

8. EXPOSURE PATHWAYS

Exposure pathways applicable to DU include external radiation from contamination in soil (or water); inhalation of contaminated dust; and ingestion of water, plant-derived food, meat, milk, aquatic food, and incidental ingestion of soil (see Figure 7-1). Each of these pathways is explicitly considered pursuant to the determination of potential critical groups and the respective doses to the average member of the critical group. As defined by NRC in 10 CFR 20.1003, critical group means the group of individuals reasonably expected to receive the greatest exposure to residual radioactivity for any applicable set of circumstances (NRC 2012a). NRC baseline scenarios that may be determined to be the critical group include rural resident farmers, urban residents, workers, and sportspersons/outdoorsperson/recreational scenarios. Exposure to uranium in its various forms, including oxides, is a much-studied material and its toxicity is relatively well known (Battelle 2005). In sufficient amounts, uranium that is ingested or inhaled can be harmful because of its chemical toxicity. Like mercury, cadmium, and other heavy-metal ions, excess uranyl ions depress renal function (i.e., affect the kidneys). High concentrations in the kidney can cause damage and, in extreme cases, renal failure. The general medical and scientific consensus is that in cases of high intake, uranium is likely to become a chemical toxicology problem before it is a radiological problem. Although uranium is mildly radioactive and irradiates internal organs once taken into the body, the primary health effect is associated with its chemical action on body functions (Battelle 2005).

Uranium is introduced into the body mainly through ingestion of food and water and inhalation of air. When inhaled, uranium is attached to particles of different sizes. The size of the uranium aerosols and the solubility of the uranium compounds in the lungs and gut influence the transport of uranium inside the body. Coarse particles are caught in the upper part of the respiratory system (nose, sinuses, and upper part of the lungs) from where they are exhaled or transferred to the throat and then swallowed. Fine particles reach the lower part of the lungs (alveolar region). If the uranium compounds are not easily soluble, the uranium aerosols will tend to remain in the lungs for a longer period of time (up to 16 years), and deliver most of the radiation dose to the lungs. They will gradually dissolve and be transported into the blood stream. For more soluble compounds, uranium is absorbed more quickly from the lungs into the blood stream. About 10 percent of uranium will initially concentrate in the kidneys (NRC 2012a).

Most of the uranium ingested is excreted in feces within a few days and never reaches the blood stream. The remaining fraction will be transferred into the blood stream. Most of the uranium in the blood stream is excreted through urine in a few days, but a small fraction remains in the kidneys and bones and other soft tissue (NRC 2012b). Uranium does not present a significant dermal hazard.

Consistent with 10 CFR 20.1403 requirements for restricted release mandate that the licensee make provisions for legally enforceable institutional controls that provide reasonable assurance that the TEDE from residual radioactivity distinguishable from background to the average member of the critical group will not exceed 25 millirems per year (mrem/y) (0.25 milliSieverts per year [mSv/y]). In addition, the licensee must demonstrate that residual radioactivity at the site has been reduced so that if the institutional controls were no longer in effect, there is reasonable assurance that the TEDE from residual radioactivity distinguishable from background to the average member of the critical group is as low as reasonably achievable (ALARA) and would not exceed 100 mrem/y (1 mSv/y) (or 500 mrem/y [5 mSv/y] if additional, specified, provisions are implemented). As such, two critical groups are applicable for restricted release consisting of:

- The group with the greatest exposure under circumstances such that institutional controls are implemented and function as designed
- The group with the greatest exposure under circumstances such that institutional controls are no longer in effect.

Doses to multiple potential critical groups were evaluated pursuant to selection of the critical groups for each of the two above sets of circumstances. Included among the potential critical groups for circumstances such that institutional controls are implemented and function as designed were Industrial Workers, Sportsman/Recreationists, and Offsite Resident Farmers.

8.1 INDUSTRIAL WORKERS

Industrial Workers including personnel from the Army, FWS, Indiana Air National Guard (INANG), EOD, NRC, emergency response organizations (e.g., law enforcement, emergency medical, fire response), and other Federal and contractor personnel who are authorized to access the DU Impact Area. These workers are authorized limited access to the DU Impact Area pursuant to performance of their official duties. Examples of authorized activities are cited in Section 4 of the Radiation Safety Plan (U.S. Army 2013b) and include, but are not limited to, environmental radiation monitoring activities, EOD activities, controlled burning, maintenance of signage, and wildlife monitoring and census taking. The nature of the work functions performed in the DU Impact Area seriously limits the time in the DU Impact Area and the associated doses. Nonetheless, as a conservative estimate, it is assumed that an industrial worker spends 2,000 hour per year in the primary DU contamination zone, uses water from a municipal water source, and receives dose from the following pathways:

- External exposure to DU in soil
- Inhalation of dust containing DU
- Incidental ingestion of DU-contaminated soil deposited by floods.

8.2 SPORTSMAN/RECREATIONISTS

Members of the public entering JPG areas outside the DU Impact Area for outdoor recreational purposes (e.g., hunting, fishing, bird watching, hiking) include sportsmen/recreationists. These individuals access the area north of the former firing line but are prohibited from entering the DU Impact Area. It is assumed that the maximally exposed sportsman/recreationist spends the entire time available each year (i.e., 103 days per year) that the Big Oaks NWR is open to the public. In addition, although all sportsmen/recreationist are prohibited from entering the DU Impact Area, as a conservative estimate it is assumed that activities take place in the primary DU contaminated zone. In addition, pathways included in the dose estimate included:

- External exposure to DU in soil
- Inhalation of dust containing DU
- Incidental exposure of soil containing DU
- Incidental ingestion of drinking water from surface water body
- Ingestion of game animals, which have drank water from a surface water body in the DU Impact Area and eaten plant material (grazed on vegetation) from the DU Impact Area.

8.3 OFFSITE RESIDENT FARMER

Residual radiation doses are estimated for offsite farmers presumably located downwind at the boundary of the former JPG installation approximately 1.9 mi (3 km) from the DU Impact Area. The farm family is assumed to raise all crops and livestock for consumption with minimal quantities of commercial food products. In addition, the family is assumed to live near Big Creek and to take water from a surface water body downstream from the DU Impact Area on JPG. Pathways included in the dose estimate include:

- External exposure to DU in soil deposited by flooding
- Inhalation of fugitive dust containing DU blowing in from JPG

- Ingestion of crops, meat and milk from livestock raised on soils contaminated by fugitive dust deposition
- Incidental of fish from stream or pond contaminated by DU leaching through soil and transporting from JPG
- Use of surface water downstream from JPG for irrigation of crops and consumption by livestock used for the production of milk and meat
- Incidental ingestion of DU contaminated soil
- Use of drinking water that contains DU from JPG.

As detailed in Section 4 and Appendix C, the critical group under circumstances such that institutional controls function as designed are the industrial workers. This worker is projected to receive a dose of about 5.9 mrem/y in the event of the loss of institutional controls and a proportionately lower dose with institutional controls in place. The other potential critical groups conservatively estimated with institutional controls in place (i.e., the sportsman/recreationist and offsite farmer) would receive doses of 3.3 and 0.33 mrem/y, respectively, in the event of the loss of institutional controls with a proportionately lower dose with institutional controls in place.

The onsite resident farmer with irrigation represents the group with the greatest potential exposure in the event that institutional controls are no longer in effect. The farmer is assumed to move onto the site after institutional controls fail and to construct a home onsite and raise crops and livestock for family consumption. Pathways included in this dose estimate include:

- External exposure to DU in soil
- Inhalation of fugitive dust containing DU
- Ingestion of crops, meat, and milk from livestock raised on DU contaminated soil
- Ingestion of fish from stream or pond contaminated by DU leaching through soil
- Incidental ingestion of DU-contaminated soil
- Ingestion of drinking water that contains DU
- Ingestion of crops, meat, and milk that have been produced with the contaminated water.

As detailed in Section 4 and Appendix C, the critical group under circumstances such that institutional controls are no longer in effect is the onsite resident farmer with assumed irrigation (i.e., insufficient water is available for farming at the DU Impact Area, so residual radioactivity [RESRAD] modeling conservatively assumes that irrigation and drinking water are obtained by damming of Big Creek). The dose to the average member of the critical group is 26.3 mrem/y or about one-fourth of the 100 mrem/y criteria specified in 10 CFR 20.1403 for restricted release and not statistically different from the 25 mrem/y limit prescribed by 10 CFR 20.1402 for unrestricted release.

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APPENDIX D

DISTRIBUTION COEFFICIENT (K_d) STUDY REPORT

**Depleted Uranium Impact Area
Jefferson Proving Ground, Madison, Indiana**

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TABLE OF CONTENTS

	Page
1. INTRODUCTION	1-1
1.1 SITE HISTORY	1-4
1.2 OBJECTIVES AND APPROACH	1-5
1.3 REPORT ORGANIZATION	1-5
2. BACKGROUND	2-1
2.1 URANIUM AND DU	2-1
2.2 CONCEPTUAL SITE MODEL	2-2
2.3 DISTRIBUTION COEFFICIENT AND URANIUM PARTITIONING	2-7
3. DISTRIBUTION COEFFICIENT STUDY DESIGN	3-1
3.1 K_d STUDY DESIGN MILESTONES	3-1
3.2 SOIL SAMPLE SELECTION	3-3
3.3 CONTACT SOLUTION IDENTIFICATION	3-5
3.4 SOIL AND CONTACT SOLUTION CHARACTERIZATION	3-7
3.5 K_d STUDY BATCH METHOD	3-9
4. SAMPLE LOCATION AND COLLECTION METHODS	4-1
4.1 GAMMA WALKOVER SURVEY	4-1
4.2 PENETRATOR DESORPTION-DISSOLUTION SOIL SAMPLES	4-1
4.3 BACKGROUND SOIL SAMPLES	4-3
4.4 GLACIAL TILL SAMPLES	4-3
4.5 RAINWATER CONTACT SOLUTION SAMPLE	4-5
4.6 GROUNDWATER CONTACT SOLUTION SAMPLE	4-6
5. LABORATORY ANALYTICAL METHODS	5-1
5.1 SOIL AND CONTACT SOLUTION CHARACTERIZATION	5-1
5.2 LABORATORY BATCH METHOD FOR DETERMINATION OF URANIUM K_d	5-1
5.3 STANDARD SELECTION AND SPIKE CONCENTRATION RANGE	5-4
5.4 ACID RINSATE BOTTLE BLANKS	5-5
5.5 DATA QUALITY ASSESSMENT	5-6
6. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL, TILL, AND CONTACT SOLUTIONS	6-1
6.1 SOIL CHARACTERISTICS	6-1
6.1.1 Soil Texture	6-1
6.1.2 Loess and Till Mineralogy	6-3
6.1.3 Soil Quality	6-4
6.1.3.1 Total Uranium	6-4
6.1.3.2 Nonradiological Characteristics	6-6
6.2 RAINWATER CHARACTERISTICS	6-11
6.2.1 Radiological Parameters	6-12
6.2.2 Nonradiological Parameters	6-12
6.3 WELL JP-DU-06O GROUNDWATER QUALITY	6-13
6.3.1 Radiological Parameters	6-14
6.3.2 Nonradiological Parameters	6-14
6.3.2.1 JPG-DU-06O March 2012 Groundwater Chemistry	6-14
6.3.2.2 March 2012 Relative to Historical Groundwater Quality in JP-DU-06O	6-15

TABLE OF CONTENTS (Continued)

	Page
6.3.2.3 Well JP-DU-06O Groundwater Quality Relative to General Overburden Groundwater Quality	6-18
6.3.2.4 Well JPG-DU-06O Water Quality Compared to Rainwater Quality	6-20
7. K_d STUDY RESULTS.....	7-1
7.1 BATCH TEST EQUILIBRATION, TERMINATION, AND INITIAL K _d VALUE DETERMINATION.....	7-1
7.2 BOTTLEWARE URANIUM PLATING EVALUATION.....	7-4
7.3 FINAL PLATING CORRECTED K _d VALUES	7-5
7.3.1 Plating Correction Method.....	7-5
7.3.2 Loess Soils Final Plating Corrected K _d Values	7-8
7.3.3 Glacial Till Final Plating Corrected K _d Values	7-9
7.3.4 Desorption-Dissolution Final Plating Corrected K _d Values	7-10
7.3.5 Corrected Final K _d Value Summary	7-10
7.4 CONTACT SOLUTION pH AND K _d VALUES	7-11
7.5 CALCULATED AND LABORATORY MEASURED URANIUM MASS BALANCE EVALUATION.....	7-16
7.6 URANIUM ISOTOPE DISTRIBUTION	7-19
8. BIOGEOCHEMICAL CONTROLS ON K_d STUDY OUTCOME AND DU PARTITIONING AT JPG	8-1
8.1 SOIL MATRIX CLAY MINERALS, IRON AND MANGANESE OXIDES, AND ORGANIC CARBON.....	8-2
8.2 SOLUTION pH.....	8-4
8.3 SOLUTION ALKALINITY AND IONIC STRENGTH.....	8-5
8.4 OXIDATION REDUCTION POTENTIAL AND MICROBE CATALYZED URANIUM REACTIONS	8-5
8.5 DISSOLVED URANIUM CONCENTRATION	8-7
8.6 COLLOIDAL TRANSPORT OF URANIUM	8-8
8.7 MACROPORES AND BIOTURBATION	8-8
8.8 PLANT UPTAKE OF URANIUM.....	8-9
8.9 ADSORPTION AND DESORPTION-DISSOLUTION KINETICS	8-10
8.10 ENVIRONMENTAL FATE OF DU AT JPG	8-12
9. K_d VALUE RECOMMENDATIONS FOR DU IMPACT AREA.....	9-1
10. REFERENCES	10-1
 ATTACHMENT BATCH SAMPLE K_d VALUE CALCULATION SUMMARY AND INDIVIDUAL BATCH SAMPLE CALCULATION DATA SHEETS	

LIST OF FIGURES

	Page
Figure 1-1 Regional Location of Jefferson Proving Ground	1-2
Figure 1-2 Jefferson Proving Ground and Depleted Uranium Area.....	1-3
Figure 2-1 Working Conceptual Site Model of the DU Impact Area Hydrogeology.....	2-3
Figure 2-2 Example Soil Density Profile through Loess Soil and Glacial Till at Well Location JP-DU-06	2-5
Figure 3-1 Soil Sample Locations for K_d and Desorption-Dissolution Testing	3-6
Figure 3-2 JPG Monitoring Well Location Map	3-8
Figure 4-1 2008 Gamma Walkover Survey Results	4-2
Figure 4-2 Rainwater Collection Station	4-5
Figure 6-1 Particle Size Comparison of JPG Soil Types.....	6-3
Figure 6-2 Average Iron, Manganese, and TOC Concentration Comparison of JPG Soil Types	6-8
Figure 6-3 Average pH, CEC, and Total Uranium Comparison of JPG Soil Types	6-8
Figure 6-4 Correlation of Total Uranium and Iron in Background Soils and Glacial Till	6-9
Figure 6-5 Correlation of Total Uranium and Manganese in Background Soils and Glacial Till.....	6-10
Figure 6-6 Correlation of Total DU in Soils Beneath Penetrators and Soil pH.....	6-10
Figure 6-7 Correlation of Total DU in Soils Beneath Penetrators and CEC	6-11
Figure 6-8 Correlation of Total DU in Soils Beneath Penetrators and TOC	6-11
Figure 6-9 Stiff Diagram for Rainwater	6-13
Figure 6-10 JPG-DU-06O March 2012 Groundwater Chemistry	6-16
Figure 6-11 JPG-DU-06O April 2008 Groundwater Chemistry	6-16
Figure 6-12 JPG-DU-06O July 2008 Groundwater Chemistry	6-17
Figure 6-13 JPG-DU-06O October 2008 Groundwater Chemistry	6-17
Figure 6-14 JPG-DU-06O February 2009 Groundwater Chemistry	6-18
Figure 6-15 JPG-DU-06O Groundwater Chemistry – Piper Diagram	6-19
Figure 6-16 JPG-DU-06O Groundwater Chemistry Relative to Overburden Groundwater Quality	6-19
Figure 6-17 Combined Stiff Diagrams for March 2012 JPG-DU-06O Groundwater and Rainwater	6-21
Figure 6-18 JPG-DU-06O Groundwater and Rainwater March 2012.....	6-22
Figure 7-1 Loess Soil Contact Solution Uranium Concentration Versus K_d Value	7-3
Figure 7-2 Acid Rinsate Blank Total Uranium Concentrations Over Time and Average Values Used in K_d Value Correction	7-6
Figure 7-3 Correlation of Uranium Plating Correction Factor Versus Original K_d Value	7-8
Figure 7-4 Avonburg-Cobbsfork Soil Contact Solution Extract pH Over Time.....	7-13
Figure 7-5 Cincinnati-Rossmoyne Soil Contact Solution Extract pH Over Time.....	7-13
Figure 7-6 Grayford-Ryker Soil Contact Solution Extract pH Over Time.....	7-14
Figure 7-7 Glacial Till Contact Solution Extract pH Over Time	7-14
Figure 7-8 Loess Soil Under Penetrator Contact Solution Extract pH Over Time.....	7-15

LIST OF FIGURES (Continued)

	Page
Figure 7-9 Correlation of Loess Soil Contact Solution Extract pH Versus Laboratory Blank pH.....	7-15
Figure 7-10 K_d Values Versus pH	7-16
Figure 7-11 Correlation of Calculated Versus Laboratory Determined Uranium Soil Mass in Loess Soils	7-18
Figure 9-1 Histogram Showing Comparison of Frequency Distributions of Plating Corrected K_d Values for Loess Soils (Sorption and Desorption-Dissolution) and Glacial Till.....	9-3
Figure 9-2 Histogram of Frequency Distribution of Lumped Plating Corrected K_d Values for Loess Soils and Glacial Till	9-3
Figure 9-3 Histogram of Frequency Distribution of Plating Corrected K_d Values for Loess Soils.....	9-4
Figure 9-4 Histogram of Frequency Distribution of Plating Corrected K_d Values for Loess Soils.....	9-4
Figure 9-5 Typical Conceptual Soil Profile Showing Variation of K_d Values for Key Locations in Loess Soils and Till	9-7

LIST OF TABLES

	Page
Table 2-1 Percent U-235 by Mass in Different Types of Uranium.....	2-1
Table 2-2 Amount of Isotope Present by Alpha Activity in Natural Uranium	2-2
Table 2-3 Relative Isotopic Activity in DU	2-2
Table 2-4 DU Impact Area Mapped Soil Series and Total Acreage	2-3
Table 2-5 Taxonomy of Soil Series Found Within the DU Impact Area.....	2-4
Table 3-1 Distribution Coefficient Study Design Basis Milestones	3-1
Table 3-2 Summary of Site-Specific K_d /Desorption-Dissolution Testing and Contact Liquid by Soil Type.....	3-4
Table 3-3 Sample Recollection Locations for K_d and Desorption-Dissolution Testing.....	3-4
Table 4-1 March 2012 Soil Sample Summary	4-1
Table 4-2 Desorption-Dissolution Test Sample Locations Under Penetrators	4-3
Table 4-3 Background Adsorption Soil Sample Locations.....	4-4
Table 4-4 Till Adsorption Soil Sample Locations.....	4-4
Table 5-1 Radiological and Nonradiological Laboratory Analytical Summary.....	5-1
Table 5-2 K_d Study Contact Solutions and Initial Spike Concentrations	5-2
Table 5-3 Laboratory Spiked Contact Solution Batch Data.....	5-3
Table 5-4 Contact Solution Contact Duration and Analytical Date Range.....	5-4
Table 5-5 Total Uranium Activity Versus Mass Concentration for Soil, Sediment, Surface Water, and Groundwater from Long-Term ERM Monitoring.....	5-5
Table 5-6 Acid Rinsate Blanks to Evaluate Uranium Plating	5-5
Table 6-1 Soil Texture Summary	6-1
Table 6-2 Soil Total/Isotopic Uranium Analysis Summary	6-5

LIST OF TABLES (Continued)

		Page
Table 6-3	Nonradiological Parameter Values	6-6
Table 6-4	Uranium Content of Rainwater	6-12
Table 6-5	Rainwater Composition	6-12
Table 6-6	Uranium Content of Groundwater Relative to Rainwater	6-14
Table 6-7	Groundwater Quality in Well JPG-DU-06O.....	6-15
Table 6-8	Well JPG-DU-06O Groundwater Quality Relative to Rainwater Quality	6-20
Table 7-1	Acid Rinsate Blank Isotopic Uranium Analytical Results.....	7-4
Table 7-2	Corrected K_d Values After Discounting Uranium Plating	7-7
Table 7-3	K_d Study Loess Soil Contact Solution Extract pH Over Time.....	7-11
Table 7-4	K_d Study Till and Loess Desorption-Dissolution Contact Solution Extract pH Over Time.....	7-12
Table 7-5	K_d Study Mass Balance Summary for Loess Soils and Glacial Till	7-17
Table 8-1	Soil and Water Geochemical Processes Affecting Uranium Mobility and Distribution	8-1
Table 8-2	Percent Decline in Extract Total Uranium Concentration from Initial Spike to Day 3 in Loess Soils in Rainwater	8-10
Table 8-3	Percent Change in Extract Total Uranium Concentration from Initial Spike to Day 3 and Test Termination in Till in Groundwater	8-11
Table 8-4	Percent Change in Extract Total Uranium Concentration from Day 3 to Test Termination in Loess Soils Beneath Penetrators	8-12
Table 8-5	DU Activity With Depth in Shallow Loess Soils	8-15
Table 9-1	Summary of DU Batch Testing Plating Corrected K_d Results.....	9-2
Table 9-2	Soil Type and Group Acreage Across DU Impact Area.....	9-5
Table 9-3	DU Impact Area Soil Group Weighted Average K_d Values.....	9-6

LIST OF ACRONYMS AND ABBREVIATIONS

ac	Acre
ASTM	American Society for Testing and Materials
BGS	Below Ground Surface
BRAC	Base Realignment and Closure
CEC	Cation-Exchange Capacity
CFC	Chlorofluorocarbon
CLP	Contract Laboratory Program
cm	Centimeter
CO ₂	Carbon Dioxide
CoC	Chain-of-Custody
CSM	Conceptual Site Model
DGPS	Differential Global Positioning System
DI	Deionized
DO	Dissolved Oxygen
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DPT	Direct Push Technology
DQA	Data Quality Assessment
DU	Depleted Uranium
EE&S	Environmental Equipment & Supply
ERM	Environmental Radiation Monitoring
FSP	Field Sampling Plan
ft	Feet
g/g	Gram per Gram
gal/day/ft ²	Gallons per Day per Square Foot
GIS	Geographic Information System
gpm	Gallons per Minute
GPS	Global Positioning System
HCl	Hydrochloric Acid
HDPE	High-Density Polyethylene
I.D.	Identification
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
in	Inch
JPG	Jefferson Proving Ground
K _d	Distribution Coefficient
kg	Kilogram
km ²	Square Kilometer
lb	Pound
LCS	Laboratory Control Sample
LEU	Low Enriched Uranium
LLNL	Lawrence Livermore National Laboratory
µg	Microgram
µg/L	Microgram per Liter
µm	Micrometer
µM	Micromole
m	Meter
MDC	Minimum Detectable Concentration
MDL	Method Detection Limit
meq/100 g	Milliequivalents per 100 Grams of Soil

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

meq/kg	Milliequivalents per Kilogram
mg/kg	Milligram per Kilogram
mL/g	Milliliter per Gram
mi	Mile
mL	Milliliter
MS/MSD	Matrix Spike/Matrix Spike Duplicate
mV	Millivolt
NaI	Sodium Iodide
NRC	U.S. Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NTU	Nephelometric Turbidity Unit
ORP	Oxidation-Reduction Potential
pCi/g	PicoCuries per Gram
pCi/L	PicoCuries per Liter
PNNL	Pacific Northwest National Laboratory
PZC	Point of Zero Change
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
R ²	Correlation of Coefficient
R _d	Desorption-Dissolution Ratio
redox	Oxidation-Reduction
RESRAD	Residual Radioactivity
Rf	Retardation Factor
RPD	Relative Percent Difference
RQD	Rock Quality Determination
SAIC	Science Applications International Corporation
SDG	Sample Delivery Group
SEM-EDS	Scanning Electron Microscopy-Energy Dispersive Spectroscopy
SOP	Standard Operating Procedure
SOW	Scope of Work
SW	Solid Waste
TC	Total Carbon
TDS	Total Dissolved Solids
TEAP	Terminal Electron-Accepting Process
TestAmerica	TestAmerica Laboratories, Inc.
TOC	Total Organic Carbon
U ⁺⁴	Uranous Ion
U ⁺⁶	Uranyl Ion
U-234	Uranium-234
U-235	Uranium-235
U-238	Uranium-238
UO ₂	Uranium Dioxide
UO ₃	Uranium Trioxide
UO ₄ •nH ₂ O	Hydrated Uranous Oxide
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

UXO	Unexploded Ordnance
XPS	X-Ray Photoelectron Spectroscopy
XRD	X-Ray Diffraction

1. INTRODUCTION

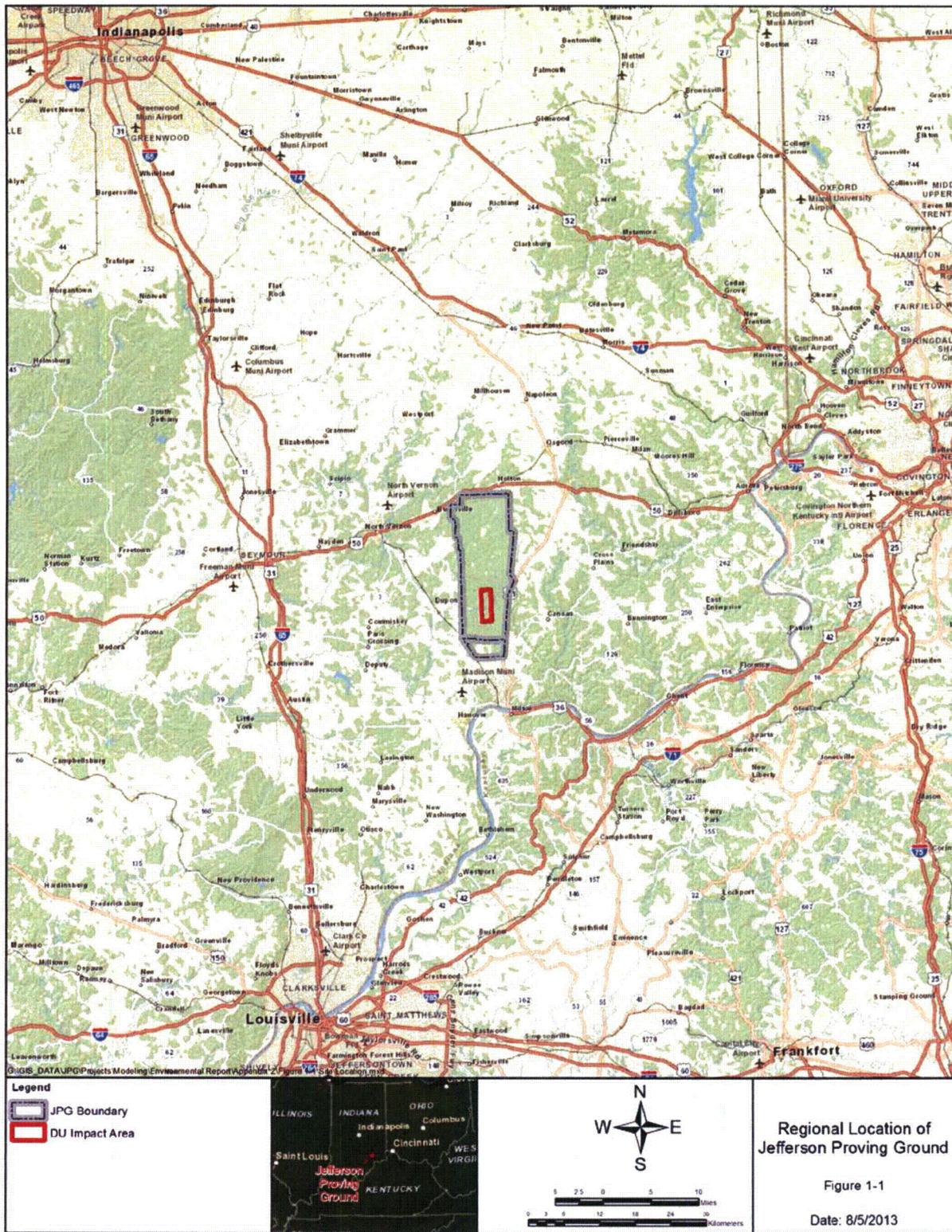
This report provides the results of the laboratory study to determine site-specific depleted uranium (DU) distribution coefficient (K_d) values for select soils and sediment in the DU Impact Area at the Jefferson Proving Ground (JPG) in Madison, Indiana (Figures 1-1 and 1-2). The DU K_d is a required parameter to enable simulation of DU transport through the environment to support the Army's Decommissioning Plan and Environmental Report, both of which are required to be submitted to the U.S. Nuclear Regulatory Commission (NRC) no later than 30 August 2013 (U.S. Army 2012). Published uranium K_d values are plentiful in the literature but only generally applicable to a specific DU site. A site-specific DU K_d for the DU Impact Area was requested by NRC in a letter dated 5 October 2004 (NRC 2004) to the Army to evaluate the residual radiation dose assessment documented in the original Decommissioning Plan (U.S. Army 2002) for the DU Impact Area.

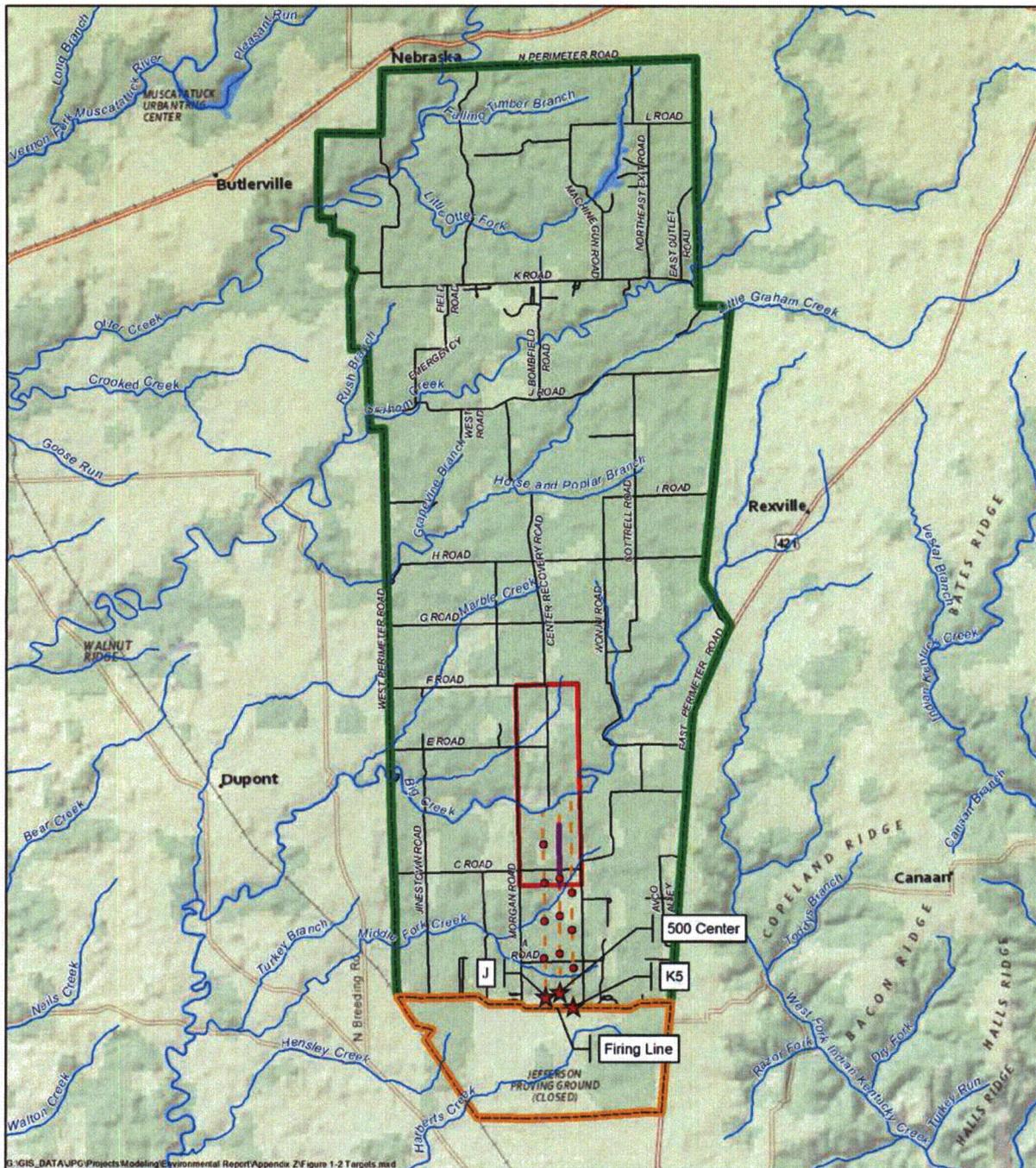
Exposure modeling conducted for the DU Impact Area includes simulating the potential migration of DU in surface water and groundwater and on sediment and the potential exposure to present and future receptors. In order to complete this modeling, various geochemical parameters or inputs to the models either must be selected from previously established literature ranges for the surface and subsurface conditions believed to be present at the site or by collecting site-specific data to estimate those geochemical parameters. The K_d is one of the geochemical parameters required by the models selected for use at JPG. Research and experience by the Army and other researchers have shown that the K_d has significant sensitivity in terms of end-point prediction of risk to receptors. An accurate assessment of K_d is critical to ensuring accurate modeling of residual radioactivity (RESRAD), particularly future doses.

The K_d value represents the degree to which a chemical will attach or partition to the geologic matrix during transport in surface water or groundwater. The K_d value is integral to accurate determination of the rate a chemical travels through geologic media relative to the rate of groundwater advection or flow and, therefore, is an important site-related input parameter for contaminant modeling. Values for K_d vary greatly between contaminants and also as a function of aqueous and solid phase chemistry and can fluctuate over six orders of magnitude because they are "a lumped parameter representing a myriad of processes" (NRC 2006). As a result, NRC encourages licensees to perform site-specific K_d determination when values could be overly conservative or under protective. Development of site-specific K_d values is also the approach recommended by the U.S. Environmental Protection Agency (USEPA) (1999).

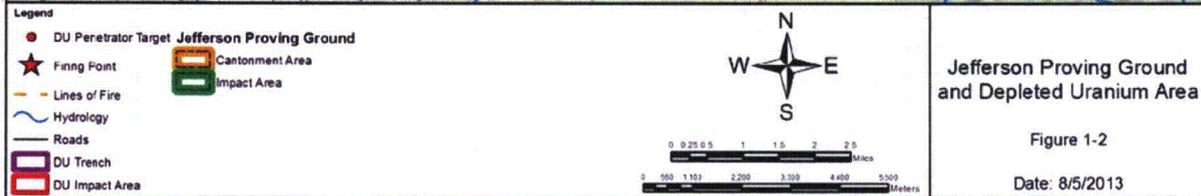
The Army agreed to research and develop site-specific K_d values for applicable geologic substrates in the DU Impact Area. The rationale and procedural basis for the Army's K_d study was developed collaboratively with NRC, culminating in a final design agreed to by NRC on 2 November 2011. The design of the study was based on the detailed understanding of the hydrogeologic setting of JPG and the methods presented in the American Society for Testing and Materials (ASTM) Method C1733-10, *Standard Test Method for Distribution Coefficients of Inorganic Species by the Batch Method* (ASTM 2010). Representative soil and aqueous contact solution samples were collected for the K_d study in late March 2012. The batch method analysis of samples over time for uranium occurred from May 2012 to February 2013.

This report presents background on the environmental fate of DU and the K_d term in general. The rationale, design, timing, and implementation of the K_d study are presented. Lastly, results of the K_d study are presented and discussed, with recommended ranges of K_d values presented for use during DU transport simulations.





B:\GIS_DATA\JPG\Projects Modeling\Environmental Report\Appendix Z\Figure 1-2 Targets.mxd



1.1 SITE HISTORY

JPG was established in 1941 as a proving ground for the production line acceptance test firing of a wide variety of conventional military munitions. The facility is approximately 55,264 contiguous acres (ac) (224 square kilometers [km²]) in size and is located in Jefferson, Jennings, and Ripley Counties in southeastern Indiana (Figure 1-1). A firing line with 268 gun positions used for testing munitions separates JPG into two areas: an approximate 4,000-ac (16.1-km²) southern portion and an approximate 51,000-ac (206-km²) northern portion (SAIC 1997). The area north of the firing line consists of undeveloped and heavily wooded land and contains the NRC-licensed DU Impact Area (approximately 2,080 ac) (SAIC 1997). The DU Impact Area is located entirely in Jefferson County.

The Army used JPG as a proving ground from 1941 to 1994. The Army test fired DU projectiles as part of its munitions acceptance testing program. DU is uranium from which some fraction of the uranium-235 (U-235) isotope has been removed and is used as a component in the manufacturing of munitions that penetrate armor plating. The possession and test firing of DU penetrators were conducted under a license issued by NRC (Materials License SUB-1435). The test firing of DU projectiles occurred between 18 March 1984 and 2 May 1994 in the DU Impact Area, which is located in the south-central area north of the firing line of JPG, as shown in Figure 1-2. Although the rounds may have fragmented upon impact, these tests were designed to be nondestructive (i.e., no aerosolization occurred) because they were not testing armor penetrating capability. No hard target testing of DU was conducted at JPG. Only accuracy testing conducted using soft cloth targets spaced at 1,000-meter (m) intervals from the three DU test firing positions.

Approximately 220,000 pounds (lb) (100,000 kilograms [kg]) of DU projectiles were fired at soft targets (i.e., nonarmored targets that are made of materials such as cloth or wood) in the 2,080-ac (8.4-km²) DU Impact Area. A total of approximately 58,400 lb (26,500 kg) of DU projectiles and projectile fragments were recovered at or near the ground surface during periodic collection events to ensure that the total 100,000-kg license limit was not exceeded. Approximately 162,000 lb (73,500 kg) of DU remain in the DU Impact Area (Personal Communication 2013).

JPG was closed in September 1995 under the Defense Authorization Amendments and Base Realignment and Closure (BRAC) Act of 1988 (Public Law 100-526). The NRC license for the DU Impact Area north of the firing line was amended for possession-only of DU in May 1996. In 2005, NRC granted a 5-year extension to the Army's license to collect site-specific data needed to support the Decommissioning Plan and Environmental Report. The license again was amended on 27 December 2012, which stipulated the following condition 13:

The Army shall submit a decommissioning plan for NRC review and approval under an alternate schedule identified in its May 25, 2005, Field Sampling Plan, its responses to action items from a September 8, 2005, public meeting by letter dated October 26, 2005; its Field Sampling Plan addendum dated November 2005 and all subsequent addendums; its responses to NRC's request for additional information by letter dated February 9, 2006; and its May 2, 2012 letter. The Army will also submit an Environmental Report using the guidance in NUREG-1748 for NRC to use in preparing an Environmental Impact Statement. The Decommissioning Plan and Environmental Report will be submitted no later than August 30, 2013.

Due to a series of comments, questions, and concerns from NRC regarding the details and specifics for conducting the K_d study at JPG, including the withdrawal of the initial analytical method (ASTM D4319-93 without explanation), the subsequent publishing by ASTM of a new K_d analytical method (C1733-10) several years later, and obtaining a new set of media (i.e., soil, groundwater, and rainwater) samples, an extension request for the submittal of the JPG Decommissioning Plan and Environmental Report was submitted to NRC on 2 May 2012. NRC issued amendment 17 to JPG's DU Materials

License SUB-1435 on 27 December 2012, granting the Army's extension request for the submittal of the Decommissioning Plan and Environmental Report with a submittal date of not later than 30 August 2013. Additional details are provided in Section 3.1.

1.2 OBJECTIVES AND APPROACH

The primary objective of this study was to determine at a laboratory bench-scale the site-specific K_d values for DU for applicable geologic media where DU resides and where DU will potentially migrate over time to support accurate computer simulation of DU transport through the environment to potential environmental and human receptors. A secondary objective of the K_d study was basic laboratory analysis of soil, rainwater, and groundwater geochemical characteristics for evaluation of the geochemical processes controlling DU partitioning to better understand the potential magnitude and rate of DU partitioning throughout the DU Impact Area.

The basic approach to achieving the above-stated objectives was as follows:

- Review of the DU Impact Area conceptual site model (CSM) for: 1) identification of DU penetrator occurrence and distribution, and 2) identification of the surface water and groundwater flow paths and geologic media that likely control the migration of DU.
- Development and implementation of a sampling approach to characterize DU distribution and the hydrogeology in the DU Impact Area and to characterize natural background conditions through collection of representative soil, rainwater, and groundwater samples for laboratory testing.
- Design and implementation of a laboratory testing approach for basic characterization of soil and water and specific determination of K_d values according to a recognized, industry standard method.
- Reduction and evaluation of soil and water data for calculation of K_d values and to understand baseline geochemical characteristics that controlled DU partitioning at laboratory scale and for estimation of DU partitioning at field scale.
- Review and reporting of prior uranium K_d studies by other researchers for comparison and corroboration with the results of this study for a thorough understanding of current and future probable DU environmental fate at JPG.

The methods and procedures in this report were completed in accordance with the scope of work (SOW) for "Continued Site Characterization of the Depleted Uranium Impact Area" under U.S. Army Corps of Engineers (USACE) Contract No. W912QR-08-D-0008, Delivery Order No. 0010, dated 1 January 2009.

1.3 REPORT ORGANIZATION

This report is organized as follows:

- Section 2 provides background information on DU, the CSM, K_d values, and uranium partitioning.
- Section 3 details the K_d study design, its progressive development over time, soil and contact solution selection and analysis, and an overview of the ASTM K_d batch method and the limitations of laboratory scale approximation of K_d values.
- Section 4 presents sample location and collection methods.
- Section 5 presents the laboratory analytical methods.

- Section 6 reviews the physical and chemical characteristics of the site-specific determined soil, glacial till, rainwater, and groundwater contact solutions.
- Section 7 presents the K_d study plating corrected K_d values.
- Section 8 discusses biogeochemical controls on K_d study outcome and DU partitioning in general in the DU Impact Area.
- Section 9 provides the recommended ranges of K_d values to further refine in DU transport modeling.
- Section 10 includes all of the references cited in this document.

2. BACKGROUND

This section presents background information relevant to understanding the design, execution, and interpretation of the K_d study. Background regarding the occurrence and speciation of uranium and DU is presented first. This is followed by a review of pertinent elements of the CSM presented in detail in Appendix C of the Environmental Report. Lastly, background regarding the K_d parameter and the environmental fate of uranium and DU are presented to aid understanding of the interpretation of the K_d study.

2.1 URANIUM AND DU

Uranium is a naturally occurring metal that can be found throughout the environment in rocks, soil, water, plants, and animals. Natural uranium has three primary isotopes (forms): uranium-234 (U-234), uranium-235 (U-235), and uranium-238 (U-238). U-235 and U-238 are the two most abundant isotopes in terms of mass. U-234 is formed during the natural radioactive decay of U-238. Naturally occurring uranium consists of approximately 99.27 percent U-238, approximately 0.72 percent U-235, and approximately 0.0055 percent U-234 (Royal Society 2001). Humans and wildlife are exposed to natural uranium on a daily basis both in soil and in their food and water (Royal Society 2002). As a result, humans ingest approximately 2 micrograms (μg) of natural uranium each day in food and fluids. A similar quantity is excreted each day in the feces and urine (DOE 2009). This presents a uranium balance in which uranium is always present in the tissues.

A modified form of uranium metal can be used as fuel in nuclear power plants. For use as a nuclear fuel, it is necessary to have uranium with a higher content of U-235; therefore, uranium undergoes an enrichment process to convert natural uranium into low enriched uranium (LEU). DU is defined by NRC as "...uranium with a percentage of U-235 lower than the 0.7 percent (by mass) contained in natural uranium." DU is created as a byproduct of the uranium enrichment process. However, because of its high density, DU can have other uses, such as radiation shielding. The military also uses DU for tank armor, armor-piercing projectiles, and counterweights in missiles and aircraft.

Although the percent by weight of U-235 can vary significantly, U.S. Department of Defense (DOD) DU generally contains approximately 0.20 percent of U-235 by mass, with the remainder of the mass being U-238 with a very small amount of U-234. The difference in U-235 content (by mass) can be used to distinguish natural uranium from DU (DOE 2009). The percent by mass of U-235 for each type of uranium is provided in Table 2-1.

**Table 2-1. Percent U-235 by Mass in Different Types of Uranium
Jefferson Proving Ground, Madison, Indiana**

Type of Uranium	Percent U-235 by Mass
Natural Uranium	0.71
DU	Approximately 0.20

Source: DOE 2009

The decay of each atom of uranium gives off radiation that, to some degree and efficiency, can be detected by laboratory and field instruments. Although each isotope of uranium (U-238, U-235, and U-234) decays at its own characteristic rate, U-234 and U-238 are generally present in about the same activity-concentration in natural uranium (i.e., are in secular equilibrium) with the activity-concentration of U-235 being about 2.3 percent of the total activity. The contributions of alpha activity for each isotope of uranium in natural uranium are provided in Table 2-2.

**Table 2-2. Amount of Isotope Present by Alpha Activity in Natural Uranium
Jefferson Proving Ground, Madison, Indiana**

Isotope	Percent
U-238	47.3
U-235	2.3
U-234	50.4

Source: DOE 2009

Since the radiation from the radioactive decay of uranium isotopes is relatively easy to detect, the levels of activity in a sample can be used to determine the relative amounts of the individual isotopes in the sample. In other words, the activity values of the uranium isotopes are used to determine the amounts of the uranium isotopes present, and hence the levels of enrichment.

When uranium is enriched, the level of U-235 is increased in the product. As the mass of the U-234 atom is both very close to and lower than the mass of the U-235 atom, the levels of U-234 also are increased in LEU resulting in lower residual U-234 in DU. Given that the enrichment process results in the preferential removal of U-234 and U-235, DU exhibits roughly 60 percent of the alpha radiation as naturally occurring uranium (U.S. Army 1995). The contributions for each isotope by activity of uranium in DU are provided in Table 2-3.

**Table 2-3. Relative Isotopic Activity in DU
Jefferson Proving Ground, Madison, Indiana**

Isotope	Percent
U-238	84.7
U-235	1.1
U-234	14.2

Source: WISE 2006

Because natural uranium and DU are identical except for their isotopic composition (percentage of U-234, U-235, and U-238), their chemical characteristics are the same. Thus, their biochemical action and fate in the environment are the same (Royal Society 2001 and 2002).

The radioactive decay of DU results in the emission of alpha particles along with beta particles and gamma photons. Alpha particles taken internally deposit relatively large amounts of energy in comparatively small volumes of tissue and are, therefore, more biologically harmful than beta particles or gamma rays if taken into the body. By contrast, alpha particles, which are located outside the body, cannot penetrate the outer dead layer of the skin and do not, therefore, constitute an external hazard. In large quantities, beta particles located outside the body can damage skin cells and underlying tissues as well as tissues of the eyes. Nonetheless, given the decay rates of uranium series radionuclides, uranium isotopes and their daughter products do not represent a significant external hazard. Similarly, although gamma photons are capable of penetrating internal organs, the very long decay rates of uranium and actinium decay series radionuclides together with other characteristics, such as energy and percent abundance, serve to minimize the gamma hazards associated with uranium.

2.2 CONCEPTUAL SITE MODEL

The DU Impact Area is within the Muscatatuck Plateau physiographic region and is characterized by broad uplands covered by glacial till with entrenched valleys (Gray 2000). The glacial deposits overlie Paleozoic bedrock consisting of interbedded limestone, dolomite, and shale, and overburden thicknesses based on previously installed groundwater monitoring wells range from 10 to greater than 65 feet (ft)

thick (U.S. Army 2002) (Figure 2-1). According to Franzmeier, Steinhardt, and Schulze (2004), the glacial till is pre-Wisconsinan age and thought to be Illinoian age or older and is covered with a thick (>6-ft-thick) mantle of Wisconsinan age loess, or wind-deposited silt.

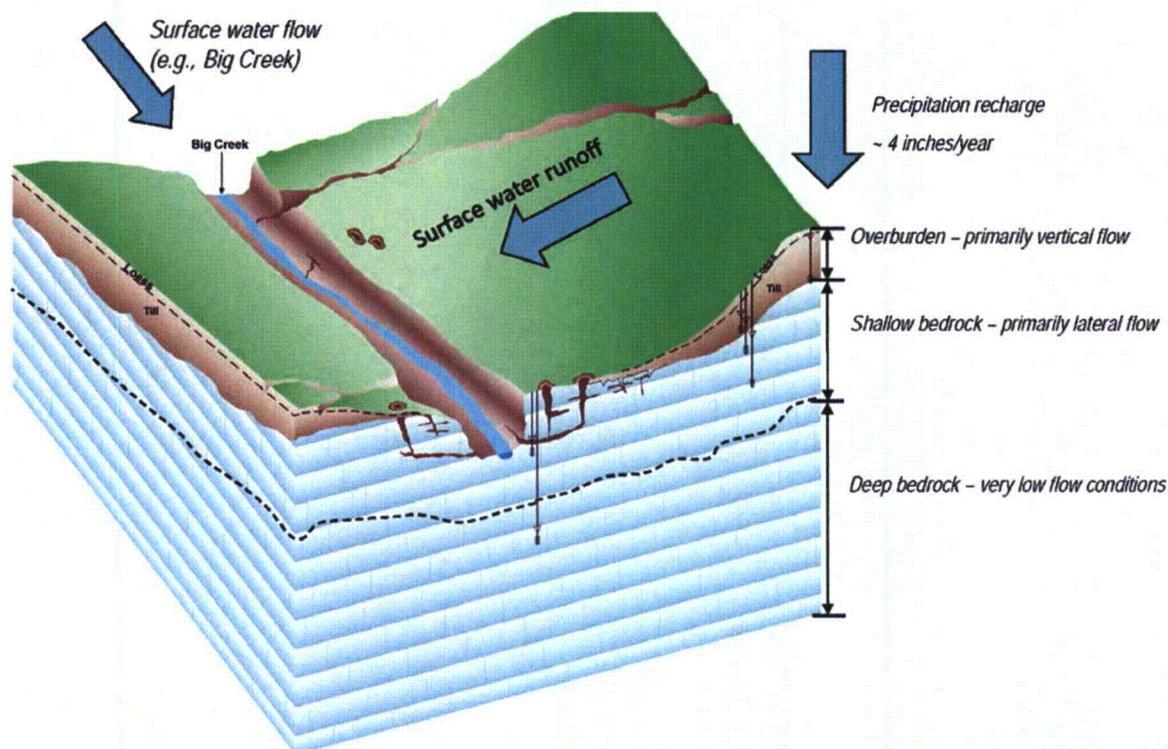


Figure 2-1. Working Conceptual Site Model of the DU Impact Area Hydrogeology

The DU Impact Area is a broad loess-covered till plain incised by two streams: Middle Fork Creek and Big Creek and associated tributaries. Soils that encompass the DU Impact Area are described as “moderately thick loess over weathered loamy glacial till” (USDA NRCS 1999). From the review of available soil data, the following soil series are mapped in the DU Impact Area: Avonburg, Cincinnati, Cobbsfork, Grayford, Holton, Rossmoyne, and Ryker. Table 2-4 lists the respective soil series in the DU Impact Area, their approximate total acreage, and respective percentages of total acreage. Taxonomic descriptions of each soil series are listed in Table 2-5.

**Table 2-4. DU Impact Area Mapped Soil Series and Total Acreage
Jefferson Proving Ground, Madison, Indiana**

Soil Series	Total Acreage as Mapped*	Percent of Total Acres
Avonburg	311.97	14.8
Cincinnati	409.12	19.4
Cobbsfork	861.47	40.7
Grayford	144.81	6.8
Holton	36.22	1.7
Rossmoyne	259.85	12.3
Ryker	90.8	4.3

* Mapped by NRCS within the DU Impact Area/SSURGO data base (USDA NRCS 2005)

**Table 2-5. Taxonomy of Soil Series Found Within the DU Impact Area
Jefferson Proving Ground, Madison, Indiana**

Soil Series	Taxonomic Classification*
Avonburg	Fine-silty, mixed, active, mesic Aeric Fragic Glossaqualf
Cincinnati	Fine-silty, mixed, active, mesic Oxyaquic Fragiudalf
Cobbsfork	Fine-silty, mixed, active, mesic Fragic Glossaqualf
Grayford	Fine-silty, mixed, active, mesic Ultic Hapludalf
Holton	Coarse-loamy, mixed, active, nonacidic, mesic, Aeric Endoaquept
Rossmoynne	Fine-silty, mixed, superactive, mesic Aquic Fragiudalf
Ryker	Fine-silty, mixed, active, mesic Typic Paleudalf

* Information derived from Soil Survey Staff, NRCS Official Soil Series Descriptions (NRCS OSD 2006)

The total acreage of each soil series mapped by the Natural Resources Conservation Service (NRCS) was measured using a geographic information system (GIS). The measurements indicate that the majority (>40 percent) of soil mapped is the poorly drained Cobbsfork series. Loess-derived soils extend to depths of 9 to 12 ft below ground surface (BGS) and are characterized by moderate to poorly drained, fine- to very fine-grained loams (Table 2-5).

Three principal hydrostratigraphic layers have been identified in the DU Impact Area and consist of the following:

- “Overburden” or saturated till
- “Shallow” bedrock consisting of the upper 40 to 60 ft of bedrock
- “Deep” bedrock below depths of 40 to 60 ft.

The overburden hydrostratigraphic layer ranges in thickness from several to 72 ft in one location in the DU Impact Area, with an average thickness on the order of 25 ft in the inter stream divides. As indicated above in the soils description, loess-derived soils extend to depths of 9 to 12 ft BGS, where soil density increases markedly based on the number of hammer blow repetitions required to advance split barrel samplers. Figure 2-2 presents a typical soil density profile developed from data collected at the well cluster JP-DU-06 location (Figure 3-2) that was sampled for contact solution (i.e., groundwater for contact liquid) for the K_d study. The profile illustrates the change in soil density in the 9- to 12-ft range and the relationship to groundwater occurrence and bedrock. Coupled with the increased density is the occurrence of gravel (chert and limestone fragments) at approximately 5 to 15 percent of the till textural composition, with the assemblage characteristic of the pre-Wisconsinan till that underlies the loess and overlies bedrock (Franzmeier, Steinhardt, and Schulze 2004).

The till is variably saturated in the lower 10 to 20 ft above bedrock, with wells completed in the till typically having low yield (<1 to 2 gallons per minute [gpm]). Permeability testing of several overburden wells indicated moderate till hydraulic conductivities, ranging from 0.00093 to 5.7 gallons per day per square foot (gal/day/ft²), for an average of 3.27 gal/day/ft² (SAIC 2010). The U.S. Geological Survey (USGS) implemented a groundwater age dating study and found the groundwater to be decades old (USGS 2010). Chlorofluorocarbon (CFC) and tritium-based age dates of groundwater in the till suggest a mix of typically post-1960 to 1980 age recharge that “mixes” with older recharge from less permeable or less interconnected strata in the till. Groundwater flow directions in the till generally follow surface topography with groundwater flow in the DU Impact Area off of the inter stream divides toward Big Creek and Middle Fork Creek under hydraulic gradients in the range of 0.005 to 0.04 (SAIC 2010). USGS has investigated groundwater flow rates at JPG and have found flow directions locally divergent from regional trends inferred from monitoring wells, owing to locally complex fracturing.

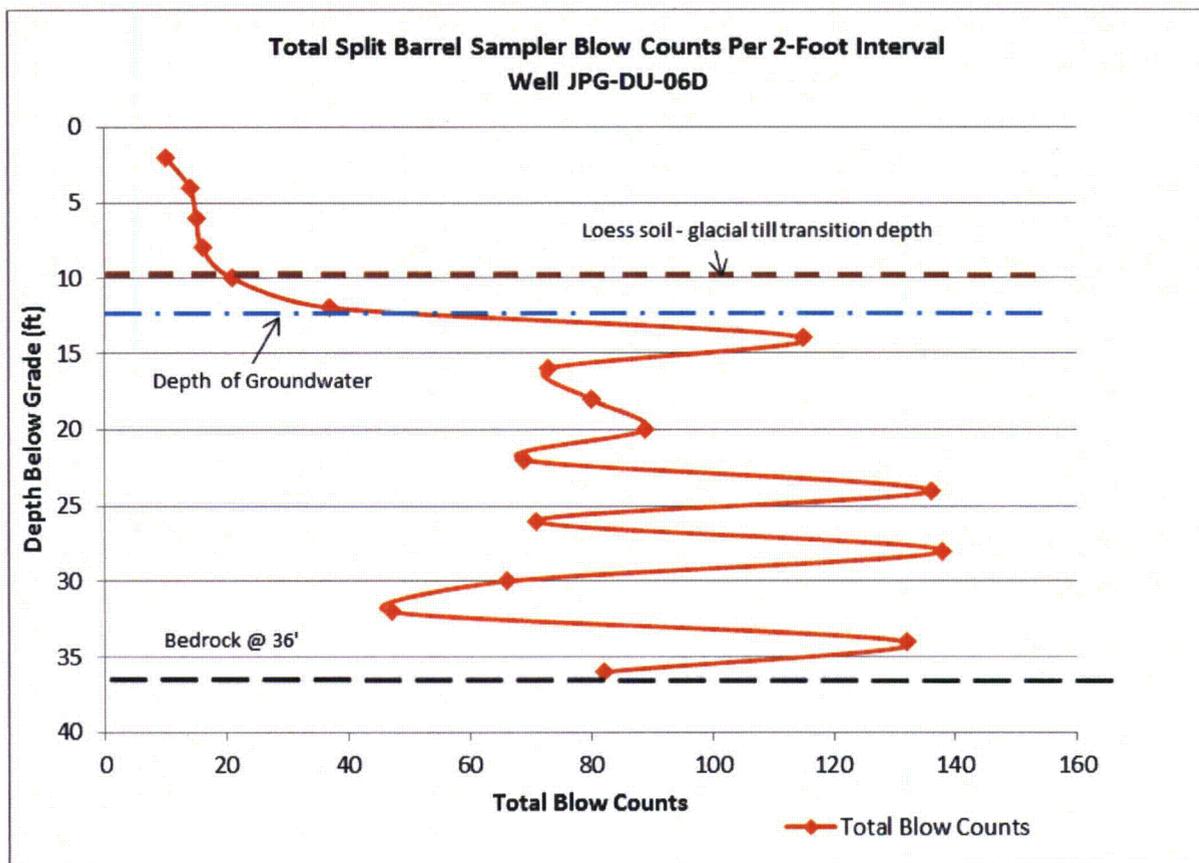


Figure 2-2. Example Soil Density Profile through Loess Soil and Glacial Till at Well Location JP-DU-06

The shallow bedrock zone consists of the top 40 to 60 ft of the carbonate bedrock. Generally, the bedrock encountered consisted of nearly horizontally bedded limestone, shaly interbedded limestone, dolostone, and shaly interbedded dolostone. As evident from the observations from the well installations and from the logs for the existing monitoring wells, there is limited secondary porosity consisting of weathering near the bedrock surface, fractures, and very limited solution features (Figure 2-1). In addition, there was very little evidence of weathering along observed fracture surfaces. The amount and severity of the fractures generally decreased with depth. The only void of significance that was observed during well installation was approximately 6 inches (in) in size at a depth of 23 ft BGS in the boreholes for both JPG-DU-02I and JPG-DU-02D (Figure 3-2).

Karst features have been observed at JPG in the shallow bedrock hydrostratigraphic layer only and specifically within the DU Impact Area consisting of surface expressions of sinkholes, caves along Big Creek, and weathered jointing (fracturing) of bedrock observed at outcrops along Big Creek (Figure 2-1). Karst development and the presence of a karst controlled groundwater flow network appears to be limited to within the narrow erosional plain along Big Creek and offsite along lower sections of Middle Fork Creek. Observations by Science Applications International Corporation (SAIC) soil scientists and geologists indicate no sinkholes or closed depressions in the elevated areas above this plain. Sheldon (1997) reported on extensive field reconnaissance work completed from January 1994 to April 1997 in and surrounding the DU Impact Area, in which caves, sinkholes, and karst features were recorded and catalogued. Sheldon's only reported, observed, and documented cave locations within the DU Impact Area were only along Big Creek (Sheldon 1997). The observations of karst features and weathering

onsite concur with the following statements by Herring (2004) “the majority of sinkholes or depressions occur along the larger stream valleys (especially Big Creek),” “water well records...indicate a few feet of crevices, broken limestone, or mud seams within the limestone bedrock, generally at depths less than 50 ft below land surface” and “The Silurian carbonates...show limited karst development in Jefferson County. These rocks contain thinner limestones and more layers of shale, conditions that significantly limit karst development.” As mentioned above, of all the wells installed, only a single very minor solution feature was observed in each of the borings at the JPG-DU-02 well pair location (along Big Creek) during the well installation. The solution feature was located at 23 to 23.5 ft BGS. The absence of karst/weathered conditions in 19 borings cored in 10 locations that were expected to be preferentially developed demonstrates that karst weathering is not a predominant feature onsite.

