# Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington – 14216

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## ABSTRACT

A performance assessment (PA) of the Environmental Restoration Disposal Facility (ERDF) located at the U.S. Department of Energy's (DOE) Hanford Site in southeastern Washington is conducted per DOE Order 435.1, *Radioactive Waste Management*. [1] The purpose of the ERDF PA is to demonstrate long-term environmental protection after the facility is closed. The analysis is required to maintain a Disposal Authorization Statement for the DOE-operated facilities that dispose low-level radioactive waste. The fundamental objective of ERDF is to support the timely removal and disposal of low-level Hanford Site remediation waste derived primarily from cleanup of contaminated waste sites. ERDF started accepting waste in 1996 and as of July 2013, approximately 13.6 million metric tons of waste has been disposed. Two additional decades of waste receipts are expected but for the purpose of conducting the PA a closure date of 2035 is assumed.

Groundwater and atmospheric pathways are evaluated to determine exposure to radiation once radionuclides are released to the environment due to degradation of the engineered barriers. The results of the analyses indicate a peak dose of 0.01 mSv/yr within the compliance time period (1,000 years after closure) from transport along the atmospheric pathway (primarily from carbon-14). The post-compliance peak dose of 0.018 mSv/yr occurs past 7,000 years and results from the groundwater pathway (primarily from technetium-99). Both values are significantly smaller than the All Pathways performance objective of 0.25 mSv/yr and the Atmospheric pathway performance objective of 0.10 mSv/yr, indicating that ERDF can easily meet the DOE Order 435.1 [1] safety requirements after closure. The results also indicate that groundwater protection limits based on federal drinking water standards will not be exceeded at any time.

## INTRODUCTION

The ERDF is located within the Central Plateau portion of the Hanford Site in southeastern Washington (Fig. 1). The projected impacts of disposal of radionuclides to the environment are compared with DOE and U.S. Environmental Protection Agency (EPA) standards in DOE O 435.1 Change 1. [1] A comprehensive PA for ERDF is documented in the *Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington*. [2]

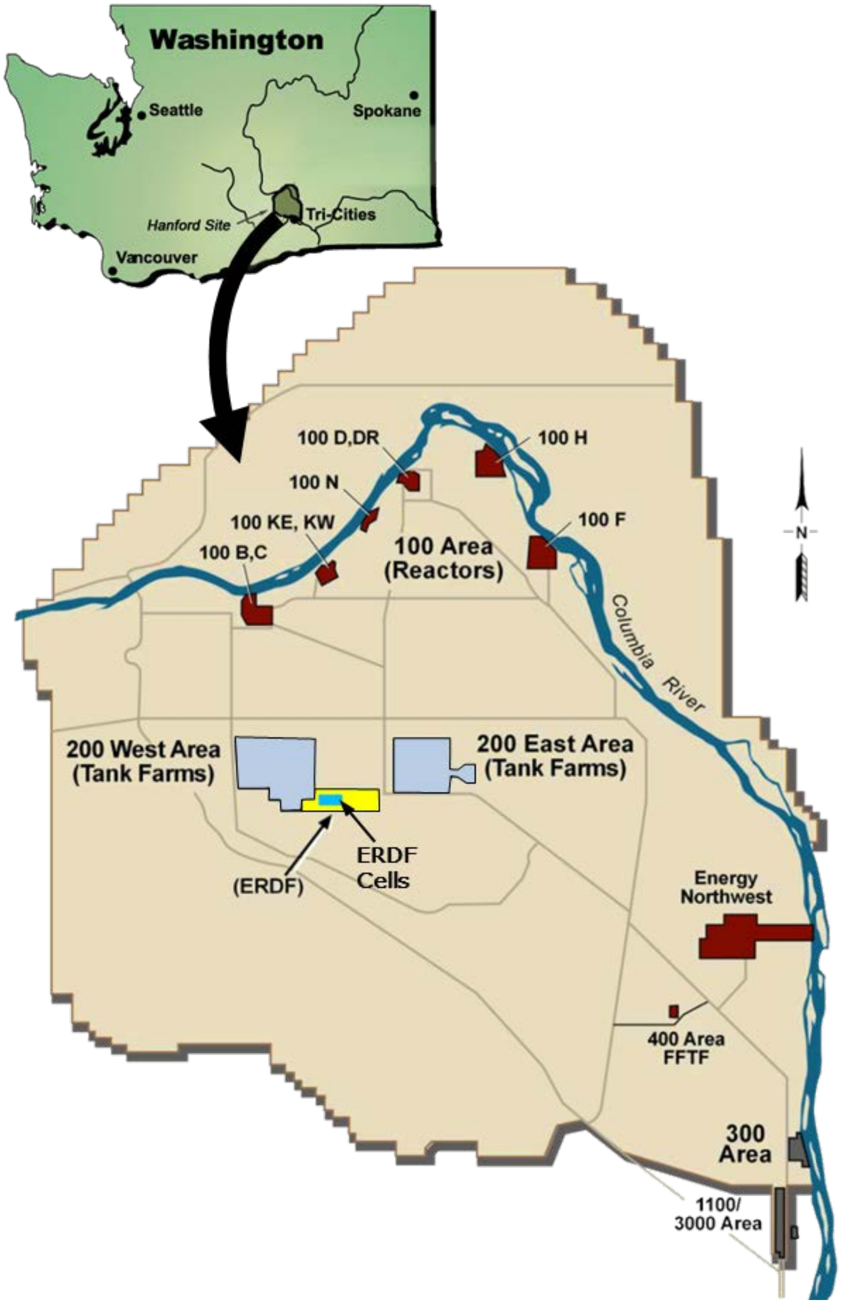



Fig. 1. Location of ERDF in Relation to Hanford Site.

