ABSTRACT

The Department of Energy Office of River Protection and its subcontractors have performed a performance assessment for the near-surface disposal of low-level and mixed low-level waste at the Hanford Integrated Disposal Facility. The long-term performance of the Hanford Integrated Disposal Facility to be protective of human health and the environment was evaluated under the requirements of United States Department of Energy Order 435.1, Radioactive Waste Management. Computer simulations were performed to evaluate whether or not the disposal facility would comply with the performance objectives specified in the order. The evaluation was performed using numerical models to simulate source term releases from vitrified and cement-based waste forms. Source term releases were subsequently transported through the facility into the natural system beneath the facility (comprised of an 85-meter thick vadose zone and thinner but highly conductive saturated zone overlying basalt) to a point of compliance 100-meters downstream the disposed waste. Due to the differing scales in the finite difference models developed for the source terms and those developed for the natural system, numerical models for source term release and natural system flow and transport were not directly coupled. Instead, the output from the source term simulations were used as input to the natural system flow and transport simulations. The decoupling of the modeled systems makes it difficult to explore synergies and investigate the impact of parameter uncertainties. In order to explore system synergies and evaluate parameter uncertainty, an integrated system model was developed that includes source term release models, natural system transport models, and dose calculations. This paper will describe how the numerical models were used to develop abstractions that could be incorporated into the integrated system-level model that was then used to explore system synergies and parameter uncertainties.

INTRODUCTION

In 2014, the U.S. Department of Energy (DOE) Office of River Protection (ORP) and its subcontractors began to develop a performance assessment (PA) for the disposal of low-level waste (LLW) and mixed low-level waste (MLLW) at the Hanford Integrated Disposal Facility (IDF), a near-surface disposal facility on the Hanford Site in southeast Washington State. The IDF is a double-lined trench that was constructed between 2004 and 2006 and is expected to be the disposal facility for the vitrified low-activity waste (LAW) that will be produced at the Hanford Waste Treatment and Immobilization Plant (WTP). The IDF is also expected to receive solid secondary waste (SSW) produced at the WTP and other solid wastes from site activities. The constructed facility is in a pre-operational state awaiting authorization to receive waste.

PURPOSE

No waste destined for the facility is currently being generated; however, waste disposal operations cannot begin until the facility has received a Disposal Authorization Statement from DOE and a permit modification from the State of Washington Department of Ecology. Both the Disposal Authorization Statement and permit modification require a demonstration that the system of engineered and natural features of the disposal facility will limit releases from the facility and be protective of human health and the environment. DOE has been developing a PA to evaluate the long-term human health and
environmental impacts from the disposed waste. A PA uses computer model simulations to evaluate the long-term fate and transport of radionuclides disposed in the facility. Conducting the PA is a DOE requirement under DOE Order 435.1, Radioactive Waste Management[1].

BACKGROUND

The Hanford Site contains approximately 53 million gallons of radioactive and chemical waste stored in 177 underground tanks, many of which date back to the early days of the Manhattan Project during World War II. DOE is currently constructing the WTP that will separate the tank waste into high-level and low-activity fractions that will be vitrified in separate parts of the facility. The vitrified high-level waste will be disposed off-site at a deep geologic repository. The vitrified LAW will be disposed onsite at the IDF. In addition to the immobilized low-activity waste (ILAW), the IDF is also the planned disposal location for SSW generated during the waste treatment mission and other secondary waste generated onsite.

Facility

The IDF is a double-lined, near-surface disposal facility with two isolated disposal cells, one for DOE LLW and a second MLLW cell that is permitted under the Resource Conservation and Recovery Act of 1976 (RCRA) by the State of Washington Department of Ecology. Phase I construction of the IDF was completed in 2006. The two constructed cells each contain a leachate collection and recovery system consisting of a liner and sump. The two cells are identical to one another but are hydraulically separated; water infiltrating each cell flows into separate sumps and is collected in separate leachate recovery tanks. There is a leak detection system between the primary (upper) liner and secondary (lower) liner and a secondary leak detection system under the secondary liner. A compacted layer of fill material was placed over the leachate collection and recovery system for the lower operational layer that will receive waste.