Permeability testing of shallow bedrock wells resulted in calculated hydraulic conductivities on the order of 3.7 to 23.2 gal/day/ft² for an average of 6 gal/day/ft². These hydraulic conductivities indicate the shallow bedrock is slightly more permeable than the till, yet in the low range for karst carbonate terrain (Freeze and Cherry 1979).

The deep bedrock zone consists of the bedrock below the shallow bedrock zone (i.e., below 40 to 60 ft BGS). The bedrock in the deep zone consisted generally of the same bedrock types of the shallow bedrock zone. Within the deep zone, the fractures observed were extremely limited and fresh (e.g., practically nonexistent weathering). No evidence of solution features were observed within the deep zone. The minimum rock core recovery for all of the core holes was 93.1 percent and all but two were greater than 95 percent. In the deep zone, the measured and calculated rock quality determination (RQD) was very high, indicating competent bedrock with little fracturing or weathering. The deep bedrock wells were constructed with screen intervals located within the interval that appeared to have the highest potential for permeability. After several months, a number of the deep bedrock wells were still recovering from pumping that occurred during the well development activities. Deeper bedrock permeability is lower than overburden or shallow bedrock, although remains unquantified due to the incomplete recovery of wells following development or incomplete recovery following installation of the data logger transducer/slug the night before testing. The above traits have led to a qualitative estimate of permeability for the deep bedrock on the order of 0.02 gal/day/ft², which is at the low end of published values for limestone (Freeze and Cherry 1979).

The quantitative annual water budget for the DU Impact Area developed for detailed surface and groundwater flow modeling (SAIC 2008a) indicates that the majority of the average annual 49 in of precipitation to JPG is lost either through evapotranspiration (26 in or 56 percent) or runs off (18 in or 36 percent) to local streams, leaving only approximately 4 in or 8 percent available to infiltrate to groundwater in the overburden and shallow bedrock (Figure 2-1).

DU that had been distributed on or immediately below the ground surface and/or within the surface water (streams) of the DU Impact Area as a result of the DU penetrator testing may be transported throughout the environment by several different processes (Figure 2-1). DU in the soil or surface water can be subject to physical movement by erosion (during floods and high runoff events) and these processes may cause migration and transport of DU penetrators along the ground surface and along the surface water drainage ways. Corrosion of the DU in the surface water or soil could enable soluble forms of DU to be absorbed by plants and incorporated within the plant matter for uptake by wildlife. Although vegetation may be burned as part of a management effort or unintended fires (e.g., from lightning), the levels of DU carried in smoke associated with natural vegetation (such as the controlled burns at JPG) are not likely significant (Williams et al. 1998, U.S. Army 2001). Leached DU from the penetrators and/or fragments in the surface water potentially could be transported to groundwater and surface water, which in turn could migrate to drinking water sources and be ingested by humans, livestock, and wildlife.

2.3 DISTRIBUTION COEFFICIENT AND URANIUM PARTITIONING

The K_d is used to determine the rate of contaminant transport relative to that of groundwater and, thus, is a very important site-related input parameter for contaminant modeling. Values for K_d vary greatly between contaminants and also as a function of aqueous and solid phase chemistry. K_d values for uranium can fluctuate over six orders of magnitude because they are “a lumped parameter representing a myriad of processes” (NRC 2006). As a result, NRC encourages licensees to perform site-specific K_d determination when values could be overly or under conservative. Development of a site-specific K_d value is also the approach recommended by USEPA (USEPA 1999).

As water migrates through geologic media, a variety of geochemical reactions occur due to the chemistry of both the pore water and solids in contact over time. These geochemical reactions can slow or retard the movement of dissolved species, like DU, through the geologic media relative to the rate at which groundwater alone may move. Research has shown the geochemical and other environmental processes that contribute to retarding the transport of chemicals, ions, metals, and the like through the environment include ion exchange, adsorption, complex formation, precipitation and coprecipitation, oxidation-reduction (redox), microbial activity, and colloid-facilitated transport (USEPA 1999, USEPA 2006, ASTM 2010). The K_d is an empirical ratio that quantifies the aggregate effect of the above processes that combine to retard contaminant migration and is defined as:

$$K_d = \frac{S}{C_w}$$

Where:

S	=	Mass of chemical species sorbed per unit mass of soil
C_w	=	Mass of chemical species per volume of solution
Common Units	=	Milliliters (mL) or cubic centimeters (cm^3) per gram (g) of solid medium; milliliters per gram (mL/g) or cm^3/g .

ASTM C1733-10 states the K_d is used “...to assess the degree to which a chemical species will be removed from solution (permanently or temporarily) as the fluid migrates through the geologic medium.” Once the K_d for a particular chemical species is determined, the K_d is used with the bulk density and porosity of the lithology of interest through which contaminant transport occurs to determine the retardation factor (R_f) of the contaminant or the degree to which soils slow the migration of the contaminant relative to the rate of groundwater flow. The R_f factor for DU will be defined further in subsequent respective surface and groundwater model appendices as it applies to each unique geologic medium and transport simulation.

Use of the K_d to evaluate the sorption of chemicals to soils assumes that rapid equilibrium is reached between the dissolved and sorbed concentrations of a chemical species, and that these two concentrations are linearly related through the K_d factor. In theory, the K_d is used to characterize the reversible adsorption of a chemical species on solid surfaces, including soil minerals and organic matter. However, other chemical processes, including mineral precipitation, diffusion into dead end pores, and attachment to microbes, can influence the experimental measurement of K_d . Although research efforts have attempted to differentiate adsorption from these other processes, there are no universally accepted standard methods for doing so. As such, K_d values presented herein represent a K_d integrated over all these possible processes rather than a strict partitioning-related K_d .

ASTM Method C1733-10 (ASTM 2010) also states the batch method is simply a measurement technique for determining chemical partitioning between liquid and solid under specific conditions for a contaminant of interest. Although better than literature values as a starting point for model simulation of

the fate of a material in the environment, laboratory-determined K_d values have limitations in the approximation of real world hydrogeochemical processes, as briefly described below.

First, the concept of partitioning or the broader umbrella of geochemical processes called distribution assumes that reactions are first-order, drive to equilibrium, and are fully reversible. Integral to these assumptions are the kinetics or rates of geochemical reactions involving the chemical(s) of interest. Under laboratory-controlled conditions, mineral and sediment surface exposure areas may be artificially increased by sample collection and laboratory preparation beyond the natural system, increasing resultant chemical reaction rates in excess of what is experienced in the large-scale system being replicated in the laboratory. In a typically heterogeneous groundwater system, whether it be a porous media flow system like the till at JPG or a fracture flow system variably enhanced by rock dissolution as in the shallow bedrock below the till, precipitation infiltrate and groundwater (i.e., collectively pore water) are moving at variable rates, or not moving at all, as in the case of dead-end pores, and geochemical conditions like pH, dissolved oxygen (DO), oxidation-reduction potential (ORP), pore water ionic strength, and alkalinity are changing spatially and over time. Under these real-world conditions, reaction kinetics may slow significantly or prevent equilibrium comparable to rates of reaction (kinetics) produced in the laboratory setting. The Army and USGS's careful and thorough investigation of JPG, as discussed above, have demonstrated great variability in geologic heterogeneity (SAIC 2008a), hydraulic conductivity (SAIC 2010), groundwater flow path tortuosity and velocity, and groundwater age (USGS 2010), indicating that uranium distribution in the DU Impact Area is highly variable and not entirely predicted by porous media flow conditions and laboratory controlled or equilibrium reaction kinetics, as discussed further in Section 7.

Clay minerals, particularly montmorillonite characteristic of loess soils and weathered tills, provide important reaction sites for uranium/DU partitioning. Clay minerals attract organic carbon within their sheet silicate structure, which in turn is conducive to uranium partitioning. The negative electrical charge that clay minerals develop on the outer edges at typical soil pH between 5.5 and 8 promotes cation exchange. Although cation exchange likely does not play an important role in the DU Impact Area because most uranium/DU complexes are negatively charged in oxic waters within this pH range, some cation exchange may occur with cationic complexes like uranyl hydroxide (USEPA 2006, 2009). Clay mineral surfaces are also important reaction sites for iron oxyhydroxide precipitation, for example goethite, which can coprecipitate with uranium to bind up the uranium in a relatively insoluble state (USEPA 1999).

Organic carbon in the soil matrix associated with clays or not, has been shown to promote uranium partitioning whereas organic carbon in pore water has been demonstrated to promote increased uranium mobility. USEPA (1999) stated at the time that partitioning to soil matrix organics, most prevalent for the uranyl ion (UO_2^{+2}), was possible via two mechanisms, one involving adsorption to humic substances via rapid ion-exchange for relatively stable complexation with acids and the other mechanism was a sedimentary organic mediated reduction of U(VI) to uranous ion (U[IV]). In contrast, pore fluids with fulvic and humic acids can form stable complexes with U^{+6} and U^{+4} , increasing the solubility and mobility of uranium.

Iron and manganese oxide minerals in a soil matrix under oxic conditions can promote uranium (uranyl) complexation preferentially over clay surfaces and solid matrix organic carbon. These uranium sinks are only marginally reversible in terms of releasing the uranium back into solution. The attraction of uranium to these oxides is influenced by carbonate and organic (fulvic and humic acids) complexants in the pore fluids. Uranium in low ionic strength solutions with low alkalinity (limited dissolved carbonate) and limited organic carbon will readily adsorb to iron and manganese oxide mineral surfaces before clay and organic surfaces described above, resulting in a higher measured K_d in an empirical study if the soil matrix is high in these oxides. However, in the presence of increasing carbonate and organic complexants in the pore water, uranium will tend to complex with the carbonate ($UO_2[CO_3]$) and organics

and adsorb to these same iron and manganese oxide surfaces less and less to the point where uranium adsorption is essentially prevented (USEPA 1999, Krupka and Serne 2002).

Pore water characteristics that research has shown affect uranium partitioning, in addition to carbonate and organic substrates as mentioned above, principally include pH, ionic strength, oxidation state controlled mineral precipitation and coprecipitation, and the dissolved concentration of uranium itself (USEPA 1999). Pore water pH has a significant effect on uranium adsorption. Empirical estimates of uranium K_d can vary over four orders of magnitude between pH from 3 to 10, with highest estimates in pore fluids with a pH of approximately 6. In carbonate solutions with a pH of 3 or less, uranyl is most stable as a cation (UO_2^{2+}). Because most host clay and mineral surface exchange sites have a net positive charge at low pH, cation exchange does not occur. As solution pH increases, clay mineral and oxide surface polarity changes to net negative values, which promote cation (e.g., U^{+6} and complexes) exchange. As solution pH increases above 8, uranium is more stable as uranium carbonate anion ($UO_2(CO_3)_3^{4-}$) and is therefore incompatible with the net negative polarity of most exchange sites, preferring to remain in solution.

Pore water ionic strength might be second only to pH in controlling dissolved uranium partitioning. The lower the ionic strength of pore fluids, the greater the potential for uranium partitioning to the variety of solid matrix exchange or partitioning surfaces mentioned above. Fewer ions in solution present less competition to uranium for exchange sites. As the ionic strength of a solution increases, the presence of other cations, like calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+), out compete uranyl ions for exchange sites, forcing it into solution and increasing its mobility. In addition, complexation of uranium to donor groups is very important and might be less sensitive to ionic strength. In this case, increased occurrence of Ca^{2+} and Mg^{2+} can interfere with uranium sorption through the formation of calcium and magnesium carbonate complexes [$Ca/Mg UO_2(CO_3)_3$] that are less sorptive.

Abiotic and biotic mediated precipitation or co-precipitation of uranium is an important process affecting mobility and is directly controlled by pore water ORP and chemistry. Uranium can form mineral precipitates with very slight changes in oxidation state. In an oxidizing setting, near a source of uranium, like a penetrator in shallow soils, where pore water may be temporarily elevated in dissolved uranyl concentration following a precipitation event and the influx of infiltrate, passing of the wetting front and the resultant decrease in pore water volume may concentrate uranium to its solubility limit for the given temperature and pressure of the pore fluid, thereby promoting precipitation of uranium (VI) minerals like schoepite and carnotite. In anoxic or reducing waters, or in micro-reducing zones associated with organic particles in an otherwise oxidizing system, uranyl in solution will be reduced to U^{+4} and precipitated as uranium (IV) minerals like uraninite and coffinite. A special case of uranium precipitation can occur under reducing conditions and the presence of certain anaerobic microbes like *Geobacter*. Once these minerals form, the subsequent dissolution of these minerals under a reversed oxidation state is understood to be slow.

Research has shown the dissolved concentration of uranium itself can influence the degree to which it will partition, with partitioning declining in most oxic water settings as the concentration increases (USEPA 1999). Under toxic conditions with a pH of 5 or higher, as uranyl dissolved in water increases in concentration, the potential increases for uranyl to complex and form more polynuclear species than at lower concentrations. These complexes keep uranium in solution, increasing its mobility and lowering its affinity to partitioning (PNNL 2002).

The role of naturally occurring microbes in catalyzing uranium oxidation and reduction is increasingly more apparent from continuing research in uranium mining applications and groundwater remediation (Finneran et al. 2002). Research suggests that in certain geochemical settings, microbes may be a dominant contributor in controlling the fate or mobility of uranium in the environment. Microbial mediated processes in a batch experiment like this K_d study could artificially influence the outcome of derived K_d values if sample container conditions were to deviate from field conditions.

Lastly, uranium bound to colloids, consisting of clay mineral particles, nanoscale precipitated secondary minerals like aluminosilicates or siderite, and organic nanoparticles, can undergo facilitated transport, depending on the oxidation state of the system, in either porous media or fracture/conduit flow (USEPA 1999, USEPA 2006, Zanker et al. 2007). Colloids can influence the mobility of uranium independent of the prevailing geochemical conditions of the geologic system at the time.

It is recognized that the processes of sample collection and preparation can influence the characteristics of the sample set relative to the large-scale system and potentially contribute to empirically derived K_d values that may differ from the actual system. Collection and preparation of soil samples can break down soil structure, reorganize grain size stratification, affect mineral surface exposure, and not comprehensively capture all pore fluid flow paths, as discussed further in Section 8. Care must be taken to ensure water samples collected from monitoring wells represent actual groundwater in the system of interest and more importantly contaminant pathway(s) and geochemical parameters like pH, ORP, DO, and temperature remain stable and representative of actual groundwater system conditions. All samples for this K_d study were collected in accordance with USEPA and industry standard and acceptable best practices, as detailed in Section 4.

In summary, numerous hydrogeochemical factors combine with sample collection practices and laboratory-scale methods to influence the final outcome of any site-specific K_d determination or study. The above governing and contributing controls on the outcome of K_d determination were taken into account in the design, execution, and analysis of results of the K_d study, to the extent feasible. This includes discussion of the above factors through direct or indirect measure, or through applicable corollary research where the direct or indirect measure of the influence of a particular geochemical factor was beyond the reasonable scope of this study. Indeed, each of the above geochemical influences on uranium partitioning has been studied in detail, individually to ensure isolation of the process and measurement of its direct effect on uranium partitioning and mobility. To isolate and test each of the above individual factors and its influence on the resultant K_d values represented an ideal that could not be approached practically.

3. DISTRIBUTION COEFFICIENT STUDY DESIGN

The K_d study design was a collaboration between the Army and NRC early on, undertaken with their concurrent knowledge of the significant role that partitioning plays in controlling contaminant migration through the environment, the broad range of K_d values for DU predetermined elsewhere in the literature, and the inherent sensitivity of partitioning in any type of contaminant migration simulation. The K_d study design was influenced and progressively modified by the CSM, which was further refined via additional site characterization over the same time period. Representation of the glacial till hydrostratigraphic layer in the final K_d study was a consequence of CSM refinement. The final design was influenced by changes in K_d determination methods and resultant testing protocols established, rescinded, and re-established by ASTM in 2008 and 2010. Environmental sample holding times, rainwater contact solution geochemistry, and laboratory glassware influence on uranium were contributing factors influencing changes in the final design. Progressive development of the K_d study design resulted in two phases of subject soil and leachant sample collection in October 2008 and December 2009, without use, before a final set of samples from approved locations and media was collected in March 2012 for use in the final K_d study.

3.1 K_d STUDY DESIGN MILESTONES

Provided below is an identification and brief review of the principal K_d study design points of collaboration or milestones, from initiation of design conceptualization in 2005 (NRC 2004, SAIC 2004 and 2005) through the final design implemented in 2012, which shaped the scope and timing of the final K_d study. The sections that follow this review focus on specific components of the final design implemented in 2012, which determined the starting point for K_d values for the various DU environmental fate simulations.

The K_d study design was developed and communicated between the Army and NRC via the principal deliverables identified and summarized in Table 3-1.

**Table 3-1. Distribution Coefficient Study Design Basis Milestones
Jefferson Proving Ground, Madison, Indiana**

Date	Document	Stakeholders	Concern/Response
8 September 2004	Technical Memorandum	SAIC to Army and NRC	Army identifies key site-specific data to enhance the accuracy and reliability of RESRAD modeling of the DU Impact Area.
5 October 2004	Letter	NRC to Army	NRC confirms offsite transport models should be validated with site-specific transport parameters, not literature values.
4 January 2005	Technical Memorandum	SAIC to Army and NRC	Army identifies the four parameters that affect RESRAD outputs most significantly: extent and concentration of DU, thickness of contaminated zone, DU distribution coefficient, and DU penetrator corrosion and solubility rates.
January 2008	FSP Addendum 5	Army to NRC	Army details the soil, sediment, surface water, and groundwater sampling procedures; sampling handling; and data QA procedures to characterize JPG.
October 2008	FSP Addendum 7 – Revised Final	Army to NRC	Army initial proposed K_d study design detailing background soil and contact solution (rainwater) collection locations and methods, scope of laboratory analysis (characterization and K_d -specific), and use of TestAmerica SOP based on withdrawn ASTM short-term batch method for K_d determination (ASTM D4319-93).
6 November 2008	Letter	Army to NRC	Army transmittal of TestAmerica SOP for batch testing for K_d determination based on ASTM Method D4319-93.

**Table 3-1. Distribution Coefficient Study Design Basis Milestones
Jefferson Proving Ground, Madison, Indiana (Continued)**

Date	Document	Stakeholders	Concern/Response
23 July 2009	Letter	Army to NRC	Army response to NRC comments during 15 December 2008 teleconference where NRC raised concerns about: 1) DU solubility, overestimation of sorption, and underestimation of dose radiation; and 2) rationale for sample selection for batch testing. Solubility controlled through selection of samples with DU < 360 pCi/g based on the highest concentration (989 mg/kg) (PNNL 2002). Identification of 24 samples representing main soil types within DU Impact Area.
21 September 2009	Letter	Army to NRC	Army request to NRC to revise 10 of the 24 identified sample locations where soil volume actually collected was less than required by K_d SOP.
October 2009	FSP Addendum 8	Army to NRC	Army revised, second phase design for soil and contact solution sample collection. Introduces hydraulic direct-push sampling methods for collection of six glacial till samples to expand scope of K_d study to loess soils and deeper till. TestAmerica SOP based on ASTM D4319-93 remains available analytical method.
16 October 2009	Letter	Army to NRC	Army response to NRC comments during 22 September 2009 teleconference where NRC raised concerns about the spatial distribution of proposed K_d study soil sample locations. Eighteen loess samples from three principal soil types where DU penetrators predominate and six background samples from three main loess soil types outside DU Impact Area where no penetrators found.
14 January 2011	Letter	Army to NRC	Army response to NRC comments during 21 and 25 January 2010 teleconferences where NRC raised concerns about: 1) representativeness of rainwater as contact solution for deep soil samples > 1 to 2 ft BGS, 2) degradation of intended K_d study soil samples since collection in October 2008, and 3) potential losses of uranium adhering to filter container walls. The Army recollected rainwater in February 2010 and ran laboratory tests in the spring of 2010 to evaluate rainwater representativeness; found rainwater of a similar pH but lower in alkalinity than surface or groundwater ranges. Army reanalyzed in the summer of 2010 for wet chemistry characterization parameters in six of the preserved soil samples from the October 2008 collection event intended for K_d study batch testing; found statistically significant increase in TOC levels. Army proposes a method to evaluate potential DU loss to glassware and filter ware.
10 March 2011	Letter	NRC to Army	NRC response to Army responses to NRC concerns over rainwater representativeness, sample integrity, and uranium loss in sample were raised during the 21 and 25 January 2010 teleconference. NRC expressed: 1) higher alkalinity of groundwater will promote more dissolved uranium so less alkaline rainwater used in K_d study will under predict uranium mobility by over prediction of sorption; 2) suggested collection of representative groundwater samples or pre-equilibrate rainwater samples to pH and alkalinity of overburden groundwater for testing deeper (e.g., till) soil samples; 3) 70 percent increase in TOC in retested October 2008 samples likely reflects bacterial growth since collection and could influence radionuclide sorption; and 4) agreement with Army proposed measures to evaluate uranium losses to laboratory ware. NRC further guided that loess soil desorption-dissolution test results do not constitute partitioning, and as such should not be expressed as K_d (termed "distribution ratio" or " R_d ").
5 August 2011	Letter	Army to NRC	Army response to NRC comments in NRC letter from 10 March 2011. Army proposes to recollect dedicated K_d samples from prior locations established in FSP Addendums 7 and 8 and use the new ASTM standard (C1733-10) for batch sample determination of K_d and desorption-dissolution coefficients.

**Table 3-1. Distribution Coefficient Study Design Basis Milestones
Jefferson Proving Ground, Madison, Indiana (Continued)**

Date	Document	Stakeholders	Concern/Response
2 November 2011	Letter	NRC to Army	NRC response to Army response, dated 5 August 2011, responding to Army's proposed revised K_d study design incorporating sample recollection and new ASTM standard. NRC expressed: 1) approval of the Army plan to resample soils and to use the original Army profile depth for loess soils (4 ft), 2) approval of the use of the new ASTM standard C1733-10, and 3) justification for any further critical milestone characterization work.
28 November 2011	Letter	Army to NRC	Army request for 20-month extension to submit the Decommissioning Plan no later than September 2013. Identification that the samples to be recollected from the three principal loess soils and from under DU penetrators will be composited from intervals of 0 to 4 ft below grade.
2 April 2012	Letter	NRC to Army	NRC questions about Army's November 2011 letter.
2 May 2012	Letter	Army to NRC	Transmittal of NRC Form 313 for 20-month extension and responses to NRC's questions from 2 April 2012 letter.
17 August 2012	Letter	NRC to Army	Staff's finding of license application and references submittal acceptable for detailed technical and environmental review.
27 December 2012	Letter	NRC to Army	NRC acceptance of alternate schedule for submission of Decommissioning Plan and Environmental Report with License Amendment 17.

ASTM = American Society for Testing and Materials
 DU = Depleted Uranium
 FSP = Field Sampling Plan
 JPG = Jefferson Proving Ground
 K_d = Distribution Coefficient
 NRC = U.S. Nuclear Regulatory Commission

PNNL = Pacific Northwest National Laboratory
 R_d = Distribution Ratio
 RESRAD = Residual Radiation
 SOP = Standard Operating Procedure
 TOC = Total Organic Carbon

The outcome of the multi-year comment and response collaboration process (as illustrated in Table 3-1) produced a robust design that the Army presented to NRC in letter format on 5 August 2011 (U.S. Army 2011) and which NRC agreed with in their letter dated 2 November 2011. To expedite initiation of the proposed K_d soil and contact solution resampling, another addendum to the Field Sampling Plan (FSP) was not prepared. The *Army's Plan for Sample Recollection and K_d /Desorption Testing* was transmitted in the above-referenced August 2011 letter to NRC incorporating and relying on retained components of FSP Addendums 5, 7, and 8, as well as NRC's comments and suggestions summarized in Table 3-1. A concise review of the principal components of the final K_d study design implemented by the Army is provided below.

3.2 SOIL SAMPLE SELECTION

During the intervening years after identification of the importance of the need for a site-specific starting point for DU partitioning in 2005 to development of the initial scope of the K_d study in 2008, the Army rigorously characterized the hydrogeochemical setting of JPG and the DU Impact Area in particular. These characterization efforts led to the understanding and development of the CSM reviewed in Section 2. That characterization confirmed the presence of soil types mapped by others as derived from loess- or windblown-deposited fine sediment (silt and clays) to depths on the order of 6 to 12 ft BGS underlain by pre-Wisconsinan, dense glacial till, to depths upwards of 47 ft and characterized by a bi-modal distribution of fine silts and clays, gravel, and sand stringers. The K_d study had to be representative of both shallow loess-derived soils, where the preponderance of DU penetrators remain and over which the substantial portion of annual rainfall runs off and the deeper till where DU liberated from corroded penetrators, carried as dilute solute in infiltrating precipitation, could eventually migrate to and move with groundwater.

As a result, the final sampling plan for the K_d study included representation of the three principal loess-derived soil types: Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and the lesser Grayford/Ryker, where DU penetrators have been found, and the deeper lying till. Table 3-2 summarizes the general scope and quantity of soil samples planned and eventually collected for the K_d study, while Table 3-3 lists the specific sample locations resampled in March 2012. Figure 3-1 shows the locations of the various samples listed in Table 3-2.

**Table 3-2. Summary of Site-Specific K_d /Desorption-Dissolution Testing and Contact Liquid by Soil Type
Jefferson Proving Ground, Madison, Indiana**

Test	Avonburg/Cobbsfork	Cincinnati/Rossmoyne	Grayford/Ryker	Glacial Till	Total
K_d	Soil from nine background locations with rainwater for contact liquid	Soil from nine background locations with rainwater for contact liquid	Soil from three background locations with rainwater for contact liquid	Soil from six locations with groundwater for contact liquid	27
Desorption-Dissolution	Soil from under one penetrator with rainwater for contact liquid	Soil from under one penetrator with rainwater for contact liquid	Soil from under one penetrator with rainwater for contact liquid	Not applicable	3
Total	10	10	4	6	30

**Table 3-3. Sample Recollection Locations for K_d and Desorption-Dissolution Testing
Jefferson Proving Ground, Madison, Indiana**

Soil Types	Test	Site I.D./Depth BGS (ft)	October 2008 Concentration (pCi/g)
Avonburg/Cobbsfork	K_d	JP-SAC-001 / 0-4	1.45+/-0.327
Avonburg/Cobbsfork	K_d	JP-SAC-002 / 0-4	1.32+/-0.300
Avonburg/Cobbsfork	K_d	JP-SAC-003 / 0-4	1.50+/-0.340
Avonburg/Cobbsfork	K_d	JP-SAC-004 / 0-4	1.30+/-0.296
Avonburg/Cobbsfork	K_d	JP-SAC-005 / 0-4	1.77+/-0.400
Avonburg/Cobbsfork	K_d	JP-SAC-006 / 0-4	1.42+/-0.323
Avonburg/Cobbsfork	K_d	JP-SAC-007 / 0-4	1.36+/-0.310
Avonburg/Cobbsfork	K_d	JP-SAC-008 / 0-4	1.59+/-0.362
Avonburg/Cobbsfork	K_d	JP-SAC-009 / 0-4	1.55+/-0.346
Avonburg/Cobbsfork	Desorption-Dissolution	JP-PNAC-001 / 0-4	15,095+/-159
Cincinnati/Rossmoyne	K_d	JP-SCR-001 / 0-4	1.57+/-0.354
Cincinnati/Rossmoyne	K_d	JP-SCR-002 / 0-4	1.08+/-0.250
Cincinnati/Rossmoyne	K_d	JP-SCR-003 / 0-4	1.64+/-0.366
Cincinnati/Rossmoyne	K_d	JP-SCR-004 / 0-4	1.55+/-0.350
Cincinnati/Rossmoyne	K_d	JP-SCR-005 / 0-4	1.68+/-0.379
Cincinnati/Rossmoyne	K_d	JP-SCR-006 / 0-4	1.61+/-0.362
Cincinnati/Rossmoyne	K_d	JP-SCR-007 / 0-4	1.81+/-0.402
Cincinnati/Rossmoyne	K_d	JP-SCR-008 / 0-4	1.53+/-0.343
Cincinnati/Rossmoyne	K_d	JP-SCR-009 / 0-4	1.79+/-0.400
Cincinnati/Rossmoyne	Desorption-Dissolution	JP-PNCR-001 / 0-4	27,496+/-190
Grayford/Ryker	K_d	JP-SGR-001 / 0-4	1.15+/-0.266
Grayford/Ryker	K_d	JP-SGR-002 / 0-4	1.56+/-0.351
Grayford/Ryker	K_d	JP-SGR-003 / 0-4	1.47+/-0.330
Grayford/Ryker	Desorption-Dissolution	JP-PNGR-001 / 0-4	4,180+/-72

Table 3-3. Sample Recollection Locations for K_d and Desorption-Dissolution Testing Jefferson Proving Ground, Madison, Indiana (Continued)

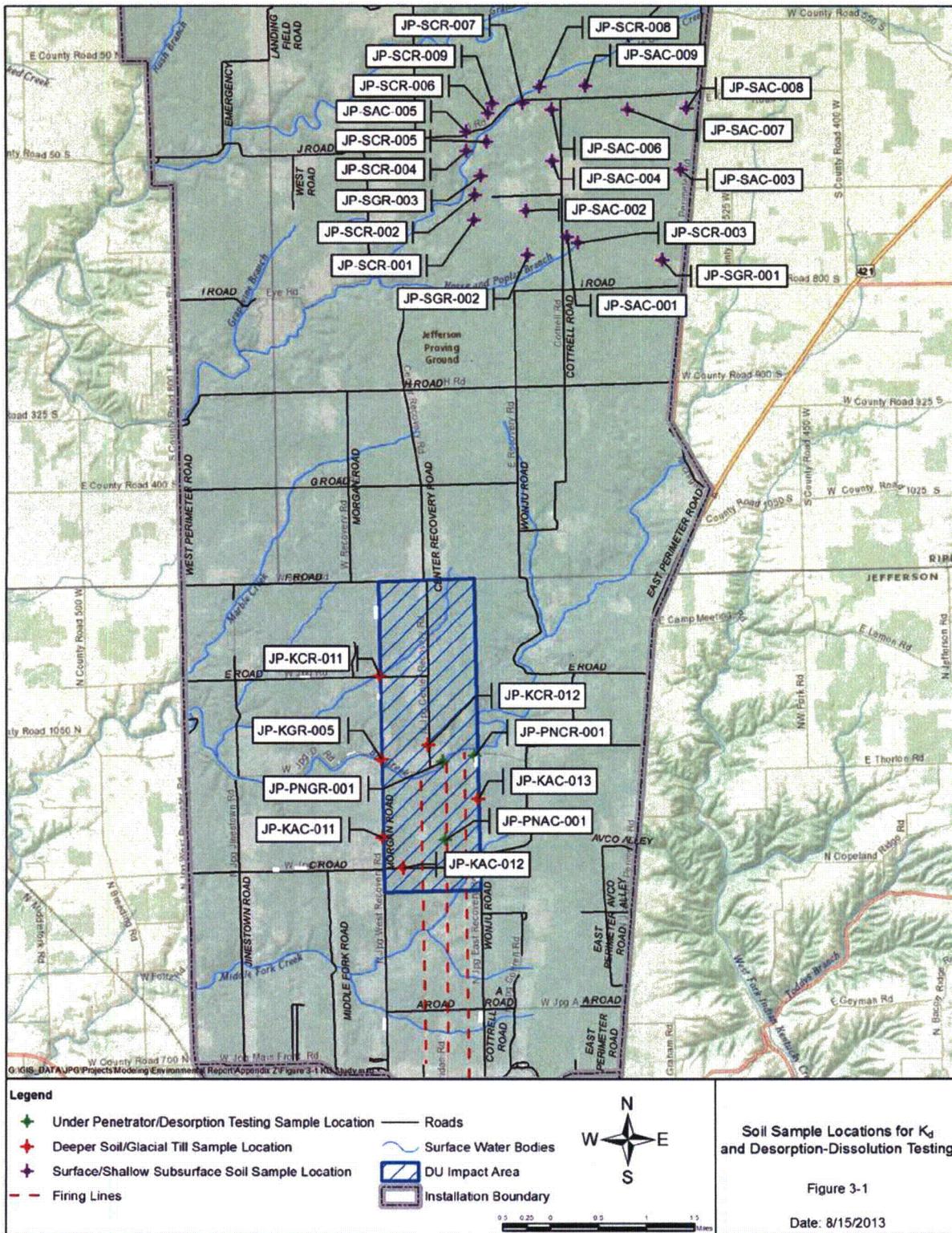
Soil Types	Test	Site I.D./Depth BGS (ft)	October 2008 Concentration (pCi/g)
Pre-Wisconsinan Till	K_d	JP-KAC-011 / 10-16	1.96 +/- 0.359
Pre-Wisconsinan Till	K_d	JP-KAC-012 / 10-18	2.16 +/- 0.400
Pre-Wisconsinan Till	K_d	JP-KAC-013 / 10-16	1.64 +/- 0.310
Pre-Wisconsinan Till	K_d	JP-KCR-011 / 10-16	3.48 +/- 0.520
Pre-Wisconsinan Till	K_d	JP-KCR-012 / 8-14	0.920 +/- 0.220
Pre-Wisconsinan Till	K_d	JP-KGR-005 / 6-10	1.87 +/- 0.350

Twenty-one soil samples representative of the three loess soil types away from the DU Impact Area and from background locations were to be recollected from the same locations originally established by the FSP Addendum 7 and the subsequent field event in October 2008, where sample locations were screened with a gamma walkover survey and recorded with a digital global positioning system (DGPS) accurate to less than 1 m (Table 3-3 and Figure 3-1). The six deep samples from the till, the locations of which were established in the FSP Addendum 8 and field located in a similar manner as the loess soil samples during the Addendum 8 field event in December 2009, were to be resampled with the original GPS coordinates (Figure 3-1). To evaluate desorption-dissolution of DU from shallow impacted soils directly under penetrators, three samples were collected from the three principal loess soils, one for each soil type, from the same general location sampled in 2008. Because the penetrators from these three original locations were removed in October 2008, the final plan was to approach the same areas via GPS and find new penetrators nearby via a sodium iodide (NaI) gamma scintillation radiation detector. Lastly, these soil samples were supported with four duplicate samples, one each from the three loess soil types and a fourth from one of the till sample locations (Figure 3-1). Section 4 presents information on sample location and collection methods.

3.3 CONTACT SOLUTION IDENTIFICATION

The majority of the DU penetrators and corrosion that has occurred to date is present at or near ground surface; thus, rainwater (and snowmelt) was identified as a strategic contact solution in the DU Impact Area and a contact solution for the K_d study. The CSM and quantitative annual water budget for the DU Impact Area indicate that the majority of the annual precipitation to JPG either evaporates or transpires via vegetation during the growing season back into the atmosphere (56 percent) or runs off (36 percent) to local streams, leaving only approximately 8 percent available to infiltrate to groundwater in the overburden and shallow bedrock (Figure 2-1). The smallest percentage of annual rainfall that washes over DU penetrators and corrosion products, dissolving DU in the process, has the potential to transport DU solute down through the vadose zone to groundwater in the till, where DU can potentially continue to migrate with groundwater. In situ permeability or slug testing and age dating of overburden groundwater indicates it moves very slowly, collecting for years in pockets poorly connected either laterally in overburden or deeper within shallow bedrock (SAIC 2010, USGS 2010). Therefore, overburden groundwater was identified as another important although proportionally much smaller volume reactant/contact solution in the DU pathway. Consequently, to best emulate the full-scale system, the final K_d study design planned to use rainwater as the primary contact solution, with till groundwater the secondary contact solution.

Table 3-2 lists what type of contact solution or contact liquid was to be used with each type of soil sample. The 21 soil samples (and 3 duplicates) representative of the loess soils would be in contact with rainwater, as would the 3 soil samples and 1 duplicate collected from beneath penetrators. Rainwater was proposed to be collected from the same previous location west of the DU Impact Area, using plastic sheeting directed into a plastic drum.



The six till soil samples and one duplicate would be in contact with groundwater from overburden well JPG-DU-06O. Figure 3-2 shows the location of the well relative to the DU Impact Area. Overburden monitoring well JPG-DU-06O was selected to provide groundwater contact solution for the following reasons:

- This well is situated south of Big Creek in an area that is approximately 70 ft higher in elevation than the elevation of Big Creek within the DU Impact Area. With groundwater migration generally in a northerly direction toward Big Creek in this area and the center firing line trench situated to the west/northwest, JPG-DU-06O is hydraulically side gradient or upgradient of potential DU sources.
- The well is completed in a thick sequence of overburden (37 ft) with a yield in the middle to upper range for the till and a hydraulic conductivity of 5.3 gal/day/ft², which compares closely to the average overburden well hydraulic conductivity of 2.95 gal/day/ft², ensuring timely collection of the required volume for soil sample contact.
- Four quarters of groundwater sampling from April 2008 to February 2009 indicate DU has not impacted overburden groundwater in this area. Reported DU concentrations in filtered and unfiltered samples from JPG-DU-06O ranged from 2.11 to 4.00 picoCuries per liter [pCi/L], for an overall average total uranium activity of 2.9 pCi/L. Uranium concentrations for filtered and unfiltered samples across all wells ranged from 0.1 to 47 pCi/L, for an overall mean of 2.1 pCi/L.
- Groundwater quality in JPG-DU-06O is well-representative of groundwater quality in the overburden within the DU Impact Area as compared to other groundwater monitoring wells installed in the overburden in terms of radiological and nonradiological laboratory analyses completed on samples.

3.4 SOIL AND CONTACT SOLUTION CHARACTERIZATION

Soils and contact solutions collected for the K_d study were subjected to broad characterization analyses prior to commencing the K_d study as well as specific total uranium analyses during the batch analyses for K_d and desorption-dissolution potential determination. The general chemistry parameters for both soil and water were selected from ASTM C1733-10 recommendations and geochemical processes known to affect uranium mobility, as discussed in Section 2.2. The principal objectives of the general chemistry analyses were to: 1) characterize the composition of principal soil types, till, rainwater, and groundwater with respect to geochemical parameters that research has shown can influence the environmental fate of uranium and partitioning in particular, 2) perform a comparative analysis of geochemical trends or character of principal soils relative to one another and the till and of rainwater relative to groundwater, and 3) provide a basis to help understand and explain the empirically derived K_d values and desorption-dissolution potentials and uranium mobility at JPG in the various media of interest.

Scrape samples taken from 34 penetrators were collected from JPG and analyzed using X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and scanning electron microscopy-energy dispersive spectroscopy (SEM-EDS). The major uranium phase for the samples determined with XRD was hydrated uranium trioxide (UO₃). The minor phase was hydrated uranium dioxide (UO₂), the mineral uraninite (pitchblende). Metallic uranium (U) and hydrated uranous oxide (UO₄·nH₂O) were also detected. A number of samples contained several trace-sized and minor-sized peaks that are unassigned to a phase. These unassigned peaks were not uranium-bearing compounds. The XPS determined that each sample contained a mixture of uranium in the +6 and +4 oxidation states with good match to a mixture of UO₃ and UO₂. No uranium metal was detected. Cross-sections of penetrators were analyzed by SEM-EDS. The major elements present in each sample include uranium (U) and oxygen (O). Silicon (Si) also was present in the samples as a major or minor component. Minor and trace elements also present were aluminum (Al), magnesium (Mg), calcium (Ca), titanium (Ti), and iron (Fe).

Characterization of soil samples for the K_d study was completed through laboratory analysis for the following parameters and geochemical modeling, which is discussed further in Section 6.4:

- Moisture content
- Soil pH
- Grain size distribution
- Total organic carbon (TOC)
- Total carbon (TC)
- Total iron
- Total manganese
- Cation-exchange capacity (CEC).

The moisture content of soil samples is essential to determine the concentration of a substance, in this case total and isotopic uranium, on a dry weight basis. The other parameters represent soil characteristics or components of soil geochemical processes, as discussed in Sections 2.2 and 7, that can control uranium mobility and partitioning and therefore aid in interpreting resultant empirically determined K_d values for a particular sample or soil series.

A portion of the collected rainwater sample and groundwater sample from overburden monitoring well JPG-DU-06O was analyzed for general wet chemistry parameters, as follows, for similar objectives as described for soils:

- TOC
- TC
- Total iron
- Total manganese
- Major cations
- Major anions
- Alkalinity.

3.5 K_d STUDY BATCH METHOD

There are two laboratory approaches for measuring K_d : the batch and the column methods. The batch method (ASTM C1733-10) for measuring K_d consists of equilibrating a measured mass of soil with a selected contact desorption-dissolution solution such as rainwater, a synthetic mixture, or background groundwater. In the more commonly used adsorption mode for K_d value determination, the contact solution is spiked with a measured mass of the chemical species of interest, which then distributes onto or into the soil over time as the solid matrix equilibrates to the solution. It is also possible to use contaminated soils, in which case the chemical species of interest dissolves or leaches from the soil into an unspiked contact solution.

Using this method, each soil sample of interest representative of strategic contaminant pathway substrate is subdivided into separate aliquots and saturated with the spiked contact solution to provide a cross-section of samples that can be individually analyzed (liquid and if needed solid phase) over a period of days to months. The batch method returns time series results to allow determination of concentration changes over time for equilibration determination and batch study termination.

The batch method was used for the K_d study, following the guidance provided by ASTM Method C1733-10 (ASTM 2010), as agreed to by NRC in their letter dated 2 November 2011, and a proprietary laboratory standard operating procedure (SOP) developed by TestAmerica Laboratories, Inc. (TestAmerica) based on the ASTM guidance. Section 5 reviews the batch method sample preparation and analytical methods. Some important assumptions and aspects of the ASTM guidance essential to successful application are presented here.

The batch method recommends oven/air drying and disaggregation of the solid sample for the purpose of achieving uniformity of application and consistency in solid sample surface area exposure to contact solution, despite acknowledging that this can potentially change sample representativeness in terms of flow paths and grain reaction surface areas as discussed in Section 2.2.

Both the solid and liquid contact solution should be characterized for contaminants of interest and for parameters affecting the mobility/partitioning as discussed in Section 2.2 prior to disaggregating and mixing for batch analysis. The solid to liquid ratio of batch samples can influence the resultant K_d determination, so a 1:25 solid to contact solution mass ratio is recommended based on the sources that the ASTM method consulted for to develop their procedure. The soil portion is recommended at 1 to 5 grams, with the balance of contact solution at a factor of 25. If the method will be applied to radioactive tracers, like uranium for the K_d study, the guidance recommends pretreating the solid samples with intended contact solution, in this case rainwater and groundwater. If the contaminant of interest or tracer is found in the environmental setting over a range of concentrations, contact solutions should be spiked with a similar range of concentrations. Uniform ORP and pH is essential throughout the process to ensure geochemical changes affecting contaminant partitioning are not inadvertently influenced artificially. The pH of the contact solution should be determined on receipt at the laboratory and then monitored in the batch samples over the life of the study, which was accomplished by TestAmerica by extracting a separate aliquot of contact solution from the test vessels used for uranium species determination on a given day. Lastly, the K_d can be determined from the ratio of the tracer concentration in the reference solution analyzed at the start of the batch study relative to the tracer concentration in the contact solution, or by dividing the solid phase tracer concentration by the final contact solution tracer concentration.

4. SAMPLE LOCATION AND COLLECTION METHODS

With the final K_d study design agreed to in the fall of 2011, following the winter of 2011/2012, SAIC mobilized to JPG to recollect soil and contact solutions from 27 through 30 March 2012. Sample locations established in 2008 were relocated and sampled again, along with collection of rainwater from the same area and in accordance with the same method as used previously. Collection of the groundwater sample from overburden groundwater well JPG-DU-06O for use as the contact solution for the till was new to the scope of sampling in 2012. The sample location and collection methods employed for the K_d study are summarized below. Table 4-1 summarizes the scope of the 2012 sample collection program for the final K_d study and the sections that follow summarize sample location and collection methods.

**Table 4-1. March 2012 Soil Sample Summary
Jefferson Proving Ground, Madison, Indiana**

Test	Avonburg/Cobbsfork	Cincinnati/Rossmoyne	Grayford/Ryker	Glacial Till	Total
K_d	Soil from nine background locations plus one duplicate test with rainwater for contact liquid	Soil from nine background locations plus one duplicate test with rainwater for contact liquid	Soil from three background locations plus one duplicate test with rainwater for contact liquid	Soil from six locations plus one duplicate test with groundwater for contact liquid	31
Desorption-Dissolution	Soil from under one penetrator with rainwater for contact liquid	Soil from under one penetrator with rainwater for contact liquid	Soil from under one penetrator with rainwater for contact liquid	Not applicable	3
Total	11	11	5	7	34

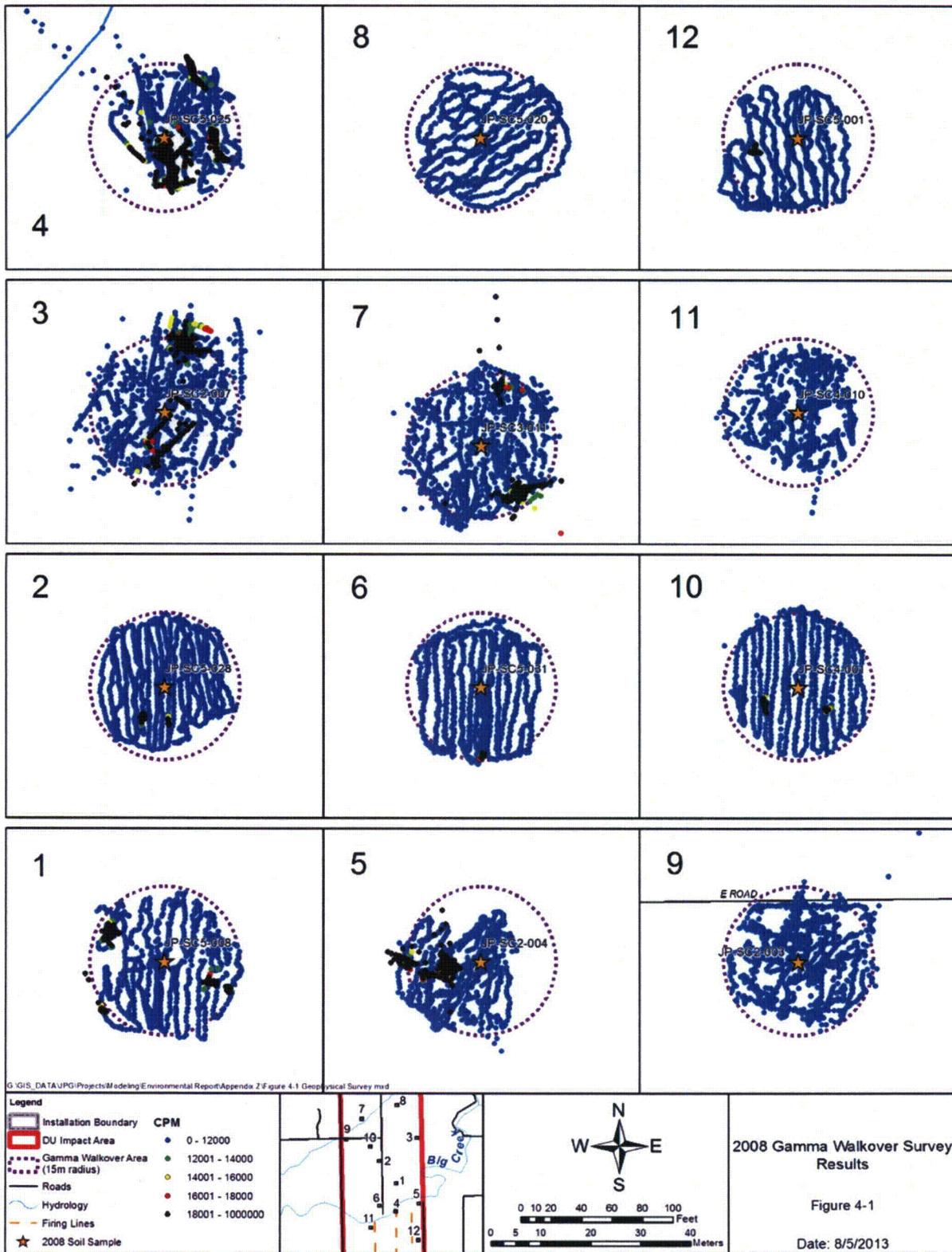
4.1 GAMMA WALKOVER SURVEY

Both the background locations at JPG approximately 3.5 miles (mi) north of the DU Impact Area and the locations to be sampled beneath penetrators incorporated a gamma walkover survey in 2008 to either help ensure that background soils were not impacted by DU or to aid in the identification of penetrators in the DU Impact Area (Figure 4-1). The gamma surveys were implemented concurrently with radiological protection screening and anomaly avoidance by a qualified health physicist and unexploded ordnance (UXO) specialist, respectively (SAIC 2008b).

Gamma walkover surveys served as a screening tool to identify areas that exhibit gamma radioactivity that was elevated with respect to background count rates. The survey completed in 2008 used an NaI gamma scintillation radiation detector (detector), connected to a data collection (logging) device and a GPS. The detector was maintained about 10 cm (4 in) above ground surface while the datalogger collected gamma emissions and location coordinates at 1-second intervals. The detector provided both an audible response and an arm meter reading proportional to the detected gamma count rate. The survey was performed at a speed of about 0.5 meters per second while moving the detector in a serpentine manner. Gamma data were downloaded at the office, and a gamma response contour map was developed for the areas of interest (Figure 4-1). Results of the gamma survey in the background area north of the DU Impact Area did not indicate any response above background. Results of the gamma survey along the firing lines aided in the detection of 24 penetrators, at that time needed for broader characterization reasons such as soil depth concentration profiling, corrosion studies, and the early intentions of the K_d study.

4.2 PENETRATOR DESORPTION-DISSOLUTION SOIL SAMPLES

GPS coordinates of penetrator locations in 2008 were used to navigate to the general areas in March 2012 to locate three additional penetrators, one from each principal soil type, in the same general area as the original ones that were found and removed. These samples were intended for desorption-dissolution tests using rainwater. These relocated sample locations are listed in Table 4-2 and shown in Figure 3-1.



**Table 4-2. Desorption-Dissolution Test Sample Locations Under Penetrators
Jefferson Proving Ground, Madison, Indiana**

Sample I.D.	Soil Type	Sample Date
JP-PNAC-001_SAIC05	Avonburg/Cobbsfork	30 March 2012
JP-PNCR-001_SAIC05	Cincinnati/Rossmoyne	30 March 2012
JP-PNGR-001_SAIC05	Grayford/Ryker	30 March 2012

Once a new penetrator was located in the vicinity of the old penetrator, an SAIC staff scientist collected a soil sample in accordance with the FSP Addendums 5, 7, and 8 (SAIC 2005, 2008b, 2009). SAIC used a hand auger to progressively remove soils to a depth of 4 ft BGS. Soils were described as collected and the sample location was photographed. A copy of the log and photograph is provided in the Environmental Report. Soils removed from the hand auger were placed on plastic sheeting, homogenized at the completion of hand augering, and then transferred to sample containers provided by TestAmerica. Approximately 1 kg (2.2 lb) of soil was transferred to bottleware for the batch analyses, total uranium determination, and general characterization analyses. Following sample collection, sample containers were labeled with the Army identification convention, stored in coolers, and iced to a temperature of 4°C for overnight courier delivery under chain-of-custody (CoC) protocols to TestAmerica in Earth City, Missouri. Auger holes were backfilled with tamped cuttings and soil sampling equipment was decontaminated in accordance with procedures identified in FSP Addendum 5 (SAIC 2005).

4.3 BACKGROUND SOIL SAMPLES

A total of 21 soil samples and 3 duplicates for a total of 24 samples were recollected from 3 background locations originally established in 2008. Background soil samples collected from the three principal loess soils are listed in Table 4-3.

Sample location GPS coordinates collected in 2008 were used to relocate background locations in 2012, as shown in Figure 3-1. Once a location was navigated to with the GPS in March 2012, the SAIC staff scientist advanced a hand auger boring to 4 ft BGS to collect a representative soil sample in the same manner as described above, in accordance with the designated FSP Addendums. The field notes associated with collection of the 21 soil lithologic logs are included in the Environmental Report. Samples were labeled and shipped to TestAmerica, as described earlier. Following sample collection, auger holes were backfilled with tamped cuttings.

4.4 GLACIAL TILL SAMPLES

Six direct push soil borings were collected at the same six locations originally sampled in December 2009 as replicates of the glacial till. Table 4-4 lists the sample locations and respective sampling depths.

Locations selected for the 2009 till sampling effort were chosen near monitoring well locations representative of the three principal loess soil types, where previous radiological and UXO clearance had been performed. Selected locations are adjacent to wells that reported overburden with characteristics of glacial till above bedrock, and with sufficient thickness to produce the necessary sample volume. Further, these original locations were expected to produce till samples with minimal to no DU impact due to the intended sample depth below grade. Till samples were recollected in accordance with the procedures detailed in FSP Addendum 8 (SAIC 2009) and as summarized below.

**Table 4-3. Background Adsorption Soil Sample Locations
Jefferson Proving Ground, Madison, Indiana**

Sample I.D.	Soil Type	Sample Date
JP-SAC-001_SAIC05	Avonburg/Cobbsfork	29 March 2012
JP-SAC-001_SAIC05D	Avonburg/Cobbsfork	29 March 2012
JP-SAC-002_SAIC05	Avonburg/Cobbsfork	29 March 2012
JP-SAC-003_SAIC05	Avonburg/Cobbsfork	27 March 2012
JP-SAC-004_SAIC05	Avonburg/Cobbsfork	29 March 2012
JP-SAC-005_SAIC05	Avonburg/Cobbsfork	28 March 2012
JP-SAC-006_SAIC05	Avonburg/Cobbsfork	27 March 2012
JP-SAC-007_SAIC05	Avonburg/Cobbsfork	27 March 2012
JP-SAC-008_SAIC05	Avonburg/Cobbsfork	27 March 2012
JP-SAC-009_SAIC05	Avonburg/Cobbsfork	27 March 2012
JP-SCR-001_SAIC05	Cincinnati/Rossmoyne	29 March 2012
JP-SCR-001_SAIC05D	Cincinnati/Rossmoyne	29 March 2012
JP-SCR-002_SAIC05	Cincinnati/Rossmoyne	29 March 2012
JP-SCR-003_SAIC05	Cincinnati/Rossmoyne	29 March 2012
JP-SCR-004_SAIC05	Cincinnati/Rossmoyne	28 March 2012
JP-SCR-005_SAIC05	Cincinnati/Rossmoyne	29 March 2012
JP-SCR-006_SAIC05	Cincinnati/Rossmoyne	28 March 2012
JP-SCR-007_SAIC05	Cincinnati/Rossmoyne	28 March 2012
JP-SCR-008_SAIC05	Cincinnati/Rossmoyne	28 March 2012
JP-SCR-009_SAIC05	Cincinnati/Rossmoyne	28 March 2012
JP-SGR-001_SAIC05	Grayford/Ryker	30 March 2012
JP-SGR-001_SAIC05D	Grayford/Ryker	30 March 2012
JP-SGR-002_SAIC05	Grayford/Ryker	29 March 2012
JP-SGR-003_SAIC05	Grayford/Ryker	29 March 2012

**Table 4-4. Till Adsorption Soil Sample Locations
Jefferson Proving Ground, Madison, Indiana**

Sample I.D.	Soil Type	Sample Date	Sample Depth (ft BGS)
JP-KAC-011_SAIC01R	Avonburg/Cobbsfork	28 March 2012	10-16
JP-KAC-012_SAIC01R	Avonburg/Cobbsfork	29 March 2012	10-18
JP-KAC-013_SAIC01R	Avonburg/Cobbsfork	29 March 2012	10-16
JP-KCR-011_SAIC01R	Cincinnati/Rossmoyne	27 March 2012	10-16
JP-KCR-012_SAIC01R	Cincinnati/Rossmoyne	28 March 2012	8-14
JP-KGR-005_SAIC01R	Grayford/Ryker	27 March 2012	6-10
JP-KGR-005_SAIC01DR	Grayford/Ryker	27 March 2012	6-10

SAIC's equipment division Environmental Equipment & Supply (EE&S) mobilized a Geoprobe® 6620DT-1 hydraulic direct push drilling rig to the site to advance the till boings to depths of 15 to 25 ft BGS. Continuous 5-ft macrocores were collected to total depth to allow an SAIC staff scientist to record the lithologic description of recovered soils, perform field screening for radiation exposure, and collect laboratory soil samples. Radiation exposure measurements were collected at 6-in intervals.

Soil recovered from the target depth intervals listed in Table 4-4 was described, screened for radiation, and then placed on plastic sheeting for light mixing. The above sample intervals were determined from the required sample weight (1 kg or 2.2 lb), the 2.5-in-diameter of the macrocore sampler, and the expected density of soils penetrated. Laboratory samples then were collected as described above. A duplicate sample was collected from sample location JP-KGR-005_SAIC01DR by alternately filling identical sample containers with the same volume of soil as for the field sample. Following collection, samples were labeled and shipped to TestAmerica, as described above. All soil sampling equipment coming into contact with potentially contaminated soil (i.e., auger buckets, direct-push technology [DPT] sample core, stainless-steel bowls, and spoons) was decontaminated between each soil sampling station in accordance with the procedures detailed in FSP Addendum 5 (SAIC 2005). At the completion of sampling, soil borings were filled with tamped cuttings.

4.5 RAINWATER CONTACT SOLUTION SAMPLE

During the original mobilization to collect K_d study samples in October 2008, a rainwater collection station was established approximately 0.5 mi south of MW-RS-05 and west of the DU Impact Area (Figure 3-1). As shown in Figure 4-2, the rainwater station was constructed as a large funnel using plastic (high-density polyethylene [HDPE]) sheeting to collect rainfall and direct it to a plastic drum with an HDPE liner. The rainwater tarp was tied at the corners to adjacent utility poles and pulled over the top of the collection drum for the funnel effect. A hole was cut in the tarp on top of the collection drum and a wire mesh filter screen was placed underneath the opening to reduce the amount of debris captured in the rainwater drum.



Figure 4-2. Rainwater Collection Station

During the March 2012 recollection event, a Fultz pump was used to pump the rainwater from the collection drum into designated sample containers that consisted of 2.5-gallon plastic carboys. A total of eight 2.5-gallon carboys of rainwater were removed from the drum. Care was taken to ensure the removal of any debris from the sample containers.

Prior to removal of rainwater, SAIC measured the following field parameters using a Horiba U-22 water quality meter: pH, specific conductance, ORP, DO, temperature, and turbidity. Section 6 presents the results of field parameter measurements. The filled carboys were labeled by sample identification, packed individually in coolers, iced to a temperature of 4°C, and shipped under CoC to TestAmerica. The Fultz pump was decontaminated according to the decontamination procedure described in FSP Addendum 7 (SAIC 2008b) prior to sampling and after.

4.6 GROUNDWATER CONTACT SOLUTION SAMPLE

SAIC collected groundwater from monitoring well JPG-DU-06O in accordance with FSP Addendum 5 (SAIC 2005). A review of the sampling procedure is provided below.

SAIC utilized two general well sampling methods at JPG, depending on the yield of a well. A well yield matched purge sampling technique was used at monitoring wells where a yield could be sustained and low-yield technique at wells where a yield could not be sustained and the well dewatered. Well JPG-DU-06O historically sustained a yield and was therefore sampled in accordance with the matched purge technique, as summarized below.

The well yield matched purge sampling technique incorporates some of the aspects of the USEPA low-flow or micro-purge sampling techniques in an attempt to acquire samples that are representative of the actual conditions within the aquifer and to ensure reproducible sampling results. Several other benefits of the described sampling methods are as follows:

- Reduced “stress” in the aquifer by pumping at a rate equal to or less than well yield
- Reduced well-bore mixing after completion of purging by sampling directly from purging equipment
- Reduced turbidity of samples by not stirring up or “stressing” the well, purging from the water-bearing zones
- Not causing the filter pack or water-bearing zone to be exposed to air or aerated.

Because well JPG-DU-06O had been sampled during the quarterly events in 2008 and 2009, the response of the well to sampling was well-understood, a criterion for the selection of this well to provide contact solution groundwater for the K_d study.

