1

DR-0171-6

I-15510

ORNL--6061

DE84 013765

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Geochemical Information for the West Chestnut Ridge Central Waste Disposal Facility for Low-Level Radioactive Waste

F. G. Seeley
A. D. Kelmers

MASTER

OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-6061
Dist. Category UC-70B

Chemical Technology Division

GEOCHEMICAL INFORMATION FOR THE WEST CHESTNUT RIDGE CENTRAL WASTE DISPOSAL FACILITY FOR LOW-LEVEL RADIOACTIVE WASTE

F. G. Seeley
A. D. Kelmers

Date of Issue: June 1984

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

CONTENTS

CONTENTS

(continued)

CONTENTS

(continued)

LIST OF FIGURES

LIST OF FIGURES

(continued)

LIST OF FIGURES

(continued)

LIST OF FIGURES

(continued)

LIST OF TABLES

LIST OF TABLES

(continued)

GEOCHEMICAL INFORMATION FOR THE WEST CHESTNUT RIDGE CENTRAL WASTE DISPOSAL FACILITY FOR LOW-LEVEL RADIOACTIVE WASTE

F. G. Seeley
A. D. Kelmers

ABSTRACT

Geochemical support activities for the Central Waste Disposal Facility (CWDF) project included characterization of site materials, as well as measurement of radionuclide sorption and desorption isotherms and apparent concentration limit values under site-relevant laboratory test conditions. The radionuclide sorption and solubility information is needed as input data for the pathways analysis calculations to model expected radioactivity releases from emplaced waste to the accessible environment under various release scenarios.

Soil samples from the West Chestnut Ridge candidate facility site were physically and chemically characterized. The site soil (residue from the weathering of a dolomite ridge) was found to be a uniform, well-leached material containing quartz, illite, minor amounts of kaolinite, and no residual dolomite. Soil samples had a moisture content of ~13 to 27%, a maximum surface area of ~46 m^2/g, and a fairly uniform particle size distribution (60% <6 μm). Groundwater and surface waters from the site were chemically analyzed and found to be dilute sodium chloride/bicarbonate solutions. The very low concentrations of dissolved constituents present in these groundwaters, in combination with the well-leached soil characteristics, provided highly unbuffered soil-groundwater test systems.

Batch contact methodology was used to construct sorption and desorption isotherms for a number of radionuclides likely to be present in waste to be disposed of at the site. The sorption rates for uranium and europium were rapid (>99.8% of the total radionuclide present was adsorbed in ~30 min). Sorption isotherms were determined under two test conditions. An "ambient-pH" technique was employed for uranium, strontium, cesium, cobalt, europium, thorium, technetium, and iodine. At initial radionuclide concentrations of 5 mg/L, favorably high sorption ratio (Rs) values of 1,600 to 11,000 L/kg were obtained for strontium, cesium, and cobalt, indicating that good retention could be expected at the site. Very high Rs values of 11,000 to 61,000 L/kg were obtained for uranium, europium, and thorium; values of less than 2 L/kg were obtained for technetium and iodine.

Since technetium and iodine would be present as anions in the groundwater, they would not be expected to be significantly adsorbed. No hysteresis due to sorption-desorption disequilibrium was observed for uranium, indicating that steady-state conditions were attained in these tests.

With a "constant-pH" isotherm technique, uranium, strontium, cesium, and curium exhibited maximum Rs values of 4800 to >30,000 L/kg throughout the pH range 5 to 7. Sorption ratios were generally lower at higher or lower pH levels. Uranium exhibited no apparent solution concentration limit except when the initial concentration and/or the contact time was increased. This behavior could result from the formation of colloidal suspensions of hydrated uranium oxide, solution supersaturation, or the formation of soluble complexes. The apparent concentration limit achieved with strontium (~68,000 mg/L) may also indicate some colloidal formation since the apparent solution concentration limit observed is significantly above that expected. The apparent concentration limit shown by cesium (~50,000 mg/L) is unexplained since that value is considerably lower than would be expected for a saturated solution of $CsNO_3$.

Retardation factors for uranium, strontium, and cesium, explored by column chromatographic tests, were consistent with the high sorption ratios measured in batch tests for these radionuclides. The column tests showed a low retardation factor for iodine, in agreement with the sorption ratio of <2 L/kg. An initial breakthrough of a small amount of strontium and cesium activity indicated a minor, but significant, transport of these radionuclides with the groundwater, possibly as colloids. Most of the activity of these two radionuclides was found in the upper 1 cm of the column.

The addition of as little as 0.01 M organic reagent capable of forming strong soluble complexes with metals [e.g., ethylenediaminetetraacetic acid (EDTA) or citric acid] was found to reduce the sorption ratio for uranium by as much as two orders of magnitude. Substitution of an actual low-level waste site trench water for groundwater in these tests was found to give a similar reduction in the sorption ratio.

1. EXECUTIVE SUMMARY

The Central Waste Disposal Facility (CWDF) project is responsible for developing a new low-level radioactive waste disposal facility which may accept waste from each of the three plants (X-10, Y-12, and K-25) in the Oak Ridge area. The candidate site location is in Chestnut Ridge (1050 ft above sea level), which is centrally located between the plants and rises 100 to 200 ft above the valleys on either side. The ridge is covered with 60 to 80 ft of soil that has developed as a result of weathering of the underlying dolomite. The disposal facility may consist of suitable trenches or pits in this soil which may be lined and/or covered to reduce groundwater and rain ingress into emplaced waste. Quantified information describing the radionuclide behavior in the soil/groundwater system is a prerequisite to modeling the migration of radioactivity which could occur after waste emplacement in certain groundwater-intrusion—groundwater-migration events. Both the limiting solubility condition and the sorption process onto soil constituents may be significant radioactivity migration barriers in geologic systems. Preparation of the pathways analysis for the Environmental Impact Statement required values for both radionuclide solubilities and sorption behavior. The objective of this geochemical support effort was to supply the needed radionuclide behavior information, as well as to characterize the site soil and groundwater geochemically. Because of time constraints established by the CWDF schedule, accelerated test procedures were employed in some cases; time did not permit exploration of anomalous or ambiguous results. The present report summarizes all the geochemical information developed by this support activity for the candidate site at West Chestnut Ridge.

Initially, the CWDF project considered two candidate sites, one in the central portion and one in the western portion of Chestnut Ridge. These sites were essentially indistinguishable in terms of geochemical properties or radionuclide sorption and solubility behavior in the initial geochemical investigations. After a decision was made to select the West Chestnut Ridge location as the candidate site, no additional geochemical work was done with Central Chestnut Ridge material. Primarily, only West Chestnut Ridge site information is presented here; in a few cases, however, Central site data have been used to help explain or develop information needed for the West site.

1.1 SOIL CHARACTERIZATION

All soil samples were very similar. They were composed primarily of <10-μm-sized particles. The principal minerals detected were quartz and illite. Essentially no residual dolomite was present; thus, the soils displayed very little ability to buffer the acidity (pH) of soil/groundwater systems in subsequent tests with radionuclides.

Nine soil samples from two boreholes at the West Chestnut Ridge candidate site (hereafter identified as the site), covering soil depths from 10 to 60 ft, were received in sealed Shelby tubes. The samples were similar in appearance (red-brown clayey material) when removed from the Shelby tubes, and subsequent physical and chemical characterization showed no significant difference in soil properties with borehole location or sample depth. Quartz and illite were the principal crystalline minerals identified; minor amounts of kaolinite were also present. Particle-size analysis confirmed that fine-sized particles predominated and that the soils were typical of silt- and/or clay-size materials. Chemical analyses of the samples showed major elements typically expected for clays (aluminum, iron, potassium, and silicon) and, surprisingly, very little residual carbonate from the dolomite. These soils have apparently been extensively weathered. The absence of minerals such as dolomite which could be capable of buffering the acidity (pH) of groundwater in contact with the soil has important implications for radionuclide migration experiments; these are subsequently discussed. The core samples were analyzed for uranium and radium to establish baseline or pre-waste emplacement values. The uranium and ^{226}Ra concentrations were 5.5 ± 2.5 µg/g and 3.4 ± 1.3 pCi/g, respectively. These concentrations are typical of those found for many rocks or soils; all materials on the earth contain some natural uranium and uranium decay products.

1.2 GROUNDWATER CHARACTERIZATION

Actual or synthetic groundwater samples were very dilute sodium chloride/bicarbonate solutions at pH 5.7 to 6.0.

Since no groundwater was encountered in the two boreholes at the site, information was obtained for two groundwater samples from a perched water table at a 50-ft depth in the Central Chestnut Ridge location. Synthetic groundwater was also prepared by contacting distilled water and soil from the site for most of the radionuclide sorption and solubility tests; it was very similar in composition to the actual groundwater. The pH of the groundwater was about 5.7 to 6.0. Stable pH values were difficult to obtain; the groundwater is relatively unbuffered and, therefore, its pH was easily perturbed by test conditions.

Chemical analyses of both actual groundwater and synthetic groundwater showed extremely low concentrations of sodium and calcium cations and chloride and bicarbonate anions. Silicon, probably present as dissolved silicates and/or colloidal silica, was also detected. Most other elements were at, or below, analytical detection limits. Analyses of samples of surface water from the site and water from a nearby embayment of the Clinch River revealed a composition similar to that of the groundwater except that the pH was closer to neutral and low concentrations of nitrate, sulfate, and phosphate were also detected. All the waters associated with the site appear to be primarily very dilute sodium chloride/bicarbonate solutions.

1.3 RADIONUCLIDE TEST METHODOLOGY

Two variations of the conventional batch contact methodology were used to measure radionuclide sorption isotherms and apparent concentration limit values in site soil/synthetic groundwater systems. Two different experimental approaches were utilized because of the unbuffered nature of these systems, which allowed significant changes *in the pH to occur during the test. A few desorption tests were run to explore sorption-desorption disequilibrium. Two column chromatographic runs were made to obtain a preliminary evaluation of radionuclide multiple speciation effects on sorption ratios and to test for radionuclide transport as colloids.*

Batch contact methodology was used to measure sorption ratios and to construct sorption isotherms for nine radionuclides in site soil/synthetic groundwater systems. These radionuclides were selected because they are likely to be present in waste to be disposed of at the site and to represent a variety of actinide and fission product elements. Soil and radionuclide-traced groundwater were usually contacted at a solution/solids ratio of 10 for 0.5 to 4 h at 22°C. (Longer contact times were used in a few tests.) The solution was then recovered by centrifugation for analysis by gamma or alpha counting techniques. The sorption ratio was determined from the solution concentration, and the concentration of adsorbed radionuclide was plotted vs the concentration in solution to construct the sorption isotherms.

The unbuffered nature of the soil and groundwater from the site caused the solution pH to decrease during batch contacts under ambient-pH conditions (i.e., the soil and the groundwater were allowed to establish the test pH). Although such behavior may be characteristic of the site and may reflect acid released by ion exchange reactions with the clay constituents, it was thought desirable to also construct sorption isotherms under constant-pH conditions, where the pH was held at a predetermined fixed value by the addition of acid or base as necessary. Sorption ratios, sorption isotherms, and apparent concentration limits are presented in the report for both ambient-pH and constant-pH conditions.

Sorption ratios are valid for predicting accurate radionuclide retardation factors only when a steady-state condition has been reached in the test (i.e., the sorption ratio and the desorption ratio are equal). Under this condition, the sorption ratio is actually a distribution coefficient (Kd). In cases where equilibrium has not been established, the sorption ratios are still useful for modeling conservative radionuclide retardation factors since disequilibrium always leads to lower sorption ratios. Desorption ratios were measured in a few experiments with uranium to study sorption-desorption equilibrium. In these experiments, the sorption of the soil was followed by four batch contacts with fresh synthetic groundwater and the solutions were recovered and analyzed.

Apparent concentration limit values were measured for the various radionuclides by extending the sorption isotherm to higher solution concentrations to attempt to define the maximum or limiting radionuclide concentration attainable. Apparent concentration limit values are distinguished from solubility limit or saturated solution values since the latter imply knowledge of the saturating solid phase. Such information is seldom available for these complex geologic systems.

Two exploratory column chromatographic experiments were performed to test for radionuclide multiple speciation effects and possible radionuclide transport as colloids. Either of these effects could make the sorption ratios and sorption isotherms measured in batch tests nonconservative for radionuclide retardation calculations. A simple gravity-flow column was used. Much more column work would be required to explore these factors rigorously.

1.4 SUMMARY OF RADIONUCLIDE SORPTION AND APPARENT CONCENTRATION LIMIT INFORMATION

High to very high sorption ratios were measured for all radionuclides (uranium, strontium, cesium, cobalt, europium, thorium, and curium) that are present as cations in the site soil/synthetic groundwater system. The sorption process will serve as a very favorable migration barrier for these elements and probably for other radionuclides which would be present as cations. The site was unique in giving the highest sorption ratios we have measured for uranium with any geologic material. The two elements tested which would be present as anions (technetium and iodine) in the site soil/synthetic groundwater system showed very low sorption ratios and would not be well retained by the site by the sorption process. Such behavior is typical of anionic species in geologic systems.

Only minimal apparent concentration limit information was obtained. Uranium showed no concentration limit in either ambient-pH or constant-pH condition tests; solution values as high as 2400 mg/L were measured in some cases. Uranium precipitation was observed only if the experimental contact time was extended to periods as long as [illegible] weeks. Even with such long contact times, the data were scattered; however, a value of $\sim$45 mg/L may represent an apparent *concentration limit. At least that value is not inconsistent with what is generally believed to represent uranium limiting solubility. The cause of the apparent slow uranium precipitation rate is not known. Slow uranium precipitation kinetics could be considered a potentially unfavorable site aspect. Relatively high strontium and cesium apparent concentration limits of 68,000 and 50,000 mg/L, respectively, were measured. The information obtained does not suggest that solubility limits may be a significant favorable radionuclide migration barrier at the site.*

A summary of the radionuclide sorption and apparent concentration limit information obtained under both ambient-pH and constant-pH test conditions is given in the following table:

Element	Rs (L/kg)	Concentration limit (mg/L)
Ambient-pH condition		
U	25,000	>2,400
Sr	1,600	>8,800
Cs	11,000	>13,000
Co	7,900	>6,000
Eu	61,000	>150
Th	11,000	>50
Tc	1.6	—
I	1.8	—
Constant-pH condition		
U	20,000	>1,500
Sr	4,800	68,000
Cs	13,000	50,000
Cm	>30,000	—

Since the radionuclide concentration present in groundwater at the site in groundwater-intrusion–groundwater-migration events is likely to be low, for the purposes of this summary the sorption ratios obtained at initial radionuclide concentrations of 5 mg/L were tabulated for comparison. These are the highest sorption ratio values measured; lower values were obtained at higher radionuclide concentrations. The full sorption isotherms are included in the body of the report. The apparent concentration limit values obtained at the highest radionuclide concentrations tested are also given in the table. In most cases, the sorption isotherms did not indicate approach to a concentration limit.

Significant differences are observed in the maximum sorption ratios for the various elements (see table above). Site soil constituents such as illite or kaolinite clays, or active silica surfaces, are known to exhibit favorable sorption capabilities for elements which exist in solution as cations but usually have little, or no, ability to adsorb anionic species. This information correlates well with the measured sorption ratios. Uranium, strontium, cesium, cobalt, europium, thorium, and curium, which would be expected to be present as cations in the site groundwater, had high to very high sorption ratios ranging from 1,600 L/kg for strontium to 61,000 L/kg for europium. Technetium and iodine would be expected to be present as anions in the site groundwater. These two elements had low sorption ratios of 1.6 to 1.8 L/kg.

Major differences in the maximum sorption ratio values were not observed for ambient-pH vs constant-pH experiments. For both test methods, the maximum sorption ratios were obtained in the pH range of 5 to 7; somewhat lower values were obtained at higher or lower pH levels.

The most important observation is that high to very high sorption ratios were obtained for all cationic species tested in these soil/synthetic groundwater systems. The sorption ratio of 25,000 L/kg for uranium is the highest we have observed with any geologic material. This may be a particularly important aspect of the site since uranium is likely to be a major radioactive contaminant of the waste. Sorption of radionuclides that will exist as cations is likely to be an important migration barrier, and the sorption process will probably be a generally favorable site aspect. Radionuclides that exist as anions will probably be poorly retarded because of the low sorption ratios measured and will not be well retained by the site if they become solubilized. This is generally true for most geologic materials, however, and is not a uniquely less favorable aspect of the site.

Only minimal radionuclide apparent concentration limit information was obtained. None of the ambient-pH tests were carried to sufficiently high element concentrations to reach the concentration limit. The apparent concentration limit for strontium measured under constant-pH conditions was 68,000 mg/L (0.78 mol/L), which is lower than the saturated solution value for strontium chloride but higher than that for strontium hydroxide. Strontium was added as the chloride in these tests and may be only partially hydrolyzed to the hydroxide in these soil/groundwater systems at the pH levels tested. The apparent concentration limit for cesium in the constant-pH tests was 50,000 mg/L (0.38 mol/L). Cesium, which was added as the nitrate, would not be expected to hydrolyze in these systems; however, the apparent concentration limit was significantly lower than the saturated solution concentration for cesium nitrate.

The solubility behavior of uranium in these site soil/groundwater systems was surprising. No apparent concentration limit for uranium was observed at solution concentrations as high as 2400 mg/L in ambient-pH tests and 1500 mg/L in constant-pH tests. An accurate value for the solubility of uranium oxide in solutions of near-neutral pH has never been established because of the tendency of the uranium to form colloidal hydrated oxyhydroxide precipitates. It is generally accepted that the apparent concentration limit may be in the range of 2 to 20 mg/L. We have obtained apparent concentration limit values in this range in tests with Wyoming montmorillonite at solution pHs of 6.5 to 9. The lack of uranium precipitation in these site soil/groundwater systems could be due to solution supersaturation, colloidal particulate dispersion, or formation of soluble uranium complexes. Modeling calculations of the speciation of uranium in the site groundwater, assuming a pH of 5.7 and an Eh value of 0.8 V, indicated that the uranium exists as schoepite and the predominant species would be $(UO_2)_3(OH)_5^+$ and $UO_2CO_3^\circ$. A few constant-pH tests at pH 7 were extended for contact times of up to 3 weeks. Solution concentration data for these tests showed considerable scatter but suggested a possible apparent concentration limit at ~45 mg/L. For reasons that are not understood, these site soil/synthetic groundwater systems apparently permit only very slow uranium precipitation rates. This behavior could be considered a potentially unfavorable site aspect. We have not experienced such slow uranium precipitation with other geologic systems.

1.5 URANIUM DESORPTION TESTS

Uranium desorption ratios were equivalent to sorption ratios, indicating that the sorption process was at steady state under the test conditions.

One series of uranium desorption experiments was carried out to test for sorption-desorption disequilibrium. The sorption ratios and desorption ratios measured were equivalent, indicating that the sorption reaction(s) reached steady state during the test contact time of 16 h. Thus, the sorption ratio values measured are valid for the calculation of accurate uranium retardation factors. Time did not permit the investigation of sorption-desorption disequilibrium for the other radionuclides.

1.6 EFFECT OF ORGANIC COMPLEXING AGENTS ON URANIUM SORPTION

The addition of organic complexing agents to the batch contact tests gave a two-order-of-magnitude decrease in uranium sorption values. This would lead to a concomitant decrease in the retardation factor and establishes the potential for an increase in the release of uranium from the site.

Organic complexing agents are frequently used in cleaning or decontaminating solutions during plant cleanup operations; therefore, it is conceivable that such reagents could be included in waste disposed of at the facility and could subsequently contaminate the disposal facility groundwater. The effect of these organics on uranium sorption was explored in tests with two organic complexing reagents, ethylenediaminetetraacetic acid (EDTA) and citric acid. Uranium sorption isotherms were constructed in the presence of 0.01 and 0.05 mol/L concentrations of each of these organic acids. An approximately two-order-of-magnitude decrease in uranium sorption was obtained in each case. This reduction in uranium sorption ratio values would produce an equivalent decrease in the retardation factor. No uranium apparent concentration limit was obtained in the presence of these complexing reagents. Although time did not permit tests to be made with other radionuclides, similar greatly reduced sorption values and increased solubility effects would be expected for most other cationic species since they are known to form stable complexes. The presence of such reagents in groundwater at the disposal facility would be highly detrimental to the ability of the geologic system to retain radioactivity.

1.7 COLUMN CHROMATOGRAPHIC TESTS

Scouting tests suggested that some portion of the strontium and cesium activity may be transported rapidly, possibly as colloidal material. This is a potentially unfavorable site aspect, and more work to understand this problem would be desirable. One test gave iodine sorption behavior that was consistent with the sorption ratios obtained in the batch test.

Two scouting tests with a simple gravity-flow column chromatographic system were carried out to explore possible multiple speciation effects on the radionuclide sorption ratios by directly measuring retardation factors and to look for evidence of colloidal transport of radioactivity. The limited time available permitted only preliminary testing; however, several interesting observations can be made. The first test with the addition of a ^{233}U spike to flowing synthetic groundwater on the top of a site soil column showed that all the uranium activity was retained in the first 1 cm of the column. This observation confirms that uranium has a large retardation factor in the soil/groundwater systems but does not permit quantification of the value. The second test was made with strontium-, cesium-, and iodine-traced groundwater. A portion (1 to 2%) of the strontium and cesium activity (but not iodine) promptly passed through the column in the first void volume of groundwater eluate. This was very surprising and suggests transport of activity by a colloidal material (e.g., colloidal silica) or the presence of radionuclide colloids. The iodine was retarded by a few column volumes, as would be expected from the low (but not zero) sorption ratios measured in the batch tests. Transport of radioactivity on colloidal particles that can move freely with groundwater through the soil could be a significant mode of activity release from the facility.

1.8 URANIUM SORPTION ON DOLOMITE

The amount of uranium sorbed by a sample of the underlying dolomite was surprisingly high and the formation of stable uranium-carbonate anionic complexes did not seem to be occurring. Thus, uranium in groundwater which migrates from the soil into the bedrock may still be subject to substantial retardation. This is an unexpected favorable site aspect.

Uranium sorption might be expected to be lower, and solubility higher, in groundwater in the dolomite underlying the soil due to the presence of carbonate in the dolomite. This situation could lead to formation of the soluble stable uranyltricarbonate anionic complex. Dolomite chips were recovered from drilling operations at the site and used in ambient-pH and constant-pH batch contact tests with synthetic soil groundwater (no groundwater from within the dolomite bedrock was available). Moderately high uranium sorption ratios (100 to 300 L/kg) were obtained. Apparently, this dolomite has better sorption capability for uranium than is usually observed with carbonate rocks.

1.9 FIELD VERIFICATION

Uranium sorption and solubility behavior was dramatically different when trench water from an actual waste facility was used in experiments in place of the synthetic site groundwater. Uranium sorption was decreased by more than two orders of magnitude, and rapid uranium precipitation and establishment of an apparent concentration limit at 25 mg/L were observed. It would be desirable to conduct geochemical work as the West Chestnut Ridge site is developed in order to verify the radionuclide behavior results obtained in the laboratory.

It is always highly desirable to verify the geochemical data obtained in small-scale, short-time laboratory experiments with those from larger-scale field experiments conducted over longer times. Many geochemical reactions exhibit slow kinetics, and geochemical parameters are often sensitive to the test protocol. Field verification of site radionuclide sorption or solubility behavior measured in this laboratory support work was considered worthwhile, but the CWDF schedule did not permit such an activity.

In order to explore "real-world" conditions in a few laboratory tests, a sample of trench water from an existing Y-12 waste disposal facility was obtained and used in an ambient-pH test with site soil to construct a uranium sorption isotherm. Chemical analyses showed that the trench water had a pH of 7.1 and contained appreciable quantities of sulfate, nitrate, and nitrite, as well as carbonate and chloride, anions. Sodium was the predominant cation. The trench water also contained 41 μg/mL of unidentified organic carbon compound(s). The uranium sorption isotherm obtained was remarkably different from a parallel isotherm constructed with synthetic groundwater. The uranium sorption ratios were lower by more than two orders of magnitude. Further, the uranium-traced trench water showed rapid uranium precipitation at higher uranium concentrations, and an apparent concentration limit of 25 mg/L was observed. The parallel synthetic groundwater isotherm showed no concentration limit at uranium concentrations as high as 240 mg/L.

This test with actual trench water and site soil exemplifies the problems and uncertainties that can be encountered in extrapolating laboratory results to field conditions. It would be desirable to conduct additional geochemical work through the facility development and waste disposal phases to vertify radionuclide data measured in the laboratory.

2. INTRODUCTION

The most credible scenario for the release of emplaced radionuclides from a near-surface disposal site to the accessible environment involves groundwater intrusion of the waste, followed by dissolution and migration of the radionuclides in groundwater to the surface or into a subsurface aquifer. The radionuclides may be transported either as dissolved species or as insoluble colloids or other suspended particulates. The geochemical processes or conditions that control migration as dissolved species are, in sequence of action: (1) groundwater intrusion, including both volume and migration rate; (2) dissolution of the emplaced radionuclide(s); (3) solubility product limitations of the radionuclide concentration in the groundwater; and (4) sorption of the dissolved radionuclide by soil and rock at the site. In general, the quantity of any radionuclide that is released or is migrating from a disposal site can be no greater than its saturated solution concentration times the groundwater volume, and the radionuclide migration rate can be no faster than the groundwater migration rate. Migration of the radionuclide may be further retarded by sorption on surfaces of the soil and/or rock with which it comes in contact.

The degree of retardation of migrating radionuclides dissolved in groundwater by the geochemical sorption process is generally expressed as a retardation factor ($\underline{R}$), which is related to the experimentally measured Kd by the relationship

$$\underline{R} = 1 + Kd(\phi/\rho) \ , \tag{1}$$

where

$\underline{R}$ = retardation factor (dimensionless),

Kd = distribution coefficient (L/kg),

ϕ = bulk density of geologic media (kg/L),

ρ = porosity of geologic media (dimensionless).

