STATUS OF PERFORMANCE ASSESSMENT STUDIES FOR THE DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE IN THE 218-W-5 BURIAL GROUND, 200 WEST AREA, HANFORD SITE

M. I. Wood
Westinghouse Hanford Company

ABSTRACT

A performance assessment analysis is being performed at the Hanford Site to support the disposal of low-level waste. The analysis is required to achieve compliance with U.S. Department of Energy Order 5820.2A, which states that a performance assessment analysis be submitted and approved for a particular disposal facility. Performance objectives defined in the order and other informal guidance are used to define the types of analyses and associated data collection tasks that must be completed to produce a satisfactory analysis. In this paper, the types of tasks being conducted at the Hanford Site are discussed and progress made in different areas is summarized.

INTRODUCTION

Performance assessment analyses are being completed at the Hanford Site to support disposal of low-level radioactive waste which is in compliance with the U.S. Department of Energy (DOE) Order 5820.2A, *Radioactive Waste Management* (1). The order requires that a performance assessment (PA) analysis be completed that justifies disposal of low-level waste following the issuance of the order (1). A preliminary set of analyses have been completed for a particular area on the Hanford Site, the 218-W-5 Burial Ground in the 200 West Area. These results will be incorporated into a more complete analysis, which will be presented for review and comment to the Peer Review Panel in fiscal year 1992. The panel has been established by the order (1) to review and determine the acceptability of PA analyses for low-level waste disposal at DOE sites.

The primary task of the PA analysis is to evaluate radionuclide release pathways from the proposed disposal facility to a receptor. This analysis must estimate the ability of the disposal facility and the natural setting to isolate or control the release of radionuclides. The order (1) defines two types of radionuclide release pathways, the first being a groundwater pathway, and the second being inadvertent intrusion scenarios. Both types are being considered through modeling and supporting data collection. Areas of work being pursued include the following: (1) a hydrogeologic data summary of the 218-W-5 area, (2) laboratory data collection of waste material leaching, (3) measurements of hydrologic properties of vadose zone soils, (4) measurement of radionuclide sorption in vadose zone soils, (5) completion of groundwater contaminant flow and transport analyses, and (6) development of intrusion scenarios and associated dose estimates. Progress in these areas is summarized along with a brief description of ongoing work.

SUMMARY OF HYDROGEOLOGIC DATA FROM THE 218-W-5 BURIAL GROUND AND VICINITY

The geohydrologic data base provides the information needed to define a computer geometry that (1) represents the contaminant flow path from a proposed disposal facility to a receptor well downstream from the facility, and (2) can be quantified by a numerical simulation. The data have been documented in detail (2).

The bulk of the data used to characterize the geohydrology of the 218-W-5 burial ground was derived from the characterization of soil samples taken from groundwater monitoring wells in or near the 218-W-5 Burial Ground area. The 218-W-5 Burial Ground is located in the northwest corner of the 200 West Area of the Hanford Site (Fig. 1). The location of the monitoring wells is also shown in Fig. 1. Some data were summarized from previous characterization work while other data have recently been collected as part of the Hanford Site groundwater monitoring program.

Typical soil characterization data were taken for soil samples from different depths below the surface and include particle size distribution, ambient moisture content, calcium carbonate content, and gross gamma radiation counts. The data base shows that Hanford Site soils are predominantly sandy with ambient moisture contents in the range of 3 to 15 volume percent. Calcium carbonate is generally present to control the pH of the groundwater solution.

The data base was then interpreted using the general hypothesis developed from the accumulated knowledge from Hanford Site investigations concerning the genesis of the geologic stratigraphy on site. Primary attention was placed on the evolution of the vadose zone.

On a gross scale, the Hanford Site vadose zone is composed of two major formations, the Hanford Formation and the underlying Ringold Formation. The Ringold Formation overlies the uppermost basalt flow of the Columbia River Basalt Group. The Ringold Formation consists of fluvial and lacustrine sediments while the Hanford Formation consists of catastrophic flood deposits. Numerous interfingering subunits are observed in both formations with variable distributions of sands, silts, and gravels. The total thickness of the vadose zone and the relative thickness of the two main formations vary depending on the location of interest on the Hanford Site. Beneath the burial ground, depth to the water table is ~75 m.