Collection of the groundwater sample from monitoring well JPG-DU-06O using the well yield matched purge sampling technique was accomplished in the following four general steps:

1. Set the purge flow rate
2. Control drawdown in the well by adjusting flow to match or be less than well yield
3. Obtain stabilized water quality indicator parameters
4. Collect groundwater samples.

Prior to sampling, the depth to water in the well was measured. A Fultz pump then was installed in the well to the mid-point of the screen. Discharge line from the pump was directed to a flow-through cell where a Horiba U-22 water quality meter sonde was installed to measure water quality parameters. The Environmental Report includes a copy of the well sampling data sheet. The pump was turned on and the

flow rate out of the well was adjusted to an average rate of 0.1 to 0.2 gpm to moderate drawdown to 2.5 ft by the end of purging. Field water quality parameters were monitored during purging at a frequency of approximately 5 minutes, as follows: pH, ORP, specific conductance, temperature, DO, and turbidity. Following a total purge time of 90 minutes and removal of 9.5 gallons of water, water quality had stabilized in the well and a groundwater sample was collected. SAIC disconnected the purge tubing from the flow cell and filled bottleware provided by TestAmerica. Following collection, sample bottles were labeled with the Army identification convention, placed in a cooler, iced to a temperature of 4°C, and shipped under CoC to TestAmerica for analysis, as discussed in Section 5.

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5. LABORATORY ANALYTICAL METHODS

Laboratory analytical services for the K_d study were provided by TestAmerica at their Earth City, Missouri laboratory. TestAmerica performed the total and isotopic uranium analyses for soil, contact solution, and batch extract samples and performed the nonradiological characterization analyses on the soil and contact solutions. Following receipt of analytical results, SAIC validated the data for quality assurance (QA) purposes to confirm data were suitable for conclusive use. A concise review of the laboratory analyses performed for the K_d study and the methods and results of the SAIC QA/Quality Control (QC) review is provided below.

5.1 SOIL AND CONTACT SOLUTION CHARACTERIZATION

All soil, rainwater, and groundwater samples collected for the K_d study were subjected to broad characterization of radiological and nonradiological parameters for the objectives detailed in Section 3.4. Table 5-1 identifies the characterization parameters, analytical method, and laboratory method detection limits (MDL) employed by each laboratory. Following receipt of samples at the laboratories, TestAmerica checked the temperature of the coolers, logged the samples in, and then proceeded to prepare and analyze the samples in accordance with the procedures detailed below.

**Table 5-1. Radiological and Nonradiological Laboratory Analytical Summary
Jefferson Proving Ground, Madison, Indiana**

Parameter	Medium	Analytical Method	Detection Limit
Total and Isotopic Uranium	Soil	ICP-MS/SW 6020A	0.0003-0.08/ $\mu\text{g/L}$
Moisture Content	Soil	ASTM D2216-05	Not applicable
Soil pH	Soil	ASTM D4972-01/E9045C	Not applicable
Particle Size Distribution	Soil	ASTM D422-63	Not applicable
Total Organic Carbon	Soil	SW9060/415.2	200 mg/kg
Total Carbon	Soil	SW9060/415.2	2,000 mg/kg
Total Iron	Soil	SW6010	20 mg/kg
Total Manganese	Soil	SW6010	1 mg/kg
Cation-Exchange Capacity	Soil	SW 9080	2.5 meq/100 g
Total and Isotopic Uranium	Water	ICP-MS/SW 6020A	0.0003-0.054/ $\mu\text{g/L}$
pH	Water	ASTM D1293-12	Not applicable
Nitrate	Water	E300/SW9056	600 $\mu\text{g/L}$
Chloride	Water	E300/SW9056	3,000 $\mu\text{g/L}$
Sulfate	Water	E300/SW9056	1,000 $\mu\text{g/L}$
Calcium, Sodium, Magnesium, and Iron	Water	SW6010	1,000 $\mu\text{g/L}$
Potassium	Water	SW6010	5,000 $\mu\text{g/L}$
Manganese	Water	SW6010	100 $\mu\text{g/L}$

5.2 LABORATORY BATCH METHOD FOR DETERMINATION OF URANIUM K_d

To implement a batch study outlined in the ASTM guidance, TestAmerica developed a proprietary SOP for SAIC for K_d testing based on the ASTM C1733-10 batch method. The principal laboratory analyses performed on the batch samples consisted of total and isotopic uranium analyses on extracts of the contact solutions, pursuant to the above-referenced method. In addition, a separate aliquot of contact solution extract from a given sample was analyzed for pH. No other characterization of either the batch

sample soils or contact solutions was performed as the K_d study progressed to completion, with the exception that total and isotopic uranium analyses performed on the last batch sample soils. These measurements were made to compare the calculated sorbed masses determined from the ratios of uranium concentrations in the original spiked contact solutions relative to the final contact solution extracts. A brief review of the sample preparation and analytical process implemented by TestAmerica is provided below.

1. Upon receipt of the soil samples identified in Table 5-2, TestAmerica dried each sample and disaggregated it with a ball mill.

**Table 5-2. K_d Study Contact Solutions and Initial Spike Concentrations
Jefferson Proving Ground, Madison, Indiana**

Sample I.D.	Soil Type	Contact solution	Initial Spike Concentration (µg/L)
Adsorption K_d Tests – Loess Soils			
JP-SAC-001_SAIC05	Avonburg/Cobbsfork	Rainwater	10
JP-SAC-001_SAIC05D	Avonburg/Cobbsfork	Rainwater	10
JP-SAC-002_SAIC05	Avonburg/Cobbsfork	Rainwater	20
JP-SAC-003_SAIC05	Avonburg/Cobbsfork	Rainwater	3
JP-SAC-004_SAIC05	Avonburg/Cobbsfork	Rainwater	15
JP-SAC-005_SAIC05	Avonburg/Cobbsfork	Rainwater	10
JP-SAC-006_SAIC05	Avonburg/Cobbsfork	Rainwater	10
JP-SAC-007_SAIC05	Avonburg/Cobbsfork	Rainwater	10
JP-SAC-008_SAIC05	Avonburg/Cobbsfork	Rainwater	6
JP-SAC-009_SAIC05	Avonburg/Cobbsfork	Rainwater	10
JP-SCR-001_SAIC05	Cincinnati/Rossmoyne	Rainwater	15
JP-SCR-001_SAIC05D	Cincinnati/Rossmoyne	Rainwater	10
JP-SCR-002_SAIC05	Cincinnati/Rossmoyne	Rainwater	20
JP-SCR-003_SAIC05	Cincinnati/Rossmoyne	Rainwater	10
JP-SCR-004_SAIC05	Cincinnati/Rossmoyne	Rainwater	10
JP-SCR-005_SAIC05	Cincinnati/Rossmoyne	Rainwater	10
JP-SCR-006_SAIC05	Cincinnati/Rossmoyne	Rainwater	10
JP-SCR-007_SAIC05	Cincinnati/Rossmoyne	Rainwater	6
JP-SCR-008_SAIC05	Cincinnati/Rossmoyne	Rainwater	3
JP-SCR-009_SAIC05	Cincinnati/Rossmoyne	Rainwater	10
JP-SGR-001_SAIC05	Grayford/Ryker	Rainwater	10
JP-SGR-001_SAIC05D	Grayford/Ryker	Rainwater	10
JP-SGR-002_SAIC05	Grayford/Ryker	Rainwater	10
JP-SGR-003_SAIC05	Grayford/Ryker	Rainwater	10
Adsorption K_d Tests – Glacial Till			
JP-KAC-011_SAIC01R	Avonburg/Cobbsfork	Groundwater	10
JP-KAC-012_SAIC01R	Avonburg/Cobbsfork	Groundwater	10
JP-KAC-013_SAIC01R	Avonburg/Cobbsfork	Groundwater	10
JP-KCR-011_SAIC01R	Cincinnati/Rossmoyne	Groundwater	10
JP-KCR-012_SAIC01R	Cincinnati/Rossmoyne	Groundwater	10
JP-KGR-005_SAIC01R	Grayford/Ryker	Groundwater	10
JP-KGR-005_SAIC01DR	Grayford/Ryker	Groundwater	10
Desorption-Dissolution Tests – Loess Soils			
JP-PNAC-001_SAIC05	Avonburg/Cobbsfork	Rainwater	Not applicable
JP-PNCR-001_SAIC05	Cincinnati/Rossmoyne	Rainwater	Not applicable
JP-PNGR-001_SAIC05	Grayford/Ryker	Rainwater	Not applicable

ASTM Method D 4319-93 (ASTM 2001) prescribed the duration of the testing and number of uranium concentration measurements as follows, "...The contact periods shall be for a minimum of 3 days, and the longest shall extend to 14 days or longer. The contact periods shall differ by at least a 3-day period..." ASTM C1733-10 states, "...the time required for the tracer/solid system to achieve constant solution concentrations for each species of interest...is best done by doing a preliminary K_d batch experiment..." Based on previous experience and using information from withdrawn ASTM Method D 4319-93 (ASTM 2001), the K_d study duration was extended to potentially 120 days or 4 months to ensure equilibration of soils and contact solution. Therefore, following drying and disaggregation, TestAmerica subdivided each of the samples referenced above into 4-gram aliquots for the following designated soaking durations: 3, 7, 10, 14, 21, 28, 35, 45, 60, 90, and 120 days. In all, 11 subset samples were prepared for each background loess, till, and penetrator sample. Section 7.1 discusses the careful monitoring of each K_d test to determine when equilibration had been reached and when each test should be terminated.

2. Because uranium was the parameter of interest, in conformance with the ASTM method, TestAmerica pre-equilibrated each subset soil aliquot with the intended contact solution, rainwater, or groundwater following the ASTM C1733-10 guidance three-step process (i.e., wash, centrifuge, and decant). Per TestAmerica's SOP, approximately 40 mL of as-received contact solution, without added uranium, was used to equilibrate a 4-gram aliquot of soil. The aliquot of soil was soaked with the 40 mL of contact solution in a centrifuge tube for approximately 15 minutes, followed by centrifuging, decantation, and a second soaking for another 15 minutes. Following centrifuging and decantation the second time, the aliquot of soil was soaked a third time with the decanted contact solution, this time for approximately 24 hours.
3. Following the 24-hour soak, the soil-water solution was centrifuged, with both decanted liquid and soil placed in a 125 mL HDPE plastic bottle. To this bottle was added an additional 40 mL of pH adjusted contact solution (to match pH of original contact solution as received at the laboratory), spiked with a known concentration of uranium, as listed in Table 5-2. The spiked contact solution portion was prepared in larger batches for QC, as listed in Table 5-3 from the TestAmerica process documentation. Lastly, the residual soil and water in the centrifuge tube was rinsed into the above-referenced plastic bottle using 20 mL of reserved, unspiked contact solution to arrive at 4 grams of soil in 100 mL of solution, the prescribed 1:25 soil to water mass ratio. This resulted in an approximate 25 mL headspace of atmospheric air in each bottle at the time of container sealing for the duration of the study.

**Table 5-3. Laboratory Spiked Contact Solution Batch Data
Jefferson Proving Ground, Madison, Indiana**

	<u>Concentration of Contact Fluid (µg/L)</u>	<u>Amount of Rainwater (mls)</u>	<u>Amount of Concentrated Spike (mls)</u>	<u>Final Volume (mls)</u>	<u>pH of Rainwater</u>	<u>pH of Spiked Rainwater</u>	<u>Prepared By</u>
Rainwater	7.5	992.5	7.5	1000	6.88	7.18	FC
	15	985	15	1000	6.88	7.01	FC
	25	975	25	1000	6.88	6.84	FC
	37.5	962.5	37.5	1000	6.88	6.72	FC
	50	950	50	1000	6.88	6.78	FC
Groundwater							
	25	975	25	1000	7.45	7.47	FC

4. Following the combining of the 4-gram aliquot of soil with the composite 100 mL of contact solution, soil-water solutions were agitated for 15 minutes, then placed on a shelf at room temperature to await the designated date of extraction.
5. The three desorption-dissolution samples of soils collected below penetrators did not undergo the contact solution equilibration step. Four gram aliquots of soil were combined with 100 mL of unspiked contact solution, agitated, and stored on a shelf at room temperature.
6. Samples were agitated for approximately 15 minutes every 3 to 4 days.
7. On the appropriate day for analysis and at least 1 day after any sample agitation, TestAmerica extracted the contact solution by filtering through a 0.45-micrometer (μm) membrane disposable filter. From this, two aliquots of the filtrate were removed, one for pH determination and the other for preservation with nitric acid to adjust the pH to < 2.0 for total and isotopic uranium analysis.

Batch subset sample preparation and contact solution soaking were staggered to accommodate the number of total and isotopic uranium analyses that the laboratory could manage per day, especially within the first 2 months of sample extraction and analysis. Table 5-4 identifies the soaking duration relative to the extract sample analysis calendar window. Day 3 contact solution contact extracts started to be analyzed from 10 through 15 May 2012, with 120-day contact solution extract analyses completed by late January to early February 2013. It should be noted that extracts were pulled and preserved, then scheduled by the laboratory for analysis according to the laboratory's overall sample analytical backlog.

**Table 5-4. Contact Solution Contact Duration and Analytical Date Range
Jefferson Proving Ground, Madison, Indiana**

Reactant Contact Duration (days)	3	7	10	14	21	28	35	45	60	90	120
Sample Analysis Date Range	May 10-15	May 16-22	May 19-25	May 25-30	June 1-14	June 13-15	June 26 - July	June 26 - July	July 28-31	Sept 20-26	Jan 10 - Feb-8

Batch sample soil was not analyzed for uranium until the final batch contact solution extract sample analysis was completed for a given sample at the conclusion of each test, typically at day 60, 90, or in some cases day 120. The samples used as the uranium plating laboratory control sample (LCS) blanks did not have sufficient residual soil volume to perform the post-test isotopic uranium analyses (Table 5-3).

5.3 STANDARD SELECTION AND SPIKE CONCENTRATION RANGE

TestAmerica used a uranium reference standard from Inorganic Ventures of Christiansburg, Virginia, to spike the contact solutions. The form of uranium was uranyl nitrate hexahydrate with an isotopic composition of 99.8 percent U-238 and 0.21 percent U-235. This standard was familiar to TestAmerica via successful use in the past and readily dissociated in K_d study sample solutions releasing uranyl to interact with solution chemistries, as demonstrated by geochemical modeling presented in Section 6.

The uranium spike concentrations of 3 to 20 micrograms per liter ($\mu\text{g/L}$) for contact solutions were determined from the range of uranium activity concentrations, converted to mass concentrations, detected during the 30 years of Environmental Radiation Monitoring (ERM) program sampling at JPG, particularly the last 9 years from 2004 through 2012, as measured and reported semi-annually to the Army. Table 5-5 lists the range and average activities and respective mass concentrations found in soil, sediment, surface water, and groundwater at JPG.

Table 5-5. Total Uranium Activity Versus Mass Concentration for Soil, Sediment, Surface Water, and Groundwater from Long-Term ERM Monitoring Jefferson Proving Ground, Madison, Indiana

Medium	Total Uranium Activity Concentration			Total Uranium Mass Concentration		
	Average	Standard Deviation	Maximum	Average	Standard Deviation	Maximum
Soil	1.5	0.3	2.2 +/- 0.5	4.46	0.89	6.5 +/- 1.5
Sediment	0.97	0.49	2.4 +/- 0.4	2.88	1.46	7.1 +/- 1.2
Surface Water	0.88	2.4	19 +/- 2	2.61	7.13	56.4 +/- 5.9
Groundwater	1.4	1.2	5.7 +/- 0.6	4.16	3.56	16.9 +/- 1.8

Soil and sediment: activity concentrations in pCi/g; mass concentrations in mg/kg

Groundwater and Surface Water: activity concentrations in pCi/L; mass concentrations in mg/L

Although pore water concentrations of DU immediately beneath a penetrator could be higher in concentration than these design basis concentrations, the average annual water budget for JPG, overburden hydraulic conductivities (SAIC 2010) and age of till groundwater (USGS 2010) combine to indicate little of this pore water infiltrates deeper into soils (8 percent). The portion expected to run off overland (36 percent) will do so quickly (hours), mixing with accumulated precipitation along narrow drainage paths to the receptor streams (Big Creek and Middle Fork Creek). As a result, the uranium spike concentrations chosen for this study best reflect expected DU concentrations over the longest and most prevalent transport pathways, the stormwater sheet flow and open channel flow routes through the uplands to the streams.

5.4 ACID RINSATE BOTTLE BLANKS

TestAmerica developed four acid rinsate samples to evaluate the potential for uranium plating on bottlenecks, a concern of NRC, as discussed in Section 3.1. Table 5-6 lists the field samples selected for use as the acid rinsate blanks.

Table 5-6. Acid Rinsate Blanks to Evaluate Uranium Plating Jefferson Proving Ground, Madison, Indiana

Sample I.D.	Soil Type	Contact Solution	Initial Spike Concentration (µg/L)	Laboratory Sample Description
Adsorption K_d Tests – Loess Soils				
JP-SAC-007_SAIC05	Avonburg/Cobbsfork	Rainwater	10	Bottleware A
JP-SCR-004_SAIC05	Cincinnati/Rossmoyne	Rainwater	10	Bottleware B
JP-SGR-002_SAIC05	Grayford/Ryker	Rainwater	10	Bottleware C
Adsorption K_d Tests – Glacial Till				
JP-KAC-011_SAIC01R	Avonburg/Cobbsfork	Groundwater	10	Bottleware D

Every time an analysis was required on the subsample aliquot for a given day for each of these four samples, following extraction of the contact solution for analysis, remaining soil and contact solution were transferred to another bottle and the original bottle was rinsed with deionized (DI) water, then filled with dilute nitric acid and allowed to soak for several minutes. A portion of the acid rinsate then was removed and analyzed for total and isotopic uranium.

5.5 DATA QUALITY ASSESSMENT

A comprehensive QA/QC program was followed during the 2008/2009 DU Impact Area site characterization sampling activities, spring JPG 2012 resampling, and K_d study to ensure that analytical results and the decisions based on these results are representative of the environmental conditions at the DU Impact Area.

SAIC performed data verification on 40 percent of the data (i.e., all analytical QC results and laboratory documentation) based on the guidelines and specifications in the JPG DU site characterization Quality Assurance Project Plan (QAPP) (SAIC 2005) and *Contract Laboratory Program (CLP) National Functional Guidelines for Inorganic Data Review* (USEPA 2002) with modifications for non-CLP methods. CLP-like Forms 1 through 14 were reviewed to ensure that the QC results fall within appropriate QC limits for holding times, blank contamination, calibrations, matrix spikes/matrix spike duplicates (MS/MSDs), LCSs, internal standards, laboratory duplicates, serial dilutions, detection limits, isotopic tracers, and any other required QC data. Laboratory QC forms were reviewed to ensure that the QC results fall within the appropriate QC limits. An additional 10 percent of the data were validated using the guidelines described above but also included recalculations from the raw data. Any resulting data validation qualifiers were applied and a data validation checklist was prepared for each analytical parameter for each sample delivery group (SDG) that received verification or validation. This data review process was followed for both the 2008/2009 site characterization samples and the spring 2012 resampling and K_d study resulting in a thorough review of 50 percent of the data. A complete Data Quality Assessment (DQA) is provided for both the 2008/2009 site characterization samples and the spring 2012 resampling and K_d study in the Environmental Report (U.S. Army 2013), Appendix M.

Data verification and validation was conducted on 2008/2009 DU Impact Area site characterization data. As determined by the verification/validation process, results have been flagged or qualified U (undetected at limit of detection), J (quantitation is estimated due to discrepancies in meeting certain analyte-specific QC criteria), or UJ (undetected at limit of detection and quantitation is estimated due to discrepancies in meeting certain analyte-specific QC criteria) for various reasons encountered minor analytical problems with limited impact on the data quality. Analytical data were qualified as (R for rejected data) due to significant QA errors. Only 11 of 11,637 data points were rejected for the 2008/2009 DU Impact Area samples, but none of these rejected samples were used in this K_d study. Additional details are included in Environmental Report (U.S. Army 2013), Appendix M.

Data verification and validation was conducted on the spring 2012 resampling and data generated for the K_d study. As determined by the verification/validation process, results have been flagged or qualified U, UJ, or J for various reasons encountered minor analytical problems, with limited impact on the data quality. No data points were rejected during the verification and validation process, indicating that the data were 100 percent complete and all of the spring 2012 resampling and K_d study data can be used in assessing results and providing recommendations.

6. PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOIL, TILL, AND CONTACT SOLUTIONS

As explained previously, NRC and USEPA encourage the determination of site-specific K_d values because values provided in literature are a function of site-specific aqueous and solid phase chemistry and can fluctuate over six orders of magnitude (NRC 2006). Thus, the primary objective of this study was to determine the site-specific K_d values in a laboratory environment using geologic substrates collected from JPG to support computer modeling of DU transport and potential residual radiation doses for human receptors. The site-specific physical and chemical characteristics of the soil are described and evaluated in Section 6.1. The site-specific physical and chemical characteristics of rainwater and groundwater are discussed in Sections 6.2 and 6.3, respectively. Lastly, the speciation of uranium in soil and pore water is evaluated in Section 6.4 via the USGS computer model PHREEQC.

6.1 SOIL CHARACTERISTICS

This section discusses soil texture (Section 6.1.1) as related to grain size for the predominant soil types present at JPG and the effect of sorption on different textures (i.e., clay, silt, and sand). Section 6.1.2 presents the concentrations of total uranium present in soil used for the site-specific study, discusses the effect of sorption based on characteristics of the soil, (e.g., pore water pH, TOC, iron [Fe], manganese [Mg], and CEC), and loess soil and till clay mineralogy based on corollary research on glacial loess and till.

6.1.1 Soil Texture

Soil texture was quantified through sieve analysis according to ASTM Method 422D, as indicated in Section 4, to compliment soil descriptions made during soil sample collection at the DU Impact Area and northerly JPG background locations. Results of the grain size analyses are provided in the Environmental Report. Soil texture can influence contaminant partitioning, with finer-grained soils, particularly clay minerals like the expanding clay smectite, typically providing more host sites for contaminant partitioning, as described in Sections 2 and 7.

All of the loess and till samples (a total of 34 including duplicates) were analyzed for grain size distribution by TestAmerica. Soil types include the three predominant loess types (Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker) and the deeper underlying glacial till. Table 6-1 summarizes the results of the grain size analyses.

**Table 6-1. Soil Texture Summary
Jefferson Proving Ground, Madison, Indiana**

Location I.D.	Sample I.D.	Depth (ft)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Soil Description
Loess – Background Locations							
Avonburg/Cobbsfork							
JP-SAC-001	SAIC05	0 to 4	42.5	47.8	9.7	0	Clay
JP-SAC-002	SAIC05	0 to 4	28.9	57.9	13.2	0	Silt
JP-SAC-003	SAIC05	0 to 4	22.1	39.1	34.2	4.6	Silt with fine sand
JP-SAC-004	SAIC05	0 to 4	--	--	--	--	Sandy silt
JP-SAC-005	SAIC05	0 to 4	34.9	49.8	15.3	0	Not recorded
JP-SAC-005	SAIC05D	0 to 4	36.1	46.4	17.5	0	Not recorded
JP-SAC-006	SAIC05	0 to 4	32.3	53.5	14.2	0	Silt
JP-SAC-007	SAIC05	0 to 4	30.0	55.3	14.7	0	Silt
JP-SAC-008	SAIC05	0 to 4	29.5	55.6	14.9	0	Silt
JP-SAC-009	SAIC05	0 to 4	37.4	40.2	20.7	1.7	Silt with clay
Average			32.6	49.5	17.2	0.7	
Standard Deviation			5.9	6.8	7.1	1.6	

**Table 6-1. Soil Texture Summary
Jefferson Proving Ground, Madison, Indiana (Continued)**

Location I.D.	Sample I.D.	Depth (ft)	Clay (%)	Silt (%)	Sand (%)	Gravel (%)	Soil Description
Cincinnati/Rossmoyne							
JP-SCR-001	SAIC05	0 to 3.3	23.4	44.3	32.1	0.20	Sandy silt with clay
JP-SCR-002	SAIC05	0 to 3	16.5	34.2	41.6	7.7	Not recorded
JP-SCR-003	SAIC05	0 to 4	24.2	40.7	33.9	1.2	Silt
JP-SCR-004	SAIC05	0 to 4	25.7	37.8	28.7	0.60	Not recorded
JP-SCR-005	SAIC05	0 to 4	34.9	58.0	6.8	0.30	Silt with clay
JP-SCR-006	SAIC05	0 to 4	35.0	47.4	17.6	0	Not recorded
JP-SCR-007	SAIC05	0 to 4	35.8	55.4	8.8	0	Clay and silt
JP-SCR-008	SAIC05	0 to 4	42.4	40.2	17.4	0	Silt with clay
JP-SCR-008	SAIC05D	0 to 4	38.9	38.6	21.9	0.60	Silt with clay
JP-SCR-009	SAIC05	0 to 4	34.0	53.1	12.9	0	Not recorded
Average			31.1	45.0	22.2	1.1	
Standard Deviation			8.2	8.2	11.6	2.4	
Grayford/Ryker							
JP-SGR-001	SAIC05	0 to 4	30.2	51.8	18.0	0	Silt
JP-SGR-002	SAIC05	0 to 4	31.1	47.7	21.2	0	Not recorded
JP-SGR-003	SAIC05	0 to 2	27.1	56.6	13.3	3.0	Not recorded
Average			29.5	52.0	17.5	1.0	
Standard Deviation			2.1	4.5	4.0	1.7	
Combined Loess Average			31.5	47.8	19.5	0.90	
Combined Loess Standard Deviation			6.6	7.4	9.2	1.9	
Glacial Till – DU Impact Area							
JP-KAC-011	SAIC01R	13 to 15	21.1	40.3	35.9	2.7	Silty clay with sand
JP-KAC-012	SAIC01R	11 to 15	30.3	35.8	33.7	0.20	Silt loam with some fine to medium gravel
JP-KAC-013	SAIC01R	12 to 14	15.3	21.2	61.2	2.3	Silty clay loam with some coarse sand and gravel
JP-KCR-011	SAIC01R	14 to 16	45.0	50.4	4.6	0	Clay loam with coarse sand and coarse gravel
JP-KCR-012	SAIC01R	10 to 14	36.5	43.0	20.3	0.20	Sandy loam
JP-KCR-012	SAIC01DR	10 to 14	34.1	45.9	19.5	0.50	Sandy loam
JP-KGR-005	SAIC01R	6 to 8.5	51.3	42.5	6.2	0	Sandy loam with some gravel
JP-KGR-005	SAIC01DR	6 to 8.5	55.8	36.9	7.3	0	Sandy loam with some gravel
Average			36.2	39.5	23.6	0.74	
Standard Deviation			14.1	8.8	19.4	1.1	
Loess – Under Penetrators at DU Impact Area							
JP-PNAC-001	SAIC05	0 to 4	28.6	54.1	17.3	0	Silt
JP-PNCR-001	SAIC05	0 to 4	34.0	54.3	11.7	0	Silt with clay
JP-PNGR-001	SAIC05	0 to 4	34.7	44.1	18.6	2.6	Silt with organics
Average			32.4	50.8	15.9	0.87	
Standard Deviation			3.3	5.8	3.7	1.5	

Grain size analysis of the 26 loess soil samples indicates the 3 shallow loess soils have very similar grain size distributions consistent with the field-determined silty clay and sandy loam soil descriptions made at the time of sampling and included in the Environmental Report. The three loess soil types are very similar, containing approximately 29 to 33 percent clay, 45 to 52 percent silt, 18 to 23 percent sand, and 1 percent or less gravel. Figure 6-1 shows the relative percent difference in grain sizes for the three soils. This textural composition is consistent with silty clay to clayey silt loam.

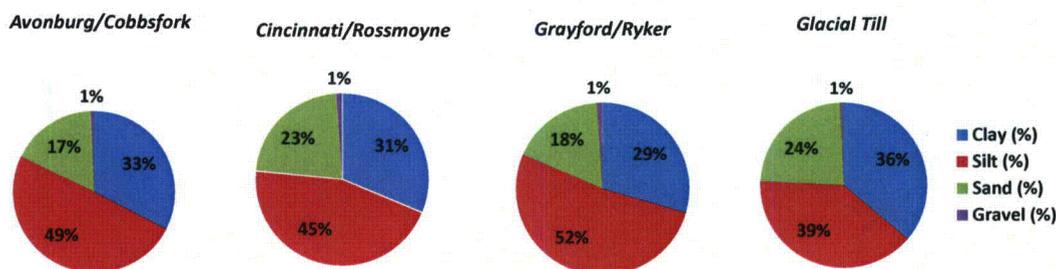


Figure 6-1. Particle Size Comparison of JPG Soil Types

Although fewer samples of the till were collected, grain size analysis of those samples indicates a similar amount of fines as the loess soils. The average weight percent fractions of clay, silt, sand, and gravel were as follows: 36 percent, 39 percent, 24 percent, and 1 percent, respectively. Only one till sample contained approximately 50 percent or more coarse-grained particles (sand and gravel). Sample JP-KAC-013 contained 63.5 percent coarse-grained particles, of which 61.2 percent were sand and 2.3 percent were gravel. The lithologic log for the soil boring advanced to collect this sample indicates it was associated with a 6-in stringer of coarse-grained sediment. Figure 6-1 shows graphically the comparison of the till grain size distribution relative to the loess. The coarse fraction as determined from sieve analysis appears lower than what is indicated by the lithologic logs in the Environmental Report. The logs suggest 5 to 20 percent gravel, consisting of limestone and chert clasts. The difference may be a function of the limitations of sample size and a single sample for representation of a thick sequence of variably sized sediments. As defined in the CSM in Section 2.1, the samples collected in March 2012 to represent the till stratigraphic horizon for the K_d study were collected from the depths where drilling indicated soil density increased markedly and a gravel fraction was consistently present.

6.1.2 Loess and Till Mineralogy

Mineral composition of the loess-derived soils and till was not specifically determined but has been estimated from corollary work completed by other researchers elsewhere in Indiana and adjacent Illinois. Review of the mineral makeup focuses on the clays in these respective media, the components that present the principal potential reaction surfaces for DU partitioning relative to the silt, sand, and gravel size single mineral and lithic fragments that make up the balance of the materials as texturally described above. The basic research suggests that the dominant clay mineral present in either soils developed from loess or in till is montmorillonite altered from lesser illite and chlorite, particularly where the loess or till has undergone chemical weathering. Chemical weathering also can leach resident carbonate out of the loess and upper reaches of till over time. The TC versus TOC ratios for the loess and till suggest carbonate desorption-dissolution has occurred at JPG, as discussed Section 6.1.3.

Murray and Leininger (1955) determined the clay mineral assemblage in three profiles of glacial material in Indiana, one of which was a 40-ft-thick profile of Illinoian till near Staunton, Clay County, Indiana. The till in the JPG area is Illinoian in age. The profile consisted of approximately 8 ft of loess, overlying 32 ft of till, of which the upper feet of till beneath the loess were oxidized and leached. This study found that montmorillonite, a hydrated sodium calcium aluminum magnesium sheet silicate hydroxide $(Na,Ca)_{0.33}(Al,Mg)_2$ in the smectite family of clay minerals was the predominant clay mineral in the weathered loess and upper till portions of the profile, with illite and chlorite more abundant in the deeper, unweathered till. The montmorillonite was reportedly an alteration product of the parent illite and chlorite clay minerals as a result of oxidation of iron, a common cation substitute. This study also determined that any resident carbonate in the loess and the upper chemically weathered and oxidized till had been leached out based on lack of observed reaction to applied hydrochloric acid in the field and the lack of carbon dioxide (CO_2) in samples as determined by acid evolution.

Beavers et. al. (1954) determined the clay mineralogy of three glacial profiles in Illinois, one of which was loess overlying Illinoian till. The loess soils each had identifiable 'A', 'B' and 'C' horizons of

which montmorillonite was the dominant clay mineral in the B and C horizons, at 80 to 90 percent. The balance of clays in these horizons was illite and chlorite. For the 'A' horizon, montmorillonite declined to about 40 percent, with illite and then less so chlorite the balance of clay minerals. For all of the loess soils in this study, montmorillonite was the principal clay mineral as appears to be the case for weathered loess throughout the Midwest (Davidson and Handy 1953). The Beavers study also suggested the occurrence of montmorillonite was as an alteration product of the illite and chlorite.

The consequence of these study findings to JPG soils and the upper till represented in the K_d study samples is that the likely principal clay mineral present is the expanding clay montmorillonite. This clay has a significant CEC, retains water and organic carbon between its crystal structure, and provides reaction surfaces favorable for DU partitioning and iron and manganese oxyhydroxide precipitation relative to other clay minerals, including illite and chlorite found in lesser proportions elsewhere.

The studies also suggest that, though not directly measured in K_d study samples, the carbonate content of the background loess soils and possibly the till is greatly diminished through dissolution since deposited 140,000 years ago, improving the potential for DU partitioning. The measures of TC and TOC determined for loess soils (and till samples) indirectly support the above finding from loess soils elsewhere in Indiana and neighboring glaciated states. TOC is equal to the sum of total inorganic carbon (carbon from calcium and magnesium carbonate: respectively, limestone and dolomite) and TOC. Table 6-3 in the next section lists the TC and TOC values determined for individual K_d study samples. Ratios of TC to TOC are very different for loess soils relative to the six glacial till samples. On an average basis, the reported TOC content of loess soils is only approximately 3 percent less than the TC content, indicating total inorganic carbon, the fraction of inorganic carbon attributable to limestone and dolomite, is only 3 percent on average. This carbon relationship indicates the loess soils, despite having formed from regional carbonate terrane, are principally leached of resident carbonate. This is further strengthened from review of the carbon ratios in the till samples, also formed from regional carbonate terrane. For the till samples, the average reported TOC content was approximately 47 percent of the TC reported average, indicating TOC was 54 percent of the TC average, suggesting limestone and dolomite constituted a larger proportion of the till composition relative to the loess soil.

6.1.3 Soil Quality

This section presents the concentrations of total uranium (Section 6.1.3.1) and nonradiological components (Section 6.1.3.2) of the soil used for the site-specific study.

6.1.3.1 Total Uranium

Total and isotopic uranium analysis was conducted by TestAmerica on all of the samples, as indicated in Section 5. The background samples were subjected to the uranium analyses to ensure selected locations were not impacted by any DU and that any uranium present in the samples was naturally occurring uranium. The soil samples beneath penetrators needed DU content quantification directly for the desorption-dissolution tests and determination of the distribution ratio (R_d). Table 6-2 presents the results of the isotopic analyses and also lists the weight percentage of U-235 present in a given sample for evaluation as naturally occurring uranium or DU.

Total uranium concentrations among the three background loess soil types averaged 0.63 milligram per kilogram (mg/kg) in the Avonburg/Cobbsfork, 1.07 mg/kg in the Cincinnati/Rossmoyne, and 0.84 mg/kg in the Grayford/Ryker. The average total uranium content in the three loess soils was 0.85 mg/kg. By comparison, the average concentration of total uranium in the glacial till deposits was 0.82 mg/kg, over a range of 0.46 to 1.3 mg/kg. The loess soil and glacial till concentrations reported for the uranium isotope U-235, converted to a percent of total uranium, aligned closely with the literature reported abundance of U-235 in naturally occurring uranium at 0.72 percent, as discussed in Section 2 and Table 6-2. The trace uranium present in the background loess soils and deeper till appears to be natural uranium.

**Table 6-2. Soil Total/Isotopic Uranium Analysis Summary
Jefferson Proving Ground, Madison, Indiana**

Location I.D.	Sample I.D.	Depth (ft)	Total Uranium (mg/kg)	U-238 (mg/kg)	U-235 (mg/kg)	U-234 (mg/kg)	Weight % U-235
Loess – Background Locations							
Avonburg/Cobbsfork							
JP-SAC-001	SAIC05	0 to 4	0.77	0.77	0.0052	0.0066	0.68%
JP-SAC-002	SAIC05	0 to 4	0.43	0.42	0.0028	0.0067	0.65%
JP-SAC-003	SAIC05	0 to 4	0.51	0.50	0.0037	0.0062	0.73%
JP-SAC-004	SAIC05	0 to 4	0.55	0.55	0.0042	0.0060	0.76%
JP-SAC-005	SAIC05	0 to 4	0.68	0.67	0.0048	0.0063	0.71%
JP-SAC-005	SAIC05D	0 to 4	0.79	0.79	0.0057	0.0063	0.72%
JP-SAC-006	SAIC05	0 to 4	0.52	0.52	0.0036	0.0063	0.69%
JP-SAC-007	SAIC05	0 to 4	0.54	0.53	0.0040	0.0066	0.74%
JP-SAC-008	SAIC05	0 to 4	0.85	0.85	0.0066	0.0065	0.78%
JP-SAC-009	SAIC05	0 to 4	0.70	0.70	0.0050	0.0061	0.71%
Average			0.63	0.63	0.0046	0.0064	0.72%
Percentage				99.37%	0.72%	0.63%	
Cincinnati/Rossmoyne							
JP-SCR-001	SAIC05	0 to 3.3	1.10	1.10	0.0079	0.0062	0.72%
JP-SCR-002	SAIC05	0 to 3	2.80	2.80	0.0190	0.0061	0.68%
JP-SCR-003	SAIC05	0 to 4	0.44	0.44	0.0031	0.0062	0.70%
JP-SCR-004	SAIC05	0 to 4	0.80	0.79	0.0055	0.0061	0.69%
JP-SCR-005	SAIC05	0 to 4	0.99	0.98	0.0070	0.0065	0.71%
JP-SCR-006	SAIC05	0 to 4	0.82	0.81	0.0058	0.0062	0.71%
JP-SCR-007	SAIC05	0 to 4	1.10	1.10	0.0081	0.0068	0.74%
JP-SCR-008	SAIC05	0 to 4	0.88	0.88	0.0066	0.0062	0.75%
JP-SCR-008	SAIC05D	0 to 4	0.92	0.91	0.0070	0.0062	0.76%
JP-SCR-009	SAIC05	0 to 4	0.84	0.84	0.0061	0.0065	0.73%
Average			1.07	1.07	0.0076	0.0063	0.71%
Percentage				99.63%	0.71%	0.59%	
Grayford/Ryker							
JP-SGR-001	SAIC05	0 to 4	0.56	0.56	0.0037	0.0064	0.66%
JP-SGR-002	SAIC05	0 to 4	0.75	0.75	0.0050	0.0061	0.67%
JP-SGR-003	SAIC05	0 to 2	1.20	1.20	0.0084	0.0064	0.70%
Average			0.84	0.84	0.0057	0.0063	0.68%
Percentage				100%	0.68%	0.75%	
Combined Loess Average			0.85	0.85	0.0060	0.0063	0.71%
Glacial Till – DU Impact Area Locations							
JP-KAC-011	SAIC01R	13 to 15	0.46	0.46	0.0033	0.0058	0.72%
JP-KAC-012	SAIC01R	11 to 15	0.76	0.75	0.0056	0.0057	0.74%
JP-KAC-013	SAIC01R	12 to 14	0.45	0.45	0.0031	0.0058	0.69%
JP-KCR-011	SAIC01R	14 to 16	1.30	1.30	0.0093	0.0061	0.72%
JP-KCR-012	SAIC01R	10 to 14	0.91	0.90	0.0065	0.0062	0.71%
JP-KCR-012	SAIC01DR	10 to 14	1.20	1.10	0.0082	0.0057	0.68%
JP-KGR-005	SAIC01R	6 to 8.5	0.93	0.92	0.0066	0.0070	0.71%
JP-KGR-005	SAIC01DR	6 to 8.5	0.55	0.54	0.0038	0.0067	0.69%
Average			0.82	0.80	0.0058	0.0061	0.71%
				97.87%	0.71%	0.75%	

**Table 6-2. Soil Total/Isotopic Uranium Analysis Summary
Jefferson Proving Ground, Madison, Indiana (Continued)**

Location I.D.	Sample I.D.	Depth (ft)	Total Uranium (mg/kg)	U-238 (mg/kg)	U-235 (mg/kg)	U-234 (mg/kg)	Weight % U-235
Loess – Under Penetrators at DU Impact Area							
JP-PNAC-001	SAIC05	0 to 4	65	65	0.1	0.01	0.20%
JP-PNCR-001	SAIC05	0 to 4	2,960	2,950	5.6	0.02	0.19%
JP-PNGR-001	SAIC05	0 to 4	47,500	47,400	92.1	0.32	0.19%
Average			16,842	16,805	32.6	0.12	0.19%
Percentage				99.78%	0.19%	0.001%	

Total uranium in the three loess soil samples collected beneath the penetrators ranged from 65 to 47,400 mg/kg, for an average of 16,842 mg/kg. As discussed in Section 2, DU contains approximately 0.20 percent of U-235 by mass; therefore, with the average percentage of the U-235 isotope present in each sample at 0.19 percent, the samples collected under penetrators indicate the presence of DU.

6.1.3.2 Nonradiological Characteristics

The 34 loess and till samples collected from the DU Impact Area and northerly background locations also were analyzed by TestAmerica for nonradiological parameters, including iron, manganese, pH, TC, TOC, and CEC by the methods specified in Section 5.2. Table 6-3 presents the results of the nonradiological parameters.

**Table 6-3. Nonradiological Parameter Values
Jefferson Proving Ground, Madison, Indiana**

Location I.D.	Sample I.D.	Depth (ft)	Iron (mg/kg)	Manganese (mg/kg)	pH	Total Carbon (mg/kg)	Total Organic Carbon (mg/kg)	Cation Exchange Capacity (meq/100 g)
Loess – Background Locations								
Avonburg/Cobbsfork								
JP-SAC-001	SAIC05	0 to 4	10,100	40	5.0	3,730	3,950	18.0
JP-SAC-002	SAIC05	0 to 4	3,430	4	4.7	4,840	3,980	8.30
JP-SAC-003	SAIC05	0 to 4	7,600	307	6.7	4,160	2,810	11.3
JP-SAC-004	SAIC05	0 to 4	9,540	26	5.3	1,840	2,020	8.00
JP-SAC-005	SAIC05	0 to 4	18,200	47	4.6	2,680	2,940	8.50
JP-SAC-005	SAIC05D	0 to 4	17,500	83	4.6	1,660	2,230	7.80
JP-SAC-006	SAIC05	0 to 4	7,290	7	6.3	2,650	2,360	8.30
JP-SAC-007	SAIC05	0 to 4	6,690	7	6.5	3,000	3,310	7.80
JP-SAC-008	SAIC05	0 to 4	8,240	62	7.6	3,420	3,430	9.00
JP-SAC-009	SAIC05	0 to 4	13,900	249	6.1	3,370	2,520	9.60
Minimum			3,430	4	4.6	1,660	2,020	7.8
Maximum			18,200	307	7.6	4,840	3,950	18
Average			10,249	83	5.7	3,135	2,955	9.7
Standard Deviation			4,815	107	1.0	987	696	3.1

**Table 6-3. Nonradiological Parameter Values
Jefferson Proving Ground, Madison, Indiana (Continued)**

Location I.D.	Sample I.D.	Depth (ft)	Iron (mg/kg)	Manganese (mg/kg)	pH	Total Carbon (mg/kg)	Total Organic Carbon (mg/kg)	Cation Exchange Capacity (meq/100 g)
Cincinnati/Rossmoyne								
JP-SCR-001	SAIC05	0 to 3.3	38,000	662	6.3	7,640	7,510	8.00
JP-SCR-002	SAIC05	0 to 3	55,900	1,940	5.6	9,140	9,530	13.3
JP-SCR-003	SAIC05	0 to 4	6,270	181	6.0	2,720	2,670	8.50
JP-SCR-004	SAIC05	0 to 4	34,100	411	6.5	1,910	1,180	9.70
JP-SCR-005	SAIC05	0 to 4	19,300	1,610	5.4	5,490	4,780	11.8
JP-SCR-006	SAIC05	0 to 4	21,700	151	4.9	2,040	2,080	8.60
JP-SCR-007	SAIC05	0 to 4	22,000	1,130	4.7	2,530	2,700	9.00
JP-SCR-008	SAIC05	0 to 4	28,300	158	4.7	2,370	2,810	9.00
JP-SCR-008	SAIC05D	0 to 4	33,200	136	4.4	3,300	3,240	9.20
JP-SCR-009	SAIC05	0 to 4	19,200	821	4.7	3,520	3,620	7.60
Minimum			6,270	151	4.4	1,910	1,180	7.6
Maximum			55,900	1,940	6.5	9,140	9,530	13.3
Average			27,797	720	5.3	4,066	4,012	9.5
Standard Deviation			13,513	652	0.8	2,522	2,598	1.8
Grayford/Ryker								
JP-SGR-001	SAIC05	0 to 4	10,900	64	4.8	1,870	1,870	7.50
JP-SGR-002	SAIC05	0 to 4	9,220	75	5.3	1,930	2,000	13.1
JP-SGR-003	SAIC05	0 to 2	20,300	1,170	5.4	11,300	11,000	14.0
Average			13,473	436	5.2	5,033	4,957	11.5
Loess Minimum			3,430	4	4.4	1,660	1,180	7.50
Loess Maximum			55,900	1,940	7.6	11,300	11,000	18.0
Loess Average			18,299	406	5.5	3,787	3,676	9.8
Loess Standard Deviation			12,691	555	0.9	2,473	2,441	2.6
Glacial Till – DU Impact Area Locations								
JP-KAC-011	SAIC01R	13 to 15	12,900	315	8.0	28,000	483	5.60
JP-KAC-012	SAIC01R	11 to 15	16,600	931	8.3	8,440	580	9.80
JP-KAC-013	SAIC01R	12 to 14	9,660	307	8.9	10,000	80	18.3
JP-KCR-011	SAIC01R	14 to 16	30,800	104	8.5	1,490	1,120	12.0
JP-KCR-012	SAIC01R	10 to 14	19,700	646	7.4	25,300	4,860	7.30
JP-KCR-012	SAIC01DR	10 to 14	12,900	541	7.7	23,100	4,680	6.00
JP-KGR-005	SAIC01R	6 to 8.5	32,700	1,110	10	7,140	5,010	17.3
JP-KGR-005	SAIC01DR	6 to 8.5	36,300	1,190	9.8	10,600	5,450	17.8
Minimum			9,660	104	7.4	1,490	80	5.6
Maximum			36,300	1,190	10.0	28,000	5450	18.3
Average			21,445	643	8.6	14,259	2,783	11.8
Standard Deviation			10,325	400	1.0	9,769	2,396	5.4
Loess – Under Penetrators at DU Impact Area								
JP-PNAC-001	SAIC05	0 to 4	7,610	9	4.8	3,580	3,670	10.5
JP-PNCR-001	SAIC05	0 to 4	20,900	1,040	5.2	3,950	2,950	12.0
JP-PNGR-001	SAIC05	0 to 4	8,800	837	6.8	26,300	23,800	27.2
Minimum			7,610	9	4.8	3,580	2,950	10.5
Maximum			20,900	1,040	6.8	26,300	23,800	27.2
Average			12,437	629	5.6	11,277	10,140	16.6
Standard Deviation			7,354	546	1.1	13,012	11,835	9.2

Figure 6-2 graphically depicts the relative abundance of iron, manganese, and TOC in the three soil types and glacial till. Figure 6-3 shows a relative comparison of total uranium, CEC, and soil pH for each of the above soils. Figures 6-2 and 6-3 do not suggest any distinct relationships between the parameters in any particular soil type other than the general proportion relationships. For example, each soil type and the till have significantly more iron than TOC than manganese. Trace levels of uranium are fairly uniform and the CEC of each respective soil and till is relatively similar. Soil pH is noticeably higher in the till than the loess soils. Values in Table 6-3 are reviewed below.

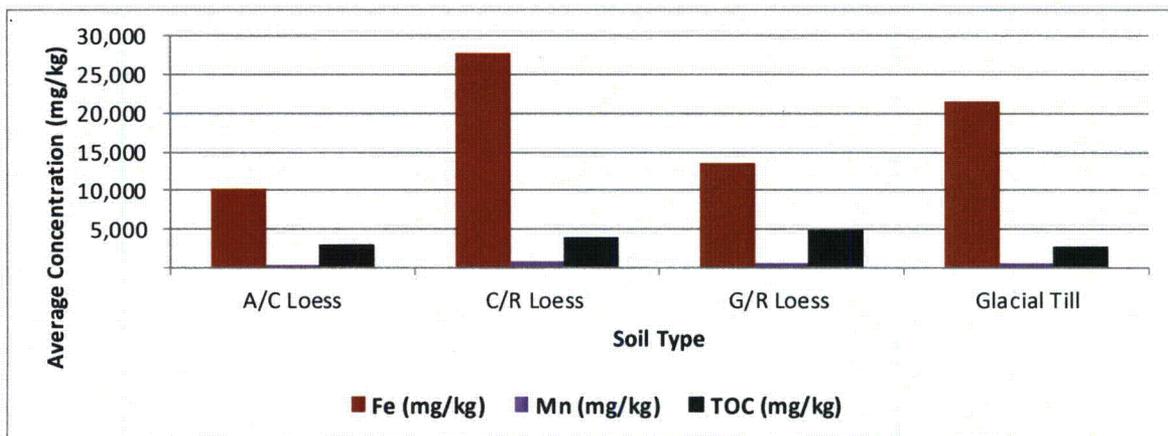


Figure 6-2. Average Iron, Manganese, and TOC Concentration Comparison of JPG Soil Types

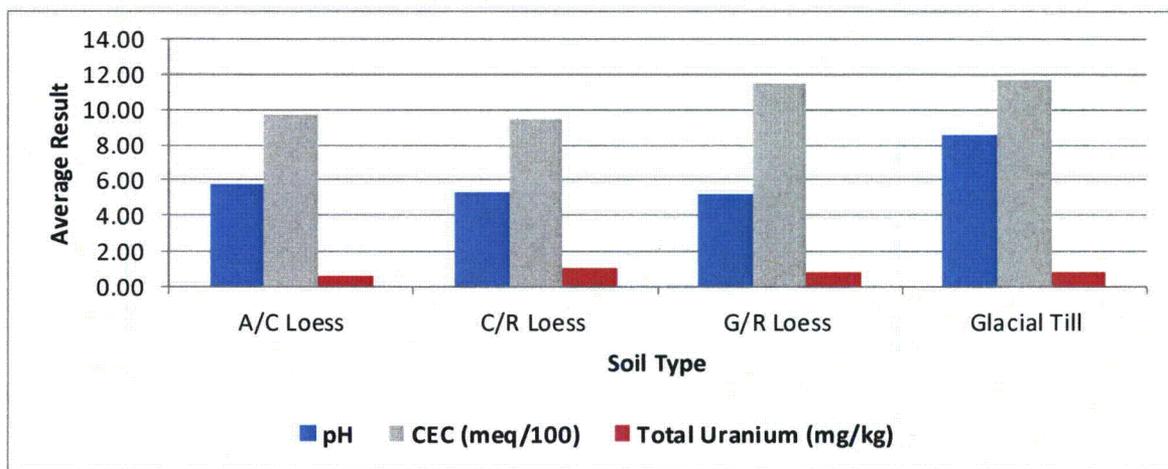


Figure 6-3. Average pH, CEC, and Total Uranium Comparison of JPG Soil Types

At background locations, iron was detected at average concentrations of 10,249, 27,797, and 13,473 mg/kg in the Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker soils, respectively. At the DU Impact Area, iron was detected at an average concentration of 21,445 mg/kg in the glacial till and at 12,437 mg/kg in loess deposits under penetrators.

Manganese was detected at much lower average concentrations of 83, 720, and 436 mg/kg in the Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker soils, respectively, at background locations. At the DU Impact Area, manganese was detected at an average concentration of 643 mg/kg in the glacial till and 629 mg/kg in loess deposits under penetrators.

TOC was detected at average concentrations of 2,955, 4,012, and 4,957 mg/kg in the Avonburg/Cobbsfork, Cincinnati/Rossmoyne, and Grayford/Ryker soil types, respectively, at background locations. At the DU Impact Area, TOC was detected at an average concentration of 2,783 mg/kg in the glacial till and 10,140 mg/kg in loess deposits under penetrators.

CEC among the four soil types ranged in average concentration from 9 to 17 milliequivalents per 100 grams of soil (meq/100g). CEC is the total negative charge of the soil representing its ability to hold positively charged cations. Both clay and organic matter have a net negative charge.

In general, pH values ranged from 4.4 to 7.6 within the background loess soil types. pH values increase with depth and range from 7.4 to 10.4 in the deeper glacial till material where there is an increased percentage of clay-sized particles.

Relationships between the trace total uranium concentrations in background soils and in the till relative to percent clay fraction, pH, CEC, TOC, iron, and manganese were evaluated more closely through tests of linearity and correlation. Concentrations of uranium for each loess soil sample and the till were correlated relative to values of the above parameters. No correlation was seen between the total uranium concentrations in loess soils relative to the average clay fraction ($R^2 = 0.026$) or soil pH ($R^2 = 0.002$) and only a very slight correlation to CEC (0.14).

In contrast, despite the very slight variation in average uranium content of the background soils and till, there was a moderate correlation with iron, manganese, and TOC content of these soils. Figures 6-4 and 6-5 show graphically the resultant correlations for iron and manganese. The correlation with iron was strongest, at an R^2 value of 0.53. Correlation with manganese was only slightly less at an R^2 value of 0.40. The distribution and correlation of TOC to uranium was very similar to that presented for iron and manganese, with the R^2 value 0.48. Correlations are consistent with the role iron, manganese, and TOC play in providing preferential partitioning sites for uranium as identified in Section 2 and discussed further in Section 8.

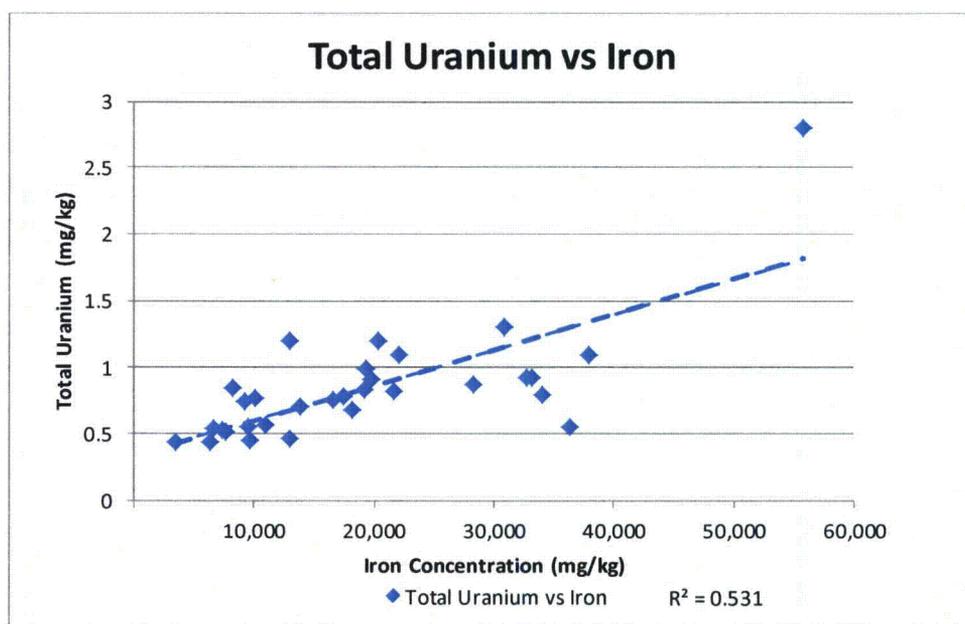


Figure 6-4. Correlation of Total Uranium and Iron in Background Soils and Glacial Till

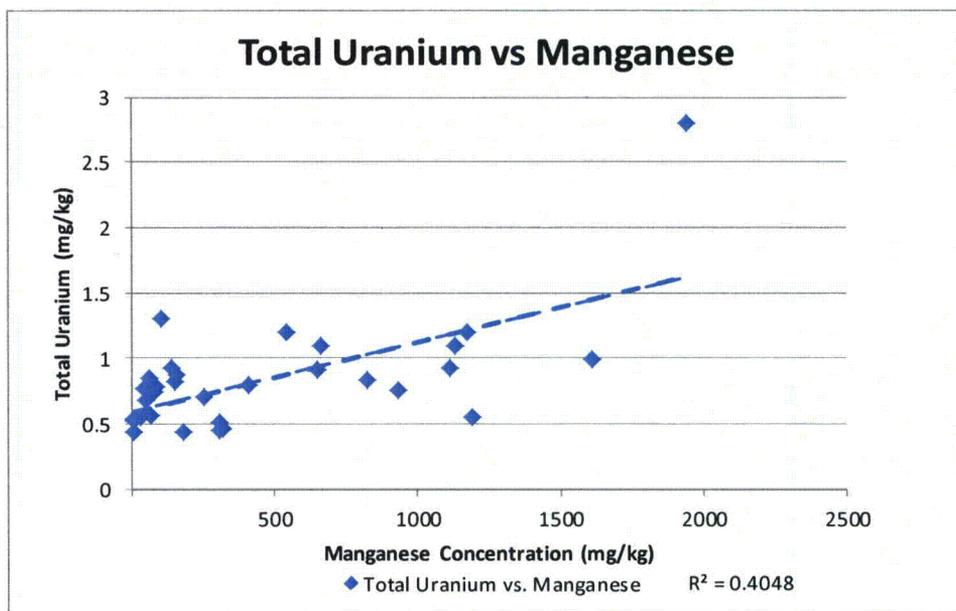


Figure 6-5. Correlation of Total Uranium and Manganese in Background Soils and Glacial Till

Given the relationship identified between trace levels of total uranium and iron and manganese, these relationships were evaluated with respect to DU in the soil samples beneath the penetrators. The evaluation indicated there was only a very slight correlation between DU and iron or manganese, with R^2 values on the order of 0.14 and 0.15, respectively. A relationship was evaluated between DU and clay fraction, soil pH, CEC, and TOC. This evaluation revealed a moderate correlation between DU and clay fraction ($R^2 = 0.40$) and nearly perfectly linear relationships with soil pH, CEC, and TOC with R^2 values of 0.98, 0.9993, and 0.993, respectively. It should be noted that the correlation factors are a function of only three data points and that additional data points would likely provide more scatter and slightly less correlation. Figures 6-6 through 6-8 graphically illustrate the relationship of DU with soil pH, CEC, and TOC.

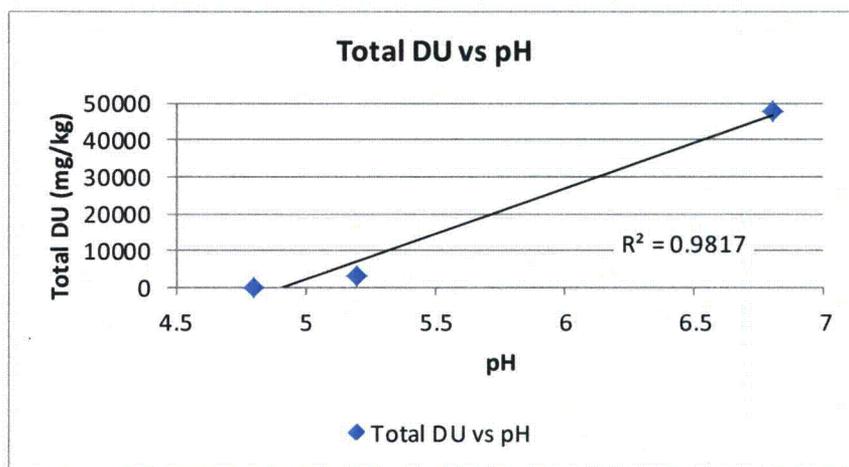


Figure 6-6. Correlation of Total DU in Soils Beneath Penetrators and Soil pH

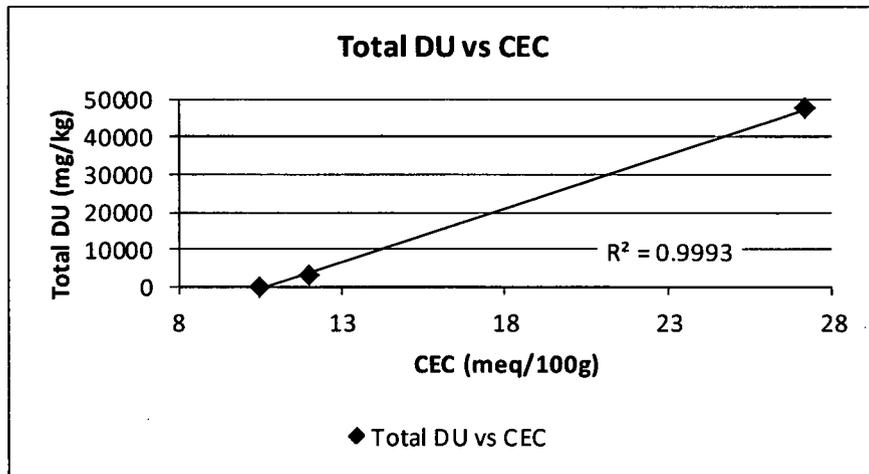


Figure 6-7. Correlation of Total DU in Soils Beneath Penetrators and CEC

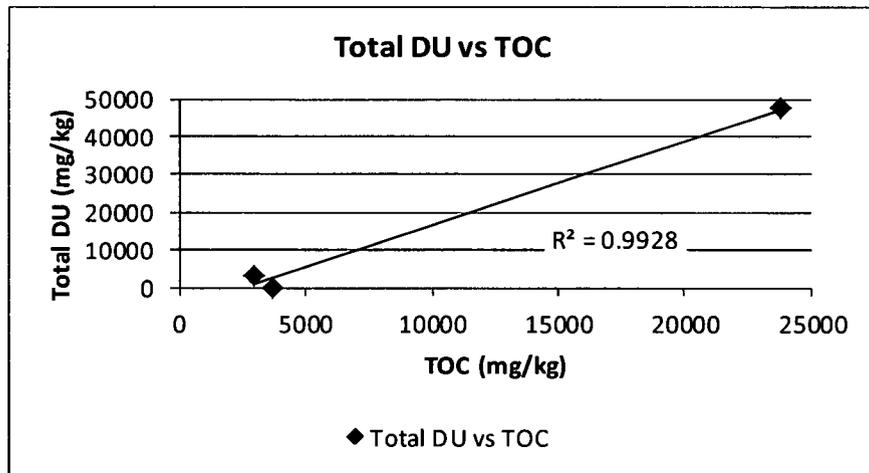


Figure 6-8. Correlation of Total DU in Soils Beneath Penetrators and TOC

Since uranium and DU have the same environmental fate due to the preponderance of U-238 isotope, these relationships suggest that at lower concentrations, uranium/DU will preferentially react with iron and manganese before other reaction surfaces and then as the concentration/mass of uranium/DU moves through the soil complex, pore water not taken into consideration at this juncture, soil pH or alkalinity, CEC, and TOC associated with clay minerals become ever more important reaction sites for partitioning.