This expression is rigorously valid only when Kd is independent of radionuclide concentration, the sorption process is thermodynamically reversible, and a single species exists in solution. These conditions are seldom met in most practical applications; therefore, judgment must be exercised in designing the experiments employed to measure the Kd values and in extrapolating small-scale laboratory tests to predict geologic-scale behavior of the radionuclides.

The philosophy, or approach, used in the experimental work reported here has been developed by taking into consideration the technical and theoretical aspects of the geochemical sorption process, the solubility limit condition, and the programmatic information needs. Sorption values are frequently calculated as an empirical ratio (i.e., an effective Kd or sorption ratio). This is simply the ratio of the concentration of the species on the test solid adsorbent divided by the concentration of the solute in the test solution after contact. Since volume is being divided by mass in calculating the sorption ratio, the units are liters per kilogram (L/kg). In the past, there has been no generally accepted standard symbol(s) to represent sorption ratios or distribution coefficients. Recently, standard symbols and terminology have been recommended.[1] The symbol "Kd" should be reserved for distribution coefficients that have been obtained under thermodynamic equilibrium conditions. Few practical experiments can be demonstrated as being at true equilibrium; thus, most experimentally derived sorption values should be represented by the symbol "Rs" for sorption ratio or "Rd" for desorption ratio. We have chosen to express our short-term laboratory measurements of the distribution of radionuclides between groundwater and a solid adsorbent in terms of a "sorption ratio" (Rs value), which does not imply ideal behavior. At thermodynamic equilibrium,

$$Rs = Rd = Kd \ , \tag{2}$$

where

Rs = sorption ratio (L/kg),

Rd = desorption ratio (L/kg),

Kd = equilibrium distribution coefficient (L/kg).

Only when sorption-desorption equilibrium has been established is the sorption ratio a true distribution coefficient (provided that multiple speciation does not exist).

The solubility product constant for a solid is expressed as:

$$Ksp = [A^{y+}]^{x}[B^{x-}]^{y} \tag{3}$$

for the hypothetical equilibrium:

$$AxBy = xA^{y+} + yB^{x-}. \tag{4}$$

Ksp is unique for each solid phase and solution species and is rigorously valid only for ionic activities. The activity coefficient for dilute species is often 1, thus, ionic concentrations can be substituted for activities. Since the solid phase, solution species, and activity coefficients are frequently difficult to determine or are not known for complex geologic soil/groundwater systems, an observed or apparent saturated solution concentration is usually obtained experimentally. The apparent saturated concentration is dependent on several experimental and site-specific parameters and, consequently, must be redetermined for each new soil/groundwater combination. In our work, we have defined this an "apparent concentration limit."

Many nuclear facilities (power plants, uranium production facilities, and disposal/storage sites) are located in the eastern United States in areas that experience high rainfall and have clay-rich soils derived from sedimentary rocks. A review of the published literature revealed little information describing sorption behavior for uranium species with water-saturated clay-rich soils. Uranium is potentially one of the most important radionuclides in future disposal activities at the CWDF site. Most of the reported values are for fission products or transuranic elements, are related to arid soils more typical of the western United States, or are for specific geological material such as salt or granite. Borovec[2] describes the uptake of UO_2^{2+} on kaolinite, illite, and montmorillonite from pure uranyl chloride solutions at pH 6. Natural waters, however, may contain low concentrations of many ionic species which can complex dissolved uranium, causing increased solubility.

Nonideal sorption behavior of uranium may be expected because of the multiple species possible under soil/groundwater conditions. Langmuir[3] has reviewed the stability data for uranium complex species, and Baes and Mesmer[4] have examined the solubility data for uranium species. The following conclusions for uranium(VI), the oxidation state to be expected in air-saturated groundwaters, have been reached: (1) below pH 5 the predominant ionic species in groundwaters would be UO_2^{2+}, and UO_2F^- if fluoride is present; (2) in the pH range from 5 to 7, the complex $UO_2(HPO_4)_2^{2-}$ would be the principal species, but in the absence of PO_4^{3-} the hydrolyzed species would probably be $(UO_2)_2(OH)_2^{2+}$ or $UO_2(OH)^+$; and (3) above pH 7 the ion $UO_2(CO_3)_3^{4-}$ becomes the dominant form in the presence of dissolved CO_2, while insoluble uranium hydroxide and the ion $(UO_2)_3(OH)_5^+$ would be formed in the absence of CO_2. Lemire and Tremaine[5] have recently compiled the existing information on uranium solution equilibria and calculated equilibrium constants for pertinent reactions. According to Baes and Mesmer,[4] the uranium oxide solid phases in equilibrium with pure water (no complexing ions present) are not well characterized, and several modifications of $UO_2(2H_2O)$ and $UO_2(OH)_2$ are believed to exist; thus, an accurate value for the solubility of these forms has not been established. Giblin et al.[6] evaluated the effects of carbonate and kaolinite in natural waters containing complexing ions on the mobility of uranium. Carbonate substantially increased mobility, while kaolinite reduced mobility, reportedly by immobilizing colloidal uranium oxides.

Single sorption ratio values obtained for a given adsorbent and test solution may be presented in data tables, which frequently consist of a comparison of various adsorbents under one set of fixed experimental conditions. Such tables, although convenient for screening or gross comparison purposes, have only limited usefulness for a sorption behavior or retardation analysis since single Rs values give no hint of how sorption behavior may vary with changes in test conditions or geochemical parameters.

It has long been recognized that the sorption ratio is frequently a function of the solute concentration, and plots of adsorbed concentration vs solution concentration have been employed as a method of presenting the data. Such plots are called isotherms, although in practice all test parameters other than concentration must be held constant, not just the temperature. Adsorbed species, including many radionuclides on soils or rocks, sometimes display a nonlinear dependency of adsorbed concentration vs solution concentration similar to that classically observed for the sorption of gases on solids. Such behavior was initially described by Freundlich in 1907, and his name has become a generic label for any type of sorption plot showing such a curve. Similarly, Langmuir, in 1926, developed an adsorption isotherm for gases on solids based on the assumption of a unimolecular surface, and plots of a function of the total gas pressure on the adsorbed gas concentration yield a straight line for ideal systems. Some data for the adsorption of solutes from solution have been successfully plotted using a Langmuir isotherm approach. Sorption of radionuclides on soil and rocks from groundwater is much more complex and involves many more factors than those dealt with by Freundlich or Langmuir isotherms; nonetheless, such data treatments have proven useful as a means of organizing and presenting sorption data. The Dubinin-Raduskevitch isotherm was developed as a means of obtaining linear plots of sorption values for gases on charcoal. It has also found application in describing the sorption of sparingly soluble solutes since, unlike the Langmuir and Freundlich isotherms, it does not assume a homogeneous surface, constant adsorption potential, or monolayer surface saturation. In the Dubinin-Raduskevitch isotherms, the log of the concentration of the adsorbed species is plotted vs a function of the sorption potential energy. Such plots have been used to successfully linearize sorption data for uranium in geologic materials.[7]

The sorption data in this report are presented as isotherms, insofar as possible, supplemented by detailed tabulation of the test results in the appendixes. Single sorption ratio values may not reveal adequate information for accurate and defensible migration modeling. The apparent concentration limit or saturated solution concentration is inferred from the sorption isotherm whenever possible. Sorption rate and sorption/desorption experiments are shown to indicate the existence of, or proximity to, steady-state conditions. In some cases, the Rd values may be much larger than the Rs values because of chemisorption or other irreversible sorption processes. When this occurs, Rd will dominate the calculation of the retardation factor and should be used in place of Rs for migration modeling calculations. If the radionuclide is present in more than one dissolved form (i.e., multiple speciation exists) during the test, the measured sorption ratio will be an average of the sorption ratios for the various species, weighted by their relative abundance. Use of a single sorption value or single isotherm to model retardation for a system containing multiple speciation could lead to large errors and nonconservative migration predictions. Column chromotography is employed as a means of supplying experimental backup for the batch test determinations of sorption isotherms to explore the existence of multiple speciation.

3. SITE CHARACTERIZATION

3.1 SOIL CHARACTERIZATION

Soil samples from two boreholes in the West Chestnut Ridge site — four from hole B1 and five from hole B2 were received in Shelby tubes. These samples were recovered from the 10-, 20-, 30-, and 40-ft levels of hole B1 and from the 20-, 30-, 40-, 50-, and 60-ft levels of hole B2. The tubes, which were sealed when received, were stored in a cold room at 4°C to retard soil dehydration prior to characterization.

The Shelby tubes were opened by lateral sawing with an abrasive saw, such that the cut just penetrated the inner wall of the tube. This method was chosen to minimize any possible contamination of the soil with metal fragments. Each of the 3-ft Shelby tubes contained ~1 to 2 ft of recovered soil core, which appeared to be a red-brown clayey material containing inclusions of gravel and chert. The top 1 or 2 in. of each sample appeared somewhat darker in color, suggesting possible surface material knockdown during the coring operation.

3.1.1 Physical Characterization

Moisture content was determined for most of the core samples (Table 1). The samples were dried to constant weight by lyophilization at 50°C. The mean weight loss and standard deviation (1 σ) was 24.4 ± 3.5%. No significant trend with core depth or between cores was noted.

Selected soil samples were lightly ground to pass a 50-mesh screen in order to yield homogeneous samples for testing and analysis.

Table 1. Moisture content of samples from West Chestnut Ridge cores B1 and B2

Sample No.[a]	Moisture[b] (%)	Sample No.[a]	Moisture[b] (%)
B1-10-A	22.5	B2-20-B	21.9
B1-10-B	26.9	B2-20-C	20.2
B1-10-C	27.8	B2-30-A	ND
B1-10-D	27.1	B2-30-B	20.9
B1-20-A	25.6	B2-30-C	ND
B1-20-B	27.2	B2-30-D	18.2
B1-20-C	23.0	B2-40-A	22.2
B1-30-A	28.0	B2-40-B	21.8
B1-30-B	28.3	B2-50-A	26.9
B1-30-C	ND[c]	B2-50-B	21.3
B1-40-A	ND	B2-60-A	ND
B1-40-B	28.7	B2-60-B	23.2
B1-40-C	ND	B2-60-C	ND
B1-40-D	30.9	B2-60-D	23.2
B1-40-E	ND	B2-60-E	ND
B2-20-A	20.4		

[a] The first designation is the core (B1 or B2), the second is the Shelby tube core depth in ft, and the third refers to the position of the sample in the Shelby tube (A - top, etc.).

[b] Sample weight loss on drying to a constant weight by lyophilization.

[c] ND = not determined.

Gravel and chert, if present in the samples, were removed by physical separation techniques before grinding since freshly exposed surfaces of silicaceous material might result in unrealistically high sorption values.

The crystalline phases present were determined by x-ray diffraction (XRD) techniques for three samples each from two core. (These samples, selected for sorption studies, are identified in Table 1.) The results, presented in Table 2, show major amounts of silica (quartz) in each sample and intermediate amounts of illite in every sample except B2-30-B, which appeared to have been recovered from a sand lens. Minor amounts of kaolinite were found in three samples. Illite and kaolinite are common clay minerals formed during the weathering of silica-containing minerals.

Surface area analyses by nitrogen adsorption BET (Brunauer-Emmett-Teller) techniques show (Table 3) relatively high surface areas, 38.7 ± 6.2 m^2/g, for all samples except B2-30-B.

Particle-size distribution analysis of the six selected core samples were performed by the Technical Services Department at the Oak Ridge Gaseous Diffusion Plant. Micromerograph techniques were employed to obtain the data, which are summarized in Table 4. These data show that 60% of the particles were less than 4.5 to 6.0 µm for all six of the samples tested, and 10% were less than 1.6 to 2.4 µm in size. The mean density and standard deviation (1 σ) for the six samples was 2.95 ± 0.16 g/mL. Details of the particle-size distribution data are shown graphically in Figs. A-1 and A-2 in Appendix A.

Table 2. X-Ray diffraction analyses of samples from West Chestnut Ridge cores B1 and B2

Sample No.	Crystalline phases		
	Major	Intermediate	Minor
B1-10-B	SiO_2 (quartz)	Illite	-
B1-30-B	SiO_2 (quartz)	Illite	Kaolinite (VW)[a]
B1-40-B	SiO_2 (quartz)	Illite	-
B2-20-B	SiO_2 (quartz)	Illite	Kaolinite
B2-30-B	SiO_2 (quartz)	-	Illite
B2-60-B	SiO_2 (quartz)	Illite	Kaolinite (VW)[a]

[a] VW = very weak pattern.

Table 3. Surface area and density analyses for soil samples from West Chestnut Ridge cores B1 and B2

Sample No.	Surface area (m^2/g)	Density (g/cm^3)
B1-10-B	37.13	3.1
B1-30-B	46.54	3.1
B1-40-B	43.76	3.1
B2-20-B	33.56	2.8
B2-30-B	9.80	2.7
B2-60-B	32.71	2.9

Table 4. Particle-size distribution analysis of core samples from West Chestnut Ridge

Core sample No.	Density (g/cm^3)	Particle-size distribution[a] (μm) 60%	10%
B1-10-B	3.1	4.8	2.0
B1-30-B	3.1	4.5	1.8
B1-40-B	3.1	4.8	1.7
B2-20-B	2.8	6.0	2.0
B2-30-B	2.7	6.0	2.4
B2-60-B	2.9	4.5	1.6

[a] Equal to, or less than, stated values.

Based on the XRD, surface area, and particle-size distribution analyses, sample B2-30-B appears to be characteristic of sand or sandy silt while the other samples bear more resemblance to silt and/or clay materials.

3.1.2 Chemical Characterization

The carbonate contents of the six selected samples, obtained by wet chemical methods, were low (Table 5), varying from 0.12 to 0.33% in the upper part of the two cores and decreasing to 0.04% in the lower part of both cores. This information may be consistent with the site stratigraphy that identifies West Chestnut Ridge as being derived from Knox Group cherty dolomite,[8] if it is assumed that all the dolomite had been removed during rock weathering.

Table 5. Carbonate analyses of samples from West Chestnut Ridge cores B1 and B2

Sample No.	Carbonate (%)
B1-10-B	0.12
B1-30-B	0.35
B1-40-B	0.034
B2-20-B	0.35
B2-30-B	0.041
B2-60-B	0.041

The six samples were analyzed for elemental contents by inductively coupled plasma (ICP) spectrometry. These data, shown in Table 6, are fairly typical for this type of soil. It should be noted that the calcium and magnesium contents are relatively low, which corresponds well with the low carbonate content that was found. The sodium analysis (<1000 μg/mL in each case) is the result of a low sensitivity and a high dilution factor in the ICP method.

It is desirable to obtain site radionuclide data which can serve as background values for any future study of radionuclide migration after emplacement of waste has occurred. Radium and uranium concentration profiles were determined for West Chestnut borings B1 and B2 (Table 7). The in-situ uranium analysis was performed by delayed-neutron activation of the natural ^{235}U content, and the ^{226}Ra analysis

Table 6. Elemental analysis of West Chestnut Ridge core samples by ICP spectrometry

(Concentrations are in μg/g, except for Si)

Element	Core sample					
	B1-10-B	B1-30-B	B1-40-B	B2-20-B	B2-30-B	B2-60-B
Ag	<4.5	<4.5	<4.5	<4.5	<4.5	<4.5
Al	80,000.	110,000.	95,000.	97,000.	26,000.	99,000.
B	37.	31.	40.	<19.	21.	21.
Ba	78.	160.	240.	76.	55.	84.
Be	1.9	5.1	8.3	2.	1.8	3.9
Ca	150.	1400.	2200.	350.	96.	1100.
Cd	7.	7.3	7.8	7.1	4.6	5.6
Co	8.	48.	21.	12.	36.	9.3
Cr	73.	64.	78.	37.	15.	58.
Cu	24.	36.	30.	43	43.	49.
Fe	35,000.	47,000.	48,000.	45,000.	28,000.	38,000.
Ga	21.	<18.	<18.	20.	<18.	22.
Hf	25.	34.	34.	27.	19.	28.
K	18,000.	20,000.	2,900.	11,000.	6,100.	14,000.
Mg	7000.	8200.	9700.	3700.	2100.	5000.
Mn	140.	1800.	1200.	330.	2000.	540.
Mo	33.	51.	41.	23.	27.	35.
Na	<1000.	<1000.	<1000.	<1000.	<1000.	<1000.
Ni	37.	77.	71.	42.	74.	58.
P	<83.	<83.	<83.	<83.	<83.	<83.
Pb	<65.	<65.	<65.	<65.	<65.	<65.
Sb	<35.	<35.	<35.	<35.	<35.	<35.
Se	<110.	<110.	<110.	<110.	<110.	<110.
Si	32.(%)	28.(%)	27.(%)	31.(%)	40.(%)	31.(%)
Sr	15.	24.	28.	19.	6.3	16.
Ti	3700.	3300.	2300.	3000.	1300.	3100.
V	80.	65.	86.	88.	31.	93.
Zn	250.	480.	410.	310.	26.	360.
Zr	120.	120.	120.	120.	120.	120.

Table 7. Radium-226 and uranium analyses of soil samples from West Chestnut Ridge borings B1 and B2

Sample No.	Core depth (m)	Core depth (ft)	Radium content (pCi/g)	Uranium content (µg/g)
B1-10-B	3.05	10	2.71	3.82
B1-10-C	3.05	10	2.88	5.8
B1-10-D	3.05	10	4.36	7.36
B1-20-B	6.1	20	4.37	8.0
B1-20-C	6.1	20	3.95	4.94
B1-30-B	9.1	30	3.00	5.0
B1-30-C	9.1	30	3.73	4.72
B1-40-B	12.2	40	3.23	5.1
B1-40-D	12.2	40	4.71	3.9
B2-20-B	6.1	20	3.54	5.55
B2-20-C	6.1	20	2.76	5.63
B2-30-B	9.1	30	2.28	4.1
B2-30-D	9.1	30	4.00	6.52
B2-40-B	12.2	40	3.91	6.8
B2-50-B	15.2	50	2.49	5.25
B2-60-B	18.3	60	2.98	5.67
B2-60-D	18.3	60	2.92	5.65

was made by integrating the gamma activity in the 0.609-MeV ^{214}B peak after establishing secular equilibrium. The ^{226}Ra content of the soil samples in these two cores ranged from 2.21 to 4.71 pCi/g (mean ± standard deviation of all the samples = 3.4 ± 1.3 pCi/g). The uranium content of the samples ranged from 3.82 to 8.0 µg/g (mean ± standard deviation of all the samples = 5.5 ± 2.5 µg/g). No significant trend with depth or difference in location was observed.

3.2 GROUNDWATER CHARACTERIZATION

3.2.1 Central Chestnut Ridge Site

Since groundwater was not encountered in the boreholes at the West Chestnut Ridge site, two samples of groundwater were recovered from a perched water table at ~16.8-m (50-ft) depth of boring N2 at the Central Chestnut Ridge site to serve as a comparison standard for synthetic groundwater prepared by contacting West Chestnut Ridge soil with distilled water. One sample, designated N2-1, was obtained from very wet mud from the auger return and consisted of ~500 g of mud from which ~300 mL of clear groundwater was recovered. The pH of this sample was 5.7 ± 0.2. The second sample, designated N2-2, was obtained after the auger was withdrawn and the well casing was put in place. It consisted of ~19 L (5 gal) of mud from which ~4 L (1 gal) of clear groundwater was recovered by centrifugation and double filtration through 0.2-µm filter media. The pH of this sample was measured as 6.0 ± 0.2.

Anion analyses of these two groundwater samples showed low concentrations of HCO_3^- and Cl^- (9 to 12 and 2 to 24 µg/mL, respectively).

The concentrations of all other commonly present anions were below the sensitivity limits of the analytical procedure employed. These data are shown in Table 8.

Elemental analyses of the two groundwater samples via ICP spectrometry showed only very minor amounts of calcium, sodium, and silicon (Table 9). Most of the other elements were below the detection limits of the method.

3.2.2 West Chestnut Ridge Site

Synthetic groundwater was prepared by contacting a composite sample of wet West Chestnut Ridge soil with distilled water at a solution/solids ratio of 10 for 24 h and recovering a clear solution by centrifugation and double filtration though a 0.2-μm filter medium. Anion and element analyses, shown in Tables 10 and 11 respectively, compare very favorably with those for actual groundwater from Central Chestnut Ridge. Since only very small amounts of the clay mineral constituents are dissolved in the natural or synthetic groundwaters, this type of groundwater will result in a highly unbuffered test system.

3.2.3 Surface Water

Anion analyses of surface water samples taken by J. R. Jones on April 18, 1983, from seven flow monitoring and sampling stations in the West Chestnut Ridge area are presented in Table 12. These stations, located on Ish Creek, have been described in detail by Huff et al.[9] The results showed that only very minor amounts of anions were present. The pH of each sample was measured immediately after

Table 8. Anion analysis of groundwater[a] from Central Chestnut Ridge boring N2

(Concentrations are in μg/mL)

Anion	Sample No.	
	N2-1	N2-2
SO_4^{2-}	<4	<4
NO_3^-	<4	<4
NO_2^-	<2	<2
F^-	<1	<1
Cl^-	2	24
Br^-	<5	<5
PO_4^{3-}	<4	<4
HCO_3^-	12	9
CO_3^{2-}	0	0

[a] The groundwater was recovered by centrifugation and double filtration through 0.2-μm filter medium.

Table 9. Elemental analysis of groundwater from Central Chestnut Ridge boring N2 by ICP spectrometry

(Concentrations are in μg/mL)

	Sample No.	
Element	N2-1	N2-1
Ag	<0.018	<0.018
Al	<0.058	<0.058
B	<0.076	<0.076
Ba	0.029	0.094
Be	<0.0013	<0.0013
Ca	0.5	2.1
Cd	0.029	0.029
Co	<0.013	<0.013
Cr	<0.023	<0.023
Cu	<0.032	<0.032
Fe	<0.02	<0.02
Ga	<0.07	<0.07
Hf	0.043	0.044
K	<4.	<0.5
Mg	0.17	1.1
Mn	0.14	1.5
Mo	<0.027	0.034
Na	2.8	15.
Ni	<0.11	<0.11
P	<0.33	<0.33
Pb	<0.26	<0.26
Se	<0.43	<0.43
Si	3.3	3.5
Sr	<0.016	<0.016
Ti	0.026	0.024
V	<0.015	<0.015
Zn	<0.018	<0.018
Zr	0.065	0.064

Table 10. Anion analysis of synthetic groundwater[a] from West Chestnut Ridge soil

(Concentrations are in μg/mL)

Anion	Groundwater from composite soil
SO_4^{2-}	1
NO_3^-	1
F^-	<1
Cl^-	1
Br^-	<1
PO_4^{3-}	<1
CO_3^{2-}	0
HCO_3^-	0.152
pH	6.7

[a] Synthetic groundwater was prepared by contacting distilled water with a composite soil sample from the West Chestnut Ridge site at a solution/solids ratio of 10 for 24 h at ambient temperature. The groundwater was recovered by centrifugation and double filtration through 0.2-μm filter medium.

Table 11. Elemental analysis of synthetic groundwater[a] from West Chestnut Ridge soil

(Concentrations are in μg/mL)

Element	Groundwater from composite soil
Ag	0.0407
Al	0.104
As	<0.64
B	<0.076
Ba	0.00943
Be	<0.0013
Ca	<4.
Cd	<0.0092
Co	<0.013
Cr	<0.023
Cu	<0.032
Fe	<0.02
Ga	<0.07
Hf	<0.04
K	<4.
Li	<0.1
Mg	0.162
Mn	0.0075
Mo	<0.027
Na	0.678
Ni	<0.11
P	<0.33
Pb	<0.26
Sb	0.188
Se	<0.43
Si	2.33
Sr	<0.016
Ti	0.056
V	<0.015
Zr	<0.016

[a] Synthetic groundwater was prepared by contacting distilled water with a composite soil sample from the West Chestnut Ridge site at a solution/solids ratio of 10 for 24 h at ambient temperature. The groundwater was recovered by centrifugation and double filtration through 0.2-μm filter medium.

Table 12. Anion analysis of surface water samples from West Chestnut Ridge area

(Concentrations are in μg/mL)

Anion	Surface water sample No.						
	S-1	S-2	S-3	S-4	S-5	S-6	S-7
CO_3^{2-}[a]	0.1	0.1	0.1	0.1	0.1	0.1	0.1
SO_4^{2-}	4.	4.	4.	4.	4.	4.	4.
$NO3^-$	4.	4.	4.	4.	4.	4.	4.
F^-	1.	1.	1.	1.	1.	1.	1.
Cl^-	2.	1.	2.	4.	1.	2.	1.
Br^-	5.	5.	5.	5.	5.	5.	5.
PO_4^{3-}	4.	4.	4.	4.	4.	4.	4.
pH	7.3	7.4	7.1	7.1	7.0	6.5	8.0

[a] CO_3^{2-} is reported as $CaCO_3$ in μg/mL. It was present as HCO_3^-.

the plastic containers were opened in the laboratory. The pH values for the seven samples ranged from 6.5 to 8.0.

The elemental analyses of these seven surface water samples by the ICP technique are summarized in Table 13. Calcium, potassium, magnesium, sodium, and silicon are the most prominent elements found. It should be noted that there is a significant imbalance between the cations and anions. For example, the calcium and magnesium would be expected to be present as either the carbonate or chloride; however, these anions were not found in sufficiently high concentrations to be equivalent to the two cations. The reason for this discrepancy in the cation-anion balance is not known, but a reasonable speculation would be that some of the analyses are in error.