Beneath the burial ground, two thin erosional layers appear between the Ringold and Hanford Formations and are continuous across the burial ground. The Plio-Pleistocene layer, which overlies the upper Ringold, is a fine grained sandy mud that has been reworked by plant and animal activity and is variably cemented with calcite. In some places, permeability is very low due to the cementing action. The unit thickness ranges from ~6 m to 12 m from south to north. Overlying the Plio-Pleistocene unit is the early Palouse soil unit, an unconsolidated, muddy sand layer that may have been deposited by wind erosion and then reworked by animal burrowing and root growth. This unit is ~3 m thick across the burial ground.

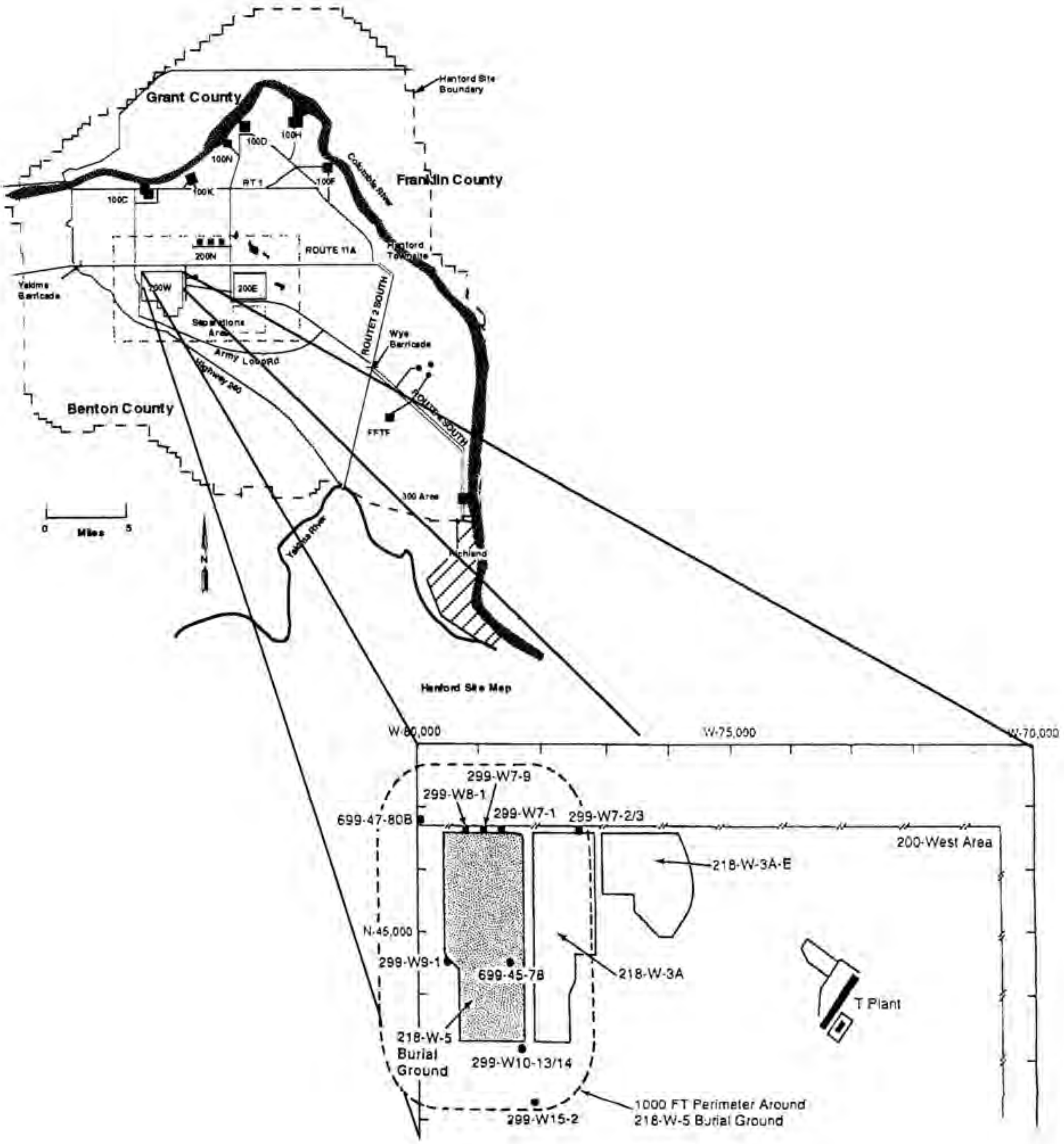

Fig. 1. *Location* of the 218-W-5 burial ground at the Hanford Site, south central Washington state.