The disposal concept calls for four disposal layers (called “lifts”), each approximately the height of an ILAW waste container, separated by 1 meter of compacted fill that serves as the operational layer for the next lift. Packages of SSW are expected to be stacked two-high in each lift. Waste containers are expected to be placed as close as practical. The void space between adjacent waste packages will be backfilled. Future construction phases can extend the capacity to a total of six similarly constructed cells.

The facility is constructed but has yet to receive any waste. The IDF is being maintained in a pre-operational condition. Without waste, the surface cover design is a conceptual design. The conceptual design is a modified RCRA Subtitle C barrier intended to reduce infiltration into the disposal facility for 500 years. The engineered surface cover is a sloped surface comprised of multiple hydraulic and structural layers intended to promote evapotranspiration, divert water around the facility, and prevent bio-intrusion into the waste zone. The performance of the conceptual design is informed by local climate, by similar barrier performance, and by modeling.

Model Components

The modeling approach for the IDF PA was to break down the disposal system into a series of components that could be represented by computer models, develop the numerical models for the different components, develop the inputs for each component model, run each component model, and integrate the results of the simulations into a base case result. The integrated result would be used to evaluate whether or not the IDF would comply with the performance objectives specified in DOE M 435.1-1, Radioactive Waste Management Manual[2]. The evaluation was performed using a suite of numerical models that simulated different features, events, and processes (FEPs) related to waste disposal.
in the facility. Two- and three-dimensional, finite difference models were developed in STOMP©, Subsurface Transport Over Multiple Phases, to simulate the relevant processes of each model component.

Due to the differing scales in the finite difference models developed for the near-field flow models, source term release models and fate and transport model for the natural system, numerical models were not directly coupled. Instead, the outputs from the different component models were used as input to the other models. To fully integrate the results, information must be passed between model components, which necessitates a hierarchy in simulation order (see Figure 1).

The key model components for evaluating impacts to groundwater are: Near-Field Flow, ILAW Glass Source Term, Non-Glass Source Term, Vadose Zone Flow and Transport, and saturated Zone Flow and Transport.

![Diagram of model components](image)

**Fig. 1. Integration of Information Between Computer Models.**

**NOTES:**
Non-Glass source terms include separate models for rectangular boxes w/ and w/o encapsulation and drums w/ and w/o encapsulation.
Vadose and Saturated Zone model was a coupled model that could run vadose or saturated zone only calculations.

**Simulation Types**

The long-term evaluation of the disposal system includes a deterministic base case, numerous sensitivity studies, and a probabilistic integrated system-level model.

The deterministic base case couples together the results of several finite difference simulations performed with STOMP©. Several two-dimensional and three-dimensional models (see Figure 1) were developed and used in the PA because the different processes that were included required different simulation techniques and different scales. Modeling at the smallest scale for the entire system was not

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1 STOMP is copyrighted by Battelle Memorial Institute.
computationally practical. With detailed representations of the key FEPs captured in these finite difference models, these types of models are referred to as “process-level” models.

Sensitivity analyses used the same or modified process-level models to investigate the response of the system to changes in the conceptual models and/or the input parameters and starting conditions. For the IDF PA, hundreds of sensitivity studies were performed with the process-level models. However, sensitivity results were not always propagated through the entire model hierarchy to calculate groundwater concentrations. Sensitivity studies were used to identify important aspects of each component that needed to be propagated into the base case.

A separate model was developed that integrated the entire disposal system into one system-level model. The system-level model was developed in GoldSim© and uses abstractions of the process-level models to create a computationally efficient and integrated analysis of the different model components. Abstractions were developed and compared to the analogous process model results to ensure that the abstractions honor the key behaviors of the process models even though the abstractions could be less rigorous (i.e., one-dimensional transport versus three dimensional transport).

The abstractions are fully integrated in the GoldSim© framework so that the system-level model was used to extend the base case evaluation to other constituents of potential concern (COPC), extend the simulated duration, and evaluate the impact of parameter uncertainty on the simulated performance.

The remaining sections describe the integration of the different model components.

