

**ATTACHMENT 6N
SUBSURFACE FATE AND TRANSPORT MODELING
OF RADIONUCLIDES FOR
USDOE/NNSA PANTEX PLANT
AMARILLO, TEXAS**

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6N.0 SUBSURFACE FATE AND TRANSPORT MODELING OF RADIONUCLIDES

This attachment provides an evaluation, using unsaturated zone fate and transport modeling, of potential migration of radiological SRCs in soil to points of exposure via the soil-to-groundwater pathway. For this pathway to be complete, SRCs in soil (surface and subsurface) at Pantex Plant would have to migrate from source areas to potential exposure points in groundwater (i.e., the Plant boundary in perched groundwater of the Ogallala Aquifer for offsite exposure or Plant production wells in the Ogallala Aquifer for onsite exposure).

6N.1 INTRODUCTION

A one-dimensional fate and transport analysis was performed to investigate potential SRC migration in the unsaturated zone and to ascertain if SRCs may potentially reach perched groundwater in measurable quantities within 1,000 years. All SRC release sites at Pantex Plant are in upland areas. Results of this modeling are used to assess the potential for SRCs in soil to impact perched groundwater and to quantify the potential impact beneath these upland areas. The evaluation presented in this attachment provides a specific assessment of radionuclide fate and transport at Pantex Plant and supplements the other fate and transport modeling conducted as part of this risk assessment.

To provide a conservative assessment of radionuclide migration, Firing Site 5 (FS-5) was selected for this analysis. FS-5 was constructed in 1953 to test the behavior of simulated weapons components made from depleted uranium under compression by high explosives. This testing, terminated in 1984, resulted in the dispersion of depleted uranium in FS-5 soils. An interim corrective measure was conducted at FS-5 in the late 1990s and included identification of depleted uranium anomalies (hotspots), removal of impacted soil, confirmation of cleanup by field screening and soil sampling and analysis, and backfilling/grading/reseeding of disturbed areas. Details of the cleanup are presented in *Firing Site 5 Interim Corrective Measures Draft Final Soil Remediation Implementation Report* (Stoller, 1998).

Although FS-5 was previously addressed in a separate risk assessment, it was selected for this analysis because it represents the largest release of radiological material at Pantex Plant. A similar fate and transport analysis was conducted as part of the FS-5 Risk Assessment documented in the *RI Report*. However, site-specific measurements of uranium sorption were not available at that time, and the sorption coefficients used were higher than values measured in laboratory column studies.

6N.2 MODEL SELECTION AND DEVELOPMENT

A one-dimensional flow and transport analysis was used to investigate the potential for migration of radionuclides through the unsaturated zone. The Los Alamos Finite Element Heat and Mass (FEHM) code (v2.20), adopted by the Pantex Groundwater Modeling Technical Advisory Group (BWXT Pantex, 2002), was used for this analysis with the linear (K_d) sorption and first-order decay capabilities selected.

Transport of SRCs was modeled through a soil column representative of subsurface conditions beneath FS-5. Two primary hydrostratigraphic units comprise the soil column: an upper unit of approximately 75 ft of silty clay loam representing the Blackwater Draw Formation and a lower unit of approximately 190 ft of sandy loam representing the upper Ogallala sediments. The caprock caliche was not simulated as a low permeability unit, but was assigned hydraulic properties consistent with the upper Ogallala Formation

sediments. Site-specific K_d values for uranium for each hydrostratigraphic unit, presented in Table 6N-1, were used in the column modeling.

Table 6N-1. Uranium K_d Values for Blackwater Draw and Upper Ogallala Sediments

SRC	K_d (L/Kg)		Source	Rationale
	Blackwater Draw	Upper Ogallala		
Uranium	22	0.4	Rainwater, et al. 2006, EPA 2000	Blackwater Draw: Rainwater, et al. (2006) present an average value for uranium based on the results of laboratory flow-through column experiments using Blackwater Draw soils. Upper Ogallala Formation: Default value from Table 5-3 (EPA 2000).