Hydrologic flow patterns across the 218-W-5 Burial Ground were also estimated based on hydraulic conductivity data from site-wide soil samples and hydraulic head data from wells in the vicinity of the burial ground. As with the geologic interpretation, the hydrologic flow patterns were estimated in the context of our understanding of the Hanford Site hydrologic regime. The gradient across the burial ground is very slight. The general direction of flow is currently to the north-northeast. This direction of flow will gradually swing to the east as the influence of a groundwater mound south of the burial grounds decreases over time. The mound was created by a liquid discharge pond that has been deactivated. Hydraulic conductivity data reported in the document show a reduction in hydraulic conductivity in the soils as a function of depth from 10^{-2} to 10^{-3} cm/s in the Hanford Formation to 10^{-3} to 10^{-4} cm/s in the Ringold Formation. This trend is presumably the result of compaction by the soil column.

SUMMARY OF HYDROLOGIC PROPERTY DATA FROM LABORATORY TESTS

A continuous core sample was taken from the 299-W7-9 well (see Fig. 1) both for the purpose of interpreting the stratigraphy and for laboratory tests using samples that were as close to undisturbed as possible. The core extends from the surface into the middle Ringold unit at a depth of ~43 m. The core was sectioned into test size samples as a function of depth. Some samples were placed in permeameters to measure saturated hydraulic conductivity values. Other samples were tested to measure moisture retention curves (soil moisture content as a function of suction pressure). By combining saturated hydraulic conductivity data with moisture retention curve data, hydraulic conductivity as a function of moisture content was estimated with an empirical curve fitting relationship (3). Measured hydraulic conductivity values from the saturated samples were ~10^{-2} cm/s for the Hanford Formation and ~10^{-4} cm/s for the underlying units. Estimated hydraulic conductivity values of partially saturated soils are highly sensitive to moisture content. Partially saturated hydraulic conductivity values were estimated to decrease nonlinearly with decreasing moisture content. At the lowest, near ambient moisture content, the estimated conductivity is ~5 orders of magnitude below that of the saturated value.

Hydraulic conductivity measurements were made on Hanford Formation soil excavated from a trench in the 218-W-5 area. The samples were ~8 m below grade. An unsaturated flow apparatus was used to measure directly the hydraulic conductivity of soil samples at different moisture contents (4). This is a new technique and has the decided advantage of allowing rapid and direct measurement of hydraulic conductivity as opposed to calculated values. Other methods of direct measurement exist but are extremely time consuming and less flexible. The device uses centrifugal force to replace gravitational force and head pressure. By varying the rotational speed, different steady state moisture contents can be achieved. The soils were packed in the apparatus at a density comparable to field conditions and the data was collected.

Hydraulic conductivity values on samples from moisture contents of ~5 wt% to near saturation were collected. Intrinsic diffusion coefficients were also collected. The data demonstrated a nonlinear decrease in hydraulic conductivity with decreasing moisture content. Hydraulic conductivity values near saturation were approximately 10^{-4} cm/s. At a moisture content of ~5 wt% (~8 vol%), a hydraulic conductivity value of ~10^{-7} cm/s was measured. Moisture retention curve data and estimated hydraulic conductivity data were also developed and compared with direct data. A good correlation was observed.

SUMMARY OF WASTE MATERIAL/WASTE FORM RADIONUCLIDE RELEASE DATA FROM LABORATORY TESTS

Testing efforts have been concentrated on the development of fundamental information required to quantify radionuclide release behavior from low-level solid waste. These data included collection and characterization of 218-W-5 trench soil, confirmatory radionuclide sorption studies in the soil-groundwater environment, and characterization of leachant solution from solid waste materials, particularly organic constituents. In addition, developmental work was completed to find methods for characterizing hydrologic and radiological transport of contaminants under partially saturated conditions representative of the Hanford Site vadose zone.

Approximately 68 kg of soil were collected from the bottom of an unused trench in the 218-W-5 area. The soil was characterized for particle size distribution, mineralogy, and cation exchange capacity. The soil is a typical Hanford Formation soil that is predominantly a sand particle size with quartz and feldspar as the major minerals. The soil has a small cation exchange capacity (~5 meq/0.1 kg).