Beginning in 1996, ERDF started accepting low-level radioactive, hazardous, and mixed wastes that were generated during the cleanup activities at the Hanford Site. Designed to be expanded as needed, ERDF is composed of a series of cells or disposal areas (Fig. 2). For cells 1 through 8, each cell is 21 m (70 ft) deep and 152 m (500 ft) by 152 m (500 ft) at the base. Cells 9 and 10 are supercells and each are equal to two regular cells in length (152 m [500 ft ] by 305 m [1,000 ft] at the base) but have the same depth of 21 m (70 ft). As of July 2013, approximately 13.6 million metric tons of waste has been disposed at ERDF, which occupies approximately 6.5 million m$^3$ of volume. Another two decades of waste receipt is expected from *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*

(CERCLA) [3] waste site remediation efforts across the Hanford Site. No offsite (non-Hanford Site) waste is permitted in ERDF. For the purpose of conducting the PA the ERDF closure was assumed to occur at year 2035.

Fig. 3 shows various pathways of possible exposure evaluated in the PA. The major pathways for contamination entering the environment are the groundwater pathway, the air pathway, and an inadvertent intruder pathway (through drill cuttings brought to the surface). The most important exposure pathway for hydrologic transport is groundwater use for drinking water, irrigation, livestock watering, and biotic transport. Under the groundwater pathway it is assumed that moisture from rain and snowfall enters the subsurface, contacts waste, and carries dissolved contaminants through the thick heterogeneous vadose zone to the unconfined aquifer.

During the compliance and post-compliance periods, the receptor is assumed to reside 100 m (328 ft) downgradient from the eastern edge of the facility (the edge of the ERDF berm).

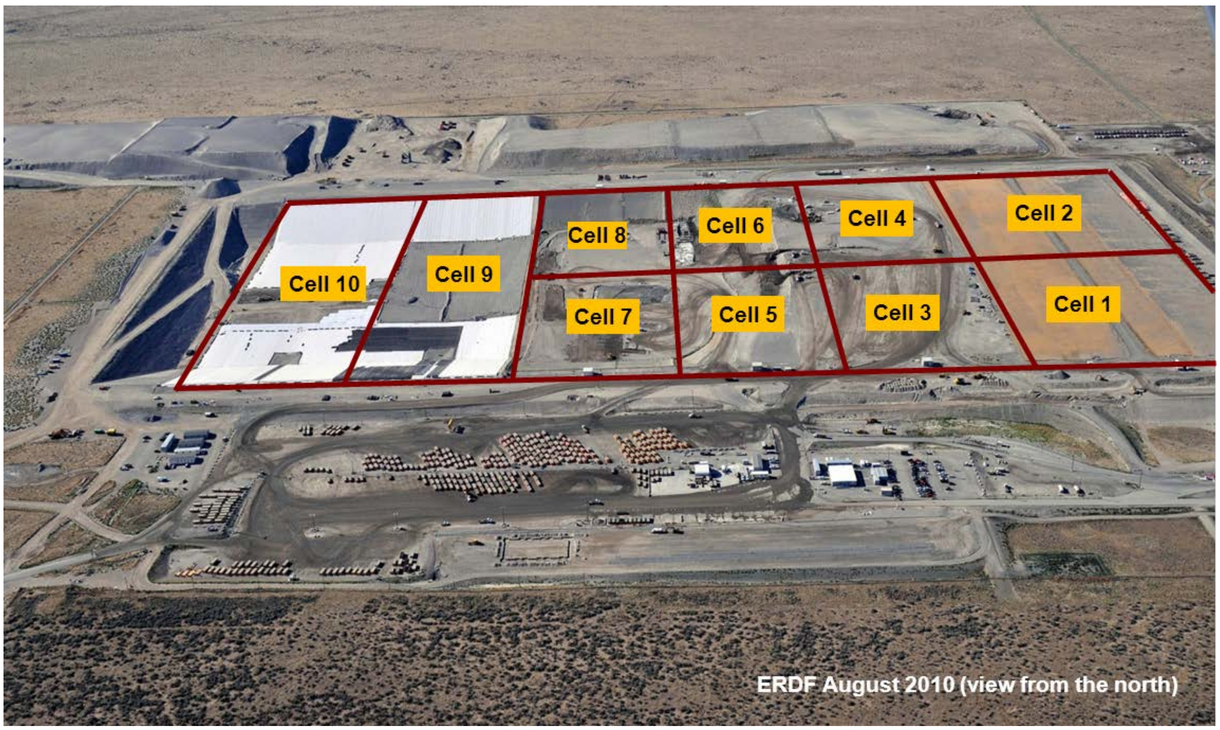



Fig. 2. ERDF Site During its Construction Phase (August 2010).