Near-Field Flow

The Near-Field Flow model is a two-dimensional, finite difference models that uses the water operational mode of the STOMP® code (STOMP-W). The model was developed to evaluate the spatial distribution of saturation and flow rates within and around the disposed waste. The Near-Field Flow model accounts for the presence of the surface barrier, the waste forms, and the liner system when it calculates the near-field flow fields. The surface barrier is an engineered cover with assumed performance equal to specifications for a Modified RCRA Subtitle C barrier. The function of the surface barrier is to limit the flow of water into the waste zone and mitigate bio-intrusion into the waste zone. The barrier has inclined slopes, capillary breaks, and low-permeability layers that help to divert net infiltration water away from the waste zone. The Near-Field Flow model was used to determine the saturation of the backfill in the waste disposal zone and the Darcy flux in and around the ILAW glass and non-glass waste forms. These results were used as input to the source term release models for ILAW glass and non-glass waste forms (see Figure 1).

The Near-Field Flow model was also used to simulate the rate of water movement through the liner system into the vadose zone beneath the disposal facility (see Figure 1). The liner system is an engineered system comprised of low-permeability geosynthetic clay liner, drainage gravels, and an admix layer that diverts water flowing through the waste zone to sumps located at the bottom of the facility. The liner and sumps were installed to recover any water that flows through the disposed waste zone (i.e., the leachate). The disposal facility also includes leak detection systems intended to monitor the integrity of the liner system. In the Near-Field Flow model, no water movement or COPC transport from the facility into the vadose zone beneath the facility is simulated while the liner system is intact and the leachate collection and recovery system is operational.

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2 GoldSim© is a copyrighted by the GoldSim Technology Group, Issaquah, Washington.
A few key results of the Near-Field Flow model are shown in Figure 2 and include:

- the surface barrier creates a local drying zone beneath the cover, consequently saturations in the near-field and below the facility are reduced while the surface cover is intact,
- although some leakage into the disposed waste zone occurs, water is diverted away from the disposed waste zone by the surface barrier when it is intact,
- with the exception of a shadow underneath the apex of the surface barrier, the infiltration rate at the top of the waste disposal zone underneath the surface barrier is fairly uniform, varying by ±10% across the top of the waste zone area
- when the surface barrier is assumed to be degraded, water flow into the disposed waste zone increases but flows through the backfill around the waste rather than through the waste,
- water tends to flow along the liner system to the sumps rather than through the liner, even when degraded properties of the liner are assumed.

![Simulated Water Fluxes for an Intact Surface Barrier and Liner System (top) and a Degraded Surface Barrier and Liner System (bottom).](image)

NOTE: The surface barrier is assumed to have degraded performance at 500 years after closure.

The Near-Field Flow model was exercised for different net infiltration rates, 1.7 mm/yr, 3.5 mm/yr, 5.2 mm/yr, and 33 mm/yr. The net infiltration rate propagated in the base case was 3.5 mm/yr. The output of the Near-Field Flow model that is fed to the source term models include the saturation of the backfill and
range of flow rates that are experienced in the backfill around each waste form. These are treated as initial and boundary conditions in the source term models. The flow rate in the backfill above each waste form is treated as a sensitivity parameter that is used to explore the impact of higher flow rates on source term releases.

The output of the Near-Field Flow model that is fed to the Vadose Zone Flow and Transport model is a spatial distribution of flow underneath the liner system. Different flow rates are applied to the upper layer of grid cells in the vadose zone model according to their location underneath the facility. There is a temporal variation as well that accounts for the change in flow as the engineered barriers degrade.

**ILAW Glass Source Term**

The ILAW Glass Source Term model is a two-dimensional, finite difference model that uses the water with reactive transport operational mode of the STOMP© code (STOMP-W-R). The model simulates kinetic dissolution of the glass in the disposal environment using a rate model developed from transition state theory and parameter values derived from laboratory experiments.

The dissolution model includes an aqueous flow component in the backfill that is used to transport released COPCs and other secondary minerals that are formed during the dissolution process, including rate controlling minerals, away from the surface of the waste form where the dissolution reaction occurs. Initial saturations and the rate of flow of water into the model domain are derived from the results of the Near-Field Flow model and are applied as initial and boundary conditions. Once the simulation begins, the STOMP© model calculates the changes to backfill saturation and the rate of flow of water around the waste form. The output of the ILAW glass source term model is the fractional release rate of COPCs from the bottom of the model domain, which is assumed to be the bottom of the disposal facility. Calculated dissolution rates are converted to COPC fluxes into the vadose zone by multiplying the fractional release rate by the total COPC inventory in ILAW glass and uniformly spreading the release over the release footprint.

