation of key fate and transport processes identified in the previous analyses, including an assessment of important assumptions. Secondly, the availability of site-specific data for the two primary candidate sites will be reviewed in the context of the process models. As discussed, most of the site-specific data for the two site-specific analyses are available for use without additional interpretation. However, because transport through the proposed locations have not been previously evaluated, additional assumptions and data extensions will be necessary.

4.1 Subsurface Fate and Transport Processes and Assumptions

Important assumptions and descriptions of primary subsurface fate and transport processes and parameters are presented in this section. This discussion provides the fundamental basis for overall fate and transport conceptual models for both sites. Differences between the sites and parameters specific to each are presented in the following section. The fundamental process model assumes that contaminants released near land surface could be transported downward through the stratigraphic layers comprising the vadose zone and into the aquifer by infiltration from natural precipitation, anthropogenic waters, and from the Big Lost River. Along this transport pathway, the dilute radionuclides can undergo advection, phase-partitioning, sorption, diffusion, dispersion, and radioactive chain decay and ingrowth. Once in the aquifer, similar transport and decay processes occur as contaminants move with the regional groundwater flow. The relative influence of these processes is, in part, determined by site-specific hydrogeochemistry and is, in part, contaminant specific. Advection, dispersion, and sorption are largely determined by the geostratigraphy and localized infiltration at each individual site. Gas-phase transport and radioactive decay are contaminant specific, with the contaminant inventory dictated by the waste source. The important parameters and characteristics from a predictive perspective are discussed as follows:

- **Infiltration** – Infiltration is the process by which surface water enters the soil. After surface water has infiltrated into the soil, it is redistributed in response to gravity and capillary forces. The redistribution process ultimately partitions the infiltrated water into (1) surface losses to evaporation and transpiration, (2) drainage that eventually becomes aquifer recharge, and (3) storage that remains in the vadose zone. Infiltrating water moves down through the facility, contacting the waste and backfilled materials, mobilizing contaminants, and eventually transporting them to the aquifer. The storage or residual moisture is important because it determines the amount of water in contact with soil, which affects the sorption characteristics. Determination of net infiltration has been accomplished by analyzing field data using numerical models. Recharge resulting from precipitation is strongly dependent on soil type, topography, and surface vegetation type as determined by comprehensive studies at the INTEC tank farm and the RWMC SDA. Given this observation, specific values will be selected for each site representative of the local conditions.

  Sources of infiltrating water at INL include anthropogenic water discharges, losses from the Big Lost River, and natural precipitation in the form of rain and snowmelt. Anthropogenic water discharges across the INL are facility specific, with little or no man-made water near some facilities and significantly higher than precipitation-derived infiltration near others. Both proposed RH-LLW facility locations are outside the areas influenced by significant anthropogenic water. Additionally, the proposed sites are outside the floodplain of the ephemeral Big Lost River. However, increased infiltration at depth while the river is flowing has been observed near the proposed locations, with the extent of river influence dictated by local geostratigraphy. Precipitation-derived infiltration across INL is seasonal, but largely uniform, with local, small-scale focusing of infiltration occurring in natural and man-made depressions. At either of the proposed facilities, it will be assumed that engineered controls will be emplaced to mitigate small-scale focusing of infiltration during the operational and post-operational periods. These controls will be effective for some period post-closure.

- **Geostratigraphy** – Geostratigraphy at INL was built up by periodic eruptions of basalt lava flows followed by periods of volcanic quiescence, during which alluvial, lacustrine, and aeolian sediments were deposited. These alternating periods of volcanic eruption and quiescence have resulted in stratigraphy characterized by extensively interfingered basalt units and sedimentary interbeds. The basalts are relatively non-sorptive to contaminants, allowing contaminants to move through them with the rate of either aquifer water or surface-originating infiltration water. The sedimentary interbed structure controls the downward migration of contaminants through the vadose zone, serving to retard contaminants. In the aquifer, the interbeds serve as semiconfining layers, but serve to add little adsorptive capacity because of their parallel-to-flow structure.

- **Advection** – In the vadose zone, advective transport of water occurs through the alluvial sediments, sedimentary interbeds, and fractured basalts. Previous transport models constructed for locations near both of the proposed sites have assumed water transport occurs through these sedimentary porous media differentially, based on local heterogeneity and soil texture. For strictly dissolved-phase contaminant transport, flow in the fractured basalt portion of the subsurface is considered to occur only in the fracture network to emulate an anisotropic medium with a low effective porosity and a high permeability. Gas phase transport in the vadose zone is typically much more rapid than aqueous transport with the rate strongly depending on soil-moisture content. Soil moisture retards vapor migration by reducing the pore space available for vapor movement and through partitioning of the vapor phase into the aqueous phase. For contaminants that partition into the gaseous phase, the exchange of water between the fracture network and the basalt matrix and flow within the basalt matrix affect advective transport.

- **Fluid phase partitioning** – Fluid phase partitioning in the vadose zone occurs as compounds seek an equilibrium condition between the vapor, aqueous, and solid phases. The relative amount of chemical in two neighboring phases in equilibrium is described by partition coefficients. Partitioning between vapor and aqueous phases is described by Henry's Law. Henry's Law coefficients are simply the vapor pressure of pure compound divided by the aqueous solubility. Partitioning from fluid phases onto the solid phases is compound and sorption process specific.

- **Sorption** – Solid phase sorption involves mass transfer between solutes and solids. Sorption is a general term that can be further classified based on the type of process that binds the solute to the solid. These processes include (1) adsorption (solutes held at the mineral surface as a complex), (2) absorption (solutes incorporated into the mineral structure at its surface), and (3) ion exchange (ions sorbed to a surface through changing places with a similarly charged ion on the mineral surface) (Kehow 2001). Contaminant sorption to the subsurface media can significantly slow transport of many contaminants. At INL, nearly all vadose zone and groundwater models have assumed sorption processes to be linear, instantaneous, and reversible. This allows the sorption process to be lumped into a single soil/water Kd. In contrast, for the very high ionic strength acidic raffinate release at site CPP-31, a geochemical model considering precipitation/dissolution, CO_2 production, gas phase transport, and competitive cation exchange was used (DOE-ID 2006a; Hull and Schafer 2008). These simulation results indicated that under dilute transport conditions a linear Kd approach should adequately describe the sorption process.