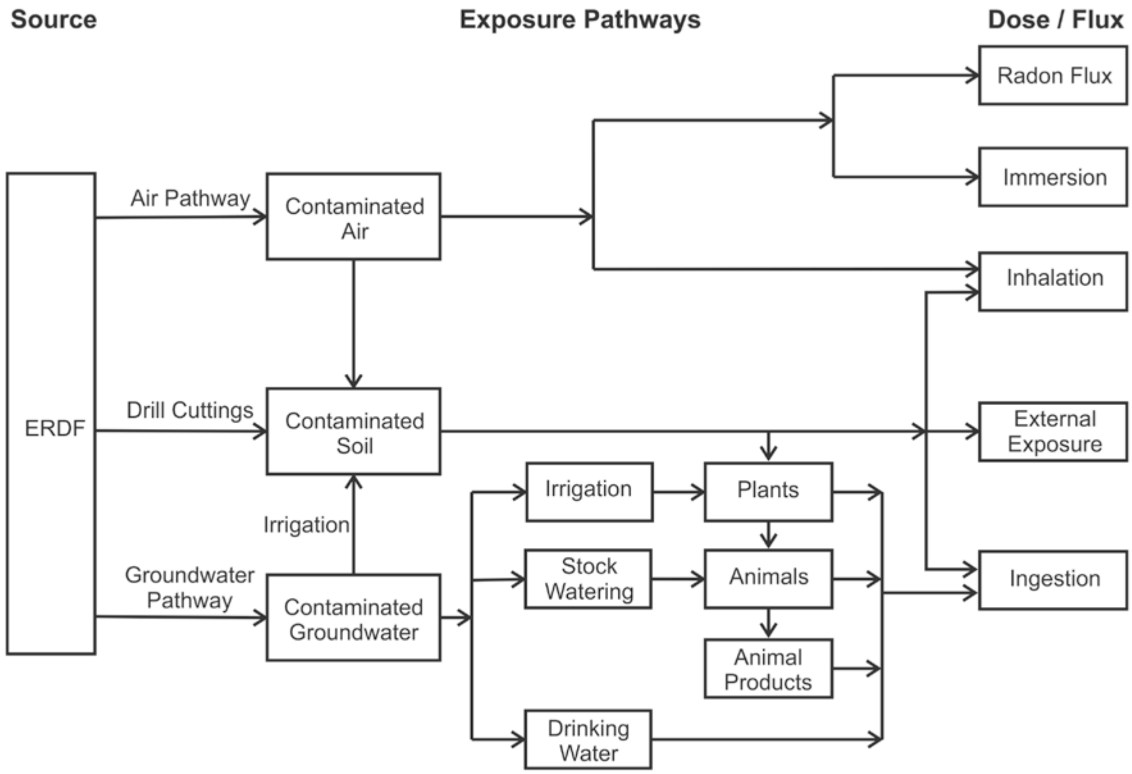



Fig. 3. Overview of the Analysis of Performance for the ERDF PA.

## DISCUSSION

The ERDF PA methodology includes deterministic calculations of the estimated impacts from the proposed closure action. The dose impacts are calculated with the numerical models and a set of input values and assumptions that are most representative of the disposal system. This case is referred to as the compliance case. The compliance case provides the expected estimate for how the system may perform given the information available; it is assumed to provide a reasonable estimate of the expected performance. Uncertainty and sensitivity analyses are also performed to understand the importance of key input parameters on transport behavior and dose.

All disposed radionuclides at ERDF with relatively long half-lives (greater than 6 years) and/or non-negligible inventories (greater than 37 GBq or 1 Ci) are considered for the purpose of the PA. Few radionuclides, regardless of inventory, that were deemed important to PA analysis dose estimates are also included in this group (e.g., radium-226, iodine-129). In addition, certain radionuclides are added to the list for which no current inventory is available but that may in-grow from the decay of parent radionuclides. A total of 46 radionuclides are evaluated in the ERDF PA.

The source term for the compliance case analysis considered two waste forms (untreated waste [contaminated soil] and activated metals) present in ERDF for all radionuclides, except carbon-14. Some waste emplaced at ERDF is grouted waste, however, the fraction is very small and conservatively included as part of the untreated waste. For carbon-14, most of the inventory (93%) is associated with insoluble waste (derived from graphite blocks) with the remaining inventory associated with activated metals (predominantly steel components) and untreated waste (derived from disposal of reactor gas condensate). The inventory used in the source term model includes the currently disposed inventory (as of August 2010) and the forecasted inventory from waste sites where cleanup has been planned from fiscal year 2011 to assumed closure in 2035. The majority of the forecasted inventory is estimated to come from 100 Area reactor buildings (including pipelines with associated soil, solid waste, and building debris), remaining solid waste sites (e.g., 118-K-1 Burial Ground), and the two solid waste sites in the 300 Area (618-10 and 618-11 Burial Grounds that contain uranium metals and research waste).