Sensitivity studies were performed to investigate the effects of parameter and conceptual model changes, including a range of long-term net infiltration rates that were plausible outputs of the Near-Field Flow model. Figure 3 shows the sensitivity to the variation in net infiltration rate on ILAW glass source term fractional release rates. The model results show that the peak release rate and long-term release rates are not that sensitive to the variations in net infiltration.

In the integration of process-model results for the base case, the fractional release rate calculated by the STOMP© model for a long-term net infiltration rate of 3.5 mm/yr was applied to determine the COPC flux to the top of the vadose zone once leachate collection at the sumps ceases. The fractional release rate was multiplied by the COPC inventory and then released into the vadose zone STOMP© cells that are both directly below the waste footprint and beneath the sumps. This is treated as a source term in the Vadose Zone Flow and Transport model.
In the system model, the long-term fractional release rate for ILAW glass was estimated from a regression model that was derived from numerous simulations exploring uncertainty in the laboratory developed parameters for the kinetic dissolution model at a fixed long-term net infiltration rate of 3.5 mm/yr. The regression model was implemented without a dependence on the net infiltration rate and was applied as a step function to a constant release rate from the bottom of the facility once leachate collection at the sumps ceases.

The fractional dissolution rate was multiplied by the COPC inventory and then released into the vadose zone transport elements (GoldSim© cell pathway elements) that represent the top of the vadose zone directly beneath the sumps.

**Non-Glass Source Term**

The Non-Glass Source Term models are a suite of three-dimensional, finite difference models that use the water operational mode of the STOMP© code (STOMP-W). The models are used to simulate debris waste that is encapsulated by a clean grout and non-debris waste (typical particle size less than 60 mm) that is solidified in a grout. The numerical models represent two waste containers stacked within a single lift, assuming that the releases from waste containers in the adjacent lifts are additive. Many different Non-Glass Source Term models were developed to simulate different disposal conditions, including: rectangular versus cylindrical waste packages, encapsulated versus solidified waste forms, and single versus stacked waste package configurations. For each model type, parameter values for the waste and grout waste form were also varied based on COPC, waste stream, and disposal method leading to hundreds of simulations being performed.

The Non-Glass Source Term models simulate source term releases from the waste form and surrounding backfill by advection and diffusion. The different models include processes that retard COPC release from the waste forms using diffusion and sorption coefficients derived from laboratory experiments. Different waste streams may use different grout properties to be consistent with assumed disposal options for the different waste streams. The different grouts used for the different wastes are assumed to be partially saturated representing oxidizing conditions that affect the sorption of redox sensitive COPCs. The STOMP© model calculates the changes in saturation in the backfill and waste form for the given infiltration rates. The output of these models is the fractional release rate of COPCs from the bottom of...
the model domain, which is assumed to be the bottom of the disposal facility. Calculated fractional releases rates for each SSW waste stream were converted to COPC fluxes and are summed to yield a total SSW release rate into the vadose zone. The total release was uniformly spread over the release footprint. Calculated fractional release rates for solidified Liquid Secondary Waste (LSW) were similarly converted to COPC fluxes into the vadose zone.

Sensitivity studies were performed to investigate the effects of parameter and conceptual model changes, including a range of long-term net infiltration rates that were plausible outputs of the Near-Field Flow model. Figure 4 shows the sensitivity to the variation in long-term net infiltration rate on different non-glass source terms; the plotted result is the cumulative release of each COPC at 1,000 years assuming a net infiltration rate of either 1.7 mm/yr or 5.2 mm/yr divided by cumulative release at 1,000 years, assuming an infiltration rate of 3.5 mm/yr. The results show a correlation between net infiltration rate and the cumulative fraction of COPCs released.

In the base case, the time history of fractional release rates calculated by the STOMP© models for a long-term net infiltration rate of 3.5 mm/yr for each waste stream are multiplied by the COPC inventory in each waste stream to provide a source term input to the Vadose Zone Flow and Transport model. The calculated flux history is applied to the vadose zone STOMP© cells that are both directly beneath the sump cells and the disposed waste footprint. This is treated as a source term in the Vadose Zone Flow and Transport model.

Fig. 4. Comparison of Cumulative Waste Form Releases from Non-Glass Waste Forms at Different Infiltration Rates.