  At INL, sorption is assumed to occur on sediments, while sorption on basalts is considered negligible. Some subsurface transport models have considered basalt sorption based on the assumption that water travels primarily through the fractures and the fracture surfaces are coated with fine-grained sediment or chemical alteration products. In these cases, sorption coefficients were calculated based on an estimated fracture surface area. Magnuson and Sondrup (1998) list sorption coefficients for sediments and fractures, and the fracture sorption coefficients are approximately four to six orders of magnitude smaller. Based on this, sorption on basalts will not be considered.

- **Diffusion** – Because aqueous diffusion is often very slow compared to aqueous advection and vapor diffusion, it will not be considered. Vapor diffusion in porous media is described by Fick's first law, which states that the diffusive flux is proportional to the concentration gradient. The proportionality constant is called the effective diffusion coefficient. In a porous medium, contaminant molecules must travel longer diffusion paths because of the structure of the medium and moisture in the pore space. To account for the longer diffusion paths, the effective vapor phase diffusion coefficient is the product of the free-air diffusion coefficient and the gas or air-filled porosity, divided by a parameter of the medium called the tortuosity. Diffusion coefficients and gaseous-phase tortuosity have been obtained through model calibration for INL media.

- **Dispersion** – Hydrodynamic dispersion is velocity dependant and accounts for small-scale solute mixing in macroscopic continuum porous media flow equations. In practice, dispersion is a function of the degree to which the variability in velocity is captured explicitly by model parameterization. For example, in an analytic model parameterized with a single velocity, dispersivity might be quite large, while in a numerical model incorporating a large degree of heterogeneity and allowing for variations in velocity, dispersivity might be quite small. Transferring dispersivity between models is complicated by dimensionality, grid discretization, and specific numerical implementation. Previous models of transport at INL have been first order accurate in space and have used large irregularly shaped grid blocks and large time steps that result in significant numerical dispersion. Simplified models used for other INL PAs have used dispersivity values determined through calibration to the more complex three-dimensional process-level models of transport, resulting in much larger dispersivity values.

- **Facilitated transport** – Facilitated transport mechanisms (e.g., colloidal transport) are thought to affect contaminant migration in the subsurface. Colloids are small particles, generally less than 10 microns, and are transported by advective movement of water, with limited or no chemical interaction with the surrounding soil matrix. Natural and intrinsic colloids may exist in the waste. Natural colloids are derived from clay-rich soil. Intrinsic colloids are formed as a result of high-temperature reactor processes. Contaminants can sorb onto either type of colloid and undergo facilitated transport. Facilitated transport is implemented in numerical models by assigning a distribution coefficient of zero to the colloidal fractions. Facilitated transport that might occur for other contaminants sorbing onto natural colloids is neglected because they comprise a very small fraction relative to intrinsic colloids.

4.2 Site-Specific Data Availability

Predictions of groundwater concentration have been performed near the two candidate sites and for other hydrologically similar sites in support of previous CERCLA evaluations at INL. Similar methodology and data used to parameterize these previous models will form the basis of the predictive models for this PA. As discussed below, most of the site-specific data for this analysis is available for use without additional interpretation. However, because these sites have not been previously evaluated, where these data are not available, model assumptions can be made, additional analyses will need to be performed, and some additional data will be necessary.

4.2.1 Available Vadose Zone Data for Idaho Nuclear Technology and Engineering Center Site

Data availability at the INTEC site is reasonably complete. Detailed studies of the hydrologic, stratigraphic, and geochemical data relevant to the proposed site south of INTEC were completed during preparation of the Operable Unit (OU) 3-13, Group 4, Monitoring Well and Tracer Study (DOE-ID, 2003b), the OU 3-13 Remedial Investigation and Baseline Risk Assessment (RI/BRA) (DOE-ID 1997, Appendix F), and the OU 3-14 RI/BRA (DOE-ID 2006a, Appendices A and J). These studies evaluated the following data:

- **Lithologic data** – Basalt and interbed core, geochemical, paleomagnetic, K-Ar age date, and petrographic data have been collected and studied extensively to determine the lithology near INTEC. These data indicate that several distinct lithologic layers exist beneath INTEC that were used to delimit the surficial alluvium and five major sedimentary interbeds between land surface and the aquifer. To assess the horizontal and vertical spatial extent, a geostatistical analysis was performed on the interbed top elevations and thicknesses. An analysis of these data was used to construct the full three-dimensional vadose zone model used to predict downward transport from land surface contaminant sources to the vadose zone-aquifer interface in the OU 3-14 RI/BRA analysis. Stratigraphy for the proposed site south of INTEC will be derived from these analyses.

- **Hydrologic data** – Alluvium and interbed properties, including soil moisture characteristics, particle size distribution, porosity, effective porosity, bulk density, and moisture content, have been studied extensively at the INTEC site. The alluvium at INTEC varies in texture from inorganic clays and silts to well-sorted gravels, but is primarily a mixture of poorly graded gravel and sand. Saturated hydraulic conductivity and an assessment of geochemical characteristics is available for the alluvium. The sedimentary interbeds at INTEC consist of fluvial, lacustrine, and aeolian deposits of clays, silts, sands, and gravels. Saturated hydraulic conductivity and van Genuchten parameters are available for a range of depths and soil-textural classes obtained from pump tests and laboratory core analyses for the interbed materials. Direct measurements of unsaturated hydraulic characteristics are unavailable for the highly heterogeneous basalts. However, saturated hydraulic conductivity is available for the perched water tests conducted at INTEC. Unsaturated hydraulic characteristics that were estimated for a large-scale infiltration test conducted at INL (Magnuson 1995) have been widely used to represent basalt properties in most vadose zone models constructed at INL. This information will be used in evaluating the proposed INTEC site.

- **Infiltration data** – Analyses quantifying net infiltration have been performed for disturbed conditions at INL's INTEC and RWMC (Martian 1995) and for undisturbed and vegetated conditions (Cecil et al. 1992). These data are applicable for the proposed RH-LLW site when infiltration is not being controlled by the cover.
- **Perched water data** – There are several discontinuous perched water zones beneath INTEC associated with the alluvium/basalt interface: the shallow primary interbeds at 110 ft and 140 ft below land surface (bls), the interbed below the middle-massive basalt unit (about 280 ft bls), and the deep interbed at 380 ft bls. Perched water also appears to be associated with low permeability basalt and numerous other thin and discontinuous interbeds. The shallow and intermediate depth perched water zones appear to be associated with precipitation infiltration and anthropogenic waters. The deep perched water associated with the 380 ft interbed appears to be the result of recharge attributed to a combination of the Big Lost River and anthropogenic water. The proposed RH-LLW site south of INTEC is further south than the documented extent of perched water at INTEC.
- **Big Lost River infiltration data** – The Big Lost River flows intermittently as it crosses the northwest corner of the INTEC facility. After passing the INL spreading areas, the streamflow infiltrates through the river channel as it flows near INTEC, ultimately infiltrating into the playas located at the river's terminus, which is located approximately 15 miles north of INTEC. The Big Lost River recharge near INTEC has been estimated using stream infiltration losses occurring between the INL diversion dam and the Lincoln Boulevard bridge near INTEC. These data are sufficient for use in evaluating the proposed INTEC site.