Representative samples of solid waste materials used on the Hanford Site were collected and leached in Hanford Site groundwater for varying periods of time to identify the dissolving constituents. These materials were divided into similar chemical types (wood, cardboard, and paper in one group; plastics in another; and miscellaneous items in a third group such as rubber, cotton, cloth, and canvas). In a fourth group, Portland cement was added to a mixture of all the waste materials to represent a grout type solidifying agent. Batch leaching experiments were performed by mixing each of the groups of materials with ambient groundwater solutions. The experiments ran for 4 weeks and were periodically sampled and analyzed. Of particular interest are the organic constituents, which could potentially interact with radionuclides and influence their mobility.

Hanford Site groundwater is a mildly alkaline (pH ~8), low-salt solution whose dominant cations are Ca (~50 mg/L), Na (~30 mg/L), Mg (~15 mg/L) and K (~10 mg/L),and dominant anions are HCO_3^- (~140 mg/L), SO_4^- (~75 mg/L), and Cl^- ~30 mg/L). Total organic carbon (TOC) is $\leq$ 1 mg/L. The following changes in solution chemistry were observed:

- Wood, paper, cardboard group - Interaction with groundwater had the effect of decreasing ph to a slightly acidic value of 5, increasing Na content from 32 mg/L to 125 mg/L, HCO_3^- from 137 to 320 mg/L, and total organic carbon (TOC) from 1 to 561 mg/L.
- Plastics group and miscellaneous materials group - Relatively minor changes in groundwater composition were observed, including a drop in pH from ~7.5 to 7.3 and a small increase in TOC from 1 to ~65 to 80 mg/L.
- Portland cement group - The pH changes to very alkaline conditions (pH ~12) and significant

increases in Ca, K, and Na concentrations (49 to 296, 10 to 235, and 32 to 96 mg/L, respectively) indicate the dominance of cement water interactions. The TOC concentrations also increased from 1 to 245 mg/L.

Characterization of the organic constituents has proven to be a difficult task because of the many compounds existing in solution. Some of the volatile and semi-volatile components have been identified. These compounds consist of less than 5% of the total organic concentration in mg/L.

To observe the effect of these changes on radionuclide mobility, batch sorption experiments were completed with the two leachate solutions most affected by interaction with the waste materials (i.e., the wood, cardboard, and paper group and the cement plus all waste group). A number of elements, including Tc, I U, Cr, Se, Sr, Cs and Co, were tested by spiking the solutions with these elements and placing the solutions in contact with Hanford Site soil. The sorption results were compared to general knowledge about sorption of these elements in clean soil water conditions. The following observations were made:

- Typically anionic elements (Tc, I, Se, and Cr) did not sorb at all or sorbed very poorly (Se), which is consistent with their behavior in soil groundwater systems.
- Real decreases in sorption values of Sr and Cs (from ~500 to 50 and 12 to 4 ml/g), were observed in the cement leachate. This behavior is also observed in nonorganic systems in the presence of cement and is probably due to competition for sorption sites from other cations (e.g., Ca, Na and K) dissolving out of the cement. The Sr also appears to be slightly less sorptive due to organic presence, but the increased Ca concentration may also be contributing effective competition.
- Co sorption decreases noticeably in the cement system. This may be a reflection of deprotonation of organic molecules (loss of H^{+}), thereby enhancing their ability to complex Co and form net negative or nonsorbing aqueous species.

Based on these observations, it appears that the influence of inorganic and organic species dissolved from typical waste materials has no significant effect on the mobility of these nuclides relative to soil-groundwater interactions.

SUMMARY OF GROUNDWATER TRANSPORT CALCULATIONS

In the conceptual model for groundwater transport, radionuclides are assumed to be leached from a waste source and transported by groundwater flow down through the vadose zone (partially saturated sediments) to the unconfined aquifer. A well in the unconfined aquifer then intercepts contaminated liquids, which are subsequently consumed by man. Input data required to perform the analysis included (1) site specific hydrogeologic and geochemical data; (2) identification of inventory isotopes, waste release mechanisms, and radionuclide sorption coefficients; and (3) hydrologic and geochemical properties of disposal facility features.

