SUPPLEMENTAL DATA REPORT NO. 2

DISTRIBUTION COEFFICIENTS (Kd) LABORATORY TEST RESULTS

NORTH ANNA POWER STATION COL PROJECT

REV. 1
DECEMBER, 2007

MACTEC PROJECT NO. 6468-06-1472

SUPPLEMENTAL DATA REPORT No. 2, Rev. 1
LABORATORY Kd TESTING RESULTS

1.0 INTRODUCTION

This report is a supplement to the MACTEC Geotechnical Data Report issued as Rev. 0 on January 23, 2007 and last revised as Rev. 1 on September 28, 2007. Laboratory Kd testing was performed by Savannah River National Laboratory, Washington Savannah River Company (SRNL). It was agreed with Dominion Nuclear North Anna, LLC (Dominion) that the test results would be issued as a supplemental report, not as a revision to the Geotechnical Data Report. Supplemental data report No. 2, Rev. 0 was issued in November, 2007. As a result of review comments provided by Bechtel, minor changes have been made, and Rev. 1 has been issued. A summary of the Bechtel comments and our responses is attached. The information in Supplemental Data Report (Rev. 1) is submitted for entry into the project document system and release for use.

2.0 SCOPE OF WORK

Sixteen soil samples and four rock core samples were assigned for Kd testing by Bechtel Corporation on their assignment sheet dated 11/28/06. Section 13.5 of the Technical Scope of Work document issued by Dominion as revised January 22, 2007 described the scope of work. The scope included:

- Laboratory adsorption testing for isotopes to be assigned by Dominion
- Physical and chemical characterization of soil samples, including pH, cation exchange capacity, grain size distribution and clay content
- X-Ray diffraction, X-Ray fluorescence and Brunauer-Emmett-Teller analysis of surface area and confirmation of particle size of ground material using calibrated sieves for selected rock samples.

3.0 METHODOLOGY

3.1 Locations

Samples for testing were obtained from standard penetration test samples or rock core samples obtained during the subsurface exploration. Samples were initially transported from the field temporary storage area to MACTEC's Raleigh laboratory under chain of custody following methods of ASTM D 4220-95 (2000) for Group A samples because physical disturbance of the samples was not a concern. Soil samples were split using the quartering method and approximately half of each sample was shipped under chain of custody to TestAmerica (formerly STL) for chemical analysis. The remaining portions were shipped under chain of custody to SRNL. Pieces of rock core from the sample received in the Raleigh lab were shipped under chain of custody to SRNL.

Because the size of sample needed to conduct both the Kd and the chemical tests on the soils did not leave enough material to perform particle size distribution tests, results from previous tests on boring soil samples obtained above or below the Kd sample depths were used to indicate the physical composition. Only one Kd sample did not have a particle size distribution test on an adjacent sample. The general characteristics of the soils at the North Anna site within the depth range of the Kd samples do not indicate large variations in particle size distribution among the tested samples.

3.2 Subcontractors

The soil sample chemical testing (pH and Cation Exchange Capacity) was performed by TestAmerica under subcontract to MACTEC. The Kd testing was done by SRNL under a Technical Agreement between MACTEC and the Washington Savannah River Company.

3.3 Technical Procedures

3.3.1 SRNL Procedures

The Kd determinations were based on ASTM D 4646-03: Standard Test Method for 24-h Batch-Type Measurement of Contaminant Sorption by Soils and Sediments. Deviations from the ASTM D 4646 method adopted by SRNL, as discussed in their report, included a pH adjustment step, equilibrating for 2 days with twice daily shaking rather than continuously agitating for 24 hours, using a 0.1 μm filter instead of a 0.45 μm filter to separate solids from liquids and grinding rock samples so they could be used in the Kd measurement. Procedures for other testing conducted at SRNL followed SRNL standard operating procedures as described in the attached report. MACTEC reviewed and accepted the test procedures.

3.3.2 Soil Chemical Tests

The soil pH and Cation Exchange Capacity (CEC) tests were performed by TestAmerica using current EPA methods as listed below:

pH – EPA SW846 9045D
CEC – EPA SW846 9081

4.0 QUALITY ASSURANCE

4.1 Procurement

SRNL and TestAmerica were procured for the work in accordance with the procedures in section QS-7 of the MACTEC Quality Assurance Project Document (QAPD).

4.2 Personnel

Personnel at SRNL and TestAmerica were qualified and operated under their respective Quality Assurance plans.

4.3 Equipment Calibration

Equipment in the SRNL and TestAmerica laboratories was calibrated in accordance with their respective Quality Assurance Programs. Copies of the calibration records for the SRNL equipment are included in their report and are maintained in MACTEC QA files.

4.4 Surveillances

MACTEC QA personnel conducted an audit of SRNL prior to their work and a surveillance of the SRNL laboratory during the course of the Kd testing. Records of the audit and surveillance are maintained in MACTEC QA files.

5.0 RESULTS

The test results reports from TestAmerica and SRNL were reviewed and accepted by MACTEC. The reports are attached.

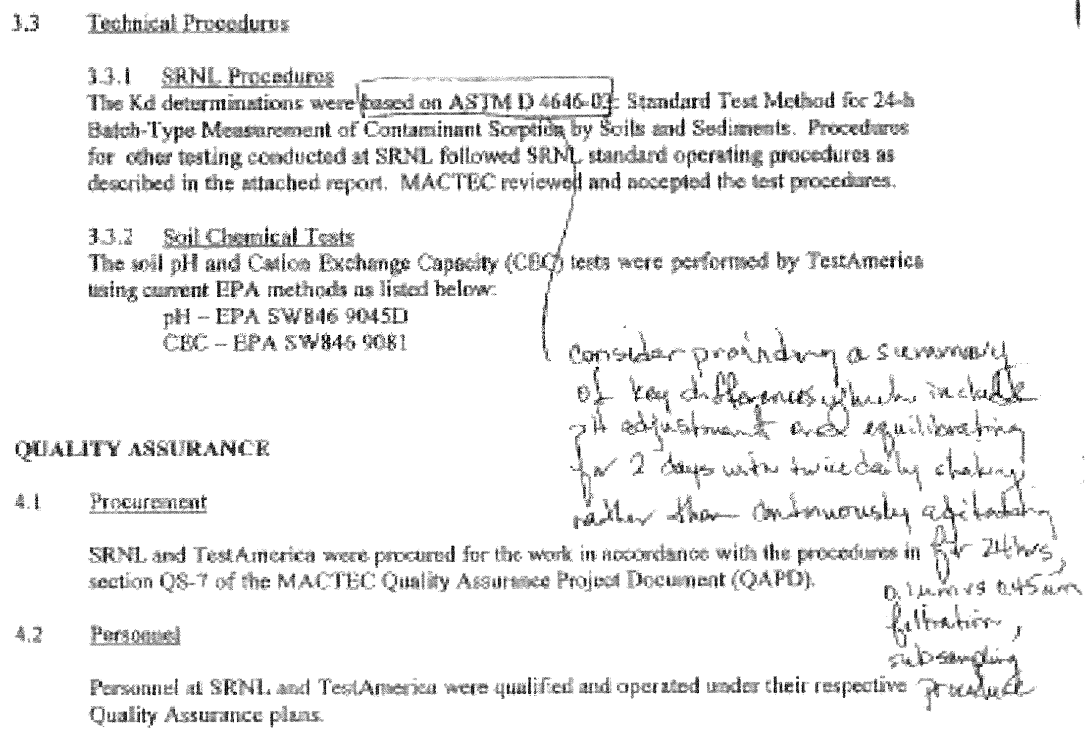
Results of previous particle size distribution tests on samples above or below the Kd samples are summarized in the attached Table SR-1 prepared using selected data from Table 3.1 of the Geotechnical Data Report, Rev. 1.

Results of the pH and CEC tests are summarized in the attached Table SR-2.

The Kd test results are presented in tables 2 and 3 of the attached SRNL report titled “Distribution Coefficients for the Combined Construction and Operating License (COL) Applications at the North Anna Site, Rev. 2.”

Summary of Revisions
SUPPLEMENTAL DATA REPORT 2, Rev. 1

Review comments made by Bechtel on Rev. 0 and the associated revisions are documented below:
1. The SRNL report containing their revisions is designated as Rev. 2 due to their internal revision tracking system. Their Rev. 1 report issued to MACTEC contained some editorial errors that were subsequently corrected in the Rev. 2 report that is submitted in this Supplemental Data Report 2, Rev. 1.



3.3 Technical Procedures

3.3.1 SRNL Procedures
The Kd determinations were based on ASTM D 4646-03: Standard Test Method for 24-h Batch-Type Measurement of Contaminant Sorption by Soils and Sediments. Procedures for other testing conducted at SRNL followed SRNL standard operating procedures as described in the attached report. MACTEC reviewed and accepted the test procedures.

3.3.2 Soil Chemical Tests
The soil pH and Cation Exchange Capacity (CEC) tests were performed by TestAmerica using current EPA methods as listed below:
pH – EPA SW846 9045D
CEC – EPA SW846 9081

4 QUALITY ASSURANCE

4.1 Procurement

SRNL and TestAmerica were procured for the work in accordance with the procedures in section QS-7 of the MACTEC Quality Assurance Project Document (QAPD).

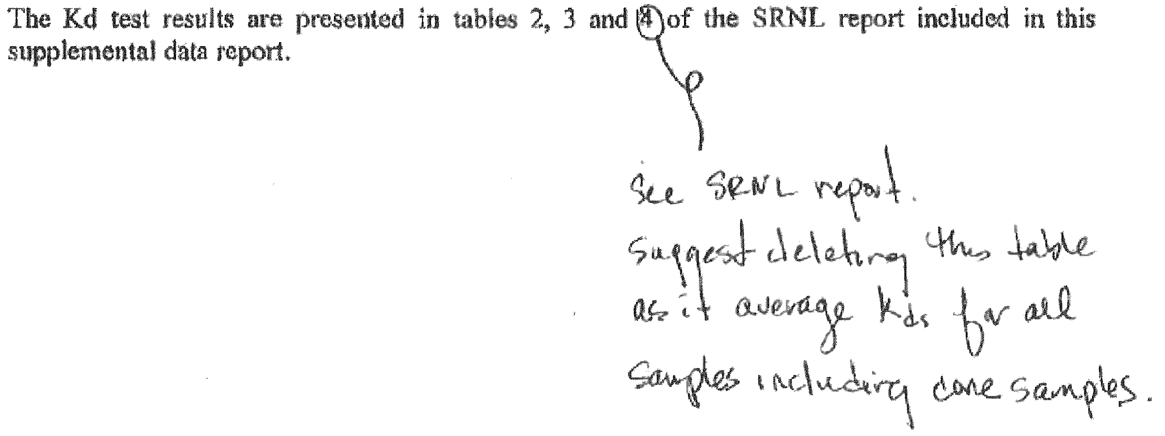
4.2 Personnel

Personnel at SRNL and TestAmerica were qualified and operated under their respective Quality Assurance plans.