NOTES: SSW-HEPA are encapsulated high efficiency particulate arrestance (HEPA) filters, SSW-GAC is solidified carbon adsorption media, SSW-IX is solidified ion-exchange resin, SSW-AgM is solidified silver mordenite waste.

In the system model, non-glass waste form release rates are calculated using the Radionuclide Transport module in GoldSim©. Abstraction models were developed to simulate diffusive releases from the non-glass waste forms. The abstraction models used a one-dimensional GoldSim© cell pathway network (Figure 5); a GoldSim© cell pathway network is mathematically equivalent to a finite difference network of nodes. The cell pathway network was used to simulate two stacked waste packages containing either a solidified waste form or encapsulated debris, the backfill placed around the waste packages, and the
compacted backfill separating the different disposal lifts. Each waste package was compartmentalized into 5 or 6 diffusive shells depending on the waste stream. The geometry of each compartment, including diffusive areas and lengths between compartments, was derived from the three-dimensional representation assuming that the compartments were concentric shells within the rectangular or cylindrically-shaped waste packages. In the GoldSim implementation a coarse grid of 5 or 6 nodes was used to calculate diffusive transport from the waste form to the backfill and advective and diffusive transport through the backfill areas. Total water flow in the model domain was equated to the net infiltration rate applied over the simulated footprint containing the waste package and backfill between adjacent waste packages. However, the total water flow was transported through the backfill; process model simulations showed that there was very little, if any, flow through the waste forms. Releases from the bottom of the operational layer below the bottom waste package in a lift were passed to the system-level model representation for the vadose zone.

To be consistent with the process models, in the system model non-glass source term releases were only computed for the lower lift and the entire SSW inventory was released as if it were all released from the lower lift into the top of the vadose zone; in other words, transport from the upper lifts to the bottom of the facility was neglected.

Vadose Zone Flow and Transport Model

The Vadose Zone Flow and Transport model is a three-dimensional, finite difference model that uses the water operational mode of the STOMP© code (STOMP-W). Inputs to the top layer of the vadose zone model include water flow rates from the Near-Field Flow model and COPC releases from the bottom of the IDF that are calculated using the source term models.

The Near-Field Flow model provides the water flux rate into the top of the vadose zone. However, the Near-Field Flow model is a two-dimensional model, whereas the Vadose Zone Flow and Transport model is a three-dimensional model. In addition, the grid spacing between the two models differs; the vadose zone model grid cells are larger than those used in the Near-Field Flow model. The grids from the two models were superimposed (Figure 6) so that the flow into the vadose zone from each cell in the two-dimensional flow model could be mapped to a larger cell in a two-dimensional cross section of the three-dimensional vadose zone model. The mapping from many small cells in the Near-Field Flow model to a larger cell in the vadose zone model is illustrated in Figure 7. Once the flow from one model to the
other was mapped in two dimensions, the results were applied in the third dimension, neglecting surface effects around the edges or the slight northward slope that allows flow to collect in the sumps.

As shown in Figure 6 and Figure 7, there are two vadose zone cells in the top layer of the vadose zone model that are underneath each sump line (cells 22 and 23 in the west and cells 38 and 39 in the east). These cells receive most of the flow leaving the facility when the applied net infiltration rate is 3.5 mm/yr. For a net infiltration rate of 3.5 mm/yr, COPC releases from ILAW glass and Effluent Treatment Facility-Liquid Secondary Waste (ETF-LSW) sources are placed equally into the top layer of the vadose zone model at cells 22 and 23 in the west and cells 38 and 39 in the east. Because SSW is disposed east of the eastern sump line, SSW releases are only placed into the top layer of the vadose zone model at Cell 39. It should be noted that these cell indices only refer to one row of nodes in the north-south direction; there are additional nodes in the north-south direction that are treated equivalently. Therefore, the total source term flux added to each cell is the fractional release rate multiplied by the total inventory divided by the number of cells receiving the release.

The number of cells receiving the ILAW glass and ETF-LSW release is the number of cells that are both underneath the waste footprint and underneath the sump lines (see Figure 8). The number of cells receiving the SSW release is the number of sump cells that span the width of the SSW footprint in the north-south direction. From Figure 8 the number of nodes receiving the ILAW glass release at the top of the vadose zone is 80, the number of cells receiving the ETF-LSW releases is 8, and the number of cells receiving the SSW releases is 4. The release into the vadose zone is converted to a flux by dividing the release into each cell by the area represented by each grid cell.