  Flooding potential of the Big Lost River near INTEC has been investigated by several researchers, most notably Koslow and Van Haaften (1986), Hortness and Rousseau (2003), and Ostenna and O'Connell (2005). This information will be used to assess potential flooding impacts.
- **Sorption data** – Reasonably conservative contaminant-specific Kd values have been identified for three material types (i.e., alluvium, basalt, and interbed) at INTEC and have been used in previous vadose zone and groundwater fate and transport models. An in-depth discussion of the Kd uncertainty and variability also is available (DOE-ID 2006a, Appendix D). These data are sufficient for use in evaluating the proposed INTEC site.
- **Dispersion data –** In the OU 3-13 RI/BRA (DOE-ID 1997), a 5-m longitudinal and 0-m transverse dispersivity were used for the aquifer. Dispersivity in the vadose zone model was adjusted to match the observed concentration in the perched water wells. In those simulations, the TETRAD simulator was used. It is a first order accurate numerical solution scheme in space; the model used large irregularly shaped grid blocks and large time steps. All these factors resulted in significant numerical dispersion, with the effective model dispersion being significantly higher than the specified value. In comparison, the composite analysis of ICDF (DOE-ID 2003c) used a one-dimensional vadose zone transport model, which was calibrated to the arrival of Sr-90 and Tc-99 predicted by the OU 3-13 RI/BRA model. The calibrated one-dimensional model used 45 m of sediment and a 5-m longitudinal dispersivity, which is on the order of 11% of the domain length. Both of these parameters sets are sufficiently justified for use in evaluating the proposed INTEC site.

4.2.2 Available Vadose Zone Data for Advanced Test Reactor Site

Data availability at the site near the ATR Complex (formerly the Reactor Test Complex and the Test Reactor Area) is sufficient to bound the facility performance. As discussed in the following, the geostratigraphic detail could be augmented in the area adjacent to the proposed disposal facility.

Hydrologic and geochemical data relevant to the proposed site southwest of the ATR Complex were compiled in support of the *Remedial Investigation for the Test Reactor Area Perched Water System* (Lewis et al. 1992) and for the *Comprehensive Remedial Investigation/Feasibility Study for the Test Reactor Area OU 2-13* (Burns et al. 1997), with additional data contained in the *Environmental Characterization Report for the Test Reactor Area* (Doornbos et al. 1991). Detailed studies of the stratigraphic sequences near the ATR Complex also were analyzed using well data available in 2005 in an effort to understand the general stratigraphy of the south-central INL (Helm-Clark et al. 2005). These studies evaluated the following data:

- **Lithologic data** – Basalt and interbed core, geochemical, paleomagnetic, K-Ar age date, and petrographic data have been collected and studied extensively to determine the lithology near the ATR Complex. Relevant to vadose zone transport, the stratigraphic studies provided cross-sections showing sediments and basalts that can be correlated to depths of 500 ft bls near the ATR Complex. These correlations allow delimiting up to seven sediment units, comprised primarily of silty sands with very few gravels identified in the well logs. To assess the horizontal and vertical spatial extent, a geostatistical analysis will be performed on the interbed top elevations and thicknesses. This analysis will be used to construct a three-dimensional representation of sedimentary structure in the region south of the ATR Complex. Predicted uncertainty in the form of kriging variance will be used to help guide future data collection and well density for this site.

- **Hydrologic data** – Hydraulic conductivity, soil moisture characteristics, particle size distribution, porosity, effective porosity, bulk density, and moisture content data have been collected. Saturated hydraulic conductivity and van Genuchten parameters are available for a range of depths and soil-textural classes obtained from pump tests and laboratory core analyses for the interbed and basalt materials. The basalt values are often subject to local scale effects and will be compared to the large-scale infiltration results of Magnuson (1995) prior to use. Additional hydrologic data for sedimentary interbeds from the nearby Vadose Zone Research Park have been collected and analyzed by the United States Geological Service (Winfield 2003). These data are available for wells with interbeds that can be correlated to wells near the proposed site and provide complete parameterization of the silty-loams comprising the three relatively thick interbeds at about 115, 150, and 180 ft in depth found near the Big Lost River.

  The alluvium near the ATR Complex has been extensively characterized for hydraulic properties in support of the OU 2-12 RI/BRA (Lewis et al. 1992). These studies indicate that the surficial materials consist of alluvial and terrace deposits of the Big Lost River and are composed of unconsolidated fluvial deposits of silt, sand, and pebble gravel. Saturated hydraulic conductivity and an assessment of geochemical characteristics are available for the alluvium and will be used for this analysis.

- **Infiltration data** – Analyses have been performed for disturbed soil conditions at INTEC and RWMC SDA and for undisturbed and vegetated conditions. Recharge resulting from precipitation is strongly dependent on soil type, topography, and surface vegetation type, which differ between INTEC, the SDA, and ATR. However, the sites are similar enough that the background infiltration data for the other sites is appropriate for times when infiltration is not being controlled by the cover.

- **Perched water data** – Historically the presence of perched water at the ATR Complex primarily has been due to infiltration of wastewater from ponds, including the warm waste, cold waste, sanitary waste, and chemical waste ponds. Lesser sources include percolation from lawn irrigation at the ATR Complex, and infiltration of rainfall, snowmelt, and flow in the Big Lost River. Two perched water zones (shallow and deep) generally have been recognized beneath the ATR Complex.

  In the vicinity of the ponds and retention basin, the shallow perched water zone forms within the alluvium above the interface between the surficial sediments and the underlying basalts at a depth of about 50 ft bls. Finer grained sediments or fracture infilling at the alluvium/basalt interface areas impede the downward movement of water resulting in perched conditions. The shallow perched water eventually percolates through the underlying basalt to the deeper perched water zone. Although shallow perched water could pose operational constraints on the RH-LLW facility, the facility is located beyond the historical extent of shallow perched water (DOE/NE-ID 2005).