Radionuclides in untreated waste are assumed to be mixed homogeneously in the soil and readily leachable (soluble) in the presence of infiltrating water. The inventory of carbon-14 associated with insoluble waste and the small fraction associated with activated metal is released based on graphite leach rates. For other activated metal, such as niobium-94, nickel-59, and nickel-63, a conservative solubility limit based on solubility of hydrous ferric oxide is imposed for source term release, assuming congruent dissolution. The ERDF conceptual model is composed of manmade as well as natural components (Fig. 4). The manmade components of the system that influence contaminant migration include a closure surface barrier, a double-liner leachate collection system, the ERDF cells and infrastructure, and the distribution of waste in the subsurface.

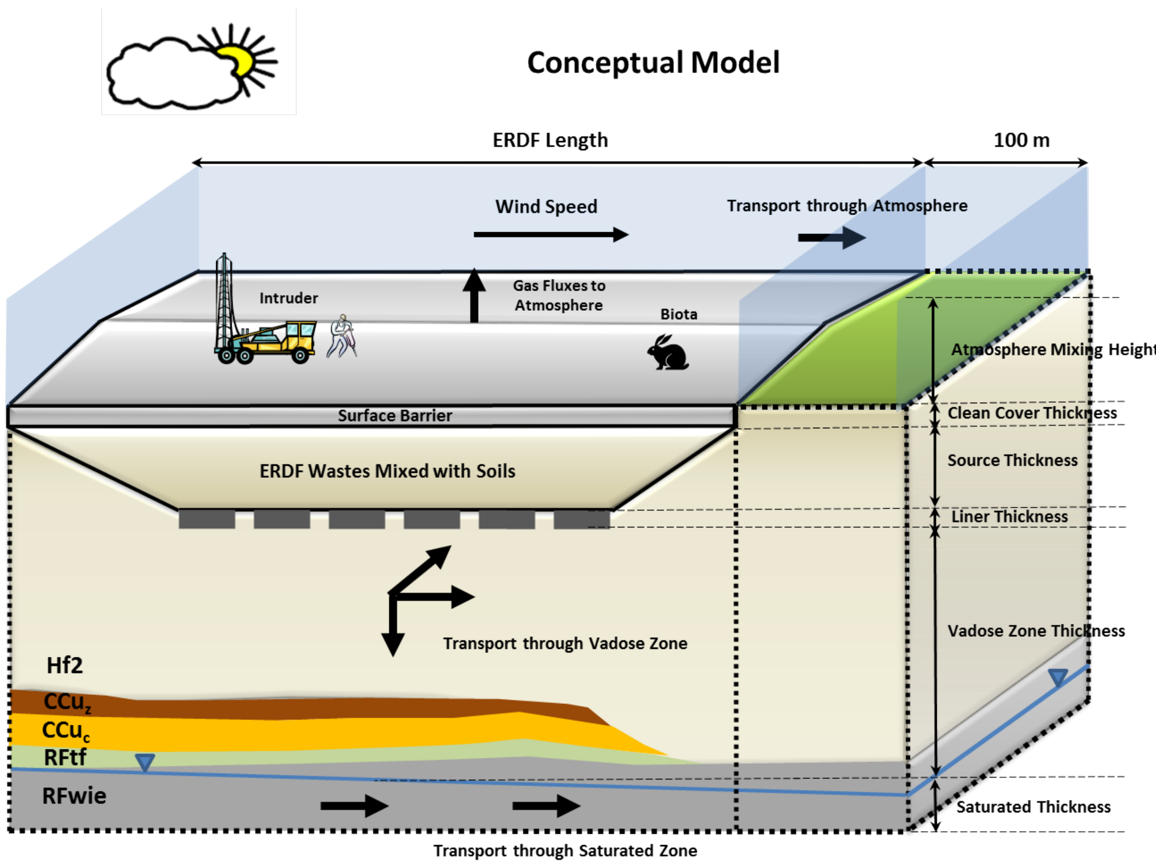



Fig. 4. Schematic Conceptual Representation of the ERDF Site and Various Pathways.

The natural components of the system that influence contaminant migration are the several underlying, nearly horizontal stratigraphic layers within the vadose zone and the unconfined aquifer. The PA modeling considered reduction of net infiltration from the presence of a double-leachate collection liner system at the base and an engineered cover (surface barrier) over ERDF. The liner system is installed during construction of the cells, and the surface barrier is assumed to be installed on ERDF at closure in 2035. The surface barrier and double leachate collection liner system are assumed to remain intact and allow only negligible amounts of net infiltration for the first 100 years (i.e., 2035 to 2135), coinciding with the institutional control time period.

For the purpose of assessing the long-term performance, closure date 2035 is assumed for ERDF. In the post-closure assessment, four time periods are considered that are presented in Table I:

- A 100-year institutional control period when the engineered surface cover (overlying ERDF) and double leachate liner (underlying ERDF) are working to their full barrier capability resulting in effectively zero recharge rate under the base of ERDF

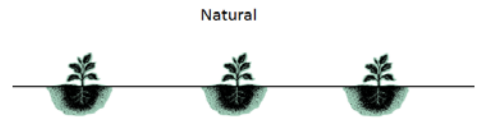
- A 400-year degraded liner period (from 100 years to 500 years following closure) within which the double-leachate liner is assumed to be effectively degraded but the surface cover remains intact

- The time period from 500 years after closure up to the DOE O 435.1 [1]-defined compliance time period of 1,000 years during which the surface cover barrier function is assumed to be fully degraded at the start of the time period (assuming a design life of 500 years)

- The post-compliance period (beyond 1,000 years) up to 10,000 years for the purpose of evaluating uncertainty and sensitivity on dose estimates. Maximum dose from long-lived mobile contaminants occurs within this time period.