Consider providing a summary of key differences which include pH adjustment and equilibrating for 2 days with twice daily shaking rather than continuously agitating for 24 hrs, 0.1um vs 0.45um filtration, subsampling procedure

Response: The text in section 3.3.1 has been modified to incorporate the deviations between SRNL procedures and the cited ASTM. In addition, SRNL modified text in their report section 2.0 to describe the deviations.

2.

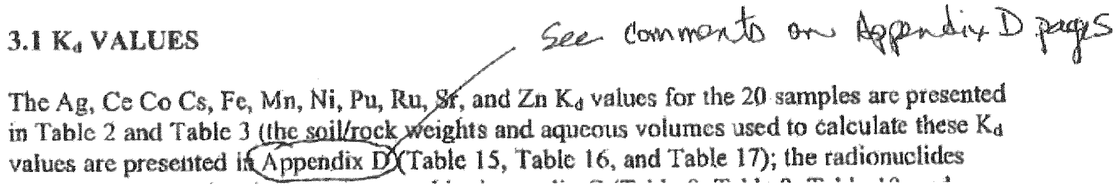


The Kd test results are presented in tables 2, 3 and 4 of the SRNL report included in this supplemental data report.

See SRNL report.
Suggest deleting this table as it average Kds for all samples including core samples.

Response: SRNL deleted Table 4 from their report and renumbered succeeding tables.

3.



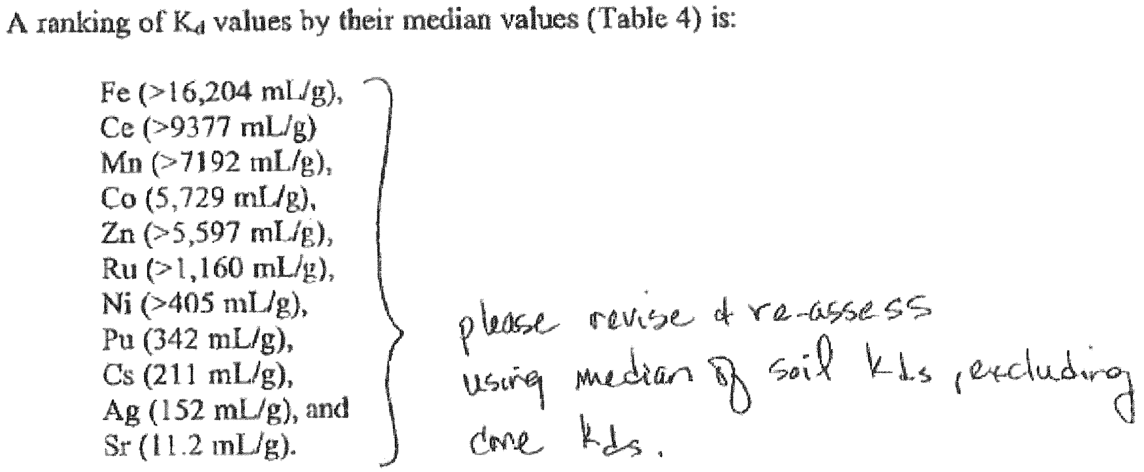
3.1 K_d VALUES

See comments on Appendix D pages

The Ag, Ce Co Cs, Fe, Mn, Ni, Pu, Ru, Sr, and Zn K_d values for the 20 samples are presented in Table 2 and Table 3 (the soil/rock weights and aqueous volumes used to calculate these K_d values are presented in Appendix D (Table 15, Table 16, and Table 17); the radionuclides

Response: Comments marked in Appendix D have been made by SRNL in their Rev. 1 report.

4.



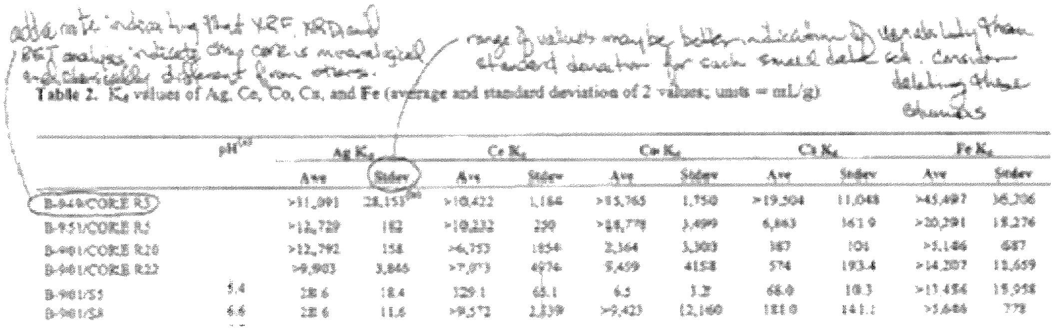
A ranking of K_d values by their median values (Table 4) is:

Fe (>16,204 mL/g),
Ce (>9377 mL/g)
Mn (>7192 mL/g),
Co (5,729 mL/g),
Zn (>5,597 mL/g),
Ru (>1,160 mL/g),
Ni (>405 mL/g),
Pu (342 mL/g),
Cs (211 mL/g),
Ag (152 mL/g), and
Sr (11.2 mL/g).

please revise & re-assess using median of soil Kds, excluding core kds.

Response: The listing was revised to include only soil Kd's as requested. This change is in the SRNL report Rev. 1.

5.



add note indicating that XRF, XRD and BET analyses indicate this core is mineralogical and chemically different from others.

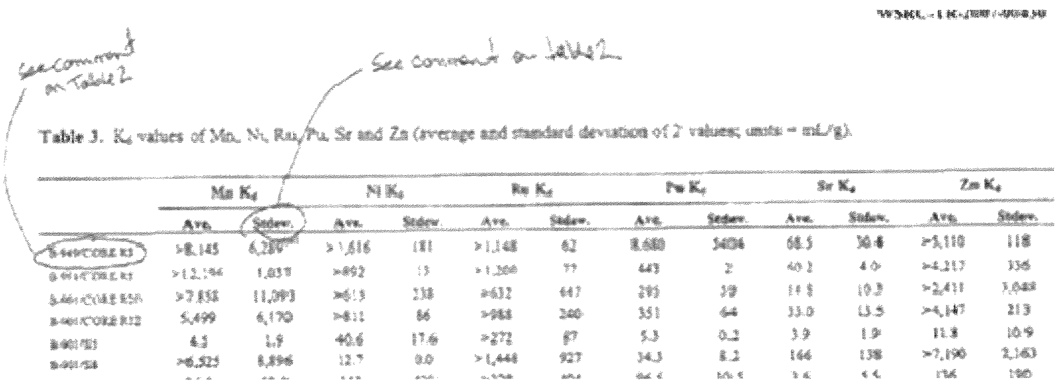
range of values may be better indication of variability than standard deviation for each small data set. Consider deleting these columns

Table 2. K_d values of Ag, Ce, Co, Cs, and Fe (average and standard deviation of 2 values; units = mL/g)

	pH[a]	Ag K_d		Ce K_d		Co K_d		Cs K_d		Fe K_d	
		Ave	Stdev	Ave	Stdev	Ave	Stdev	Ave	Stdev	Ave	Stdev
B-949/CORE R3		>11,091	28,153[b]	>10,422	1,164	>15,765	1,750	>19,504	11,048	>45,497	36,306
B-951/CORE R5		>12,729	182	>10,232	250	>18,779	3,499	6,863	161.9	>20,291	18,276
B-901/CORE R20		>12,792	158	>6,753	1854	2,364	3,303	387	101	>5,146	687
B-901/CORE R22		>9,903	3,845	>7,073	4974	5,459	4158	574	193.4	>14,207	11,659
B-901/S5	5.4	28.6	18.4	329.1	65.1	6.5	3.2	68.0	10.3	>13,456	15,958
B-901/S8	6.6	28.6	11.6	>9,572	2,339	>9,423	12,160	181.0	141.1	>3,686	778

Response: A footnote was added to indicate that the designated sample had different mineralogy. SRNL elected to leave the standard deviation in the table.

6.



WSRC-TR-2007-00430

See comment on Table 2

See comment on Table 2

Table 3. K_d values of Mn, Ni, Ru, Pu, Sr and Zn (average and standard deviation of 2 values; units = mL/g).

	Mn K_d		Ni K_d		Ru K_d		Pu K_d		Sr K_d		Zn K_d	
	Ave.	Stdev.	Ave.	Stdev.	Ave.	Stdev.	Ave.	Stdev.	Ave.	Stdev.	Ave.	Stdev.
[illegible]	>8,145	6,289	>1,616	181	>1,148	62	8,680	5404	68.5	30.4	>5,110	118
[illegible]	>12,194	1,038	>892	13	>1,200	77	443	2	40.2	4.0	>4,217	336
[illegible]	>7,838	11,093	>613	238	>632	447	295	39	14.8	10.3	>2,411	3,048
[illegible]	5,499	6,170	>811	66	>988	240	351	64	33.0	13.5	>4,147	213
[illegible]	4.3	1.9	40.6	17.6	>272	87	5.3	0.2	3.9	1.9	11.8	10.9
[illegible]	>6,525	8,896	12.7	0.0	>1,444	927	34.3	8.2	166	138	>7,190	2,163

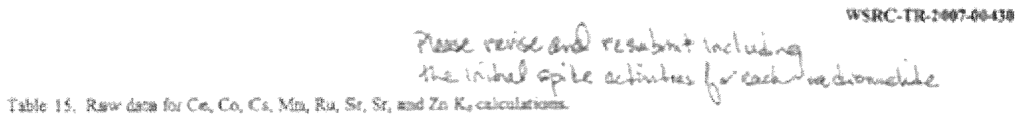
Response: See response to comment 5 above.

7.

Please consider deleting this table or revise to include core Kds from summary statistics. Also consider basing statistics on individual replicate measurements presented in Appendix D rather than averages presented in Tables 2 + 3.

Response: The comment note was on Table 4 in the Rev. 0 SRNL report. That table was deleted in Rev. 1 and succeeding tables renumbered.

8.



WSRC-TR-2007-00430

Please revise and resubmit including the initial spike activities for each radionuclide

Table 15. Raw data for Ce, Co, Cs, Mn, Ru, Sr, Sr, and Zn K_d calculations.