6.2 RAINWATER CHARACTERISTICS

A presentation of the results of rainwater analyses for radiological and nonradiological parameters as analyzed by TestAmerica is provided below. Uranium isotopes were not detected at concentrations in excess of respective laboratory MDLs. Rainwater quality can be characterized as having low ionic strength and a low alkalinity.

6.2.1 Radiological Parameters

Uranium isotopes U-234, U-235, and U-238 were analyzed in the rainwater sample to confirm the sample was not impacted by DU and to aid in determining the addition of uranium tracer to the batch samples for the K_d study. Table 6-4 lists the results of the analyses.

**Table 6-4. Uranium Content of Rainwater
Jefferson Proving Ground, Madison, Indiana**

Parameters	JPG DU Area Rainwater 27 March 2012 ($\mu\text{g/L}$)
Total Uranium	ND (<0.25)
U-234	ND (<0.05)
U-235	ND (<0.05)
U-238	ND (<0.05)

None of the uranium isotopes and therefore total uranium was detected in the rainwater sample at concentrations in excess of the laboratory MDLs indicated below.

6.2.2 Nonradiological Parameters

Rainwater collected for the K_d study as described in Section 4 was tested for general chemistry parameters as listed in Section 5 to understand the characteristics of the rainwater relative to those constituents research has shown can influence uranium distribution, as discussed in Section 2. At the time of sample collection, the following field parameters were measured with a Horiba U-22 water quality meter, with the following results: temperature was 17.4°C, pH was 6.00, ORP was 376 millivolts (mV), DO was 9.13 mg/L, and turbidity was 6.3 nephelometric turbidity units (NTUs). Table 6-5 summarizes the results of the laboratory analyses for the rainwater sample.

**Table 6-5. Rainwater Composition
Jefferson Proving Ground, Madison, Indiana**

Parameters	JPG DU Area Rainwater 27 March 2012 ($\mu\text{g/L}$)
Aluminum	30
Calcium	2,930
Iron	491
Magnesium	228
Manganese	12
Potassium	423
Sodium	323
Chloride	640
Nitrate	280
Sulfate	1,000
Alkalinity	3,500
TOC	3,500
Total Inorganic Carbon	550
Silicon	128

The composition of rainwater at JPG is generally consistent with typical rainwater and can be characterized by low concentrations of dissolved ions. To aid in the characterization of the rainwater, major ions were plotted on a Stiff diagram, like the one shown in Figure 6-9. Stiff diagrams display the relative abundances of the main ionic components of water samples in milliequivalents per kilogram (meq/kg) to normalize the data. Once the data are plotted along four horizontal axes and one vertical axis, a polygonal shape develops. By convention, the anions carbonate and bicarbonate concentrations are added together for one value, as are the cations sodium and potassium for another value. Cation concentrations are plotted on the left side of the graph and anion concentrations are plotted on the right side of the graph. The resulting shape formed by connecting the data points can be used to visually group similar water samples and identify ionic imbalances, if appropriate.

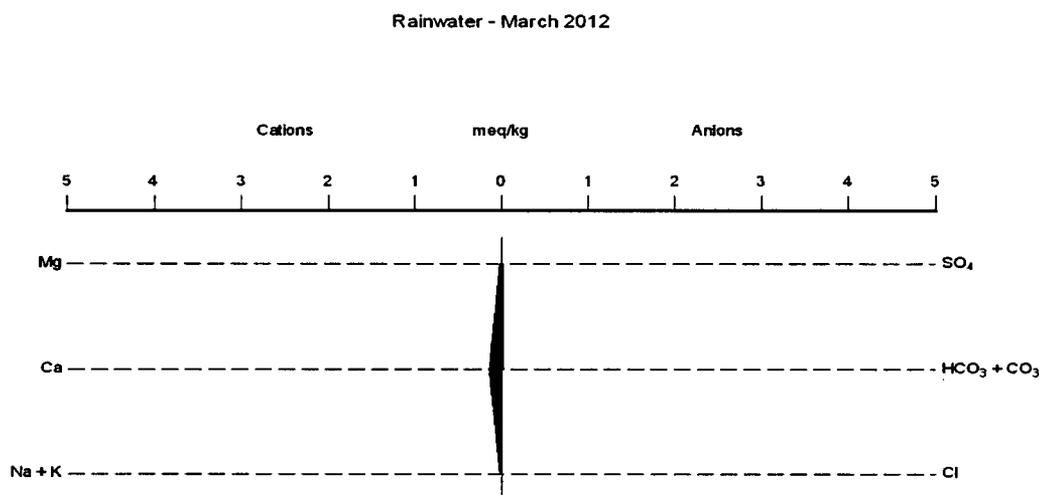


Figure 6-9. Stiff Diagram for Rainwater

The resultant Stiff diagram for the rainwater sample in Figure 6-9 shows the concentrations of the major ions listed in Table 6-5. The three major cation concentrations for the rainwater sample (sodium and potassium, magnesium, and calcium) are greater than the concentrations of the anions, carbonate and bicarbonate, sulfate, and chloride, resulting in an unbalanced ionic composition. The Stiff diagram reveals that the rainwater is soft (i.e., relatively low in calcium and very low in magnesium) and relatively low in alkalinity. USGS characterized the chemistry of rainfall from Indianapolis, Indiana, and reported the concentrations of sodium, potassium, calcium, chloride, sulfate, and nitrate at 260, 120, 690, 180, 4,000, and 2,060 $\mu\text{g/L}$, respectively. The role of the geologic setting is significant in the chemical composition of rainwater. The abundance of calcium in the local rainfall is likely the result of the extensive carbonate terrane in southern Indiana.

6.3 WELL JP-DU-060 GROUNDWATER QUALITY

The results of the laboratory analysis performed by TestAmerica for radiological and nonradiological parameters in the groundwater sample collected from overburden well JP-DU-060 are provided below. Naturally occurring uranium was detected at 4.0 $\mu\text{g/L}$, principally the U-238 isotope. Overburden groundwater quality is considerably more mineralized than rainwater and therefore has a greater ionic strength and is more alkaline.

6.3.1 Radiological Parameters

Uranium isotopes U-234, U-235, and U-238 were analyzed in the groundwater sample from JP-DU-06O to confirm the well was not impacted with DU and to aid in determining the addition of uranium tracer to the glacial till batch samples for the K_d study. Table 6-6 lists the results of the analyses.

**Table 6-6. Uranium Content of Groundwater Relative to Rainwater
Jefferson Proving Ground, Madison, Indiana**

Parameters	JPG-DU-06O Groundwater 27 March 2012 ($\mu\text{g/L}$)	JPG DU Area Rainwater 27 March 2012 ($\mu\text{g/L}$)
Total Uranium	4	ND (<0.25)
U-234	4	ND (<0.05)
U-235	0.028	ND (<0.05)
U-238	0.05	ND (<0.05)

Trace levels of naturally occurring uranium were detected in the samples as indicated below, with the principal isotope being U-238.

6.3.2 Nonradiological Parameters

Nonradiological laboratory analytical results for the March 2012 groundwater sampling event at well JP-DU-06O are presented and discussed below. These results then are compared to the historical results for rounds completed at this well in April 2008, July 2008, October 2008, and February 2009 to evaluate if the March 2012 sampling event is characteristic of the ambient groundwater quality in this well. All five of these rounds then are compared to sampling results for all overburden wells to evaluate the representativeness of JP-DU-06O groundwater relative to overburden groundwater in general. Lastly, the March 2012 groundwater analytical data are compared to rainwater to demonstrate the basic geochemical differences in the types of water. Results of these comparisons indicate that groundwater collected during the March 2012 sampling event is characteristic of ambient groundwater quality in JP-DU-06O; representative of ambient groundwater quality in overburden in general; and older, more mineralized, and more alkaline than the younger, lower ionic strength, softer rainwater.

6.3.2.1 JPG-DU-06O March 2012 Groundwater Chemistry

Groundwater collected in March 2012 for the K_d study as described in Section 4 was tested for general chemistry parameters as listed in Section 5 to understand the character of the groundwater relative to those constituents that research has shown can influence uranium distribution, as discussed in Section 2. At the time of sample collection, the following field parameters were measured with a Horiba U-22 water quality meter installed in a flow cell as described in Section 4, with the following results: temperature was 11.8°C, pH was 7.28, ORP was 13 mV, DO was 0.0 mg/L, and turbidity was 233 NTUs. Table 6-7 summarizes the results of the laboratory analyses for the groundwater sample collected in March 2012.

To further aid characterization of the JPG-DU-06O groundwater quality, a Stiff diagram was prepared to visually display the ionic composition of the groundwater sample. The Stiff diagram was prepared using the average pH of 6.97 measured during the four previous quarterly groundwater monitoring events from April 2008 through February 2009 and the value of 7.28 measured in March 2012. The range of pH was narrow, from 6.49 to 7.64.

**Table 6-7. Groundwater Quality in Well JPG-DU-060
Jefferson Proving Ground, Madison, Indiana**

Parameters	JPG DU Area Groundwater 27 March 2012 (µg/L)
Aluminum	2,380
Calcium	86,800
Iron	2,360
Magnesium	27,500
Manganese	167
Potassium	1,070
Sodium	25,800
Chloride	8,300
Nitrate	16
Sulfate	51,600
Alkalinity	329,000
TOC	1,100
Total Inorganic Carbon	79,500
Silicon	16.400

The resultant Stiff diagram prepared for the JPG-DU-060 groundwater sample collected in March of 2012, as shown in Figure 6-10, displays the relative abundances of the main ionic components found in the groundwater sample. Concentrations were first converted to meq/kg to normalize the data. Carbonate and bicarbonate concentrations were added together, as were sodium and potassium concentrations, as described for the rainwater sample. Cation concentrations then were plotted on the left side of the graph, and anion concentrations were plotted on the right side of the graph. Figure 6-10 reveals that the sum of milliequivalent concentrations of carbonate and bicarbonate is greater than either the sulfate or chloride concentrations, and the milliequivalent concentration of calcium is greater than either the sum of sodium and potassium or magnesium. The cation and anion compositions seem to be fairly equal based on the areas on either side of the graph.

6.3.2.2 March 2012 Relative to Historical Groundwater Quality in JP-DU-060

Piper and Stiff diagrams of the ionic composition of groundwater samples for the four previous sampling rounds from 2008 to 2009 referenced above were constructed to confirm that the ionic composition of the unfiltered groundwater sample collected from JPG-DU-060 in March 2012 is representative of the previous four samples collected at JPG-DU-060 and the groundwater samples collected at other overburden wells.

The Stiff diagrams created for the five total groundwater samples collected from JPG-DU-060 (Figures 6-10 through 6-14) were compared, and it was visually confirmed that the ionic composition of the March 2012 groundwater sample is consistent with three of the four other groundwater samples collected prior to 2012. The July 2008 groundwater sample (Figure 6-12) shows a marked decrease in anion concentrations. This decrease in anion concentrations also is seen for other overburden groundwater samples collected in July 2008.

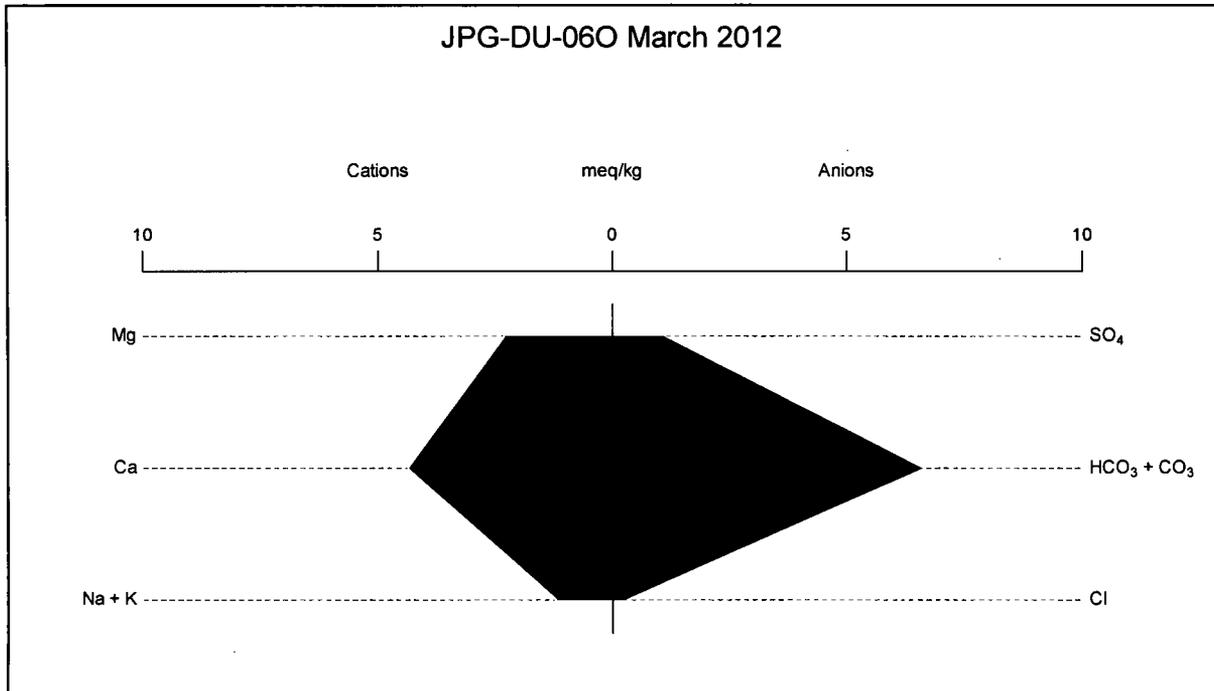


Figure 6-10. JPG-DU-060 March 2012 Groundwater Chemistry

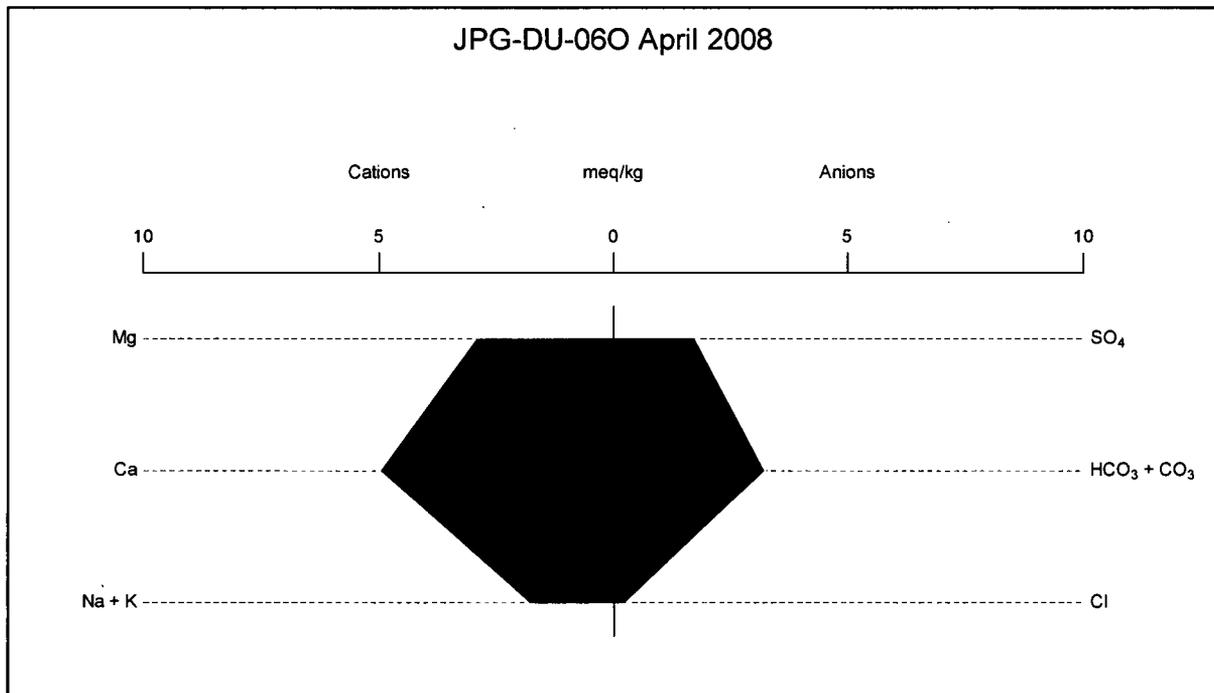


Figure 6-11. JPG-DU-060 April 2008 Groundwater Chemistry

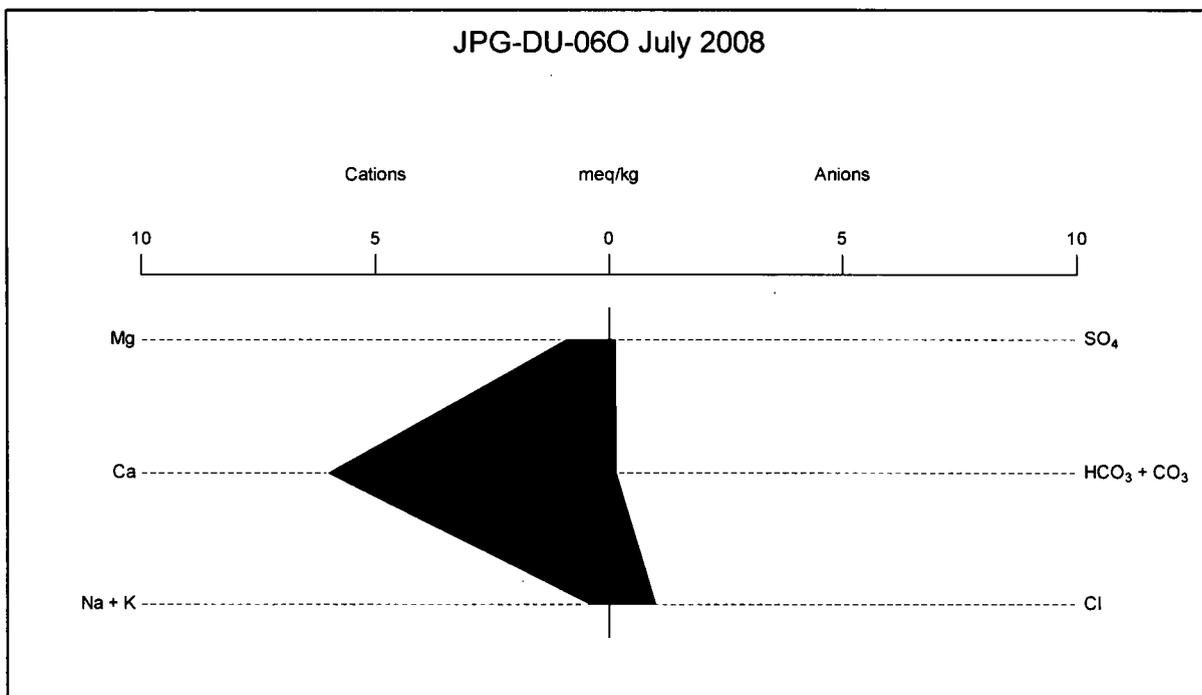


Figure 6-12. JPG-DU-060 July 2008 Groundwater Chemistry

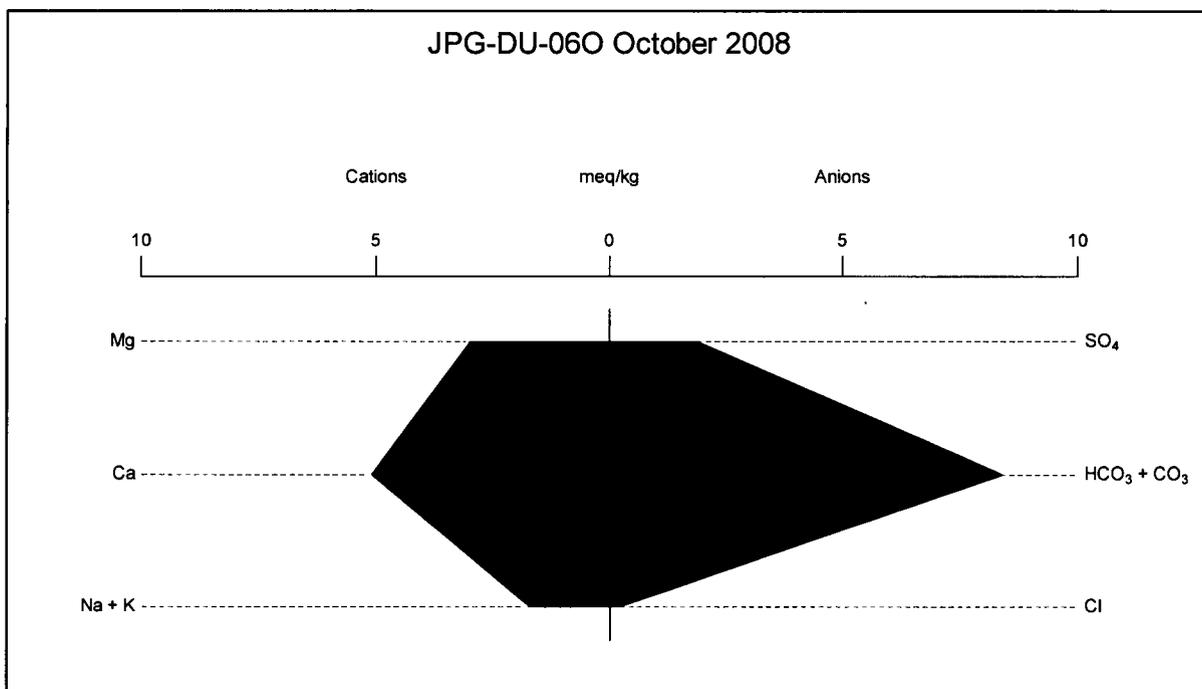


Figure 6-13. JPG-DU-060 October 2008 Groundwater Chemistry

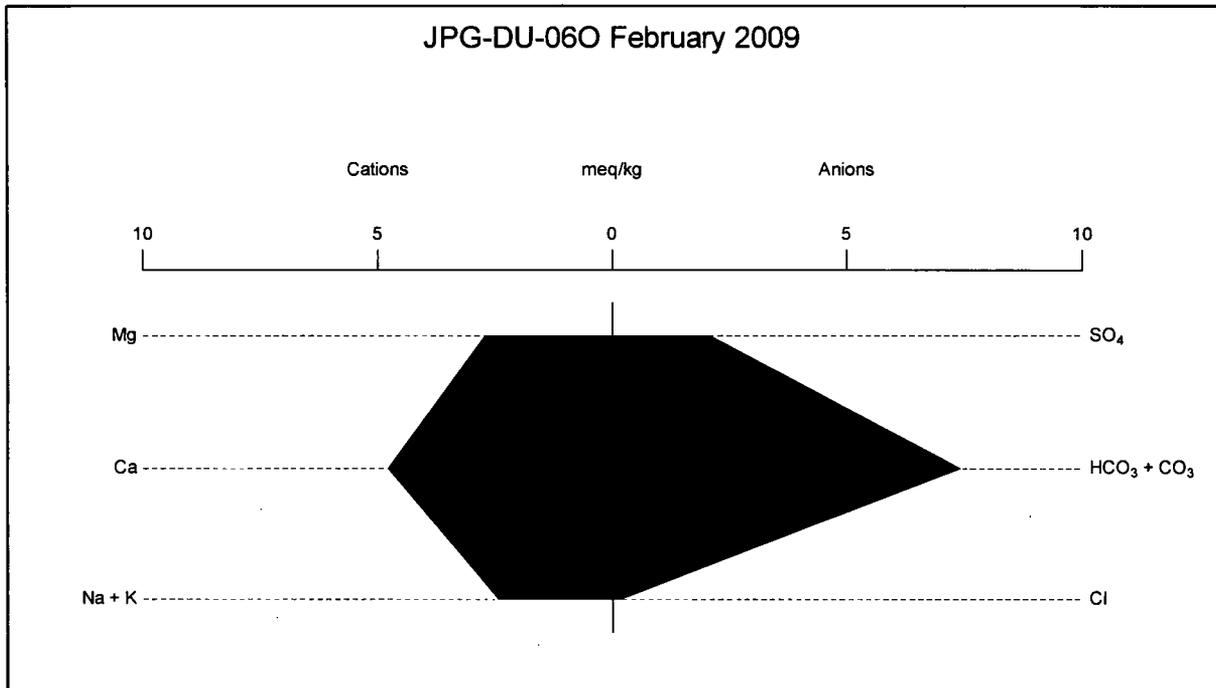


Figure 6-14. JPG-DU-060 February 2009 Groundwater Chemistry

A Piper diagram also was created to visually display the similarities and differences between the groundwater samples collected from JPG-DU-060 through time. Ionic milliequivalent concentrations are plotted on two tertiary plots, one for the cations (bottom left of Figure 6-15) and the other for the anions (bottom right of Figure 6-15). The same ions that are plotted in the previously mentioned Stiff diagrams are used in the tertiary plots. These two tertiary plots then are translated to a quaternary plot, the large diamond shape in Figure 6-15. Four of the five data points, each representing a different sampling event, are located in a relatively tight cluster. The July 2008 data point is clearly an outlier. As mentioned previously, all overburden wells sampled in July 2008 showed a large decrease in the abundance of anions. The Piper diagram shown in Figure 6-15 visually confirms that the March 2012 groundwater sample collected from JPG-DU-060 is representative of the ambient groundwater quality typically present in this well.

6.3.2.3 Well JP-DU-060 Groundwater Quality Relative to General Overburden Groundwater Quality

Ion concentrations for the March 2012 sampling event at JP-DU-060 were plotted on a Piper diagram along with the April 2008 through February 2009 sampling round data for all overburden wells to evaluate how representative groundwater from JPG-DU-060 is relative to overburden groundwater in general. On Figure 6-16, the black circle represents March 2012 groundwater from JPG-DU-060. The black circle is generally tightly surrounded by a large cluster of points representing other overburden well water quality. Three points representing JPG-DU-100 are outliers from the main cluster of points.

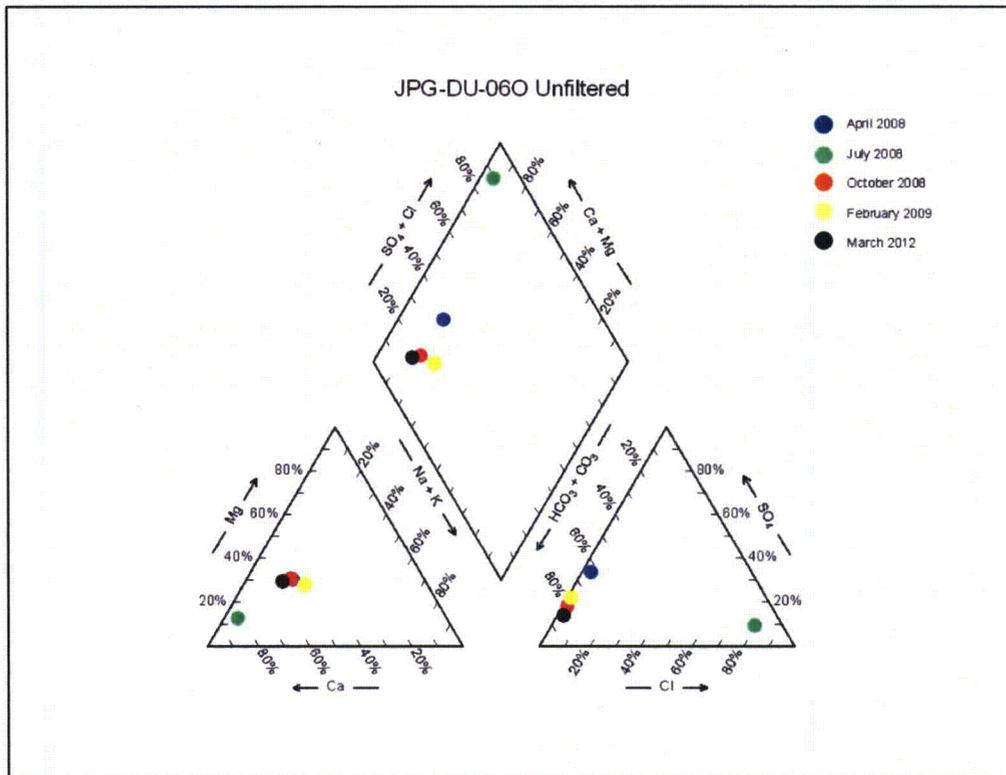


Figure 6-15. JPG-DU-060 Groundwater Chemistry – Piper Diagram

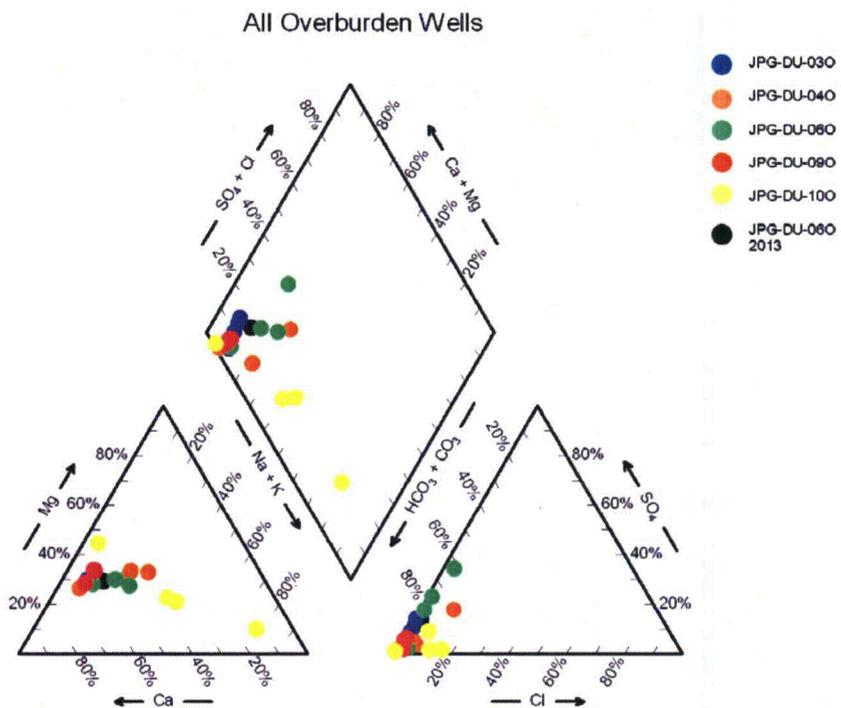


Figure 6-16. JPG-DU-060 Groundwater Chemistry Relative to Overburden Groundwater Quality

Figure 6-16 also shows that the groundwater collected from the overburden wells is characterized by high concentrations of calcium, magnesium, carbonate, and bicarbonate, similar to groundwater quality in JP-DU06O. Other ions are present in the water samples but the aforementioned ions dominate the ionic composition of the water. The three points representing JPG-DU-100 that are outliers are dominated by sodium, potassium, carbonate, and bicarbonate. Because the point representing the March 2012 groundwater collected from JPG-DU-06O is located within a cluster of points representing other overburden wells, the March 2012 groundwater sample is representative of groundwater samples collected from the five other overburden wells that were sampled during the 2008 to 2009 sampling events.

6.3.2.4 Well JPG-DU-06O Water Quality Compared to Rainwater Quality

Finally, groundwater quality in JPG-DU-06O was compared to rainwater quality to demonstrate the differences in water quality, specifically ionic strength. Table 6-8 shows the laboratory analytical results for the groundwater and rainwater samples discussed above, for comparative analysis. Table 6-8 shows the contrast in the more mineralized higher ionic strength groundwater relative to the low concentrations found in the softer, ionically weak rainwater. The concentrations of 12 of the analytes listed in Table 6-8 are greater for the March 2012 groundwater sample collected at JPG-DU-06O than the March 2012 rainwater. The concentrations of two analytes, nitrate and TOC, are greater for the rainwater sample than the groundwater sample. The seven metals listed in Table 6-8 are all more abundant in the groundwater sample. The groundwater concentrations of the metals vary from 2.5 times the concentration of the rainwater (potassium) to 120 times the concentration of the rainwater (magnesium). The concentrations of chloride, sulfate, alkalinity, and total inorganic carbon found in the groundwater also are greater than those found in the rainwater. The groundwater concentrations of these compounds vary from 13 times the concentration of the rainwater (chloride) to 145 times the concentration of the rainwater (total inorganic carbon). The concentration of silicon in the groundwater is also 128 times greater than the rainwater concentration. Nitrate and TOC are, however, more abundant in the rainwater sample. The nitrate concentration for rainwater is 17.5 times greater than that of the groundwater, and the TOC concentration is 3 times greater than that of the groundwater.

**Table 6-8. Well JPG-DU-06O Groundwater Quality Relative to Rainwater Quality
Jefferson Proving Ground, Madison, Indiana**

Parameters	JPG-DU-060 Groundwater 27 March 2012 (µg/L)	JPG DU Area Rainwater 27 March 2012 (µg/L)
Aluminum	2,380	30
Calcium	86,800	2,930
Iron	2,360	491
Magnesium	27,500	228
Manganese	167	12
Potassium	1,070	423
Sodium	25,800	323
Chloride	8,300	640
Nitrate	16	280
Sulfate	51,600	1,000
Alkalinity	329,000	3,500
TOC	1,100	3,500
Total Inorganic Carbon	79,500	550
Silicon	16,400	128
TDS	205,993	6,357

Major ions for samples collected in March 2012 were compared using Stiff and Piper diagrams. The Stiff diagrams presented earlier for each sample are shown in Figure 6-17 to visually demonstrate the differences in ionic strength of the two waters. The Stiff diagram for JPG-DU-06O shows that both anions and cations are present in significant quantities. In contrast, the Stiff diagram for rainwater shows that ionic contributions are very small. Cations and anions are equally represented in the March 2012 groundwater sample; however, cations dominate the rainwater sample with very little anionic contribution.

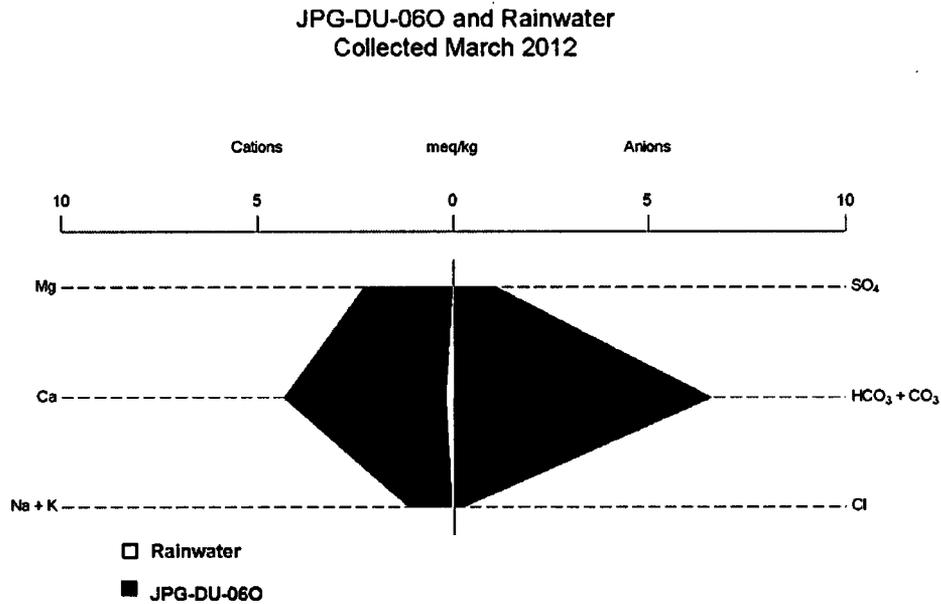


Figure 6-17. Combined Stiff Diagrams for March 2012 JPG-DU-06O Groundwater and Rainwater

A Piper diagram (Figure 6-18) also was created to compare the groundwater and rainwater samples collected in March 2012. The two points are located on different sides of the diamond plot, clearly showing that the groundwater and rainwater samples have different ionic compositions.

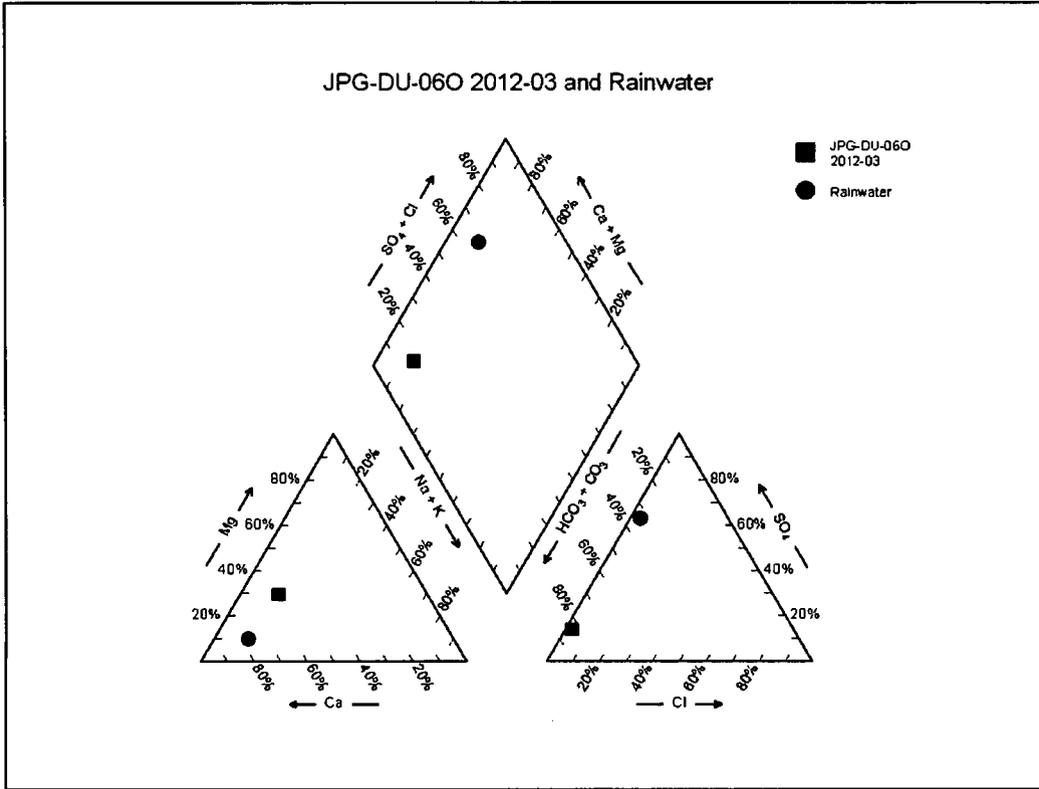


Figure 6-18. JPG-DU-06O Groundwater and Rainwater March 2012

7. K_d STUDY RESULTS

As indicated in Section 4, SAIC recollected soil samples and contact solution from 27 through 30 March 2012. Samples were submitted to TestAmerica, who processed the soil samples, characterized soil and contact solution samples, and performed the batch analyses for uranium for determination of the uranium K_d . At the completion of a round of contact solution analyses, TestAmerica reported the uranium analyses for the contact solutions. These analytical results were progressively forwarded to SAIC for QA/QC review, calculation of K_d values, and progressive reduction and analysis. The results of the total uranium analytical results used to calculate respective K_d values are summarized in a spreadsheet in the Attachment herein.

As the K_d study proceeded, these data were reviewed to determine the point at which a sample had reached equilibrium and the batch analyses for a given sample could cease. A review of the basic characteristics and tests that SAIC utilized to decide when to cease further batch testing and make a final determination of individual sample K_d values is provided below. Following discussion of equilibration determination, results of the assessment of uranium plating to bottleware are presented. These results are important to the K_d study because the laboratory-derived K_d values required correction for this plating effect. Following the presentation of plating corrected K_d values, the calculated sorbed uranium masses for loess and till sorption tests is compared to the laboratory determined final mass of uranium sorbed to soil for perspective on the calculated mass balance. The section concludes with presentation of uranium isotope partitioning.

7.1 BATCH TEST EQUILIBRATION, TERMINATION, AND INITIAL K_d VALUE DETERMINATION

A number of semi-quantitative and quantitative measures were utilized to evaluate batch sample data to arrive at: 1) identification of solid-contact solution equilibration, 2) a consistent set of criteria to terminate batch testing, and 3) determination of a sample representative K_d value. The ASTM guidance provides information to guide the setup and execution of the batch method for K_d determination; however, it is up to the user of the guidance to determine when the above objectives have been reached. The principal trait sought in the resultant string of batch tests was that point in time at which concentrations of the contaminant of interest, in this case uranium, did not change significantly from one analysis to the next, or asymptotically plateau, indicating that the uranium in solution has effectively partitioned to the soil matrix to the extent possible for that sample or removed from solute phase by other phenomena such as precipitation or co-precipitation. Evaluation of the data sets for each sample set in the K_d study indicated that: 1) batch sample concentrations did eventually plateau, beginning typically in 20 to 30 days from the start of a test, allowing termination of testing typically after 60 days but sometimes not until 120 days; and 2) although there is some subjectivity in determining when the concentration plateau appears, the resultant calculation of K_d is not that sensitive to late time changes in concentration out on the plateau, with very robust K_d values the end result.

The principal techniques used to arrive at the objectives stated above were as follows:

- Concentration-time scatter plots
- Best-fit straight line correlation
- Mann-Kendall statistical testing
- Outlier testing
- Relative percent differences (RPDs).

Results of the above analytical techniques collectively provided the basis for judgment regarding when a batch test had reached equilibrium or effective uranium partitioning had been reached and a reliable K_d value had been obtained. Each technique is discussed briefly below.

Critical to understanding the progression of analytical results over time from the batch testing of a sample were observations from scatter plots of uranium concentrations over time. Figure 7-1 provides an example of the type of scatter plots produced for each batch sample, in this case one of the loess soil samples. The graphs served to illustrate: 1) changes in contact solution uranium concentrations over time, 2) the transition to relatively stable concentrations or the plateau defined above, and 3) the basis for best-fit line correlation analysis. The graphs provided the first, best feel for solid-contact solution equilibration and uranium partitioning in a given sample.

Once a preliminary understanding of sample equilibration was gained from scatter plot shape, late time concentration data were analyzed quantitatively to assess concentration stabilization and equilibration. The first quantitative measure of equilibration was fitting a best-fit straight line through concentrations at 28 days through day 60, the test duration at which many batch tests ended, with R^2 calculated for two subsets of time, one for day 28 through 45 and one for day 28 through 60. Best-fit straight line correlation is an automatic statistical fit of a trend line through all or a portion of a data string to test for linearity, with linearity being a trait of solid-contact solution equilibration and demonstration of effective uranium adsorption. Once contact solution uranium concentrations changed little from one analysis to the next, scatter plots of paired concentration and time data should be very linear. Perfect linearity is equivalent to an R^2 value of 1, with lack of linearity equal to -1.

A test of linearity alone does not ensure confirmation of equilibration. Concentrations increasing or decreasing uniformly over time can display good linearity just as a constant concentration over time does. Therefore, late time data (day 14 to 45 and day 14 to 60) were subjected to the Mann-Kendall statistical test (USEPA 2007) to determine with a statistical degree of certainty whether concentrations were increasing, decreasing, or whether no change or true equilibration had been achieved. The Mann-Kendall test is a nonparametric test, where no assumption of normality of data is required, which uses time to determine the trend in a central value, in this case uranium concentrations. The Mann-Kendall test determines if a central value is increasing, decreasing, or not changing (no trend) over time.

Another statistical test applied to late time batch data was outlier testing to determine if a value deviated markedly from other sample observations. The outlier testing was performed to help identify a value whose origin may have been other than sample variation. Rosner outlier testing (USEPA 2007) was performed on two data sets: day 14 to 45 and day 14 to 60, at significance levels of 10, 5, and 1 percent.

Lastly, RPD were calculated for late time analyses beginning with day 7, as a semi-quantitative measure of stability and equilibrium. As a given sample approached equilibrium over time, relative changes in uranium concentration from the last analytical result, expressed as a percentage, should change very little.

Figure 7-1 presents a scatter plot for sample JP-SAC-002, a background loess soil from the Avonburg/Cobbsfork soil series, to demonstrate the evaluation of batch data for test termination determination and K_d value selection. The Attachment contains batch sample K_d calculation summary sheets with contact solution uranium concentration data and calculated K_d values and scatter plots of uranium concentration over time and K_d values over time. The Attachment also contains a summary sheet of quantitative analysis results described above for each batch sample.

Figure 7-1 shows two plots, one of uranium concentration changes over time (blue line) and the other K_d value changes over time (green line). First, the scatter plot of uranium concentrations over time illustrates the early decline in extract uranium concentrations seen at most samples within the first 20 to 30 days of test initiation, followed by relatively stable concentrations thereafter. From day 28 to the last test before termination (day 60 in the case of this test), uranium concentrations changed very little, on the order of 1 to 2 hundredths of a $\mu\text{g/L}$ in a range from 0.25 to 0.27 $\mu\text{g/L}$. Visually, the scatter plot looks very stable. Values of K_d from day 28 to the end of the test varied from 1,826 to 1,974 mL/g, for an average of 1,899 mL/g. These values compare to values for K_d of 475 to 1,548 mL/g from day 3 to 21.

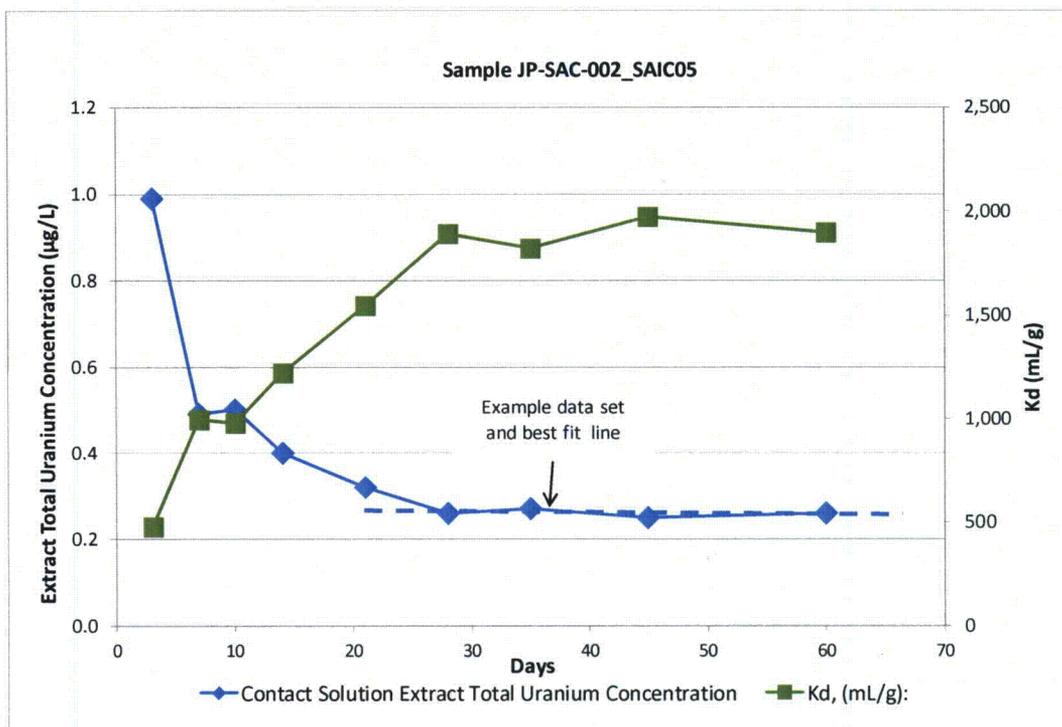


Figure 7-1. Loess Soil Contact Solution Uranium Concentration Versus K_d Value

Visually, the scatter plot of uranium concentrations suggests very good linearity, with essentially no change in the trend of concentrations after day 28. Calculation of day 28 to 60 correlation coefficient returned an R^2 value of 0.09 and 0, a value that suggested little systematic increase or decrease in value. Comparison of the R^2 values of this sample relative to samples that returned R^2 values in the range of 0.7 to 0.9 or higher experienced late time concentration variations on the order of thousands of $\mu\text{g/L}$ as opposed to hundredths of $\mu\text{g/L}$ as in this sample. More importantly, the slope of the best fit line through the late time data (day 28 to 60) at -0.0002 is almost indistinguishable from zero, indicating essentially no net change in value, a relatively stable uranium concentration in solution and therefore inferred soil partitioning equilibrium.

The Mann-Kendall test of late time uranium concentrations from day 28 to the end of the test period indicated no trend, indicating an absence of statistically significant change in uranium concentrations after day 28. Outlier testing for this sample for day 14 to 45 or day 14 to 60 did not identify any outliers at a significance level of 1 percent, suggestive of a uniform data set. Lastly, RPDs from day 28 onward were in the range of 3.8 to 7.7 percent, which compares to the average RPDs of 13.6 to 18.6 percent for all of the sample sets for this same timeframe.

Using the visual observations from the scatter plot combined with the quantitation metrics discussed above, the day 28 to 60 batch samples were felt to be most representative of solid-contact solution equilibration and effective partitioning. The resultant K_d value for sample JP-SAC-002 then was an average of the day 28 to 60 calculated K_d values, or 1,899 mL/g. The remainder of the K_d values were selected with the same analytical evaluation process, with some slight variations as discussed in the K_d results in Section 7.3.

7.2 BOTTLEWARE URANIUM PLATING EVALUATION

As listed in Table 3-1, the 14 January 2011 letter from the Army to NRC reiterates that NRC was concerned about potential losses of uranium adhering to filter container walls and other laboratory ware, or uranium plating. The four acid rinsate blanks prepared and analyzed by TestAmerica confirmed that the uranium isotope U-238 will “plate” or sorb slightly to HDPE plastic bottleware. Neither of the other isotopes U-235 or U-234 was detected in the acid rinsate at concentrations in excess of the laboratory MDL. The mass of U-238 plated to the containers can directly influence the final calculated K_d value for a sample.

The acid rinsate blanks were prepared as described in Section 5. To briefly summarize, four of the field samples (three loess soils, one type each and one glacial till) were identified for use as the blanks (see Table 7-1). After the batch sample for a given day had the contact solution extracted and analyzed for isotopic uranium, the sample container was emptied and rinsed with deionized water, followed by a rinse with dilute nitric acid to etch the inside of the bottle to remove any potentially sorbed uranium. A portion of the nitric acid solution used to etch the bottle then was analyzed for uranium isotopes to determine the potential for glassware plating.

Table 7-1 lists the results of the acid rinsate blank isotopic uranium analyses. The U-238 isotope was detected in acid rinsate from every batch sample bottle. Concentrations ranged from 0.012 to 0.20 $\mu\text{g/L}$, for an average of 0.06 $\mu\text{g/L}$. This average concentration sorbed to glass represented anywhere from 0.1 to 556 percent of the contact solution extract uranium concentration. Average plated U-238 concentrations for the three loess soil samples varied widely, from 4.5 percent up to the maximum of 556 percent of the contact solution extract U-238 concentration. The percentage of bottle sorbed U-238 in the till sample was negligible in concentration relative to the concentration in the contact solution extracts.

**Table 7-1. Acid Rinsate Blank Isotopic Uranium Analytical Results
Jefferson Proving Ground, Madison, Indiana**

Day	JP-SAC-007-SAIC05			JP-SCR-004-SAIC05			JP-SGR-002-SAIC05			JP-KAC-011-SAIC01R		
	Acid Rinsate Blank U-238 (ug/L)	Contact Solution Extract (ug/L)	Blank-to-Extract (%)	Acid Rinsate Blank U-238 (ug/L)	Contact Solution Extract (ug/L)	Blank-to-Extract (%)	Acid Rinsate Blank U-238 (ug/L)	Contact Solution Extract (ug/L)	Blank-to-Extract (%)	Acid Rinsate Blank U-238 (ug/L)	Contact Solution Extract (ug/L)	Blank-to-Extract (%)
Day 3	0.025	0.46	5.4%	0.026	1.1	2.4%	0.046	0.032	143.8%	0.018	13.4	0.1%
Day 7	0.036	0.22	14.1%	0.025	1.2	2.1%	0.059	0.033	178.8%	0.016	14	0.1%
Day 10	0.021	0.23	8.4%	0.049	0.88	5.6%	0.11	0.033	333.3%	0.012	13.5	0.1%
Day 14	0.033	0.16	17.1%	0.046	1.2	3.8%	0.16	0.036	444.4%	0.013	14.9	0.1%
Day 21	0.016	0.14	10.3%	0.057	1.6	3.6%	0.17	0.039	435.9%	0.028	13.3	0.2%
Day 28	0.042	0.15	21.9%	0.082	1.2	6.8%	0.17	0.033	51.5%	0.024	13.7	0.2%
Day 35	0.044	0.14	23.9%	0.2	1.5	13.3%	0.14	0.038	368.4%	0.018	13.4	0.1%
Day 45	0.070	0.15	31.8%	0.054	2.5	2.2%	0.2	0.036	555.6%	0.025	13.7	0.2%
Day 60	0.035	0.14	20.0%	0.018	2.6	0.7%	0.14	0.029	482.8%	0.021	14.1	0.1%
Day 90	--	--	--	--	--	--	--	--	--	--	--	--
Day 120	--	--	--	--	--	--	--	--	--	--	--	--
AVERAGE:	0.036	0.20	17.0%	0.062	1.53	4.5%	0.13	0.034	332.7%	0.019	13.78	0.1%
Day 14-60 Average:	0.040		Day 21-60 Average:	0.082		Day 21-60 Average:	0.163	Day 21-60 Average:	0.023			

7.3 FINAL PLATING CORRECTED K_d VALUES

Uranium results for the acid rinsate blanks indicate that U-238 likely plated to each container within the experimental range defined by the acid rinsate blanks, requiring correction of the strictly laboratory-derived K_d values. The principal assumption for correcting the K_d values was that the mass of uranium plated to the containers was uranium mass that should have remained in solution and not further partitioned to the solid phase in each sample. The sound basis for this assumption was that each of the four samples that were used for the acid rinsate blanks had a residual amount of U-238 in the contact solution extracts, indicating that U-238 in solution had effectively partitioned to the soil phase, so that any U-238 sorbed to the bottles was a fraction artificially removed from each contact solution, or liquid phase. Central to this explanation of plating is that using acid to rinse each blank bottle removed all of the plated uranium mass and all of that uranium mass hypothetically would have returned to each contact solution to raise the uranium concentration in the solute with a mass equivalent to the concentration measured in the acid rinsate blanks. The close range of plated uranium concentrations in the acid rinsate from day to day and the appearance of a late time plateau in uranium concentrations leads to the conclusion that all plated mass was removed. The sections that follow present the methods and results of K_d value correction for loess soils, the till, and the dissolution-desorption samples

7.3.1 *Plating Correction Method*

Original laboratory determined K_d values determined through the process reviewed in Section 7.1 were corrected by combining the average total uranium concentration from all acid rinsates determined for each loess soil type with the laboratory measured concentrations determined for each contact solution for each testing day. Table 7-1 above lists the individual total uranium concentrations for each acid rinsate blank and plated uranium averages at the bottom of the table. The table also indicates the range of days that the average values were determined from. The range of days corresponded to the general range of days used to determine the original K_d values for that soil type, as explained in Section 7.1. For example, K_d values for samples from the Avonburg-Cobbsfork soils, as represented by sample SAC-007_SAIC05, were generally determined from K_d values determined for batch samples between day 21 and 60. So, the average plating concentration from sample SAC-007_SAIC05 was calculated from the range of values for acid rinsate samples from day 21 to 60. Figure 7-2 is a graph that shows the concentrations of uranium measured in acid rinsate blanks over time. The graph also shows (text boxes and dashed lines) the average values used in the K_d value corrections for that set of samples for a given soil type. Although there were some variations in total uranium concentrations in acid rinsate collected later in the testing period, the average values were selected to best represent the magnitude of uranium plating.

Table 7-2 lists the original calculated K_d value for a given sample as determined by the process described in Section 7.1 relative to the recalculated value adjusting for the average plated mass of U-238 for a given soil type, as described above in this section. The table shows original and recalculated individual and average soil type K_d values. Lastly, the table presents what is termed the 'K_d Correction Factor,' which is simply the percent change or percent decrease in concentration from the original to corrected value. K_d values corrected in direct proportion to the magnitude of partitioning, which is shown graphically in Figure 7-3. The figure shows the correlation between original K_d values and the correction factor expressed as a decimal. The relationship appears exponential, as the K_d value increases in magnitude, the net effect of uranium plating becomes more significant to the K_d value correction. This relationship is explained as follows. The more that uranium partitions to soil in the sample bottle, the lower the remaining mass that is left in solution. The addition then of the plating mass with the low remaining solution mass significantly changes the original ratio of the soil sorbed mass relative to the dissolved mass; therefore, the K_d values decline.