Net infiltration (recharge) estimates for each of the time periods is presented in Table II. The recharge rates can vary spatially within each time period depending upon the type of vegetation or state of engineered barrier.

TABLE I. Timeline Considered for Representing the Evolution of ERDF.

<table>
<tr><th>Phase</th><th>Conditions</th><th>Duration</th><th>Conceptual Half Cross Section of the ERDF Area</th></tr>
<tr><td>Pre-operations</td><td>Before construction of ERDF</td><td>Until steady-state moisture conditions are achieved for the year.</td><td>
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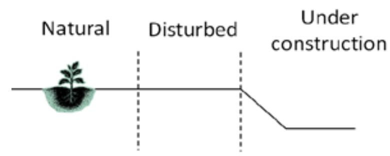
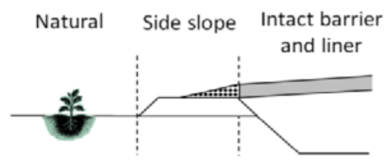
<tr><td>Operations</td><td>Current conditions</td><td>1996 to 2035</td><td>
</td></tr>
<tr><td rowspan="2">Early Post-Closure</td><td>Transition to conditions of restricted recharge due to RCRA[a]-compliant barrier and intact liner during the first 100 years of institutional control</td><td>2035 to 2135</td><td>
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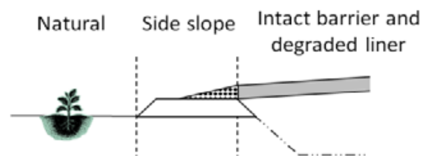
<tr><td>Intact surface barrier and degraded liner after its assumed service life of 100 years</td><td>2135 to 2535</td><td>
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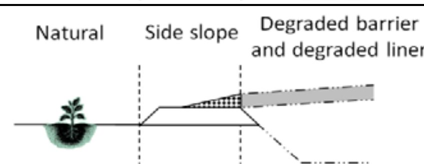
<tr><td>Late Post-Closure</td><td>Degraded surface barrier conditions</td><td>Time needed to reach the groundwater table. At least 2535 to 3035 (possible extension to 12035)</td><td>
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**Footnote:**

[a] *Resource Conservation and Recovery Act* [4]

TABLE II. Recharge Estimates for Various Time Periods Considered.

| Period | ERDF Region | Recharge Rate (mm/yr) Compliance Value |
|---|---|---|
| Pre-construction (before 1996) | Undisturbed region (Rupert sand with vegetation) | 1.7 |
| Operational period (1996-2035) | Undisturbed region (Rupert sand with vegetation) | 1.7 |
| | Disturbed region (Rupert sand without vegetation) | 45 |
| | Region under construction (ERDF cells) | 0 |
| Early post-closure (2035-2535) | Undisturbed region (Rupert sand with vegetation) | 1.7 |
| | Side slopes (compacted silt) | 2 |
| | Top portion of the barrier (2035-2135) | 0 |
| | Top portion of the barrier (2135-2535) | 0.5 |
| Late post-closure (2535-3035 and beyond) | Undisturbed region (Rupert sand with vegetation) | 1.7 |
| | Degraded side slopes with vegetation | 2 |
| | Degraded top portion of the barrier | 1 |

Based on the conceptual models for different pathways, numerical models were developed to estimate the contaminant concentrations within water, air, or soil as a function of time. A three-dimensional flow and transport model was developed using the Subsurface Transport Over Multiple Phases code developed by Pacific Northwest National Laboratory [5] to evaluate the impact to the environment from the groundwater pathway. The model assumed that infiltration of moisture from precipitation eventually enters the facility but most of the moisture is diverted around ERDF during operations and for the first 100 years after closure. Once the double liner is assumed to be degraded, the contaminants, based on their relative inventories associated with a given waste form type, are released into the vadose zone by contact with recharge water (the release of carbon-14 inventory associated with graphite and activated metals is based on the graphite leaching rate). The infiltrating moisture, along with contaminants, travels through the vadose zone with the contaminant transport times influenced by the equilibrium sorption characteristics (determined by the distribution coefficient [$K_d$]). Fig. 5 presents the spatial distribution of Technetium-99, which travels unretarded through the vadose zone and the saturated zone at the end of 1,000 years of simulation.

Fig. 6 presents the groundwater breakthrough curves of various radionuclides over the 10,000-year simulation period at the compliance location (100 m [328 ft] downgradient of the ERDF). Only chlorine-36, technetium-99, niobium-94, molybdenum-93, and iodine-129 show breakthrough at the point of compliance. Iodine-129 is the only radionuclide with a $K_d$ value greater than zero ($K_d$ = 0.2 mL/g for sand dominated units) to do so. The initial breakthrough for radionuclides (except iodine-129) occurs around 3,000 years and reaches peak values by about 7,000 years, whereas the iodine-129 breakthrough occurs past 9,000 years. Technetium-99 has the largest peak concentration (27.05 Bq/L [731 pCi/L]) due to the greatest inventory (1961 GBq [53 Ci]) compared to any of these radionuclides; others have inventories less than (37 GBq [1 Ci]). Although the results of the different radionuclides vary because of differing radioactive decay rates, the results indicate that for long-lived nonsorbing radionuclides approximately (37 GBq [1 Ci]) of inventory translates to a maximum concentration of approximately 0.52 Bq (14 pCi/L) in groundwater at the downgradient point of calculation.