Response: Another table was created to provide the requested information. It is included as Table 15 in Rev. 1 and succeeding tables were renumbered.

Prepared By__________
Checked By__________

TABLE SR-1

SUMMARY OF PARTICLE SIZE DISTRIBUTION TEST RESULTS - SAMPLES NEAR Kd SAMPLES
NORTH ANNA NUCLEAR POWER STATION - COL PROJECT
MACTEC PROJECT # 6468-06-1472

Boring Number	Sample Number	Depth (ft)	Sample Type	Gravel (1) (%)	Sand (1) (%)	Fines (2) (%)	Silt (1) (%)	0.005 mm Clay (1) (%)
B-901	B-901-4	11.5-13.0	SPT	0.0	76.6	23.4	16.0	7.4
B-901	B-901-6	22.2-23.7	SPT	0.0	76.8	23.2	▨	▨
B-901	B-901-9	37.2-38.7	SPT	0.7	71.9	22.5	15.2	7.3
B-913	B-913-8	43.5-48.5	SPT	0.0	72.3	27.7	▨	▨
B-917	B-917-13	48.5-53.5	SPT	0.0	81.9	18.1	15.0	3.1
B-919	B-919-7	18.9-19.4	SPT	3.7	75.5	20.8	10.8	10.0
B-919	B-919-13	51.3-52.8	SPT	0.0	65.9	34.1	26.0	8.1
B-920	B-920-9	27.3-28.8	SPT	0.0	79.9	20.1	▨	▨
B-928	B-928-6	14.0-15.5	SPT	0.0	77.0	23.0	17.8	5.2
B-928	B-928-8	22.1-23.6	SPT	0.0	78.7	21.3	▨	▨
B-929	B-929-11	43.0-44.5	SPT	0.7	81.4	17.9	▨	▨
B-929	B-929-13	53.0-54.5	SPT	0.0	80.0	20.0	▨	▨
B-931	B-931-10	47.3-48.8	SPT	0.0	78.5	21.5	15.9	5.6
B-932	B-932-5	19.0-20.5	SPT	0.0	77.7	22.3	15.7	6.6
B-951	B-951-8	23.0-24.5	SPT	0.2	82.9	16.9	10.5	6.4

(1) Due to computer roundoff, particle size fractions may total 100 ± 1.

(2) Fines include silt plus clay.

(3) Shaded cells ▨ indicate that information not obtained.

TABLE SR-2
SUMMARY OF SOIL pH and CATION EXCHANGE CAPACITY TESTS
NORTH ANNA NUCLEAR POWER STATION - COL PROJECT
MACTEC PROJECT # 6468-06-1472

Source of Sample	Sample No. [(3)]	Depth [(1)] (ft)	pH [(2), (4)]	CEC [(2), (4)] (meq/100g)
B-901	901-5	15-16	5.4	8.5
B-901	901-8	32.2-33.2	6.6	10.4
B-904	904-10	33-34	6.7	11.0
B-913	913-1-9	26.8-27.8	6.5	17.1
B-913	913-10	53.5-54.5	7.0	10.1
B-917	917-12	43.5-44.5	6.2	12.9
B-917	917-14	53.5-54.5	6.6	11.5
B-917	917-15	58.5-59.5	6.9	9.9
B-919	919-8	23.9-24.9	6.7	15.7
B-920	920-11	38.5-39.5	7.2	18.2
B-928	928-7	18.2-19.2	6.5	11.5
B-929	929-12	48-49	7.2	8.3
B-931	931-11	53.8-54.8	7.4	13.1
B-932	932-6	25-26	7.1	18.5
B-951	951-7	19.5-20.5	9.2	5.8
B-951	951-9	17.7-18.7	8.3	11.0

Notes:

(1) Depth represents complete interval sampled

(2) Tests performed by STL-St. Louis (now known as TestAmerica)

(3) Sample number in STL report included an S; i.e. STL sample B-901 S-5 is recorded on boring log for B-901 as sample 901-5.

(4) pH and CEC testing was conducted on samples obtained during 2006 field exploration. Samples were stored in glass jars with moisture-tight lids in a controlled temperature environment until shipped to STL for testing.

Prepared by: L. Saal
Checked by:

MACTEC

DOCUMENTATION OF TECHNICAL REVIEW
SUBCONTRACTOR WORK PRODUCT

Project Name: North Anna COL
Project Number: 6468-06-1472

Project Manager: Steve Criscenzo

Project Principal: Al Tice

The report described below has been prepared by the named subcontractor retained in accordance with the MACTEC QAPD. The work and report have been reviewed by a MACTEC technically qualified person. Comments on the work or report, if any, have been satisfactorily addressed by the subcontractor. The attached report is approved in accordance with section QS-7 of MACTEC's QAPD

The information and date contained in the attached report are hereby released by MACTEC for project use.

REPORT : "Distribution Coefficients for the Combined Construction and Operating License (COL) Applications at the North Anna Site", Rev. 2 issued by Dr. Daniel Kaplan, Savannah River National Laboratory, Washington Savannah River Site, December 13, 2007

Note: Rev. 2 replaces Rev. 1 which was found to have some typo and editing errors and was not accepted. SRNL internal procedures required that the minor changes in Rev. 1 be issued as a revision 2.

SUBCONTRACTOR: Savannah River National Laboratory

DATE OF ACCEPTANCE : 12-13-07

TECHNICAL REVIEWER: J Allan Tice

PROJECT PRINCIPAL J Allan Tice

DCN NA COL 263

KEY WORDS:
Distribution coefficients, manganese, zinc, ruthenium, cerium, cesium, cobalt, iron, nickel, plutonium, silver, and strontium

RETENTION:
Permanent

DISTRIBUTION COEFFICIENTS FOR THE COMBINED CONSTRUCTION AND OPERATING LICENSE (COL) APPLICATIONS AT THE NORTH ANNA SITE

Daniel I. Kaplan

DECEMBER 13, 2007

Savannah River National Laboratory
Washington Savannah River Company
Savannah River Site
Aiken, SC 29808

REVIEWS AND APPROVALS

Daniel I. Kaplan 12/13/2007

Daniel I. Kaplan, Author, Environmental & Chemical Processing Technology Date

Kimberly P. Crapse 11/12/07

Kim Crapse, Peer Reviewer, Environmental & Chemical Processing Technology Date

B. T. Butcher 11/12/07

B. T. Butcher, Level 4 Manager, Environmental & Chemical Processing Technology Date

The changes made to revision 1 of this report were editorial. Therefore only the author and not the peer reviewer or manager resigned revision 2 of this document.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ACRONYMS AND ABREVIATIONS

Ag	silver
avg	average
BET	Brunauer, Emmett, Teller (surface-area analysis)
Ce	cerium
Co	cobalt
COL	Combined Operating and Construction License
Cs	cesium
Fe	iron
ICP-MS	Inductively Coupled Plasma – Mass Spectroscopy
K_d	distribution coefficient
Mn	manganese
Ni	nickel
Pu	plutonium
RSD	relative standard deviation
Ru	ruthenium
Sr	strontium
SRNL	Savannah River National Laboratory
stdev	standard deviation
XRD	X-ray diffraction
XRF	X-ray fluorescence
Zn	zinc

ABSTRACT

Soil distribution coefficients, K_d values (the concentration ratio of radionuclides present on the solids to that present in the aqueous phase), were determined in support of the Construction and Operating License (COL) application for the North Anna new nuclear plant. Four rock and 16 soil samples and a representative groundwater sample from the North Anna site were provided for the Savannah River National Laboratory to conduct site-specific K_d determinations of cerium (Ce), cobalt (Co), cesium (Cs), iron (Fe), manganese (Mn), nickel (Ni), plutonium (Pu), ruthenium (Ru), silver (Ag), strontium (Sr), and zinc (Zn). All K_d measurements were conducted in duplicate using radioactive and stable isotopes. Additionally, X-ray diffraction (XRD), X-ray fluorescence (XRF), and surface area analyses were conducted on the four cored rock samples. The median K_d values of the rock samples were greater than those for the sediment samples. The surface area, XRD and XRF data indicated that three of the four rock samples had similar surface areas, and mineralogical and elemental compositions. The fourth rock sample tended to have larger K_d values than the other three rock samples and contained greater concentrations of phosphorus, manganese, calcium, titanium, and iron (the latter two are commonly associated with minerals that have a high capacity to sorb metals). The K_d values reported here will provide useful input data for assessing the risk associated with subsurface movement of Ag, Ce, Cs, Co, Fe, Mn, Ni, Pu, Ru, Sr, and Zn at the North Anna site.

.

1.0 INTRODUCTION

Distribution coefficients, K_d values, when used in reactive transport codes are conditional on the sediment type and groundwater (Krupka et al 1999a). For this reason it is ideal to use K_d values derived from site-specific materials when possible. The objective of this project was to provide site-specific cerium (Ce), cobalt (Co), cesium (Cs), iron (Fe), manganese (Mn), nickel (Ni), ruthenium (Ru), plutonium (Pu), strontium (Sr), silver (Ag), and zinc (Zn) K_d values for the Combined Construction and Operating License (COL) application at the North Anna site. Four rock core samples, 16 soil samples, and one groundwater sample from the site were collected by MACTEC Engineering (Raleigh, NC) and provided to Savannah River National Laboratory (SRNL) for these tests. Additionally, X-ray diffraction (XRD), X-ray fluorescence (XRF), and surface area analyses were conducted on the four rock samples.

2.0 MATERIALS AND METHODS

The materials and methods for this project are described in detail in Appendix A. The following is a brief description to permit understanding of the results. The K_d determinations were based on "ASTM D 4646-03: Standard test method for 24-hr batch-type measurement of contaminant sorption by soils and sediments" (Appendix A). The key differences between the procedure used here and ASTM D 4646-03 is this procedure included 1) a pH adjustment step, 2) equilibrating for 2 days with twice daily shaking rather than continuously agitating for 24 hours, 3) using a 0.1 µm filter instead of a 0.45 µm filter to separate solids from liquids, and 4) grinding rock samples so they could be used in the K_d measurement.

Procedures used for the XRF, XRD, BET, ICP-MS, and gamma analyses were taken from the SRNL's standard operating procedures (which have been transmitted to MACTEC under separate cover):

- XRD: "Panalytical X'pert Pro 3040, X-ray Diffraction System." Manual L.16.1, Procedure ADS-1120, Rev. 0.
- BET: "Procedure for Operating the Micromeritics ASAP 2010 Surface Area and Pore Volume Analyzer." Manual L16.1, Procedure: ADS-1.114, Rev 2.
- XRF: "Rigaku ZSX 101E, Wavelength Dispersive X-ray Fluorescence System." Manual L.16.1, Procedure ADS-115, Rev. 2.
- ICP-MS: "Inductively /coupled Plasma-Mass Spectrometer Elemental and Isotopic Analysis for Aqueous Liquid Samples, Plasmaquad II (U) RADICPMS" (Manual L16.1, Procedure ADS-1543, Rev. 4.
- Gamma Analysis: "Gamma Sample Preparation and Analysis (γ-PHA)" (Manual L16.1, Procedure ADS-2420, Rev. 4.