  The deep perched water is caused by low-permeability sediments within the interbedded basalt-sediment sequence at depths of about 140 to 200 ft bls. These interbed sediments include silt, clay, sand, cinders, and some gravel. In the initial OU 2-12 investigation (Lewis et al. 1992), it was thought perched water was continuous. However, based on a geochemical investigation performed in support of the first 5-year review for OU 2-13 (DOE/NE-ID 2005), there are several disconnected perched water bodies. Additionally, it appears from the 5-year review that there are two separate deep perched zones in the 140 to 200 ft depth range based on differences in hydraulic heads. This is consistent with the interpretation of sedimentary structure. Given the historical extent of the deep perched water body illustrated in DOE/NE-ID (2005), the proposed facility location is outside the anthropogenically derived perched water.

- **Big Lost River infiltration data** – The Big Lost River is an ephemeral or intermittent stream that flows roughly south to north about 4,000 ft from the southeast corner of the ATR Complex. Big Lost River recharge near the ATR Complex has been estimated using stream infiltration losses occurring between the INL diversion dam and the Lincoln Boulevard bridge near INTEC. Wells on the northwest side of the Big Lost River have historically shown increased deep perched water formation in response to flows of the Big Lost River. During periods of high flows in the Big Lost River and low anthropogenic water infiltration, many of the deep perched water wells go dry. To address the question of perched water origin, a detailed geochemical signature analysis was performed in support of the first 5-year CERCLA review of OU 2-13 (DOE/NE-ID 2005). The geochemical signatures suggest that deep perched water levels increase near the river as infiltrating Big Lost River water prevents the lateral spread of infiltrating anthropogenic water. This suggests that the extent of anthropogenic water bounds the influence of the Big Lost River, and that Big Lost River losses will not impact the proposed facility unless significant increases occur in the anthropogenic discharges, which is not likely.

  Flooding potential of the Big Lost River near the ATR Complex has been investigated by several researchers, most notably Koslow and Van Haaften (1986), Hortness and Rousseau (2003), and Ostenna and O’Connell (2005). This information will be used to assess potential flooding impacts.

- **Sorption data** – Clay content, bulk density, saturation, and porosity data are available for the alluvium at the ATR Complex. Potential releases from the RH-LLW facility are expected to be low in ionic strength, allowing the use of contaminant-specific Kd values. For specific radionuclides, Kd values will be estimated for the alluvium and interbed sediments based on the mineralogy and cation-exchange capacity.

- **Dispersion data** – Given the overall similarity in geologic media and transport mechanisms, the dispersivities derived for the OU 3-13 RI/BRA (DOE ID 1997), and for the ICDF PA (DOE-ID 2003a) will be used for analysis of the ATR site.

4.2.3 Available Aquifer Data and Model for Both Proposed Sites

An extensively calibrated aquifer model was constructed in support of the *OU 10-08 Sitewide Groundwater and Miscellaneous Sites Remedial Investigation/Baseline Risk Assessment* (DOE-ID 2008a). This model will form the basis for determining downgradient concentrations for dose assessment for radionuclides potentially released from either prospective site in addition to being used to determine composite concentrations from the proposed site and pre-existing contaminant plumes from RWMC, ATR, INTEC, Central Facilities Area, and the Naval Reactors Facility. No other data will be needed in support of the aquifer portion of this analysis.

Key attributes of the aquifer model are the domain (spatial extent), variability in hydraulic properties, and spatially variable recharge. These are discussed in the following paragraphs:

- **Model domain -** The spatial extent of the OU 10-08 model is shown in Figures 6 and 7 for the horizontal and vertical planes. The horizontal domain was selected to include a subregional area larger than the INL site based on (1) an approximate flow line for the southeast boundary, (2) the approximate edge of the SRPA on the northwest boundary, (3) an extent to the northeast that captured the entire INL Site but excluded the complex hydrologic nature of the highly irrigated Mud Lake area, and (4) a distance to the southwest sufficient to capture any commingling contaminant plumes but still have sufficient well coverage and water level data to constrain the model.

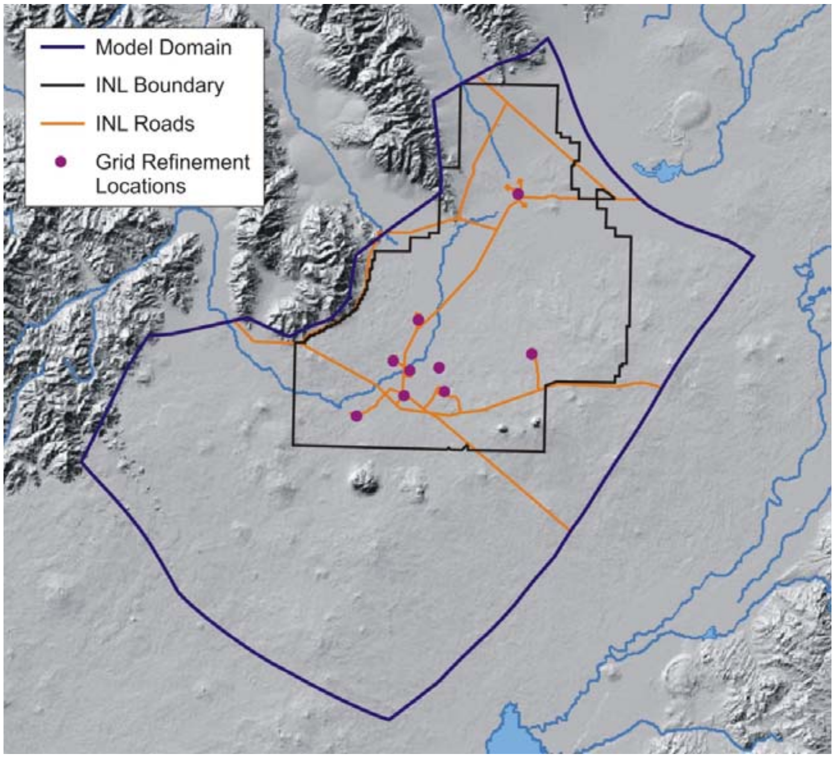

Figure 6. Horizontal extent of the Operable Unit 10-08 aquifer model.