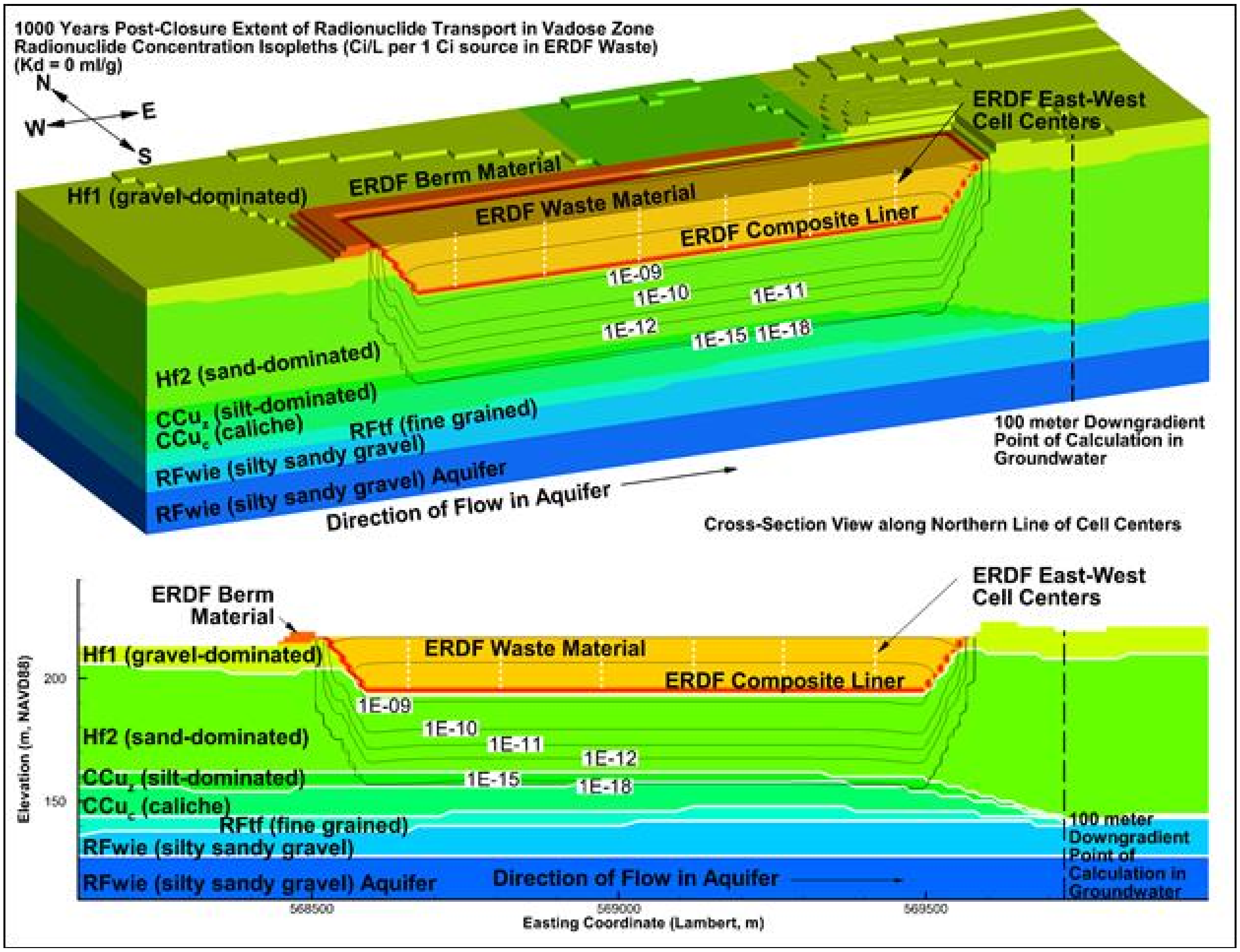


Fig. 5. Extent of Transport of the Most Mobile Radionuclides Such as Technetium-99 (Kd = 0 mL/g) in the Vadose Zone at the End of the 1,000-year Compliance Period for 37 GBq (1 Ci) Initial Inventory in ERDF. (top) Cross-section view along northern line of ERDF cells, (bottom) cross-section view along southern line of ERDF cells. (Note: 1 pCi/L = 0.037 Bq/L)