Whittig and Allardice (1986) was used for interpreting the XRD results. The simple statistics reported in this report (averages, median, and standard deviations) were generated by EXCEL (Microsoft Inc). The lab notebook used to record the activity of this work was WSRC-NB-2007-00029, pages 97 – 114. This unclassified notebook will be kept "permanently" by the Department of Energy.

2.1 MATERIALS

The soil/rock samples and their corresponding SRNL identification number are presented in Table 1. The radionuclides used in the K_d measurements were purchased from Eckert & Ziegler Analytics (Atlanta, Georgia, this company use to be Analytics, Inc.). The radioisotope certifications are provided in Appendix B. Silver K_d values were measured using stable isotope techniques; inductively coupled plasma–mass spectroscopy (ICP-MS) was used to detect aqueous Ag during these tests. The Ag spike solution was an 1000 mg/L Ag Standard in 2% HNO_3 (1000 ± 3 mg/L; Spex, Certiprep; Plasma Grade; Expires June 2008).

The solid/groundwater suspensions used in the K_d determinations were spiked to yield the following concentrations:

- 127 µg/L Ag (stable)
- 1.2e-6 Ci/L ^{139}Ce,
- 1.6e-6 Ci/L ^{57}Co,
- 2.1e-6 Ci/L ^{137}Cs,
- 6.4 e-6 Ci/L ^{55}Fe,
- 1.6e-6 Ci/L ^{54}Mn,
- 1.7e-7 Ci/L ^{59}Ni,
- 1.5e-6 Ci/L ^{106}Ru,
- 5.7e-7 Ci/L ^{238}Pu,
- 6.0e-7 Ci/L ^{85}Sr, and
- 1.6e-6 Ci/L ^{65}Zn.

The concentrations of the radionuclides and Ag used in these tests were carefully selected to insure that the concentrations of the spiked solutes would not exceed the linear sorption range. In the linear range, the K_d construct is appropriate to use. At higher concentrations, it is often necessary to use more complicated models, such as the Freundlich model. Another concern with using elevated radionuclide concentrations is the increased likelihood of promoting radionuclide precipitation. If precipitation occurs, the measurement would incorrectly attribute reversible sorption to the K_d values, where in fact “less reversible” precipitation occurred. (Precipitation should be described with a solubility constant and not a K_d value.) The tests were conducted at concentrations expected to be several orders of magnitude less than that necessary to induce precipitation. Regarding non-linear sorption, Krupka et al. (1999b) reported that non-linear sorption of Cs occurs at concentrations greater than about 10^{-5} M (or 0.12 Ci/L ^{137}Cs) and Sr at about 10^{-7} M (or 1.2e-3 Ci/L ^{90}Sr).

The magnitude of sorption to geological materials does not vary with isotope. So even if the COL is interested in making transport calculations with different isotopes of the elements mentioned above, the K_d values will remain the same. At these very low concentrations, competition for sorption sites as a result of introducing more than one radionuclide at a time is essentially non-existent.

Table 1. Soil and rock core samples used in K_d measurements.

SRNL Sample ID #	Boring/Sample ID
101	B-949/CORE R3
102	B-951/CORE R5
103	B-901/CORE R20
104	B-901/CORE R22
105	B-901/S5
106	B-901/S8
107	B-904/S10
108	B-913/S9
109	B-913/S10
110	B-917/S12
111	B-917/S14
112	B-917/S15
113	B-919/S8
114	B-920/S11
115	B-928/S7
116	B-929/S12
117	B931/S11
118	B932/S6
119	B951/S7
120	B-951/S9

[a] The four samples (101 – 104) with the word “CORE” in their names were rock cores; all other samples were soils.

2.2 METHODS

2.2.1 K_d Values

Detailed descriptions of the methods used to measure radioisotope and stable isotope K_d values is presented in Appendix A. Briefly, four near identical sets of measurements were conducted:

- the first was spiked with ^{139}Ce, ^{57}Co, ^{137}Cs, ^{54}Mn, ^{106}Ru, ^{85}Sr, and ^{65}Zn,
- the second was spiked with ^{55}Fe and ^{238}Pu
- the third was spiked with ^{59}Ni, and

- the fourth was spiked with stable Ag.

These radionuclides were separated in this manner to ease analytical detection of the tracer. The rock samples, identified in Table 1 as "Core" samples were received in two-inch (5-cm) diameter cores. They were crushed into smaller particles by cutting a thin cross-section from the middle of the core with a thin-section saw. Approximately 20-g of the thin-section was then placed in a Spex 8510 Shatter box for 5 minutes, ground, and passed through a #400 (38-µm) sieve (Sieve Certificates of Compliance are presented in Appendix I). The <38 µm fraction was saved for K_d measurements. The soil samples were passed through a 2-mm (#270) sieve. The soil and rock samples were air dried.

A 0.25- or 0.5-g aliquot of the dried solid phase and 12 mL of groundwater were added to a 15-mL centrifuge tube. The suspension was mixed overnight to pre-equilibrate the soil or rock with the groundwater prior to adding the radionuclides. To separate the liquid and solid phases, the tubes were centrifuged and the aqueous phase was decanted and disposed.

Following pre-equilibrating the soil/rock samples, 10 mL of groundwater was added to the tubes followed by 170 µL of the appropriate spike solution (the ^{139}Ce/^{57}Co/^{137}Cs/^{54}Mn/ ^{106}Ru/^{85}Sr/^{65}Zn mixture, ^{55}Fe/^{238}Pu mixture, ^{59}Ni single isotope spike, or the stable Ag single element spike). Because the background solutions of the spikes were very acidic (~0.1 M HCl for the radioisotopes spike solutions and 2% HNO_3 for the Ag spike solution), it was necessary to adjust the pH by adding base to each suspensions until the pH returned to approximately that of background. The pH of the soil samples were measured by STL-St Louis (now known as TestAmerica; data provided by MACTEC). It is important to maintain background pH levels in K_d measurements because pH can influence the extent that radionuclides sorb to sediments. The suspensions were shaken twice a day for ~10 seconds over a ≥2 day contact period. At the end of the contact period, the samples were permitted to settle and the aqueous phase was passed through a 0.1µm filter. The radionuclides were analyzed by standard gamma spectroscopy. Ag was analyzed by inductively couple plasma – mass spectroscopy (ICP-MS).

All K_d measurements were conducted in duplicate. Three positive controls (spikes only in groundwater, no solid phase added) and two negative controls (groundwater only samples, without solid phase or spike). Therefore a total of 180 test tubes prepared for this study:

> For the ^{139}Ce/^{57}Co/^{137}Cs/^{54}Mn/ ^{106}Ru/^{85}Sr/^{65}Zn K_d determinations: (2 reps x 20 soil/rock) + 3 positive controls + 2 negative controls = 45 test tubes
>
> For the ^{55}Fe/^{238}Pu K_d determinations: (2 reps x 20 soil/rock) + 3 positive controls + 2 negative controls = 45 test tubes
>
> For the ^{59}Ni determinations: (2 reps x 20 soil/rock) + 3 positive controls + 2 negative controls = 45 test tubes
>
> For the Ag determinations: (2 reps x 20 soil/rock) + 3 positive controls + 2 negative controls = 45 test tubes

The three positive controls provided estimates of spike concentrations in the absence of soil or rock and accounted for any precipitation or sorption to the labware that may have occurred as an experimental artifact. It provided a direct measure of the radionuclide and Ag concentrations introduced to the samples. The negative controls provided a measure of how much of the radionuclides and Ag were in the native groundwater, either as a cross contaminations during the assay or as an existing contaminant at the study site. All negative controls had below detection limit concentrations of radionuclides. The negative controls were not used in the calculation of K_d values. The positive controls were used in the K_d calculations; they provided a measure of the amount of spike added to each tube.

There were no problems encountered in sample receipt, login, and analysis. One of the six 1-L glass containers, all containing the identical groundwater, was received broken: “Kd-04.” As a result, the sample container was empty. This was noted on the Chain-of-Custody sheets (Appendix E). The five other 1-L glass containers, provided sufficient groundwater to complete these tests. Additionally, The glass jar holding soil sample, B-951-S7, was also received broken. As noted on the Chain-of-Custody sheet (Appendix E), the “Contents (were) uncompromised and transferred to new container. Original label saved.” Based on a thorough visual inspection, no glass pieces were observed in sample B-951-S7. Subsequent testing of this sample produced no unusual results.

2.3 ANALYTICAL STANDARDS

The M&TE approval of balances and weight standards used in this study are presented in Appendix F. The list of equipment used in this study is presented in Appendix G. Personnel qualifications are presented in Appendix H.

2.3.1 ICP-MS Analyses

ICP-MS was used to measure aqueous Ag concentrations for the Ag K_d determinations. The raw data from the ICP-MS analyses are presented in Table 10 in Appendix C. Among the QA samples included in the analyses was a 10 µg/L Ag standard that was assayed at the start, mid-way, and end of each run of 15 unknowns (samples). The results of these nine 10 µg/L standard analyses were acceptable (9.92, 10.3, 10.1, 10.1, 10.3, 10.1, 10.0, 9.83, and 9.95 µg/L; Appendix C; Table 10). These standards are within the relative standard deviation (RSD) of 10%.

2.3.2 Gamma Analyses

The QA standards contained the peak energies of seven isotopes; the peak energies spanned the gamma energy range of interest. These were measured each working day prior to the start of any sample analyzes. The 49 QA analyses, each reporting the peak energies of seven isotopes are presented in Appendix C; Table 13. A mark in the QA results in the “Deviation/Flags” column of “In” means the measured value needs to be “investigated”, but the instrument is within specifications of the standard. A “Deviation/Flags” comment of “Ac” means the measured value is outside the acceptable range and “action” is required. The “action” flag indicates that the analyses results are unacceptable. From these 49 QA analyses, there were a total of 343 isotopes standards reported, of which five “investigate” flags and zero “action” flags were identified. Since the five “investigate” flags were not three back-to-back days on the same instrument, no action was required. Together, these QA results indicate that all measurement were within specifications.