The horizontal and vertical discretization of the model domain is shown in Figure 6N-1. The plan dimensions of the column are 180 ft by 180 ft. This area is divided into nine cells measuring 60 ft by 60 ft. Vertically, the model is divided into 28 layers based on field-scale evaluation of the FEHM model. The field-scale evaluation indicated that 28 layers were needed to minimize numerical instabilities in the variably saturated model over the range of potential hydraulic conductivities present. Table 6N-2 provides the discretization and hydraulic conductivities of the soil column. The bottom of the model is set at a depth representative of the FGZ from the surface. To evaluate travel times to perched groundwater, the SRC concentration was calculated at roughly 10 ft above the top of the FGZ at 280 ft bgs.

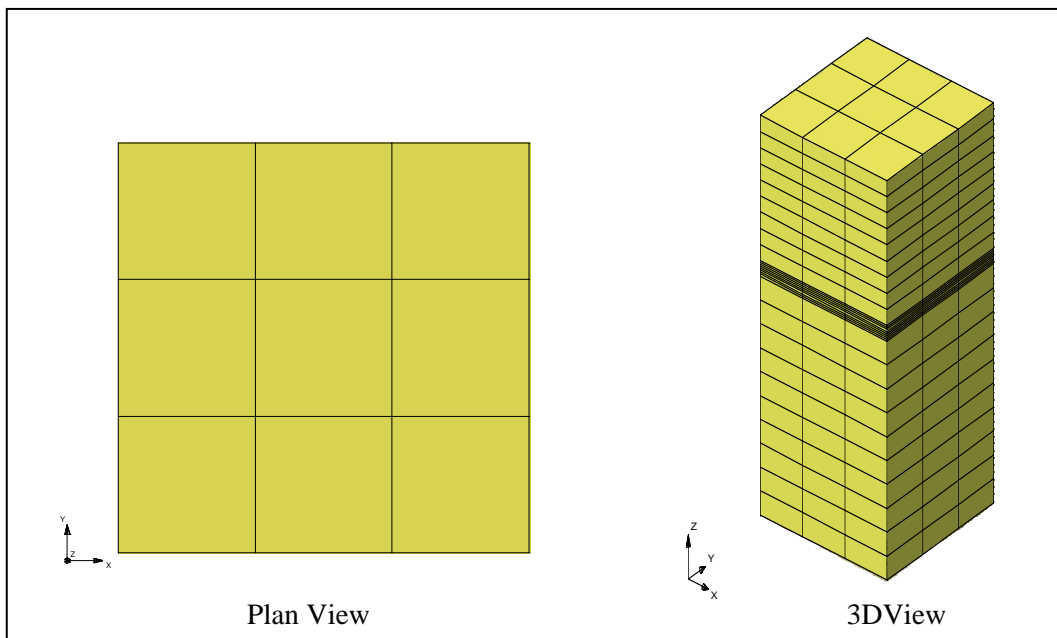


Figure 6N-1. Model Domain and Discretization

The hydraulic conductivities of subsurface materials at Pantex Plant have been established using lithologic descriptions from boring logs and data from field and laboratory test results. The site-specific saturated hydraulic conductivity of the materials beneath FS-5 is shown in Table 6N-2. These conductivity values were derived from the larger site-wide model for Pantex Plant.

Recharge is the primary transport mechanism for the movement of radionuclides through the soil column. Recharge rates at Pantex Plant vary greatly depending on water availability because of the semi-arid climate and flat topography. All SRC release areas at Pantex Plant are in upland areas. Therefore, the upland recharge rate of 0.13 inch/year (obtained from the calibrated site-wide flow model) was used for this analysis.