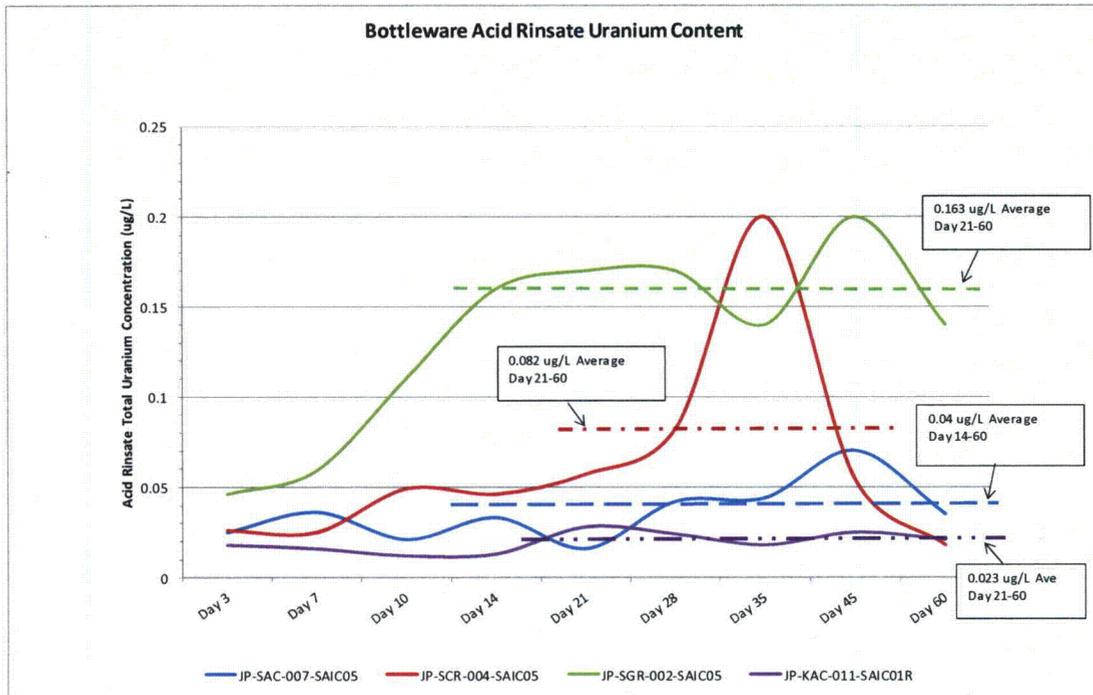


Figure 7-2. Acid Rinsate Blank Total Uranium Concentrations Over Time and Average Values Used in K_d Value Correction

**Table 7-2. Corrected K_d Values After Discounting Uranium Plating
Jefferson Proving Ground, Madison, Indiana**

Soil Type	Sample ID	Lab ID	Original K_d (mL/g)		Bottleware Plating Adjusted K_d (mL/g)		K_d Correction Factor (%)
			Individual Test	Soil Type	Individual Test	Soil Type	
Desorption by Loess Soil Types				429		429	
Avonsburg/Cobbsfork	JP-PNAC-001_SAIC05	F2C310414-007	189		189		0%
Cincinnati/Rossmoyne	JP-PNCR-001_SAIC05	F2C310414-005	591		591		0%
Greyford/Ryker	JP-PNGR-001_SAIC05	F2C310414-006	507		507		0%
Groundwater Sorption for Glacial Till				8.4		8.4	
Avonsburg/Cobbsfork	JP-KAC-011_SAIC01R	F2C290434-004	0.93		0.93		0%
Avonsburg/Cobbsfork	JP-KAC-012_SAIC01R	F2C300498-003	1.03		1.03		0%
Avonsburg/Cobbsfork	JP-KAC-013_SAIC01R	F2C300498-004	0.97		0.96		1%
Cincinnati/Rossmoyne	JP-KCR-011_SAIC01R	F2C290416-002	11.7		11.70		0%
Cincinnati/Rossmoyne	JP-KCR-012_SAIC01R	F2C290434-002	--		--		
Greyford/Ryker	JP-KGR-005_SAIC01DR	F2C290416-004	16		16.00		0%
Greyford/Ryker	JP-KGR-005_SAIC01R	F2C290416-003	20		20.00		0%
Rainwater Sorption for Loess Soil Types				7,069		1,954	
Avonsburg/Cobbsfork				4,008		2,290	
Avonsburg/Cobbsfork	JP-SAC-001_SAIC05	F2C300498-014	4,184		2,501		40%
Avonsburg/Cobbsfork	JP-SAC-001_SAIC05D	F2C300498-016	4,010		2,435		39%
Avonsburg/Cobbsfork	JP-SAC-002_SAIC05	F2C300498-012	1,899		1,646		13%
Avonsburg/Cobbsfork	JP-SAC-003_SAIC05	F2C290416-005	2,455		1,058		57%
Avonsburg/Cobbsfork	JP-SAC-004_SAIC05	F2C300498-008	6,496		3,831		41%
Avonsburg/Cobbsfork	JP-SAC-005_SAIC05	F2C290434-010	6,308		3,132		50%
Avonsburg/Cobbsfork	JP-SAC-006_SAIC05	F2C290416-009	3,007		2,024		33%
Avonsburg/Cobbsfork	JP-SAC-007_SAIC05	F2C290416-007	1,722		1,347		22%
Avonsburg/Cobbsfork	JP-SAC-008_SAIC05	F2C290416-006	2,843		1,610		43%
Avonsburg/Cobbsfork	JP-SAC-009_SAIC05	F2C290416-008	7,159		3,315		54%
Cincinnati/Rossmoyne				8,714		2,363	
Cincinnati/Rossmoyne	JP-SCR-001_SAIC05	F2C300498-009	9,458		3,069		68%
Cincinnati/Rossmoyne	JP-SCR-001_SAIC05D	F2C300498-015	8,463		2,234		74%
Cincinnati/Rossmoyne	JP-SCR-002_SAIC05	F2C300498-011	17,043		4,470		74%
Cincinnati/Rossmoyne	JP-SCR-003_SAIC05	F2C300498-013	9,328		2,284		76%
Cincinnati/Rossmoyne	JP-SCR-004_SAIC05	F2C290434-012	59		57		3%
Cincinnati/Rossmoyne	JP-SCR-005_SAIC05	F2C300498-007	12,538		2,436		81%
Cincinnati/Rossmoyne	JP-SCR-006_SAIC05	F2C290434-009	9,028		2,270		75%
Cincinnati/Rossmoyne	JP-SCR-007_SAIC05	F2C290434-007	8,467		1,500		82%
Cincinnati/Rossmoyne	JP-SCR-008_SAIC05	F2C290434-005	2,413		656		73%
Cincinnati/Rossmoyne	JP-SCR-009_SAIC05	F2C290434-008	10,340		2,347		77%
Greyford/Ryker				8,485		1,208	
Greyford/Ryker	JP-SGR-001_SAIC05	F2C310414-003	3,893		1,089		72%
Greyford/Ryker	JP-SGR-001_SAIC05D	F2C310414-004	3,655		1,073		71%
Greyford/Ryker	JP-SGR-002_SAIC05	F2C310414-002	6,860		1,248		82%
Greyford/Ryker	JP-SGR-003_SAIC05	F2C300498-010	19,533		1,421		93%

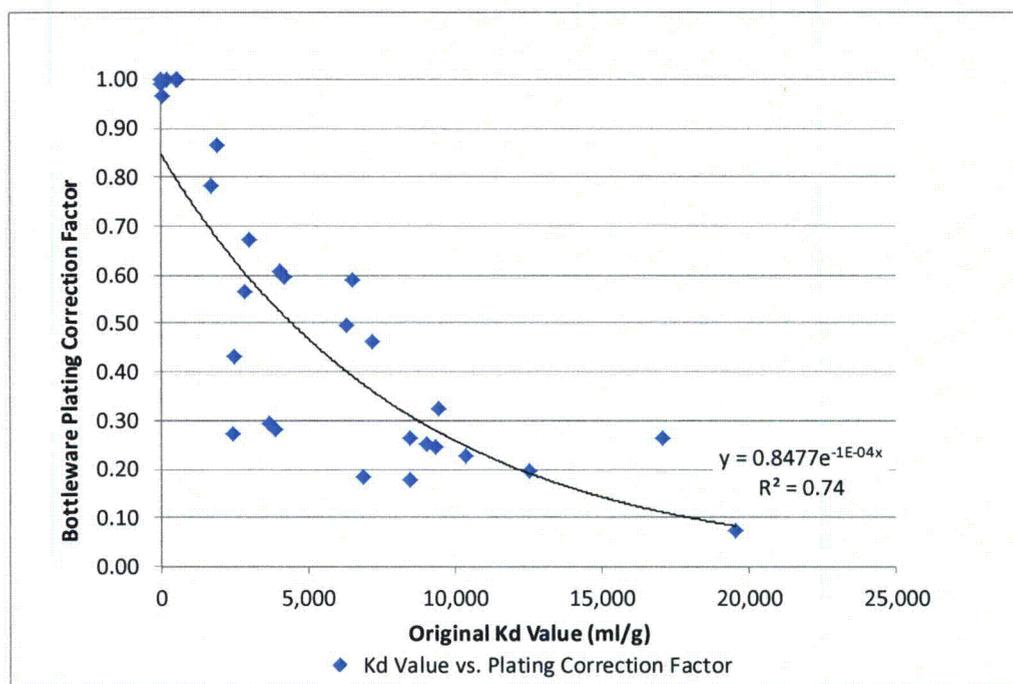


Figure 7-3. Correlation of Uranium Plating Correction Factor Versus Original K_d Value

For the till and dissolution-desorption samples, the remaining mass of uranium in solution by the end of these tests was higher than the small mass plated to the bottle, so combining the solution and plated mass had a negligible effect on the solid to solution mass ratio. The corrected K_d values for the till and desorption-dissolution samples hardly differ from the original K_d values. For the loess soil samples where the combination of soil and water characteristics promoted strong partitioning, leaving little uranium in solution by the end of these tests, addition of the plated mass significantly changed the solid to solution mass ratio. As a result, plating corrected K_d values for loess soils adjusted lower in value from initial laboratory-derived values by 3 to 93 percent, for an average decline of 62 percent.

7.3.2 Loess Soils Final Plating Corrected K_d Values

The plating corrected K_d values calculated for loess-derived soils ranged from 57 to 4,470 mL/g, for an overall average for the three groups of 1,954 mL/g. Initial K_d values arrived at through the batch process reviewed in Section 7.1 were very robust for a sample given the typical stability or uniformity of total uranium concentrations after effective partitioning was achieved. Uranium concentrations in the respective late time (typically day 28 to end of batch test at day 60 to 120) batch samples only varied by 10 percent. K_d values calculated for each principal soil type are presented below.

Table 7-2 lists the final plating corrected K_d values for the nine Avonburg/Cobbsfork samples and one duplicate from 0 to 4 ft BGS. Minimum and maximum K_d values were 1,347 and 3,831 mL/g, respectively. The average for this soil group was 2,290 mL/g, close to the loess soil average of 1,954 mL/g. Batch samples for this soil type appeared to reach equilibration or effective adsorption within 14 to 21 days, with the uranium spike in sample JP-SAC-004-SAIC05 principally partitioned by day 3. Two samples, JP-SAC-002-SAIC05 and JP-SAC-003-SAIC05, reached effective partitioning in 28 days. Uranium in the contact solution extracts for four samples, listed below, declined to estimated concentrations less than the laboratory reporting limit/minimum detectable concentration (MDC) but above the MDL within 7 to 21 days and by day 3 for JP-SAC-009-SAIC05.

Final plating correct K_d values for the nine Cincinnati/Rossmoyne samples from 0 to 4 ft BGS ranged from 57 to 4,470 mL/g, for an average for this soil group of 2,363 mL/g. Samples for this soil type appeared to reach equilibration or effective adsorption within 14 to 28 days, with the uranium in the contact solution in JP-SCR-009-SAIC05 principally adsorbed by day 3. Uranium concentrations in the contact solutions for all nine Cincinnati/Rossmoyne samples declined to less than the laboratory MDC but above the laboratory MDL of 0.025 $\mu\text{g/L}$ early in the batch analyses, typically less than 28 days. Eight of the nine samples had uranium reported at estimated concentrations between the laboratory MDC/MDL by day 21, with six of the nine samples beginning with the first batch samples at day 3. Lastly, the K_d value calculated and corrected for JP-SCR-004-SAIC05 was anomalously low for the group, at approximately 57 mL/g. Uranium concentrations in extracts for this sample appeared to equilibrate between day 14 and 35 at 1.2 to 1.6 $\mu\text{g/L}$ but then steadily increased thereafter to the end of the test at day 120, suggesting the geochemistry of the solid-contact solution had changed and uranium was desorbing from the solid. Nonetheless, the resultant K_d value remains for consideration in the soil group.

Lastly, final plating corrected K_d values for the three Grayford/Ryker samples and one duplicate from 0 to 4 ft BGS ranged from 1,073 to 1,421 mL/g, respectively. The average for this soil group was 1,208 mL/g, which was approximately 50 percent of the average K_d values for the other two more predominant loess soil types. Samples for this soil type appeared to reach equilibration or effective partitioning within 14 to 28 days, with the uranium spike in JP-SGR-002-SAIC05 principally partitioned by day 3. Uranium in the contact solution for two of the three samples, listed below, reached estimated concentrations less than the laboratory MDC but above the MDL early in the batch analyses, in less than 3 days.

7.3.3 Glacial Till Final Plating Corrected K_d Values

Table 7-2 lists the final plating corrected K_d values for the six glacial till samples and one duplicate sample collected from depths between 6 and 16 ft BGS that used groundwater as the contact solution. The dominant characteristic of these tests was the apparent low affinity for uranium distribution from groundwater migrating through the till horizon. Plating corrected K_d values did not differ from original values calculated from the laboratory determined uranium concentrations, for the reasons presented in Section 7.2. Corrected K_d values for till ranged from 0.93 and 20 mL/g, for an average of 8.4 mL/g. A K_d value was not reported in Table 7-2 for sample JP-KCR-012-SAIC01R because the resultant uranium soil-solution ratios yielded a negative value.

The groundwater from JP-DU-06O was used as the contact solution for all six samples and the duplicate. Groundwater from this background well contained naturally occurring uranium at a concentration of approximately 4.0 $\mu\text{g/L}$, as reported in Section 6. This groundwater was then spiked with a mass of uranium equivalent to 10.0 $\mu\text{g/L}$, to bring starting uranium concentrations to 14 $\mu\text{g/L}$. Successive analyses of batch sample contact solution extracts indicated little of this naturally occurring and supplemented uranium sorbed to the till samples. Contact solution uranium concentrations were on the order of 13 to 14 $\mu\text{g/L}$ from day 3 onwards, with uranium concentrations in sample JP-KCR-012-SAIC01R in the range of 18 to 20 $\mu\text{g/L}$ for the entire test duration. There was generally greater variability in contact solution uranium concentrations for these till samples over the course of each test than for the loess samples. Only the till sample (and duplicate) JP-KGR-005 from beneath the Grayford/Ryker soil series showed a steady decline in uranium concentrations over time. Uranium in the day 3 batch sample was reportedly at a concentration of 10.6 $\mu\text{g/L}$, with day 60, 90, and 120 samples containing uranium at concentrations in the range of 7 to 8.6 $\mu\text{g/L}$. Although there was greater variation in concentrations over time in the till samples, the magnitude of that variation was not that significant, resulting in fairly robust K_d values estimated typically from the day 21 to 60 subsets of uranium concentrations.

7.3.4 Desorption-Dissolution Final Plating Corrected K_d Values

Table 7-2 lists the desorption-dissolution distribution ratios (R_d) for the three loess soil samples from beneath penetrators subjected to soaking in rainwater. These tests evaluated the capability for rainwater to desorb and possibly dissolve DU from the most impacted soils onsite and therefore do not constitute partition coefficients, or K_d values, which predict the ease with which uranium would partition to those soils from an aqueous solution. These R_d values can be used to infer analogous partitioning or K_d values. Results of the desorption-dissolution tests provided further insight into DU distribution in terms of: 1) the reversible nature of DU partitioning, and 2) the role of adsorption versus precipitation/coprecipitation in contributing to DU distribution. Both of these aspects are discussed further in Section 8.

Desorption-dissolution tests consisted of soaking soils with elevated concentrations of DU corroded off the penetrators and further dissolved and sorbed onto soils beneath a penetrator in rainwater. Because the soil fraction already was impacted with DU, as presented in Section 6, rainwater was not spiked further with uranium.

Resultant R_d values ranged from 189 to 591 mL/g, for an average of 429 mL/g. Plating corrected values did not change from the initial values calculated from the batch samples. As presented in Section 6, DU concentrations in soil at the start of the tests ranged from 64.8 to 47,500 mg/kg and by the end of the test (day 6 to 120) ranged slightly lower from 57.3 to 39,973 mg/kg. On a percent mass basis, desorption-dissolution of uranium over 60 to 120 days resulted in removal of from 10.2 to 15.8 percent of the original uranium. Uranium concentrations in final batch sample contact solution extracts ranged from 297 to 304 mg/L.

In terms of equilibration, sample JP-PNAC-001, where the initial uranium concentration in soil was 64.8 mg/kg, achieved an equilibrium desorption-dissolution rate within approximately 14 days. Samples JP-PNCR-001 and JP-PNGR-001 peaked early in the test, stabilized over the middle portion of the test, then began to increase in the rate of desorption-dissolution from day 60 to 120 (Attachment). The R_d values for these last two samples were determined from the middle portion of the batch tests, with the R_d value for sample JP-PNAC-001, terminated at day 60, was from a similar range of data.

7.3.5 Corrected Final K_d Value Summary

In summary, the uranium plating evaluation indicated that container sorption will occur and can influence K_d values. The evaluation indicates that principally U-238 will sorb to the container matrix, thereby lowering the apparent mass of uranium remaining in solution. The net effect appears to be the potential for over prediction of partitioning and under prediction of mobility, particularly where geochemical conditions are optimum for promoting partitioning as in the shallow loess soils. Where the potential for partitioning is low based on controlling geochemical factors, the influence of uranium plating on K_d value estimation is reduced, possibly to a level of little to no impact.

Correction of the empirically derived K_d values was judged prudent based on the apparent relationships between solution mass, soil sorbed mass, and plating mass, and the subsequent effects on the solid-to-solution mass ratio. Uranium plating to bottleware at the laboratory scale is a factor that must be evaluated on a sample by sample basis and potentially accounted for. The corrected values listed in Table 7-2 are discussed in Section 8 relative to the biogeochemical factors, which were introduced in Section 2 that can influence uranium/DU partitioning at the laboratory and field scale. This discussion is then taken into consideration in Section 9, where final recommended K_d values are presented within the context of the DU Impact Area CSM.

7.4 CONTACT SOLUTION pH AND K_d VALUES

As indicated in Section 5, the pH of the contact solution extract was measured on each extraction day along with the pH of a laboratory blank consisting of a similar type bottle filled with the same type of unspiked contact solution, but with no soil. Tables 7-3 and 7-4 list the measured pH values over time for loess soils and till, respectively. Table 7-4 also lists the dissolution-desorption pH values.

**Table 7-3. K_d Study Loess Soil Contact Solution Extract pH Over Time
Jefferson Proving Ground, Madison, Indiana**

Sample Identification	Initial pH of Contact Solution ¹	Post Standard Spike Adjusted pH ²	Contact Solution Extract pH On Extraction Day										
			3	7	10	14	21	28	35	45	60	90	120
Avonsburg/Cobbsfork - Adsorption Tests - Rainwater													
SAC Bottleneck Blank	6.88	6.91	6.83	6.43	6.57	6.08	6.19	5.32	5.52	5.26	5.83	5.76	
JP-SAC-001_SAIC05			7.35	5.67	5.68	4.95	5.46	4.87	5.25	4.85	4.92	4.89	5.37
JP-SAC-001_SAIC05D			7.24	5.69	5.66	5.08	5.37	4.98	5.07	4.84	5.22	5.07	5.34
JP-SAC-002_SAIC05			7.25	5.30	5.20	4.68	4.99	4.53	4.9	4.66	5.35	4.83	5.07
JP-SAC-003_SAIC05			7.34	6.18	6.34	5.84	6.37	5.40	5.68	5.20	5.88	5.62	6.44
JP-SAC-004_SAIC05			7.27	5.61	5.73	5.08	5.34	4.85	5.14	4.64	5.28	5.12	5.39
JP-SAC-005_SAIC05			7.29	5.69	5.73	5.03	5.20	4.71	5.07	4.91	5.19	4.95	5.28
JP-SAC-006_SAIC05			7.34	5.53	5.53	5.07	5.24	4.67	5.10	4.76	5.91	5.02	5.42
JP-SAC-007_SAIC05			7.14	5.48	5.41	4.84	4.97	4.57	4.90	5.31	4.96	4.92	5.27
JP-SAC-008_SAIC05			7.09	6.33	6.32	5.74	5.96	5.36	5.70	4.67	5.95	5.70	6.27
JP-SAC-009_SAIC05	7.33	6.10	6.18	5.59	5.89	5.29	5.52	4.78	5.82	5.80	5.99		
SAC Average:			7.26	5.76	5.78	5.19	5.48	4.92	5.23	4.86	5.45	5.19	5.58
Cincinnati/Rossmoyne - Adsorption Tests - Rainwater													
SCR-SGR Bottleneck Blank	6.88	6.91	6.88	7.05	6.88	5.70	6.00	6.05	5.71	5.36	5.75	5.45	6.90
JP-SCR-001_SAIC05			6.92	7.01	7.12	6.36	6.74	6.62	6.23	6.30	6.56	6.19	6.12
JP-SCR-001_SAIC05D			7.09	6.98	7.19	6.68	7.29	6.61	6.20	6.24	6.40	6.17	6.20
JP-SCR-002_SAIC05			6.45	6.54	6.75	5.91	6.77	6.07	5.81	5.83	6.15	5.68	5.75
JP-SCR-003_SAIC05			6.73	6.71	6.87	6.07	6.90	6.31	6.00	6.06	6.27	5.83	5.99
JP-SCR-004_SAIC05			7.69	7.70	7.73	7.16	7.89	7.35	7.17	7.28	7.64	7.56	7.29
JP-SCR-005_SAIC05			5.86	6.08	6.48	5.61	6.53	5.75	5.64	5.73	6.25	5.78	5.82
JP-SCR-006_SAIC05			5.24	5.48	5.56	5.02	5.53	5.24	5.22	5.09	5.71	5.44	5.42
JP-SCR-007_SAIC05			5.39	5.62	5.75	5.18	5.93	5.35	5.32	5.08	5.96	5.52	5.33
JP-SCR-008_SAIC05			4.85	4.87	5.01	4.49	4.61	4.00	4.57	4.39	4.77	4.49	4.48
JP-SCR-009_SAIC05	5.28	5.49	5.61	5.10	5.68	5.24	5.14	4.92	5.67	5.36	5.35		
SCR Average:			6.15	6.25	6.41	5.76	6.39	5.85	5.73	5.69	6.14	5.80	5.78
Greyford/Ryker - Adsorption Tests - Rainwater													
SCR-SGR Bottleneck Blank ³	6.88	6.91	6.88	7.05	6.88	5.70	6.00	6.05	5.71	5.36	5.75	5.45	6.90
JP-SGR-001_SAIC05			5.31	5.42	5.37	5.14	5.61	5.11	5.14	5.30	5.57	5.13	5.30
JP-SGR-001_SAIC05D			5.23	5.35	5.40	4.98	5.58	5.10	5.02	5.20	5.43	5.23	5.27
JP-SGR-002_SAIC05			6.33	6.42	6.55	6.21	6.73	6.18	5.83	5.92	6.33	5.91	5.88
JP-SGR-003_SAIC05			6.25	6.55	6.76	6.51	6.96	6.18	5.76	5.79	6.13	5.72	5.82
SGR Average			6.00	6.16	6.19	5.71	6.18	5.72	5.49	5.51	5.84	5.49	5.83

1: measured on receipt of rainwater and groundwater samples at laboratory.

2: Average value for rainwater between 6.72 and 7.18; see Table 5-3

3: Same blank as for the Cincinnati-Rossmoyne soils.

LCS Blank: Laboratory blank consisting of unspiked contact solution only, no soil, in same type of bottle/ware for each extraction/analysis day.

NM: not measured

NA: not applicable

**Table 7-4. K_d Study Till and Loess Desorption-Dissolution Contact Solution Extract pH Over Time
Jefferson Proving Ground, Madison, Indiana**

Sample Identification	Initial pH of Contact Solution ¹	Post Standard Spike Adjusted pH ²	Contact Solution Extract pH On Extraction Day										
			3	7	10	14	21	28	35	45	60	90	120
Glacial Till - Adsorption Tests - Groundwater													
Till Bottleneck Blank	7.45	7.47	7.72	6.76	6.26	6.74	8.08	7.52	7.55	7.95	7.83	7.78	7.86
JP-KAC-011_SAIC01R			7.79	7.79	7.83	7.96	8.11	7.65	7.70	6.27	7.94	7.92	7.91
JP-KAC-012_SAIC01R			7.85	7.78	7.80	8.08	8.16	7.52	7.65	7.96	8.06	8.02	7.93
JP-KAC-013_SAIC01R			7.83	7.81	7.78	7.97	8.18	7.70	7.65	7.96	8.04	8.03	7.99
JP-KCR-011_SAIC01R			7.39	7.52	7.40	7.79	7.96	7.35	7.13	7.53	8.01	7.58	7.36
JP-KCR-012_SAIC01R			7.71	7.68	7.63	7.95	7.96	7.41	7.53	5.87	7.92	7.73	7.78
JP-KGR-012_SAIC01DR			NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
JP-KGR-005_SAIC01DR			7.65	7.62	7.54	7.87	7.82	7.17	7.31	7.91	7.85	7.69	7.64
JP-KGR-005_SAIC01R			7.57	7.55	7.55	7.89	7.87	7.19	7.29	7.68	7.92	7.60	7.75
Till Average:					7.68	7.68	7.65	7.93	8.01	7.43	7.47	7.31	7.96
Loess Soil Beneath Penetrator - Desorption Tests - Rainwater													
Desorption Bottleneck Blank	6.88	6.91	7.01	7.85	7.90	8.24	5.82	5.98	5.85	5.45	6.60	5.87	5.88
JP-PNGR-001_SAIC05			7.75	7.54	7.47	7.82	7.41	7.29	7.44	7.10	7.63	7.54	7.02
JP-PNAC-001_SAIC05			4.92	5.02	5.78	5.30	4.34	4.53	4.75	5.09	4.97	4.85	5.02
JP-PNCR-001_SAIC05			5.28	5.24	5.25	5.35	4.69	4.89	5.00	4.88	5.02	5.23	5.29
Desorption Average:					5.98	5.93	6.17	6.16	5.48	5.57	5.73	5.69	5.87

1: measured on receipt of rainwater and groundwater samples at laboratory.

2: Average value for rainwater between 6.72 and 7.18; see Table 5-3

3: Same blank as for the Cincinnati-Rossmoyne soils.

LCS Blank: Laboratory blank consisting of unspiked contact solution only, no soil, in same type of bottle are for each extraction/analysis day.

NM: not measured

NA: not applicable

Figures 7-4 through 7-8 show the average variation in pH over time for the three principal loess soil groups, the till and the desorption-dissolution tests, respectively, relative to the variation in laboratory blank pH. The tables and particularly the figures for the loess soils show how the samples and the laboratory blank acidified slightly over time. The rate and magnitude of the pH changes in respective laboratory blanks was very similar to the general changes in the pH of the field sample extracts. This effect was quantified by correlating field sample and blank pH values in Figure 7-9, where correlation coefficients were on the order of 0.3 to 0.7.

The trend in pH for the till sample extracts was to remain fairly uniform in a tight range of 7 to 8, consistent with the initially determined contact solution pH values. The laboratory blank for the till samples acidified slightly early on but then appeared to rebound back to a similar range as the soil solution extract pH. Lastly, the loess soils beneath penetrators subjected to desorption-dissolution tests were split. Sample JP-PNGR-001_SAIC05 maintained a slightly alkaline pH between 7 and 7.5 for the duration of the tests relative to measured pH values for the other two slightly acidic samples with pH values in the range of 4.3 to 5.8. The laboratory blank for this sample set started at a neutral pH (7.01), increased to 8.24 by day 14, then progressively acidified (5.88) to the end of the test (day 120).

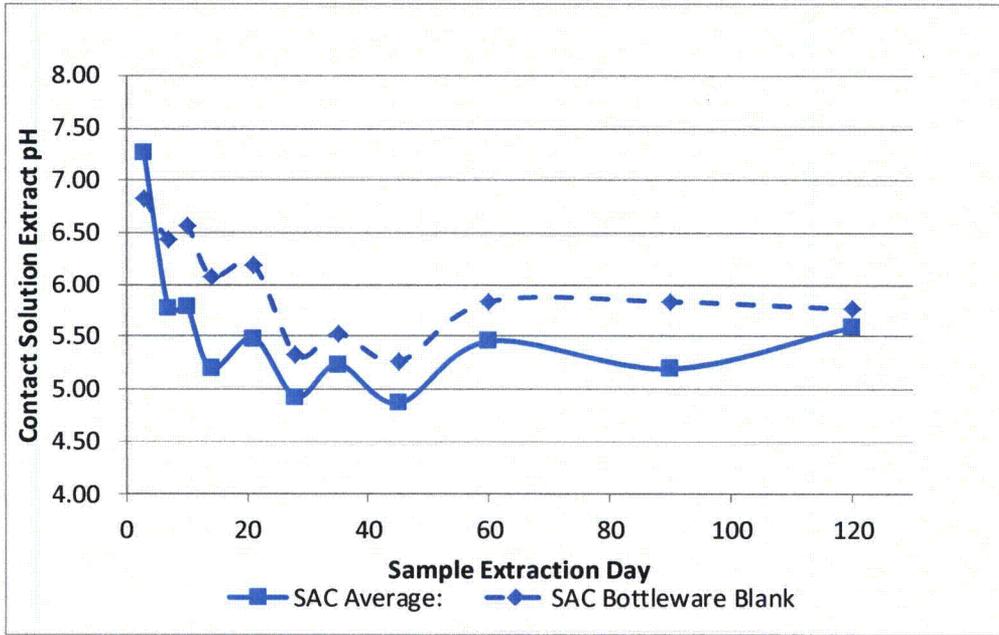


Figure 7-4. Avonburg-Cobbsfork Soil Contact Solution Extract pH Over Time

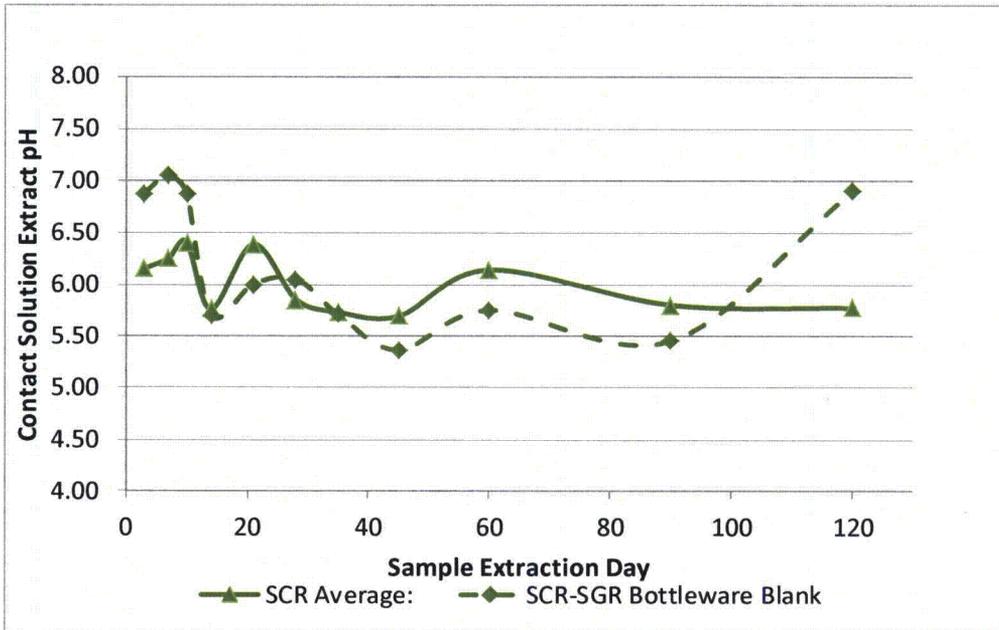


Figure 7-5. Cincinnati-Rossmoyne Soil Contact Solution Extract pH Over Time

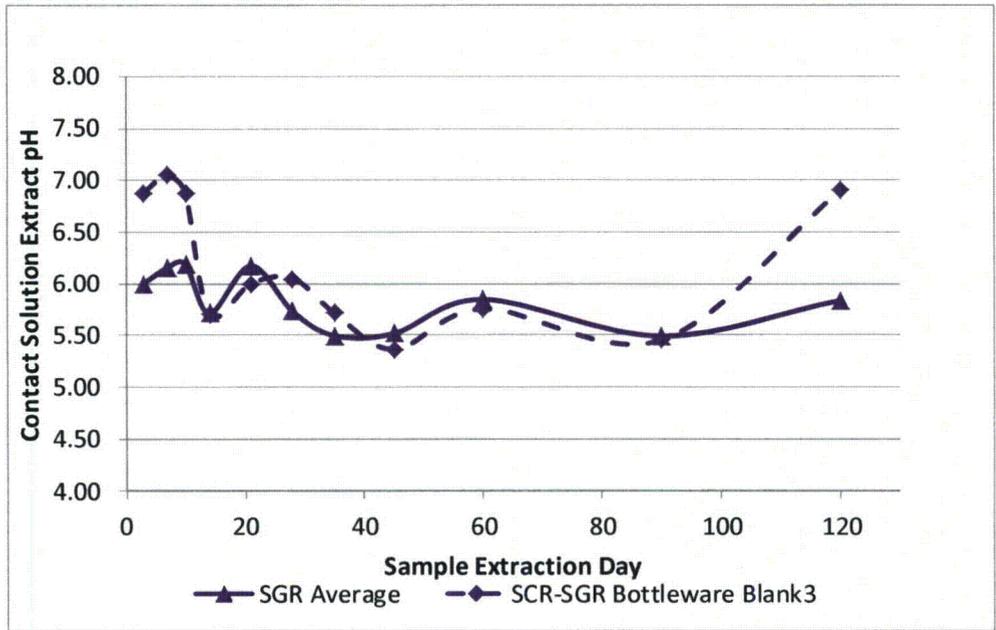


Figure 7-6. Grayford-Ryker Soil Contact Solution Extract pH Over Time

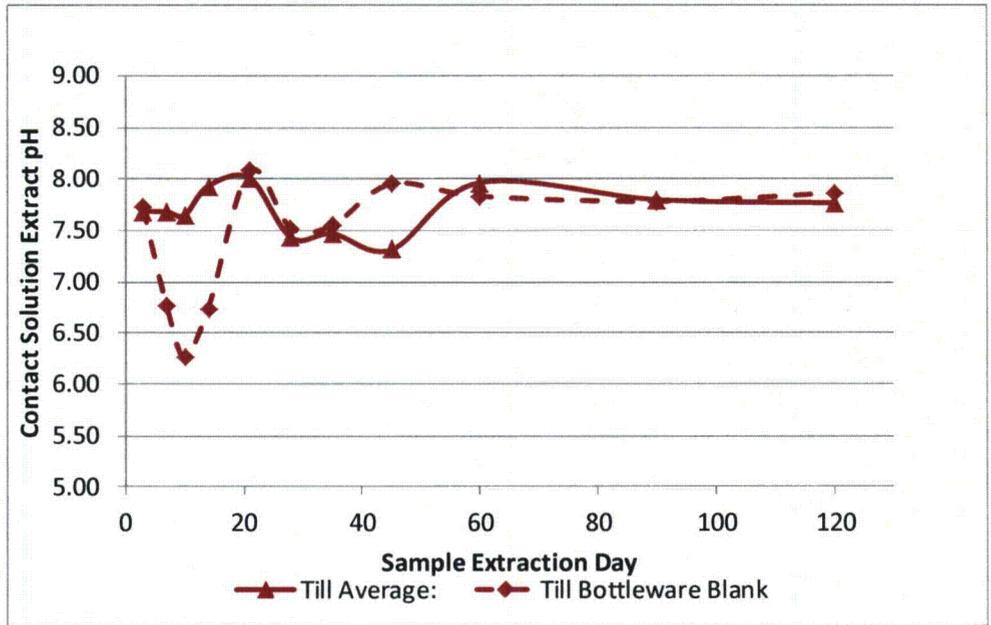


Figure 7-7. Glacial Till Contact Solution Extract pH Over Time

For all of the tests, the variation in pH values provided another perspective of sample stability or equilibrium. Review of Tables 7-3 and 7-4, and as approximated by the average trends in pH for a soil/till type in Figures 7-4 through 7-8, reveal that typically by day 20 or so, pH was relatively stable within a narrow range of variation for the balance of the test. Most of all, pH had stabilized by the particularly important period between days 20 and 60, which is the time period that most initial K_d values were determined from because it appeared that equilibrium had been reached.

Lastly, Figure 7-10 shows the variation in laboratory determined K_d values relative to pH and relative to other available research derived K_d values. The base figure was reproduced from the USEPA compendium on understanding variation in uranium coefficient values (USEPA 1999). The figure indicates that final corrected K_d values determined from this study closely align with other research and similar pH ranges. Where loess soil-solution pH is closer to the typical soil range of 5 to 8, K_d values group approximately in the middle of the range for similar pH mixtures. For the till samples where pH tended to be slightly alkaline, values again align with research derived values for similar pH mixtures.

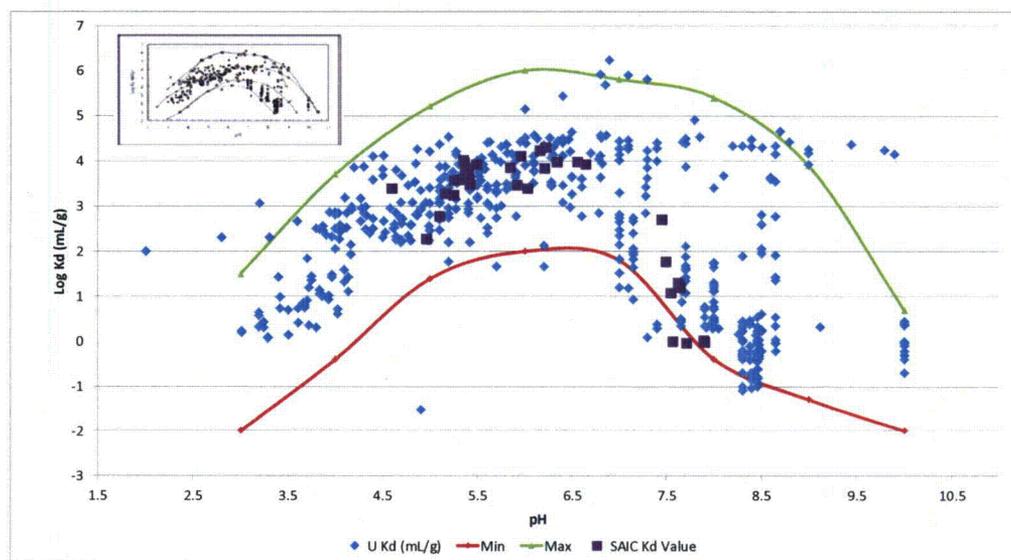


Figure 7-10. K_d Values Versus pH

7.5 CALCULATED AND LABORATORY MEASURED URANIUM MASS BALANCE EVALUATION

In accordance with ASTM C1733 and as reviewed in the analytical methods in Section 5, the mass of uranium partitioned to soil was calculated from the difference between the concentration of uranium in the batch sample contact solution extract and the original spiked concentration of uranium in the reference contact solution prepared at the beginning of the study, as listed in Table 5-2. As a check on the calculated mass of uranium for loess soils and till sorption tests, the soil in each terminal sample of a given batch of samples was analyzed for isotopic uranium. The four acid-rinsate bottleware samples used to assess potential uranium plating did not have any remaining soils for analysis. Table 7-5 lists the original uranium mass determined during characterization of the background loess and till samples relative to the terminal K_d study batch sample speciation mass. The difference is termed the laboratory measured sorbed mass. Lastly, the table compares this laboratory measured mass to the calculated sorbed mass via an RPD, assuming the calculated mass as the reference mass.

**Table 7-5. K_d Study Mass Balance Summary for Loess Soils and Glacial Till
Jefferson Proving Ground, Madison, Indiana**

Sample Identification	Initial Characterization Concentration		Kd Study Terminal Sample Concentration		Calculated Sorbed Mass (mg/kg)	Laboratory Determined Sorbed Mass (mg/kg)	RPD (%)
	Total Uranium	Weight % ²³⁵ U	Total Uranium	Weight % ²³⁵ U			
Avonsburg/Cobbsfork - Adsorption Tests							Average: -19.0%
JP-SAC-001_SAIC05	0.782	0.67	1.11	0.63	0.249	0.33	-28%
JP-SAC-001_SAIC05D	0.802	0.71	0.66	0.71	0.248	-0.14	NA
JP-SAC-002_SAIC05	0.430	0.65	0.89	0.55	0.493	0.46	7%
JP-SAC-003_SAIC05	0.510	0.73	0.67	0.66	0.074	0.16	-73%
JP-SAC-004_SAIC05	0.560	0.75	1.41	0.57	0.374	0.85	-78%
JP-SAC-005_SAIC05	0.681	0.70	0.95	0.62	0.249	0.27	-8%
JP-SAC-006_SAIC05	0.530	0.68	0.76	0.64	0.248	0.23	8%
JP-SAC-007_SAIC05	0.541	0.74	Acid Rinsate Blank		0.248	NM	NA
JP-SAC-008_SAIC05	0.863	0.76	0.91	0.63	0.149	0.05	103%
JP-SAC-009_SAIC05	0.711	0.70	1.31	0.61	0.249	0.60	-83%
Cincinnati/Rossmoyne - Adsorption Tests							Average: 14.7%
JP-SCR-001_SAIC05	1.114	0.71	1.21	0.58	0.373	0.10	117%
JP-SCR-001_SAIC05D	0.923	0.76	1.21	0.61	0.249	0.28	-13%
JP-SCR-002_SAIC05	2.825	0.67	2.72	0.63	0.497	-0.11	NA
JP-SCR-003_SAIC05	0.449	0.69	0.76	0.57	0.248	0.31	-22%
JP-SCR-004_SAIC05	0.802	0.69	Acid Rinsate Blank		0.173	NM	NA
JP-SCR-005_SAIC05	0.994	0.70	1.11	0.69	0.249	0.11	74%
JP-SCR-006_SAIC05	0.822	0.71	0.99	0.63	0.249	0.17	38%
JP-SCR-007_SAIC05	1.115	0.73	1.41	0.67	0.149	0.29	-65%
JP-SCR-008_SAIC05	0.893	0.74	0.97	0.68	0.074	0.08	-6%
JP-SCR-009_SAIC05	0.853	0.72	1.11	0.68	0.249	0.26	-4%
Greyford/Ryker - Adsorption Tests							Average: 66.4%
JP-SGR-001_SAIC05	0.570	0.65	0.69	0.70	0.248	0.12	70%
JP-SGR-001_SAIC05D	0.570	0.65	0.70	0.66	0.248	0.13	63%
JP-SGR-002_SAIC05	0.761	0.66	Acid Rinsate Blank		0.249	NM	NA
JP-SGR-003_SAIC05	1.215	0.69	1.11	0.69	0.250	-0.10	NA
Glacial Till - Adsorption Tests							Average: -193.8%
JP-KAC-011_SAIC01R	0.469	0.70	Acid Rinsate Blank		0.012	NM	NA
JP-KAC-012_SAIC01R	0.761	0.74	0.53	0.70	0.014	-0.23	NA
JP-KAC-013_SAIC01R	0.459	0.68	0.27	0.97	0.013	-0.19	NA
JP-KCR-011_SAIC01R	1.315	0.71	7.20	0.67	0.102	5.88	-193%
JP-KCR-012_SAIC01R	0.913	0.71	17.45	0.57	NM	16.54	NA
JP-KCR-012_SAIC01DR	1.114	0.74	NA		0.113	-1.11	NA
JP-KGR-005_SAIC01DR	0.551	0.69	8.60	0.58	0.113	8.05	-194%
JP-KGR-005_SAIC01R	0.934	0.71	0.71	0.62	0.155	-0.22	NA

1: Laboratory determined total sorbed uranium mass is difference between final and initial soil concentrations.

Uranium isotope concentration units in milligrams per kilogram (mg/kg)

Calculated sorbed mass of uranium equals difference between reference solution spiked concentration and final contact solution extract concentration.

RPD: Relative percent difference between final laboratory measured total uranium soil mass vs. starting and calculated total uranium mass.

NA: not applicable

NM: Not measured.

Some variation exists between calculated and laboratory measured the degree of uranium to soil. The average RPDs for the three soil groups varied from -19 to 66 percent, indicating calculated sorbed mass on average ranged from 19 percent less than laboratory measured mass, up to 66 percent greater than laboratory determined mass. The average RPDs for the loess soils represent a range for calculated sorbed mass from -65 to 117 percent of laboratory measured mass. Figure 7-11 shows the correlation between measured and calculated mass. Three of the terminal batch loess samples had laboratory measured total uranium concentrations less than the original samples. Results for these samples are listed in Table 7-5 but do not have calculated RPDs and are not included in the averages or correlation graph.

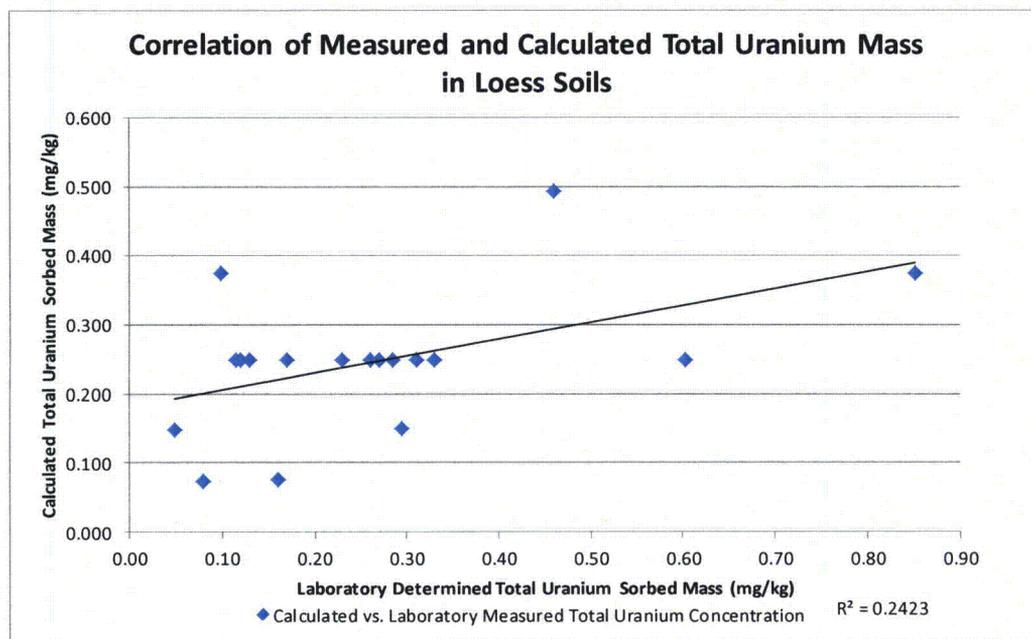


Figure 7-11. Correlation of Calculated Versus Laboratory Determined Uranium Soil Mass in Loess Soils

The variation between measured and calculated sorbed mass is believed to be a function of: 1) the inherent greater variability in soil composition or heterogeneity and subsequent soil blending, 2) soil matrix interference effects, and 3) analytical instrument performance at the limits of detection resolution. Soil, by its very complex compositional nature, presents a medium more difficult to represent through analysis than an aqueous medium. Despite drying and ball milling the field samples, the aliquot of soil used to characterize the initial concentration of isotopic uranium may not have been uniform with the 11, 4-gram aliquots into which each field sample was further separated.

All isotopic uranium analyses were performed using the inductively coupled plasma-mass spectrometry (ICP-MS) solid waste (SW) Method 6020A with a detection capability in the range of 0.0003 to 0.08/ $\mu\text{g/L}$. Despite the methods sensitivity, the detection of uranium mass can be interfered with by high ion currents at adjacent masses such as alkaline earth metals beryllium, magnesium, calcium, strontium, and barium and also aluminum and iron, especially when the uranium to metal concentration ratios are so high, as demonstrated for some of these metals in both loess and till (Dionex 1998, USEPA 2007). Iron is ubiquitous in the loess and till.

The uniformity of the aqueous samples and the significant reduction in potential neighboring ion mass interference indicate that the estimate of soil sorption through the liquid ratio is a better, more consistent means of estimating soil sorbed uranium mass.

7.6 URANIUM ISOTOPE DISTRIBUTION

A component of the K_d study was evaluation of the distribution potential of individual uranium isotopes. Consistent with the known isotopic composition of naturally occurring uranium reviewed in Section 2 and the relative isotopic percentages detected in soil and contact solutions for the K_d study as presented in Section 6, the U-238 isotope is the principal isotope of uranium involved in batch samples and therefore environmental partitioning.

Environmentally, isotopes U-234 and U-235 were sparingly detected in loess soils at background locations to the DU Impact Area and beneath penetrators and in the till. They were not detected in rainwater and only U-235 was detected in groundwater from JP-DU-06O at 0.028 $\mu\text{g/L}$. The isotope U-238 was the dominant isotope, based on mass or concentration, in the above locations, most notably beneath penetrators. With respect to batch samples, the isotope U-234 was not detected in any of the rainwater contact solution extracts for any of the K_d study batch samples. The isotope U-235 was only detected in the groundwater contact solution extracts associated with the till samples at concentrations in the range of 0.04 to 0.073 $\mu\text{g/L}$.

The uranium standard used for the K_d study reference contact solution spike, as described in Section 5, did not contain the isotope U-234, so evaluation of the partitioning of this specific isotope was not possible. The isotope U-235 was present in the spike standard at a percent mass fraction of 0.21 percent and also was present in groundwater so U-235 partitioning in the till could be evaluated. Groundwater selected as the contact solution with the till had a native U-235 concentration of 0.028 $\mu\text{g/L}$. The till batch samples were initially spiked with 10 $\mu\text{g/L}$ of the standard, which provided for approximately 0.021 $\mu\text{g/L}$ of U-235, for an approximate total U-235 spike concentration of 0.049 $\mu\text{g/L}$. Because the contact solution extract concentrations of U-235 averaged closer to 0.06 to 0.07 $\mu\text{g/L}$, or slightly higher than the initial estimated spike concentration, calculation of U-235 K_d values resulted in slightly negative values on the order of -0.01 to -0.03 mL/g. Therefore, although K_d values were omitted because they appear to be outliers, the contact solution concentrations were close to the initial spike concentrations, suggesting limited potential to partition to the till matrix, very similar to the U-238 isotope. This review suggests that prediction of U-238 partitioning tendencies will be representative of the lesser uranium isotopes behavior.

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8. BIOGEOCHEMICAL CONTROLS ON K_d STUDY OUTCOME AND DU PARTITIONING AT JPG

Corrected K_d values are discussed in this section relative to the myriad biogeochemical factors that can affect uranium/DU partitioning in the environment and at the laboratory scale as introduced in Section 2, to the extent understood for the DU Impact Area and the K_d study specifically. This discussion centers on: 1) the direct and indirect measures of soil and water properties reviewed in Section 6; 2) geochemical modeling performed with the USGS computer program PHREEQC, as presented in the CSM in Appendix C of the Environmental Report; and 3) characteristics and behaviors of uranium partitioning eluted from established research literature, where direct or indirect measure of the characteristic at JPG was beyond the scope of the K_d study, more akin to dedicated, specialized research, as referenced.

Table 8-1 lists the biogeochemical processes that researchers, experienced with uranium partitioning and mobility in geologic systems, have found influence the environmental fate of uranium in the environment. The various factors are broken out by soil, water, and plant/animal influences, but many are a function of the combined soil-water chemistry and are so discussed following Table 8-1.

**Table 8-1. Soil and Water Geochemical Processes Affecting Uranium Mobility and Distribution
Jefferson Proving Ground, Madison, Indiana**

Biogeochemical Controls Governing Uranium Distribution and Environmental Fate	
Soil	
1.	Natural uranium in soil and rock U-234 and U-238 in secular equilibrium (identical activities).
2.	Uranyl ion or complexes in oxidizing solution within a pH range of 5.0 to 8.5 readily partition to clays, organic matter, and iron and manganese oxides in soil matrix and is reversible.
3.	In oxidizing solution within a pH range of 5.0 to 8.5, clay minerals, particularly the family of expanding minerals like smectites, will attract uranium/DU via cation exchange.
4.	Uranyl ion (U^{6+} or UO_2^{2+}) or ligand complexes, listed below, dissolved in water can be reduced to insoluble uranous (U^{4+}) precipitates (uraninite, coffinite) by humus and peat in the soil matrix, and once reduced are relatively insoluble and not reversible.
5.	Resident carbonate content of soil can provide a source of dissolved carbonate that will strongly complex with uranium and promote stability and mobility in oxidizing conditions.
6.	Naturally occurring soil microbes can speed the corrosion of uranous (U^{4+} or IV) bearing minerals like uraninite and coffinite to uranyl (U^{6+} , or IV; UO_2^{2+}) in oxidizing, severe low pH aqueous settings or reduce dissolved uranyl (U^{6+} , or IV; UO_2^{2+}) in anaerobic soil pore water back to insoluble uranous (U^{4+}) bearing minerals uraninite and coffinite.
7.	Colloids consisting of clay mineral particles, nanoscale precipitated secondary minerals like aluminosilicates, or siderite and organic nanoparticles can entrain and move uranium/DU advectively through saturated pores, immune from any partitioning effects otherwise promoted by the ambient biogeochemical setting the colloids are moving through, thereby preferentially increasing uranium mobility over partitioning.
Water	
1.	In natural waters, U-234 slightly more soluble than U-238 due to natural decay of U-238 to ^{234}Th to ^{234}Pa , which are more soluble, so U-234 appears to move while U-238 remains sparingly soluble.
2.	The acidity or pH of pore water controls mobility of uranyl ion; UO_2^{2+} complex dominates in oxidizing acidic waters, whereas carbonate complexes dominate in near-neutral and alkaline oxidizing waters. Iron oxide, clay, and organic carbon exchange sites decline as pH declines below 5.0.
3.	Alkalinity of pore fluids under oxidizing conditions can limit or inhibit uranium partitioning by promoting uranyl complexation with carbonate, a stable ligand in solution, promoting mobility over partitioning with increasing alkalinity.
4.	Dissolved organic carbon, in the form of fulvic and humic acids, can complex with uranous (U^{4+}) and uranyl, increasing solubility and mobility and reducing partitioning.
5.	As the ionic strength of pore water increases, uranium/DU mobility can increase due to increasing cation competition for clay exchange sites, but not if uranium is complexed by iron and manganese minerals or organics.

**Table 8-1. Soil and Water Geochemical Processes Affecting Uranium Mobility and Distribution
Jefferson Proving Ground, Madison, Indiana (Continued)**

Biogeochemical Controls Governing Uranium Distribution and Environmental Fate	
Water (Continued)	
6.	The ORP of the soil-water system plays a significant role in governing uranium mobility in solution. Under oxidizing conditions, uranyl (U^{6+} , or IV; UO_2^{2+}) and weaker uranyl ligands like uranyl carbonate (and less so uranyl nitrate, uranyl sulfate, uranyl fluoride, and uranyl phosphate where solution pH < 3, which is not typical groundwater) are most soluble and therefore mobile, with a reduced potential for partitioning, especially where pH is > 5.0. Under reducing conditions, uranyl and uranyl ligands readily reduce to uranous (U^{4+} or IV) and precipitate out of solution as uraninite and coffinite, relatively insoluble minerals.
7.	Families of reducing microbes in soil can catalyze reduction of dissolved uranyl complexes to insoluble uranous ion (U^{4+}) bearing minerals; likewise families of soil microbes tolerant of severely low pore water pH (1 to 2) can catalyze oxidation of uranous bearing minerals to free uranyl.
8.	The concentration of uranium in solution indirectly affects the affinity for uranium partitioning. As the dissolved concentration of uranium increases, the affinity for partitioning declines and a resultant laboratory determined K_d value declines.
Plant and Animal	
1.	Macropores and bioturbation of soil structure by plant roots and animal burrows changes soil structure and short-circuits soil pore water retention times, changing sorption kinetics in the field from those simulated in the laboratory. Collection of the laboratory sample, drying, and disaggregation at the laboratory further change soil structure and soil pore geometry.
2.	Plant root uptake of uranium dissolved in soil pores during the growing season for retention in the root between growing seasons can reduce the mass of uranium in solution.

These biogeochemical processes carry over to the laboratory and therefore influence K_d study outcomes, or K_d values. The sections that follow discuss each major characteristic or process in terms of what direct measure parameters, computer modeling, or existing research can explain about the process, both in the laboratory and in the field at JPG. If a particular biogeochemical factor is believed to influence DU partitioning in the field beyond what was predicted in the laboratory, the discussion attempts to qualify, in most cases qualitatively, the impact to the laboratory determined partitioning coefficient. For example, as discussed below, several lines of evidence from the field indicate DU Impact Area soils are likely reducing, at least during wetter parts of the year. Under these conditions, penetrator corrosion will slow or essentially stop and any dissolved uranyl will reduce to uranous as identified in Table 8-1, effectively halting DU mobility until oxic conditions return. The net effect of this reducing condition on present K_d values for loess soils would be to bias the values higher, possibly by an order of magnitude. Exact quantification is not possible. This discussion then finishes with the probable environmental fate of DU along the identified transport pathways through the DU Impact Area.

8.1 SOIL MATRIX CLAY MINERALS, IRON AND MANGANESE OXIDES, AND ORGANIC CARBON

The direct measure of JPG soils, till and contact solutions for iron and manganese content, TOC content and CEC combined with extensive research on the influence of these parameters on uranium partitioning indicate each is a factor, in a decreasing scale of importance as listed, in promoting uranium distribution at laboratory and field scale. The combination of soil characterization, presented in Section 6, and research findings conclude that:

- Iron and manganese hydroxides are ubiquitous in loess and till and provide ready exchange sites for uranium, especially at low dissolved concentrations

- Organic carbon is readily available in loess and till, and rainwater and groundwater, thereby providing: 1) enhancement of CEC, especially in the 'A' soil horizon; 2) an additional type of exchange site for uranium partitioning; 3) the catalyst for micro-reduction of uranium in an otherwise oxic setting; and 4) a ready carbon source for microbe growth and catalyzed uranium precipitation under oxic or anoxic conditions.

Loess soil and glacial till clay mineralogy is conducive to uranium cation exchange and surface exchange site partitioning and manganese are ubiquitous in loess and till at high concentrations on the average order of 18,299 and 1,940 mg/kg, respectively. Background loess samples showed a good correlation between uranium and iron/manganese concentrations, at least a low uranium concentration. As the iron and manganese content increased in the soils, there appeared to be a concomitant increase in uranium concentration. Research shows a strong affiliation between uranium and iron and manganese oxyhydroxides. Ames, McGarrah, and Walker (1983a as referenced in USEPA 1999) studied the effects of uranium sorption on amorphous ferric oxyhydroxide over a range of uranium concentrations (USEPA 1999). The study followed a batch method, using oxidizing contact solutions (0.01 M NaCl and 0.01 M NaHCO₃) at 25 and 60°C. Solutions were equilibrated with the iron solid for 7 days at a liquid to solid ratio of 3.58 L/g iron. Resultant K_d values were in the range of 4,313 to 1,739,877 mL/g, for an average of 598,993 mL/g. Although the form of the iron and manganese detected at JPG is not known, this study demonstrated the very high uranium adsorptive capacity of amorphous iron oxyhydroxide and suggests manganese oxyhydroxide should have a similar affinity.

The TOC content of the loess soils averaged 3,676 mg/kg or 0.37 percent, with till averaging 2,783 mg/kg, or 0.28 percent. This is after soils were homogenized over the top 4 ft and represents a complete A, B, and C horizon homogenized soil profile. As with the CECs, the TOC content of the upper 6 in of soil was likely even higher than the blended results, which would have contributed to higher K_d values for the 'A' horizon. Uranium concentrations in loess soils showed a moderate correlation with TOC (R² = 0.48), indicating it is a preferential partition site for uranium. Sheppard and Thibault (1988, as referenced in USEPA 1999) investigated the migration of uranium through three types of peat on the Canadian Shield. Resultant K_d values were on the order of 2,000 to 19,000 mL/g. Although the experiments were inferred by USEPA to have been conducted under reducing conditions, the experiments suggest a strong affinity for uranium to partition to organic substrates.

Montmorillonite, a member of the smectite expanding clay family, is the inferred predominant clay mineral fraction in the oxidized loess soils, altered from illite and chlorite, based on research presented in Section 6. Unweathered till likely has a higher illite and chlorite fraction than montmorillonite. Montmorillonite is an expanding clay, capable of taking up water and organic carbon into its sheet silicate structure and providing negatively charge reaction surfaces at typical soil pH (5 to 8). The clay mineral content of the loss and till is favorable for uranium partitioning, especially at low dissolved concentrations in low ionic strength pore fluids, as shown by research (Erickson 1980 in USEPA 1999) measured the K_d values for uranium on abyssal clay where the dominant mineral was iron-rich smectite, an expanding clay similar to montmorillonite. Erickson used a batch method, with 2-to 4-day equilibration time and a very low uranium concentration of 0.031 µg/L. Calculated K_d values were 200 mL/g at a pH of 2.8 and 790,000 mL/g at a pH of 7.1.

Ames, McGarrah, and Walker (1983b, as referenced in USEPA 1999) investigated uranium partitioning on clay minerals and sheet silicates. The study followed a batch method, using oxidizing contact solutions (0.01 M NaCl and 0.01 M NaHCO₃) at 5, 25, and 65°C. Solutions were equilibrated for 30 days at a liquid to solid ratio of 10 mL/g of solid. K_d values for the clay minerals ranged from 0.6 to 657 mL/g and for sheet silicates the range was from 0.6 to 3,490 mL/g, comparable values to the K_d study.