3.0 RESULTS

3.1 K_d VALUES

The Ag, Ce Co Cs, Fe, Mn, Ni, Pu, Ru, Sr, and Zn K_d values for the 20 samples are presented in Table 2 and Table 3 (initial spike concentrations and the soil/rock weights and aqueous volumes used to calculate these K_d values are presented in Appendix D (Table 14, Table 15, Table 16, and Table 17); the radionuclides and Ag concentration data are presented in Appendix C (Table 7, Table 8, Table 9, and Table 10). These soil/rock samples generally had quite large K_d values, with several samples sorbing all the detectable solute (radionuclide or Ag), resulting in a greater-than K_d value. The rock cores consistently had very high K_d values for all solutes. Some of the lowest K_d values were measured with soil B-901/S5. It is interesting to note that this soil has the lowest pH level, pH 5.4 (measured by STL-St Louis). The standard deviation of the duplicate measurements varied greatly, in part due to the large number of greater-than K_d values (Table 6). The standard deviations of means with greater-than values, are themselves also greater-than values. Ce, Ru Pu, Sr and Zn had relatively lower standard deviations, whereas Fe and Mn had relatively higher standard deviations.

A ranking of elements by their median K_d values (in units of mL/g) in the soil samples, not including the core samples, is:

Sr	8
Ag	43.9
Cs	156.4
Pu	322.2
Ni	355.5
Ru	>1,192
Co	5,729
Zn	>5,986
Mn	6,334
Ce	>9,377
Fe	>16,204

This ranking is largely in alignment with the elemental oxidation states expected to exist in the test solutions:

- Monovalent : Ag, Cs, Pu (as PuO_2^+),
- Divalent: Ni, Co, Zn, Sr,
- Tri- or Divalent: Mn
- Trivalent: Fe, Ce, Ru

Pu is expected to exist in the aqueous phase as PuO_2^+, but once sorbed it would reduce to Pu^{4+}. The high Mn K_d value suggests that the Mn existed as Mn(III) (or possible Mn(IV)) instead of Mn(II). The large Mn K_d values for many of the solids suggests that precipitation onto the solids may have been the sorption mechanism.

A ranking of elements by their median K_d values (in units of mL/g) in the four core samples is:

Sr	46.6
Pu	396.9
Ni	>851.8
Ru	>1,068
Cs	3,718
Zn	>4,182
Mn	>8,002
Ce	>8,653
Co	>10,612
Ag	>12,760
Fe	>17,249

The rock K_d values were larger then those in the soil. They also had a different ranking, in part due to the large number of greater-than values in the rock samples, resulting in the analytical detection limit controlling the elements K_d ranking.

Table 2. K_d values of Ag, Ce, Co, Cs, and Fe (average and standard deviation of 2 values; units = mL/g).

	pH(a)	Ag K_d		Ce K_d		Co K_d		Cs K_d		Fe K_d	
		Ave	**Stdev**	**Ave**	**Stdev**	**Ave**	**Stdev**	**Ave**	**Stdev**	**Ave**	**Stdev**
B-949/CORE R3(b)		>31,091	28,153(c)	>10,422	1,184	>15,765	1,750	>19,504	11,048	>45,497	36,206
B-951/CORE R5		>12,729	182	>10,232	250	>18,778	3,499	6,863	361.9	>20,291	15,276
B-901/CORE R20		>12,792	158	>6,753	1854	2,364	3,303	387	101	>5,146	687
B-901/CORE R22		>9,903	3,846	>7,073	4974	5,459	4158	574	193.4	>14,207	11,659
B-901/S5	5.4	28.6	18.4	329.1	65.1	6.5	3.2	68.0	10.3	>13,456	15,958
B-901/S8	6.6	28.6	11.6	>9,572	2,839	>9,423	12,160	181.0	141.1	>5,646	778
B-904/S10	6.7	73.2	23.2	4,175	5,744	58.3	81.1	241	142	>12,489	11,549
B-913/S9	6.5	43.4	0.3	>10,149	50	13,082	3,827	796	17	>14,397	14,565
B-913/S10	7.0	6.0	6.6	>9,182	2,811	5,711	871	141	17	>6,505	1,402
B-917/S12	6.2	25.7	9.8	>8,831	2,266	5,747	2,472	154	2.3	>30,209	25,590
B-917/S14	6.6	32.6	10.8	>6,893	5	6,559	255	118.9	9.0	>16,121	10,862
B-917/S15	6.9	16.6	0.8	>5,419	1,487	3,991	1,894	64.9	7.4	>4,504	139
B-919/S8	6.7	232	61.9	>7,750	3,590	3,840	1,251	378	86	>40,524	35,130
B-920/S11	7.2	>482	1.4	>12,056	364	8,768	1,940	379	34	>19,392	15,120
B-928/S7	6.5	>304	246	>11,468	2,625	3,244	2,396	104	9	>6,104	1,107
B-929/S12	7.2	2.5	0.2	>8,887	573	5,331	1,630	104.9	7.5	>19,967	18,115
B931/S11	7.4	44.4	40.0	>10,519	2,765	5,151	35	67.5	3.0	>28,132	32,507
B932/S6	7.1	>12,665	194	10,449	220	6,739	307	159	26	>16,288	3,249
B951/S7	9.2	>12,716	63	>12,914	800	>20,653	938	3,406	502	>25,330	21,471
B-951/S9	8.3	>8,190	6,563	>13,194	3,301	8,818	3,184	336	35	>24,220	23,932

(a) pH was measured by STL-St Louis (now known as TestAmerica)

(b) XRF, XRD, and BET analyses indicate this core sample is mineralogical and chemically different from the other three core samples.

(c) Standard deviations of means with greater-than values are also greater-than values.

Table 3. K_d values of Mn, Ni, Ru, Pu, Sr and Zn (average and standard deviation of 2 values; units = mL/g).

	Mn K_d		**Ni K_d**		**Ru K_d**		**Pu K_d**		**Sr K_d**		**Zn K_d**	
	Ave.	**Stdev.**	**Ave.**	**Stdev.**	**Ave.**	**Stdev.**	**Ave.**	**Stdev.**	**Ave.**	**Stdev.**	**Ave.**	**Stdev.**
B-949/CORE R3(a)	>8,145	6,289(b)	>1,616	181	>1,148	62	8,680	5404	68.5	30.4	>5,110	118
B-951/CORE R5	>12,196	1,037	>892	13	>1,200	77	443	2	60.2	4.0	>4,217	336
B-901/CORE R20	>7,858	11,093	>615	238	>632	447	295	59	14.8	10.3	>2,411	3,048
B-901/CORE R22	5,499	6,170	>811	86	>988	240	351	64	33.0	13.5	>4,147	213
B-901/S5	4.5	1.9	40.6	17.6	>272	87	5.3	0.2	3.9	1.9	11.8	10.9
B-901/S8	>6,525	8,896	12.7	0.0	>1,448	927	34.3	8.2	166	138	>7,190	2,163
B-904/S10	36.9	50.9	342	429	>328	404	96.5	10.5	3.6	5.5	136	190
B-913/S9	12,492	11,882	129	161	>1,429	25	177	1	14.5	2.5	>5,901	75
B-913/S10	7,903	4,937	162	93	>1,080	273	735	378	8.4	0.4	>6,702	2,592
B-917/S12	8,046	6,970	643	49	>1,171	286	305	118	7.6	0.9	>5,511	1581
B-917/S14	>10,470	229	17.7	6.9	>936	45	209	56	6.6	0.3	>4,563	235
B-917/S15	4,692	4,024	53.3	0.0	>524	22	192	112	3.8	0.2	>2,764	182
B-919/S8	>4,121	2,128	387	150	>1,007	419	896	373	14.8	0.7	>3,426	882
B-920/S11	>15,785	475	>623	258	>1,593	62	311	70	25.5	4.4	>7,905	2,727
B-928/S7	3,801	3,593	>424	280	>1,212	58	528	77	7.6	1.7	>8,103	1,879
B-929/S12	3,453	433	45	39	>1,264	112	536	26	7.1	0.2	>6,270	1,004
B931/S11	3,988	1,252	>369	170	>1,149	2	333	142	4.7	0.1	>6,070	518
B932/S6	9,013	2,470	766	303	>1,367	24	2,488	315	11.2	2.5	>5,684	441
B951/S7	>21,374	3,137	>806	119	>1,665	104	3,874	432	26.8	7.0	>6,991	192
B-951/S9	6,143	3,500	>658	301	>1,472	105	3,603	669	12.7	1.3	>6,162	78

(a) XRF, XRD, and BET analyses indicate this core sample is mineralogical and chemically different from the other three core samples.

(b) Standard deviations of means with greater-than values are also greater-than values.

3.2 XRD, XRF, and BET Surface Area of the Rock Core Samples

The minerals identified by X-ray diffraction (XRD) are presented in Table 4 (the actual spectra generated from this measurements are presented in Appendix C; Table 11). All four samples contained quartz, albite, and a mica, either muscovite or biotite. Quartz and albite are generally thought of as minerals that sorb solutes weakly. Muscovite and biotite are considered minerals that sorb solutes more strongly.

Table 4. Minerals in the rock core samples identified by XRD analysis.

Sample	**Minerals**
B901/Core R20	Quartz, Albite, Microcline, Muscovite, Kaolinite
B901/Core R22	Quartz, Albite, Microcline, Muscovite
B949/Core R3	Quartz, Albite, Microcline, Muscovite, Gypsum
B951/Core R5	Quartz, Albite, Magnesiohornblend, Biotite

The BET surface area results for three of the samples were very similar; the fourth sample, B949/CORE R3, had a surface area three times greater than the other samples Table 5. Because all samples were ground and sieved identically (procedure described in Appendix A), the cause for this difference is not known. The higher surface area may be a result of the presence of gypsum, a mineral that is uniquely found in this sample. The greater surface area may also have been responsible for the relatively high Ag, Cs, Fe, Ni, and Pu K_d values measured with these samples (Table 2 and Table 3) as compared to the other core samples.