The computer code VAM2DH (5) was selected to simulate flow and transport. *VAM2DH* is a numerical, two-dimensional code that has been designed to handle vadose zone conditions.

Two sets of groundwater release and transport analysis have been completed to estimate radionuclide release from a disposal facility to the underlying unconfined aquifer. The first set were scoping calculations to become familiar with the application of VAM2DH to the Hanford conditions and to get a general idea of nuclide behavior as a function of a few key parameters. The second set of analyses was designed to provide a more sophisticated representation of the hydrogeologic system, to consider additional parameters of importance, and to extend the time of computer runs to determine peak concentrations. In both cases, the vadose zone and the unconfined aquifer beneath the 218-W-5 Burial Ground were represented.

In the first set of analyses, a problem geometry was defined as a rectangular grid with five hydrogeologic layers and a small trench in the upper left hand corner. The top layer and the trench were given the same hydrologic properties as defined by moisture retention curve data and estimated hydraulic conductivity as a function of moisture content. The second layer was given a different set of hydrologic properties and the bottom three layers a third set of hydrologic properties.

Given this geometry, several parameters were varied in the analyses. Three different infiltration or recharge rates were considered, 0.05, 0.5 and 5 cm/yr. The expected values are in the 0.05 to 0.5 cm/yr range. The 5 cm/yr value represents the occurrence of a significant climate change. Three nuclides were evaluated, ^{99}TC, ^{137}Cs, and ^{90}Sr. Their half-lives and sorption values were data input and a constant concentration value of unity was used as the source term. This approach is the most conservative because it assumes that the total inventory is immediately available for transport. Computer run times were completed up to 1,144 yr.

The output from the modeling is a series of concentration contours in the rectangular grid indicating the extent and relative concentrations of the contaminant plume. The concentrations are defined as a percentage of the initial concentration of 1. By substituting a real value in place of unity, a predicted actual concentration in the plume can be calculated by ratio. The most important observations were the following:

- ^{137}Cs and ^{90}Sr plumes did not extend far away from the trench even at the longest times, presumably because the combination of short half-life, moderate sorption, and the hydrogeologic characteristics prevent wide spread transport.
- The ^{99}Tc plume spread much farther than the Cs and Sr plumes and actually intersected the unconfined aquifer at the highest flow rate. This is easily explained by the fact that neither sorption nor decay inhibits the transport of the Tc plume.

From these observations it was concluded that long lived nuclides that sorb poorly or not at all will at some point contaminate a hypothetical well. Therefore, further modeling was needed that considered longer time periods to evaluate peak concentrations and peak times for those nuclides.

In the second set of analyses, additional hydrogeologic property data were used to create a different problem geometry. The soil environment was assumed to consist of 10 layers of soils with different hydrologic properties. The property values were based on moisture retention curves measured on soils taken from a borehole at the north boundary of the 218-W-5 area. For the base case, the waste source consisted of a simple trench at the surface in the middle of the problem grid. The driving force for leaching and transport of radionuclides was assumed to be an averaged infiltration rate from atmospheric precipitation, and transport was assumed to occur down through the vadose zone to the water table. Parameters that were varied included infiltration rates (0.5 and 5 cm/yr) and sorption Kds (0, 0.25, 0.5, 0.75, 1, 5 and 10 ml/g). A sorption Kd is the ratio of the soil to water nuclide concentrations. In most of the analyses, a diffusional release from the waste was assumed at a value of 1×10^{-6} cm^2/s. One analysis assumed that all of the inventory was immediately available for release by assuming that the source was a constant concentration (i.e., C_0 equals total inventory divided by total waste volume). Two other analyses were completed assuming a lower permeability protective cover relative to normal backfill. Given these conditions, radionuclide flux across a well 100 m from the vertical boundary of the trench was calculated over time.