Giblin (1980, as referenced in USEPA 1999) evaluated uranium sorption on the clay mineral kaolinite as a function of pH in a synthetic groundwater with calcium, sodium, magnesium, chloride, and

sulfate (USEPA 1999). The study utilized a batch method at 25°C, a pH range from 3.8 to 10, and a liquid to solid ratio of 1,000 mL liquid contact solution per gram of solid substrate. The study indicated uranium would not partition to kaolinite reaction surfaces at a pH less than 5. At a solution pH between 5 and 7, uranium partitioning increased dramatically, with peak K_d values in the range of 37,000 mL/g. Uranium partitioning declined as pH increased to 10. The highest uncorrected K_d value for this study was 19,000 mL/g.

Lastly, Bovec (1981, as referenced in USEPA 1999) investigated the adsorption of uranyl to kaolinite, illite, and montmorillonite at a solution pH of 6.0. Bovec produced K_d values from 50 to 1,000 mL/g and determined the following partitioning order amongst the state clays, as follows: kaolinite K_d < illite K_d < montmorillonite K_d .

Measured CECs for loess soils and till were in the sand to low clay range (8 to 18 meq). Because loess samples were homogenized over 4 ft, CECs (and TOC content) are likely reduced from blending, compared with higher values for the top 6 in of soils where organic matter typically predominates. The attempt at correlating CEC in background loess samples to uranium revealed a weak correlation (0.14). Serkiz and Johnson (1994, as referenced in USEPA 1999) found a similar relationship between uranium and CEC and inferred that uranium was not binding to the clays by cation exchange but rather to a clay mineral surface, mediated by pore water pH. Regardless, measured CECs indicate that some cation exchange with uranium likely occurred on a laboratory sample scale and occurs at field scale in the DU Impact Area.

8.2 SOLUTION pH

Possibly the single most significant control on uranium partitioning is the pH of the solution in which uranium is dissolved. The solution pH directly controls the clay mineral, metal hydroxide, and organic substrate exchange site surface availability by controlling the point of zero charge (PZC) for that surface (USEPA 1999). In oxic, carbonate solutions with a pH of 3 or less, uranyl is most stable as a cation (UO_2^{2+}) and, therefore, tends to be mobile because most host clay and mineral surface exchange sites have a net positive charge at low pH. As solution pH increases past a given mineral or precipitate surface PZC (pH at which the surface has no net positive or negative charge), the surface polarity changes to a net negative value, which leads to an increasing surface affinity for cation (e.g., U^{+6} and complexes) attraction. Within the typical range of soil pH, 5.5 to 8.5, net clay and organic carbon surface charges are negative and optimally receptive to cation exchange. As pH increases above 8, uranium is more stable as uranium carbonate anion ($UO_2(CO_3)_3^{4-}$) and is therefore incompatible with the net negative polarity of most exchange sites, in turn becoming more mobile again.

Figure 7-10 showed the influence of pH on the range of potential uranium/DU K_d values in the environment. It also frames the plating corrected K_d values (log) derived by this study. Research has found K_d values to range from values less than 10 mL/g at the extremes of aqueous solution acidity (pH 2 to 3) and alkalinity (pH 9 to 10) to as high as 1,739,877 mL/g at a normal soil pH (5.5 to 8).

The figure also shows how the K_d study values compare closely to the balance of research findings. The K_d values for loess soils where ambient soil-contact solution extract pH was in the range of 4.59 to 7.5, were 57 to 4,470 mL/g (between 2 to 4 log K_d on the figure). The K_d values for the glacial till, where soils (pH = 8.0) and groundwater (329 mg/L versus 3.5 mg/L for rainwater) were more alkaline due to the increased carbonate content of the till relative to the leached loess soil, were in the range of 0.93 to 20 mL/g, over a pH range of 7.55 to 7.9.

All of the Army K_d values were well within research findings for uranium for a variety of substrates over the same range of pH. These consistent findings suggest plating corrected K_d values are valid and consistent with uranium behavior at laboratory scale and therefore valid at field scale.

8.3 SOLUTION ALKALINITY AND IONIC STRENGTH

Next to pH, the alkalinity and ionic strength of the pore water or the solution uranium is dissolved in further significantly controls the behavior of uranium at laboratory scale and in the environment. Both solution properties have an inverse impact on uranium partitioning, or conversely uranium mobility. As values of each increase, the affinity for uranium partitioning declines (USEPA 1999). Both of these parameters were measured in K_d study rainwater and groundwater contact solutions on initial characterization and have been thoroughly studied with respect to uranium by other researchers.

As indicated in Section 6 and above, there is a significant difference in the alkalinity of ambient precipitation at JPG relative to till groundwater. The differences are likely directly related to the progressive increase in the carbonate content of the till with depth and the residence time of groundwater in the saturated till. Section 6 reviewed the likely clay mineralogy of the loess soils and till from applicable research, which also demonstrated the leached and oxidized nature of the loess in the Midwest. The TC:TOC ratios determined from the K_d study support this presumption of carbonate leaching. These data help to explain and likely are the principal basis of the significant variation between K_d values derived for the loess versus the till.

As precipitation infiltrates the loess, the relative absence of carbonate keeps the pore water low in alkalinity and the relatively short residence time prevents significant mineral dissolution (low ionic strength). The ionic strength of the rainwater relative to JPG groundwater, expressed as total dissolved solids (TDS), was significantly different, on the order of 6.4 versus 205 mg/L, respectively. As the pore water migrates progressively deeper into unleached till, the pore water becomes more alkaline, more enriched in calcium and magnesium from the dissolution of resident carbonate, and therefore harder and generally more mineralized with respect to other cations and anions dissolved from soil minerals. Research shows that as a solution becomes progressively more alkaline under oxic conditions, uranyl will form a relatively stable carbonate ligand (UO_2CO_3) and remain mobile (USEPA 1999, PNNL 2006). Results of the PHREEQC modeling, summarized in the CSM in Appendix C of the Environmental Report, support this and show that as a solution becomes more alkaline, like in the till-groundwater system, uranyl carbonate ligands become more prevalent and stable. Further, as the ionic strength of a solution increases, there is greater competition with uranium from a broader variety of higher order cations that partition preferentially over uranium, which keeps uranium in solution and therefore mobile. Resultant laboratory derived K_d values are low.

Results for the glacial till samples appear in line with available research on a similar substrate. Bell and Bates (1988, as referenced in USEPA 1999) studied uranium partitioning under a range of parameters, such as pH, temperature, groundwater composition, and contact time. Of note, this study used groundwater from a site borehole as the contact solution and one of the geologic media evaluated was glacial till clay. Studies were performed in accordance with a batch method over a range of pH and temperatures using a liquid to solid ratio of 10 mL liquid contact solution per gram of solid substrate. The K_d value obtained for the till after 14 days equilibration with the groundwater was 46 mL/g, the same order of magnitude as the K_d study till values.

8.4 OXIDATION REDUCTION POTENTIAL AND MICROBE CATALYZED URANIUM REACTIONS

Research regarding microbe catalyzed reactions with uranium continues to reveal strong relationships between naturally occurring resident soil microbes, redox potential, and uranium mineral precipitation or mobility in the environment (Lovley et al. 1991; Anderson and Lovley 2002; Finneran et al. 2002; Mouser et al. 2009). Research shows that depending on the redox potential and pH of the environment, different families of naturally occurring microbes will either promote uranium mobility in solution or promote precipitation out of solution. These effects are important at the laboratory scale on the outcome of derived K_d values and more so at field scale at JPG, where these microbial processes

likely cycle between wet and dry seasons. Although the presence and influence of microbial catalyzed uranium oxidation and reduction has not been directly measured as a component of the K_d study, the potential role of microbes at the laboratory scale and their influence on resultant K_d values is qualitatively discussed from research findings and geochemical simulation using the USGS program PHREEQC. Findings then are applied to the seasonal wet and dry periods at JPG to help better explain potential uranium mobility.

Research shows that aerobic microbe families *Thiobacillus* and *Leptospirillum* that naturally exist in soils under oxic conditions will catalyze the oxidation of uranous uranium (U^{+4}) bearing mineral ores like uraninite and coffinite to dissociated uranyl uranium (U^{+6}) in the presence of low pH (2 or lower) fluids, mobilizing uranium for subsequent extraction (Anderson and Lovley 2002). Ferric iron will enhance the process. These microbe families have been shown to grow in tolerance to both declining pH and increasing uranium concentrations (Anderson and Lovley 2002). This situation appears principally augmented for mining purposes, as the pH range of the solution is far below natural soil pH (5.5 to 8).

Under reducing conditions, uranium reduction was principally thought to be abiotic, but the discovery of the relatively widespread anaerobic microbe family of *Geobacter* has demonstrated that these microbes will preferentially drive the reduction of uranyl- to uranous-bearing mineral precipitates (Lovley et al. 1991). Scanning and transmission electron microscopy used in conjunction with energy dispersive spectroscopy has revealed the concentration of uranium on microbial cell surfaces (Suzuki et al. 2005). Microbial catalyzed reduction of uranium appears to begin to occur within the ferric iron (Fe^{+3}) terminal electron-accepting process (TEAP) stage of reduction, a relatively weakly reducing condition requiring just slightly more anoxic conditions from the earliest stage of nitrate reduction, yet considerably weaker than methanogenesis (Anderson and Lovley 2002, Finneran et al. 2002). In this case, the presence of Fe^{+3} can slow the reduction of uranium by providing a preferential electron acceptor. The addition of organic carbon appears to stimulate uranium reduction by: 1) driving the environmental system anaerobically via acceleration of microbial consumption of available oxygen, 2) providing an alternative electron donor for cellular energy and growth, and 3) providing a source of carbon for cell growth (Mouser et al. 2009). The presence of an organic substrate with dissolved uranyl ions in laboratory experiments has shown reduction of uranyl uranium in less than 15 days (Finneran et al. 2002).

With respect to laboratory sample conditions during the course of the K_d study, there is no direct evidence of either microbial catalyzed oxidation or reduction occurring. The oxidation of uranous uranium bearing soil minerals to dissociated uranyl forms is not supported by the following factors: the likely speciation of uranium in soils, the oxidation state of the contact solutions (particularly rainwater), the initial and progressive pH of the K_d study samples, and the concentrations of isotopic uranium over time. The PHREEQC modeling presented in the Environmental Report (Appendix C) indicated penetrators are expected to corrode to schoepite, not uranous ion bearing minerals, which in turn should dissolve to uranyl complexes, specifically uranyl carbonate, not uranous complexes. Despite the strong oxic condition of the soil-solution samples at least at the start of the K_d study, sample acidity or pH never approached the severe level required for microbial release of what otherwise is a very insoluble form of uranium. If uranous complexes were somehow being oxidized in soils over time in the laboratory samples, uranium concentrations would be expected to have increased over time and not decline as most did.

At field scale, soil coloring (yellowish brown staining, evidence of surface oxide goethite) as indicated in Section 6, and research in general regarding loess soil, suggest soils are oxidized in the DU Impact Area, at least seasonally, but likely longer than they are under reducing conditions based on seasonal precipitation patterns. Any microbial catalyzed oxidation of uranous to uranyl species that might occur likely occurs at the tail end of a wet season, as soils are drying and the redox of the system is changing back to oxic. Residual uranous in solution and not yet precipitated would be expected to oxidize to uranyl ions, for complexing with carbonate or partitioning to soil. Once uranous ion bearing

minerals were precipitated during the wet season, the return to oxic conditions at the apparent ambient pH of the loess-pore water system would not be sufficient to oxidize the uranous complexes from the insoluble minerals.

Only pH was monitored in contact solution extracts during the course of the K_d study, so there is no direct evidence of the ORP changes of the samples over time. Loess soils had measured fractions of TOC on the order of 1,820 to 9,570 mg/kg. The TOC content of the till was lower, on the order of 80 to 5,450 mg/kg. The TOC content of the rainwater and till groundwater was 3.5 and 1.1 mg/L, respectively. This indicates a substrate needed for microbe cell growth was present in the samples. As indicated in Section 6, pH acidified slightly over time in many of the samples, indicating excess hydrogen buildup in solution. It is possible that microbe growth was happening in the soil solutions and that microbial catalyzed breaking of hydrogen bonds was occurring, which may have driven the solution pH lower over time. If there was some microbial catalyzed reduction of uranyl to uranous species out of the sample solutions, it likely occurred in later samples after much (98 percent) of the dissolved uranyl mass was taken out of solution, by presumably another process. There is no means to quantify the effect of a progressive lowering of redox on derived K_d values for this study other than understanding that resultant K_d values would increase as a result of a higher fraction of mass appearing to be sorbed to soil relative to the mass balance remaining in solution. Correction for uranium plating likely accounts for any microbe induced increases in K_d values.

At field scale, soil coloring (reddish brown staining and soil mottles or nodules) indicates the DU Impact Area soils are periodically under reduced conditions, likely less often than they are under oxidizing conditions. The PHREEQC modeling presented in the Environmental Report (Appendix C) provides a perspective on uranium mobility under anaerobic conditions. As biological activity drives the water saturated JPG soil system anaerobic, PHREEQC simulations indicate uranyl in solution will readily reduce to uranous and the soil pore solution will become supersaturated with UO_2 . This excess UO_2 precipitates out of solution as a trace reduced uranium mineral uraninite or pitchblende. Research shows that once uranous bearing mineral forms, it is only weakly soluble under oxic conditions within normal soil-water pH ranges (5.5 to 8) and readily oxidized in solutions with a severe pH of 2 or less (USEPA 1999, Anderson and Lovley 2002).

The PHREEQC simulation suggests that DU Impact Area soils can easily transition to a reducing condition as soils saturate, particularly during active plant growth. Research suggests only weakly reducing conditions at the Fe^{+3} TEAP stage of reduction is required to begin reducing uranyl to uranous, with PHREEQC modeling indicating that uraninite precipitation quickly follows. This indicates that during drier parts of the year when penetrators are most susceptible to corrosion to schoepite and dissolution to uranyl and uranyl complexes, partitioning is the dominant process affecting DU mobility. As these same soils begin to saturate, particularly in association with a partially or wholly buried penetrator and pieces of corroded schoepite, dissolved uranyl, complexed or not, should reduce to uranous (U^{+4}) species quickly (days), particularly in the presence of organic carbon and even in the presence of excess Fe^{+3} . As soils begin to dry and oxidize, there may be shorter periods of time (days) that excess uranous species in solution not yet precipitated as uraninite ions, may be oxidized to a uranyl form, to complex and partition as less frequent wetting fronts move through soils.

The net effect, then, of the cycle of wetting and drying soils is that when soils are saturated, DU mobility will slow to cease as uranyl and uranyl complexes reduce/precipitate out of solution. DU mobility may increase during the drier parts of the year. This cycling has continued over the life of the loess soils and will continue as the DU Impact Area remains undeveloped.

8.5 DISSOLVED URANIUM CONCENTRATION

Research has shown that the dissolved concentration of uranium itself can influence the degree to which it will partition. Partitioning appears to decline in most oxic water settings as the concentration

increases (USEPA 1999). Under oxic conditions of pH 5 or higher, as the concentration of uranyl ions dissolved in water increases, the potential increases for uranyl ions to complex and form more polynuclear species than the potential at lower concentrations. These complexes keep uranium in solution, which increase its mobility and lowers its affinity to partition. At low concentrations between 3 and 100 µg/L, Kaplan, Gerrais, and Krupka (1998, as referenced in USEPA 1999) found a linear or constant relationship between uranium concentration and K_d value for silty loam and sand samples from the Hanford U.S. Department of Energy (DOE) site in Richland, Washington. Above 100 µg/L, the relationship changes from that stated above and is no longer linear.

8.6 COLLOIDAL TRANSPORT OF URANIUM

Uranium bound to colloids, consisting of clay mineral particles, nanoscale precipitated secondary minerals like aluminosilicates, or siderite and organic nanoparticles, can undergo facilitated transport depending on the oxidation state of the system, in either porous media or fracture/conduit flow (USEPA 1999, USEPA 2006, Zanker et al. 2007).

Under reducing conditions, normally immobile uranous uranium (U^{+4}) that would otherwise precipitate out of solution as uraninite might partition to colloids, then move through the system at groundwater advection rates (Zanker et al. 2007). In oxic waters, where uranium is in the form of uranyl complexes (U^{+6}) and mobile, a potential colloid transport scenario includes ferrihydrate-rich colloids that scavenge uranyl ions out of solution, then aggregate due to low zeta potential, promoting natural attenuation of the otherwise mobile uranyl species (Zanker et al. 2007). Uranium bound colloid transport, especially humic colloids, may slow as the ionic strength of pore waters increases (Crancon, Pili, and Charlet 2010).

This understanding of colloid behavior with respect to uranium suggests the following for JPG. At the laboratory scale, colloids are not believed to have been a factor in the K_d study samples. Colloids are a transport phenomenon, which in a static sample setting, may have contributed to the overall partitioning affinity of the dried, disaggregated, and rewetted soils, but would not have contributed to the scavenging or piggy backing described above. At field scale, the presence and behavior of colloids combined with the soil composition and texture suggests that during the drier, oxic conditions in the loess soils and dry till, when a wetting event passes through, ferrihydrate-rich colloids, which could exist as a function of the high iron content of the soils, might scavenge otherwise mobile uranyl ions from pore water. As the wetter fall and spring months approach and the DU Impact Area loess soils transition to reducing conditions, reduced uranous uranium that would otherwise precipitate out of solution might partition to clay mineral particles and organic nanoparticles for increased mobility. Deeper migration of uranium bound colloids, especially organic colloids, to the till groundwater system might dead end there as a result of colloid retardation in response to the high ionic strength of that groundwater. Facilitated transport in excess of what is predicted by sediment transport during rain events is not expected as a result.

8.7 MACROPORES AND BIOTURBATION

As stated in Section 2, sample scale characteristics can never fully approximate actual system scale seasonal behavior. The presence of macropores created by plants and animals or environmental factors can never be represented at the laboratory scale. For example, the composition or texture as determined by grain size sieve analyses of samples submitted for the K_d study discussed previously herein closely approximate field descriptions made at the time of sample collection, indicating the samples are representative of the grain size distribution, particularly the clay content, of the larger, actual system.

What are not represented in the small-scale sample sets, and which cannot be accounted for at a laboratory bench scale, is the multitude of macropore flow pathways that have developed through the loess soils and in some cases till (Gabet, Reichman, and Seabloom 2003). These macropore and

bioturbation pathways, which wholly or partially circumvent purely porous media flow, can include for this setting:

- Vegetation (e.g., grass and shrub and tree root systems) that can extend to depths of several feet to > 10 ft
- Animal burrows (e.g., worms, snakes, moles, crayfish, groundhogs) that can influence the top 1 to 4 ft
- Drought desiccation stress relief fractures, which can extend several feet into the ground
- Frost heaving, which can affect soils to depths of 30 in (NRCS 1991)
- Soil raveling promoted by underlying bedrock instability, partial collapse, and soil shearing, which can affect 10s of feet of the soil column
- DU penetrator impact, which affected narrow corridors 5 or more feet deep, where remaining penetrators are most dense
- Munitions penetrations, which could extend 25 ft BGS (U.S. Army 2002), and subsequent explosions.

So, although a clay and organic rich sample could produce a seemingly high K_d value at the bench scale, the influence of macropores through those fine sediments at the site scale will short-circuit purely porous media flow and actually lower the “effective” K_d , by generally reducing pore water retention and sediment surface exposure durations, disrupting reaction kinetics from those created at the bench scale.

There are no means to quantitatively qualify K_d values from this study other than to recognize that, on an average basis, study derived values for loess soils could likely be lower in the field than at the laboratory scale. The K_d values for the deeper till samples are not likely affected by macropores and require no qualification.

8.8 PLANT UPTAKE OF URANIUM

Root uptake of uranium via root hairs has been demonstrated in the laboratory by a variety of researchers (Ebbs, Brady, and Kochian 1998; Eapen et al. 2003). Geochemical modeling by Ebbs, Brady, and Kochian (1998) found that at a solution pH of 5.5, the principal form of uranium was uranyl uranium (U^{+4}). As the pH rose to 6, uranyl complexed with carbonate ligands. Companion pot studies using beets indicated that uranyl uranium will be taken up by root hairs and translocated into the plant. Initial uranium mass concentrations of 310 mg/kg were reduced by 210 mg/kg as a plant matured. The study found that uranyl carbonate will not generally be taken up by root hairs and will not translocate.

Eapen et al. (2003) found that hairy root cultures of *Brassica juncea* (mustard plant) and *Chenopodium amaranticolor* (goosefoot or lambs quarters) developed quickly (1.5 to 5.0 grams per gram [g/g] dry weight per day) in a prepared growth medium. Uptake of dissolved uranium from 5,000 micromole (μM) initial aqueous concentrations was approximately 23 percent by mustard plant root hairs and 13 percent by goosefoot.

For the DU Impact Area, research suggests that for shallow loess soils, root uptake of uranyl species may occur where solution pH is at the low end of typical soils (e.g., 5 pH units). As uranium complexes in an oxic setting, it may be more resistant to root hair uptake. This is a seasonal phenomenon then, acting to take uranium out of pore water during the warm growing season, and then holding it through the winter for renewal of the cycle the next spring.

8.9 ADSORPTION AND DESORPTION-DISSOLUTION KINETICS

In addition to looking at factors that control the magnitude of uranium partitioning, the Army attempted to evaluate the rate or kinetics of uranium partitioning from K_d study characteristics. A perspective on reaction kinetics of the governing geochemical processes controlling uranium partitioning can be gained from the rate of change of uranium and DU concentrations in the various loess and till contact solution extracts over time. Table 8-2 illustrates the percent decline in uranium concentrations in loess soil and rainwater mixtures by day 3 of the K_d study, the first of the time series samples to be analyzed in each batch. Uranium concentrations in contact solution extracts from the various day 3 batch samples declined on average 98.3 percent from the initial spike concentration, over a very narrow range from 89 to 99.8 percent. This strongly suggests that reaction rates of partitioning processes were

Table 8-2. Percent Decline in Extract Total Uranium Concentration from Initial Spike to Day 3 in Loess Soils in Rainwater Jefferson Proving Ground, Madison, Indiana

ClientID	Initial Spike Amount (ug/L)	Batch Test Day 3	
		Total Uranium (µg/L)	Percent Mass Decline
Loess Soils in Rainwater			
JP-SAC-003_SAIC05	3	0.048	-98.4%
JP-SCR-008_SAIC05	3	0.047	-98.4%
JP-SAC-008_SAIC05	6	0.084	-98.6%
JP-SCR-007_SAIC05	6	0.036	-99.4%
JP-SAC-001_SAIC05	10	0.19	-98.1%
JP-SAC-001_SAIC05D	10	0.18	-98.2%
JP-SAC-005_SAIC05	10	0.051	-99.5%
JP-SAC-006_SAIC05	10	0.19	-98.1%
JP-SAC-007_SAIC05	10	0.46	-95.4%
JP-SAC-009_SAIC05	10	0.024	-99.8%
JP-SCR-001_SAIC05D	10	0.14	-98.6%
JP-SCR-003_SAIC05	10	0.048	-99.5%
JP-SCR-004_SAIC05	10	1.1	-89.0%
JP-SCR-005_SAIC05	10	0.019	-99.8%
JP-SCR-006_SAIC05	10	0.028	-99.7%
JP-SCR-009_SAIC05	10	0.027	-99.7%
JP-SGR-001_SAIC05	10	0.093	-99.1%
JP-SGR-001_SAIC05D	10	0.14	-98.6%
JP-SGR-002_SAIC05	10	0.032	-99.7%
JP-SGR-003_SAIC05	10	0.11	-98.9%
JP-SAC-004_SAIC05	15	0.072	-99.5%
JP-SCR-001_SAIC05	15	0.11	-99.3%
JP-SAC-002_SAIC05	20	0.99	-95.1%
JP-SCR-002_SAIC05	20	0.12	-99.4%
Average:			-98.32%

relatively rapid during the study, removing on average 98 percent of the solute mass in less than 3 days. Although solid-contact solution equilibration typically was not achieved until 20 to 30 days into a batch test, the bulk of that equilibration period accounted for little more mass recovery. The significant change in sample extract dissolved uranium mass indicates that for rainfall over the DU Impact Area that falls on corroding penetrators in shallow loess soils, the resultant DU solute that forms can be expected to partition to available soil matrix sites very rapidly down slope during the rain event and during the hours to several days of post-rainfall antecedent drainage typical of the setting.

Table 8-3 shows percent changes in uranium concentrations between the spiked reference solution concentrations in day 3 versus final termination batch sample extract concentrations for till samples in groundwater. The comparison indicates significantly less uranium mass was taken out of solution by till than by loess soils by day 3 of a given test as compared to values from 28 to 120 days later. In some cases, uranium concentrations reportedly increased to levels measured in day 3 concentrations over original spike concentrations, possibly owing to more naturally occurring uranium in a given aliquot of till than what was originally determined for the same larger bulk sample used to prepare the test solution. Comparison of day 3 versus termination day concentration changes indicate that three samples experienced principal mass uptake by day 3, whereas three other samples (two locations with one duplicate) indicated that partitioning was slower and a function of time.

Table 8-3. Percent Change in Extract Total Uranium Concentration from Initial Spike to Day 3 and Test Termination in Till in Groundwater Jefferson Proving Ground, Madison, Indiana

ClientID	Initial Spike Amount (ug/L)	Day-3 Extract Total Uranium (µg/L)	Final Extract Total Uranium (µg/L)	Termination Day	Percent Mass Change At Day 3	Percent Mass Change At Termination
Till in Groundwater						
JP-KAC-011_SAIC01R	14	13.4	13.7	45	-4.3%	-2.1%
JP-KAC-012_SAIC01R	14	13.3	13.8	28	-5.0%	-1.4%
JP-KAC-013_SAIC01R	14	14.4	13.7	60	2.9%	-2.1%
JP-KCR-011_SAIC01R	14	13.1	7.10	120	-6.4%	-49.3%
JP-KCR-012_SAIC01R	14	18.5	17.4	NA	32.1%	NA
JP-KGR-005_SAIC01DR	14	10.6	8.60	120	-24.3%	-38.6%
JP-KGR-005_SAIC01R	14	10.5	7.60	60	-25.0%	-45.7%

NA: Not applicable, sample did not produce a K_d value.

Comparison of the loess sample and the till sample concentration changes suggest that where biogeochemical conditions favor uranium partitioning, partitioning drives to equilibrium relatively rapidly. Whereas, when biogeochemical conditions are not favorable to uranium partitioning, the drive to equilibrium is longer or possibly not achieved.

Table 8-4 shows the day 3 sample and final or terminal day sample mass of DU in extracts for the loess soils beneath penetrator samples soaked in rainwater. In terms of kinetics, comparison of the DU concentrations in samples after 3 days of soaking versus 60 to 120 days of soaking indicates in two out of three samples that DU dissolution-desorption is a function of time and altogether slower than forward partitioning kinetics. The Avonburg-Cobbsfork sample (PNAC-001) had slightly less mass in the extract at the end of the test than at day 3, possibly reflecting the reuptake of uranium by soils from solution over time due to inherent changes in the biogeochemistry of the batch samples for this soil. This sample

Table 8-4. Percent Change in Extract Total Uranium Concentration from Day 3 to Test Termination in Loess Soils Beneath Penetrators Jefferson Proving Ground, Madison, Indiana

ClientID	Initial Day 3 Concentration (ug/L)	Terminal Day (60 - 120) Concentration (ug/L)	Termination Day	Day-3 Mass as a Percentage of Terminal Mass
Loess Soil Beneath Penetrators in Rainwater				
JP-PNGR-001_SAIC05	35,600	304,000	120	12%
JP-PNAC-001_SAIC05	369	297	60	124%
JP-PNCR-001_SAIC05	3,360	12,200	90	28%

results also could be a function of simply matrix interferences attributable to soil variation at the laboratory scale.

At day 3, DU concentrations in extracts are relatively high, suggesting that DU begins to release from soils relatively rapidly. This initial released mass may reflect desorption from clay mineral and oxide surfaces and soil matrix organic carbon, possibly further aided by the strong concentration gradients rapidly set up around soil sorbed DU and the clean, low ionic strength oxic rainwater. The initial mass at day 3 suggests that DU partitioning at JPG is reversible, but combined with the progressively increasing mass in extracts seen as time goes on, perhaps overall at a slower rate than forward partitioning kinetics. As soils soak longer, the increase in released DU mass may be a function of a progressive increase in the rate of desorption, or it may also be a function of the gradual inclusion of DU dissolution from particulates like the oxidized or weathered mineral schoepite found on and around penetrators at JPG. Lastly, the increase in DU concentrations over time in extracts suggests that the biogeochemistry in the individual samples was not progressively reducing. If this progressive condition developed in bottleware, reduction of schoepite released uranyl to uranous uranium bearing mineral precipitates like uraninite would progressively decrease the dissolved DU concentration in extracts, which is the opposite of what was observed in two out of three cases.

8.10 ENVIRONMENTAL FATE OF DU AT JPG

Although K_d values determined by the K_d study ranged in magnitude comparable to published literature values, the K_d study had the beneficial outcome of identifying where and qualitatively why DU partitioning varies in the DU Impact Area, something literature values from corollary studies, if available, could not reliably provide alone. In addition to calculating K_d values for the geologic media of interest, the K_d study determined key geochemical characteristics of soils and pore water used for batch sample solids and contact solutions, as presented in Section 6. These characteristics provided the basis to infer what potential geochemical processes, summarized in Table 8-1 from discussions in Sections 2 and 8 herein, might be governing DU partitioning in a batch sample at laboratory scale and in the actual regional scale system at JPG. The role of these processes in affecting calculated K_d values and controlling DU migration in the DU Impact Area, as understood from the soil and water characteristics and the detailed CSM for the DU Impact Area, are discussed below.

Characterization of rainwater collected for the K_d study indicates precipitation (i.e., rainfall, snowmelt) in the DU Impact Area is of low ionic strength (0.02 to 0.15 meq/kg), with little magnesium (228 $\mu\text{g/L}$) but some calcium (2,930 $\mu\text{g/L}$) due to evaporation off of regional carbonate terrane, yet relatively low in alkalinity (3,500 $\mu\text{g/L}$), with some native organic carbon (3,500 $\mu\text{g/L}$). Rainfall has a high DO content (9.13 mg/L) and an ORP of 376 mV, indicative of an oxidizing solution, and is slightly

acidic (pH 6.0). Native or background loess soils, which averaged more than 4 ft, have been shown to be relatively high in iron (10,000 to 27,000 mg/kg), low in manganese (83 to 720 mg/kg), have modest TOC (0.2 to 0.4 percent), and have CECs in the sand (0 to 10) to moderate clay (10 to 50) ranging from 7.5 to 18 meq/100g. Soil pH is in the range of 4.4 to 7.6, for an average of 5.5. These soil and water characteristics indicate that DU in contact with rainwater in shallow soils should readily and almost wholly partition to these soils, which is verified by the results of the K_d study for loess soils. The K_d values calculated from the batch testing for loess soil samples were high to very high, ranging from 1,722 to 19,533 mL/g, for an average of 7,004 mL/g, signifying a very strong potential for partitioning.

Factors influencing or controlling DU partitioning in loess soils are inferred from the soil and water characteristics relative to the processes summarized in Table 8-1. Through correlations identified in Section 6, it has been shown that the native uranium in the background loess soils had a moderately direct relationship with iron, manganese, and the TOC content in those soils ($R^2 = 0.40$ to 0.58). The Ames, McGarrah, and Walker study (1983a, as referenced in USEPA 1999) reviewed above indicated the very strong potential for uranium to partition to ferrous oxyhydroxide. The iron and uranium relationship in the background loess soil coupled with this study suggests that iron and manganese bearing mineral surfaces in the presence of the acidic, oxidizing, low alkalinity pore water promoted immediate, significant DU partitioning in favor of other soil matrix exchange sites like organic material and clay minerals. Although the iron content of the soils could be a product of uranium mineral precipitation or coprecipitation with iron oxide, the lack of any increase in iron content in loess soils beneath penetrators relative to background loess iron levels indicates the iron is naturally present and therefore an attractive host site for uranium and not a byproduct of the presence of DU. The strong correlation of DU in loess soils beneath penetrators to soil pH, TOC, and CEC ($R^2 > 0.97$) relative to the decline in correlation to iron and manganese ($R^2 = 0.15$ to 0.19) indicate that in the face of increasing DU concentrations in pore water, other host sites in the soil matrix like organic carbon in clay mineral silicate sheet structure and clay mineral surfaces become progressively more important and available as the iron and manganese hydroxide surfaces become utilized, provided the pore waters remain low in alkalinity and ionic strength, remain oxidizing, and in the optimum pH range of 5.0 to 8.5 (USEPA 1999). This is supported by the Ames, McGarrah, and Walker (1983b) study of various sheet silicates (as referenced in USEPA 1999) and the Giblin (1980) study of uranium sorption on the clay mineral kaolinite (as referenced in USEPA 1999), discussed in Section 7.6. The relationship of uranium to organic carbon and CEC is not as well-developed in the literature.

K_d values determined for loess soils, basic soil and water chemistry and the above research can in turn be used to infer partitioning trends along the DU transport pathways identified in the CSM. DU penetrators are densest along the lines of fire, where loess soils and glacial till are thickest, and where local soil structure, naturally disturbed by macropores identified in Section 2, are further disturbed by repeated penetrator impact and historical munition testing. As determined from the detailed water budget presented in Section 2, the bulk of average annual precipitation in the DU Impact Area will either run off or: 1) evaporate during the growing season; or 2) bind up in snow and frozen soil during the winter before running off, leaving approximately 8 percent to infiltrate down to overburden groundwater.

As the low ionic strength, low alkalinity, oxidizing, slightly acidic pH precipitation comes in direct contact with penetrators and corrosion products in surface soils, DU dissolves into the precipitation. Given the chemistry of precipitation at JPG, the valence state of uranium dissolved off corrosion products in this scenario is expected to be the U^{+6} , given its stability and solubility under oxidizing conditions. This DU solute then, as predicted by the water budget, will principally flow overland. Basic loess soil chemistry and rainfall chemistry coupled with K_d values measured for loess soils and the prior research predict that this DU will partition strongly to the loess sediment in suspension and to those surface soils in direct contact with DU solute in stormwater flow routes. Partitioning will likely occur possibly first to iron and manganese hydroxide surfaces then progressively to the other host sites as a function of increasing DU solute concentrations in circulating pore water. The limited insight into uranium

partitioning kinetics gained from the day 3 batch samples where 98 percent or better of the spiked uranium contact solution content had been sorbed, suggests uranium partitioning, at the expected ambient low $\mu\text{g/L}$ concentrations, begins immediately and is completed within hours to days or the typical time for an average to above average rainfall and latent drainage period.

The small percentage of precipitation that does manage to infiltrate surface soil in the vicinity of penetrators and associated corrosion products is expected, in the short term, to remain oxidizing, acidic, and ionically weak. This again suggests that the valence state of uranium dissolved off corrosion products in this scenario is expected to be the U^{+6} , given its stability and solubility under oxidizing conditions. The DU solute formed in the vicinity of penetrators and corrosion products in this setting can be expected to be high in concentration as a result of the ambient soil DU concentrations, the desorption-dissolution kinetics demonstrated by the K_d study desorption-dissolution tests, and the small soil pore volume.

Basic loess soil chemistry and precipitation chemistry coupled with K_d values measured for loess soils and the prior research again predict that this DU will partition strongly to clays, oxides, and organic matter in the near surface soil matrix. Uranium mineral precipitation and coprecipitation with iron oxides also may be a governing process that removes DU from solution under oxidizing conditions due to rapid changes in solubility as the soils dry in between rain events (PNNL 2002). As shallow soils saturate from precipitation, DU dissolution rates and dissolved mass reach a maximum. As the soils dry via deeper drainage via macropores and less so soil pore throats or via upward evaporation through root uptake and transpiration, remaining uranium concentrations in soil water can exceed solubilities for uranyl containing minerals and iron oxide coprecipitates, locking DU up in relatively insoluble solids in the soil matrix at shallow depths.

As the characteristically low permeable loess soils saturate for an extended period, possibly only seasonally in the late fall and spring when rainfall frequency is at a peak, characteristically oxidizing pore waters can change oxidation state to a reducing condition via aerobic microbial competition for dissolved organic carbon and the resultant consumption of DO. A penetrator in contact with reduced pore water will slow significantly in its rate of corrosion. In addition, once stable dissolved U^{+6} and associated oxidized complexes will become unstable, reduce to uranous ion (U^{+4}) and precipitate out of solution as uranous bearing minerals like uraninite and coffinite. Evidence of potential reducing conditions, at least seasonally, comes from observations of surface water along the line of fire where many penetrators impacted, rainfall aqueous chemistry, and soil characteristics observed during soil sample collection. The 500 Center line of fire will pond water for an extended period, providing for DO consumption in the near surface while the water is slowly driven into the saturated subsurface via porous media and macropore flow. Slow transport favors microbial consumption of oxygen. The rainwater sample collected for the K_d study contained 3,500 $\mu\text{g/L}$ of organic carbon, indicating an ambient source of microbial carbon before potential preferential enrichment via interaction with soil matrix organic carbon. Extensive soil sampling around and over time in the DU Impact Area indicates the portion of the DU Impact Area (>55 percent) with somewhat poorly and poorly drained soils exhibits redoximorphic features, or soil mottling, suggestive of a reducing environment in the shallow (<3 ft) subsurface for some period of time during the growing season. Soil mottling is a color pattern in the soil formed by the oxidation and reduction of iron and manganese caused by saturated or near saturated conditions within the soil. This reducing environment is sufficient to reduce oxidized ferric iron to ferrous iron, in turn coloring the soil by addition of ferrous iron or manganese precipitate.

Under the above-described potential reducing conditions, DU will be removed from solution, ending any further advancement of dissolved DU to depth. Under oxidizing conditions, infiltrated precipitation that comes in contact with penetrators and corrosion products will continue to partition to host receptors defined above, so long as migrating pore water continues to remain relatively low in dissolved solids, alkalinity, and pH, and remains strongly oxidizing. The DU activity gradation in soils

beneath penetrators provides another perspective of DU transport, supporting the above conclusions with respect to DU attenuation under either shallow reducing or oxidizing conditions. The trends in DU activity demonstrate large-scale DU partitioning consistent with the laboratory scale K_d study results for loess soils.

Table 8-5 lists the average gamma activities, based on field measurements with a NaI detector, per 6-in and 1-ft intervals between grade and a total depth of 4 ft beneath penetrators found in each soil series in October 2008.

**Table 8-5. DU Activity With Depth in Shallow Loess Soils
Jefferson Proving Ground, Madison, Indiana**

Loess Soil Series	Sample Depth	Average DU Activity (pCi/g)			
		0-0.5 (ft)	0.5-1.0 (ft)	1.0-2.0 (ft)	2.0-4.0 (ft)
Avonburg/Cobbsfork Soil Average DU Activity		14,488	1,663	368	120
Cincinnati/Rossmoyne Soil Average DU Activity		9,971	3,655	767	503
Greyford/Ryker Soil Average DU Activity		3,117	626	466	4,323

Note: DU activity determined in the field with a sodium iodide detector.

Highest average gamma activity observed in these measurements is in the top 6 in of soil, where DU corrosion products are most prevalent along with TOC. Average gamma activity trails off markedly at depths of 1 to 2 ft BGS, with values at one to two orders of magnitude lower at depths of 3 to 4 ft BGS. The one exception is the average DU activity at 2 to 4 ft BGS for Grayford/Ryker soils. This soil series is the least prevalent soil type where penetrators are found and is therefore represented by only three samples (see Table 7-4). DU activity in this depth interval at two of the three locations was similar to the Avonburg/Cobbsfork and Cincinnati/Rossmoyne soils, on the order of 191 to 288 picoCuries per gram (pCi/g). DU activity at the third sample location was 12,491 pCi/g, which influenced higher apparent average DU activity for this soil series.

Review of the average gamma activity over depth indicates that the highest activity is in the uppermost 6 in of soil. This is a function of the accumulation of corrosion solids but also likely reflects DU partitioning and possibly DU mineral precipitation due to widely fluctuating soil moisture, DU solubility so close to a uranium/DU source, and transitional reducing conditions (PNNL 2002). The rapid decline in gamma activity over a short depth interval is a reflection of the poor mobility of DU in shallow oxidizing substrate or its susceptibility to reduction and precipitation. The pore water and soil geochemical factors, as discussed above, promote DU partitioning, precipitation/coprecipitation significantly over mobility, achieving near complete attenuation by a depth of 4 ft BGS. The anomalously high DU activity in the one soil sample at a depth of 4 ft may reflect the role of macropores discussed in Section 2 in short circuiting porous media flow and laboratory scale predicted rates of DU partitioning.

Overburden groundwater chemistry, as thoroughly documented around the DU Impact Area and as represented by JPG-DU-06O as presented in Section 6, is considerably older than rainwater, on the order of decades (USGS 2010), considerably more mineralized or of a greater ionic strength (4 to 7 meq/kg), significantly more alkaline (329,000 $\mu\text{g/L}$), less oxidizing (13 mV), and higher in pH (7.28). Based on the geochemistry of the glacial till (higher pH [8.6] more carbonate rich) and groundwater in the till, DU partitioning would be expected to be minimal within the till. The results of the K_d study supported the hypothesis that minimal sorption occurs in glacial till. The K_d values returned for the batch till analyses

were very low, ranging from 0.93 to 20 mL/g, for an average of 8.4 mL/g, signifying much less potential for sorption along the overburden groundwater transport pathway. The K_d values calculated for tills from the K_d study appear to correlate to values determined by Bell and Bates (1988) for a glacial till clay (USEPA 1999). The K_d value determined in this study (USEPA 1999) was 46 mL/g.

The minimal DU solute that might make it to overburden groundwater is not expected to partition appreciably in the till hydrostratigraphic layer or groundwater system based on inferences from the till groundwater system geochemistry, and as confirmed by this K_d study, summarized above. The USGS report on groundwater age at JPG (USGS 2010), coupled with the slug test report on groundwater permeability (SAIC 2010) indicate water movement through the till groundwater system is variable, but generally slow, with pockets of slow-moving to stagnant water residing in the till for years to decades. Although longer-duration pore water residence times improve geochemical reaction kinetics, the geochemistry of the till groundwater system is significantly divergent from the optimum for uranium partitioning. The older, higher ionic strength groundwater, particularly with respect to the cations calcium (86,800 $\mu\text{g/L}$), magnesium (27,500 $\mu\text{g/L}$), and less so potassium (1,070 $\mu\text{g/L}$), will out compete invading DU solute for solid matrix exchange sites, preventing uranium from partitioning and keeping it in solution. In addition, the elevated alkalinity (329,000 $\mu\text{g/L}$) of the groundwater will compound its ionic strength in keeping uranium in solution and mobile, by promoting formation of very soluble uranyl carbonate complexes (USEPA 1999). Once DU reaches the till groundwater system, its rate of travel should only be slightly slower than groundwater advection rates.

Over the remainder of the groundwater/DU transport pathway from the till groundwater system to the underlying shallow carbonate bedrock groundwater system and eventually to the streams Big Creek and Middle Branch Creek that cross the DU Impact Area, minimal uranium partitioning is expected for the above reasons. As till thins approaching these streams, groundwater flow is primarily in the shallow carbonate, where dissolution of fractures has developed over time. Limited further uranium adsorption is expected at this point in the flow path because clay and iron oxide reaction surfaces are diminished along available fracture flow paths, and pore water chemistry is very mineralized, alkaline, marginally reducing, and higher in pH with reaction kinetics much less than optimal due to progressively increasing advection rates as groundwater converges through the narrow groundwater discharge points at local streams.

9. K_d VALUE RECOMMENDATIONS FOR DU IMPACT AREA

The K_d study was successful in framing site-specific K_d value ranges for use in the surface water, groundwater, and residual radiation modeling required for the Decommissioning Plan for JPG's Materials License (SUB-1435). The K_d study, working in cooperation with the detailed CSM, accurately quantified the partitioning potential of DU in the major hydrogeological systems in the DU Impact Area where DU penetrators remain: the loess soils and the saturated glacial till. The K_d study was an improvement over the use of prior literature-based research alone, but benefitted from that research in terms of understanding the processes driving DU distribution at the laboratory and field scale. Final, corrected K_d values shown in Table 9-1 were derived with the site-specific biogeochemical characteristics of soil, till, rainwater, and groundwater at JPG, which is essential to understanding the processes contributing to batch method K_d value determination and scaling values to an actual system. Despite real influence from uranium plating on bottleware, the batch method, carried to 30 days or better to ensure equilibrium conditions had been achieved, is a viable means to estimate uranium partitioning at a laboratory scale.

Clearly, batch results for loess soils indicate a strong potential for DU sorption, whether the processes driving that distribution are partitioning or mineral precipitation/coprecipitation under oxidizing conditions, mineral precipitation under reducing conditions, or a seasonally varying combination of all. With respect to the unsaturated till, given its similar textural and inferred clay mineral composition as loess soils and the weathering or leaching removal of original carbonate, the partitioning potential, or K_d values should be similar to the loess soils. Once saturated, the influence of the older, more alkaline, mineralized groundwater appears to significantly limit DU partitioning potential, or conversely promotes DU mobilization.

With the understanding of the various biogeochemical controls that influenced K_d value determination in the laboratory and likely influence DU partitioning in the DU Impact Area, as discussed in Section 8, the final recommended K_d values for strategic geologic media and locations along the DU transport pathways are provided below.

These final, plating corrected K_d values were further statistically analyzed via computer software (ProUCL) to evaluate data in terms of central tendencies by soil type or group and to define, with good statistical certainty, K_d values for input into the other computer models identified in the introduction that will simulate DU transport and fate along the various relevant pathways identified in the CSM for the DU Impact Area. Figures 9-1 through 9-4, produced with ProUCL, show the frequency or probability distributions of the plating corrected K_d values. The figures compare probability distributions amongst all test groups (loess sorption and desorption-dissolution and till sorption) (Figures 9-1 and 9-2), for loess soils (sorption only) (Figure 9-3), and for glacial till subgroups (Figure 9-4). For three samples, statistical analysis of the loess soil desorption-dissolution values was not performed.

Results of the statistical analysis, included in the K_d value summary attachment, indicate the loess soil sorption K_d value population is normally distributed, at a 0.05 significance level, about a raw mean of 2,044 mL/g between minimum and maximum values of 57 and 4,470 mL/g, with a standard deviation of 1,033 mL/g. The glacial till K_d values also were found to be normally distributed, at a 0.05 significance level, about a raw mean of 8.4 mL/g between minimum and maximum values of 0.93 and 20 mL/g, with a standard deviation of 8.5 mL/g.

Having established the normal bounds of the K_d values within a statistical degree of certainty for each test group, weighted average K_d values were then calculated according to the surface area of respective soils in the DU Impact Area to further connect laboratory determined and plating corrected K_d values to probable DU partitioning potential in the DU Impact Area. Table 9-2 lists the mapped acreages of each soil type in the DU Impact Area and the total mapped acreage for the principal soil groups comprising the soil types.

**Table 9-1. Summary of DU Batch Testing Plating Corrected K_d Results
Jefferson Proving Ground, Madison, Indiana**

Soil Type	Sample ID	Plating Adjusted Final K _d (mL/g)	
		Individual Test	Soil Type
Rainwater Sorption for Loess Soil Types			1,954
Avonsburg/Cobbsfork			2,290
	JP-SAC-001_SAIC05	2,501	
	JP-SAC-001_SAIC05D	2,435	
	JP-SAC-002_SAIC05	1,646	
	JP-SAC-003_SAIC05	1,058	
Avonsburg/Cobbsfork	JP-SAC-004_SAIC05	3,831	
	JP-SAC-005_SAIC05	3,132	
	JP-SAC-006_SAIC05	2,024	
	JP-SAC-007_SAIC05	1,347	
	JP-SAC-008_SAIC05	1,610	
	JP-SAC-009_SAIC05	3,315	
Cincinnati/Rossmoyne			2,363
	JP-SCR-001_SAIC05	3,069	
	JP-SCR-001_SAIC05D	2,234	
	JP-SCR-002_SAIC05	4,470	
	JP-SCR-003_SAIC05	2,284	
Cincinnati/Rossmoyne	JP-SCR-004_SAIC05	57	
	JP-SCR-005_SAIC05	2,436	
	JP-SCR-006_SAIC05	2,270	
	JP-SCR-007_SAIC05	1,500	
	JP-SCR-008_SAIC05	656	
	JP-SCR-009_SAIC05	2,347	
Greyford/Ryker			1,208
	JP-SGR-001_SAIC05	1,089	
Greyford/Ryker	JP-SGR-001_SAIC05D	1,073	
	JP-SGR-002_SAIC05	1,248	
	JP-SGR-003_SAIC05	1,421	
Groundwater Sorption for Glacial Till			8
	JP-KAC-011_SAIC01R	0.93	
Avonsburg/Cobbsfork	JP-KAC-012_SAIC01R	1.03	
	JP-KAC-013_SAIC01R	0.96	
Cincinnati/Rossmoyne	JP-KCR-011_SAIC01R	11.7	
	JP-KCR-012_SAIC01R	--	
Greyford/Ryker	JP-KGR-005_SAIC01DR	16	
	JP-KGR-005_SAIC01R	20	
Desorption by Loess Soil Types			429
Avonsburg/Cobbsfork	JP-PNAC-001_SAIC05	189	
Cincinnati/Rossmoyne	JP-PNCR-001_SAIC05	591	
Greyford/Ryker	JP-PNGR-001_SAIC05	507	

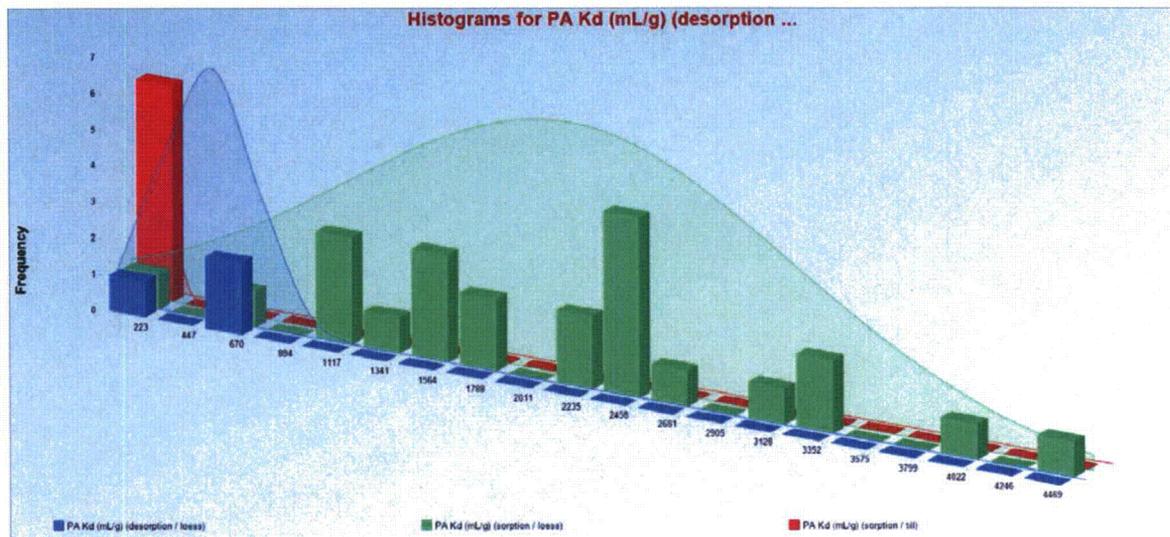


Figure 9-1. Histogram Showing Comparison of Frequency Distributions of Plating Corrected K_d Values for Loess Soils (Sorption and Desorption-Dissolution) and Glacial Till

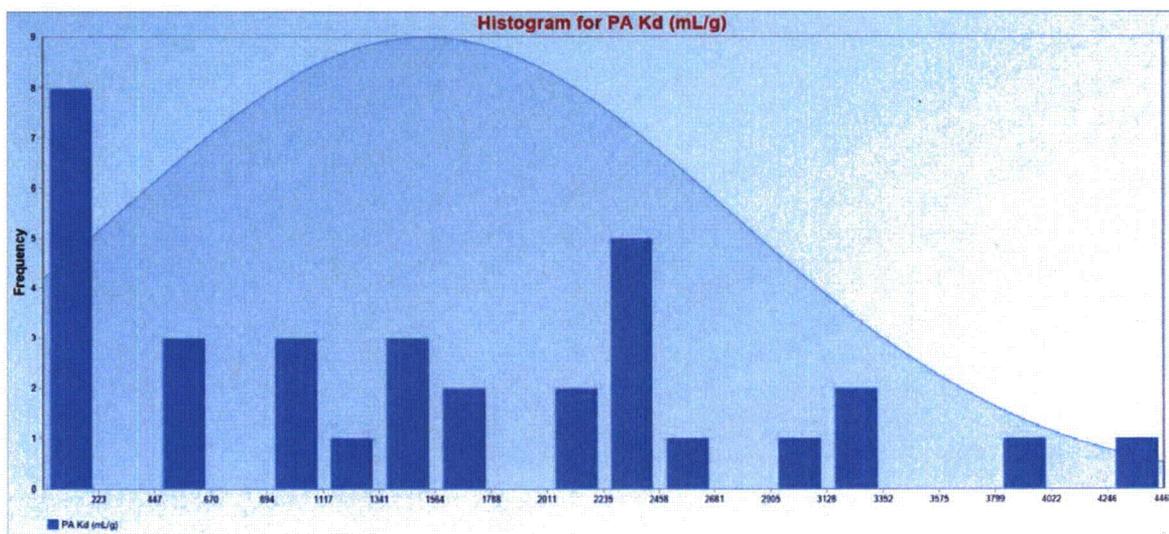


Figure 9-2. Histogram of Frequency Distribution of Lumped Plating Corrected K_d Values for Loess Soils and Glacial Till

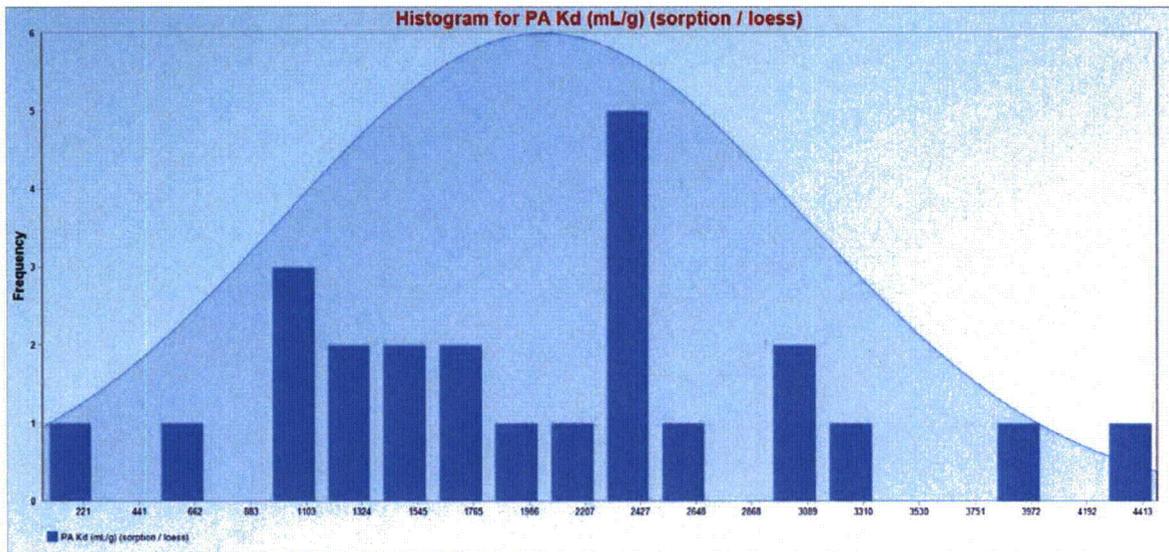


Figure 9-3. Histogram of Frequency Distribution of Plating Corrected K_d Values for Loess Soils

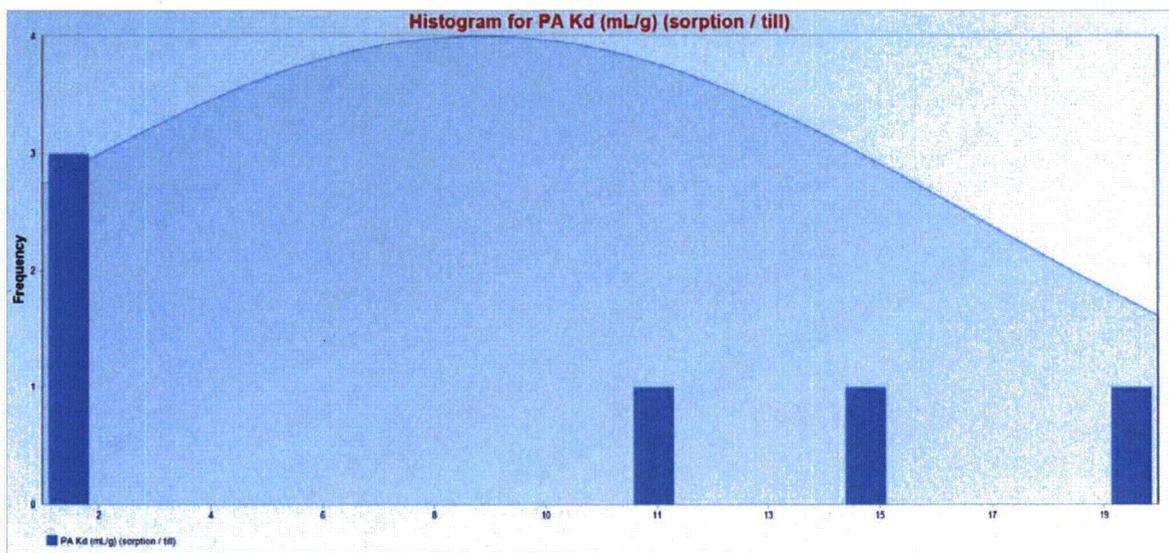


Figure 9-4. Histogram of Frequency Distribution of Plating Corrected K_d Values for Loess Soils

**Table 9-2. Soil Type and Group Acreage Across DU Impact Area
Jefferson Proving Ground, Madison, Indiana**

Soil Series	Total Mapped Acreage	Percent Total Acres
Avonburg	312	14.8
Cincinnati	409	19.4
Cobbsfork	861	40.7
Grayford	145	6.8
Holbn	36	1.7
Rossmoyne	260	12.3
Ryker	91	4.3
Soil Groups		
Avonsburg/Cobbsfork	1173	55.5
Cincinnati/Rossmoyne	669	31.7
Grayford/Ryker	236	11.1

Table 9-3 shows the calculation and presentation of the weighted average K_d values for each type of test group: loess soil sorption, loess soil desorption-dissolution, and glacial till sorption. Given the small representation of the Holton soil type in the DU Impact Area (1.7 percent) with limited potential to contain penetrators, this soil group was excluded from the soil area component of the weighted average. Respective weighted average K_d values and associated standard deviations for the three types of tests were as follows:

- Loess soil sorption: weighted average 2,116 mL/g, standard deviation 410 mL/g
- Loess soil desorption-dissolution: weighted average 354 mL/g, standard deviation 204 mL/g
- Glacial till sorption: weighted average 6.4 mL/g, standard deviation 7.5 mL/g.

A combined loess soil and glacial till sorption weighted average also was calculated and is listed below with the standard deviation:

- Loess and till sorption: weighted average 2,123 mL/g, standard deviation 1,538 mL/g.

Figure 9-5, adapted from the CSM, shows standard penetration test total blow counts with depth at monitoring well JPG-DU-06D to illustrate the typical depth profiles of loess and glacial till and depths to rock and groundwater in the DU Impact Area. The figure shows conceptually the distribution of K_d values for the geologic media and locations important for DU migration and subsequent transport simulation using RESRAD-OFFSITE, as follows:

- Contaminated Zone (0 to 1 m BGS): 354 mL/g, which is an equivalent K_d determined from the weighted average of loess soil desorption-dissolution tests
- Vadose Zone 1 – Base of Loess Soil (1 to 2.3 m BGS): 2,116 mL/g, which is the weighted average for the three loess soil groups determined from sorption tests
- Vadose Zone 2 – Top of Till (2.3 to 6 m BGS): 2,123 mL/g, which is the weighted average for the loess soils and till combined from the sorption tests
- Saturated Till (6m +): 6 mL/g, which is the weighted average from the till sorption tests.