Table 5. BET surface area analysis of the rock core samples

Customer ID	Replicate 1 (m^2/g)	Replicate 2 (m^2/g)	Avg ± Stdev (m^2/g)	Standards (m^2/g)
Standard NIST 190 – 2.85 m^2/g				2.83
B901/CORE R20 Primary	6.25	5.52	5.89 ± 0.52	
B901/CORE R22 Primary	5.06	5.05	5.06 ± 0.01	
B949/CORE R3 Primary	16.25	16.13	16.19 ± 0.08	
B951/CORE R5 Primary	5.06	5.08	5.07 ± 0.01	
Standard NIST 190– 2.85 m^2/g				2.85

The X-ray fluorescence (XRF) data strongly suggests that the elemental composition of sample B949/CORE R3 was different from the other samples (Table 6) (sample and QA results provided in Appendix C; Table 12). It contained exceptionally high Fe_2O_3, MnO, CaO, TiO_2, and P_2O_5 concentrations, and exceptionally low SiO_2 and K_2O concentrations. High TiO_2 and Fe_2O_3 concentrations are often associated with minerals with a high capacity to sorb metals and radionuclides. As mentioned above, these chemical (or more specifically, mineralogical) differences may be responsible for the relatively high Ag, Cs, Fe, Ni, and Pu K_d values measured with this sample, as compared to the other three core samples. Furthermore, the chemical composition suggests the presence of amorphous phases containing these elements. XRD detects only crystalline minerals, not amorphous minerals. Thus, the core sample with the overall highest K_d values also had the highest surface area and a relatively unique elemental composition. It is not known whether the surface area or the elemental (mineralogical) composition of the core sample was responsible for the higher K_d values.

Table 6 . XRF elemental analysis of the rock core samples (wt%).

	SiO_2		Al_2O_3		Fe_2O_3		MnO		CaO		Na_2O		K_2O		TiO_2		P_2O_5		LOI (b)	
	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev	avg	stdev
B901/CORE R20	76.72	0.01	12.94	0.01	0.81	0.01	0.013	0.001	1.15	0.00	1.80	0.01	4.98	0.00	0.13	0.00	0.016	0.001	1.18	0.02
B901/CORE R22	76.43	0.05	12.51	0.05	1.05	0.00	0.032	0.000	1.35	0.01	1.54	0.03	5.62	0.01	0.13	0.00	0.020	0.000	1.02	0.00
B949/CORE R3	49.15	0.06	13.38	0.04	9.69	0.10	0.173	0.002	9.05	0.01	1.85	0.04	1.64	0.01	0.89	0.01	0.392	0.001	2.85	0.05
B951/CORE R5	74.71	0.01	13.06	0.01	1.64	0.00	0.026	0.000	1.66	0.00	3.17	0.01	4.07	0.01	0.19	0.00	0.055	0.000	0.91	0.04
Standard Value(a)	73.42		13.55		2.01		0.043		1.07		3.78		4.76		0.21		0.062		NA	
Check Std. (start) (a)	73.74		13.49		1.98		0.046		0.93		3.76		4.86		0.20		0.061		0.59	
Check Std. (end) (a)	73.78		13.48		1.96		0.045		0.93		3.77		4.86		0.20		0.060		0.59	

(a) Standard Value is the assigned value of standard; Check Std (start) was the measured value of the standard at the start of the sample measurements; Check Std (end) was the measured value of the standard at the end of the sample measurements.

(b) LOI = lost on ignition

4.0 REFERENCES

Kaplan, D. I. 2006. Geochemical Data Package for Performance Assessment Calculations Related to the Savannah River Site. WSRC-TR-2006-00004, Rev. 0. Washington Savannah River Company, Aiken, SC.

Krupka, K. M., D. I. Kaplan, G. Whelan, R. J. Serne, and S. V. Mattigod. 1999a. Understanding Variation in Partition Coefficient, K_d, Values. Volume 1: The Kd Model, Methods of Measurement, and Application of Chemical Reaction Codes. EPA 402-R-99-004A. Office of Air and Radiation, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, DC. (http://www.epa.gov/radiation/cleanup/partition.htm)

Krupka, K. M., D. I. Kaplan, G. Whelan, R. J. Serne, and S. V. Mattigod. 1999b. Understanding Variation in Partition Coefficient, K_d, Values. Volume II: Review of Geochemistry and Available K_d Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium and Uranium. EPA 402-R-99-004B. Office of Air and Radiation, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, DC. (http://www.epa.gov/radiation/cleanup/partition.htm)

Whittig, L. D., and W. L. Allardice. 1986. “X-ray Diffraction Techniques.” *In*. A. Klute (ed.) Methods of Soil Analysis. Part 1. 2nd Edition. Soils Science Society of America, Madison, WI.

APPENDIX A. Detailed Description of the Materials and Methods for K_d Testing

R&D Directions:
K_d Determinations of Dominion Nuclear North Anna Project Sediment Samples

Objective:

Measure Ag, Ce, Co, Cs, Fe, Mn, Ni, Ru, Pu, Sr, and Zn, K_d values of 16 soil and 4 rock samples collected from the Dominion Nuclear North Anna Project. The following K_d determination method is taken from "ASTM D 4646: Standard test method for 24-hr batch-type measurement of contaminant sorption by soils and sediments." There will be four sets of identical samples used in these measurements:

- the first set will receive Co-57, Cs-137, Sr-85, Zn-65, Ce-139, Mn-54, and Ru-106
- the second set will receive Fe-55 and Pu-238, and
- the third set will receive Ni-59, and
- the forth set will receive stable Ag.

Additionally, XRD, XRF, and BET will be conducted on the four ground rock samples.

Materials:

1. 16 soil & 4 rock samples from the Dominion Nuclear North Anna site (Table A1)
2. Dominion Nuclear North Anna site groundwater sample (5 bottles were sent, all of the same groundwater sample, so any one can be used; they are Kd 01, Kd 02, Kd 03, Kd 05, Kd 06)
3. radionuclide standards: Co-57, Cs-137, Sr-85, Zn-65, Ce-139, Mn-54, Ru-106, Fe-55 and Pu-238 and Ni-59 [1]
4. 10 ± 0.05 mg/L Ag standard (High Purity Standard, Lot #604002, Cat #ICP-MS-KIT-A, in 2% HNO_3, expires 2/10/08)
5. 15-mL centrifuge tubes
6. sandwich baggies
7. large weighing boats
8. 0.1-µm syringe filters
9. 0.1-M NaOH
10. pH meter
11. Number 270 sieve (2-mm) and a Number 400 (38-µm) sieve
12. thin section saw, Spex 8510 Shatter box (for crushing rock, Step #1 below)
13. 1000 mg/L Ag standard

---

[1] The isotopes listed here differ from the isotopes of concern to facilitate measurements and save time. The degree that elements sorb to soil, i.e., their K_d value, do not differ between isotopes of the same element. For example, the K_d value for Co-60 is the same as Co-57.

Methods for Co-57, Cs-137, Sr-85, Zn-65, Ce-139, Mn-54, and Ru-106 K_d Determinations

1. **Preparing crush rock samples**: The rock (101a-A & -B, 102a-A & -B, 103a-A & -B and 104a-A & -B) will come in two-inch (5-cm) diameter cores and will need to be crushed into fine powder.
    a. Using a thin section saw, cut a piece down the middle of the rock core that weighs >20 g.
    b. Place approximately 20 g in Spex 8510 Shatter box for 5 minutes, grind, and pass through #400 (38-µm) sieves. Save the <38 µm fraction.
2. **Drying soil.** Mix the 16 field-moist soils in the jars they were received in (Samples #105a through 120a). Transfer a ~20 g aliquot to labeled aluminum weighing boats and place on counter top and permit to dry for 1 week. Pass dry soil through a 2-mm (No. 270) sieve.
3. Record "Tube Tare (g)" weight (without cap) of labeled 15-mL centrifuge tube as identified in Table A1.
4. Add 0.5±0.01-g of sieved soil or rock to each tube. Weigh and record "Soils (g)"
5. **Equilibrating soils to the groundwater.** Add 12-mL of groundwater to each tube. Put on shaker for overnight. Let sit for 1 hr. Decant liquid. If solids do not separate from the liquid, centrifuge at 15 min 6000 rpm. Then decant liquid. Throw away liquid. Error on the side of leaving liquid in tube rather than accidentally losing clays down the drain. Add 10 mL of appropriate groundwater to each tube. Also add 10-mL groundwater to the five Controls (sample # 121a-A, 121a-B, 121a-C, 122a-A, and 122a-B). Record weight of each tube in "Tube + soils + Equil + GW (g)".
6. **Adding radionuclides to suspension.** Move rack of tubes to rad hood. Add 170-µL of Co-57, Cs-137, Sr-85, Zn-65, Ce-139, Mn-54, and Ru-106 spike solution to each tube. Also add this to the No-soil Controls, (sample # 121a-A, 121a-B, 121a-C), but **not** to Blank Controls (122a-A, and 122a-B). Gently shake or swirl tube sediment and solution in each tube.
7. **pH adjust suspension.** Because the spike solution is in a ~0.1 M HCl solution, you will need to add base to bring the suspensions back to their native pH. Using 0.1 M NaOH and litmus paper, add base to bring pH back to native sediment pH (1:1) noted in Table A1. Record "Final pH" you adjusted tube to.
8. **Equilibrating radionuclides with soil suspension.** Leave samples in rad hood for minimum of 2 days. During this equilibration period, shake rack of tubes twice a day for 10 seconds.
9. Collect liquids by drawing liquids into a syringe and then passing liquid through a 0.1-µm filter.
10. **Gamma Analysis.** Submit to Analytical Development Section for high energy gamma spec analysis. Note in your order, Travel Copy, that this is an expedited order, and the rads of interest are Co-57, Cs-137, Sr-85, Zn-65, Ce-139, Mn-54, and Ru-106.

Methods for Ni K_d Determinations

This method is identical to that of above except:

- Samples will be labeled in the "100b series" (instead of the "100a series") as described in **Table A2**.
- In **step 6,** add 170 µL of the **Ni-59** spike solutions to each tube.
- In **step 11**, request expedited low energy gamma analysis of **Ni-59.**

Methods for Fe and Pu K_d Determinations

This method is identical to that of above except:

- Samples will be labeled in the "100c series" (instead of the "100a or 100b series") as described in **Table A3**.
- In **step 4** above, add **0.25±0.01**-g of sieved soil or rock to each tube. Weigh and record "Soils (g)"
- In **step 5** above:
  Equilibrating soils to the groundwater. Add 12-mL of groundwater to each tube. Put on shaker for overnight. Let sit for 1 hr. Decant liquid. If solids do not separate from the liquid, centrifuge at 15 min 6000 rpm. Then decant liquid. Throw away liquid. Error on the side of leaving liquid in tube rather than accidentally losing clays down the drain. Add **5 mL** of groundwater to each tube. Also add **5-mL** groundwater to the five Controls (sample # 121c-A, 121c-B, 121c-C, 122c-A, and 122c-B). Record weight of each tube in "Tube + soils + Equil + GW (g)".
- In **step 7,** spike with 170 µL of the **Fe-55 & Pu-238** spike solutions.
- In **step 11**, request expedited gamma analysis of **Fe-55 & Pu-238**.