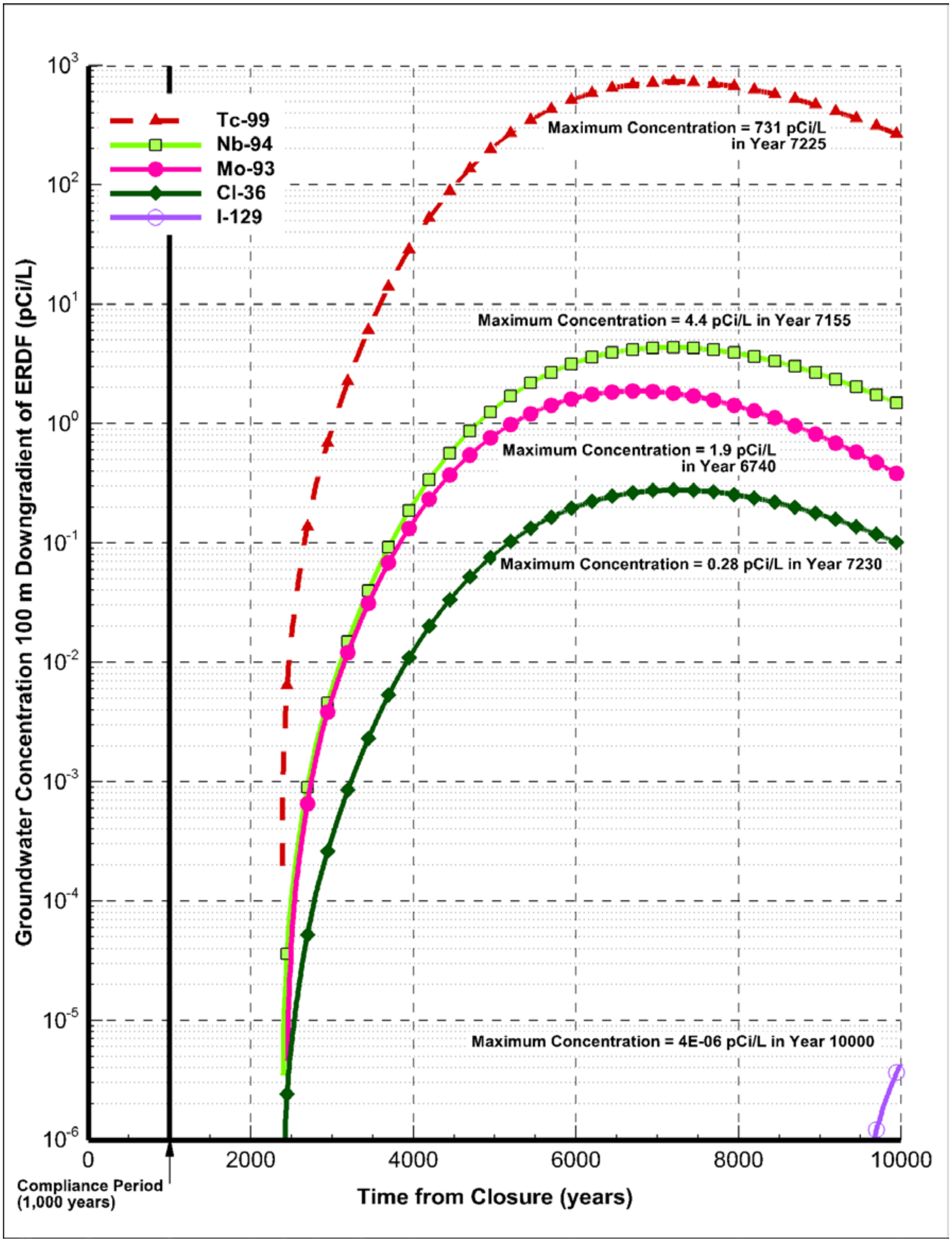


Fig. 6. Maximum Predicted Groundwater Concentration at 100 m (328 ft) Downgradient from ERDF Through the End of the Post-Closure Period. (Note: 1 pCi/L = 0.037 Bq/L)

Under the atmospheric pathway, for a limited number of radionuclides that can partition into the gas phase from dissolved phase (e.g., carbon-14, hydrogen-3, iodine-129, and radon-222), a conservative one-dimensional modeling is performed to estimate diffusive release from the ERDF into the atmosphere across the modified RCRA [4]-compliant closure cover (Fig. 4). The results indicate that the atmospheric carbon-14 release is the dominant release in comparison to other radionuclides. It is sustained by a slow continuous release from the source term as a function of the graphite leaching rate.

Under the intruder scenarios, a well is drilled through the emplaced ERDF waste all the way to the water table. The contamination is then brought to the surface as part of the drill cuttings where it can cause human exposure (Fig. 4). One acute well drilling and three chronic inadvertent intruder (commercial farm, rural pasture, and suburban garden) scenarios were evaluated. Although the likelihood of an inadvertent intrusion at ERDF is very small in the foreseeable future, for the purpose of compliance calculations, passive and active institutional controls are assumed to be ineffective in preventing temporary intrusion after 100 years following closure. In other words, loss of institutional controls is assumed after 100 years following closure and peak dose is evaluated assuming inadvertent intrusion occurs immediately after the loss of institutional controls.

## CONCLUSIONS

The PA results of the all-pathways, atmospheric, radon flux, inadvertent intruder, and groundwater (water resources) protection analyses are shown in Table III for the compliance and post-compliance periods. Only the peak values of the effective dose equivalent or peak concentrations are compared to the standards. Exposure scenario dose coefficients specific to the chosen exposure scenario are then applied to transform groundwater, air, or soil concentrations to dose quantities to determine total effective dose equivalent on a per-year basis.