![Fig. 6. Mapping of Aqueous Flux from the Two-Dimensional Near Field Flow Model to the Three-Dimensional Vadose Zone Flow and Transport Model at a Net Infiltration Rate of 3.5 mm/yr.](image-url)
Fig. 7. Two-Dimensional Near-Field Flow Model Flux Rates for a Surface Infiltration Rate of 3.5 mm/yr at Various Locations Beneath the IDF at 500 and 10,000 Years.

Fig. 8. Locations of Waste and Infiltration Boundary Condition Zones in Base Case for Combined Vadose Zone / Saturated Zone Simulations.
In the system model the vadose zone transport model uses a cell network to transport COPCs released from the facility to the water table (see Figure 9). The cell network is a one-dimensional transport model with multiple nodes representing different depths within the vadose zone underneath the IDF. The moisture content and Darcy flux from the representative depths in the STOMP© model (shown in gray in Figure 9) with an applied net infiltration rate of 3.5 mm/yr were extracted from the cells below the sumps near the center of each waste footprint. The extracted data was used to assign flow properties to the cells in the system model cell network. Due to a considerable amount of horizontal dispersion that was observed in the process models when the flow and releases from the facility are forced into a few cells at the top of the vadose zone, benchmarking against the process model results for the total release from the vadose zone showed inconsistencies for matching arrival time and long-term release to the saturated zone. When the breakthrough time to the water table was matched, the long-term release to the saturated zone exceeded the process model result; when the long-term release to the saturated zone was matched, the breakthrough arrived earlier than in the process model. An adjustment was made to split the COPC transport through the vadose zone into a fast fraction to match the breakthrough time and magnitude and a slow fraction to match the long-term release rate from the vadose zone. The fast and slow fraction and dispersivity for transporting the slow fraction were adjusted until both the breakthrough time and long-term release rate in the process and system model were in good qualitative agreement.

To accommodate different net infiltration rates that may alter the flow rates and travel times through the vadose zone for the fast fraction, correlations between the net infiltration rate and both the Darcy flux and moisture content were developed. The correlations were developed for the range of values simulated with the Vadose Zone Flow and Transport STOMP© model to scale the moisture content and Darcy flux derived from a net infiltration rate of 3.5 mm/yr. For the slow fraction, the moisture content was fixed at 7.5% and the Darcy flux was equated to the net infiltration rate for values exceeding 2 mm/yr or 80% of the net infiltration rate for net infiltration rates lower than 2 mm/yr.
Saturated Zone Flow and Transport Model

The Saturated Zone Flow and Transport model is a three-dimensional, finite difference model that uses the water operational mode of the STOMP© code (STOMP-W). The Saturated Zone Flow and Transport model is directly coupled to the Vadose Zone Flow and Transport model.

Inputs to the top layer of the saturated zone model include water flow rates from the Vadose Zone Flow and Transport model and COPC releases from the vadose zone that are calculated using the Vadose Zone Flow and Transport model.

Boundary conditions prescribe flows entering and leaving the sides of the model domain.

In the base case, the coupled Vadose Zone and Saturated Zone model is used to ensure that there is consistency between releases across the water table and observed concentrations at the point of calculation 100 meters from the edge of the excavation.

In the system model a one-dimensional aquifer element is used to transport releases from the vadose zone to the point of calculation 100 meters from the edge of the facility excavation. The aquifer thickness (5 meters) and Darcy flux (70 m/yr) are matched to the properties in the process model simulations.
However, the Darcy flux used in the system model is an average across the facility footprint and does not vary with the net infiltration rate. The dispersivity (1-meter) is matched to lower-end values from the process models to minimize spreading to simulate a pessimistic impact at the point of calculation. The width of the aquifer is matched to the width of the plume perpendicular to the direction of flow at the point of calculation derived from process model output (see Figure 10). The length of the source release into the saturated zone is equated to the source zone length from the process model output. The total length of the aquifer is derived from the plume calculated by the process model. The length is equated to the length of a streamline through the plume from the start of the plume to the point of calculation (see Figure 10). The Darcy flux in the aquifer is equated to the average value (70 m/yr) observed in the process model, which is derived from the estimated hydraulic conductivity of the saturated sediments (5 to 17,000 m/day) and the steady-state hydraulic gradient nearest the IDF (2.0E-05 m/m). The estimates of the Darcy flux in the vicinity of the IDF range from 120 m/yr in the northern part of the facility footprint (equivalent to the regional value) to a low of 40 m/yr in the southern part of the facility footprint.