Methods for Ag K_d Determinations

This method is identical to that of above method except:

- Samples will be labeled in the "100d series (instead of the "100a, 100b, or 100c series," as described in **Table A4**.
  In **step 4** above, add **0.5 ±0.01**-g of sieved soil or rock to each tube. Weigh and record "Soils (g)"
- In **step 7,** do not move samples into the rad hood. Spike with 170 µL of stable-Ag spike solutions.
- In **step 11**, request expedited ICP-MS for Ag.

Safety, Hazards Assessment Package:

SRNL-EST-2006-00-93.

Hazards:

Radionuclides, ~3 mL of strong acids, ~3 mL of strong base

Hazards Mitigation:

Radionuclides: Follow training of Rad Worker II,
Strong Acid: wear appropriate gloves and as always protective eye ware
Strong Base: wear appropriate gloves and as always protective eye ware

Table A1. Data Sheet Used to Enter Weight and Volume Data for the Co-57, Cs-137, Sr-85, Zn-65, Ce-139, Mn-54, and Ru-106 K_d Determinations.

Tube #	Boring/Sample #	Rep	Soil pH	Tube Tare (g)	Soil (g)	Tube + Soil + Equil + GW (g)	Vol added during pH adjustment (mL)
Method Step				**(3)**	**(4)**	**(5)**	**(8)**
101a-A	B-949/CORE R3	1	8.3	5.43028	0.50989	17.0894	0.3
101a-B		2		5.39566	0.5014	16.377	0.3
102a-A	B-951/CORE R5	1	8.4	5.38184	0.50263	18.0002	0.33
102a-B		2		5.41026	0.5047	16.5294	0.33
103a-A	B-901/CORE R20	1	7.2	5.38558	0.50991	15.802	0.29
103a-B		2		5.40899	0.49812	16.3512	0.29
104a-A	B-901/CORE R22	1	7.7	5.40529	0.50265	16.1532	0.3
104a-B		2		5.37297	0.5071	16.1646	0.3
105a-A	B-901/S5	1	5.4	5.40943	0.49817	16.2936	0.28
105a-B		2		5.41791	0.49516	16.3282	0.28
106a-A	B-901/S8	1	6.6	5.41849	0.49193	16.1939	0.29
106a-B		2		5.368	0.49536	16.1442	0.29
107a-A	B-904/S10	1	6.7	5.41568	0.49382	16.0948	0.29
107a-B		2		5.43015	0.50128	16.2733	0.29
108a-A	B-913/S9	1	6.5	5.40839	0.49188	16.1395	0.3
108a-B		2		5.40851	0.4963	16.3543	0.3
109a-A	B-913/S10	1	7.0	5.39522	0.50303	16.2982	0.3
109a-B		2		5.40612	0.49325	16.1134	0.3
110a-A	B-917/S12	1	6.2	5.37662	0.49446	16.2294	0.28
110a-B		2		5.42965	0.49493	16.1174	0.28
111a-A	B-917/S14	1	6.6	5.37694	0.50301	16.0942	0.3
111a-B		2		5.38318	0.4946	16.1086	0.3
112a-A	B-917/S15	1	6.9	5.40968	0.50424	16.0007	0.3
112a-B		2		5.38165	0.49181	16.116	0.3
113a-A	B-919/S8	1	6.7	5.40867	0.50893	17.099	0.3
113a-B		2		5.38185	0.50661	16.2474	0.3
114a-A	B-920/S11	1	7.2	5.41309	0.50006	16.2525	0.3
114a-B		2		5.40958	0.50339	16.0802	0.3
115a-A	B-928/S7	1	6.5	5.41884	0.49319	16.0492	0.3
115a-B		2		5.3819	0.50126	16.1665	0.3
116a-A	B-929/S12	1	7.2	5.40929	0.49883	16.126	0.3
116a-B		2		5.3856	0.50865	15.9088	0.3
117a-A	B931/S11	1	7.4	5.40455	0.50927	16.0596	0.3
117a-B		2		5.39505	0.49581	15.9808	0.3
118a-A	B932/S6	1	7.1	5.38597	0.4973	16.0467	0.3
118a-B		2		5.41086	0.49746	16.4112	0.3
119a-A	B951/S7	1	9.2	5.39573	0.49742	16.1626	0.31
119a-B		2		5.39576	0.49693	16.1829	0.31
120a-A	B-951/S9	1	8.3	5.38572	0.50179	16.1713	0.3
120a-B		2		5.42987	0.50228	16.1802	0.3
121a-A	Spike control	1		5.55851	0	15.0591	0
121a-B		2		5.41207	0	14.756	0
121a-C		3		5.42833	0	14.9352	0
122a-A	Blank control	1		5.41794	0	14.9018	0
122a-B		2		5.37732	0	14.9052	0

Table A2. Data Sheet Used to Enter Weight and Volume Data for the Ni K_d Determinations.

Tube #	Boring/Sample #	Rep	Soil pH	Tube Tare (g)	Soil (g)	Tube + Soil + Equil + GW (g)	Vol added during pH adjustment (mL)
Method Step			**(6)**	**(3)**	**(4)**	**(5)**	**(8)**
101b-A	B-949/CORE R3	1	8.3	5.40688	0.49332	16.5539	0.12
101b-B		2		5.3801	0.5007	16.2104	0.12
102b-A	B-951/CORE R5	1	8.4	5.37546	0.49342	17.2142	0.1
102b-B		2		5.58875	0.49495	16.8113	0.1
103b-A	B-901/CORE R20	1	7.2	5.3729	0.5012	17.059	0.08
103b-B		2		5.38262	0.50404	16.5134	0.08
104b-A	B-901/CORE R22	1	7.7	5.38208	0.50131	16.5701	0.09
104b-B		2		5.51739	0.49143	16.7823	0.09
105b-A	B-901/S5	1	5.4	5.43015	0.49071	16.1787	0.06
105b-B		2		5.53878	0.49352	16.9574	0.06
106b-A	B-901/S8	1	6.6	5.38286	0.49264	16.4877	0.08
106b-B		2		5.57598	0.49168	16.2208	0.08
107b-A	B-904/S10	1	6.7	5.39107	0.5052	16.2096	0.08
107b-B		2		5.5919	0.4956	16.2637	0.08
108b-A	B-913/S9	1	6.5	5.38207	0.50772	15.593	0.08
108b-B		2		5.42975	0.49578	15.5878	0.08
109b-A	B-913/S10	1	7.0	5.41734	0.50748	16.1084	0.08
109b-B		2		5.41114	0.49326	16.0748	0.08
110b-A	B-917/S12	1	6.2	5.39033	0.50349	16.9613	0.08
110b-B		2		5.4049	0.50642	16.2709	0.08
111b-A	B-917/S14	1	6.6	5.38286	0.49578	16.0812	0.08
111b-B		2		5.6206	0.50864	16.2128	0.08
112b-A	B-917/S15	1	6.9	5.38253	0.50599	15.918	0.08
112b-B		2		5.41319	0.49442	16.0021	0.08
113b-A	B-919/S8	1	6.7	5.40849	0.50911	16.0099	0.08
113b-B		2		5.41583	0.50075	16.4144	0.08
114b-A	B-920/S11	1	7.2	5.40399	0.49225	17.4714	0.08
114b-B		2		5.41274	0.49377	16.0707	0.08
115b-A	B-928/S7	1	6.5	5.43049	0.50992	16.1188	0.08
115b-B		2		5.6265	0.50942	16.7234	0.08
116b-A	B-929/S12	1	7.2	5.56337	0.50463	16.4475	0.08
116b-B		2		5.37931	0.50905	16.2765	0.08
117b-A	B931/S11	1	7.4	5.38145	0.49728	16.1864	0.08
117b-B		2		5.37923	0.49442	16.1241	0.08
118b-A	B932/S6	1	7.1	5.41566	0.4908	16.4791	0.08
118b-B		2		5.43022	0.50185	16.5479	0.08
119b-A	B951/S7	1	9.2	5.51722	0.49177	16.0445	0.1
119b-B		2		5.3957	0.50692	16.3451	0.1
120b-A	B-951/S9	1	8.3	5.43078	0.50018	16.122	0.085
120b-B		2		5.43094	0.50935	16.6519	0.085
121b-A	Spike control	1		5.4165	0	14.8029	0
121b-B		2		5.4093	0	14.9553	0
121b-C		3		5.38095	0	14.8821	0
122b-A	Blank control	1		5.40827	0	14.9229	0
122b-B		2		5.44071	0	15.1881	0

Table A3. Data Sheet Used to Enter Weight and Volume Data for the Fe and Pu K_d Determinations.

Tube #	Boring/Sample #	Rep	Soil pH	Tube Tare (g)	Soil (g)	Tube + Soil + Equil + GW (g)	Vol added during pH adjustment (mL)
Method Step			**(6)**	**(3)**	**(4)**	**(5)**	**(8)**
101c-A	B-949/CORE R3	1	8.3	5.38303	0.24634	15.9604	0.11
101c-B		2		5.39534	0.24298	16.7113	0.11
102c-A	B-951/CORE R5	1	8.4	5.37292	0.25556	16.0265	0.1
102c-B		2		5.41096	0.25345	16.1644	0.1
103c-A	B-901/CORE R20	1	7.2	5.41376	0.25061	16.1582	0.09
103c-B		2		5.41043	0.25762	16.2307	0.09
104c-A	B-901/CORE R22	1	7.7	5.37184	0.25903	16.7511	0.1
104c-B		2		5.40982	0.24255	15.808	0.1
105c-A	B-901/S5	1	5.4	5.43063	0.25751	16.7074	0.07
105c-B		2		5.50339	0.24989	15.8287	0.07
106c-A	B-901/S8	1	6.6	5.37681	0.24675	16.0003	0.07
106c-B		2		5.39014	0.25845	16.2377	0.07
107c-A	B-904/S10	1	6.7	5.40885	0.25963	15.9596	0.07
107c-B		2		5.41116	0.2452	16.011	0.07
108c-A	B-913/S9	1	6.5	5.36762	0.24168	15.5888	0.07
108c-B		2		5.38135	0.24593	15.533	0.07
109c-A	B-913/S10	1	7.0	5.41235	0.25876	16.0148	0.07
109c-B		2		5.39031	0.24362	16.0487	0.07
110c-A	B-917/S12	1	6.2	5.37929	0.25278	16.1693	0.07
110c-B		2		5.41102	0.24532	16.2097	0.07
111c-A	B-917/S14	1	6.6	5.54919	0.24778	16.1459	0.07
111c-B		2		5.41669	0.24436	16.0587	0.07
112c-A	B-917/S15	1	6.9	5.51663	0.24159	16.3025	0.07
112c-B		2		5.39504	0.25664	16.0599	0.07
113c-A	B-919/S8	1	6.7	5.3762	0.24607	16.3741	0.07
113c-B		2		5.36839	0.24946	16.3151	0.07
114c-A	B-920/S11	1	7.2	5.40877	0.24952	16.2529	0.07
114c-B		2		5.40435	0.24252	16.3352	0.07
115c-A	B-928/S7	1	6.5	5.38086	0.25128	16.3028	0.07
115c-B		2		5.5682	0.25989	16.277	0.07
116c-A	B-929/S12	1	7.2	5.38492	0.25349	15.9221	0.07
116c-B		2		5.37616	0.25993	16.0212	0.07
117c-A	B931/S11	1	7.4	5.5882	0.24101	15.8417	0.07
117c-B		2		5.43076	0.24875	15.922	0.07
118c-A	B932/S6	1	7.1	5.36899	0.24467	15.8333	0.07
118c-B		2		5.41665	0.24057	16.2011	0.07
119c-A	B951/S7	1	9.2	5.38223	0.25995	16.0049	0.1
119c-B		2		5.43055	0.2468	16.312	0.1
120c-A	B-951/S9	1	8.3	5.39133	0.25994	15.9727	0.08
120c-B		2		5.41118	0.2599	16.0222	0.08
121c-A	Spike control	1		5.38379	0	14.9109	0
121c-B		2		5.55597	0	15.0566	0
121c-C		3		5.39101	0	14.8923	0
122c-A	Blank control	1		5.4057	0	14.9142	0
122c-B		2		5.43663	0	14.9477	0