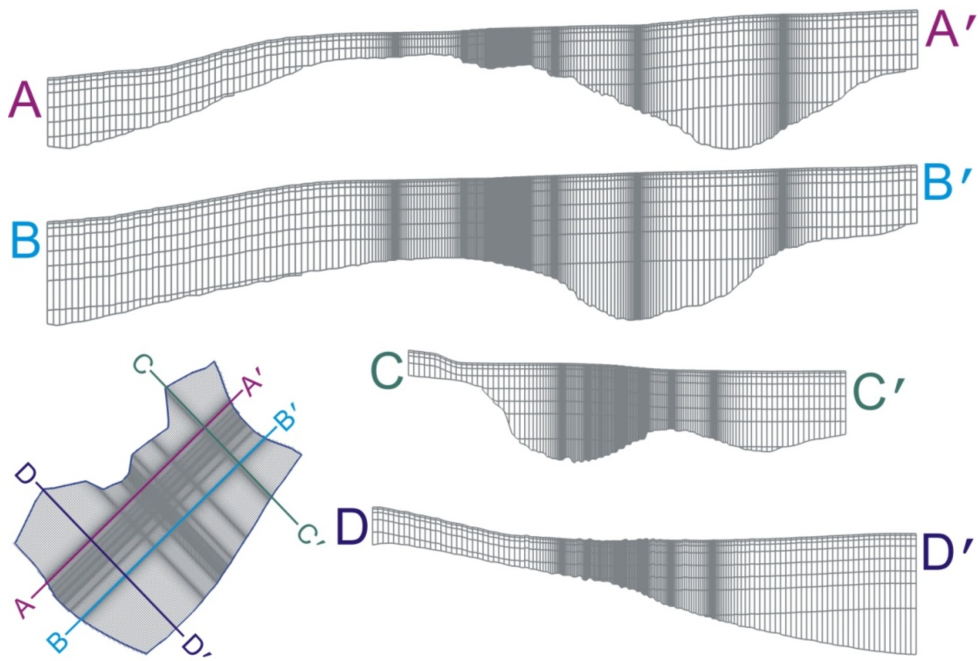

Figure 7. Vertical cross-sections and gridding of the Operable Unit 10-08 aquifer model.

The vertical model extended from the water table as defined by interpreted 2004 water level data to the effective aquifer base updated from the Smith (2002) thin aquifer scenario and using information from wells drilled in the 2002 through 2007 timeframe. The thickness of the aquifer ranges from about 50 to more than 300 m. The effective aquifer base, defining the active portion of water movement in the SRPA, thins along its northwestern boundary and is thickest in the vicinity of the Axial Volcanic High, which is along the southeastern margins of the OU 10-08 model domain. Estimates of the effective thickness of the SRPA were based on the assumption that advective mixing of groundwater creates a nearly isothermal temperature profile in the aquifer. Below the active portion of the aquifer, temperature increases linearly with depth following to the regional geothermal gradient.

- **Hydraulic properties** – Hydraulic conductivity in the OU 10-08 subregional aquifer model was assumed to be spatially variable to account for high-permeability interflow zones between basalt flow units, the more dense matrix of the unfractured basalt (flow interiors), and the influence of volcanic regions. Overall, the hydraulic conductivity was assumed to be anisotropic with the vertical hydraulic conductivity smaller than the horizontal to account for the layered nature of the aquifer, which consists of horizontal high-permeability interflow zones, low-permeability basalt flow interiors, and the semi-confining nature of the sedimentary interbeds. However, model discretization did not include explicit incorporation of these features. This poses a question with respect to model calibration because transport-derived velocities were based on selecting model parameters to optimize model predictions of contaminants originating in the aquifer from deep injection as opposed to matching the arrival of contaminants from the vadose zone. Although this assumption met the objectives of the OU 10-08 analysis, in the case of this PA/CA, the contaminants will initially impact the upper most aquifer with the depth of the locally effective impact determined largely by the position of the uppermost interbed units at INTEC and ATR sites. For near-field receptors, the PA/CA will select a model thickness representative of this depth as opposed to using the total active flow thickness of the SRPA.

- **Recharge** – Recharge to the SRPA within the area of the OU 10-08 model domain was assumed to occur as regional underflow from the northeast; underflow from tributary basins along the northwestern boundary of the aquifer (i.e., Birch Creek, Little Lost River, and Big Lost River); infiltration of streamflow along the channel of the Big Lost River, INL site spreading areas, and sinks and playas in the northern part of the INL Site; and infiltration of precipitation over land surface.

  Recharge from regional and tributary basin underflow and from infiltration of direct precipitation to the SRPA within the OU 10-08 area was evaluated for transient effects on flow. Changes in flow direction in the aquifer from annual or decadal trends in water table elevation were determined to be minimal and were neglected. Additionally, regional changes in aquifer thickness from transient changes in water table elevations were found to be small compared to the effective thickness of the aquifer.

  Although recharge from infiltrating Big Lost River streamflows is highly variable, with many years of no recharge due to no flow and short periods of large recharge when the river is flowing, the effects were assumed to be localized near the river and INL site spreading areas. Similarly, impacts of flow direction from transient changes in water use and application at facilities were assumed to be localized within or near the facilities.

  Minimally transient effects on flow direction and thickness implied that quasi-steady-state conditions occur in the SRPA within the area of the model domain at any point in time, and that steady-state regional boundary conditions are appropriate. This also implies that water levels collected in a sitewide water measurement campaign in 2004 (DOE-ID 2005) are adequate for use in calibrating the subregional scale model using steady-state recharge and discharge boundary conditions.

  The assumption of steady-state recharge for this PA/CA also is adequate based on the distance between the Big Lost River and proposed facility locations, an assessment of data during recent high flow years that indicates minimal or no impact near the proposed locations, and with consideration of the 1,000-year predictive timeframe required for the RH-LLW PA/CA.

- **Other model features** – Other features of the OU 10-08 subregional aquifer model included the use of contaminant-specific partitioning coefficients, with porosity and dispersion assigned as single parameter values, with the values determined through model calibration to plumes originating from the deep injection wells at INTEC and the ATR Complex. Given that the proposed facility locations are proximal to these calibration target origins, these values will be used for this analysis.