These surface water samples are quite similar in composition to the samples of natural groundwater from Chestnut Ridge and the synthetic groundwater derived from soil from the West Chestnut Ridge site.

Three samples of surface water, obtained from the Clinch River in the vicinity of the proposed West Chestnut Ridge low-level waste disposal site, were analyzed for cation concentrations by ICP spectrometry and for anion concentrations by ion chromatography. Of the 28 elements determined by the ICP technique (Table 14), only 8 — Ba, Ca, Hf, Mg, Na, Sr, Ti, and V — had concentrations that could be considered significant. Only four of the eight anions determined by ion chromatography — SO_4^{2-}, F^-, Cl^-, and HCO_3^- — were found in concentrations high enough to be considered significant (Table 15). One of the three samples, designated C1, was acidified with HCl to prevent biological

Table 13. Elemental analyses of surface water samples from West Chestnut Ridge area by inductively coupled plasma (ICP) spectrometry

(Concentrations are in µg/mL)

	Surface water sample No.						
Element	S-1	S-2	S-3	S-4	S-5	S-6	S-7
Ag	0.022	0.018	0.018	0.018	0.018	0.018	0.018
Al	0.31	0.35	0.37	0.4	0.16	0.5	0.093
B	0.076	0.076	0.076	0.076	0.076	0.076	0.076
Ba	0.024	0.026	0.021	0.015	0.015	0.016	0.0097
Be	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013
Ca	18.	11.	5.7	7.	7.6	4.	23.
Cd	0.0092	0.0092	0.0092	0.0092	0.0092	0.0092	0.0092
Co	0.013	0.013	0.013	0.013	0.013	0.013	0.013
Cr	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Cu	0.032	0.032	0.032	0.032	0.032	0.032	0.032
Fe	0.13	0.14	0.16	0.15	0.15	0.19	0.035
Ga	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Hf	0.04	0.04	0.04	0.04	0.04	0.04	0.04
K	4.	4.	4.	4.	4.	4.	4.
Mg	6.5	5.2	2.8	3.1	4.2	1.3	13.
Mn	0.001	0.001	0.001	0.001	0.023	0.001	0.001
Mo	0.04	0.027	0.036	0.033	0.027	0.045	0.035
Na	0.77	0.71	0.85	1.5	0.38	0.82	0.44
Ni	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Pb	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Sb	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Se	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Si	2.9	2.9	2.9	2.7	2.8	3.	2.8
Sr	0.016	0.016	0.016	0.016	0.016	0.016	0.016
Ti	0.012	0.0087	0.012	0.016	0.0077	0.014	0.0065
V	0.015	0.015	0.015	0.015	0.015	0.015	0.015
Zn	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Zr	0.018	0.018	0.018	0.018	0.018	0.018	0.018
P	0.33	0.33	0.33	0.33	0.33	0.33	0.33

Table 14. Elemental analysis of water from the Clinch River near the West Chestnut Ridge disposal area

Element	Concentration (μg/mL) Sample No. C1[a]	Sample No. C2	Sample No. C3
Ag	<0.018	<0.018	<0.018
Al	<0.058	<0.058	<0.058
B	0.41	<0.076	<0.076
Ba	0.027	0.014	0.014
Be	<0.001	<0.001	0.001
Ca	41	46	45
Cd	<0.009	<0.009	<0.009
Co	<0.013	<0.013	<0.013
Cr	<0.023	<0.023	<0.023
Cu	<0.032	<0.032	<0.032
Fe	<0.020	<0.020	<0.020
Ga	<0.070	<0.070	<0.070
Hf	0.097	0.10	0.11
K	<4.0	<4.0	<4.0
Mg	13	14	14
Mn	0.001	<0.001	<0.001
Mo	<0.027	<0.027	<0.027
Na	5.1	4.7	4.4
Ni	<0.11	<0.11	<0.11
Pb	<0.26	<0.26	<0.26
Sb	<0.14	<0.14	<0.14
Se	<0.43	<0.43	<0.43
Si	0.94	0.98	0.97
Sr	0.10	0.11	0.11
Ti	0.019	0.017	0.019
V	0.016	0.018	0.018
Zn	<0.018	<0.018	<0.018
Zr	<0.018	<0.018	<0.018

[a] Sample was acidified with HCl.

Table 15. Anion analysis of water from the Clinch River near the West Chestnut Ridge disposal area

Anion	Concentration (μg/mL) Sample No. C2	Sample No. C3
SO_4^{2-}	17	19
NO_3^-	<1	<1
F^-	7	9
Cl^-	3	3
Br^-	<1	<1
PO_4^{3-}	<1	<1
CO_3^{2-}	0	0
HCO_3^-	119	117
pH	7.9	7.8

growth or hydrolytic precipitation. This treatment was necessary to ensure that the integrity of the sample was retained for future sampling. (It is not included in Table 16 in which the cation-anion equivalent balance is shown.) The samples had an initial mean pH of 7.88 ± 0.04 and an average cation-anion equivalent balance of 1.27. These data should serve as a valid background for Clinch River water composition for future reference in the event of runoff from the disposal site.

Table 16. Cation-anion equivalent balance

Cation or anion	Concentration (equiv/L) Sample No. C2	Concentration (equiv/L) Sample No. C3
Ba	2.0E-7[a]	2.0E-7
Ca	2.3E-3	2.3E-3
Hf	2.2E-6	2.2E-6
Mg	1.1E-3	1.1E-3
Na	2.0E-4	1.9E-4
Sr	2.3E-6	2.3E-6
Ti	1.1E-6	1.1E-6
V	1.3E-6	1.3E-6
SO_4^{2-}	3.5E-4	4.0E-4
F^-	3.7E-4	4.7E-4
Cl^-	8.5E-5	8.5E-5
HCO_3^-	2.0E-3	1.9E-3
$\sum$ cations	3.61E-3	3.60E-3
$\sum$ anions	2.81E-3	2.86E-3
Cations-anions	1.28	1.26

[a] Read as 2.0×10^{-7}.

4. SORPTION AND SOLUBILITY MEASURMENTS - SOIL/GROUNDWATER SYSTEMS

4.1 METHODS

4.1.1 Ambient-pH Sorption/Desorption Isotherms

The experimental procedure for the determination of sorption and/or desorption isotherms is summarized in Table 17. In essence, it involved contacting synthetic groundwater (traced with the desired radionuclide) with samples of soil at a solution/solids ratio of 10 for 3 h in an argon atmosphere at room temperature (22°C), centrifuging at 5000 x g to recover a clear solution, and analyzing the solution to determine the radionuclide content. Details of this procedure are given in Appendix B. In our tests, the pH was allowed to equilibrate naturally with the soil and groundwater; no attempt was made to adjust or control it. In the highly unbuffered system that exists with this particular groundwater and soil combination, ambient-pH values varied considerably and were generally slightly lower than the pH of the natural groundwater. However, this was considered to be a valid compromise between "real-world" conditions and artificial conditions in which a buffering agent is added to the groundwater or the pH is arbitrarily established by the addition of acid or base.

Although many investigators contact groundwater and soil for relatively long periods of time (weeks or months), the amount of data required to fulfill our obligation to this project on schedule precluded the use of lengthy equilibration periods.

Table 17. Batch contact method for determining radionuclide sorption and apparent concentration limit values[a]

Ambient-pH method

- Batch contact (shake) 1.0 g of soil per 10 mL of radionuclide-traced synthetic groundwater for 3 h at room temperature in an argon atmosphere.
- Centrifuge sample to recover clear solution.
- Determine radionuclide activity in solution by counting and calculate radionuclide concentration in soil.
- Calculate sorption ratio, Rs (L/kg), and plot sorption isotherm.

Constant-pH method

- Stir 10 g of soil per 100 mL of radionuclide-traced synthetic groundwater in an argon atmosphere for 30 min at room temperature; hold pH constant by addition of HCl or NaOH, as necessary.
- Withdraw sample of solution for counting, add additional metal ion + tracer, and contact again for 30 min.
- Repeat, as necessary, to complete isotherm.
- Count radionuclide concentrations in solution samples; calculate concentrations in soil samples.
- Calculate Rs values and plot isotherm.

---

[a] Details of experimental protocol are presented in Appendix B.

4.1.2 Constant-pH Sorption Isotherms

A series of radionuclide sorption/solubility tests in which the pH was held constant by the addition of acid or base was performed to supplement the information derived from the ambient-pH sorption tests and to provide additional data for the pathways analysis effort for the Environmental Impact Assessment. Sorption/solubility isotherms were determined for several radionuclides at constant-pH values of 3, 4, 5, 6, 7, and 8. The experimental protocol is summarized in Table 17; details of the procedure are described in Appendix B.

It should be noted that the contact time for each of the individual steps was limited to 30 min. This was necessary so that the unit sorption isotherm could be completed in a single working day. Rate studies for uranium and europium provided data which supported this short equilibration preriod as being within experimental error of steady-state conditions.

4.1.3 Computer Program for Calculating Rs and Rd Values

A computer program written by R. E. Meyer of the ORNL Chemistry Division was used in calculating the data reported in this document. This program, which is included in Appendix B, calculates the molar concentration of the radionuclide in both solution and sorbent phases, the log of these concentrations, and the Rs or Rd values.

4.2 SORPTION RATE DETERMINATIONS

4.2.1 Uranium

Effect of initial uranium concentration. Since the time allotted for the investigations described in this report was limited, many of the sorption tests had to be performed at contact times considered to be less than optimum for steady-state or equilibrium conditions. For this reason, investigation of the sorption rate was necessary to determine how the data might vary at the short contact times. Also, in the pH range of groundwater, hydrolytic reactions may occur with many metal ions which could either remove radionuclides from solution due to precipitation or, on the other hand, produce colloidal dispersions that could migrate as rapidly as the groundwater and appear to increase solubility or decrease sorption of the radionuclide. Reactions such as these may also be rate dependent.

Samples of composite soils from the site were contacted with uranium-spiked synthetic groundwater at a solution/solids ratio of 10 and an initial pH of 7 for periods of 1 h to 3 weeks. The sorption rate test was made at three initial uranium concentrations: 5, 1000, and 25,000 mg/L. The resulting Rs values increased only slightly above the value reached in 30 min. When uranium was present at a concentration of 5 mg/L initially, the Rs value increased from 4400 L/kg at 30 min to 5900 L/kg at 24 h [Fig. 1(a)]. When the initial uranium concentration was 1000 mg/L, the Rs value increased from 430 at 30 min to 5500 at 48 h [Fig. 1(b)]. When the initial uranium concentration was 25,000 mg/L, the Rs value increased from 130,000 at 1 h to 310,000 L/kg at 3 weeks. The latter Rs values are higher than normal due to higher-than-anticipated equilibrium pH values, but the data serve to emphasize that the relatively high uranium solubility (45 mg//L) achieved during this period of contact was probably due to

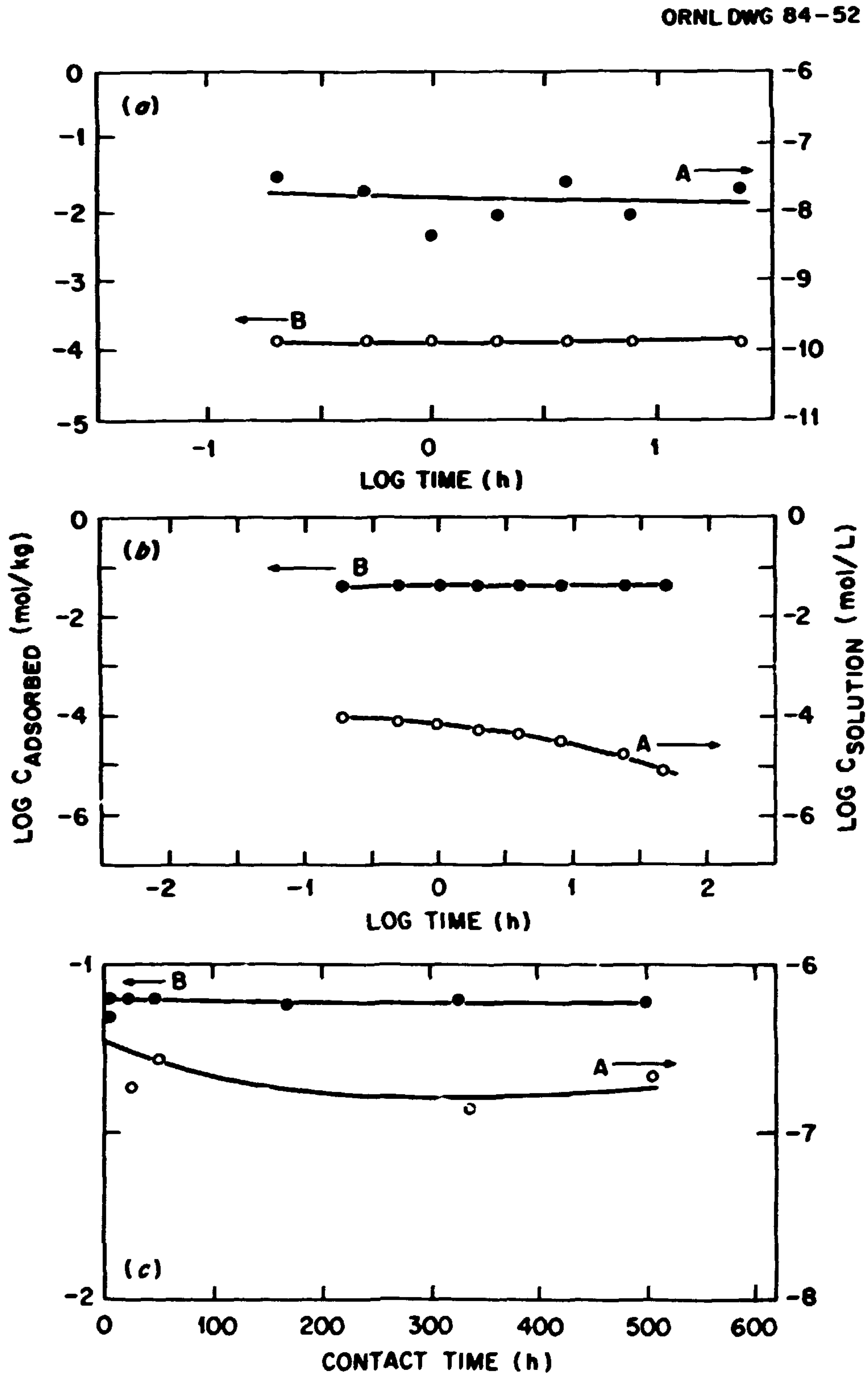


Fig. 1. Rate of uranium sorption for initial uranium concentration, in mg/L, of: (a) 5, (b) 1000, and (c) 25,000. Final concentration of uranium: (A) in solution and (B) adsorbed on the solids.

colloidal suspension. Details of the data for these sorption rate tests are shown in Tables C-1 through C-3 in Appendix C.

In order to place the sorption/precipitation rate data in proper perspective, Fig. 2 presents the results from the case in which the greatest increase in Rs values occurred, namely the test in which the initial uranium concentration was 1000 mg/L. At the 30-min contact time, ~99.8% of the total uranium had been removed from solution.

Effect of ionic strength. The groundwater in the Chestnut Ridge area contains very low concentrations of dissolved minerals, making it highly unbuffered. Therefore, uranium sorption rate determinations were made to test the effect of adding dissolved salt to the synthetic groundwater (i.e., to increase the ionic strength) on uranium sorption/precipitation kinetics. Samples of synthetic groundwater containing uranium at a concentration of 1000 mg/L and a ^{233}U tracer were contacted with samples of composite soil at a solution/solids ratio of 10 at a constant pH of 7 for periods of 10 min to 48 h. Data showing the concentration of uranium in both the solution and the solid phases as a function of contact time are presented in Fig. 3. Details of the experimental results, listed in Tables C-4 and C-5 in Appendix C, indicate a moderate increase in uranium Rs values at contact times less than 8 h. The mean Rs values for the first 4 h of contact were: (1) 698 ± 198 L/kg in the test with no NaCl in the groundwater, and (2) 1200 ± 141 L/kg in the test in which 0.5 M NaCl was added to the groundwater. Although this difference is not a very significant increase, it does serve to show that higher-ionic-strength solutions could provide an initial increase in the sorption rate.

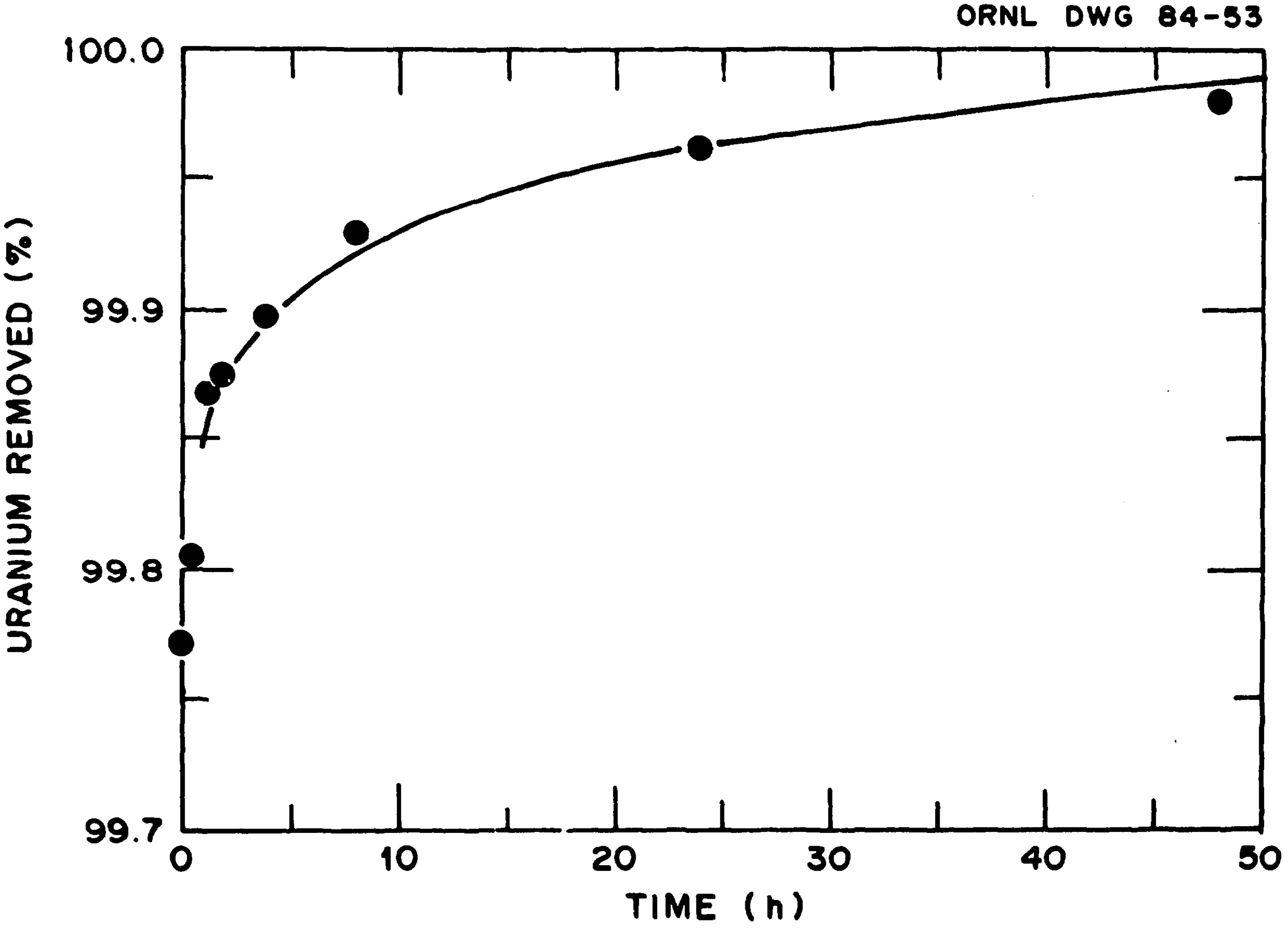


Fig. 2. Rate of uranium sorption/precipitation for initial uranium concentration of 1000 mg/L.

ORNL DWG 84-54R

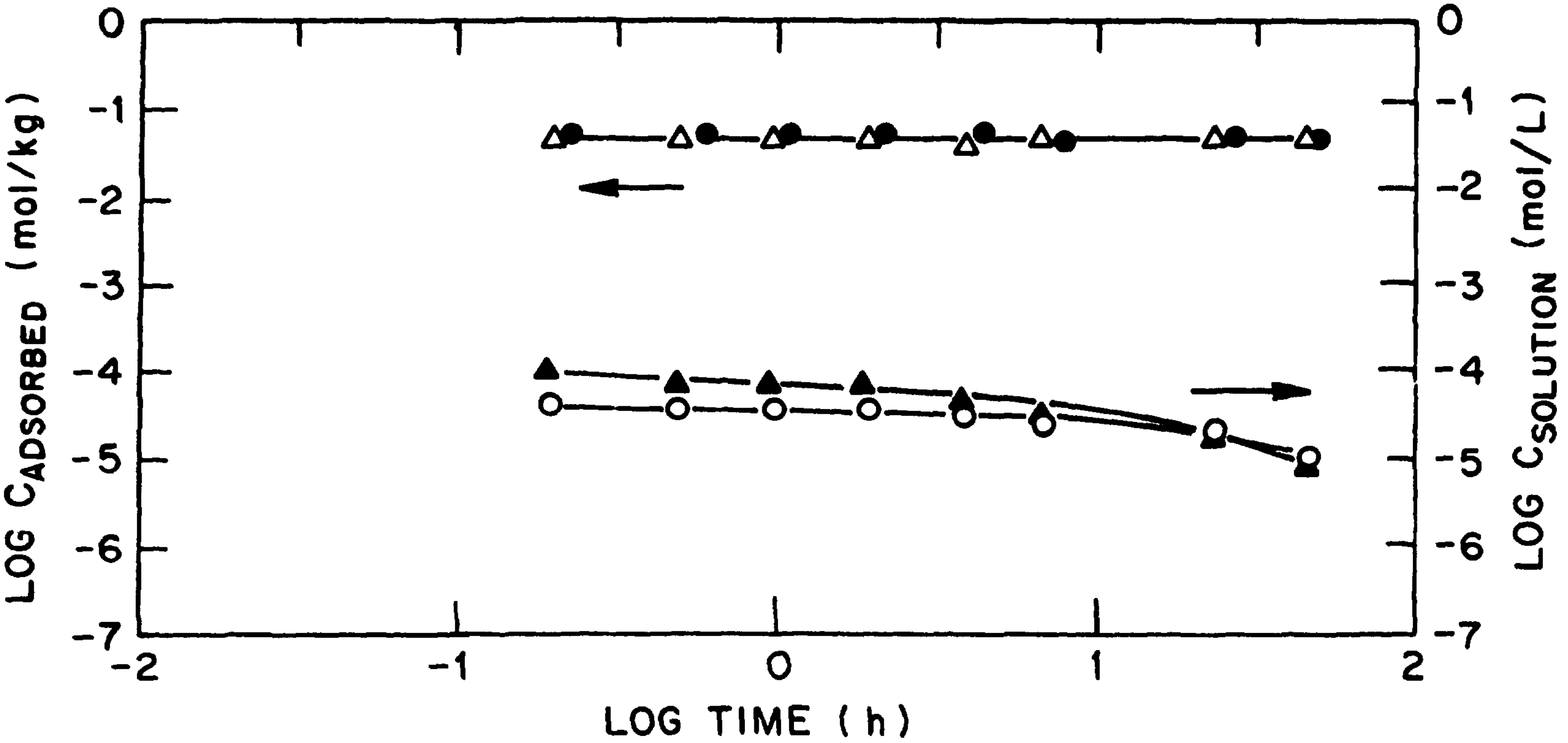


Fig. 3. Effect of ionic strength on rate of uranium sorption/precipitation for initial uranium concentration of 1000 mg/L. Constant pH of 7.0 maintained. Concentration of NaCl in the groundwater: (○) and (●), 0.0 *M*; (△) and (▲), 0.5 *M*.

Although there is an increase in the Rs value with time, 99.8% of the total uranium present was removed from the solution by either sorption or precipitation in the first 10 min of contact. A total of 99.98% of the uranium was removed from solution after 48 h of contact.

4.2.2 Europium

The europium sorption rate was determined by batch contacts of synthetic groundwater containing europium at an initial concentration of 5 mg/L plus ^{152,154}Eu tracer with composite soil from West Chestnut Ridge at pH 7 for periods of 30 min to 48 h. The resulting data are shown in Fig. 4, and details of the data are given in Table C-6 in Appendix C. The sorption rate showed a gradual increase (30,000 L/kg to 70,000 L/kg) over the 48-h period. The amount of the radionuclide removed from solution in the first 30 min was 99.997% of the total europium present.