The only dose calculated in the all-pathways analysis within the 1,000-year compliance time period is from the air pathway; there are no impacts to groundwater during this period. For the all-pathway dose calculations, the peak dose within the compliance time period (0.01 mSv/yr) is predominantly from the carbon-14 atmospheric pathway while for the post-compliance time period the peak dose of 0.018 mSv/yr is predominantly from technetium-99 from the groundwater pathway. The PA results indicate that the performance objectives and measures for atmospheric, all-pathways, radon, inadvertent intruder, and groundwater protection are met for both the 1,000-year compliance time period (2035 to 3035) and the post-compliance period (3035 to 12035). Therefore, there is a reasonable expectation that performance objectives and measures established for the long-term protection of the public and the environment will not be exceeded following closure of ERDF.

For the post-compliance time period, Table III shows the all-pathway dose to be 0.018 mSv/yr and the groundwater protection dose to be 0.033 mSv/yr. This apparent difference is due to usage of latest DOE effective dose coefficient for ingested water (DOE-STD-1196-2011 [6]) for the all-pathway dose calculation while using the EPA maximum contaminant level (40 CFR 61 [7]) for the groundwater protection calculation.

TABLE III. Comparison of Performance Objectives and the Environmental Restoration Disposal Facility Performance Assessment Results for the Compliance and Post-Compliance Periods.

| **Performance Objective and/or Measure** | **Standard** | **Performance Assessment Results** | |
|---|---|---|---|
| | | **Compliance Period (2035-3035) [a]** | **Post-Compliance Period (3035-12035) [a]** |
| All pathways[b] | 0.25 mSv/yr EDE | 0.01 mSv/yr | 0.018 mSv/yr |
| Atmospheric[c] | 0.1 mSv/yr EDE | 0.01 mSv/yr | 0.005 mSv/yr |
| Atmospheric[d] | 0.74 $Bq.m^{-2}.s^{-1}$ radon flux (at surface of disposal facility) | 0.004 $Bq.m^{-2}.s^{-1}$ | 0.003 $Bq.m^{-2}.s^{-1}$ |
| Acute inadvertent intruder[b] | 5 mSv EDE [e] | 0.055 mSv [f] | NA |
| Chronic inadvertent intruder[b] | 1 mSv/yr EDE [e] | 0.093 mSv/yr [f] | NA |
| Groundwater protection (water resources)[h] | Beta-gamma dose equivalent ≤ 0.04 mSv/yr | 0 mSv/yr | 0.033 [g] mSv/yr |
| | Gross alpha activity concentration (excluding radon and uranium) ≤ 0.55 Bq/L | 0 Bq/L | 0 [i] Bq/L |
| | Combined Ra-226 and Ra-228 concentration ≤ 0.185 Bq/L | 0 Bq/L | 0 [i] Bq/L |
| | Uranium concentration ≤ 30 µg/L | 0 µg/L | 0 [i] µg /L |
| | Sr-90 concentration ≤ 0.296 Bq/L[j] | NA | NA |
| | H-3 concentration ≤ 740 Bq/L | 0 Bq/L | 0 Bq/L |

**Footnotes:**
a Compliance at 100 m downgradient of ERDF except for inadvertent intruder scenarios.
b DOE O 435.1, Chg 1 [1]
c 40 CFR 61, Subpart H [7]
d 40 CFR 61, Subpart Q [7]
e Not applicable for post-compliance time period.
f Peak dose based on assumed inadvertent intrusion at 100 years following loss of institutional control. Peak occurs at 100 years after closure.
g Beta-gamma dose equivalent ≤ 0.04 mSv/yr (based on federal MCL) and calculated as ($C_{Peak}$/ MCL)* 0.04 mSv/yr. For Tc-99, which contributes almost the entire dose, $C_{Peak}$=27.05 Bq/L (731 pCi/L) and MCL= 33.3 Bq/L (900 pCi/L), so the equivalent dose is calculated to be 0.033 mSv/yr.
h 40 CFR 141 [8]
i Concentrations less than 3.7E-12 Bq/L (1E-10 pCi/L) are essentially zero.
j Not applicable; Sr-90 was screened out during evaluation of the groundwater pathway due to its relatively short half-life and its low mobility in the subsurface.
EDE = effective dose equivalent
MCL = maximum contaminant level
NA = not applicable

## REFERENCES


1. DOE Order 435.1, *Radioactive Waste Management*
2. WCH-520, 2013, *Performance Assessment for the Environmental Restoration Disposal Facility, Hanford Site, Washington*, Rev. 1, Washington Closure Hanford, Richland, Washington.
3. *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
4. *Resource Conservation and Recovery Act*
5. PNNL-15782, 2006, *STOMP Subsurface Transport Over Multiple Phases Version 4.0 User's Guide*, Pacific Northwest National Laboratory, Richland, Washington.

6. DOE-STD-1196-2011, 2011, *Derived Concentration Technical Standard*, U.S. Department of Energy, Washington, D.C.
7. 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," *Code of Federal Regulations*, as amended.
8. 40 CFR 141, "National Primary Drinking Water Regulations," *Code of Federal Regulations*, as amended.