5. ATMOSPHERIC TRANSPORT

5.1 Atmospheric Transport Processes and Assumptions

The methodology used to calculate the EDE in the annual National Emission Standards for Hazardous Air Pollutants (NESHAP) reports for INL (e.g., DOE-ID 2009)) will form the basis of the atmospheric pathway analysis for the RH-LLW PA. NESHAP reports are required under Section 61.94 of 40 CFR, Part 61, Subpart H, “National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities” (40 CFR 61 Subpart H 2006). The results of the NESHAP reports provide sitewide cumulative doses from all INL point and distributed-air-borne sources. To remain consistent with this approach and to allow use of the cumulative calculations, the methodology used in them also will be used to assess dose impacts for potential releases from each of the proposed facility locations. This requires an estimation or assessment of each of the following:

- **Gaseous phase radionuclides** – Radionuclides that have the potential to migrate in the gaseous phase as determined from previous INL PAs include: C-14, tritium (H-3), I-129, and Kr-85. C-14 has been shown in laboratory experiments to move in both the vapor and aqueous phase (Fox et al. 2004). These measurements formed the basis for the two-phase C-14 transport model used in the OU 7-13/14 RI/BRA (DOE-ID 2006b) and the RWMC PA (DOE-ID 2007). Field measurements of gaseous H-3 above shallow land disposals at RWMC were used to estimate emission rates of hundreds of Ci per year (Ritter and McElroy 1999). Iodine-129 can form gaseous compounds; therefore, to ensure that the risk assessment is bounding, it will be assumed that the geochemical conditions result in gaseous I-129 that is mobile in the subsurface. The behavior of gaseous-phase Kr-85 has not been investigated, but it should behave similar to radon, both being noble gases. Any additional radionuclides included in the RH-LLW inventory that have the potential to migrate in the gaseous-phase will be included in the atmospheric pathway analysis.

- **Release rates** – Release rates from the disposal facility for the operational and institutional control periods will be considered for a residential receptor at the INL site boundary. The flux rates from the proposed facility during these periods should be limited by the containers, fully functional waste vaults and an overlying infiltration and intrusion limiting cover. Nevertheless, the RWMC PA (DOE-ID 2007) assumed all gaseous phase radionuclides released to the soil were transported instantaneously to the atmosphere. In the ICDF PA (DOE-ID 2003a), it was assumed the entire inventory of gaseous phase radionuclides was released directly to the atmosphere over a 1-year period during the institutional control period.

  Atmospheric doses from the disposal facility for the compliance and post-compliance period will be considered for a receptor located 100 m from the facility boundary at the compass azimuth that yields the highest dose. During these time periods, emission rates will be determined by cover effectiveness and vault failure rates. The RWMC PA (DOE-ID 2007) assumed long-term releases would occur into the facility soil backfill during these periods for C-14, H-3, and I-129 with rates computed using the DUST model. In the ICDF PA it was assumed that the entire inventory of gas-phase radionuclides would be released to land surface during a 1-year period at the start of the compliance period, neglecting transport through the facility soils to land surface. Adopting the instantaneous availability for atmospheric transport would be very conservative. Calculating a fractional release to the atmosphere based on the RWMC PA (DOE-ID 2007) results would be less conservative, but appropriate.

- **Atmospheric data and environmental conditions** – A National Oceanic and Atmospheric Administration meteorological tower exists at the ATR Complex at an elevation of 10 m. However, a tower does not exist at INTEC. In the INL NESHAP reports, atmospheric data are used from the Grid III station located approximately 1.1 mi (1.8 km) north-northwest of INTEC. In the NESHAP approach, calm wind periods are incorporated into the lowest windspeed class. The sector-averaged options are used for atmospheric dispersion calculations because this reflects annual average conditions within a sector. The ATR Complex and GRID-III meteorological stations and 10-year meteorological data files will be used in this PA/CA. We will not project long-term climatic changes in this analysis.

- **Effective dose equivalent (EDE)** – The EDE for each of the maximally exposed individuals for each compliance period will be calculated. Previous PAs (e.g., DOE-ID 2003a and DOE-ID 2007) conducted at INL have adopted the INL NESHAP approach and have used the CAP-88 code (EPA 2007) for calculations. The output from CAP-88 is the EDE, which includes the 50-year committed EDE from internal exposure through the ingestion and inhalation pathways and the external EDE from ground deposition and air immersion.

  Doses are modeled assuming subsistence-farming scenarios in the NESHAP compliance evaluations. Local food production is assumed, with other model parameters set to the code’s default values.

  Previous INL PA/CA and NESHAP reports have used dose conversion factors from the RADRISK dosimetric database to convert the radionuclide concentrations in air and food products to EDE. The newer CAP-88-PC Version 3.0 incorporates dose and risk factors from Federal Guidance Report 13 (EPA 1998) in place of RADRISK data used in previous versions. CAP-88-PC Version 3.0 is now accepted for use in NESHAP evaluations.

6. BIOTIC TRANSPORT

The biotic intrusion assessment evaluates the all pathway receptor dose resultant from the total activity that could be brought to land surface as a result of biotransport. Biotic transport and uptake of radionuclides at INL requires that the radionuclides be available to biota. This availability is provided through small mammal and arthropod burrowing and deep plant roots. The depth of burrowing and root penetration in the case of this PA will be an additional function of final facility cover (barrier) construction, incorporation of biobarrier components, cover thickness, and cover integrity. The following subsections present a summary of biotic characteristics important to this PA and of the assumptions and calculations for the biotic intrusion analysis.

6.1 Fauna and Flora Species Characteristics of Concern

- **Small mammals –** At INL, small mammal burrowing habits and radionuclide uptake have been identified (Groves and Keller 1983). Their study identified 10 species of small mammals nesting on or near RWMC buried waste sites. The most numerous species included deer mice (Peromyscus maniculatus), montane voles (Microtus montanus), Ord’s kangaroo rats (Dipodomys ordii), and Townsend’s ground squirrels (Spermophilus townsendii). Burrow depths for these four species were subsequently studied by Reynolds and Wakkinen (1987) for undisturbed soils. The maximum depth of burrows for deer mice, montane voles, Ord’s kangaroo rats, and Townsend’s ground squirrels were 60, 70, 100, and 138 cm, respectively.

- **Invertebrates –** Many invertebrates, including ants, burrow into and nest in the soil. Of these, the harvester ant (Pogonomyrmex salins) has been studied at INL because of its potential for nesting deep in the soil and its habit of carrying soil particles to the surface (Blom 1990, Blom et al. 1991a, Blom and Johnson 1995, Markham 1987). INL site-specific sampling of harvester ant nests at the Materials and Fuel Complex ponds suggests that ants redistribute radionuclides in soil but the effect is seen mainly in the mound material (Blom et al. 1991b). Harvester ants tend to exhibit a preference for disturbed conditions similar to those found in the RWMC SDA (Fitzner et al. 1979; McKenzie et al. 1985), and it is likely that the engineered cover design will deter burrowing. In the screening analysis for the RWMC PA (DOE-ID 2007) biointrusion analysis, it was assumed that ants can burrow as deep as 2.7 m (9 ft) during the institutional control and compliance periods.