4.3 AMBIENT-pH SORPTION ISOTHERM DETERMINATIONS

In a highly unbuffered groundwater/soil system such as that which exists in the Chestnut Ridge area, any metal-ion sorption reaction may cause significant reduction in equilibrium pH values due to the exchange of the metal ion with hydrogen on the active sites on the clay particle surfaces. Thus, in the tests reported in this section, pH values ranged from 7 down to 4, depending on the total amount of the radionuclide adsorbed. No attempt was made to control the pH in these tests; and, as a result, the sorption isotherm data are grouped relatively closely since all the soil samples show very similar sorption characteristics. The tests described in this section generally involve the following

ORNL DWG 84-55

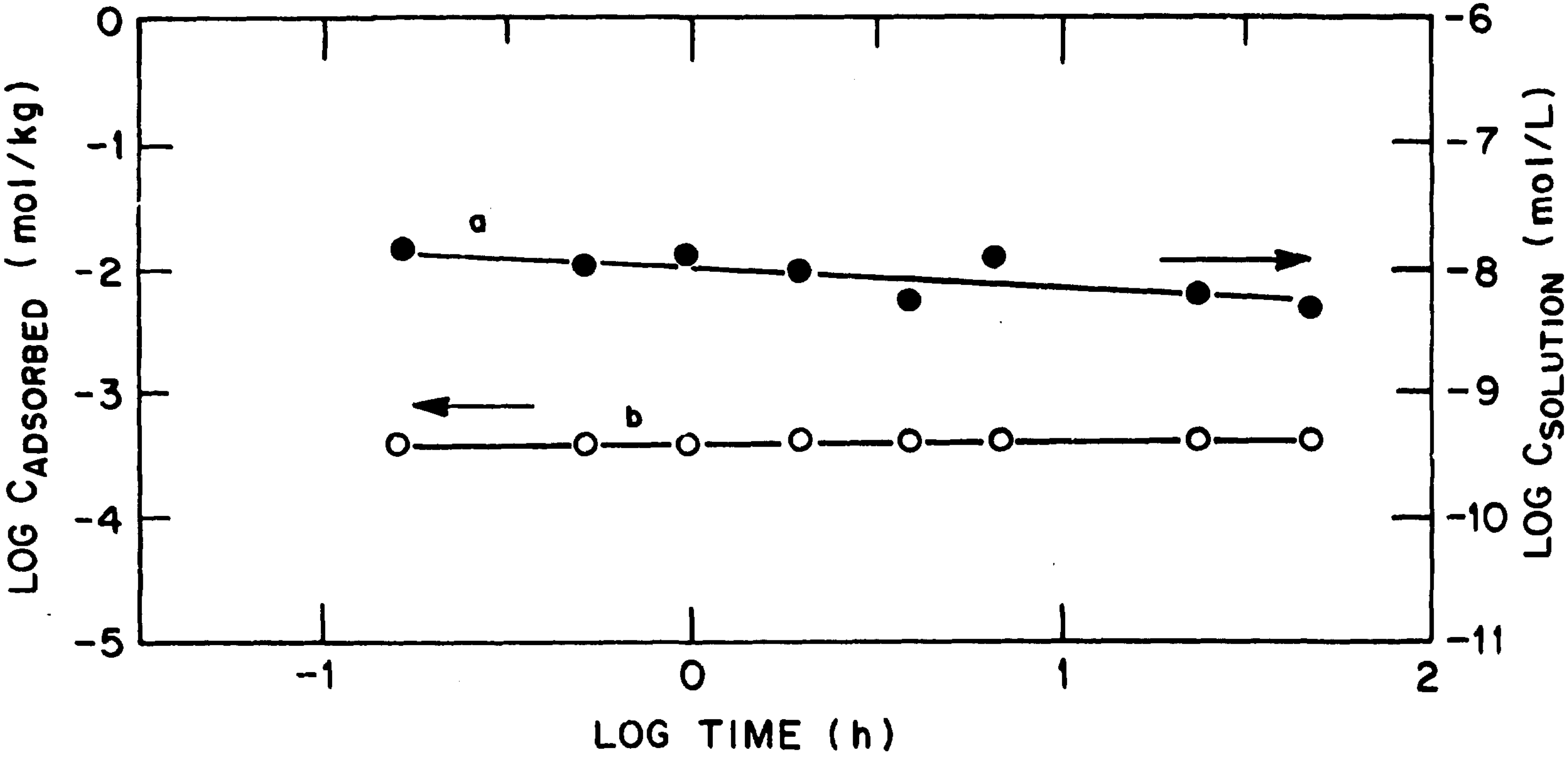


Fig. 4. Rate of europium sorption for initial europium concentration of 5 mg/L. Final concentration of europium: (a) in solution and (b) adsorbed on the solids.

procedure, which is summarized in Table 17. Synthetic groundwater containing the desired concentration of the radionuclide and an appropriate tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. Details of the experimental protocol for these tests are presented in Appendix B. Tests designed to determine the effect of pH on the sorption of radionuclides by maintaining a constant pH at several desired levels are discussed in Sect. 4.7.

4.3.1 Uranium

The conventional practice in conducting site-specific sorption and solubility experiments is to employ groundwater from a well in the geologic member of interest. Since groundwater was not available from the West Chestnut Ridge site, synthetic groundwater was used. The preparation and analysis of the synthetic solution are described in Sect. 3.2.2. Natural groundwater that has been in contact with well-leached soil will contain few soluble species, resulting in a highly unbuffered solution. In the sorption tests for uranium (and other radionuclides) described in this section, contact was made by placing 1.0 g of solid in a 16-mL centrifuge tube equipped with a tight-fitting cap and adding 10 mL of synthetic groundwater that contained the desired concentration of uranium (sulfate) plus ^{233}U tracer. After the tube had been flushed with argon (to minimize possible adsorption of carbon dioxide from air during the contact period), it was immediately capped and placed on a shaker for a period of 4 h. The sample was then centrifuged, and the clear supernate was sampled for analysis. The pH of this solution was measured and recorded as the ambient pH of the equilibrated system. This procedure is summarized in Table 17 and described further in Appendix B.

Uranium sorption isotherms were determined for three selected samples from each of two cores (B1 and B2) from the West Chestnut Ridge site. The experimental data for these sorption isotherms are summarized in Fig. 5 and are shown in detail in Tables D-1 through D-9 in Appendix D. At a low initial uranium concentration (i.e., 5 mg/L), the average sorption ratio (Rs) value was 3200 L/kg; the highest and lowest values were 25,000 and 250 L/kg, respectively (Table 18).

The data suggest that the West Chestnut Ridge soil has both a high capacity and a high binding capability for uranium. Nonideal sorption behavior of uranium may be expected because of the multiple species possible under the soil/groundwater conditions.

4.3.2 Strontium

Strontium sorption isotherms were determined for the three selected samples from each of two cores (B1 and B2) from the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of strontium plus ^{85}Sr tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. Details of the experimental protocol are listed in Appendix B. The resulting data are summarized in Fig. 6, and details are shown in Tables D-10 through D-15 in Appendix D. As in the tests with uranium, all the soil samples showed very similar sorption characteristics. In the tests with low initial strontium concentration

Table 18. Summary of radionuclide sorption data

Radionuclide (valence)	pH	Rs values[a] Range	(L/kg)
U(6+) (i.e., UO_2^{2+})	5.6 ± 1.0	Average	3.2E3
		High	2.5E4
		Low	2.5E2
Sr(2+)	6.0 ± 0.6	Average	6.9E2
		High	1.6E3
		Low	2.0E2
Cs(1+)	5.4 ± 0.7	Average	3.3E3
		High	1.1E4
		Low	1.1E2
Co(2+)	6.0 ± 1.0	Average	1.6E3
		High	7.9E3
		Low	7.1E1
Eu(3+)	5.0 ± 0.7	(One only)	---
		High	6.1E4
		Low	6.4E1
Th(4+)	4.0 ± 0.7	(One only)	---
		High	1.1E4
		Low	5.4E0
Tc(1-)	5.1 ± 0.2	(One only)	---
		High	1.6E0
		Low	1.0E0
I(1-)	5.8 ± 0.6	Average	1.8E-1
		High	1.8E0
		Low	1.4E-2

[a] Rs values are derived from contacts with low initial concentrations of the radionuclide (i.e., 5 mg/L).

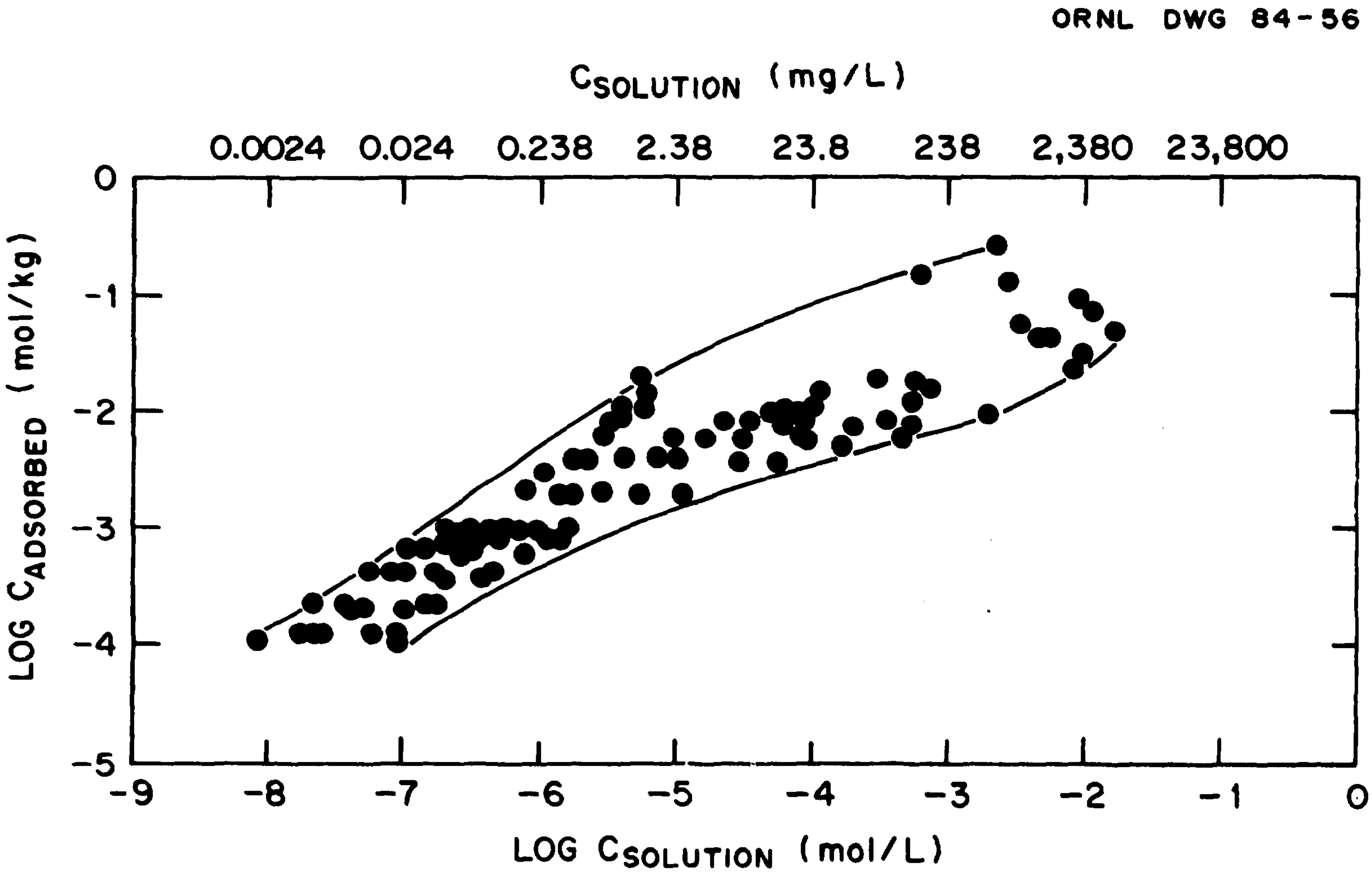


Fig. 5. Summary of uranium sorption isotherm data for soil samples from the West Chestnut Ridge site as determined by the ambient-pH method.

ORNL DWG 84-58

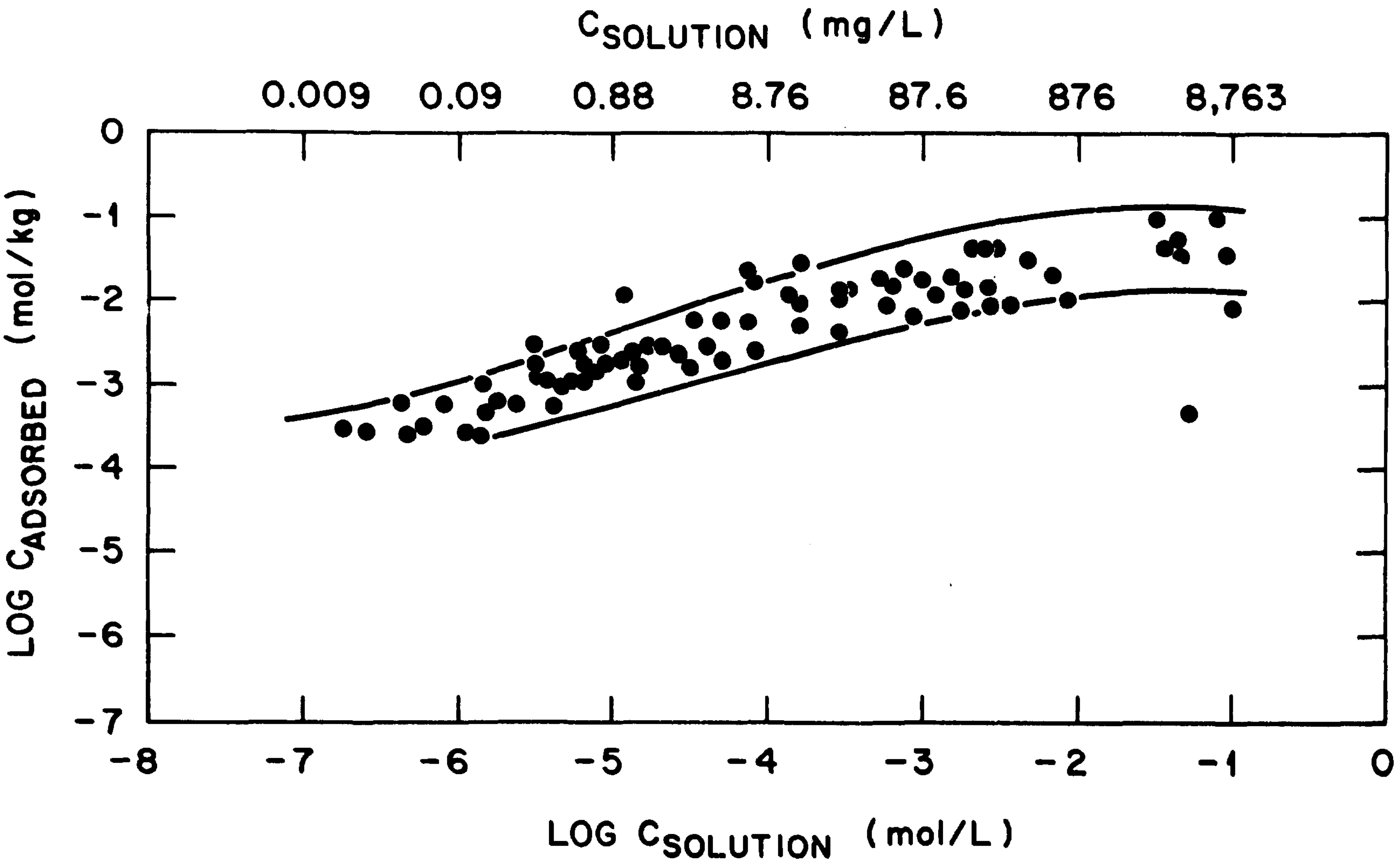


Fig. 6. Summary of strontium sorption isotherm data for soil samples from the West Chestnut Ridge site as determined by the ambient-pH method.

(i.e., 5 mg/L), an average Rs value of 690 L/kg was obtained; the values ranged from a high of 1600 L/kg to a low of 200 L/kg (Table 18).

4.3.3 Cesium

Cesium sorption isotherms were determined for the three selected samples from each of two cores (B1 and B2) from the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of cesium plus ^{134}Cs tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. The experimental protocol is included in Appendix B. The resulting data are summarized in Fig. 7, and details are listed in Tables D-16 through D-21 in Appendix D. Again, the soil samples showed very similar sorption characteristics, indicating good uniformity of the soil to the depth of their removal. At low initial cesium concentrations (i.e., 5 mg/L), an average Rs value of 3300 L/kg was obtained in these tests; the values ranged from a low of 110 L/kg to a high of 11,000 L/kg (Table D-18).

4.3.4 Cobalt

Cobalt sorption isotherms were determined for the three selected samples from each of two cores (B1 and B2) from the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of cobalt plus ^{60}Co tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. Details of the experimental protocol are listed in Appendix B. The resulting data are summarized in Fig. 8, and details are shown in Tables D-22 through D-27 in Appendix D. As can be seen in Fig. 8,

ORNL DWG 84-59

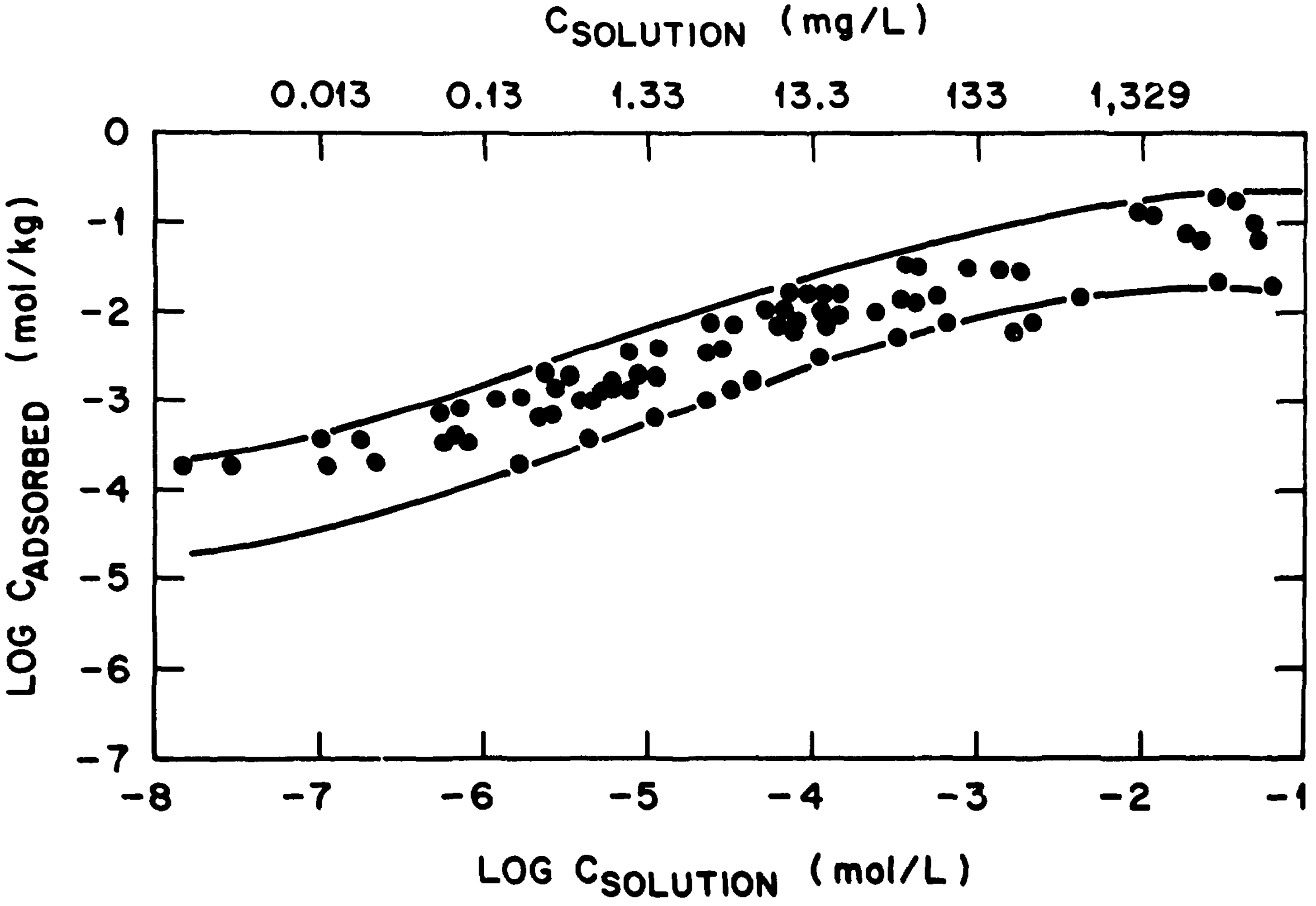


Fig. 7. Summary of cesium sorption isotherm data for soil samples from the West Chestnut Ridge site as determined by the ambient-pH method.

ORNL DWG 84-60

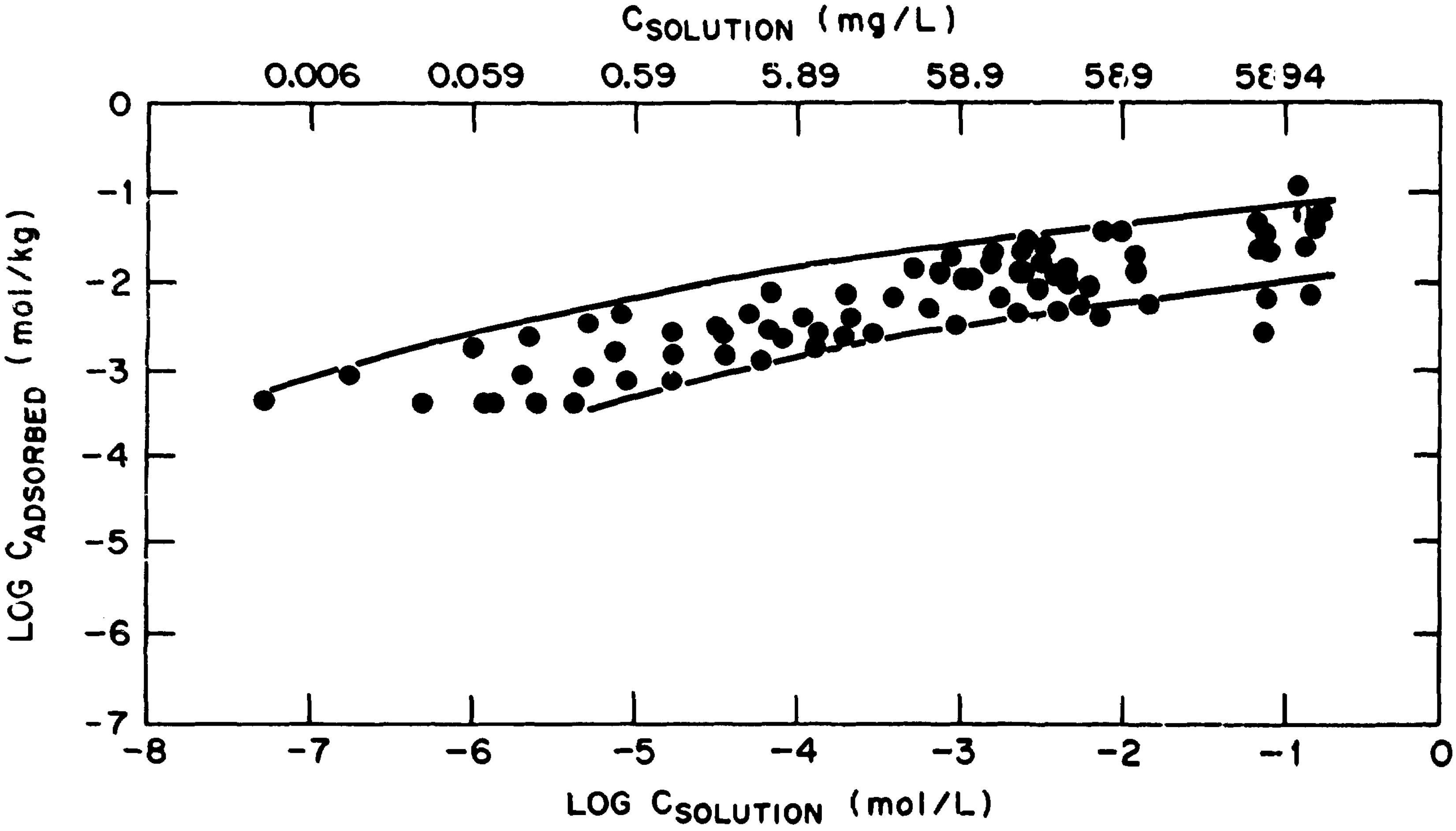


Fig. 8. Summary of cobalt sorption isotherm data for soil samples from the West Chestnut Ridge site as determined by the ambient-pH method.

the data are also closely grouped over the entire range of the sorption isotherm, confirming the uniformity of the site soil. At low initial cobalt concentration (5 mg/L), an average Rs value of 1600 L/kg was obtained in these tests; the high and low values were 7900 and 710 L/kg, respectively (Table 18).

4.3.5 Europium

Only one europium sorption isotherm was determined, and that was for soil from core sample B2-60 at the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of europium plus ^{152,154}Eu tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. Details of the experimental protocol are listed in Appendix B. The experimental data are shown in Fig. 9 and are listed in Table D-28 in Appendix D. At low initial europium concentration (5 mg/L), an Rs value of 61,000 L/kg was obtained. At high initial concentration (1000 mg/L), the Rs value decreased to 64 L/kg (Table 18).

4.3.6 Thorium

Only one thorium sorption isotherm was determined, and that was for soil from core sample B2-60 from the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of thorium plus ^{230}Th tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. The experimental data are shown in Fig. 10, and details are presented in Table D-29 in Appendix D. At low initial thorium concentration (5 mg/L), an Rs value of 11,000 L/kg was obtained; at high initial concentration (1000 mg/L), the Rs value decreased to 5.4 L/kg (Table 18).