Table 6N-2. FEHM Model Vertical Discretization

Layer	Unit	Depth (ft bgs)	K _x (ft/day)	K _y (ft/day)	K _z (ft/day)
1	Blackwater Draw	0.00	0.31	0.31	0.25
2		8.38	0.31	0.31	0.25
3		16.75	0.31	0.31	0.25
4		25.13	0.36	0.36	0.28
5		33.50	0.36	0.36	0.28
6		41.88	0.36	0.36	0.28
7		50.25	0.71	0.71	0.35
8		58.63	0.71	0.71	0.35
9		67.00	0.71	0.71	0.35
10	Caliche	75.38	1.40	1.40	0.76
11		77.05	1.40	1.40	0.76
12		78.71	1.40	1.40	0.76
13		80.38	1.40	1.40	0.76
14		82.05	1.40	1.40	0.76
15	Upper Ogallala	83.71	1.40	1.40	0.76
16		85.38	4.78	4.78	1.81
17		100.17	4.78	4.78	1.81
18		114.95	4.78	4.78	1.81
19		129.74	4.78	4.78	1.81
20		144.52	6.29	6.29	5.46
21		159.31	6.29	6.29	5.46
22		174.10	6.29	6.29	5.46
23		188.88	6.29	6.29	5.46
24		203.67	9.35	9.35	1.31
25		220.05	9.35	9.35	1.31
26		236.43	9.35	9.35	1.31
27		252.81	9.35	9.35	1.31
28	257.81	9.35	9.35	1.31	

Prior to running the transport simulation, the FEHM flow model was simulated to obtain a steady state flow solution. The predicted nodal saturations above the FGZ ranged from 0.18 to 0.34. Water travel time from land surface to the top of the FGZ is greater than 1,000 years under advective flow conditions (no sorption, no reactions, no decay). Transport of uranium was simulated for a period of 1,000 years under steady state flow conditions. A constant concentration source was applied to the recharge flux at the ground surface (source location) and was conservatively held constant throughout the 1,000-year simulation.

Other model input parameters are provided in Table 6N-3. Dispersivity values were conservatively set to zero so that the model would predict the maximum concentration at the water table surface. Although the specified dispersivity values were zero, some numerical dispersion is evident in the model results. A comparison of the transport model results to a simplified analytic transport solution indicates the amount of numerical dispersion is less than the expected physical dispersion, and use of the model is acceptable.

Table 6N-3. FEHM Input Parameters

FEHM Input Parameters	Value	Remarks
Column width	180 ft	Total
Nodal spacing (horizontal)	60 ft	Square
Column height	257.8 ft	Ground surface to top of FGZ
Nodal spacing (vertical)	varies from 1.67 ft to 16.38 ft	
Reference pressure	0.1 Mpa	Zero datum
Reference temperature	20 °C	
Maximum Saturation	1.0	Fully saturated
Matrix residual saturation	0.1	Lowest saturation
Boundary condition at the top of the model	0.13 in/yr	Upland recharge rate from calibrated site-wide flow model
Boundary condition at the bottom of the model	Saturation = 0.999	Vadose zone model
Van Genuchten model parameters	Inverse air entry head: 2.2 ft ⁻¹ Power in formula: 1.8	Values for Blackwater Draw
	Inverse air entry head: 2.4 ft ⁻¹ Power in formula: 1.9	Values for Upper Ogallala
	Inverse air entry head: 3.0 ft ⁻¹ Power in formula: 2.0	Values for perched zone
Porosity	0.30	Value for fine sand (all slices)
Total simulation time for flow simulation	1.0·10 ¹² days	Solve for steady-state flow field
Total simulation time for transport simulation	1,000 years	After flow field reaches steady-state

6N.3 MODELING RESULTS

The FEHM simulation result after 1,000 years of transport indicate that uranium migrated less than 35 ft bgs at FS-5, as shown in Figure 6N-2. The FEHM model predicted that uranium will not migrate to the depth of perched groundwater within the simulation period.

6N.4 UNCERTAINTIES IN MODELING SIMULATIONS

The largest uncertainties in the predictions for FS-5 are:

- SRC distribution is assumed to be uniform throughout the FS-5 area, while the investigation data showed that the detections were not uniformly distributed.
- The highest pre-removal detection of uranium was used to define the source concentration held constant for the 1,000 year duration of the modeling. Following completion of the ICM, the highest uranium concentration is much lower.

These assumptions result in overestimation of the uranium mass in the subsurface and overestimation of the potential for migration.