- **Flora –** The roots of plants that grow on or above buried waste can serve to extract surface soil moisture, which reduces percolation of surface water into the waste zones, but they can have negative impacts by penetrating the barrier cover, and transporting radionuclides to above ground vegetation (Abbott et al. 1991). Plants of INL have been extensively catalogued and studied through the Environmental Sciences Research Laboratory activities (e.g., DOE-ID 2008b) and have identified the key plants from an ecological perspective. To address the propensity for the key INL plants to transport radionuclides to the surface, Abbot et al. (1991) and Reynolds and Fraley (1989) have studied plant root profiles near RWMC. In the root profile studies, big sagebrush (Artemisia tridentata) roots were detected deeper in disturbed soils than in undisturbed soils (125 versus 75 cm) and were found to have a maximum rooting depth of 225 cm. The roots of green rabbitbrush (Chrysothamnus viscidiflorus) were shallower than sagebrush and are found deeper in undisturbed soil (100 versus 50 cm). The maximum rooting depth for green rabbitbrush was 190 cm. Streambank wheatgrass (Elymus lanceolatu), Crested wheatgrass (Agropyron cristatum), Bottlebrush squirrel tail (Elymus elymoides) and Great Basin wild Rye (Leymus cinereus) were investigated for rooting depth. Of these, the Great Basin wild rye was the deepest rooting at 200 cm. The maximum rooting depth of INL flora in all cases was less than 2.25 m.

6.2 Biotic Transport Processes and Assumptions

Factors that are considered in computing the impacts of biotic transport include cover layer thicknesses and intrusion barrier design, erosion and subsidence, and depth of intrusion by flora and fauna as discussed in the following subsections.

6.2.1 Cover Layer Thickness and Barrier Design

At the end of the operational period, the disposal facility will be closed and covered. Two cover performance criteria relative to biotic transport are to inhibit plant and animal intrusion and to maintain barrier performance for a 1,000-year period (institutional control and compliance period).

Closure assumptions associated with DOE Order 435.1 for the RWMC Active Low-Level Waste Disposal Facility and RWMC CERCLA assessment have determined the primary requirements. These requirements were limited by infiltration rate through the cover and by the thickness of cover assumed for intrusion scenarios. Designs meeting the primary requirements consist of a 2.1-m layered system comprised of topsoil, fine soil fill, sand, and gravel filter. The primary requirements do not require an underlying biotic intrusion barrier as incorporated in the analysis of Mattson et al. (2004). It will be determined through screening calculations in this PA/CA whether a biotic intrusion barrier is required. Conservatively, the RWMC Active Low-Level Waste Disposal Facility PA did not account for the presence of a biotic intrusion barrier at the screening calculation stage. The additional thickness of the vault plugs [5 ft (1.52m)] may be used to help meet intrusion limiting requirements.

6.2.2 Erosion and Subsidence

The nominal cover will be assumed to remain intact and stable during the institutional control period as a result of continued maintenance. Therefore, erosion and subsidence will not significantly change the cover thickness for the first 100 years after closure (institutional control period). Erosion and subsidence after the institutional control period could change the cover thickness over the waste. Potential impacts of cover erosion on biotic intrusion will be addressed. Based on Ostenna et al. (1999), the alluvium characteristics at INTEC and the ATR Complex are similar to RWMC; therefore, erosion rates are expected to be the same.

Erosion rates for an evapotranspiration cover over a contaminated site on INL was computed by Keck (1995) based on the universal soil loss equation. This calculation determines top-of-cover loss rates and side-slope loss rates. For RWMC, these values were 8E-06 m/year for the top of the landfill cover and 1.7E-04 m/year for the side slopes (Fritz 2002). Keck (1995) also included an assessment of cover erosion for a conceptual Resource Conservation and Recovery Act cover design for an INL facility. The Resource Conservation and Recovery Act cover was estimated to erode at a rate of 0.26 tons/acre-year (3E-05 m/year). For comparison, background erosion rates for natural soils at RWMC are maximally 50 cm (20 in.) over the next 10,000 years (5E-05 m/year) (Hackett et al. 1994).

Based on the preliminary design study for the RWMC SDA landfill cover (Mattson et al. 2004), specific erosion controls are expected to be incorporated into the cover design consistent with the 1,000-year period of compliance. Mattson et al. (2004) indicates that inclusion of a gravel admix in the upper soil layer of the cover and selection of a proper cover slope can help to ensure performance of engineered covers for long periods of time. The erosion rates discussed above did not consider the inclusion of a gravel admix and would be conservative.

Early versions of the RWMC PA (Maheras et al. 1994; Case et al. 2000) were based on an erosion rate of 9E-04 m/year, which is aggressive relative to the Keck (1995) studies. If the relatively aggressive erosion rate is used (roughly 1 m [3 ft] in 1,000 years), at least 4 m (13 ft) of cover would remain over a waste profile covered by an initial 15-m engineered barrier.

6.2.3 Root and Burrow Depths

- **Fauna –** Evidence suggests that harvester ants probably provide the limiting burrowing depth for fauna. Although the harvester ants tend to exhibit a preference for disturbed conditions and it is likely that the engineered cover design will deter burrowing, we will assume for this biointrusion analysis that ants can burrow as deep as 2.7 m. To account for the burrowing of harvester ants into the waste, the total activity of contaminated material brought to the surface will be estimated using the model proposed by Kennedy et al. (1985):

  Activity on the surface (Ci) = concentration in the waste (Ci/m^3) × burrow volume (m^3/colony) × fraction of burrow in waste × colony density (colonies/m^2) × surface area (m^2).

  Where, based on the work of Kennedy et al. (1985), the fraction of burrow in waste is 5%, the average burrow volume per colony is 0.002 m^3, and the colony density (colonies/m2) is 35.6 colonies/10,000 m^2 of waste.

- **Flora –** Based on extensive studies of flora at INL for this biointrusion analysis, we will assume big sagebrush to be most representative of the dominant plant species with the deepest root penetration of 2.25 m. To estimate the amount of radioactive material that plant roots could bring to the surface, a model similar that used in GENII (Napier et al. 1988) and Kennedy et al. (1985) will be used. The activity brought to the surface by the plant roots is estimated by multiplying the radionuclide concentration in the waste by the concentration ratio, the fraction of the roots that can encounter the waste, the biomass, and the area of the disposal facility:

  Activity on the surface (Ci) = waste concentration (Ci/m^3) × 1/soil bulk density (g/m^3) × fraction of roots in waste x concentration ratio (Ci/g plants/Ci/g waste) × biomass (g/m^2) × area (m^2).