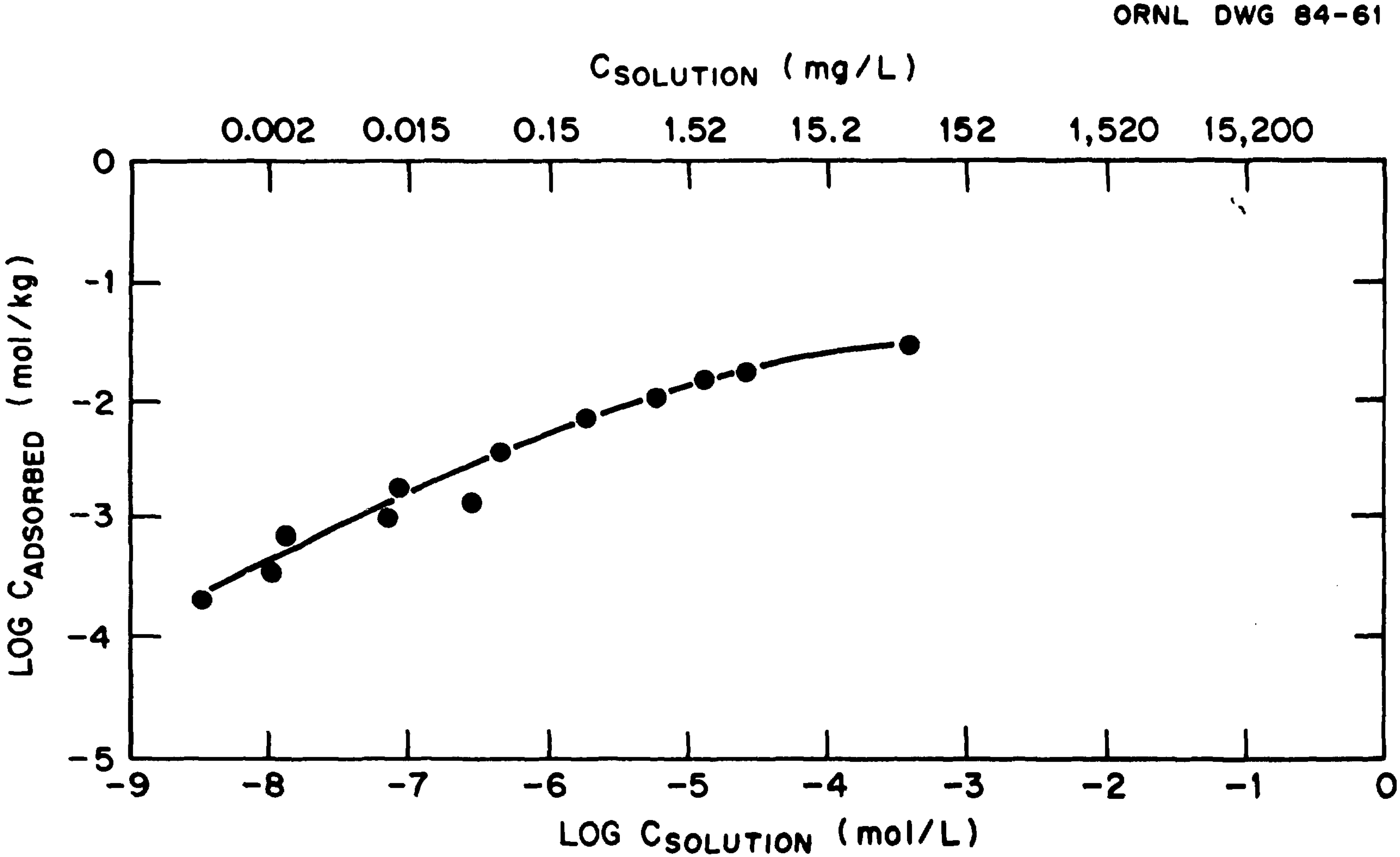


Fig. 9. Europium sorption isotherm data for soil sample B2-60 from the West Chestnut Ridge site as determined by the ambient-pH method.

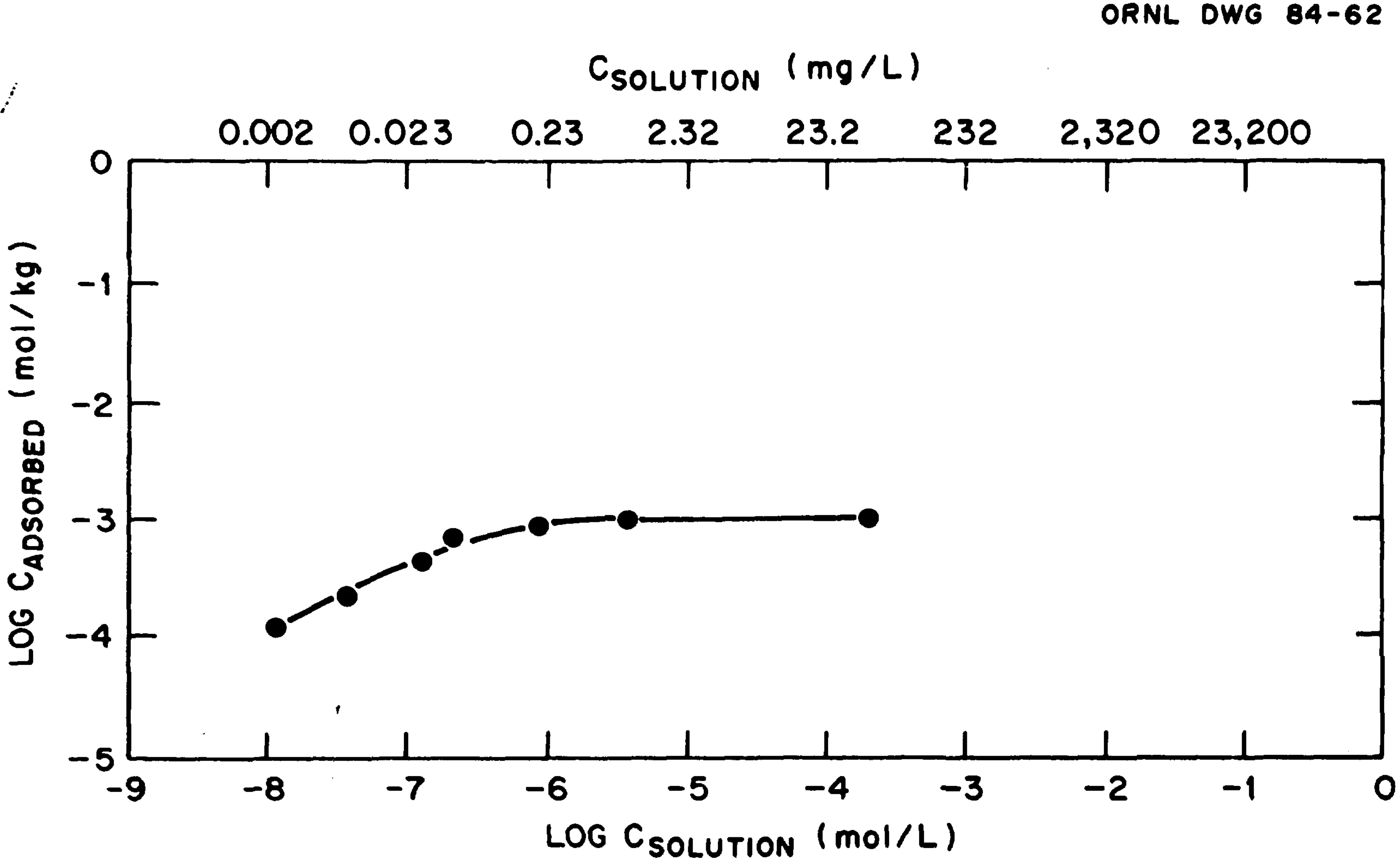


Fig. 10. Thorium sorption isotherm data for soil sample B2-60 from the West Chestnut Ridge site as determined by the ambient-pH method.

4.3.7 Technetium

Only one technetium sorption isotherm was determined, and that was for soil from core sample B2-60 from the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of ^{99}Tc plus ^{95}Tc tracer gamma activity was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. The data are shown in Fig. 11, and details are listed in Table D-30 in Appendix D. The Rs values were found to be very low (1.0 to 1.6 L/kg). Since technetium normally exists in solution as the pertechnetate anion, we were not surprised that it showed little affinity for the clay surface.

Sidall has reported[9] that a uranium-technetium complex is formed in tributyl phosphate solution. An experiment performed to determine whether this complex might be formed in contact with soil and lead to increased technetium sorption produced no higher Rs values than experiments with technetium alone. The data for this experiment are included in Table D-31 in Appendix D.

4.3.8 Iodine

Iodine sorption isotherms were determined for the three selected samples, each from core B1 and B2 from the West Chestnut Ridge site. Synthetic groundwater containing the desired concentration of iodine (as NaI) plus ^{131}I tracer was contacted with the clay soil sample at a solution/solids ratio of 10 for 4 h at ambient pH. The experimental data are summarized in Fig. 12, and details are given in Tables D-32 through D-37 in Appendix D. Under the conditions prevailing in the synthetic groundwater/soil system, the iodine would be expected to

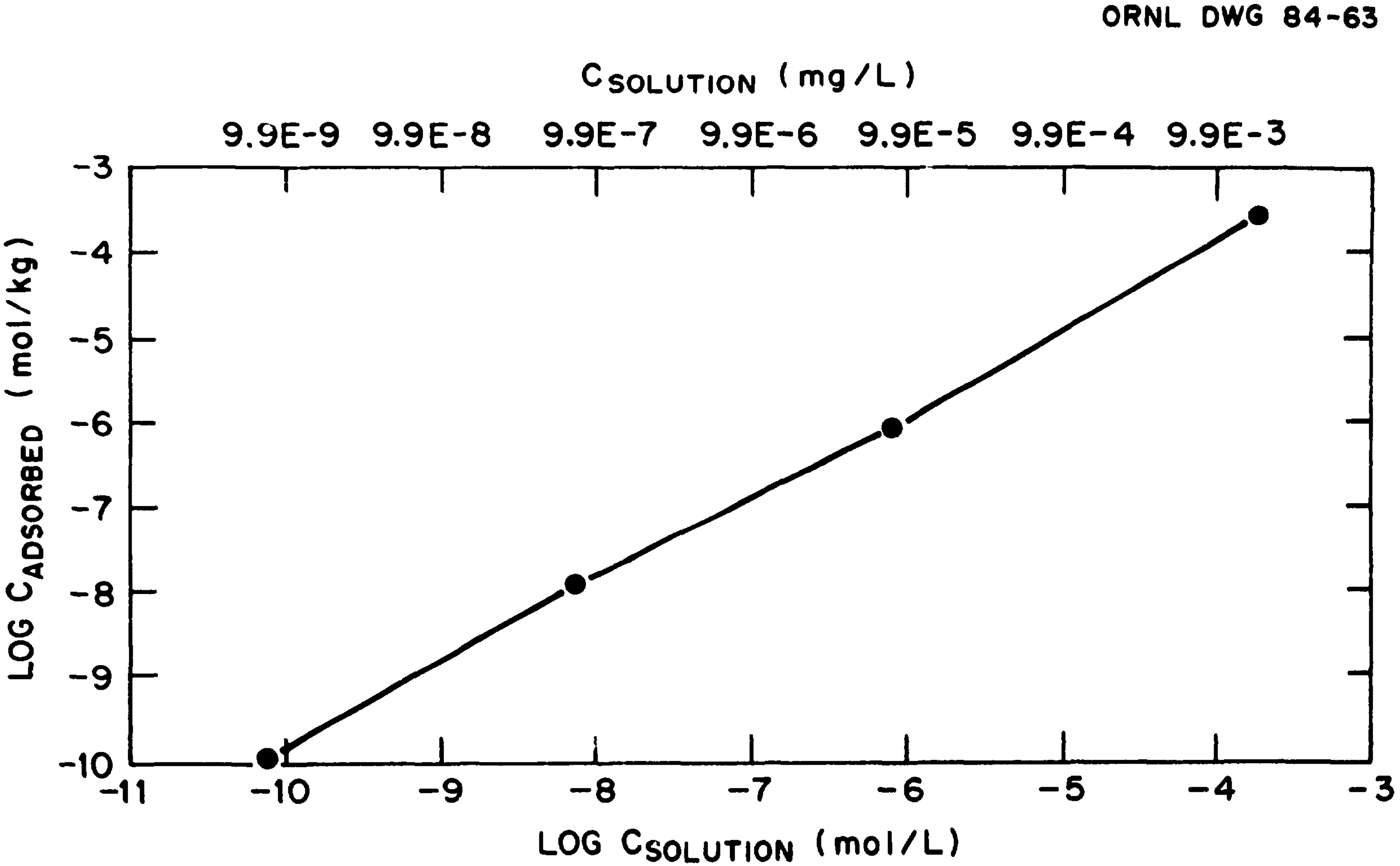


Fig. 11. Technetium sorption isotherm data for soil sample B2-60 from the West Chestnut Ridge site as determined by the ambient-pH method.

ORNL DWG 84-64

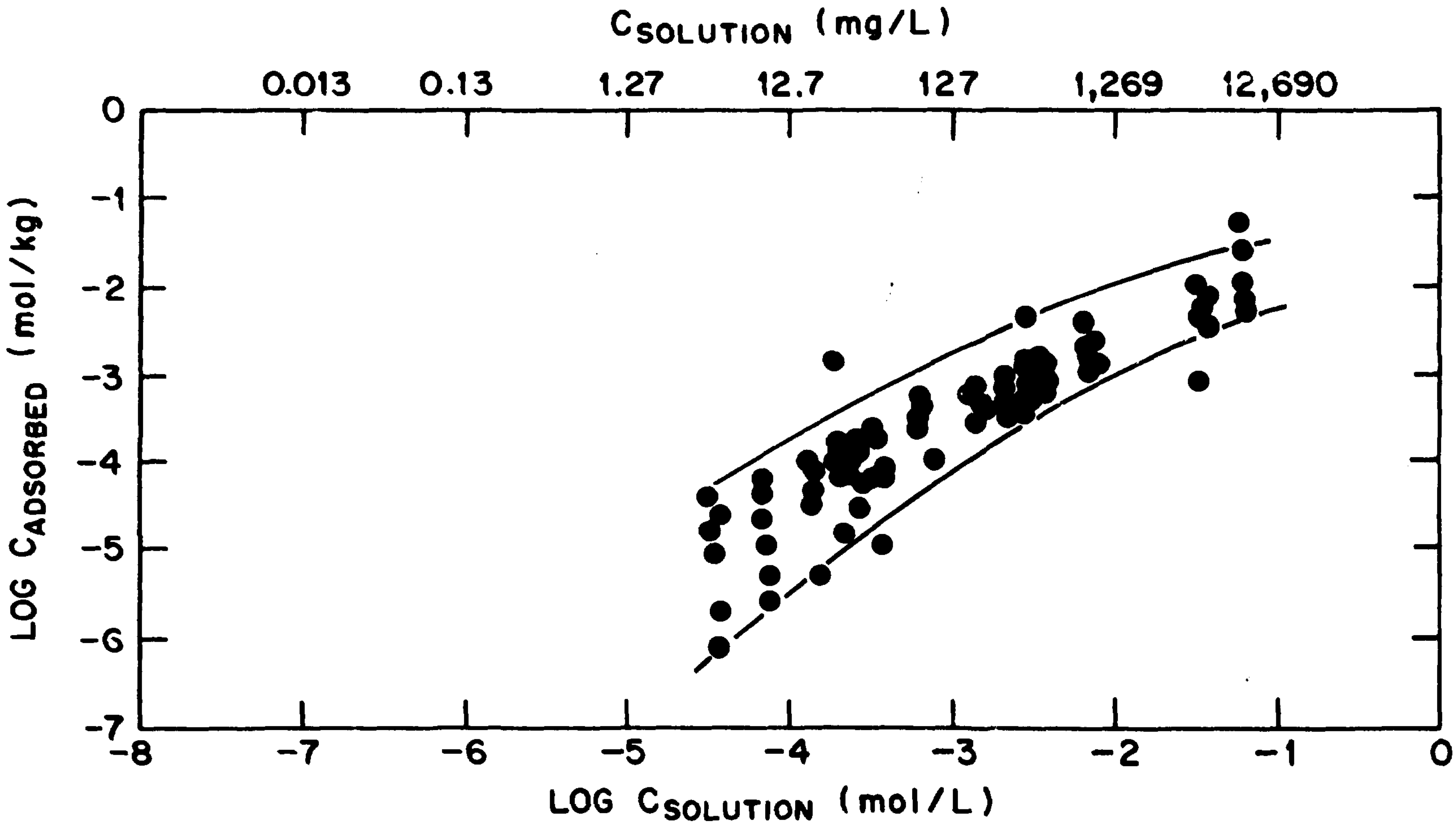


Fig. 12. Summary of iodine sorption isotherm data for soil samples from the West Chestnut Ridge site as determined by the ambient-pH method.

exist only as the iodide anion and, therefore, would show very little sorption on the clay soil. This was borne out by the data in Table 18, where the average Rs value was found to be only 0.18 L/kg at low initial iodine concentration (5 mg/L). The low and high Rs values were 0.01 and 1.8 L/kg, respectively.

4.4 DETERMINATION OF URANIUM DESORPTION ISOTHERMS UNDER AMBIENT CONDITIONS

As outlined in Sect. 2, the use of a sorption ratio (Rs) has been employed to avoid the inference of thermodynamic equilibrium. Although the sorption rate data, reported in Sect. 4.2, indicate that near-equilibrium or steady-state conditions were achieved, it would be reassuring to have confirming desorption tests to support this fact. If true chemical equilibrium does exist when a metal ion is adsorbed onto the surface of a solid, then desorption with fresh groundwater should give the same ratio of the metal-ion concentration in both phases as was obtained in the sorption cycle.
In other words,

$$Rs = Rd \ . \qquad (5)$$

Under these conditions, a desorption isotherm should lie superimposed on the initial sorption isotherm. Any disequilibrium would cause hysteresis in the two isotherms.

It was for this reason that uranium sorption and subsequent desorption isotherms were determined for soil from the West Chestnut Ridge site (B1-40). In these sorption/desorption tests, synthetic groundwater was prepared by contacting distilled water with soil from boring B1-40. Details of the method of preparation of groundwater are given in Sect. 3.2.2; the experimental protocol for the determination of sorption/desorption isotherms is described in Appendix B. A summary of the sorption behavior (Table 19) shows high Rs values (4700 L/kg) for low initial uranium concentration. Low Rs values (1.2 L/kg) were obtained for high initial uranium concentration. Desorption ratio values (Rd = 4200 L/kg) for low initial uranium concentration were approximately the same as the Rs values. Uranium sorption/desorption isotherms (Fig. 13) are essentially superimposable, showing that the systems are at, or very near, steady state. Thus, the Rs and the Rd values are nearly identical and are essentially equivalent to the Kd values. These high sorption and desorption ratios were obtained at the low uranium concentrations likely to be encountered under site migration conditions. The experimental data are summarized in Tables E-1 through E-5 in Appendix E. The computer program (see Appendix B) that was used in obtaining these data not only calculates the molar concentration of the radionuclide in both solution and sorbent phases, the log of these concentrations, and the Rs or Rd values, but also accounts for the solution holdup in the solids from the preceding contact and the accompanying correction needed for the initial radionuclide concentration in the successive contact.

4.5 URANIUM SORPTION ON DOLOMITE

Dolomite rock chips, obtained at the 23- to 41-m (75- to 135-ft) level from drilling operations at borehole B7 on West Chestnut Ridge were separated from a large quantity of accompanying chert.

Table 19. Summary of uranium sorption/desorption behavior for soil from West Chestnut Ridge

Soil sample	Sorption contact	Descorption contact	Initial conc.[a]	After contact pH	After contact Rs or Rd (L/kg)
B1-40	1	--	Low	7.1	4.7E3
			High	3.4	1.2E0
	--	1	Low	7.1	4.7E3
			High	3.4	4.9E1
	--	2	Low	7.3	5.4E3
			High	3.7	2.4E0
	--	3	Low	7.5	2.8E3
			High	3.9	1.1E1
	--	4	Low	7.9	3.9E3
			High	4.5	2.8E1

[a] Initial concentration: low = 5 mg/L; high = 10,000 mg/L.

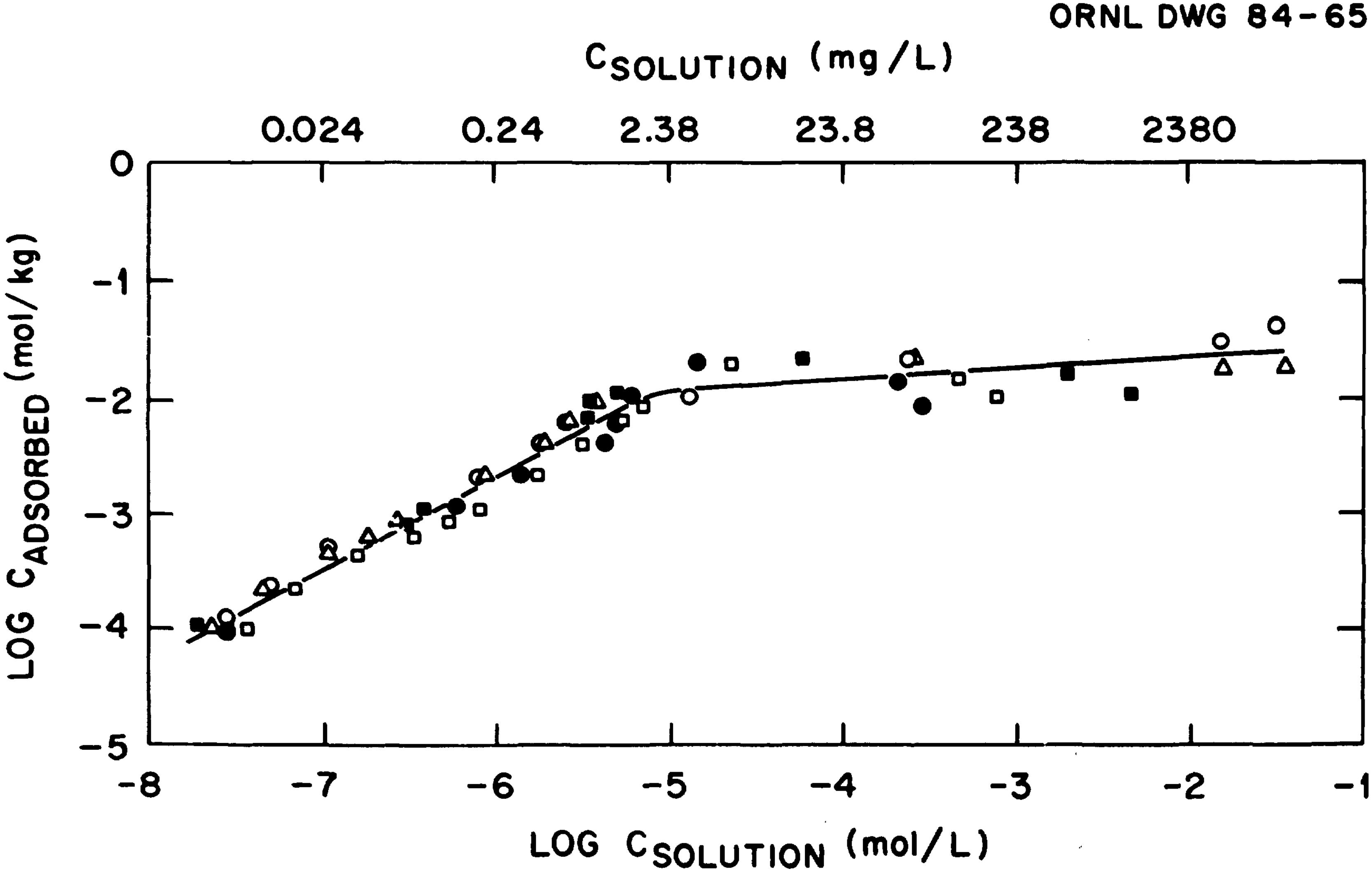


Fig. 13. Uranium sorption/desorption isotherm for soil sample B1-40 from the West Chestnut Ridge site as determined by the ambient-pH method: (○), sorption; (△), desorption-1; (■), desorption-2; (□), desorption-3; and (●), desorption-4.

Approximately 60 to 70 g of the dolomite was sized to -4 +12 mesh particles. The surface area of this material was measured by BET nitrogen adsorption surface area analysis and found to be 0.515 m^2/g. This rock has a density of 2.8 g/cm^3, and surface inspection revealed minimal voids. Uranium sorption isotherms were determined for two 10-g samples of this rock, one at natural pH (6.9 to 9.6) and one at constant pH (7.0) at a solution/solids ratio of 10. The experimental protocol used was the same as that described in Appendix B for the determination of constant-pH isotherms. The data, shown in Figs. 14(a) and 14(b), indicate a moderately effective removal of uranium from solution. This was surprising, considering that the uranium might be expected to be complexed as a soluble uranyltricarbonate species with carbonate from the rock. Mean Rs values of 288 ± 302 and 99 ± 29 L/kg were obtained for the tests at natural pH and constant pH, respectively. Details of the experimental data are shown in Tables F-1 and F-2 in Appendix F.