The following major effects of variables on radionuclide peak time and concentration values were observed:

- Of the variables considered, the effect of Kd was the most significant both in terms of peak concentrations and peak times. With regard to peak time, a linear relationship with respect to Kd was observed for a given recharge rate. At the recharge rate of 5 cm/yr, the increase in peak time is ~3000 times for every unit increase in Kd. At the recharge rate of 0.5 cm/yr, the increase in peak time is ~23,000 times for every unit increase in Kd. In terms of peak concentrations, the effect of unit increases in Kd is to rapidly decrease peak concentration at low Kd values (e.g., from 0 to 1 ml/g, and order of magnitude decrease in peak concentration). The relative decreases in peak concentration become much smaller at higher Kd values (e.g., less than an order of magnitude decrease in concentration from 5 to 10 ml per gram).
- For a given Kd value, the effect of a tenfold decrease in recharge rate (from 5 to 0.5 cm/yr) is approximately a fivefold to sevenfold decrease in peak concentration. Conversely, the travel time increases by a factor of ~7.6 with a tenfold decrease in assumed recharge rate.
- The addition of a cover dampens the effect of recharge rate on peak concentrations. At Kd = 0, only a threefold reduction in peak concentration is observed. Additional cases at higher Kd values have not been run and must be completed before this observation can be confirmed.

SUMMARY OF INTRUSION SCENARIO ANALYSES

A representative set has been developed of intrusion scenarios that are generally consistent with types of scenarios used by other agencies and sites. The major kinds of scenarios considered were drilling, excavation, and agriculture (6). Either chronic or acute exposures were assumed, based on the nature of the scenario. Dose estimates for a unit concentration of a given radionuclide were calculated as a function of time and radioisotope using the code GENII (7). These data were then used to estimate maximum allowable inventories for a given radionuclide per scenario. From this analysis, it was possible to define the most restrictive scenario for each isotope.

A potential classification system consisting of two waste classes was then defined as a function of disposal facility design assumptions and applicable scenarios. The applicability of scenarios was based upon the assumption that minimal barriers would be used for lower inventory waste and a more substantial barrier system (which could include or consist of greater depth of burial) would be used for higher inventory waste. The drilling and post drilling scenarios were considered applicable for both waste classes, but the rest of the scenarios were applied to either the high or low level waste class depending on their probability of occurrence. The most restrictive scenario was determined for each isotope by comparison of allowable maximum inventories for the set of applicable scenarios. The lowest maximum allowable inventory concentration was chosen as the classification limit. As it turned out, the most restrictive scenario was always post excavation resident for the low level waste and post drilling resident or residential garden (1 % root penetration) for the high activity low level waste class. Interestingly, these scenarios which control inventory limits are all representative of chronic exposure.

The inventory limits from this study were compared to inventory limits established in other programs including the NRC(8) and Hanford burial grounds(9). Comparison of inventory limits indicates fairly good agreement for several radionuclides (limits within an order of magnitude) but discrepancies do occur for ^{14}C and ^{99}Tc.

APPLICATION OF THE PERFORMANCE ASSESSMENT ANALYSES

To satisfy performance objectives identified in DOE Order 5820.2A, acceptable inventory limits for specific nuclides and associated design features must be identified. The performance objectives include two kinds of dose limits, the first resulting from relatively short term inadvertent intrusion, and the second resulting from groundwater contamination. At Hanford, the approach being taken is to determine inventory limits driven by inadvertent intrusion scenarios and all pathway scenarios (all pathway scenarios assume transport of nuclides through the groundwater pathway, consumption of contaminated well water,and, as appropriate, consumption of contaminated crops, meats and milk caused by the irrigation of crops with the contaminated water). The limits are estimated for each nuclide that is known to exist or may exist in the low level waste inventory. The design features that are part of the assumptions influencing the value of the limit are also identified. For a given nuclide, it can then be determined which limit is most restrictive and should be used in design, construction, and operation of the disposal facility.

The intrusion scenario and groundwater transport scenario studies have been used to quantify preliminary inventory limits for many of the radionuclides in the Hanford low level waste inventory. The status of these efforts is as follows:

- Low-level waste has been divided into Category I and Category III waste. Intrusion scenarios which are used to define limits for each category are post excavation (Category I) and post drilling (Category III).