**Table 9-3. DU Impact Area Soil Group Weighted Average K_d Values
Jefferson Proving Ground, Madison, Indiana**

K_d Study Test Type	Geologic Medium	Soil Group	Final Plating Adjusted (PA) K_d (mL/g)	Average PA K_d By Soil Type (mL/g)	Total Acreage Covered By Soil Type	Percent of Area Covered By Soil Type Based on 7 Soil Types	Percent of Area Covered By Soil Type Based on 6 Soil Types	Weighted Mean (mL/g)	Weighted Standard Deviation (mL/g)	Weighted Mean (mL/g)	Weighted Standard Deviation (mL/g)
Desorption	Loess	Avonsburg/Cobbsfork	189	189	1,173	55.5%	0.56	354	204		
		Cincinnati/Rossmoyne	591	591	669	31.7%	0.32				
		Greyford/Ryker	507	507	236	11.1%	0.11				
Sorption	Till		0.93					6.4	7.5		
		Avonsburg/Cobbsfork	1.03	0.97	1,173	55.5%	0.56				
			0.96								
		Cincinnati/Rossmoyne	11.7	11.7	669	31.7%	0.32				
		Greyford/Ryker	16	18	236	11.1%	0.11				
Sorption	Loess		2,501					2,116	410		
			2,435								
			1,646								
			1,058								
		Avonsburg/Cobbsfork	3,831	2,290	1,173	55.5%	0.56				
			3,132								
			2,024								
			1,347								
			1,610								
			3,315								
			3,069								
			2,234								
			4,470								
			2,284								
		Cincinnati/Rossmoyne	57	2,132	669	31.7%	0.32				
	2,436										
	2,270										
	1,500										
	656										
	2,347										
	1,089										
Greyford/Ryker	1,073	1,208	236	11.1%	0.11						
	1,248										
	1,421										

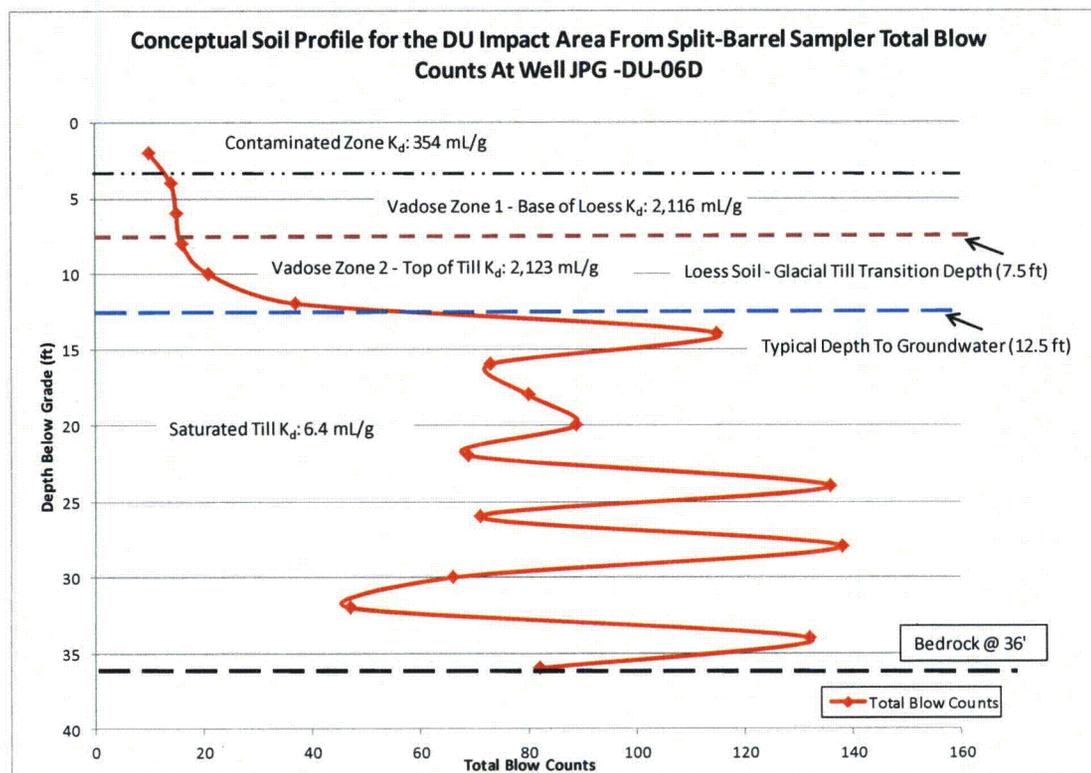


Figure 9-5. Typical Conceptual Soil Profile Showing Variation of K_d Values for Key Locations in Loess Soils and Till

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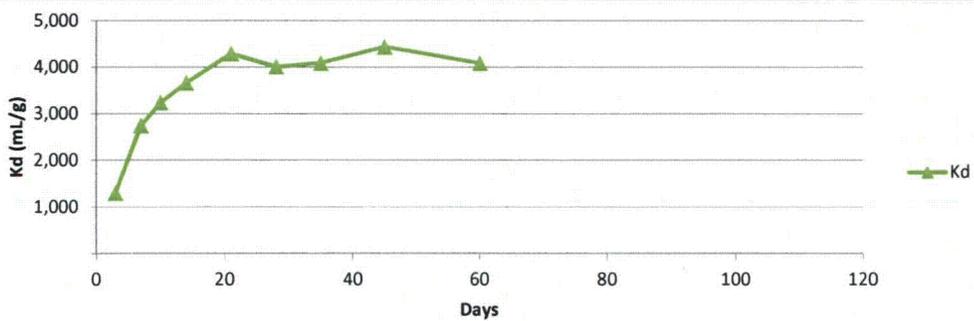
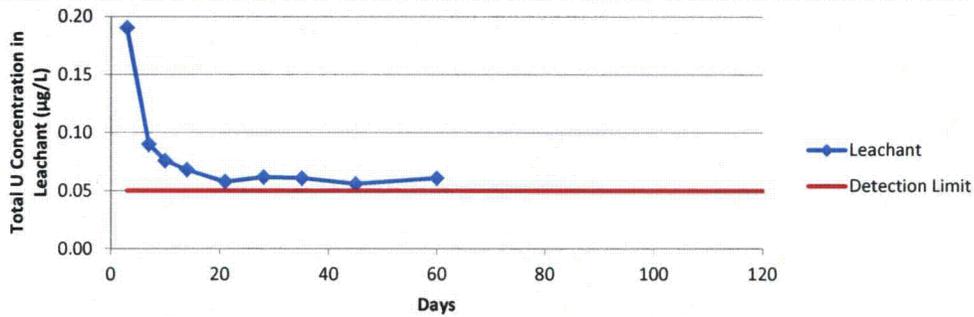
**ATTACHMENT – BATCH SAMPLE K_d VALUE CALCULATION SUMMARY AND
INDIVIDUAL BATCH SAMPLE CALCULATION DATA SHEETS**

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Soil Type	Sample ID	Lab ID	Recommended Kd (mL/g)		Soil Type	Number of Samples	Minimum Value	Maximum Value	Average Value
			Individual Test	Soil Type					
Desorption by Loess Soil Types					429				
Avonsburg/Cobbsfork	JP-PNAC-001_SAIC05	F2C310414-007	189			1	189	189	189
Cincinnati/Rossmoyne	JP-PNCR-001_SAIC05	F2C310414-005	591			1	591	591	591
Greyford/Ryker	JP-PNGR-001_SAIC05	F2C310414-006	507			1	507	507	507
Groundwater Sorption for Glacial Till					8.4				
Avonsburg/Cobbsfork	JP-KAC-011_SAIC01R	F2C290434-004	0.93			3	0.93	1.03	0.98
Avonsburg/Cobbsfork	JP-KAC-012_SAIC01R	F2C300498-003	1.03						
Avonsburg/Cobbsfork	JP-KAC-013_SAIC01R	F2C300498-004	0.97						
Cincinnati/Rossmoyne	JP-KCR-011_SAIC01R	F2C290416-002	11.7			1	11.7	11.7	11.7
Cincinnati/Rossmoyne	JP-KCR-012_SAIC01R	F2C290434-002	--	x					
Greyford/Ryker	JP-KGR-005_SAIC01DR	F2C290416-004	16			2	16	20	18
Greyford/Ryker	JP-KGR-005_SAIC01R	F2C290416-003	20.0						
Rainwater Sorption for Loess Soil Types					7,004				
Avonsburg/Cobbsfork					4,008				
Avonsburg/Cobbsfork	JP-SAC-001_SAIC05	F2C300498-014	4,184			10	1,722	7,159	4,008
Avonsburg/Cobbsfork	JP-SAC-001_SAIC05D	F2C300498-016	4,010						
Avonsburg/Cobbsfork	JP-SAC-002_SAIC05	F2C300498-012	1,899						
Avonsburg/Cobbsfork	JP-SAC-003_SAIC05	F2C290416-005	2,455	b					
Avonsburg/Cobbsfork	JP-SAC-004_SAIC05	F2C300498-008	6,496						
Avonsburg/Cobbsfork	JP-SAC-005_SAIC05	F2C290434-010	6,308	b					
Avonsburg/Cobbsfork	JP-SAC-006_SAIC05	F2C290416-009	3,007						
Avonsburg/Cobbsfork	JP-SAC-007_SAIC05	F2C290416-007	1,722						
Avonsburg/Cobbsfork	JP-SAC-008_SAIC05	F2C290416-006	2,843	b					
Avonsburg/Cobbsfork	JP-SAC-009_SAIC05	F2C290416-008	7,159	b					
Cincinnati/Rossmoyne					9,675				
Cincinnati/Rossmoyne	JP-SCR-001_SAIC05	F2C300498-009	9,458	b		9	2,413	17,043	9,675
Cincinnati/Rossmoyne	JP-SCR-001_SAIC05D	F2C300498-015	8,463	b					
Cincinnati/Rossmoyne	JP-SCR-002_SAIC05	F2C300498-011	17,043	b					
Cincinnati/Rossmoyne	JP-SCR-003_SAIC05	F2C300498-013	9,328	b					
Cincinnati/Rossmoyne	JP-SCR-004_SAIC05	F2C290434-012	59	x					
Cincinnati/Rossmoyne	JP-SCR-005_SAIC05	F2C300498-007	12,538	b					
Cincinnati/Rossmoyne	JP-SCR-006_SAIC05	F2C290434-009	9,028	b					
Cincinnati/Rossmoyne	JP-SCR-007_SAIC05	F2C290434-007	8,467	b					
Cincinnati/Rossmoyne	JP-SCR-008_SAIC05	F2C290434-005	2,413	b					
Cincinnati/Rossmoyne	JP-SCR-009_SAIC05	F2C290434-008	10,340	b					
Greyford/Ryker					8,485				
Greyford/Ryker	JP-SGR-001_SAIC05	F2C310414-003	3,893			4	3,655	19,533	8,485
Greyford/Ryker	JP-SGR-001_SAIC05D	F2C310414-004	3,655						
Greyford/Ryker	JP-SGR-002_SAIC05	F2C310414-002	6,860	b					
Greyford/Ryker	JP-SGR-003_SAIC05	F2C300498-010	19,533	b					

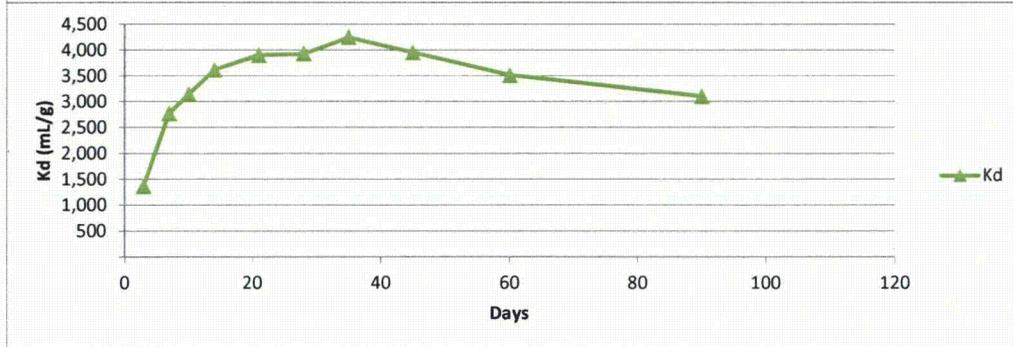
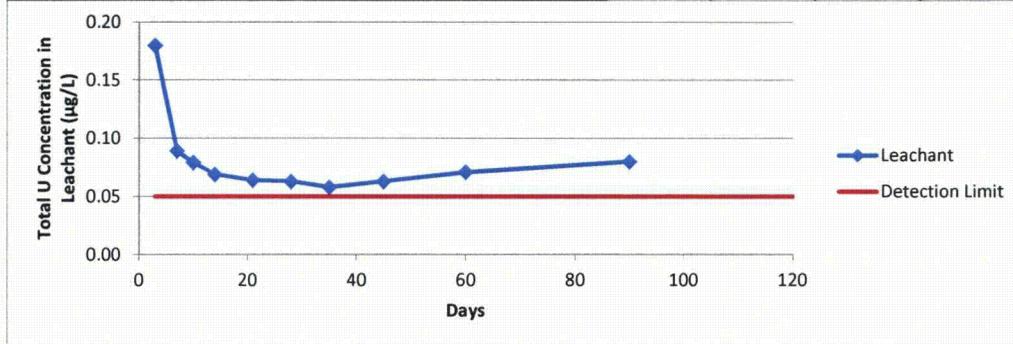
x - Result excluded from calculation of mean Kd value 2 tests
b - Some or all leachant concentrations detected below detection limit 15 tests

Sample:	JP-SAC-001_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.190	0.0900	0.0760	0.0680	0.0580	0.0620	0.0610	0.0560	0.0610	--	--
Leachant Relative Percent Difference (%), RPD:	--	71.4	16.9	11.1	15.9	6.7	1.6	8.5	8.5	--	--
Starting Soil Concentration (mg/kg), S_i :	0.77										
Dry Mass of Solid (g), M:	3.9862	4.0080	4.0329	3.9914	3.9928	3.9990	3.9822	4.0008	3.9865	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	981	991	992	993	994	994	994	994	994	--	--
Concentration of Tracer Sorbed on Solid, S:	246	247	246	249	249	249	250	249	249	--	--
K_d (mL/g):	1,295	2,747	3,238	3,659	4,293	4,008	4,092	4,438	4,087	--	--
K_d Relative Percent Difference (%), RPD:	--	71.8	16.4	12.2	15.9	6.9	2.1	8.1	8.2	--	--



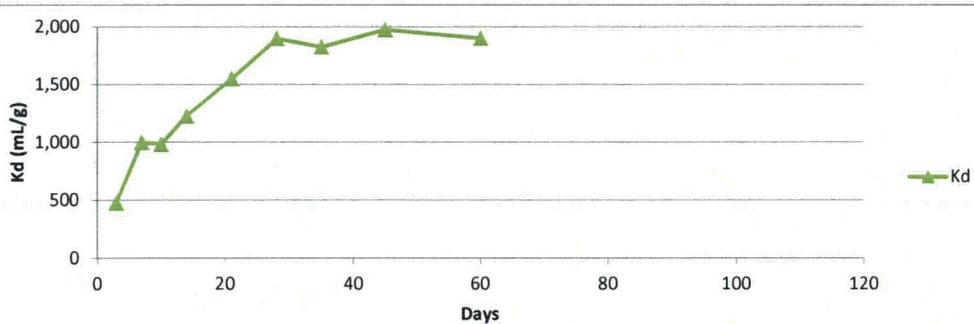
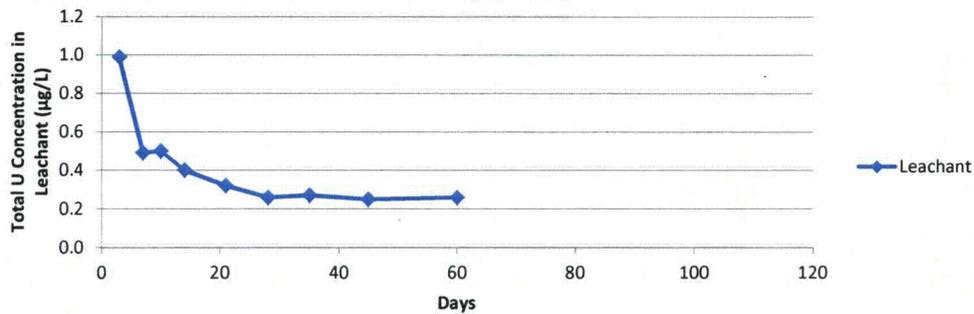
Final Soil Concentration: 1.1 mg/kg
Recommended K_d : 4184 (mL/g)
Assumes equilibrium reached between days 21 through 60.

Sample:	JP-SAC-001_SAIC05D										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V :	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.180	0.0890	0.0790	0.0690	0.0640	0.0630	0.0580	0.0630	0.0710	0.0800	--
Leachant Relative Percent Difference (%), RPD:	--	68	12	14	7.5	1.6	8.3	8.3	12	12	--
Starting Soil Concentration (mg/kg), S_i :	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	--
Dry Mass of Solid (g), M :	3.9868	4.0067	3.9945	3.9747	3.9776	4.0133	4.0339	3.9847	3.9747	3.9867	--
Quantity of Tracer Sorbed on Solid, Q_s :	982	991	992	993	994	994	994	994	993	992	--
Concentration of Tracer Sorbed on Solid, S :	246	247	248	250	250	248	246	249	250	249	--
K_d , (mL/g):	1,368	2,779	3,144	3,621	3,903	3,930	4,249	3,958	3,518	3,110	--
K_d Relative Percent Difference (%), RPD:	--	68.0	12.3	14.1	7.5	0.7	7.8	7.1	11.8	12.3	--



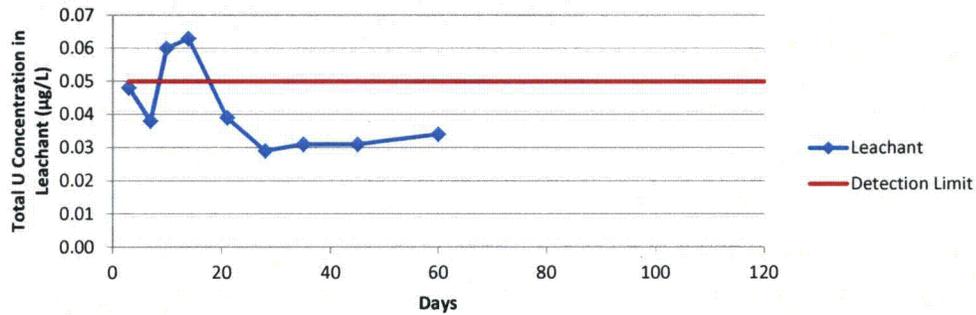
Final Soil Concentration: 0.66 mg/kg
Recommended K_d : 4010 (mL/g)
Assumes equilibrium reached between days 21 through 45.

Sample:	JP-SAC-002_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	20										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.990	0.490	0.500	0.400	0.320	0.260	0.270	0.250	0.260	--	--
Leachant Relative Percent Difference (%), RPD:	--	68	2.0	22	22	21	3.8	7.7	3.9	--	--
Starting Soil Concentration (mg/kg), S_i :	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	--	--
Dry Mass of Solid (g), M:	4.0395	3.9975	3.9733	3.9987	3.9737	4.0035	4.0020	4.0018	3.9945	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	1,901	1,951	1,950	1,960	1,968	1,974	1,973	1,975	1,974	--	--
Concentration of Tracer Sorbed on Solid, S_s :	471	488	491	490	495	493	493	494	494	--	--
K_d (mL/g):	475	996	982	1,225	1,548	1,896	1,826	1,974	1,901	--	--
K_d Relative Percent Difference (%), RPD:	--	70.8	1.5	22.1	23.2	20.3	3.8	7.8	3.8	--	--

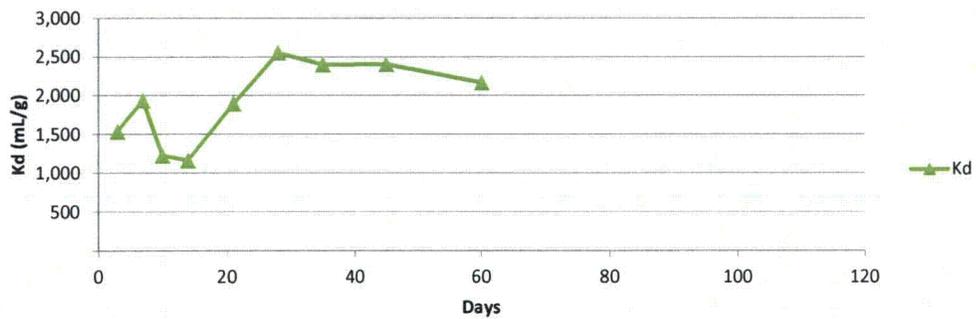


Final Soil Concentration: 0.88 mg/kg
Recommended K_d : 1899 (mL/g)
Assumes equilibrium reached between days 28 through 60.

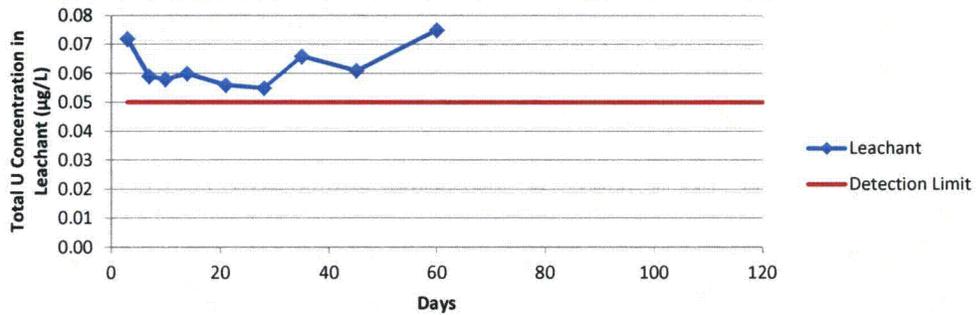
Sample:	JP-SAC-003_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$, C_i):	3										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$, C_f):	0.0480	0.0380	0.0600	0.0630	0.0390	0.0290	0.0310	0.0310	0.0340	--	--
Leachant Relative Percent Difference (%), RPD:	--	23	45	4.9	47	29	6.7	0	9.2	--	--
Starting Soil Concentration (mg/kg), S_i :	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	--	--
Dry Mass of Solid (g), M:	4.0067	4.0176	3.9909	4.0077	4.0008	4.0068	3.9877	3.9811	4.0217	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	295	296	294	294	296	297	297	297	297	--	--
Concentration of Tracer Sorbed on Solid, S_s :	74	74	74	73	74	74	74	75	74	--	--
K_d , (mL/g):	1,535	1,940	1,228	1,163	1,898	2,557	2,402	2,406	2,169	--	--
K_d Relative Percent Difference (%), RPD:	--	23.3	45.0	5.4	48.0	29.6	6.3	0.2	10.3	--	--



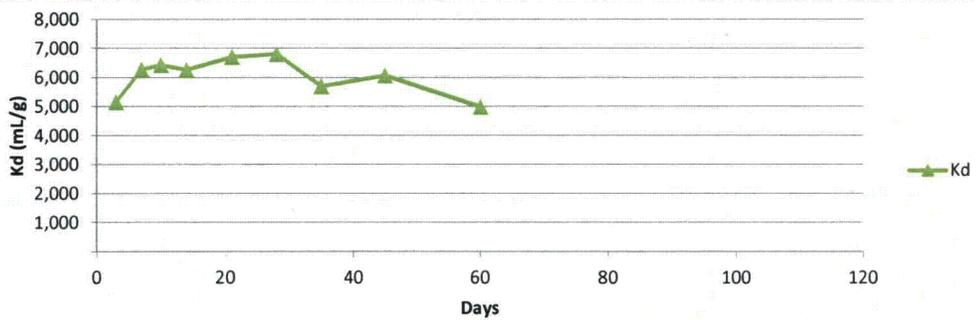
Final Soil Concentration: 0.67 mg/kg
Recommended K_d : 2455 (mL/g)
Assumes equilibrium reached between days 28 through 45.



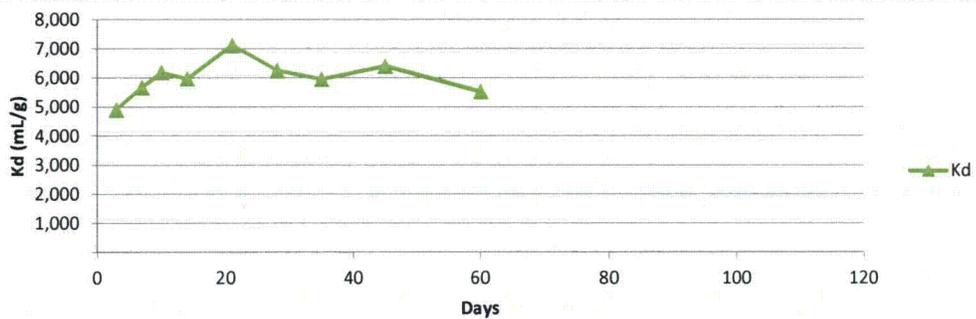
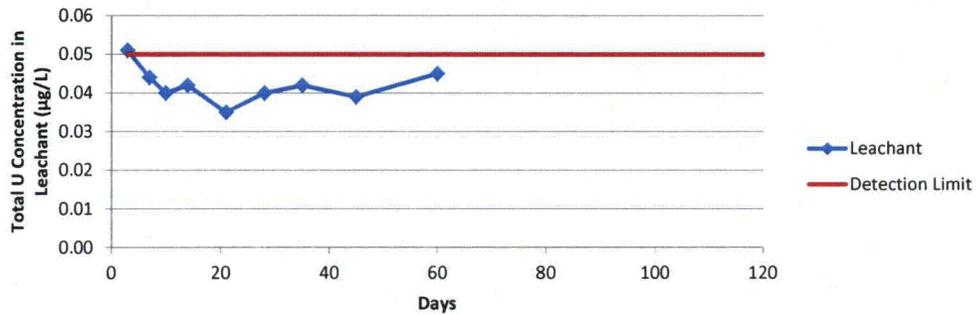
Sample:	JP-SAC-004_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	15										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0720	0.0590	0.0580	0.0600	0.0560	0.0550	0.0660	0.0610	0.0750	--	--
Leachant Relative Percent Difference (%), RPD:	--	20	1.7	3.4	6.9	1.8	18	7.9	21	--	--
Starting Soil Concentration (mg/kg), S_i :	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	--	--
Dry Mass of Solid (g), M:	4.0238	4.0375	4.0070	3.9736	3.9805	3.9917	3.9702	4.0317	3.9866	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	1,493	1,494	1,494	1,494	1,494	1,495	1,493	1,494	1,493	--	--
Concentration of Tracer Sorbed on Solid, S_s :	371	370	373	376	375	374	376	371	374	--	--
Kd, (mL/g):	5,153	6,272	6,429	6,266	6,704	6,807	5,699	6,074	4,992	--	--
Kd Relative Percent Difference (%), RPD:	--	19.6	2.5	2.6	6.7	1.5	17.7	6.4	19.6	--	--



Final Soil Concentration: 1.4 mg/kg
Recommended Kd: 6496 (mL/g)
Assumes equilibrium reached between days 7 through 28.

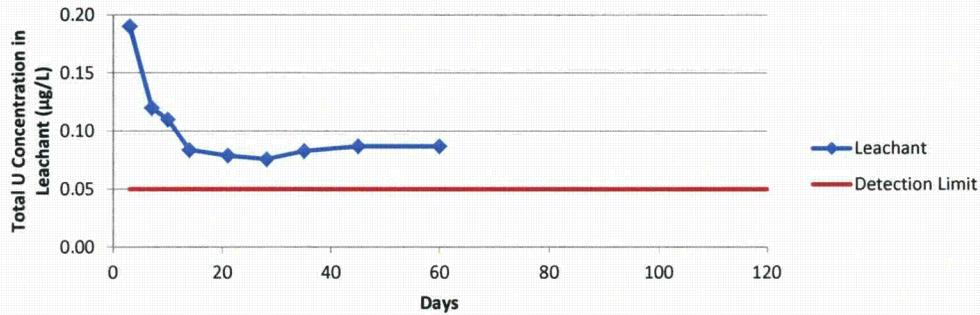


Sample:	JP-SAC-005_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0510	0.0440	0.0400	0.0420	0.0350	0.0400	0.0420	0.0390	0.0450	--	--
Leachant Relative Percent Difference (%), RPD:	--	15	9.5	4.9	18	13	4.9	7.4	14	--	--
Starting Soil Concentration (mg/kg), S_i :	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	--	--
Dry Mass of Solid (g), M:	3.9820	3.9985	4.0309	3.9740	4.0035	3.9869	3.9853	3.9937	4.0033	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	995	996	996	996	997	996	996	996	996	--	--
Concentration of Tracer Sorbed on Solid, S_s :	250	249	247	251	249	250	250	249	249	--	--
K_d (mL/g):	4,899	5,659	6,177	5,966	7,112	6,245	5,949	6,395	5,526	--	--
K_d Relative Percent Difference (%), RPD:	--	14.4	8.8	3.5	17.5	13.0	4.9	7.2	14.6	--	--

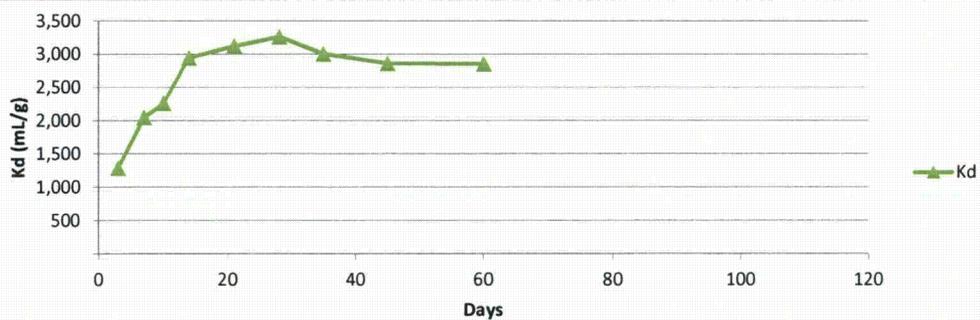


Final Soil Concentration: 0.94 mg/kg
Recommended K_d : 6308 (mL/g)
Assumes equilibrium reached between days 10 through 45.

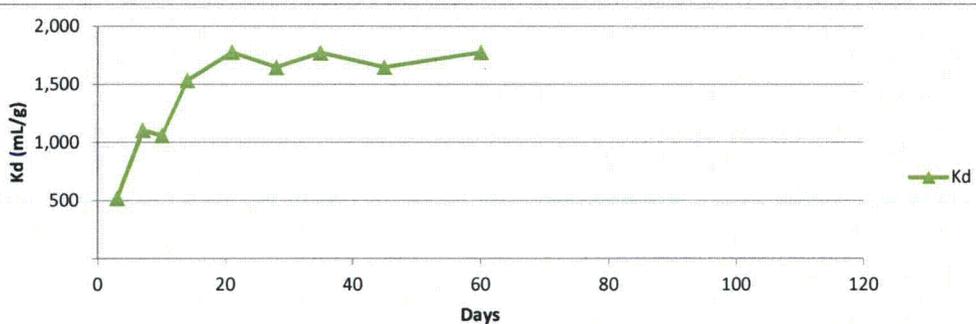
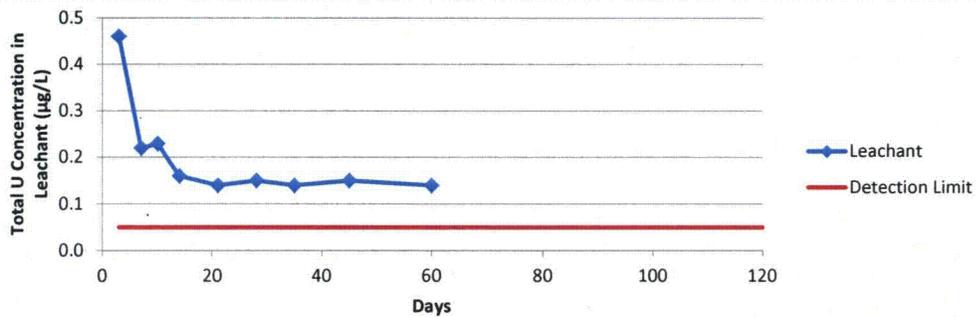
Sample:	JP-SAC-006_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.190	0.120	0.110	0.0840	0.0790	0.0760	0.0830	0.0870	0.0870	--	--
Leachant Relative Percent Difference (%), RPD:	--	45	8.7	27	6.1	3.9	8.8	4.7	0	--	--
Starting Soil Concentration (mg/kg), S_i :	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	--	--
Dry Mass of Solid (g), M:	4.0210	4.0179	3.9759	4.0122	4.0224	4.0046	3.9784	3.9833	3.9928	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	981	988	989	992	992	992	992	991	991	--	--
Concentration of Tracer Sorbed on Solid, S_s :	244	246	249	247	247	248	249	249	248	--	--
K_d , (mL/g):	1,284	2,049	2,261	2,942	3,122	3,261	3,003	2,861	2,854	--	--
K_d Relative Percent Difference (%), RPD:	--	45.9	9.8	26.2	5.9	4.3	8.2	4.9	0.2	--	--



Final Soil Concentration: 0.76 mg/kg
Recommended K_d : 3007 (mL/g)
Assumes equilibrium reached between days 14 through 60.



Sample:	JP-SAC-007_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.460	0.220	0.230	0.160	0.140	0.150	0.140	0.150	0.140	--	--
Leachant Relative Percent Difference (%), RPD:	--	71	4.4	36	13	6.9	6.9	6.9	6.9	--	--
Starting Soil Concentration (mg/kg), S_i :	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	--	--
Dry Mass of Solid (g), M:	3.9970	4.0268	4.0165	4.0192	3.9673	3.9927	3.9783	3.9885	3.9682	--	--
Quantity of Tracer Sorbed on Solid, Qs:	954	978	977	984	986	985	986	985	986	--	--
Concentration of Tracer Sorbed on Solid, S:	239	243	243	245	249	247	248	247	248	--	--
Kd, (mL/g):	519	1,104	1,058	1,530	1,775	1,645	1,770	1,646	1,775	--	--
Kd Relative Percent Difference (%), RPD:	--	72.1	4.3	36.5	14.8	7.6	7.4	7.3	7.5	--	--



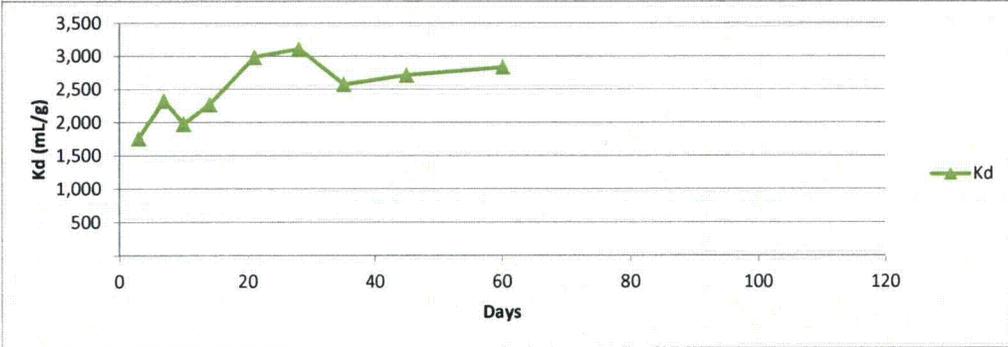
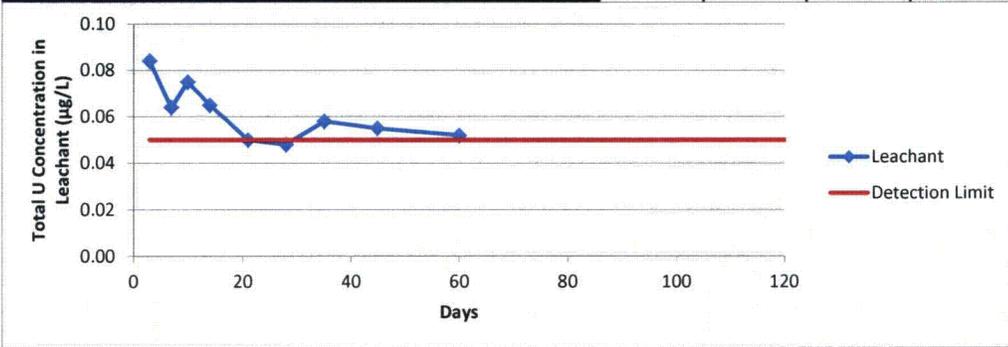
Final Soil Concentration: Not available (unable to analyze soil at conclusion of test because glassware was rinsed with deionized water and acid, then the acid was analyzed for uranium concentration to determine if any uranium had sorbed to laboratory glassware)

Recommended Kd: 1722 (mL/g)

Assumes equilibrium reached between days 21 through 60.

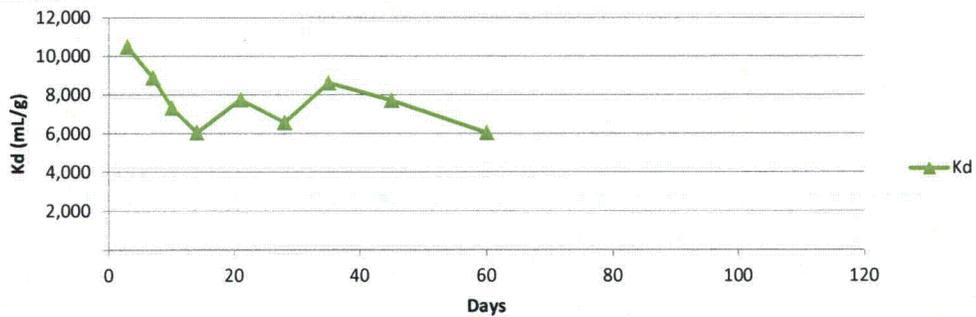
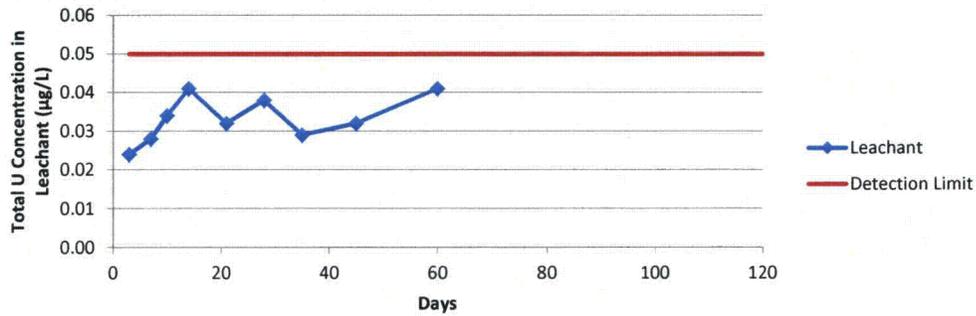
Day	Glassware Acid Rinsate Blanks				Leachant	Leachant -to-Blank Percent
	Total U	U-234	U-235	U-238		
Day 3	0.025	ND	ND	0.025	0.46	5.4%
Day 7	0.036	ND	ND	0.036	0.22	16.4%
Day 10	0.021	ND	ND	0.021	0.23	9.1%
Day 14	0.033	ND	ND	0.033	0.16	20.6%
Day 21	0.016	ND	ND	0.016	0.14	11.4%
Day 28	0.042	ND	ND	0.042	0.15	28.0%
Day 35	0.044	ND	ND	0.044	0.14	31.4%
Day 45	0.07	ND	ND	0.07	0.15	46.7%
Day 60	0.035	ND	ND	0.035	0.14	25.0%
Day 90	--	--	--	--	--	--
Day 120	--	--	--	--	--	--

Sample:	JP-SAC-008_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	6										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.084	0.064	0.075	0.065	0.050	0.048	0.058	0.055	0.052	--	--
Leachant Relative Percent Difference (%), RPD:	--	27	16	14	26	4.1	19	5.3	5.6	--	--
Starting Soil Concentration (mg/kg), S_i :	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	--	--
Dry Mass of Solid (g), M:	4.0005	3.9869	4.0033	4.0186	3.9848	3.9897	3.9839	3.9826	4.0381	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	592	594	593	594	595	595	594	595	595	--	--
Concentration of Tracer Sorbed on Solid, S:	148	149	148	148	149	149	149	149	147	--	--
Kd, (mL/g):	1,760	2,326	1,973	2,272	2,986	3,108	2,572	2,714	2,833	--	--
Kd Relative Percent Difference (%), RPD:	--	27.7	16.4	14.1	27.2	4.0	18.9	5.4	4.3	--	--



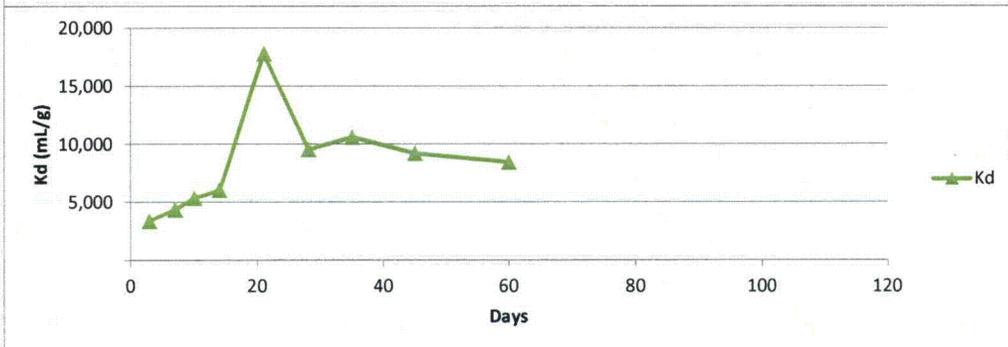
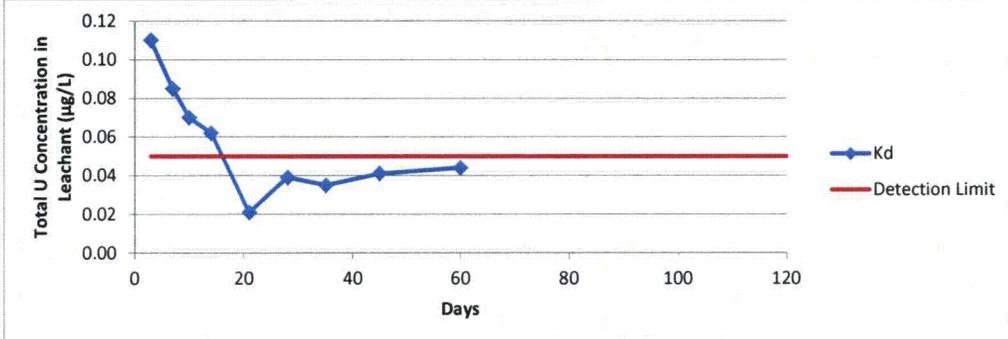
Final Soil Concentration: 0.91 mg/kg
Recommended Kd: 2843 (mL/g)
Assumes equilibrium reached between days 21 through 60.

Sample:	JP-SAC-009_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0240	0.0280	0.0340	0.0410	0.0320	0.0380	0.0290	0.0320	0.0410	--	--
Leachant Relative Percent Difference (%), RPD:	--	15.4	19.4	18.7	24.7	17.1	26.9	9.84	24.7	--	--
Starting Soil Concentration (mg/kg), S_i :	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	--	--
Dry Mass of Solid (g), M:	3.9627	4.0118	3.9997	4.0176	4.0111	3.9880	3.9837	4.0327	4.0174	--	--
Quantity of Tracer Sorbed on Solid, Qs:	998	997	997	996	997	996	997	997	996	--	--
Concentration of Tracer Sorbed on Solid, S:	252	249	249	248	249	250	250	247	248	--	--
Kd, (mL/g):	10,489	8,877	7,328	6,046	7,766	6,574	8,631	7,724	6,046	--	--
Kd Relative Percent Difference (%), RPD:	--	16.6	19.1	19.2	24.9	16.6	27.1	11.1	24.4	--	--



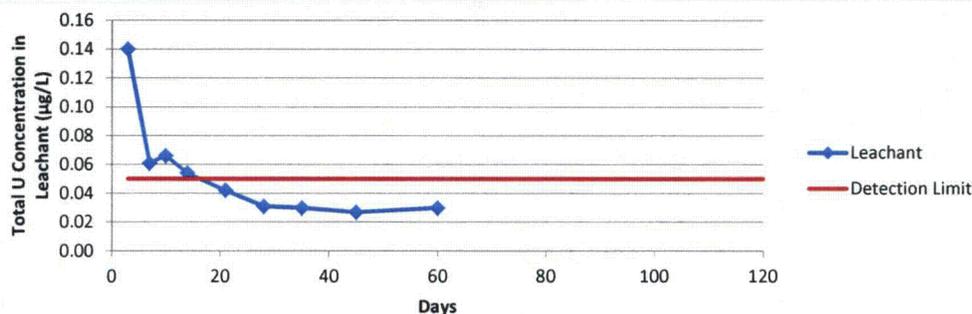
Final Soil Concentration: 1.3 mg/kg
Recommended Kd: 7159 (mL/g)
Assumes equilibrium reached between days 10 through 60.

Sample:	JP-SCR-001_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	15										
Total Volume of (Contact) Liquid (mL), V :	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.110	0.0850	0.0700	0.0620	0.0210	0.0390	0.0350	0.0410	0.0440	--	--
Leachant Relative Percent Difference (%), RPD:	--	25.6	19.4	12.1	98.8	60.0	10.8	15.8	7.06	--	--
Starting Soil Concentration (mg/kg), S_i :	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	--	--
Dry Mass of Solid (g), M :	3.9815	4.0297	3.9852	3.9999	4.0057	4.0111	4.0296	3.9636	4.0210	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	1,489	1,492	1,493	1,494	1,498	1,496	1,497	1,496	1,496	--	--
Concentration of Tracer Sorbed on Solid, S :	374	370	375	373	374	373	371	377	372	--	--
K_d , (mL/g):	3,400	4,354	5,352	6,024	17,807	9,564	10,611	9,205	8,453	--	--
K_d Relative Percent Difference (%), RPD:	--	24.6	20.6	11.8	98.9	60.2	10.4	14.2	8.5	--	--

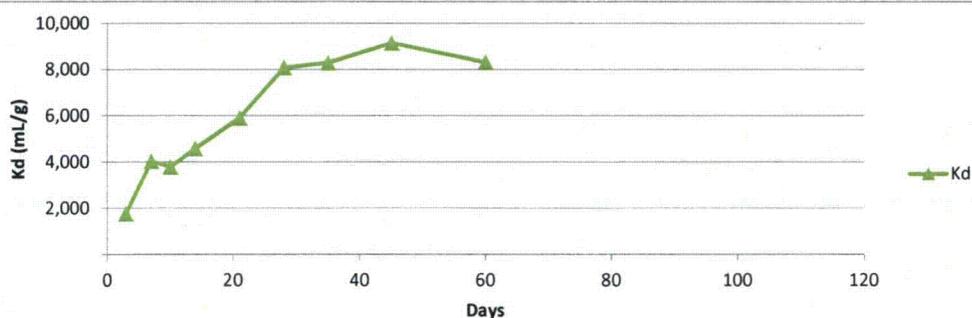


Final Soil Concentration: 1.2 mg/kg
Recommended K_d : 9458 (mL/g)
Assumes equilibrium reached between days 28 through 60.

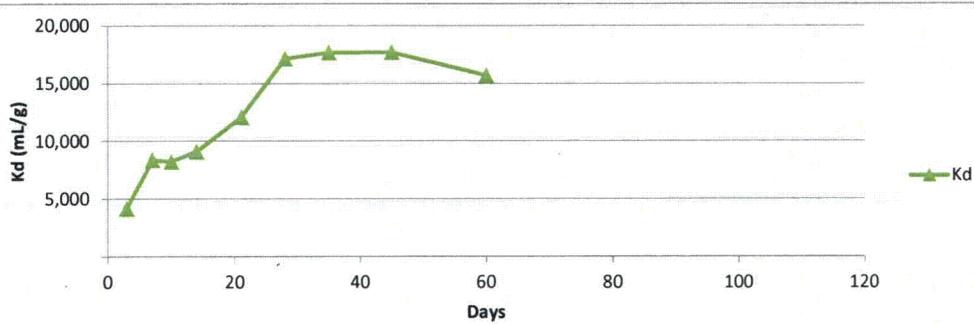
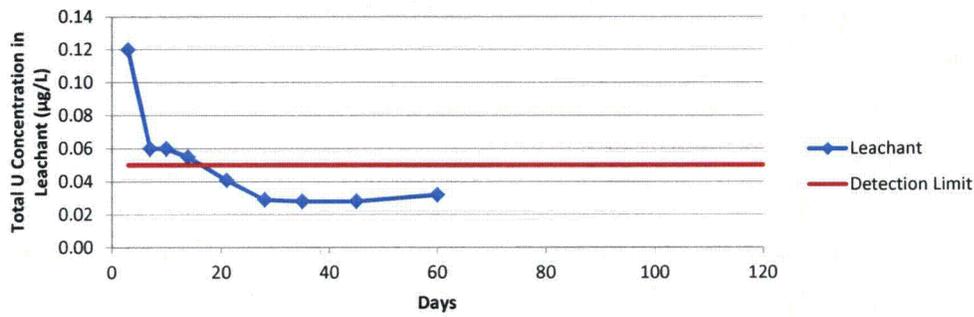
Sample:	JP-SCR-001_SAIC05D										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.140	0.0610	0.0660	0.0540	0.0420	0.0310	0.0300	0.0270	0.0300	--	--
Leachant Relative Percent Difference (%), RPD:	--	78.6	7.87	20.0	25.0	30.1	3.28	10.5	10.5	--	--
Starting Soil Concentration (mg/kg), S_i :	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	--	--
Dry Mass of Solid (g), M:	3.9982	4.0340	3.9661	4.0175	4.0156	3.9796	4.0048	4.0364	3.9939	--	--
Quantity of Tracer Sorbed on Solid, Qs:	986	994	993	995	996	997	997	997	997	--	--
Concentration of Tracer Sorbed on Solid, S:	247	246	250	248	248	251	249	247	250	--	--
Kd, (mL/g):	1,762	4,039	3,795	4,585	5,904	8,081	8,298	9,151	8,321	--	--
Kd Relative Percent Difference (%), RPD:	--	78.5	6.2	18.8	25.2	31.1	2.7	9.8	9.5	--	--



Final Soil Concentration: 1.2 mg/kg
Recommended Kd: 8463 (mL/g)
Assumes equilibrium reached between days 28 through 60.

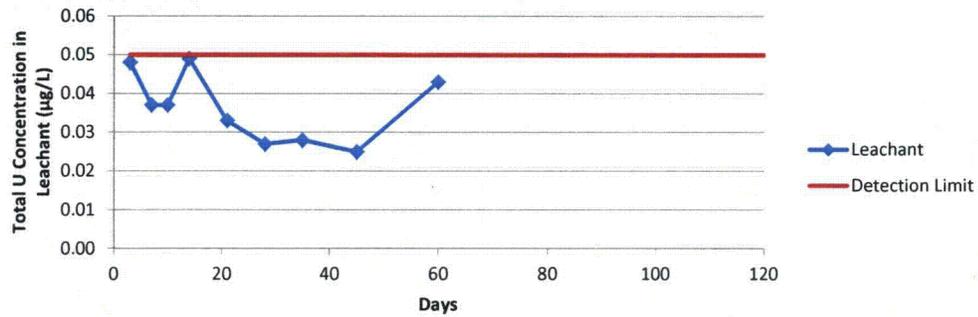


Sample:	JP-SCR-002_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	20										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.120	0.0600	0.0600	0.0550	0.0410	0.0290	0.0280	0.0280	0.0320	--	--
Leachant Relative Percent Difference (%), RPD:	--	66.7	0	8.70	29.2	34.3	3.51	0	13.3	--	--
Starting Soil Concentration (mg/kg), S_i :	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	--	--
Dry Mass of Solid (g), M:	3.9686	3.9778	4.0371	3.9888	4.0346	4.0218	4.0392	4.0309	3.9759	--	--
Quantity of Tracer Sorbed on Solid, Qs:	1,988	1,994	1,994	1,995	1,996	1,997	1,997	1,997	1,997	--	--
Concentration of Tracer Sorbed on Solid, S:	501	501	494	500	495	497	494	495	502	--	--
Kd, (mL/g):	4,174	8,355	8,232	9,091	12,066	17,123	17,659	17,695	15,695	--	--
Kd Relative Percent Difference (%), RPD:	--	66.7	1.5	9.9	28.1	34.7	3.1	0.2	12.0	--	--

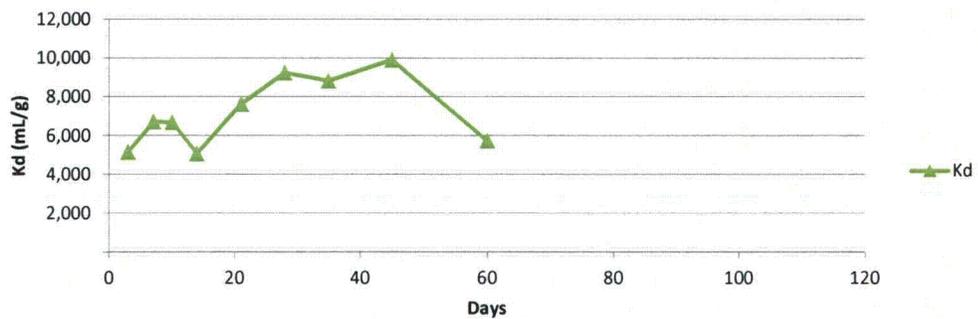


Final Soil Concentration: 2.7 mg/kg
Recommended Kd: 17043 (mL/g)
Assumes equilibrium reached between days 28 through 60.

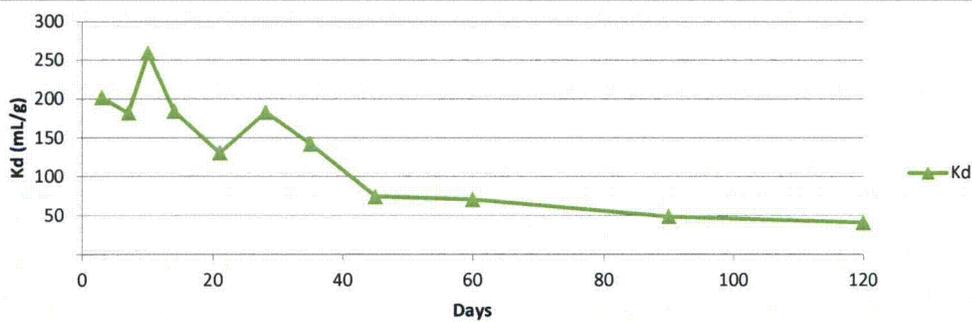
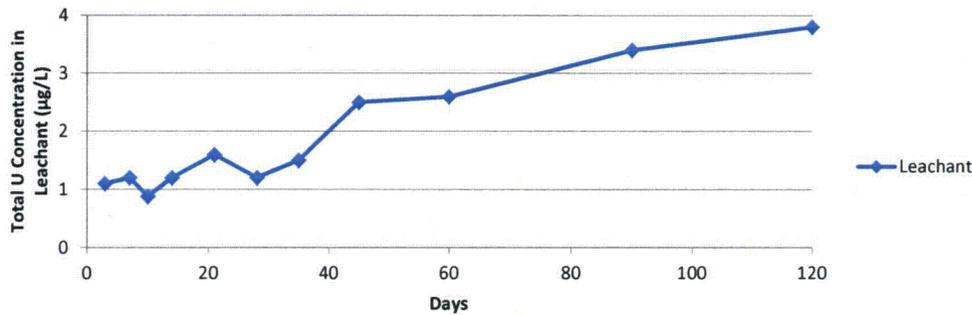
Sample:	JP-SCR-003_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V :	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0480	0.0370	0.0370	0.0490	0.0330	0.0270	0.0280	0.0250	0.0430	--	--
Leachant Relative Percent Difference (%), RPD:	--	25.9	0	27.9	39.0	20.0	3.64	11.3	52.9	--	--
Starting Soil Concentration (mg/kg), S_i :	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	--	--
Dry Mass of Solid (g), M :	4.0330	4.0120	4.0260	4.0045	3.9646	3.9965	4.0360	4.0237	4.0385	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	995	996	996	995	997	997	997	998	996	--	--
Concentration of Tracer Sorbed on Solid, S :	247	248	247	248	251	250	247	248	247	--	--
K_d , (mL/g):	5,141	6,712	6,688	5,071	7,618	9,242	8,824	9,916	5,734	--	--
K_d Relative Percent Difference (%), RPD:	--	26.5	0.3	27.5	40.1	19.3	4.6	11.7	53.5	--	--



Final Soil Concentration: 0.75 mg/kg
Recommended K_d : 9328 (mL/g)
Assumes equilibrium reached between days 28 through 45



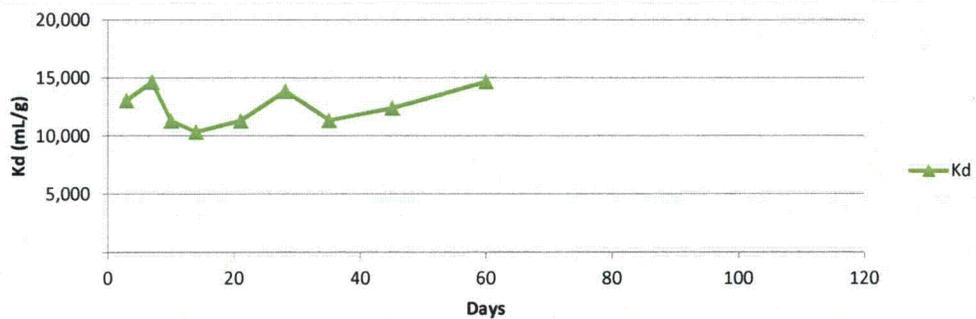
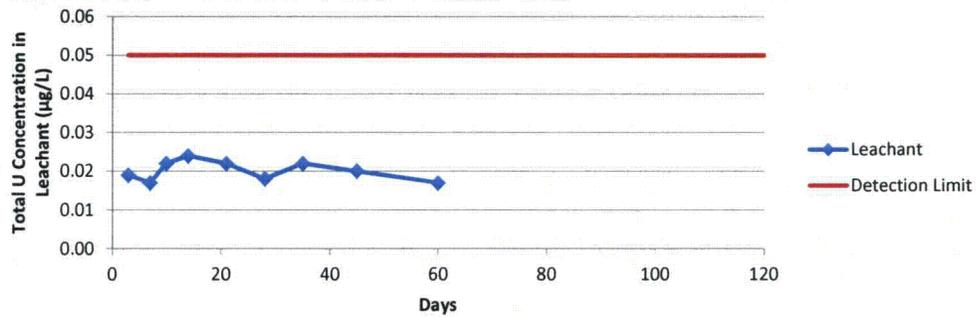
Sample:	JP-SCR-004_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	1.10	1.20	0.880	1.20	1.60	1.20	1.50	2.50	2.60	3.40	3.80
Leachant Relative Percent Difference (%), RPD:	--	8.70	30.8	30.8	28.6	28.6	22.2	50.0	3.92	26.7	11.1
Starting Soil Concentration (mg/kg), S_i :	0.80										
Dry Mass of Solid (g), M:	4.0138	4.0288	3.9960	3.9766	4.0227	4.0033	3.9854	4.0179	4.0195	3.9824	3.9619
Quantity of Tracer Sorbed on Solid, Q_s :	890	880	912	880	840	880	850	750	740	660	620
Concentration of Tracer Sorbed on Solid, S :	222	218	228	221	209	220	213	187	184	166	156
K_d , (mL/g):	202	182	259	184	131	183	142	74.7	70.8	48.7	41.2
K_d Relative Percent Difference (%), RPD:	--	10.2	35.0	33.8	34.2	33.6	25.2	62.3	5.3	36.9	16.8



Final Soil Concentration: Not available (unable to analyze soil at conclusion of test because glassware was rinsed with deionized water and acid, then the acid was analyzed for uranium concentration to determine if any uranium had sorbed to laboratory glassware)
Recommended K_d : 59 (mL/g)
 K_d based on equilibrium between days 45 through 120.