4.6 EFFECT OF pH ON THE SORPTION OF URANIUM ON MONTMORILLONITE

Batch contact sorption/solubility isotherms are useful in quantifying the sorption behavior of radionuclides as a function of concentration and also in revealing an apparent radionuclide solubility limit or saturated solution concentration when the experiments are conducted at sufficiently high radionuclide concentrations. Families of sorption/solubility curves are frequently prepared in order to quantify radionuclide behavior over a range of possible site pH parameters. In the tests reported in Sects. 4.3-4.5 of this report, the pH was allowed to attain a natural level in a steady-state condition

ORNL DWG 84-66

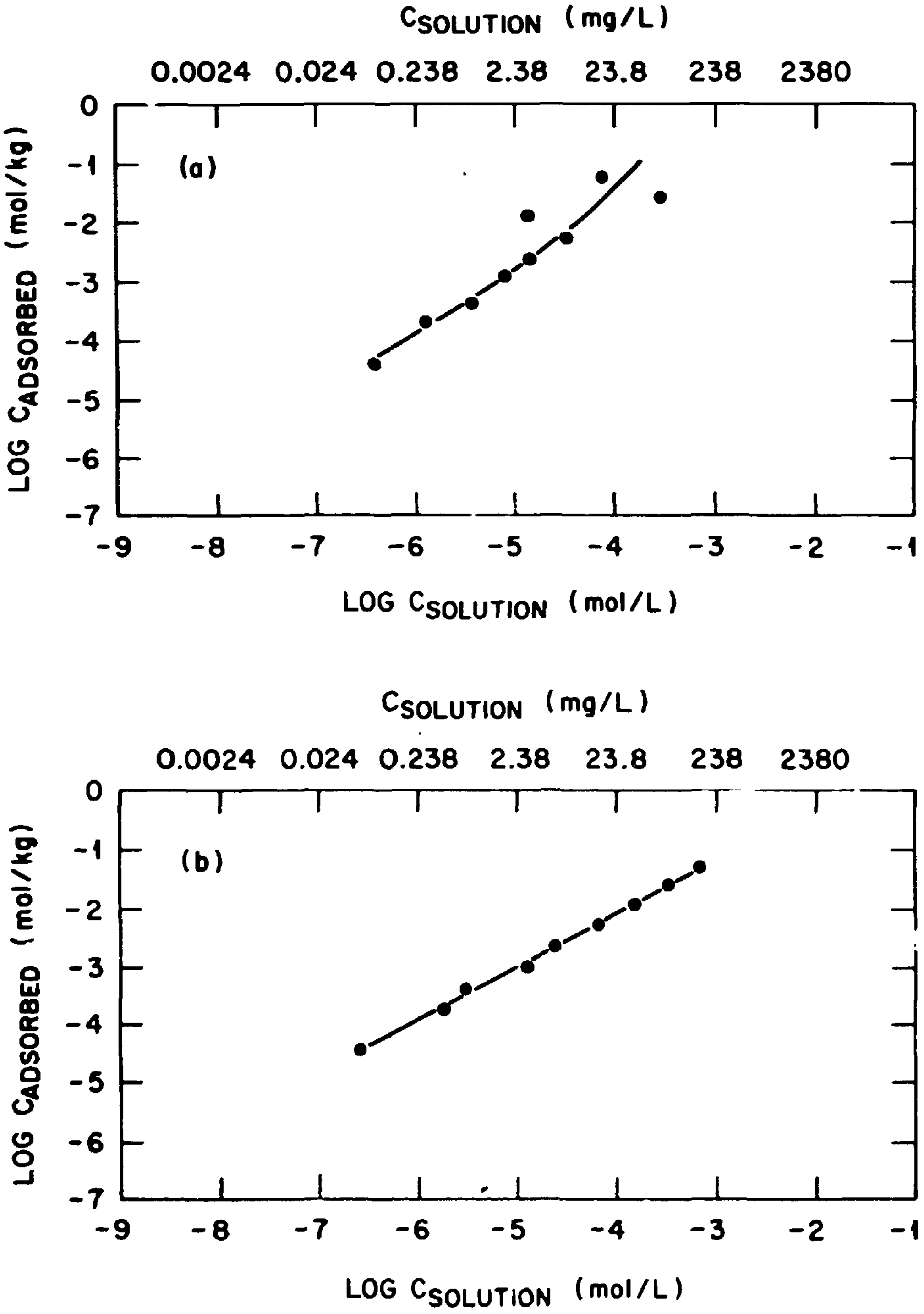


Fig. 14. Uranium sorption isotherms for dolomitic rock sample from the West Chestnut Ridge site as determined by: (a) the ambient-pH method (pH range 6.9 to 9.6) and (b) the constant-pH method (pH 7.0).

with the site soil and radionuclide-spiked synthetic groundwater. In most cases, the pH range was 4 to 6 (due to the highly unbuffered system) and, although the sorption reactions at this level gave high Rs values, it tended to preclude measurement of the expected solubility or concentration limits of the radionuclides since hydrolytic speciation would be minimal in this range. In pathways analysis calculations, not only is the Rs value (and subsequent site retardation factor) required, but also the solubility or concentration limitation of the radionuclide is of primary importance. To obtain this type of information, it is necessary to conduct sorption isotherm determination experiments in such a manner that the pH is controlled and constant during the test. An example of such an isotherm plot is shown in Fig. 15. Uranium was chosen for these tests because it exhibits a wide variety of multiple speciation. It will also be one of the major waste components at the CWDF. A relatively pure sodium montmorillonite from Wyoming was chosen for these tests.

In an effort to minimize the effect of carbonate, a titration method of equilibration was used to determine the Rs-vs-pH dependence. In this method, 10 g of the clay was mixed with 100 mL of synthetic groundwater (which contained a specific concentration of uranium plus ^{233}U tracer) under an argon atmosphere. The pH of the slurry was initially reduced to 3.0 (to remove any carbonate) and then adjusted to successive pH values of 4, 5, 6, 6.5, 7, 8, and 9. Samples of the slurry were removed at each pH adjustment level after a 15-min equilibration period and centrifuged; then the supernate was analyzed

ORNL DWG 84-67

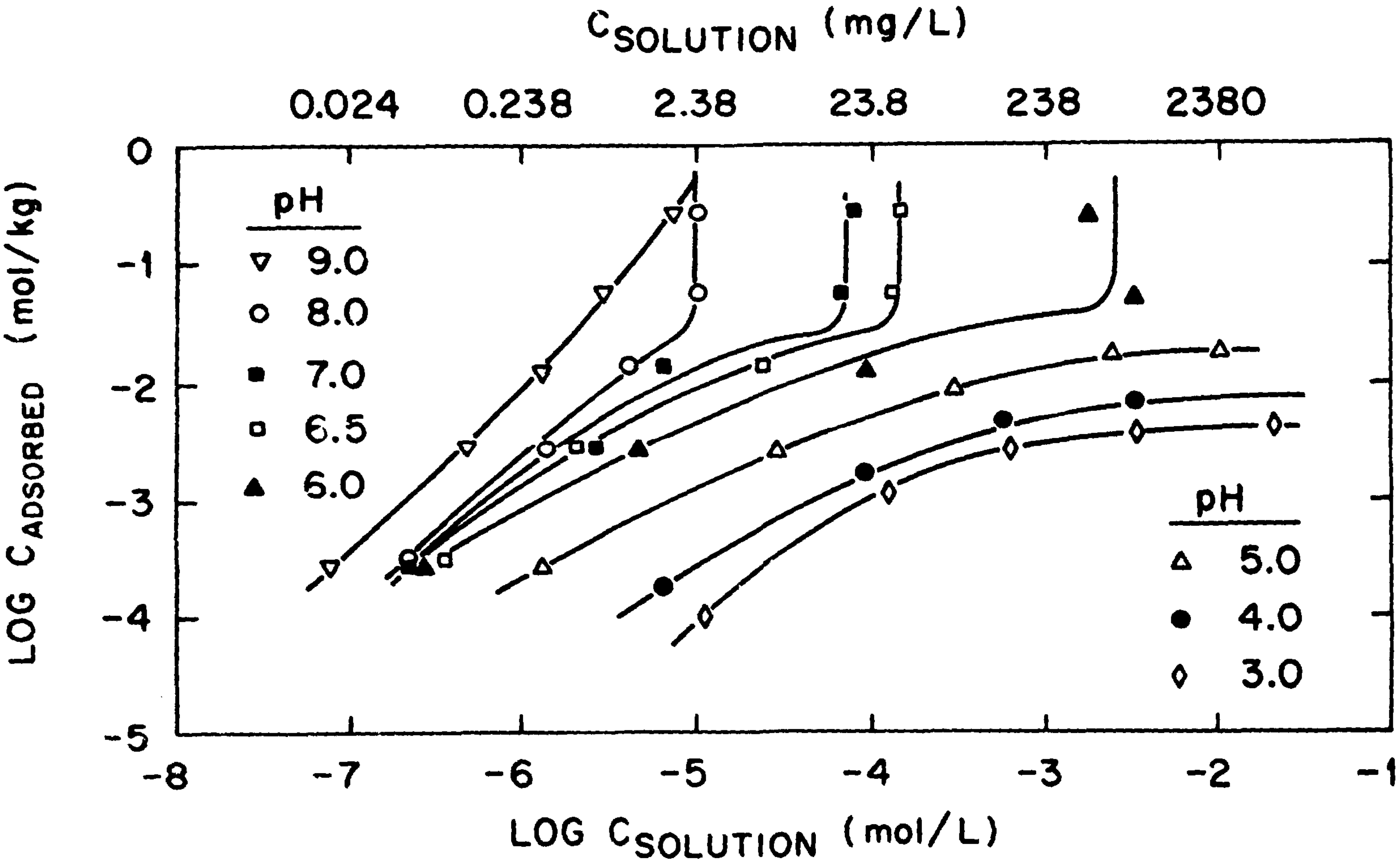


Fig. 15. Effect of pH on the sorption of uranium on montmorillonite.

for radionuclides. This procedure was repeated at several initial uranium concentration levels ranging from 5 to 5000 mg/L traced with ^{233}U. The isotherms shown in Fig. 15 were then constructed from these data. These isotherms show significant differences in uranium sorption/solubility behavior at various pH levels. At pH 3 to 5, where the uranyl ion is probably the dominant species, classic ion-exchange-type sorption isotherms were obtained and no apparent concentration limit was seen. At higher pHs, where more complex hydrolytic uranium species are probably present, the sorption behavior changed (Rs became larger) and apparent concentration limits were reached, at which point the plotted isotherm line became vertical. This vertical portion of the curve was used to experimentally establish the saturated solution concentration. At pH 8 to 9, a limiting concentration of ~2 mg/L was observed.

4.7 CONSTANT-pH SORPTION/SOLUBILITY ISOTHERM DETERMINATIONS WITH SITE SOIL AND SYNTHETIC GROUNDWATER SYSTEM

A detailed description of the experimental method for determining constant-pH sorption isotherms is given in Appendix B. This method was designed to obtain a maximum amount of information in a limited time.

4.7.1 Uranium

Six uranium sorption/solubility isotherms were determined at pH levels of 3, 4, 5, 6, 7, and 8. The data for the six isotherms are summarized in Fig. 16, and details of the experimental data are listed in Tables G-1 through G-6 in Appendix G. These data show that at low

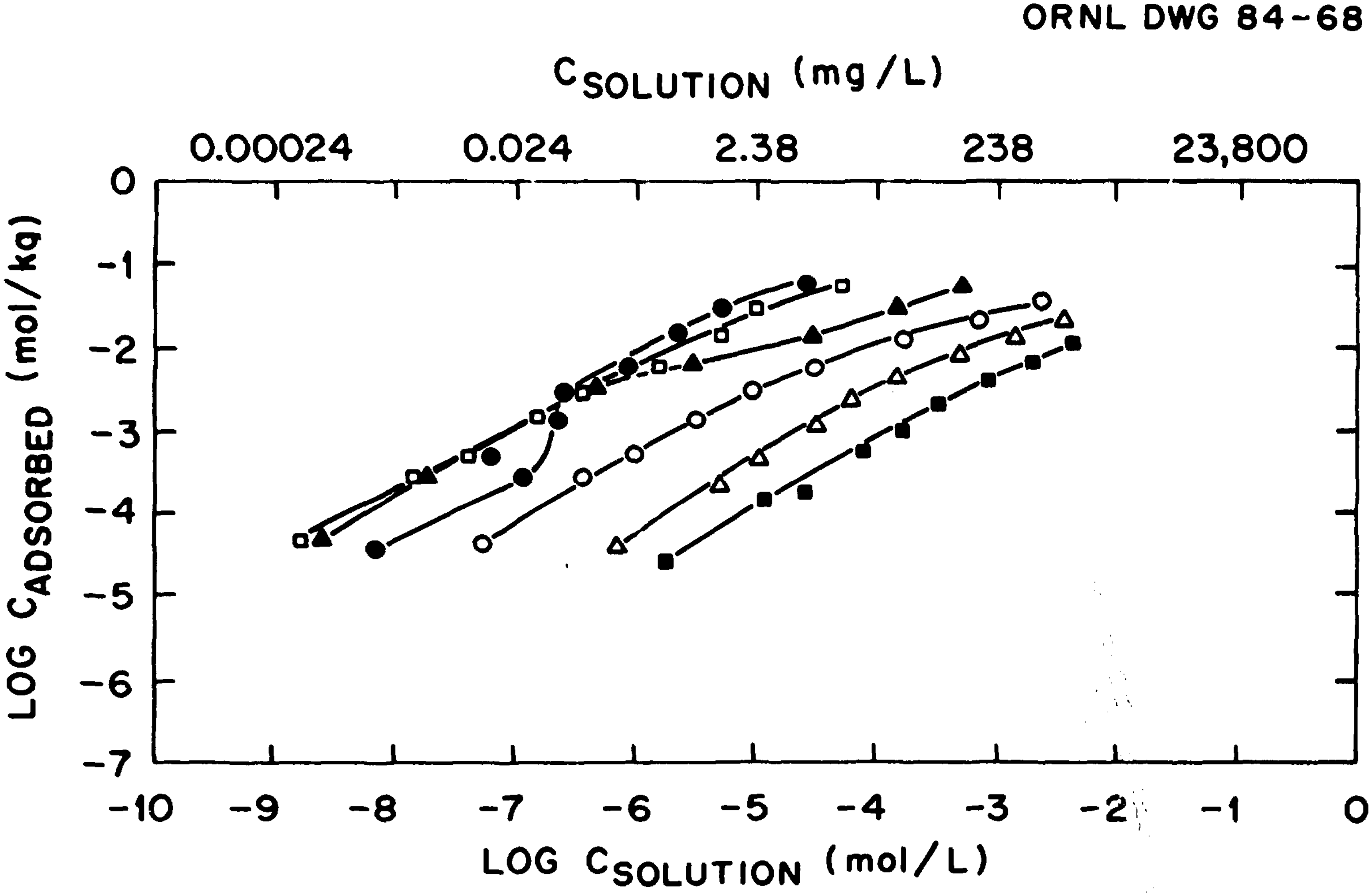


Fig. 16. Uranium sorption isotherms for composite soil sample from the West Chestnut Ridge site as determined by the constant-pH method. Contact pH: (■), 3.0; (△), 4.0; (○), 5.0; (●), 6.0; (▲), 7.0; and (□), 8.0.

initial uranium concentration the Rs values increase as the pH level increases, and that the Rs values are generally higher at higher pH levels. Rs values of >20,000 L/kg were encountered at low initial uranium concentrations; at higher concentrations, the values were still as high as 1000 L/kg. These are the highest Rs values that we have observed for uranium sorption onto natural materials and suggest the existence of very favorable uranium retardation characteristics for the West Chestnut Ridge disposal site. In Fig. 17, the log of the Rs value is plotted as a function of equilibrium pH at three different initial uranium concentrations. These data indicate that the Rs values appear to reach a maximum at a pH of ~7 at the lower initial uranium concentrations.

No apparent concentration limit was identified in any of the six experiments. This absence of a limit could result from: (1) slow precipitation reaction kinetics in the unbuffered, low-ionic-strength groundwater characteristic of the site; (2) failure to reach sufficiently high uranium concentrations in solution after contact, due to the high uranium sorption capacity of the soil and/or formation of soluble uranium complexes; or (3) possible formation of colloidal dispersions. Adsorbed uranium concentrations as high as 1.4 g per kg of soil were obtained. Again, such high sorption capacity values suggest that the site has favorable uranium retardation characteristics.

Uranium is known to form soluble complexes with certain anions (e.g., phosphate, fluoride, and silicate) that may be present in

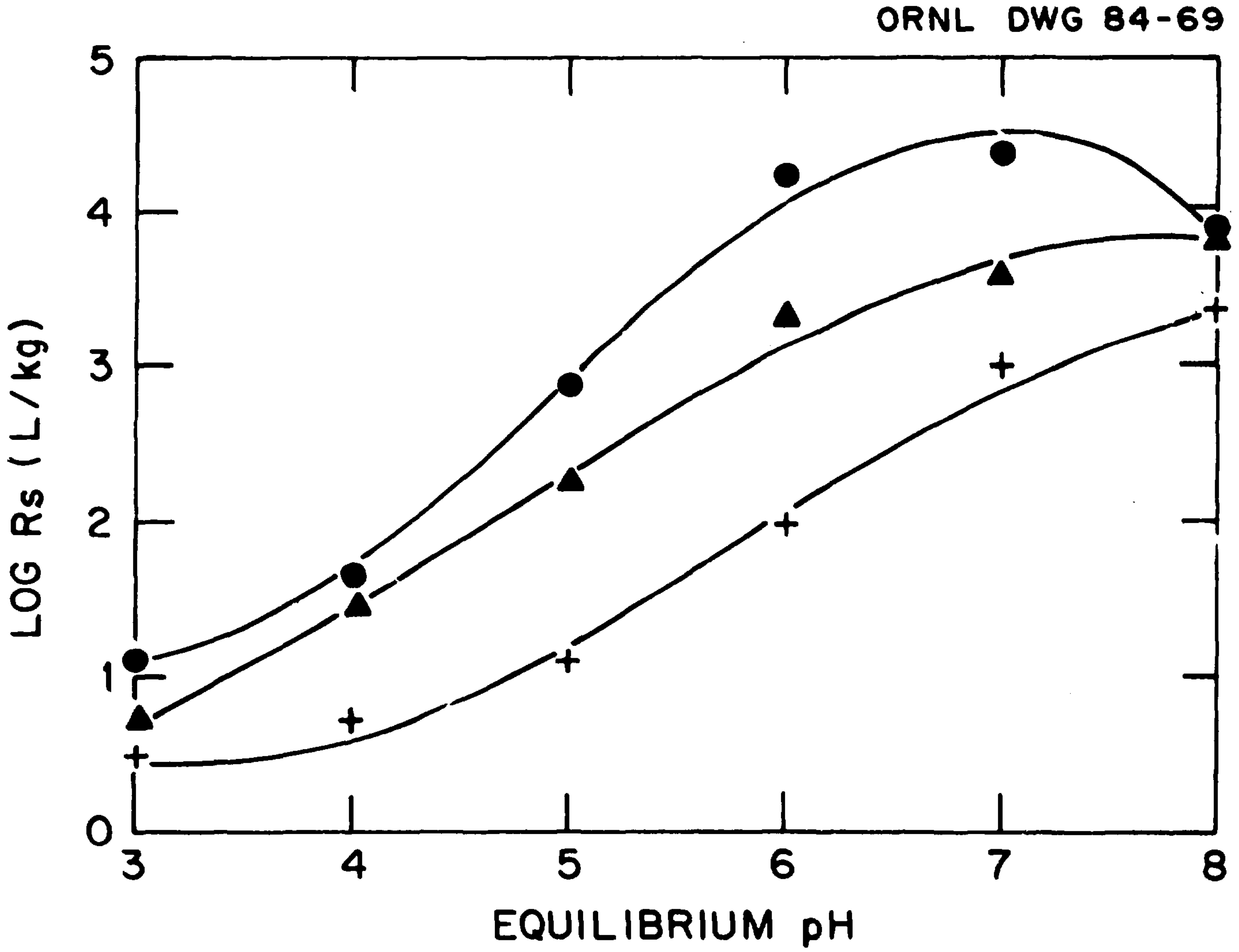


Fig. 17. Effect of pH on the sorption of uranium on composite soil sample from the West Chestnut Ridge site. Initial uranium concentration, in mg/L: (●), 1; (▲), 100; and (+), 1000.

groundwaters.[10] Analysis of the perched water table groundwater encountered at Central Chestnut Ridge did not reveal detectable quantities of fluoride or phosphate, but analysis of surface waters from the West Chestnut Ridge area showed concentrations of 5×10^{-5} mol/L and 4×10^{-5} mol/L, respectively. These concentrations are near the detection limit for the analytical method used and cannot be unequivocably accepted as accurate without further confirmation; however, if such concentrations of fluoride and/or phosphate were present in the synthetic groundwater used in these tests, they could account for some, and possibly all, of the uranium (3×10^{-5} to 5×10^{-5} mol/L) in solution after the highest-uranium-concentration contacts. Thus, it is at least possible that the failure to determine an apparent concentration limit in the sorption/solubility isotherm tests may accurately represent the solubility of uranium complexed as UO_2F^+ and/or $UO_2PO_4^-$. Additional work would be required to establish an understanding of the uranium solubility in the West Chestnut Ridge system.

A brief attempt was made to determine whether an increase in both initial uranium concentration and contact time might show some apparent concentration limitation. A uranium sorption isotherm determined at constant pH 7.0 was repeated and extended to include initial uranium concentrations as high as 25,000 mg/L. The resulting data, Fig. 18 (details are given in Table G-7 in Appendix G), show a considerable amount of scatter, which could stem from several possible sources: (1) increased multiple speciation, (2) peptization of the

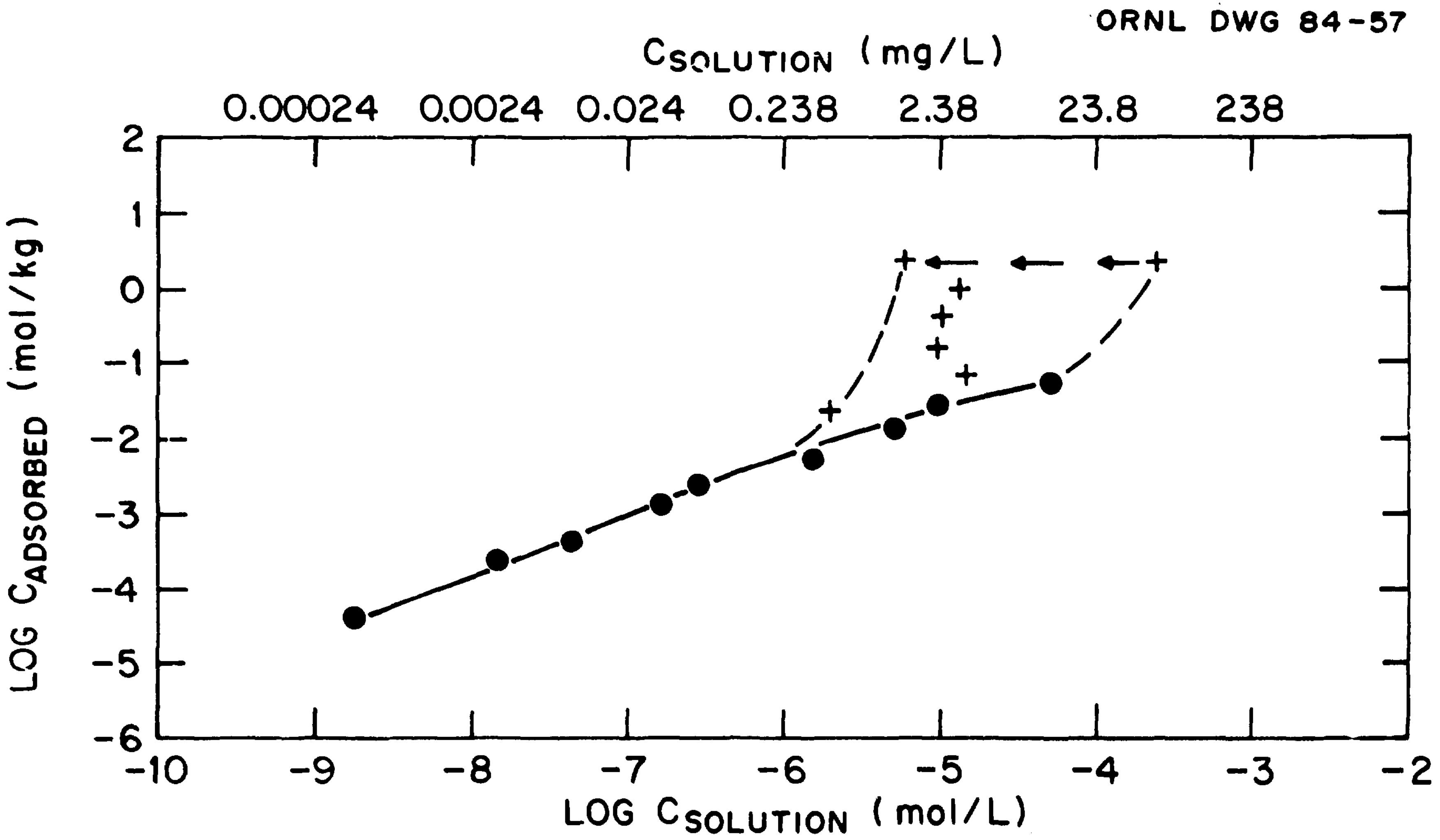


Fig. 18. Effects of increased initial uranium concentration and contact time on uranium sorption/precipitation isotherm. Contact time: (●) 30 min and (+) 24 h; initial uranium concentration, 25,000 mg/L.

precipitate, and/or (3) formation of colloidal precipitate suspensions. However, these data do begin to show the upward swing of the isotherm, indicating a solubility limit. In this case, at an initial uranium concentration of 25,000 mg/L the solubility limit appeared to be 75 mg/L after the normal 30-min contact but decreased to 14 mg/L after an additional 20-h contact. The Rs value for uranium at this point was 320,000 L/kg. These results suggest that the test should be extended in such a manner that a more accurate value could be obtained for the solubility limit for uranium in this system. Therefore, samples of groundwater spiked to obtain a uranium concentration of 25,000 mg/L and traced with ^{233}U were contacted with samples of the composite soil at a solution/solids ratio of 10 at pH 7 for periods of up to 3 weeks. The results of these tests were inconclusive. Although the final pH had increased slightly above the target pH value of 7, the Rs values were approximately the same after 3 weeks (310,000 L/kg) as those observed at 20 h. The solubility limit after 3 weeks was 45 mg/L. Again, this increase over that which was obtained at 20-h contact time may have been due to the formation of a colloidal suspension.