Table A4. Data-Sheet Used to Enter Weight and Volume Data for Ag K_d Determinations.

Tube #	Boring/Sample #	Rep	Soil pH	Tube Tare (g)	Soil (g)	Tube + Soil + Equil + GW (g)	Vol added during pH adjustment (mL)
Method Step			**(6)**	**(3)**	**(4)**	**(5)**	**(8)**
101d-A	B-949/CORE R3	1	8.3	5.38249	0.50082	17.3568	0.24
101d-B		2		5.39037	0.5701	17.8265	0.24
102d-A	B-951/CORE R5	1	8.4	5.3684	0.4959	17.7347	0.26
102d-B		2		5.53958	0.50603	17.7201	0.26
103d-A	B-901/CORE R20	1	7.2	5.55361	0.49414	17.7427	0.25
103d-B		2		5.55722	0.50288	17.5772	0.25
104d-A	B-901/CORE R22	1	7.7	5.53733	0.50518	17.0505	0.25
104d-B		2		5.40539	0.50369	17.0793	0.25
105d-A	B-901/S5	1	5.4	5.53777	0.49525	17.0088	0.23
105d-B		2		5.56891	0.50418	16.7044	0.23
106d-A	B-901/S8	1	6.6	5.5543	0.5045	16.853	0.235
106d-B		2		5.39408	0.50473	16.6033	0.235
107d-A	B-904/S10	1	6.7	5.55619	0.50313	16.7154	0.23
107d-B		2		5.51755	0.49699	16.5424	0.23
108d-A	B-913/S9	1	6.5	5.38246	0.5084	16.1798	0.24
108d-B		2		5.37618	0.49582	16.0847	0.24
109d-A	B-913/S10	1	7.0	5.62294	0.49187	16.6045	0.24
109d-B		2		5.55298	0.49544	16.4559	0.24
110d-A	B-917/S12	1	6.2	5.38536	0.49702	16.4012	0.24
110d-B		2		5.5296	0.50463	16.4432	0.24
111d-A	B-917/S14	1	6.6	5.38179	0.50135	16.4195	0.24
111d-B		2		5.53844	0.50998	16.5078	0.24
112d-A	B-917/S15	1	6.9	5.55392	0.50183	16.5525	0.24
112d-B		2		5.40594	0.49443	16.3099	0.24
113d-A	B-919/S8	1	6.7	5.57378	0.50966	16.6214	0.24
113d-B		2		5.56551	0.50343	16.5715	0.24
114d-A	B-920/S11	1	7.2	5.55541	0.49585	16.4892	0.24
114d-B		2		5.60005	0.49772	16.6324	0.24
115d-A	B-928/S7	1	6.5	5.51409	0.49457	16.6325	0.24
115d-B		2		5.41267	0.50102	16.5289	0.24
116d-A	B-929/S12	1	7.2	5.55514	0.49945	16.4979	0.24
116d-B		2		5.56769	0.50907	16.7314	0.24
117d-A	B931/S11	1	7.4	5.41076	0.50793	16.4234	0.24
117d-B		2		5.36767	0.50885	16.2443	0.24
118d-A	B932/S6	1	7.1	5.39019	0.50906	16.5095	0.24
118d-B		2		5.56572	0.49815	16.6296	0.24
119d-A	B951/S7	1	9.2	5.52766	0.50328	16.5656	0.25
119d-B		2		5.36732	0.49976	16.5182	0.25
120d-A	B-951/S9	1	8.3	5.55837	0.49703	16.6569	0.25
120d-B		2		5.41608	0.50889	16.5102	0.25
121d-A	Spike control	1		5.56965	na	15.4354	na
121d-B		2		5.38139	na	15.2841	na
121d-C		3		5.45048	na	15.3369	na
122d-A	Blank control	1		5.40807	na	15.3193	na
122d-B		2		5.39399	na	15.3002	na

APPENDIX B. RADIOISOTOPE CERTIFICATION

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75273-147

Co-57 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Co-57
ACTIVITY (Bq):	1.886 E6
HALF-LIFE:	271.79 days
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	1.7%

Impurities: γ-impurities <0.1%

5.02210 grams 0.1M HCl solution with 30 μg/g Co carrier.

P O NUMBER AC60107G, Item 2

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75276-147

Sr-85 10 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Sr-85
ACTIVITY (Bq):	1.842 E6
HALF-LIFE:	64.84 days
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	1.7%

Impurities: γ-impurities <0.1%

10.04818 grams 0.1M HCl solution with 30 μg/g Sr carrier.

P O NUMBER AC60107G, Item 1

SOURCE PREPARED BY: ____________________
M. I. Taskaeva, Radiochemist

Q A APPROVED: ____________________ 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75278-147

Cs-137 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Cs-137
ACTIVITY (Bq):	1.922 E6
HALF-LIFE:	3.007 E1 years
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	1.7%

Impurities: γ-impurities <0.1%

5.01021 grams 0.1M HCl solution with 30 μg/g Cs carrier.

P O NUMBER: AC60107G, Item 7

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75282-147

Pu-238 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated by liquid scintillation counting and alpha spectroscopy. The calibration was checked by liquid scintillation counting after source preparation.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Pu-238
ACTIVITY (Bq):	3.940 E4
HALF-LIFE:	87.7 years
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	2.0%

Impurities: γ-impurities <0.1%, α-impurities ~0.2%

5.47038 grams 3M HNO_3 solution.

P O NUMBER AC60107G, Item 11

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75281-147

Ni-59 10 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master liquid radionuclide solution source. The master source was calibrated by liquid scintillation counting.

Radionuclide purity and calibration were checked by germanium gamma-ray spectrometry and liquid scintillation counting. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Ni-59
ACTIVITY (Bq):	3.841 E3
HALF-LIFE:	7.600 E4 years
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	4.5%

Impurities: γ-impurities <0.1%

9.99750 grams 0.1M HCl solution with 30 μg/g Ni carrier.

P O NUMBER AC60107G, Item 10

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75280-147

Fe-55 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master liquid radionuclide solution source. The master source was calibrated by liquid scintillation counting.

Radionuclide purity and calibration were checked by germanium gamma-ray spectrometry and liquid scintillation counting. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Fe-55
ACTIVITY (Bq):	1.987 E5
HALF-LIFE:	1001.0 days
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	4.5%

Impurities: γ-impurities <0.1%

5.12918 grams 0.1M HCl solution with 30 μg/g Fe carrier.

P O NUMBER AC60107G, Item 9

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75272-147

Mn-54 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Mn-54
ACTIVITY (Bq):	1.866 E6
HALF-LIFE:	312.1 days
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	1.7%

Impurities: γ-impurities <0.1%

5.01962 grams 0.1M HCl solution with 30 µg/g Mn carrier.

P O NUMBER AC60107G, Item 1

SOURCE PREPARED BY: MTaskaeva
M. I.Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75277A-147

Ru-106 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with a germanium gamma spectrometer system.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Ru-106
ACTIVITY (Bq):	1.844 E5
HALF-LIFE:	373.59 days
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIIVE EXPANDED UNCERTAINTY (k=2):	3.3

Impurities: γ-impurities <0.1%

5.53767 grams 6M HCl solution.

P O NUMBER AC60107G, Item 6

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75279-147

Ce-139 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE: Ce-139
ACTIVITY (Bq): 1.878 E6
HALF-LIFE: 137.6 days
CALIBRATION DATE: June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2): 2.0%

Impurities: γ-impurities <0.1%

5.03469 grams 0.1M HCl solution with 30 μg/g Ce carrier.

P O NUMBER AC60107G, Item 8

SOURCE PREPARED BY: MTaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —

Eckert & Ziegler
Analytics

1380 Seaboard Industrial Blvd.
Atlanta, Georgia 30318
Tel 404•352•8677
Fax 404•352•2837
www.analyticsinc.com

CERTIFICATE OF CALIBRATION

Standard Radionuclide Source

75275A-147

Zn-65 5 mL Liquid in Flame Sealed Vial

This standard radionuclide source was prepared gravimetrically from a calibrated master solution. The master solution was calibrated with an ionization chamber that was calibrated by the National Physical Laboratory, Teddington, U.K., and is directly traceable to national standards.

Radionuclide purity and calibration were checked with a germanium gamma spectrometer system. The nuclear decay rate and assay date for this source are given below.

ANALYTICS maintains traceability to the National Institute of Standards and Technology through Measurements Assurance Programs as described in USNRC Reg. Guide 4.15, Revision 1.

ISOTOPE:	Zn-65
ACTIVITY (Bq):	1.854 E6
HALF-LIFE:	244.3 days
CALIBRATION DATE:	June 14, 2007 12:00 EST
RELATIVE EXPANDED UNCERTAINTY (k=2):	1.7%

Impurities: Co-60 1.189 E3 Bq
other γ-impurities <0.1%

5.01784 grams 0.1M HCl solution with 30 μg/g Zn carrier.

P O NUMBER AC60107G, Item 4

SOURCE PREPARED BY: MITaskaeva
M. I. Taskaeva, Radiochemist

Q A APPROVED: 6-14-07

ANA Form005 Rev. —