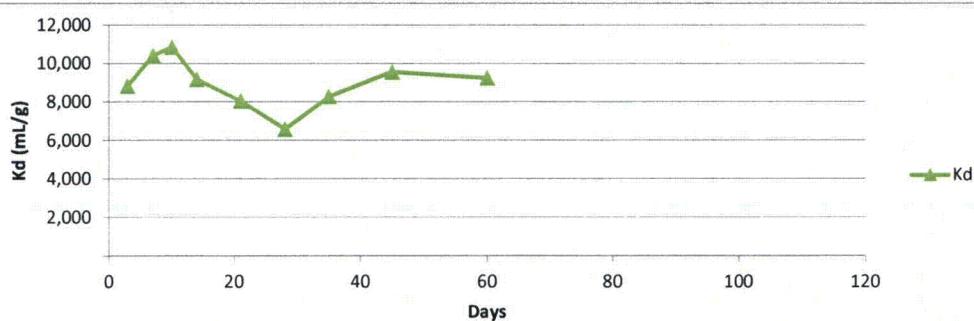
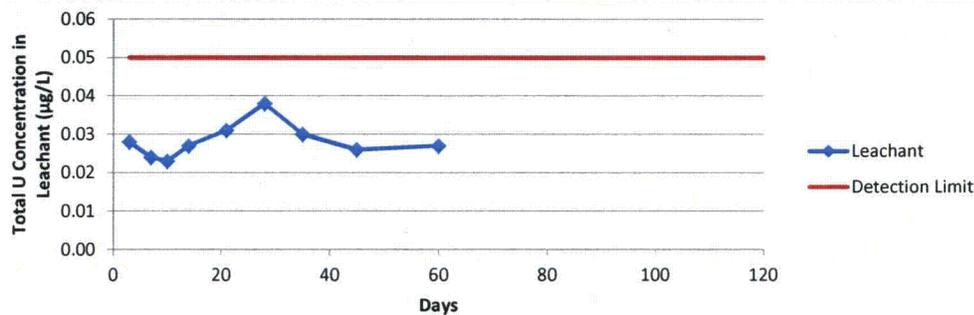
Day	Glassware Acid Rinsate Blanks				Leachant	Leachant -to-Blank Percent
	Total U	U-234	U-235	U-238		
Day 3	0.026	ND	ND	0.026	1.10	2.4%
Day 7	0.025	ND	ND	0.025	1.2	2.1%
Day 10	0.049	ND	ND	0.049	0.88	5.6%
Day 14	0.046	ND	ND	0.046	1.2	3.8%
Day 21	0.057	ND	ND	0.057	1.6	3.6%
Day 28	0.082	ND	ND	0.082	1.2	6.8%
Day 35	0.2	ND	ND	0.2	1.5	13.3%
Day 45	0.054	ND	ND	0.054	2.5	2.2%
Day 60	0.018	ND	ND	0.018	2.6	0.7%
Day 90	--	--	--	--	--	--
Day 120	--	--	--	--	--	--

Sample:	JP-SCR-005_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0190	0.0170	0.0220	0.0240	0.0220	0.0180	0.0220	0.0200	0.0170	--	--
Leachant Relative Percent Difference (%), RPD:	--	11.1	25.6	8.70	8.70	20.0	20.0	9.52	16.2	--	--
Starting Soil Concentration (mg/kg), S_i :	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	--	--
Dry Mass of Solid (g), M:	4.0261	4.0114	4.0191	4.0229	4.0193	4.0042	3.9991	4.0274	4.0028	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	998	998	998	998	998	998	998	998	998	--	--
Concentration of Tracer Sorbed on Solid, S:	248	249	248	248	248	249	250	248	249	--	--
K_d , (mL/g):	13,048	14,639	11,285	10,333	11,284	13,849	11,341	12,390	14,671	--	--
K_d Relative Percent Difference (%), RPD:	--	11.5	25.9	8.8	8.8	20.4	19.9	8.8	16.9	--	--



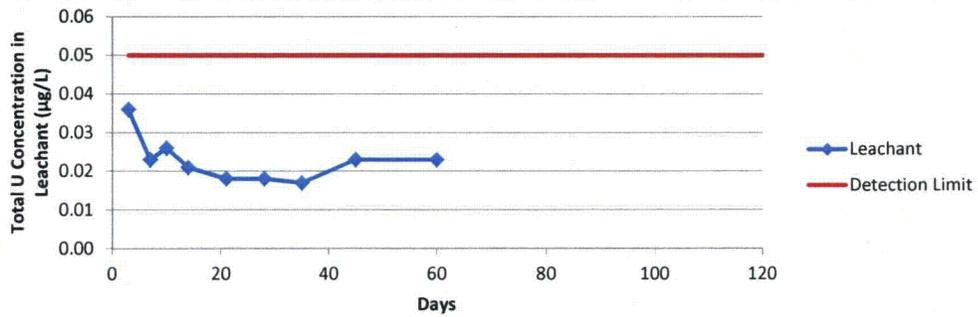
Final Soil Concentration: 1.1 mg/kg
Recommended K_d : 12538 (mL/g)
Assumes equilibrium reached between days 3 through 60.

Sample:	JP-SCR-006_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0280	0.0240	0.0230	0.0270	0.0310	0.0380	0.0300	0.0260	0.0270	--	--
Leachant Relative Percent Difference (%), RPD:	--	15.4	4.26	16.0	13.8	20.3	23.5	14.3	3.77	--	--
Starting Soil Concentration (mg/kg), S_i :	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	--	--
Dry Mass of Solid (g), M:	4.0387	3.9957	3.9940	4.0254	3.9964	3.9820	4.0126	4.0148	3.9947	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	997	998	998	997	997	996	997	997	997	--	--
Concentration of Tracer Sorbed on Solid, S:	247	250	250	248	249	250	248	248	250	--	--
Kd, (mL/g):	8,818	10,403	10,861	9,176	8,047	6,584	8,282	9,555	9,247	--	--
Kd Relative Percent Difference (%), RPD:	--	16.5	4.3	16.8	13.1	20.0	22.9	14.3	3.3	--	--

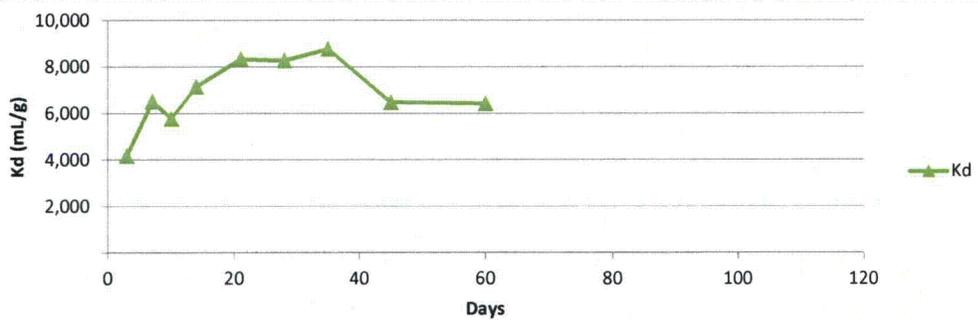


Final Soil Concentration: 0.99 mg/kg
Recommended Kd: 9028 (mL/g)
Assumes equilibrium reached between days 35 through 60.

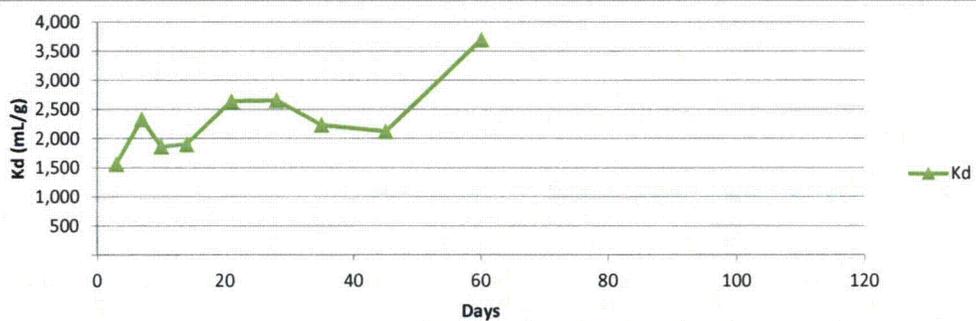
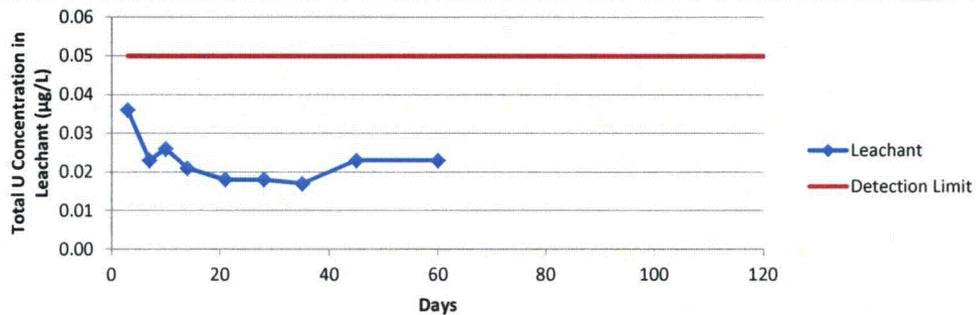
Sample:	JP-SCR-007_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	6										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0360	0.0230	0.0260	0.0210	0.0180	0.0180	0.0170	0.0230	0.0230	--	--
Leachant Relative Percent Difference (%), RPD:	--	44.1	12.2	21.3	15.4	0	5.71	30.0	0	--	--
Starting Soil Concentration (mg/kg), S_i :	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	--	--
Dry Mass of Solid (g), M:	3.9647	3.9886	3.9687	3.9783	3.9864	4.0106	4.0087	4.0032	4.0333	--	--
Quantity of Tracer Sorbed on Solid, Qs:	596	598	597	598	598	598	598	598	598	--	--
Concentration of Tracer Sorbed on Solid, S:	150	150	151	150	150	149	149	149	148	--	--
Kd, (mL/g):	4,179	6,515	5,790	7,157	8,337	8,286	8,779	6,492	6,443	--	--
Kd Relative Percent Difference (%), RPD:	--	43.7	11.8	21.1	15.2	0.6	5.8	30.0	0.7	--	--



Final Soil Concentration: 1.4 mg/kg
Recommended Kd: 8467 (mL/g)
Assumes equilibrium reached between days 21 through 35.

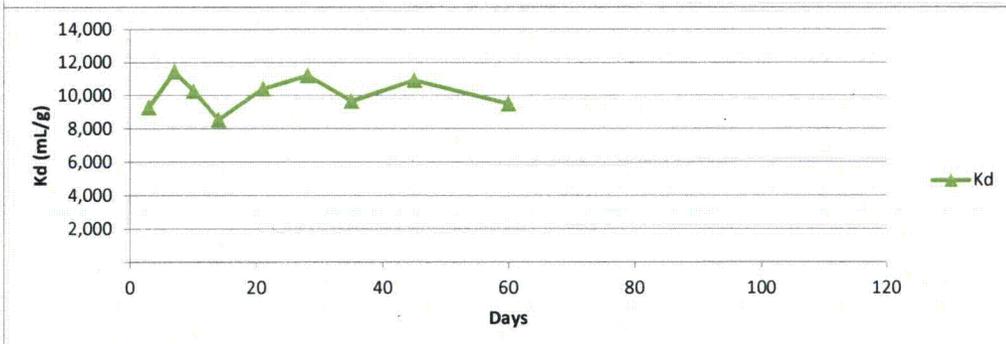
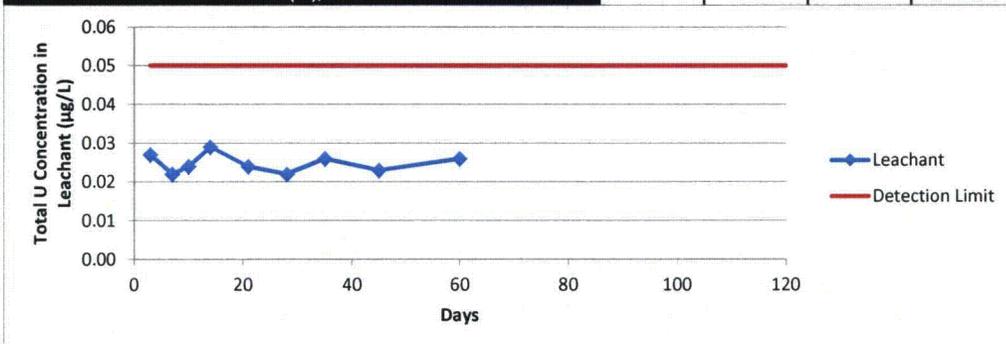


Sample:	JP-SCR-008_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	3										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0470	0.0320	0.0400	0.0390	0.0280	0.0280	0.0330	0.0350	0.0200	--	--
Leachant Relative Percent Difference (%), RPD:	--	38.0	22.2	2.53	32.8	0	16.4	5.88	54.5	--	--
Starting Soil Concentration (mg/kg), S_i :	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	--	--
Dry Mass of Solid (g), M:	4.0234	3.9820	3.9767	3.9857	4.0196	3.9991	4.0288	3.9878	4.0282	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	295	297	296	296	297	297	297	297	298	--	--
Concentration of Tracer Sorbed on Solid, S :	73.4	74.5	74.4	74.3	73.9	74.3	73.6	74.4	74.0	--	--
K_d , (mL/g):	1,562	2,329	1,861	1,905	2,641	2,654	2,232	2,124	3,699	--	--
K_d Relative Percent Difference (%), RPD:	--	39.5	22.4	2.3	32.4	0.5	17.3	4.9	54.1	--	--



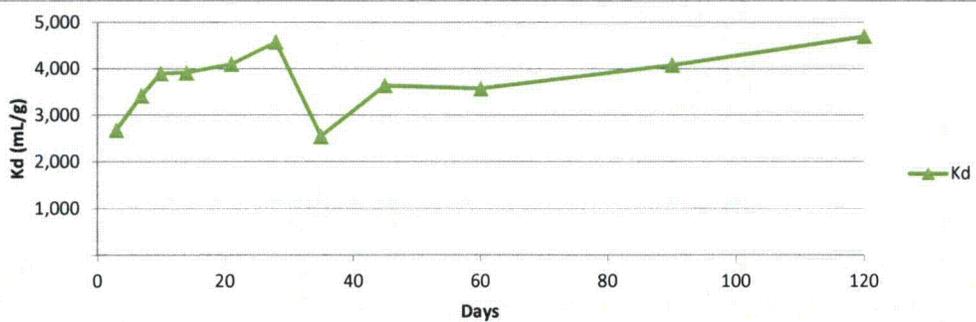
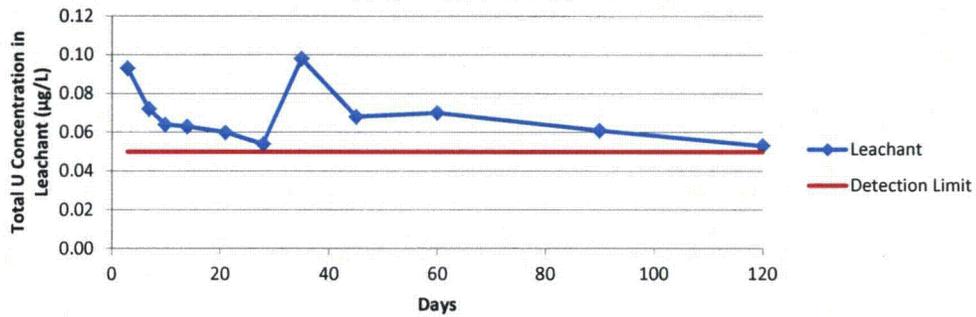
Final Soil Concentration: 0.96 mg/kg
Recommended K_d : 2413 (mL/g)
Assumes equilibrium reached between days 21 through 45.

Sample:	JP-SCR-009_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0270	0.0220	0.0240	0.0290	0.0240	0.0220	0.0260	0.0230	0.0260	--	--
Leachant Relative Percent Difference (%), RPD:	--	20.4	8.70	18.9	18.9	8.70	16.7	12.2	12.2	--	--
Starting Soil Concentration (mg/kg), S_i :	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	--	--
Dry Mass of Solid (g), M:	3.9840	3.9628	4.0447	4.0242	3.9991	4.0491	3.9663	3.9682	4.0381	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	997	998	998	997	998	998	997	998	997	--	--
Concentration of Tracer Sorbed on Solid, S_s :	250	252	247	248	249	246	251	251	247	--	--
K_d (mL/g):	9,271	11,445	10,277	8,544	10,394	11,201	9,672	10,931	9,500	--	--
K_d Relative Percent Difference (%), RPD:	--	21.0	10.8	18.4	19.5	7.5	14.7	12.2	14.0	--	--



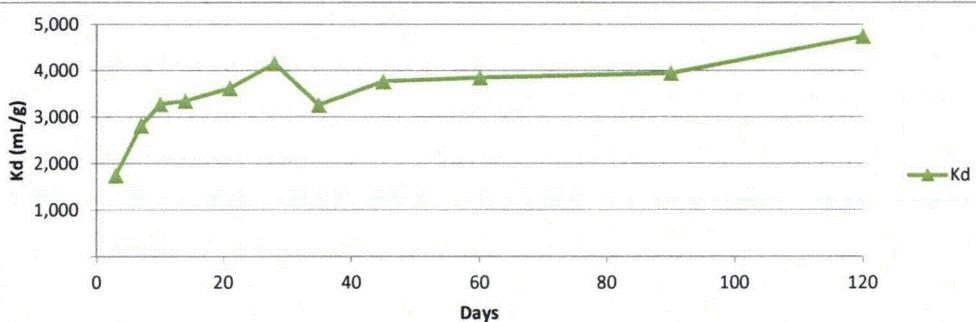
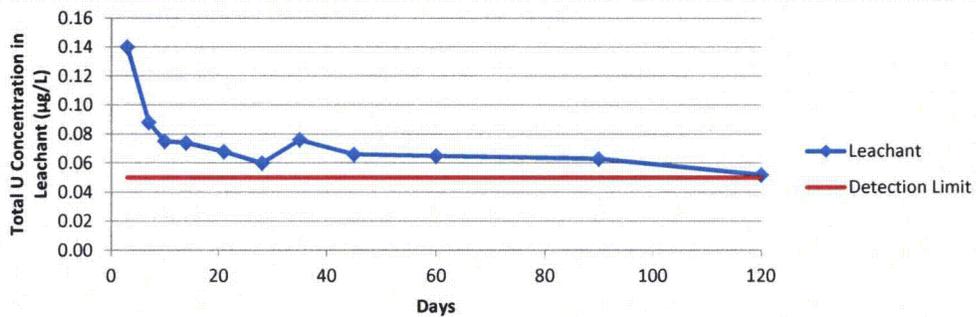
Final Soil Concentration: 1.1 mg/kg
Recommended K_d : 10340 (mL/g)
Assumes equilibrium reached between days 21 through 60.

Sample:	JP-SGR-001_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0930	0.0720	0.0640	0.0630	0.0600	0.0540	0.0980	0.0680	0.0700	0.0610	0.0530
Leachant Relative Percent Difference (%), RPD:	--	25.5	11.8	1.57	4.88	10.5	57.9	36.1	2.90	13.7	14.0
Starting Soil Concentration (mg/kg), S_i :	0.56										
Dry Mass of Solid (g), M:	3.9813	4.0297	3.9832	4.0259	4.0394	4.0256	3.9660	4.0137	3.9681	3.9919	3.9910
Quantity of Tracer Sorbed on Solid, Q_s :	991	993	994	994	994	995	990	993	993	994	995
Concentration of Tracer Sorbed on Solid, S_s :	249	246	249	247	246	247	250	247	250	249	249
K_d , (mL/g):	2,676	3,422	3,898	3,918	4,101	4,575	2,548	3,639	3,575	4,082	4,703
K_d Relative Percent Difference (%), RPD:	--	24.5	13.0	0.5	4.6	10.9	56.9	35.3	1.8	13.2	14.1



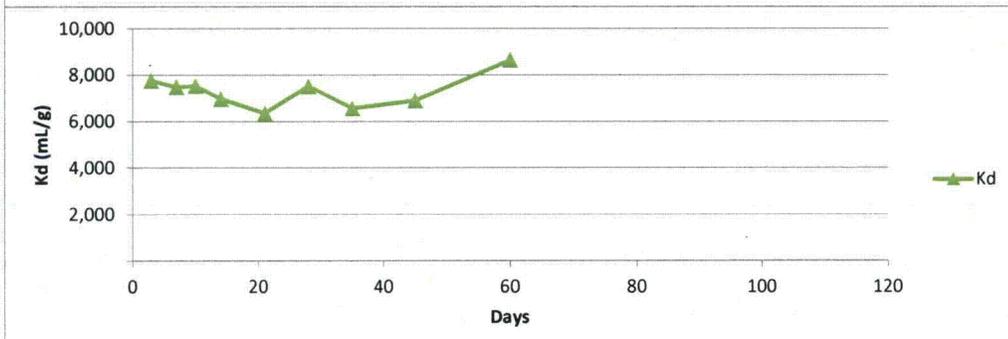
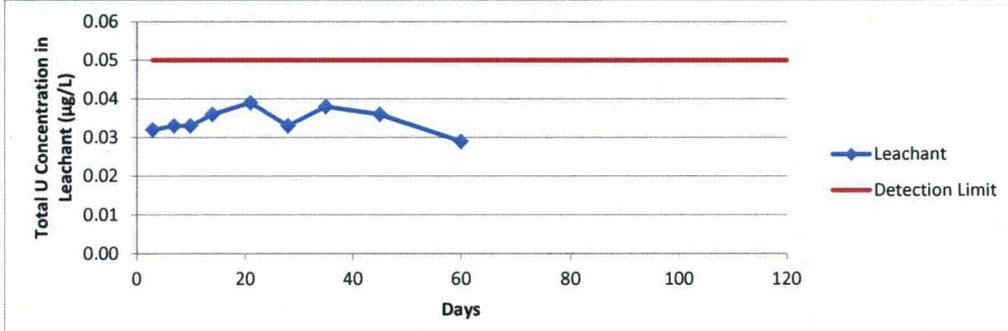
Final Soil Concentration: 0.68 mg/kg
 Recommended K_d : 3893 (mL/g)
 Assumes equilibrium reached between days 10 through 120.

Sample:	JP-SGR-001_SAIC05D										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V :	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.140	0.0880	0.0750	0.0740	0.0680	0.0600	0.0760	0.0660	0.0650	0.0630	0.0520
Leachant Relative Percent Difference (%), RPD:	--	45.6	16.0	1.34	8.45	12.5	23.5	14.1	1.53	3.13	19.13
Starting Soil Concentration (mg/kg), S_i :	0.56										
Dry Mass of Solid (g), M :	4.0385	4.0053	4.0320	4.0085	4.0304	3.9832	4.0082	3.9930	3.9683	3.9946	4.0318
Quantity of Tracer Sorbed on Solid, Q_s :	986	991	993	993	993	994	992	993	994	994	995
Concentration of Tracer Sorbed on Solid, S :	244	247	246	248	246	250	248	249	250	249	247
K_d , (mL/g):	1,744	2,812	3,282	3,346	3,624	4,159	3,258	3,769	3,852	3,949	4,745
K_d Relative Percent Difference (%), RPD:	--	46.9	15.4	1.9	8.0	13.8	24.3	14.6	2.2	2.5	18.3



Final Soil Concentration: 0.7 mg/kg
Recommended K_d : 3655 (mL/g)
Assumes equilibrium reached between days 10 through 90.

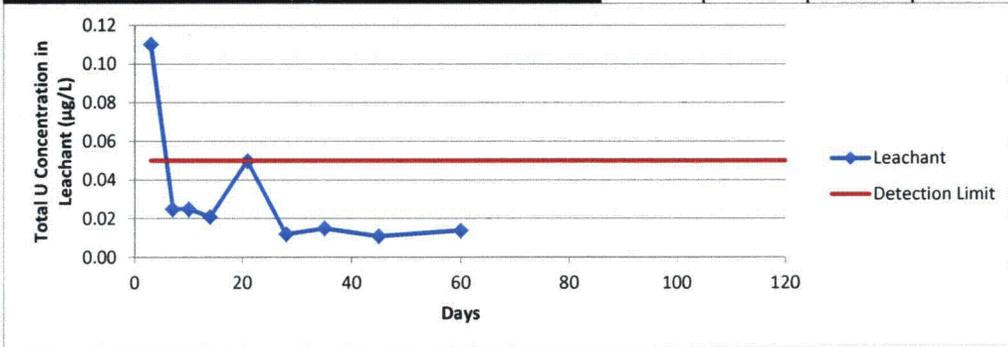
Sample:	JP-SGR-002_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	0.0320	0.0330	0.0330	0.0360	0.0390	0.0330	0.0380	0.0360	0.0290	--	--
Leachant Relative Percent Difference (%), RPD:	--	3.08	0	8.70	8.00	16.7	14.1	5.41	21.5	--	--
Starting Soil Concentration (mg/kg), S_i :	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	--	--
Dry Mass of Solid (g), M:	4.0165	4.0367	4.0108	3.9723	4.0200	4.0198	3.9923	4.0123	3.9763	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	997	997	997	996	996	997	996	996	997	--	--
Concentration of Tracer Sorbed on Solid, S_s :	248	247	249	251	248	248	250	248	251	--	--
K_d , (mL/g):	7,756	7,482	7,530	6,968	6,353	7,514	6,567	6,898	8,647	--	--
K_d Relative Percent Difference (%), RPD:	--	3.6	0.6	7.8	9.2	16.7	13.5	4.9	22.5	--	--



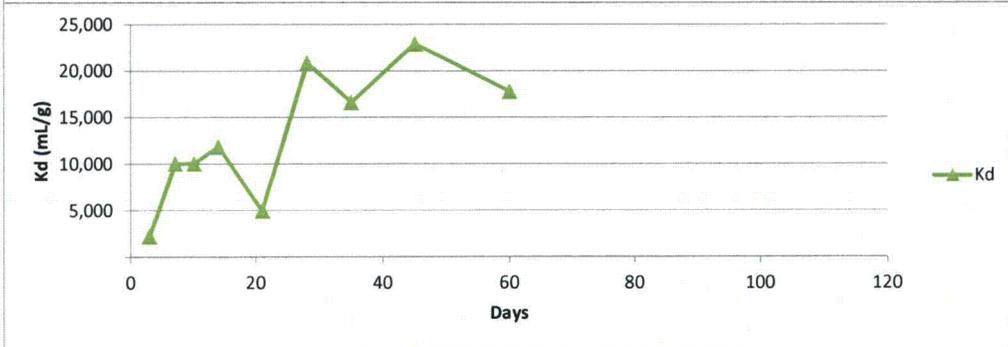
Final Soil Concentration: Not available (unable to analyze soil at conclusion of test because glassware was rinsed with deionized water and acid, then the acid was analyzed for uranium concentration to determine if any uranium had sorbed to laboratory glassware)
 Recommended K_d : 6860 (mL/g)
 Assumes equilibrium reached between days 14 through 45.

Day	Glassware Acid Rinse Blanks				Leachant	Leachant -to-Blank Percent
	Total U	U-234	U-235	U-238		
Day 3	0.046	ND	ND	0.046	0.032	143.8%
Day 7	0.059	ND	ND	0.059	0.033	178.8%
Day 10	0.11	ND	ND	0.11	0.033	333.3%
Day 14	0.16	ND	ND	0.16	0.036	444.4%
Day 21	0.17	ND	ND	0.17	0.039	435.9%
Day 28	0.017	ND	ND	0.17	0.033	51.5%
Day 35	0.14	ND	ND	0.14	0.038	368.4%
Day 45	0.2	ND	ND	0.2	0.036	555.6%
Day 60	0.14	ND	ND	0.14	0.029	482.8%
Day 90	--	--	--	--	--	--
Day 120	--	--	--	--	--	--

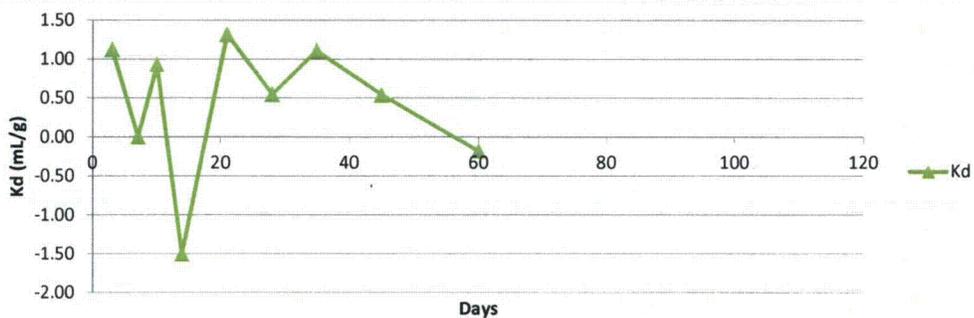
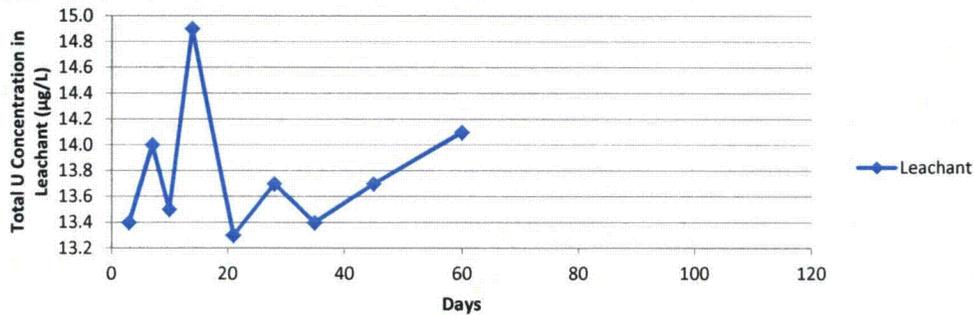
Sample:	JP-SGR-003_SAIC05										
Test:	Adsorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	10										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	0.110	0.0250	0.0250	0.0210	0.0500	0.0120	0.0150	0.0110	0.0140	--	--
Leachant Relative Percent Difference (%), RPD:	--	126	0	17.4	81.7	123	22.2	30.8	24.0	--	--
Starting Soil Concentration (mg/kg), S_i :	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	--	--
Dry Mass of Solid (g), M:	4.0169	3.9751	3.9659	4.0074	4.0060	3.9938	4.0107	3.9615	4.0135	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	989	998	998	998	995	999	999	999	999	--	--
Concentration of Tracer Sorbed on Solid, S:	246	251	252	249	248	250	249	252	249	--	--
Kd, (mL/g):	2,238	10,037	10,061	11,858	4,968	20,841	16,597	22,923	17,772	--	--
Kd Relative Percent Difference (%), RPD:	--	127.1	0.2	16.4	81.9	123.0	22.7	32.0	25.3	--	--



Final Soil Concentration: 1.1 mg/kg
Recommended Kd: 19533 (mL/g)
Assumes equilibrium reached between days 28 through 60.



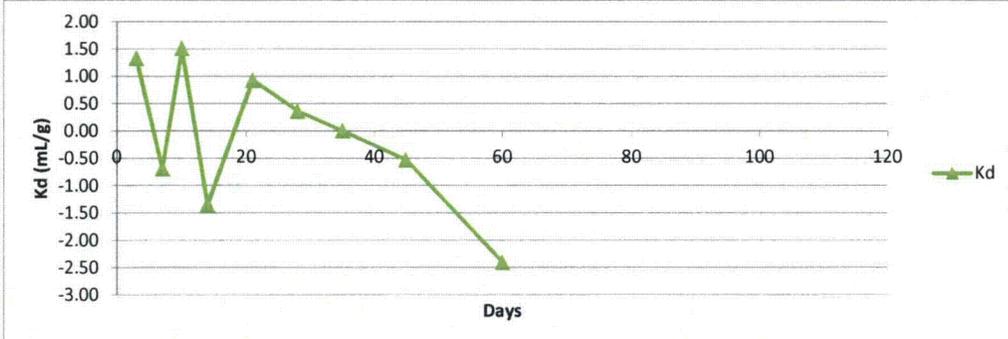
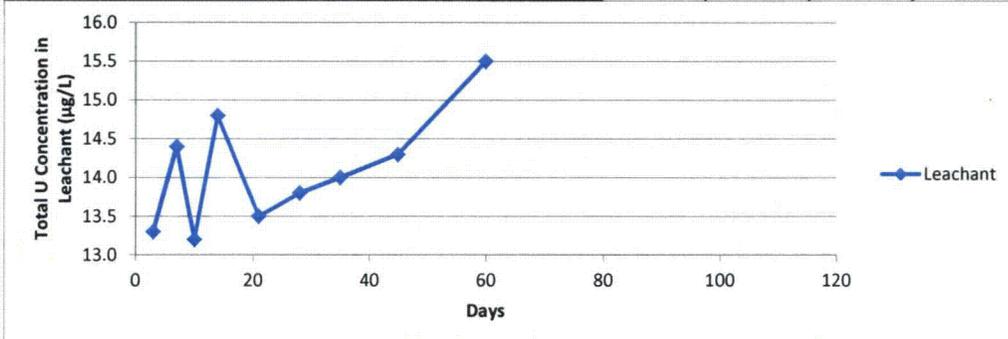
Sample:	JP-KAC-011_SAIC01R										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	14										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	13.4	14.0	13.5	14.9	13.3	13.7	13.4	13.7	14.1	--	--
Leachant Relative Percent Difference (%), RPD:	--	4.38	3.64	9.86	11.3	2.96	2.21	2.21	2.88	--	--
Starting Soil Concentration (mg/kg), S_i :	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	--	--
Dry Mass of Solid (g), M:	3.9966	3.9850	3.9778	4.0156	4.0051	3.9821	4.0385	4.0341	3.9735	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	60.0	0	50.0	-90.0	70.0	30.0	60.0	30.0	-10.0	--	--
Concentration of Tracer Sorbed on Solid, S:	15.0	0	12.6	-22.4	17.5	7.53	14.9	7.44	-2.5	--	--
K_d , (mL/g):	1.12	0	0.931	-1.504	1.31	0.550	1.11	0.543	-0.178	--	--
K_d Relative Percent Difference (%), RPD:	--	200	200	849.9	2965.3	82.0	67.4	68.5	396.0	--	--



Final Soil Concentration: Not available (unable to analyze soil at conclusion of test because glassware was rinsed with deionized water and acid, then the acid was analyzed for uranium concentration to determine if any uranium had sorbed to laboratory glassware)
 Recommended K_d : 0.93 (mL/g)
 Assumes equilibrium reached between days 3 through 60 including non-zero and positive K_d values (i.e., excluding zero and negative K_d values).

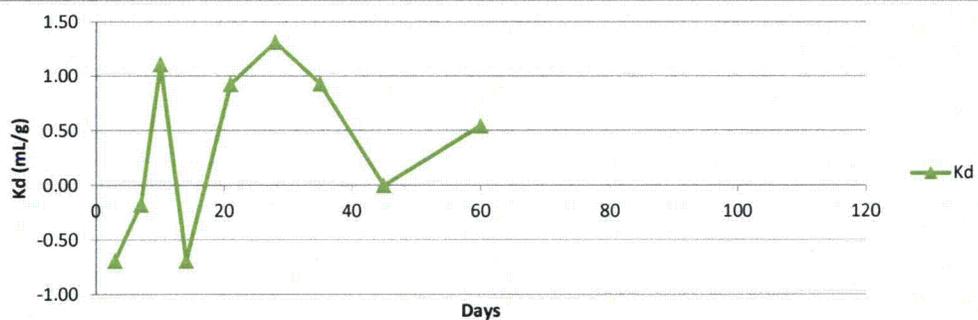
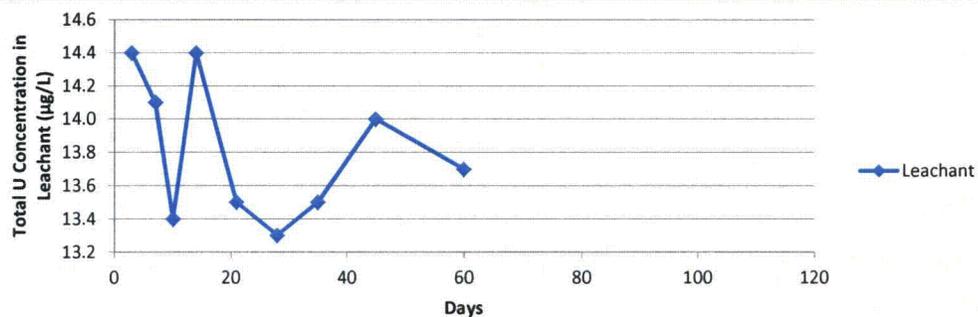
Day	Glassware Acid Rinsate Blanks				Leachant -to-Blank	
	Total U	U-234	U-235	U-238	Leachant	Percent
Day 3	0.018	ND	ND	0.018	13.4	0.1%
Day 7	0.016	ND	ND	0.016	14.0	0.1%
Day 10	0.012	ND	ND	0.012	13.5	0.1%
Day 14	0.013	ND	ND	0.013	14.9	0.1%
Day 21	0.028	ND	ND	0.028	13.3	0.2%
Day 28	0.024	ND	ND	0.024	13.7	0.2%
Day 35	0.018	ND	ND	0.018	13.4	0.1%
Day 45	0.025	ND	ND	0.025	13.7	0.2%
Day 60	0.021	ND	ND	0.021	14.1	0.1%
Day 90	--	--	--	--	--	--
Day 120	--	--	--	--	--	--

Sample:	JP-KAC-012_SAIC01R										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	14										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	13.3	14.4	13.2	14.8	13.5	13.8	14.0	14.3	15.5	--	--
Leachant Relative Percent Difference (%), RPD:	--	7.94	8.70	11.4	9.19	2.20	1.44	2.12	8.05	--	--
Starting Soil Concentration (mg/kg), S_i :	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	--	--
Dry Mass of Solid (g), M:	3.9740	4.0008	4.0082	4.0101	3.9914	3.9767	4.0257	3.9905	4.0259	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	70.0	-40	80.0	-80.0	50.0	20.0	0	-30.0	-150.0	--	--
Concentration of Tracer Sorbed on Solid, S:	17.6	-10	20.0	-19.9	12.5	5.03	0	-7.52	-37.3	--	--
K_d , (mL/g):	1.32	-1	1.512	-1.348	0.93	0.364	0	-0.526	-2.404	--	--
K_d Relative Percent Difference (%), RPD:	--	640.8	539.6	3485.6	1083.7	87.2	200	200	128.2	--	--



Final Soil Concentration: 0.53 mg/kg
Recommended K_d : 1.03 (mL/g)
Assumes equilibrium reached between days 3 through 28 including non-zero and positive K_d values (i.e., excluding zero and negative K_d values).

Sample:	JP-KAC-013_SAIC01R										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	14										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	14.4	14.1	13.4	14.4	13.5	13.3	13.5	14.0	13.7	--	--
Leachant Relative Percent Difference (%), RPD:	--	2.11	5.09	7.19	6.45	1.49	1.49	3.64	2.17	--	--
Starting Soil Concentration (mg/kg), S_i :	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	--	--
Dry Mass of Solid (g), M:	4.0153	3.9772	4.0264	4.0290	4.0005	4.0033	3.9773	4.0039	3.9977	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	-40.0	-10.0	60.0	-40.0	50.0	70.0	50.0	0	30.0	--	--
Concentration of Tracer Sorbed on Solid, S_s :	-10.0	-2.5	14.9	-9.9	12.5	17.5	12.6	0	7.50	--	--
K_d (mL/g):	-0.69	-0.18	1.11	-0.69	0.926	1.31	0.931	0	0.548	--	--
K_d Relative Percent Difference (%), RPD:	--	118.0	276.4	852.5	1366.8	34.7	34.2	200	200	--	--

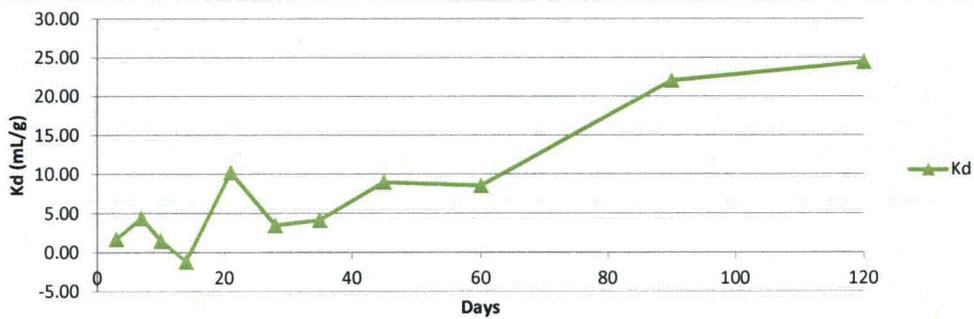
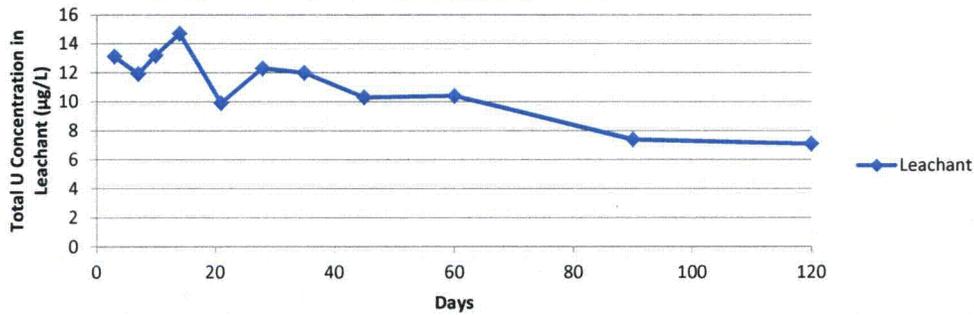


Final Soil Concentration: Not available (unable to analyze soil at conclusion of test because glassware was rinsed with deionized water and acid, then the acid was analyzed for uranium concentration to determine if any uranium had sorbed to laboratory glassware)

Recommended K_d : 0.97 (mL/g)

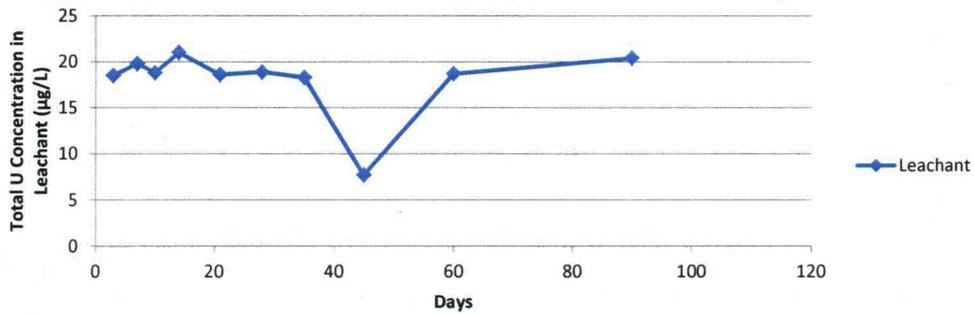
Assumes equilibrium reached between days 3 through 60 including non-zero and positive K_d values (i.e., excluding zero and negative K_d values).

Sample:	JP-KCR-011_SAIC01R										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	14										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	13.1	11.9	13.2	14.7	9.90	12.3	12.0	10.3	10.4	7.40	7.10
Leachant Relative Percent Difference (%), RPD:	--	9.60	10.4	10.8	39.0	21.6	2.47	15.2	0.966	33.7	4.1
Starting Soil Concentration (mg/kg), S_i :	1.3										
Dry Mass of Solid (g), M:	3.9930	3.9987	4.0337	4.0145	4.0352	3.9610	4.0171	3.9860	4.0375	4.0389	3.9721
Quantity of Tracer Sorbed on Solid, Q_s :	90.0	210	80.0	-70.0	410	170	200	370	360	660	690
Concentration of Tracer Sorbed on Solid, S :	22.5	52.5	19.8	-17.4	102	42.9	49.8	92.8	89.2	163	174
K_d , (mL/g):	1.72	4.41	1.50	-1.19	10.3	3.49	4.15	9.01	8.57	22.1	24.5
K_d Relative Percent Difference (%), RPD:	--	87.8	98.4	1700.0	252.3	98.5	17.3	73.9	5.0	88.1	10.2

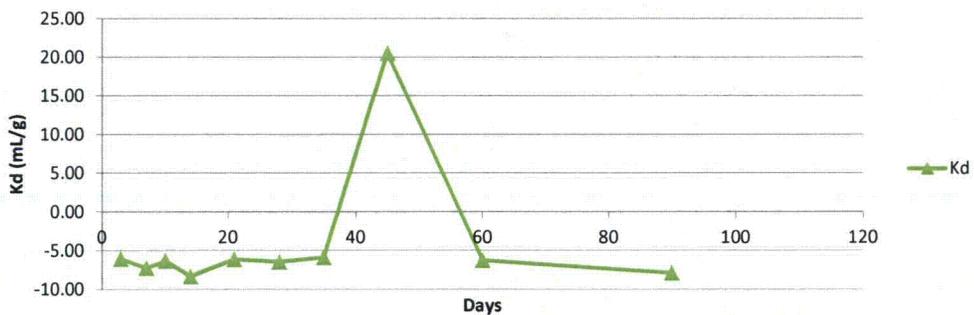


Final Soil Concentration: 7.1 mg/kg
Recommended K_d : 11.7 (mL/g)
Assumes equilibrium reached between days 21 through 120.

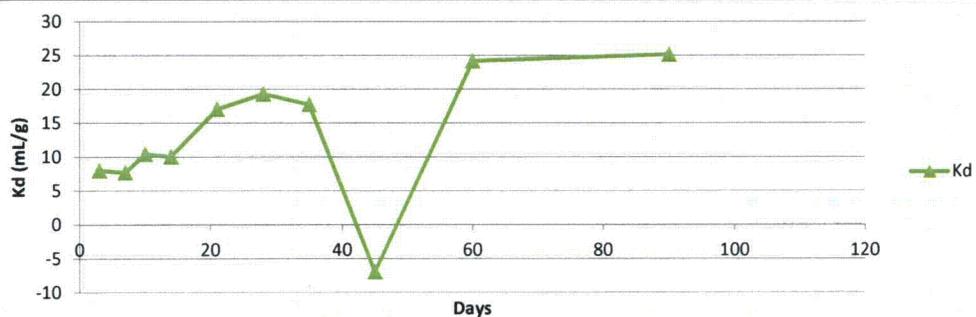
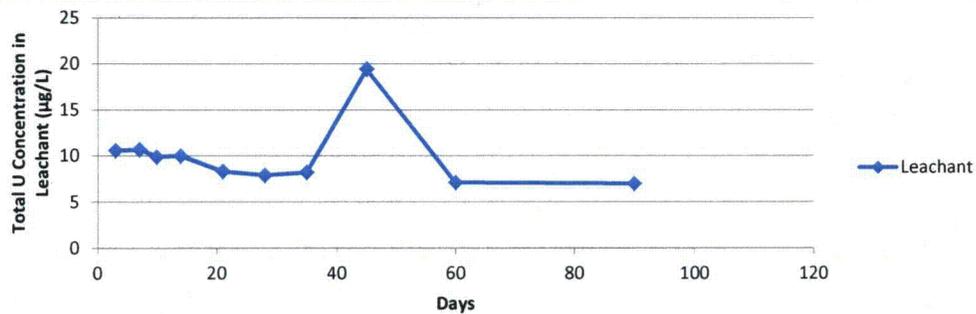
Sample:	JP-KCR-012_SAIC01R										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	14										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	18.5	19.8	18.8	21.0	18.6	18.9	18.3	7.7	18.7	20.4	17.4
Leachant Relative Percent Difference (%), RPD:	--	6.79	5.18	11.1	12.1	1.60	3.23	81.54	83.33	8.70	15.87
Starting Soil Concentration (mg/kg), S_i :	0.91										
Dry Mass of Solid (g), M:	3.9817	4.0245	4.0105	3.9964	4.0299	4.0073	3.9926	3.9822	4.0011	3.9802	4.0269
Quantity of Tracer Sorbed on Solid, Q_s :	-450.0	-580.0	-480.0	-700.0	-460.0	-490.0	-430.0	630.0	-470.0	-640.0	-340.0
Concentration of Tracer Sorbed on Solid, S_s :	-113.0	-144.1	-119.7	-175.2	-114.1	-122.3	-107.7	158.2	-117.5	-160.8	-84.4
K_d (mL/g):	-6.11	-7.28	-6.37	-8.34	-6.14	-6.47	-5.89	20.55	-6.28	-7.88	-4.85
K_d Relative Percent Difference (%), RPD:	--	17.5	13.4	26.9	30.4	5.3	9.5	360.6	376.2	22.6	47.6



Final Soil Concentration: 17.4 mg/kg
Recommended K_d : -1 (mL/g)
Assumes equilibrium reached between days 21 through 60.

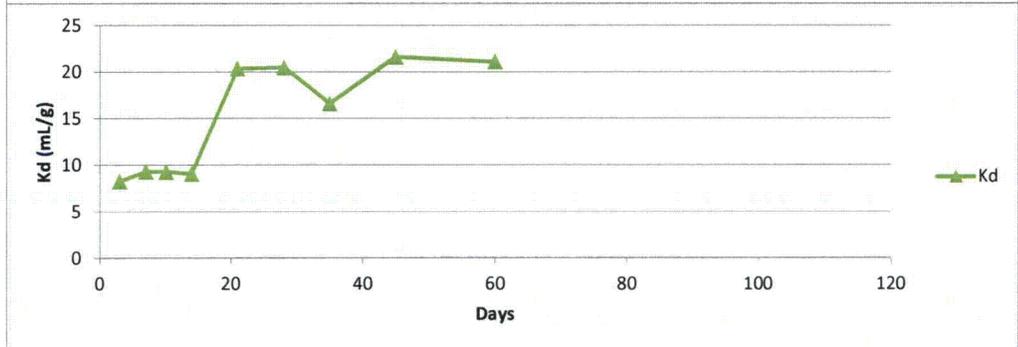
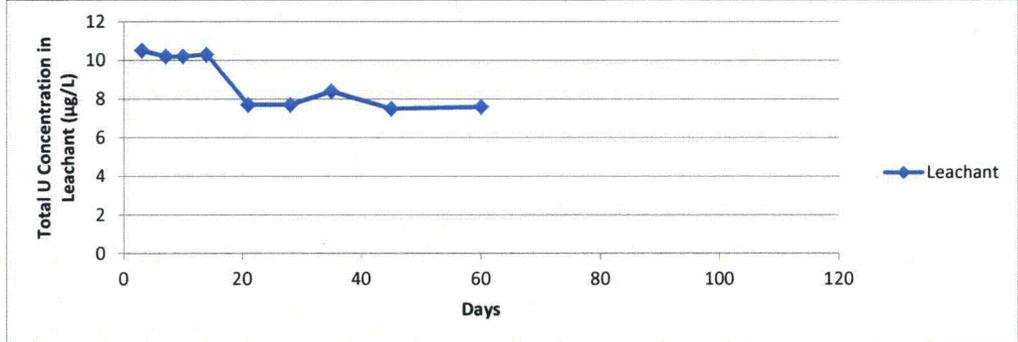


Sample:	JP-KGR-005_SAIC01DR										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	14										
Total Volume of (Contact) Liquid (mL), V :	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	10.6	10.7	9.90	10.0	8.30	7.90	8.20	19.40	7.10	7.00	8.60
Leachant Relative Percent Difference (%), RPD:	--	0.939	7.77	1.01	18.6	4.94	3.73	81.2	92.83	1.42	20.51
Starting Soil Concentration (mg/kg), S_i :	0.55										
Dry Mass of Solid (g), M :	4.0086	4.0013	3.9774	3.9762	4.0252	3.9980	3.9874	3.9994	4.0188	3.9772	3.9786
Quantity of Tracer Sorbed on Solid, Q_s :	340	330	410	400	570	610	580	-540	690	700	540
Concentration of Tracer Sorbed on Solid, S :	84.8	82.5	103	101	142	153	145	-135	172	176	136
K_d , (mL/g):	8.00	7.71	10.4	10.1	17.1	19.3	17.7	-7.0	24.2	25.1	15.8
K_d Relative Percent Difference (%), RPD:	--	3.7	29.9	3.4	51.6	12.4	8.5	458.3	361.6	3.9	45.7



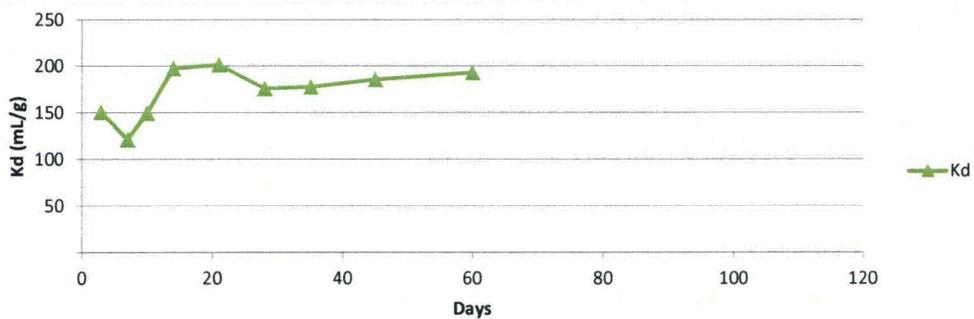
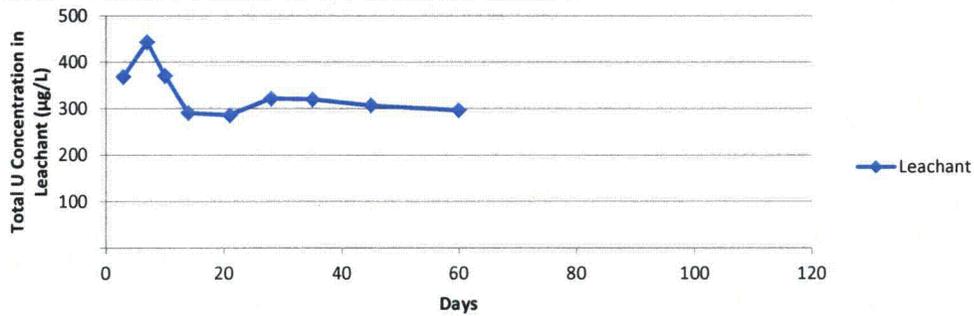
Final Soil Concentration: 8.6 mg/kg
Recommended K_d : 16 (mL/g)
Assumes equilibrium reached between days 21 through 120.

Sample:	JP-KGR-005_SAIC01R										
Test:	Adsorption										
Contact Liquid:	Groundwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	14										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	10.5	10.2	10.2	10.3	7.70	7.70	8.40	7.50	7.60	--	--
Leachant Relative Percent Difference (%), RPD:	--	2.90	0	0.976	28.9	0	8.70	11.3	1.32	--	--
Starting Soil Concentration (mg/kg), S_i :	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	--	--
Dry Mass of Solid (g), M:	4.0379	4.0037	4.0066	3.9679	4.0156	3.9931	4.0116	4.0081	3.9899	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	350	380	380	370	630	630	560	650	640	--	--
Concentration of Tracer Sorbed on Solid, S:	86.7	94.9	94.8	93.2	157	158	140	162	160	--	--
Kd, (mL/g):	8.26	9.31	9.30	9.05	20.4	20.5	16.6	21.6	21.1	--	--
Kd Relative Percent Difference (%), RPD:	--	12.0	0.1	2.7	76.9	0.6	20.9	26.2	2.4	--	--



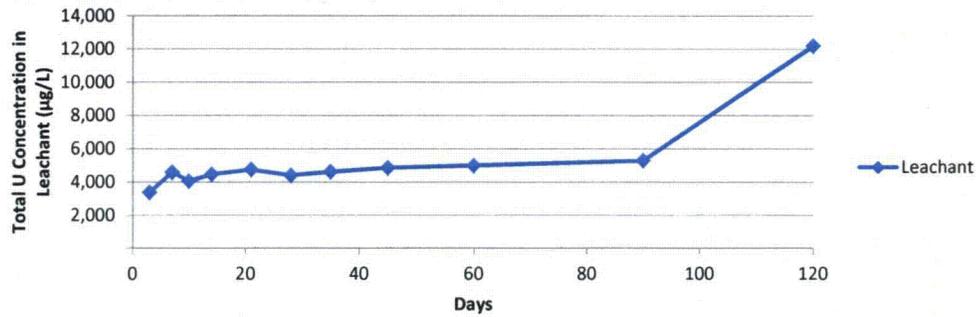
Final Soil Concentration: 0.71 mg/kg
Recommended Kd: 20 (mL/g)
Assumes equilibrium reached between days 21 through 60.

Sample:	JP-PNAC-001_SAIC05										
Test:	Desorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_s :	NA										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	369	443	371	291	286	322	320	307	297	--	--
Leachant Relative Percent Difference (%), RPD:	--	18.2	17.7	24.2	1.73	11.8	0.623	4.15	3.31	--	--
Starting Soil Concentration (mg/kg), S_i :	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	--	--
Dry Mass of Solid (g), M:	4.0332	3.9854	4.0167	4.0202	3.9802	3.9832	4.0284	3.9710	3.9827	--	--
Quantity of Tracer Sorbed on Solid, Q_s :	--	--	--	--	--	--	--	--	--	--	--
Concentration of Tracer Sorbed on Solid, S:	55.7	53.7	55.6	57.6	57.6	56.7	56.9	57.1	57.3	--	--
Kd, (mL/g):	151	121	150	198	201	176	178	186	193	--	--
Kd Relative Percent Difference (%), RPD:	--	21.8	21.1	27.6	1.8	13.4	0.9	4.5	3.8	--	--

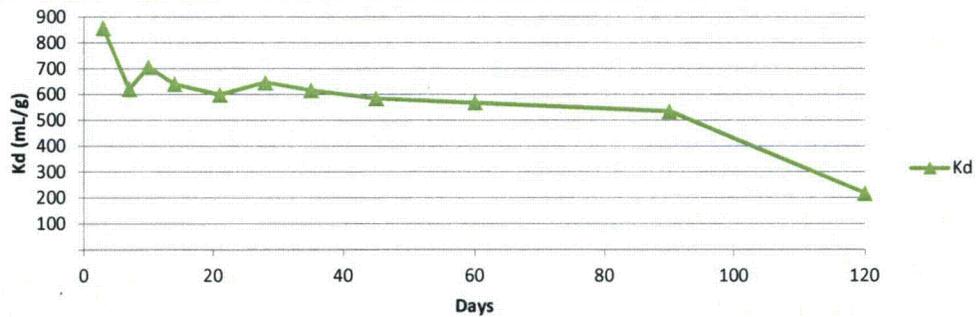


Final Soil Concentration: 420 mg/kg
Recommended Kd: 189 (mL/g)
Assumes equilibrium reached between days 14 through 60.

Sample:	JP-PNCR-001_SAIC05										
Test:	Desorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	NA										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	3,360	4,590	4,050	4,460	4,750	4,410	4,620	4,860	5,000	5,290	12,200
Leachant Relative Percent Difference (%), RPD:	--	30.9	12.5	9.64	6.30	7.42	4.65	5.06	2.84	5.64	79.02
Starting Soil Concentration (mg/kg), S_i :	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960	2,960
Dry Mass of Solid (g), M:	3.9933	3.9745	4.0176	4.0111	3.9692	3.9668	3.9826	4.0214	4.0347	3.9828	4.0231
Quantity of Tracer Sorbed on Solid, Q_s :	--	--	--	--	--	--	--	--	--	--	--
Concentration of Tracer Sorbed on Solid, S :	2,876	2,845	2,859	2,849	2,840	2,849	2,844	2,839	2,836	2,827	2,657
K_d , (mL/g):	856	620	706	639	598	646	616	584	567	534	218
K_d Relative Percent Difference (%), RPD:	--	32.0	13.0	10.0	6.6	7.7	4.8	5.2	2.9	6.0	84.2



Final Soil Concentration: 1850 mg/kg
Recommended K_d : 591 (mL/g)
Assumes equilibrium reached between days 21 through 90.



Sample:	JP-PNGR-001_SAIC05										
Test:	Desorption										
Contact Liquid:	Rainwater										
Starting Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_i :	NA										
Total Volume of (Contact) Liquid (mL), V:	100										
Day:	3	7	10	14	21	28	35	45	60	90	120
Final Concentration of Tracer in Contact Solution ($\mu\text{g/L}$), C_f :	35,600	44,500	62,400	80,700	139,000	111,000	54,500	49,300	122,000	167,000	304,000
Leachant Relative Percent Difference (%), RPD:	--	22.2	33.5	25.6	53.1	22.4	68.3	10.0	84.9	31.1	58.2
Starting Soil Concentration (mg/kg), S_i :	47,500	47,500	47,500	47,500	47,500	47,500	47,500	47,500	47,500	47,500	47,500
Dry Mass of Solid (g), M:	4.0315	3.9940	4.0012	4.0026	3.9665	3.9950	3.9942	4.0399	3.9841	3.9918	4.0389
Quantity of Tracer Sorbed on Solid, Q_s :	--	--	--	--	--	--	--	--	--	--	--
Concentration of Tracer Sorbed on Solid, S:	46,617	46,386	45,940	45,484	43,996	44,722	46,136	46,280	44,438	43,316	39,973
Kd, (mL/g):	1,309	1,042	736	564	317	403	847	939	364	259	131
Kd Relative Percent Difference (%), RPD:	--	22.7	34.4	26.6	56.2	24.0	71.0	10.3	88.2	33.6	65.4

Final Soil Concentration: 6450 mg/kg
Recommended Kd: 507 (mL/g)
Assumes equilibrium reached between days 10 through 120.