4.7.2 Strontium

Six strontium sorption/solubility isotherms were determined at pH levels of 3, 4, 5, 6, 7, and 8. The experimental data for these isotherms are summarized in Fig. 19, and details of the data are listed in Tables G-8 through G-13 in Appendix G. All of the sorption isotherms show a definite upward trend at high initial strontium concentration. Surprisingly, this trend occurs at a common point of

ORNL-DWG 84-70

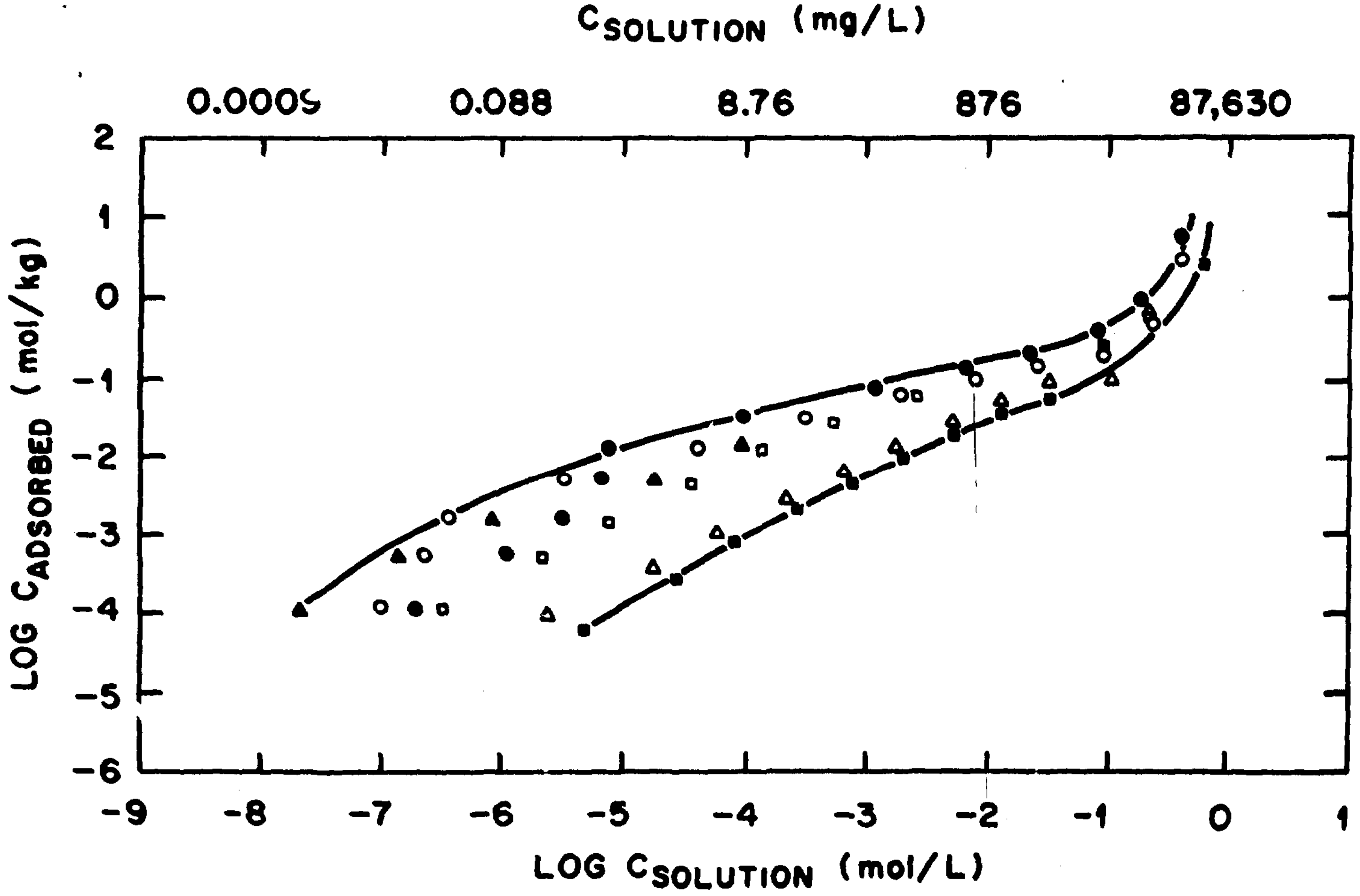


Fig. 19. Strontium sorption/precipitation isotherm data for composite soil sample from the West Chestnut Ridge site. Constant-pH values of isotherms included within the upper and lower limits are: (■), 3.0; (△), 4.0; (□), 5.0; (▲), 6.0; (○), 7.0; and (●), 8.0.

inflection for all of the isotherms, which indicates a mean apparent concentration limit for strontium of ~68,000 ± 12,000 mg/L. Although this value is somewhat higher than that which would have been anticipated from classical solubility tables [17,000 mg $Sr(OH)_2$/L at 20°C], it occurred in all six isotherms, thus suggesting the possibility of colloidal dispersion of the strontium. At low initial strontium concentration (1 mg/L), there is an indication that a maximum Rs value of 4800 L/kg is obtained at pH 6.

The possible presence of (and the subsequent effect of) various anions and complexants on the sorption behavior of radionuclides is a concern that should not be minimized. As an example of the unpredictable effect of sodium sulfate on the sorption of strontium on soil from the West Chestnut Ridge site, strontium sorption/solubility isotherm tests were made in the presence of 0.05 and 0.5 M sodium sulfate at a constant pH of 7. The resulting data are shown in Fig. 20, along with a normal isotherm with no added sodium sulfate; details are given in Tables G-14 and G-15 in Appendix G. It should be noted that at low initial strontium concentrations there is a significant reduction in the sorption ratios in the presence of increased amounts of sodium sulfate (Rs = 1000 L/kg with no sodium sulfate, 10 L/kg with 0.05 M sodium sulfate, and 1 L/kg with 0.5 M sodium sulfate). This reduction may be due, in part, to competition with sodium ion; of course, it is entirely possible that this might also be the case at a disposal site. At high initial strontium concentrations (>1000 mg/L), a definite upward inflection of the isotherm with 0.05 and 0.5 M sodium sulfate indicates apparent concentration limitations of 90 and

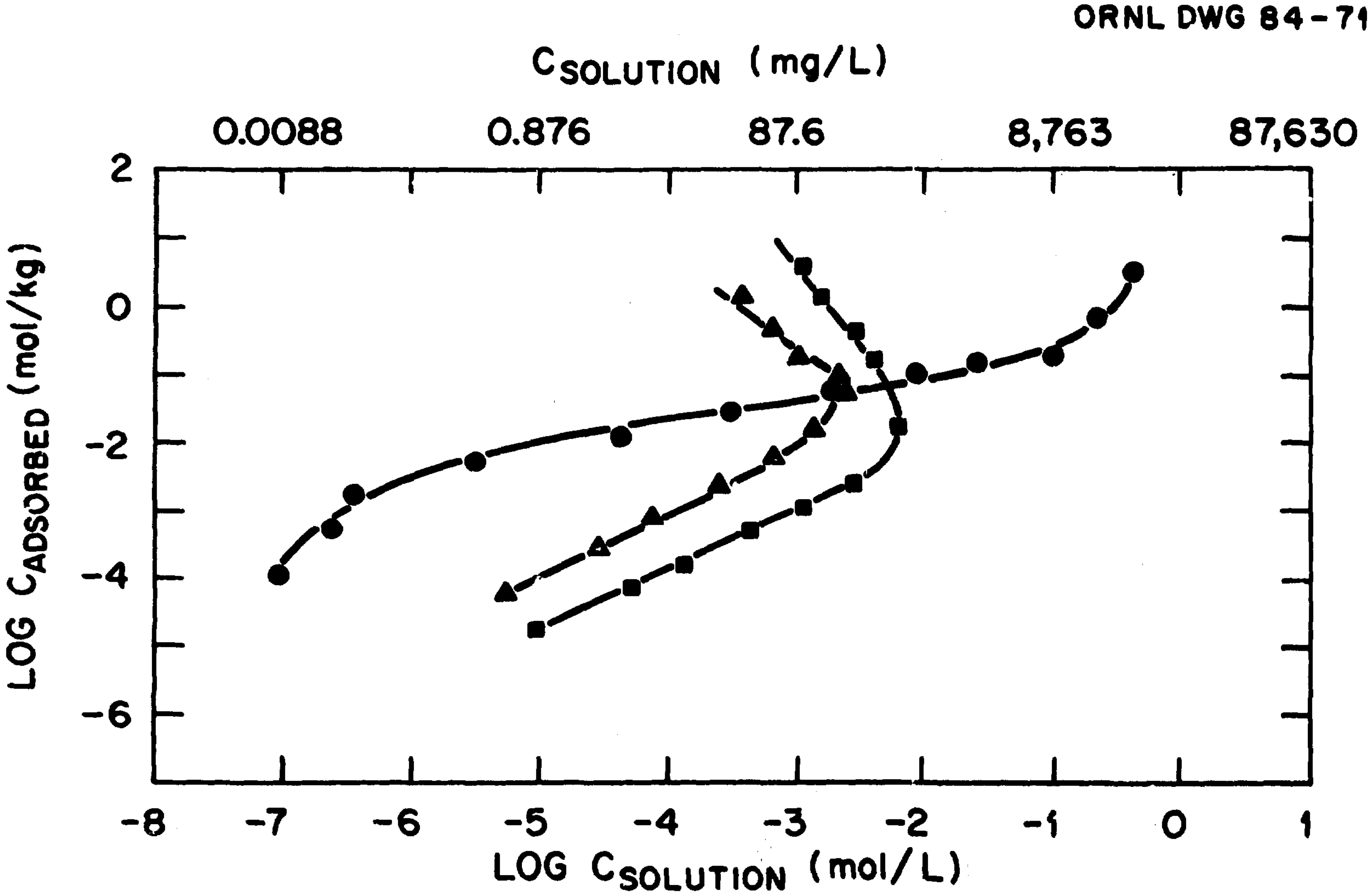


Fig. 20. Effect of sulfate concentration in the groundwater on strontium sorption/precipitation isotherm data for composite soil sample from the West Chestnut Ridge site. Constant pH of 7.0 maintained; concentration of sulfate added to the groundwater, in mol/L: (●), 0.0; (▲), 0.05; and (■), 0.5.

800 mg/L, respectively. Since the solubility of $SrSO_4$ is much lower than that of $Sr(OH)_2$, this decrease of the apparent concentration limit is not surprising.

4.7.3 Cesium

Six cesium sorption/solubility isotherms were determined at constant pH values of 3, 4, 5, 6, 7, and 8. The resulting data for these tests are summarized in Fig. 21, and details of the data are shown in Tables G-16 through G-21 in Appendix G. Each curve exhibits a common upward inflection at high initial cesium concentration (>1000 mg/L), indicating an apparent concentration limit of ~50,000 mg/L. This apparent concentration limit is unexplained since it is significantly lower than might have been predicted from solubility reference tables. The tests also indicate that a maximum Rs value of 13,000 L/kg occurs at pH 5.

4.7.4 Curium-244

Six ^{244}Cm sorption isotherms were determined at pH values of 3, 4, 5, 6, 7, and 8. The data for these isotherms are summarized in Figs. 22 and Fig. 23. Details of the experimental data are shown in Table G-22 in Appendix G. The isotherms determined at pH values below 6.0 appear to follow classical cationic sorption reaction behavior, while those above 6.0 show considerable scatter of the data points, possibly indicating multiple speciation of the radionuclide. In general, values appeared to reach a maximum (>30,000 L/kg) at pH 5, while the minimum value was observed at pH 3 (~300 L/kg).

ORNL DWG 84-72

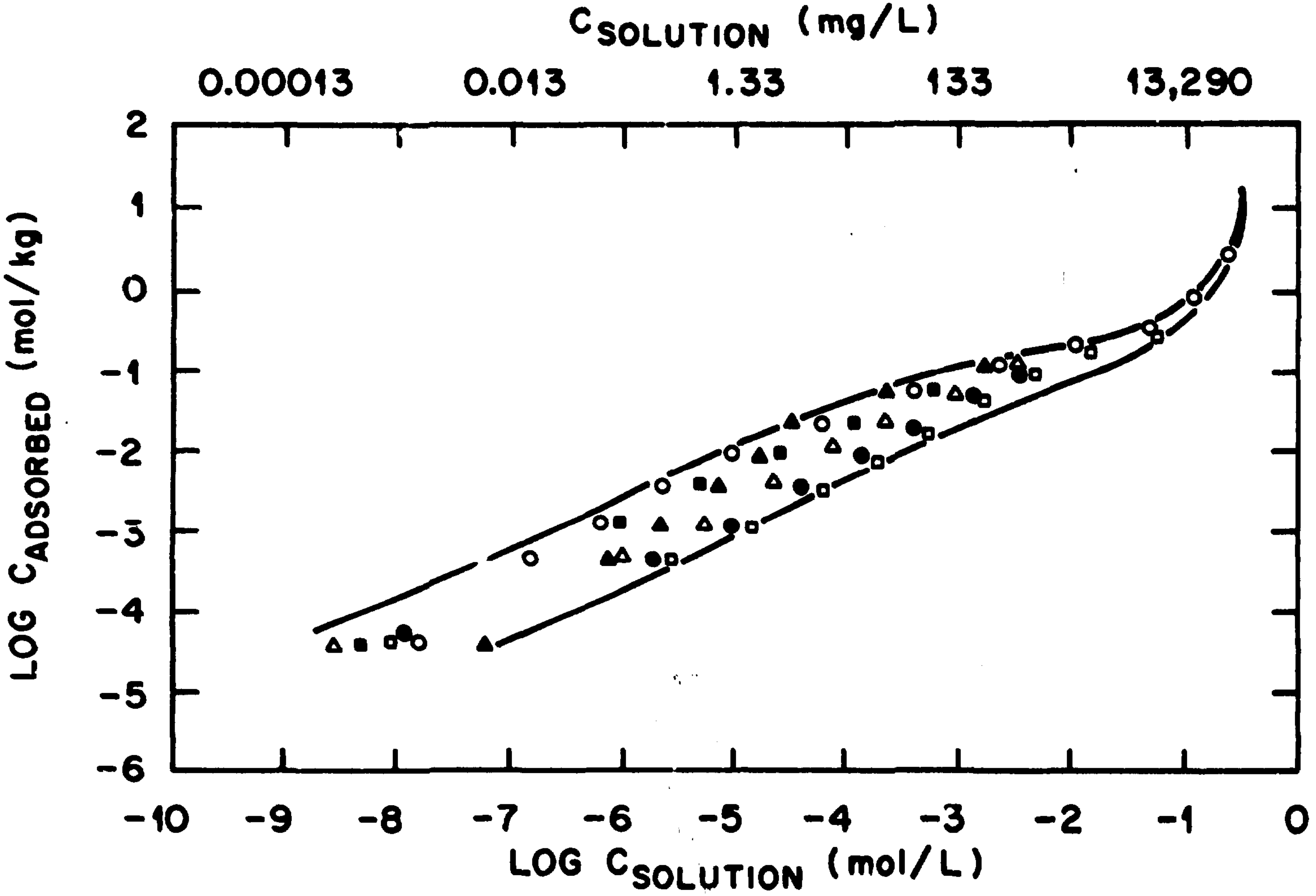


Fig. 21. Cesium sorption/solubility isotherm data for composite soil from the West Chestnut Ridge site. Constant-pH values of isotherms included within the upper and lower limits are: (□), 3.0; (■), 4.0; (△), 5.0; (▲), 6.0; (●), 7.0; and (○), 8.0.

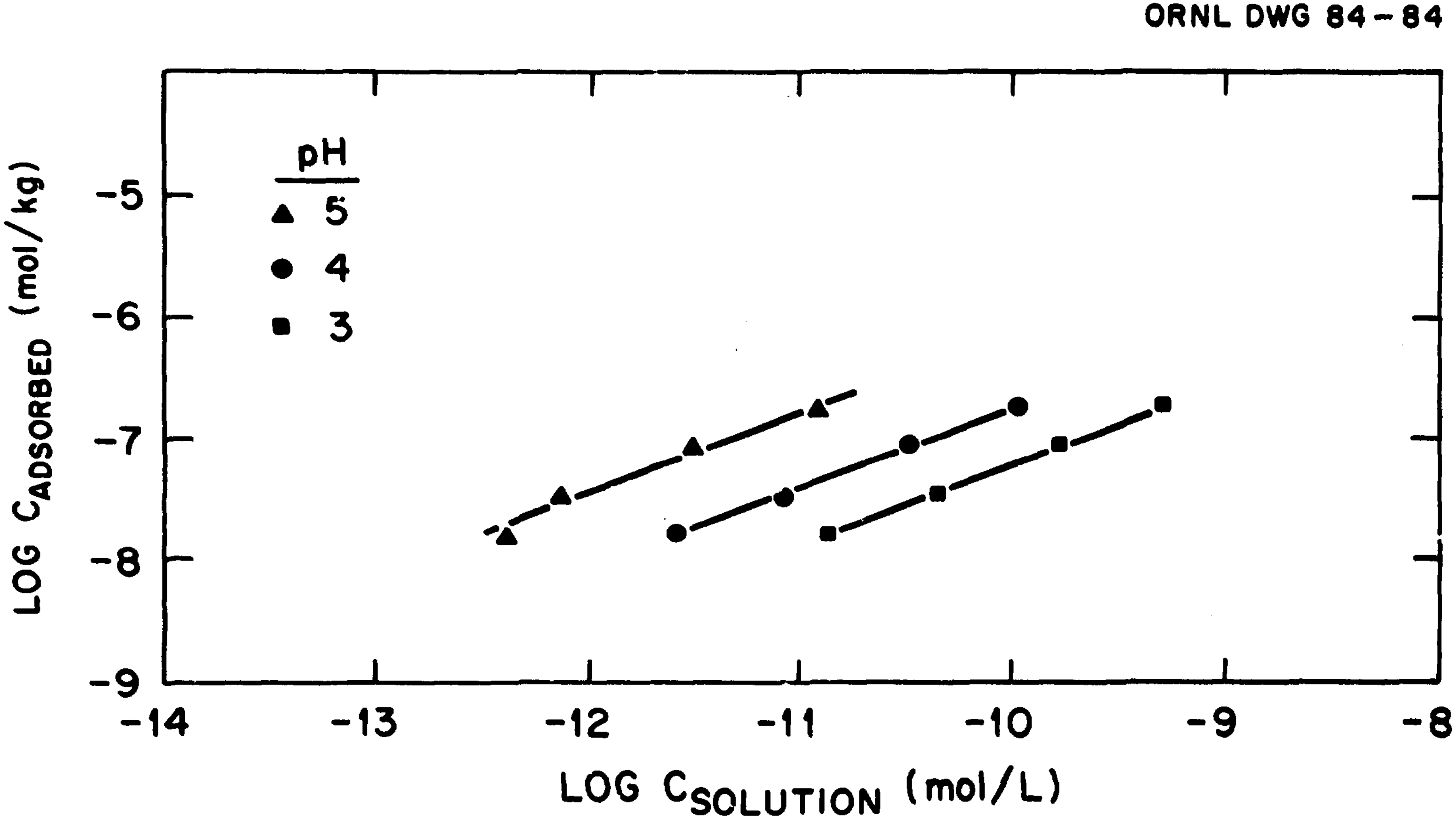


Fig. 22. Curium-244 sorption isotherms for composite soil sample from the West Chestnut Ridge site as determined by the constant-pH method.

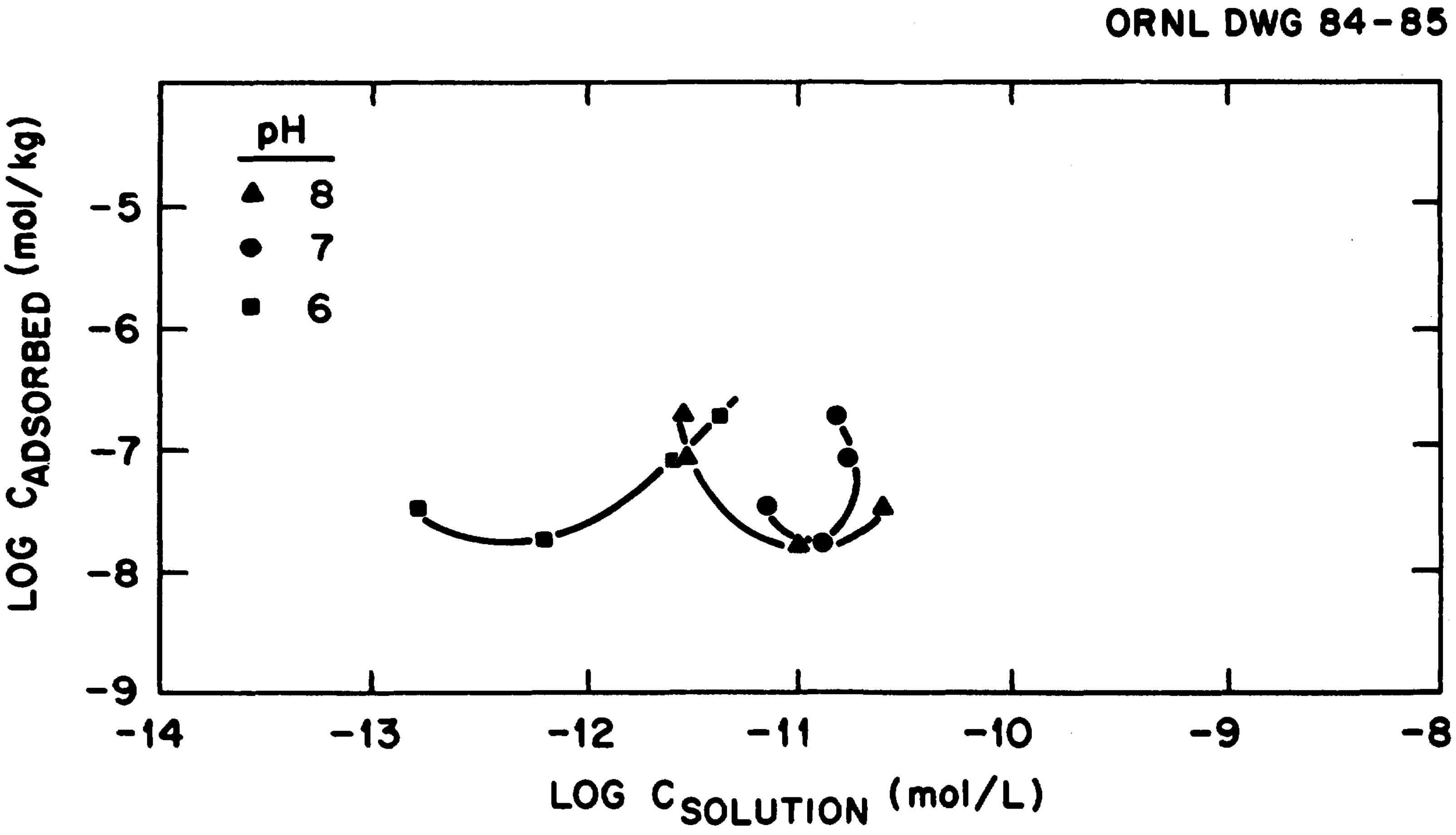


Fig. 23. Curium-244 sorption/precipitation isotherms for composite soil sample from the West Chestnut Ridge site as determined by the constant-pH method.

4.8 EFFECT OF THE PRESENCE OF ORGANIC COMPLEXING AGENTS IN THE GROUNDWATER ON URANIUM SORPTION

The possibility that waste site trench water could contain some type of aqueous-soluble organic ligand prompted the study of at least one general type of organic compound that would likely be a potential contaminant. Salts of certain organic acids such as EDTA and citric acid are commonly used in the complexation of metal ions in the cleaning or decontamination of metal surfaces, etc. To evaluate the effect of the presence of these compounds, uranium sorption isotherms were determined at pH 7.0 at the following concentrations of EDTA or citric acid in the synthetic groundwater: 0, 0.01, and 0.05 M. The experimental protocol used is described in Appendix B under the "Determination of Sorption Isotherms by Constant-pH Method." Data showing the effect of EDTA and of citric acid on the sorption of uranium on the composite soil sample from the West Chestnut Ridge site are presented in Fig. 24(a); the effect of citric acid is shown in Fig. 24(b). Details of the experimental data for these tests are listed in Tables H-1 through H-3 and Tables H-4 through H-6, respectively, in Appendix H.

The results of these tests indicate a decrease of approximately two orders of magnitude in the Rs values obtained at low initial uranium concentration (1 to 5 mg/L) and a decrease of approximately one order of magnitude at high initial uranium concentration (1000 mg/L). From these results, we conclude that the inclusion of these types of organic compounds in disposed wastes should be avoided or, at least, very closely controlled.