  Where the biomass of big sagebrush above ground on INL is estimated to be 46 g/m^2 (Fraley 1978), the fraction of roots in waste is 5% (estimated from the 5% of plant roots found at depths greater than 2 m (Kennedy et al. 1985), and concentration ratio is the element-specific concentration ratio. Concentration ratios will be obtained from Baes et al. (1984) similar to previous INL PAs.

6.2.4 Facility Operation Constraints

Conditions leading to biotic intrusion into the RH-LLW disposal facility are expected to vary during the operational, institutional control, compliance, and post-compliance periods. These conditions determine the assumed effectiveness of the biointrusion barrier during the operational lifetime of the disposal facility.

- **Operational Period** – During this time, the vaults and continuous facility maintenance will be sufficient to preclude contact of flora and fauna with waste. Further, in terms of biotic intrusion, subsidence, or erosion during waste disposal operations are not of significant concern, because the RH-LLW disposal facility will be under continuous maintenance during this time period. During the operational period, biotic intrusion into the RH-LLW disposal facility is not a credible pathway for either acute or chronic worker exposure, and a biotic intruder analysis will not be conducted for the facility operational period.

- **Institutional Control Period** – Because erosion and subsidence are controlled and the interior vaults remain intact, biotic intrusion into the RH-LLW disposal facility will not be a credible pathway for either acute or chronic exposure to a member of the public (resident) during the institutional control period, and a biotic intruder analysis will not be conducted for the institutional control period.

- **Compliance Period** – During the compliance period, significant loss of cover thickness is not expected even if an aggressive erosion rate is assumed. If subsidence occurs, the cover will remain above the waste with sloughing into the depression occurring around the perimeter. The impact of biotic intrusion will assume that 2 m of final cover remains at the end of the compliance period. This thickness is arbitrary and is much less cover than is expected to exist. However, a thickness of 2 m provides a basis to conduct some screening calculations for the depths of plant roots and burrows that are considered in the analysis. The biotic intrusion screening assessment is described in the following section.

6.2.5 Biotic Intrusion Screening Assessment Assumptions

Total activity brought to the surface through biotic intrusion is assumed to be available for resuspension, atmospheric transport, and deposition followed by direct exposure through external, inhalation, soil ingestion, and ingestion of contaminated food stuff (milk, beef, and plant). For the purposes of this biotic intrusion screening analysis, it will be conservatively assumed that the total activity brought to the surface by harvester ants and plant roots can be contacted by a resident through the chronic residential scenario used for the intruder analysis (via the following pathways: external, inhalation, soil ingestion, ingestion of contaminated plant, meat and milk). While this is a conservative assumption (assumes no dispersion and assumes receptor is located on the disposal facility not 100 m from the facility), it puts an upper bound on the material to which a receptor could be exposed.

7. DATA AND ANALYSIS NEEDS SUMMARY

Based on a review of available data, the following outstanding data and analysis needs (gaps) were identified:

- **Distribution (sorption) coefficients for resins** – The release of radionuclides from the ion-exchange resins will be modeled using an equilibrium Kd. Values determined for the SDA were dependent on pore-water chemistry. An assessment of time-evolving changes in pore-water chemistry will be made.

- **Potential flooding impacts** – Design and operation of the proposed disposal facility must consider potential adverse impacts caused by flood water. Sources of floodwater include onsite precipitation events (snow-melt and rainfall) and overland flow from the Big Lost River channel. These must be evaluated for their erosion potential and ability to overflow the disposal facility during the operational and post-operational time-periods. Although the flood potential is considered low, data and results from existing studies will be used to assess flood impacts near both proposed sites.

- **Geostatistical evaluation of lithologic data for the ATR site** – The distribution of sediments will largely control downward migration of contaminants from the disposal facility. Data regarding the thickness and lateral distribution of sediments in the vicinity of the proposed site near the ATR Complex are sparse. In order to assess the horizontal and vertical spatial extent, a geostatistical evaluation will be necessary to locate the interbed top elevations and thicknesses. This also will allow assessment of overall sediment variability in the ATR area and will provide information useful for locating monitoring and characterization wells.

- **Distribution (sorption) coefficients for soils/interbeds for the ATR site** – Reasonably conservative contaminant-specific partition coefficients have been developed for soils and interbeds at INTEC and RWMC. A review of available soil data (e.g., mineralogy and cation exchange capacity) near the ATR Complex will be performed to determine appropriate partition coefficients for use at the ATR site.

- **Aquifer thickness and flow velocity for the ATR site** – In general, concentrations and doses of contaminants arriving in the aquifer from the vadose zone will be strongly influenced by upper-aquifer velocities and by the effective aquifer mixing thickness. Aquifer velocity is primarily a function of local stratigraphy, with horizontal velocity lower through sedimentary interbeds and massive basalt interiors and higher through fractured basalt units. Aquifer velocities predicted by the OU 10-08 aquifer model undergo relatively sharp changes to the southwest of the ATR Complex. These velocities were determined based on relatively course model discretization and assignment of properties, but were adequate for the purposes of predicting long-term and long-distance concentrations. However, this PA requires assessment of concentrations within 100 m of the proposed facility location. To assess the potential impact of upper aquifer features on predicted concentrations for the proposed facility, we will (1) assess the local stratigraphy and available hydraulic conductivity in the upper aquifer near the vadose zone-aquifer interface, and (2) estimate an appropriate model thickness for use in evaluation of concentration for this PA.
- **Cover design requirements and infiltration calculations –** It is assumed the final cover will be similar in function to the covers planned for the RWMC SDA and ICDF in terms of the cover's ability to minimize infiltration and provide an intrusion barrier. We will review the technical basis for the infiltration calculations, specifically with respect to the requirements for the final cover design as determined by the PA.
- **Impacts of facility design features** – Certain aspects of the facility design that may impact contaminant release rates from the facility will be evaluated, including (1) potential for ponding in the facility; (2) water flux around the vaults, base, and cover; (3) potential effects of subsidence; (4) degradation of liners and vaults relative to contaminant transit times through the vadose zone; and (5) half-lives of key radionuclides.

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