Fig. 10. Determining Aquifer Properties (Length and Width) for the System Model.

CONCLUSIONS

The IDF PA uses process model calculations and a system model to calculate the long-term release of COPCs from low-level and MLLW that will be disposed at the site.

Due to the complexity of the processes included in each process model and the scale over which these processes are relevant, the process model simulations are decoupled from one another. As a result, synergies between models cannot be directly evaluated with the process models unless potential synergies are identified in advance and process model runs are performed to evaluate these synergies.

For the IDF PA, the flow of water into the facility and how that water is distributed through the facility and released to the vadose zone beneath the facility represents an input that affects multiple process model calculations. The PA base case was performed with the different STOMP© models and systematically follows the flow of water (and COPCs transported in that flow) from the surface barrier to the point of calculation in the aquifer 100 meters downstream from the edge of the facility excavation.

The Near-Field Flow model demonstrated that the surface barrier, waste forms, and liner system result in regions of low and high flow within the system even when the net infiltration rate is uniformly applied
directly below the evapotranspiration layer in the surface barrier. Results from the Near-Field Flow model addressing the distribution of water throughout the facility as well as the uncertainty in the long-term net infiltration rate were incorporated into the list of calculations performed with the source term models and natural system flow and transport models to evaluate any potential synergies that impact COPC fate and transport.

Multiple source term models were performed to evaluate the potential variations in the near-field flow fields. For the deterministic calculation representing the base case, the source term calculations consistently used Near-Field Flow model flow fields for a long-term net infiltration rate of 3.5 mm/yr. However, other variations were evaluated to determine whether or not synergies needed to be captured in an integrated system model. In the system model, the long-term net infiltration rate was treated as an uncertain parameter and was varied from 1.7 mm/yr to 5.0 mm/yr. The source term process-level model simulating releases from ILAW glass was used to demonstrate that variations in the net infiltration rate between 1.7 and 5.2 mm/yr did not significantly affect releases from the ILAW glass sources, so the system model source term for ILAW glass does neglects changes to the net infiltration rate. The source term process-level model simulating releases from non-glass waste forms was used to demonstrate that variations in the net infiltration rate between 1.7 and 5.2 mm/yr did affect releases from the non-glass sources. In the system model implementation, uncertainty in the net infiltration rate is propagated to non-glass source term releases so that synergies between near-field flow and non-glass releases are captured.

The near-field flow model also indicated that the liner system, even when degraded, focuses water and COPC releases from the facility into the area directly beneath the sump lines. An abstraction was developed to map the two-dimensional near-field flow results to the three-dimensional vadose zone model so that the near-field flow results could be propagated to the vadose zone model. The base case model run uses the abstraction of the near-field flow results for a long-term net infiltration rate of 3.5 mm/yr together with source term releases developed using the same net infiltration rate to transport COPCs to the water table. A regression developed from process model results addressing the impact of uncertainty on the long-term net infiltration rate on the distribution of moisture content and Darcy flux in the vadose zone was incorporated into the system-level model so that the potential impact of flow variations is propagated to the different system-level models that are performed to evaluate the performance of the disposal system.

In the base case model, the vadose zone and saturated zone are coupled so that flow synergies are captured. For the system model, the one-dimensional transport through the saturated zone is directly coupled to the vadose zone transport abstraction but the flow is decoupled. The saturated zone Darcy flux is determined independently from the net infiltration rate.

However, the Darcy flux is abstracted as an average rate to be applied across the entire footprint and was determined from input values that varied by as much as a factor of six across the footprint.

Figure 11 shows an integrated comparison between the process model results and the system model results, demonstrating good agreement between the process models and their abstractions when a long-term net infiltration rate of 3.5 mm/yr is applied consistently across all model components.
Fig. 11. Comparison of Technetium-99 Groundwater Concentrations at 100-m Boundary Between Process Model and System Model: a) ILAW Glass, b) Secondary Solid Waste.

REFERENCES