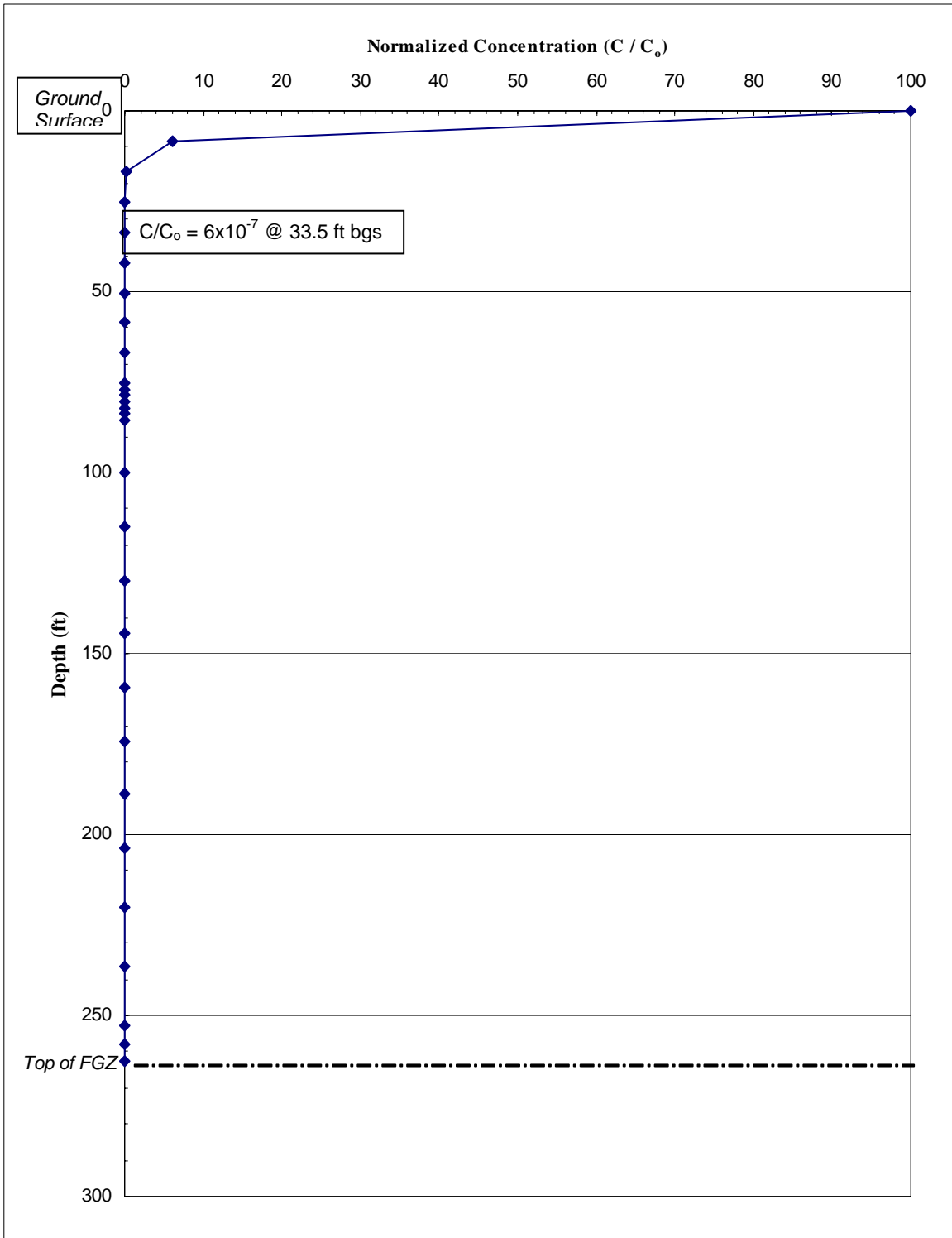


Figure 6N-2. Uranium Transport Simulation Concentration Profile at 1,000 years

6N.5 SUMMARY AND CONCLUSIONS OF UNSATURATED ZONE FATE AND TRANSPORT MODEL

The FEHM model predicted less than 35 ft of constituent migration using a constant source concentration at ground surface for the entire simulation period. The travel time for diffuse groundwater recharge from ground surface to the perched groundwater zone is over 1,000 years at upland sites with no sorption. With the observed sorption (22 L/kg) of uranium in Blackwater Draw Formation soils, it is shown that the constituent never approached the depth of perched groundwater in 1,000 years.

This simulation provides a conservative representation of SRC migration at Pantex Plant and demonstrates that, in the absence of focused recharge, SRCs in upland areas do not pose unacceptable risk via the soil-to-groundwater pathway.