- It is assumed that Category III waste will include a thick cover (~5 m) over the waste to preclude all intrusion actions except drilling. All intrusion scenarios are assumed to be applicable to Category I waste.
- A comparison of inventory limits from intrusion scenarios versus groundwater pathways that are currently available put nuclides into three categories. The largest category are short-lived (30 yrs) or short-lived and moderately sorbing nuclides (e.g., ^{63}Ni, ^{241}Am, ^{243}Am, ^{226}Ra, ^{240}Pu) which are not predicted to reach the water table in appreciable concentrations. Therefore, inventory limits will be only intrusion scenario based for these isotopes. Conversely, a small group of long-lived chemically inert elements (e.g., I, Tc, C, Se) are clearly going to provide a greater dose through the groundwater pathway. Therefore, inventory limits will be based on the all pathways performance objective. A final group of long-lived and chemically reactive isotopes (e.g., U, Th, Pu, Np) require further study to determine which performance objective will prove to be inventory limiting.
- For those nuclides that are groundwater pathway limited, the inventory limit values are going to be strongly dependent on the hydrologic and chemical properties of the disposal facility barriers (e.g., waste form and protective cover). Further sensitivity studies are underway to evaluate the appropriate design features to be matched with inventory limits.

Further work is being completed in all of the areas discussed above to complete the PA analysis. In the area of physicochemical data collection, laboratory scale waste form leaching experiments are being conducted under site specific conditions and techniques for measuring soil hydrologic properties under partially saturated conditions are refined to improve data accuracy. Intrusion scenario assumptions are being finalized and dose estimates completed and groundwater transport sensitivity analyses are being expanded to evaluate the influence engineered barriers properties, and soil hydrologic properties on release estimates.

ACKNOWLEDGEMENTS

The data collection and analysis presented in this paper have been largely completed by several individuals other than the author who have also contributed significantly to the interpretation of the results. Primary contributors include (1) B. Bjornstad of Pacific Northwest Laboratory (PNL) for the collection and summarization of hydrogeologic data of the burial ground; (2) R. J. Serne, V. L. LeGore, C. W. Lindenmeier, and J. A. Campbell of PNL for laboratory data collection of waste material leaching; (3) J. L. Conca of Washington State University-Tri Cities for measurement of soil hydraulic conductivity properties with the unsaturated flow apparatus; (4) J. F. Relyea and J. Alexander of Westinghouse Hanford Company (WHC) for measurement of moisture retention curves; (5) R. Khaleel, A. H. Lu, and C. J. Lewis of WHC and T. L. LeGore of Boeing Computer Services Richland for completion of groundwater flow and transport modeling analyses; and (6) R. L. Aaberg and W. E. Kennedy of PNL for completion of intruder scenario analyses.

REFERENCES

1. U.S. DEPARTMENT OF ENERGY (DOE), *Radioactive Waste Management*, DOE Order 5820.2A, U.S. Department of Energy, Washington D.C. (1988).
2. BJORNSTAD, B., Geohydrology of the 218-W-5 Burial Ground, 200-West Area, Hanford Site, PNL-7336, Pacific Northwest Laboratory, Richland, Washington (1990).
3. VAN GENUCHTEN, M. Th., "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils," Soil Soc. Am. J., 44 (5), 892-898 (1980).
4. CONCA, J. L, and J. WRIGHT, "Diffusion Coefficients in Gravel Under Unsaturated Conditions," Water Resources Res., 23(1), 37-46, (1990).
5. HUYAKORN, P. S., H. O. WHITE, JR., J. B. KOOL, and J. E. BUCKLEY, VAM2DH: A Variably Saturated Flow and Transport Analysis Model in Two Dimensions - Documentation and User's Manual, Version 1.0, HydroGeologic, Inc., Herndon, VA (1988).
6. AABERG, R. L., and W. E. KENNEDY, JR., Definition of Intrusion Scenarios and Example Concentration Ranges for the Disposal of Near-Surface Waste at the Hanford Site, PNL-6312, Pacific Northwest Laboratory, Richland, Washington (1990).
7. NAPIER, B. A., R. A. PELOQUIN, D. L. STRENGE, and J. V. RAMSDELL, Hanford Environmental Dosimetry Upgrade Project GENII - The Hanford Environmental Radiation Dosimetry Software Package, PNL-6584, Vols. 1-3, Pacific Northwest Laboratory, Richland, Washington (1988).
8. U.S. NUCLEAR REGULATORY COMMISSION, "Licensing Requirements for Land Disposal of Radioactive Waste, Title 10, Code of Federal Regulations, Part 61, as amended, Vol. 47, No. 248, 57463-57477, Washington D.C., December 27, 1982.
9. WILLIS, N. P., and G. C. TRINER, *Hanford Site Solid Waste Acceptance Criteria*, WHC-EP-0063-3, Westinghouse Hanford Company, Richland, Washington (1991).