ORNL DWG 84-73

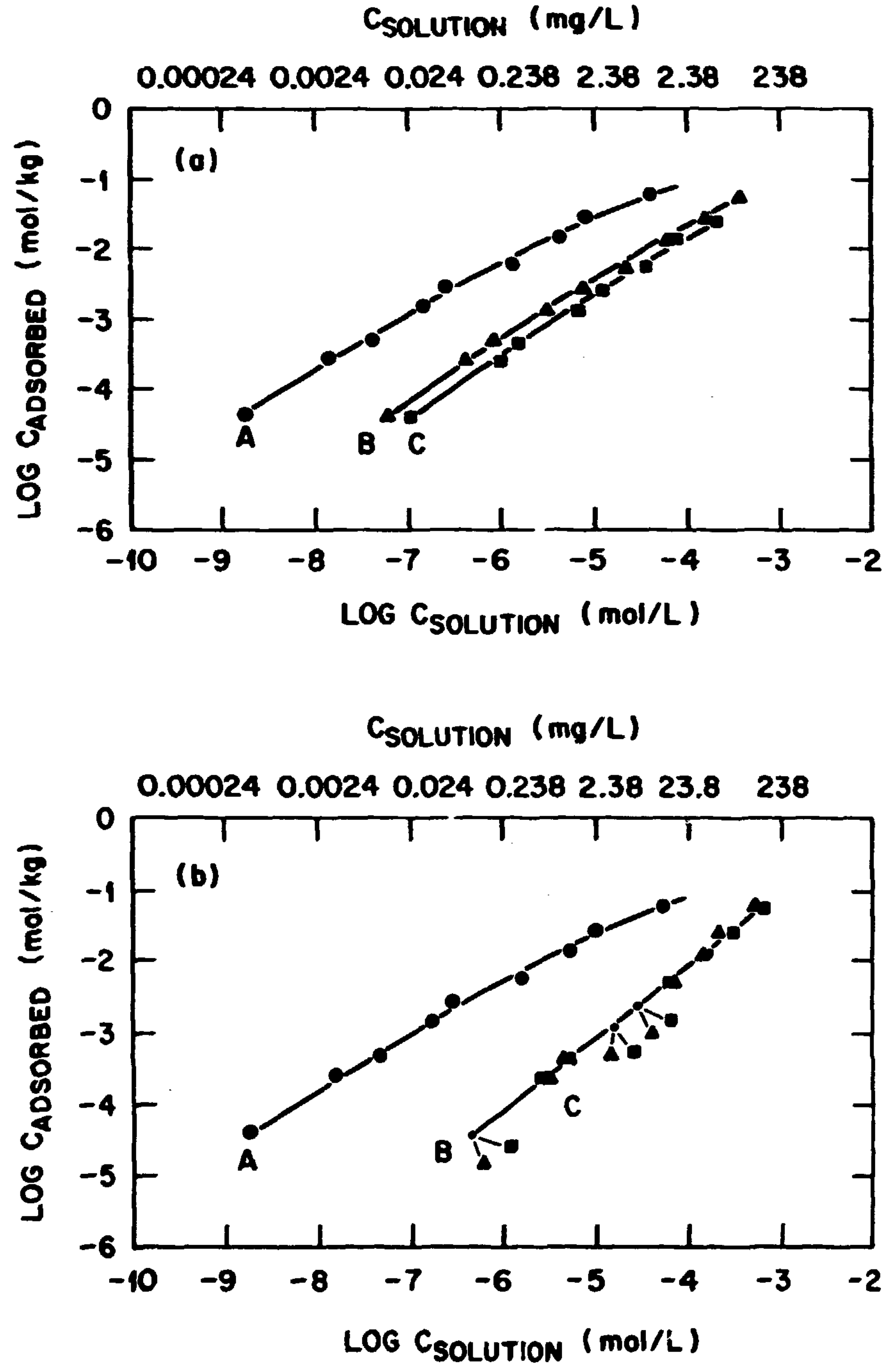


Fig. 24. (a) Effect of the EDTA on uranium sorption isotherms. Constant pH of 7.0 maintained; concentration of EDTA present in the groundwater, in mol/L: (A) 0.0, (B) 0.01, and (C) 0.05.

(b) Effect of the presence of citric acid on uranium sorption isotherms. Constant pH of 7.0 maintained; concentration of citric acid present in the groundwater, in mol/L: (A) 0.0, (B) 0.01, and (C) 0.05.

4.9 SORPTION OF URANIUM FROM Y-12 TRENCH WATER

In order to put uranium sorption values into some sort of "real-world" perspective, it seemed expedient to determine the effect that the actual constituents of an existing trench water from a low-level disposal area might have on a uranium sorption isotherm. Accordingly, a sample of trench water ("BCV" trench water) was obtained from the C-20 low-level site at the Y-12 Plant. The data that we obtained were for a specific sample, of course, and no inference is intended that this sample is representative of the type of waste expected to be placed in the CWDF. However, the results should serve as an example of the potential general effects possible at any disposal site.

4.9.1 Chemical Characterization of Y-12 Trench Water

Anion analysis of Y-12 BCV trench water (Table 20) showed significant concentrations of sulfate (162 mg/L), nitrate (74 mg/L), chloride (66 mg/L), and total carbonate (30 mg/L). Although the carbonate is shown as CO_3^{2-}, at pH 7.13 the dominant species would be HCO_3^-. Low concentrations of nitrite (17 mg/L) and fluoride (3 mg/L) were also found. Bromine and phosphate, if present, were below the limit of detection.

The sample was also analyzed for total organic carbon (TOC). Although this type of analysis does not define what type of organic is present, the results are useful. For example, the presence of significant amounts of organic carbon would be a qualitative indication of the existence of a potential organic complexing agent, which could reduce the sorption and/or increase the solubility of the radionuclides. The amount of TOC found in this sample was 41 mg/L.

Table 20. Anion analysis of Y-12 BCV trench water

Anion	Concentration (µg/mL)
CO_3^{2-}[a,b]	30
SO_4^{2-}	162
NO_3^-	74
NO_2^-	17
F^-	3
Cl^-	66
Br^-	<5
PO_4^{3-}	<4
pH	7.1

[a] Analyzed as total carbonate.
[b] Total organic carbon (TOC) = 41 µg/mL.

Elemental analysis of the Y-12 trench water by ICP spectrometry (Table 21) showed significant concentrations of calcium (78 mg/L), potassium (20 mg/L), magnesium (25 mg/L), and sodium (140 mg/L). Only very minor concentrations of several other metal ions were detected. Calculation of the equivalent balance for significant cations/anions present in the trench water revealed a ratio of 1.52. This is a very marginal value, which indicates that one or more of the analyses may be in error.

Table 21. Elemental analysis of Y-12 BCV trench water by inductively coupled plasma spectrometry

Element	Concentration (μg/mL)
Ag	<0.02
Al	0.09
As	<0.64
B	21.
Ba	0.07
Be	<0.001
Ca	78.
Cd	<0.009
Co	0.04
Cr	<0.02
Cu	<0.03
Fe	<0.02
Ga	<0.07
Hf	0.09
K	20.
Li	1.
Mg	25.
Mn	2.4
Mo	<0.03
Na	140
Ni	<0.11
P	<0.33
Pb	<0.27
Sb	<0.14
Se	<0.43
Si	4.
Sr	0.26
Ti	0.025
V	<0.015
Zn	<0.018
Zr	<0.018

A radionuclide analysis of the trench water is presented in Table 22. The trench water contained a small quantity of settled solids at the time it was received. These solids were removed by filtration, dried, and submitted for analysis, along with the solution. The isotopic analyses of both the trench water and the associated solids are listed. As might be expected, the predominant isotopes were ^{238}U (7.3 mg/L in the solution and 2974 mg/kg in the solids). The reason for the difference in the ^{235}U/^{238}U ratio between the solution and the solids is unknown. It could represent disproportionate disposal of enriched-uranium- and normal-uranium-containing materials of varying solubility, or it could suggest analytical uncertainties.

Table 22. Radionuclide analysis of Y-12 BCV trench water in precipitated solids

Radionuclide	Radioactivity (Bq/L)		Concentration (µg/mL)	
	Trench water	Solids	Trench water	Solids
^{238}U	90 ± 9	3.7E4 ± 2E4	7.3	2974
^{235}U	130 ± 10	1.6E4 ± 2E3	1.6	200
^{234}U	2.3E3 ± 1E2	1.8E5 ± 6E4	9.9E-3	7.8E-1
^{239,240}Pu	2.4 ± 2.7	3 ± 6	3.8E-9	4.7E-9
^{238}Pu	0.54 ± 0.49	2 ± 3	1.7E-7	6.4E-7

4.9.2 Uranium Sorption/Solubility in the Presence of Y-12 Trench Water

Uranium sorption isotherm data for soil from the West Chestnut Ridge site (B1-40) showed a marked decrease in Rs values when uranium-spiked trench water obtained from the Low-Level Waste Site C-20 at the Y-12 Plant was substituted for uranium-spiked synthetic groundwater. The maximum Rs value obtained at low initial uranium concentration (5 mg/L) was 21 L/kg with uranium-spiked trench water but increased to 4200 L/kg when uranium-spiked synthetic groundwater was used. It is interesting to note a definite upswing in the isotherm in the tests with trench water, indicating that an apparent concentration limit had been reached. The reason for attaining an apparent concentration limit in trench water, while failing to achieve one in tests with synthetic groundwater, is unexplained at this time. The uranium sorption isotherms for both the trench water and the reference synthetic groundwater are shown in Fig. 25. Details of the experimental data are listed in Tables I-1 and I-2 in Appendix I.

4.9.3 Uranium Sorption/Solubility as a Function of Anions Present in the Groundwater

Since uranium sorption ratios were so dramatically reduced by the substitution of Y-12 trench water for synthetic groundwater, several sorption tests were made in which anions were singly added to the synthetic groundwater in the approximate concentration that they were found in the analysis of the trench water. The soil used for these tests was taken from West Chestnut Ridge boring B2-60, and the synthetic groundwater was prepared in the usual manner (refer to Sect. 3.2.2). No significant changes in uranium sorption ratios were

ORNL DWG 84-74

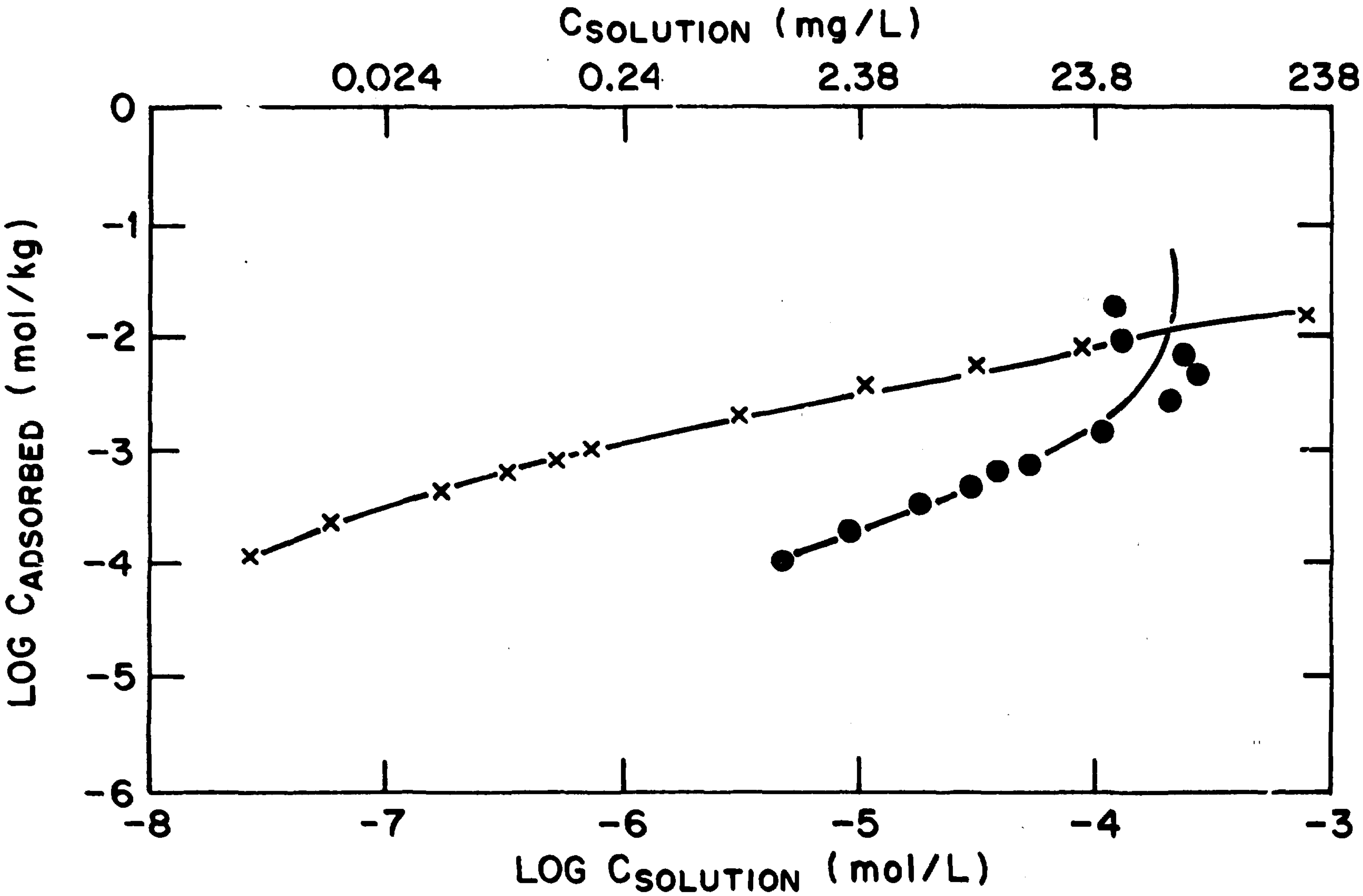


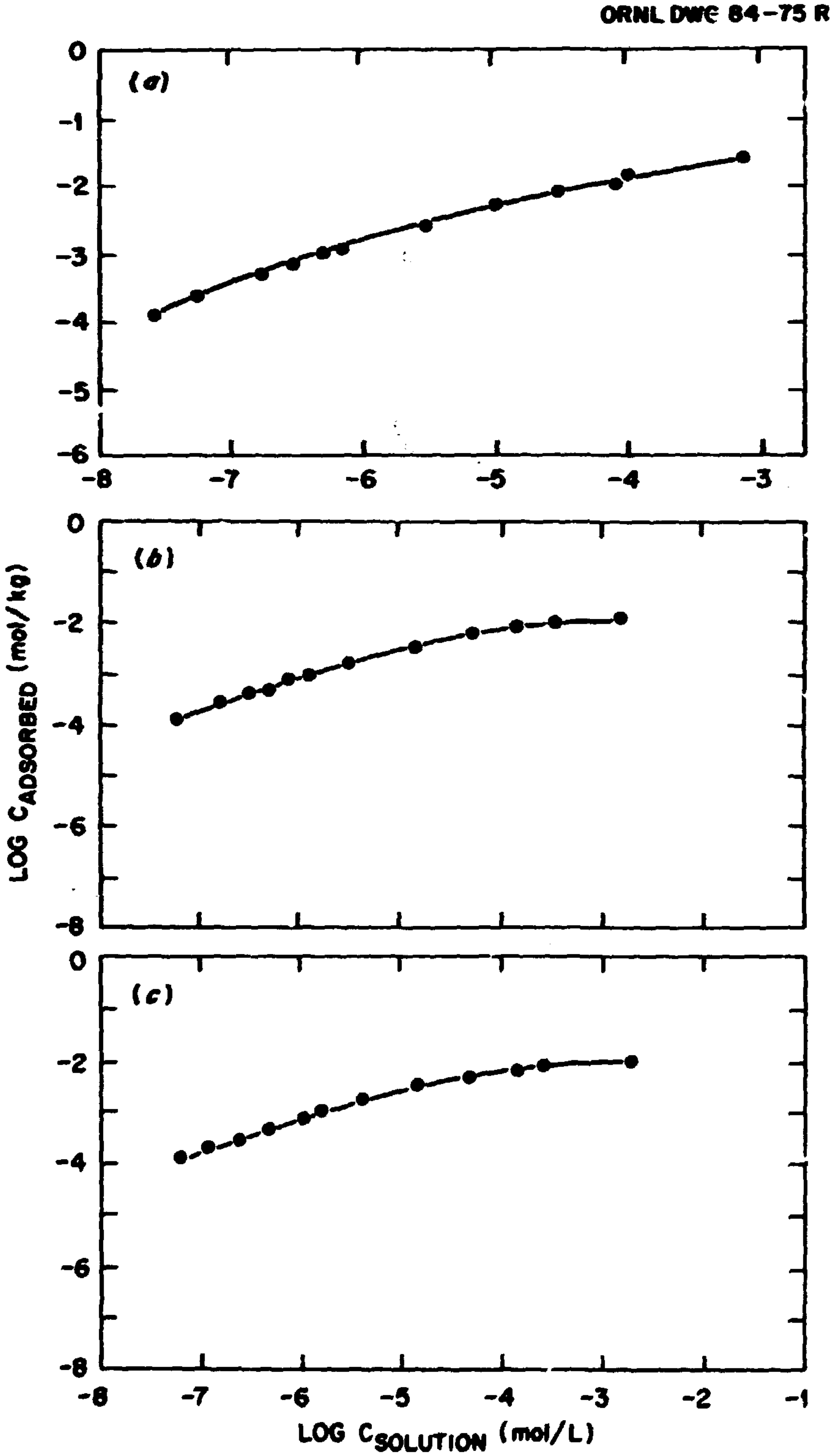
Fig. 25. Uranium sorption/solubility isotherms for soil sample B1-40 from the West Chestnut Ridge site in contact with uranium-spiked (×) synthetic groundwater or (●) Y-12 BCV-C-20 trench water.

observed when this synthetic groundwater was spiked with the following concentrations of anions, in mg/L: (1) SO_4^{2-}, 200; (2) NO_3^-, 100; (3) NO_2^-, 20; (4) F^-, 10; (5) Cl^-, 100; and (6) CO_3^{2-}, 50. Uranium sorption isotherm data for these tests are summarized in Figs. 26 and 27. Details of the experimental data are shown in Tables I-3 through I-7 in Appendix I.

Since there was no significant reduction in the Rs values in these tests with any of the anions at the approximate concentrations that were present in the Y-12 trench water, the remaining, most obvious factor that might have contributed to the dramatic reduction in Rs values is the TOC found in the trench water. Assuming that this TOC might have been present in the form of EDTA or some similar complexing agent, it is interesting to note that the reductions in the uranium Rs values are of the same magnitude from both trench water and EDTA-spiked groundwater. The apparent concentration limit observed in the trench-water test could be attributed to the slightly higher pH present in the equilibrated samples (5.5 to 7.3). This elevation in pH occurs because the trench water is not as highly unbuffered as the synthetic groundwater.

4.10 COLUMN CHROMATOGRAPHIC TESTS

The use of batch tests to obtain sorption data for soil/groundwater systems has many advantages. Chief among these is the fact that a considerable amount of data, consisting of a number of variables, can be produced in a relatively short time. However, the use of column chromatographic tests also has an important place in the



26. Uranium sorption isotherms for soil sample B1-40 from the West Chestnut Ridge site in contact with synthetic groundwater containing the following concentrations of anions, in mg/L: (a) no additive; (b) sulfate, 200; and (c) chloride, 100.

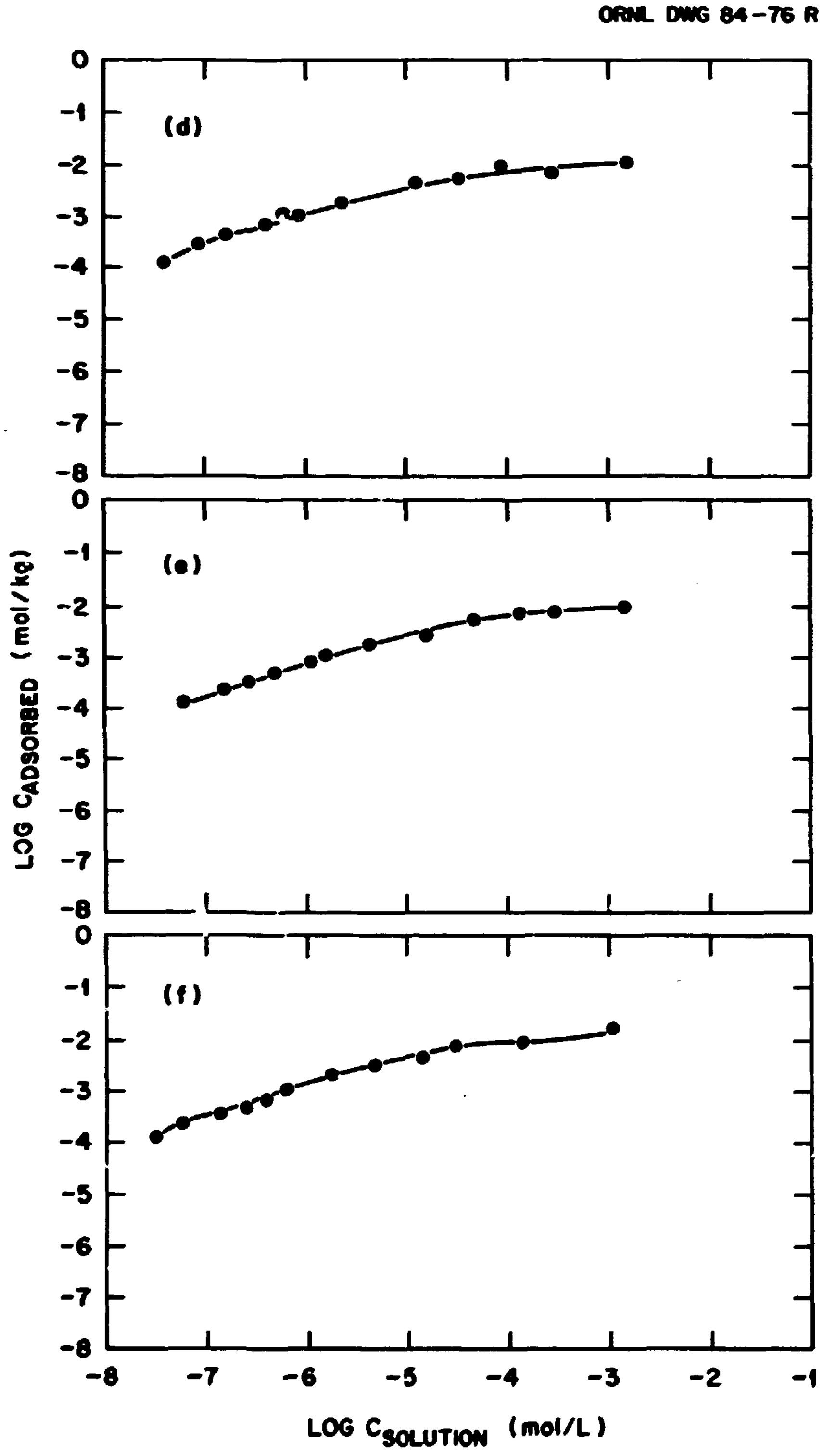


Fig. 27. Uranium sorption isotherms for soil sample B1-40 from the West Chestnut Ridge site in contact with synthetic groundwater containing the following concentrations of anions, in mg/L: (d) fluoride, 10; (e) nitrate, 100; and (f) carbonate, 50.

investigation of sorption characteristics of any soil. If time is limited, however, the amount of data that can be retrieved from such a test is rather restricted, especially if the soil being tested has been shown to exhibit high Rs values. In its favor, this method does tend to simulate the movement of groundwater through soil and, therefore, is a useful measure of the retardation of the radionuclide. In those cases where multiple speciation may occur and the duration of the test is sufficiently long for these speciation bands to migrate through the column, this method would be an extremely useful tool for exploring multiple speciation.

A column chromatographic test was set up to measure the sorption of several radionuclides onto soil from the West Chestnut Ridge site from synthetic groundwater. The equipment consisted primarily of a 6-mm-ID x 30-cm-long tube to which groundwater was fed by gravity flow from a constant-head feed tank. The effluent from the column emptied into an automatic fraction collector. The column was loaded with 3.0 g of a composite soil sample by liquid displacement. The soil occupied ~10 cm of the total column length and had a void volume of ~3.5 mL. A groundwater flow rate of ~0.1 mL/h was established through the soil.

4.10.1 Sorption of Uranium by Column Chromatography

A uranium solution traced with ^{233}U was placed in the top of the column of settled clay soil, and a downflow of synthetic groundwater was allowed to pass through the column for 10 d at an average flow rate of ~0.1 mL/h. This amounted to approximately seven column (void) volumes. The samples were collected on a timed basis, and the small volume collected in each tube required the addition of 1.0 mL of water for recovery of the effluent for analysis. Each sample was tested for alpha activity by liquid scintillation counting on a Packard Tri-Carb liquid scintillation spectrometer. As expected, no activity peak was noted since a uranium Rs value of 3100 L/kg (measured in batch tests) yields an anticipated breakthrough at ~10,000 column volumes for a calculated retardation factor of 10,464. Extrusion and sampling of the column of soil after the 10-d test revealed that the only alpha activity present was in the first 1 cm of the column. This serves to support the previously obtained high Rs values for uranium.

4.10.2 Sorption of Strontium, Cesium, and Iodine by Column Chromatography

A column sorption test was made in which strontium, cesium, and iodine activities (^{85}Sr, ^{134}Cs, and ^{131}I) were placed at the top of a column containing 3.0 g of composite clay soil from the West Chestnut Ridge site and groundwater was passed through the column by gravity flow. Considerable difficulty was encountered in maintaining a constant flow rate. However, the following observations were made: (1) an activity peak that contained only strontium and cesium was observed at approximately 1 volume throughput; (2) an activity peak that contained only iodine was noted after ~1 week; and (3) upon extrusion of the column of clay soil, the major fraction of the total strontium and cesium activity was found to be located in the top 25% of the column, the second 25% of the column contained small amounts of strontium, cesium, and iodine, and the bottom 50% contained only iodine activity.

Although the results of this test can only be considered on a semiquantitative basis, they suggest three things:

1. There is an apparent initial migration of a fraction of the strontium and cesium which is not adsorbed by the soil. This could possibly be due to the formation of a colloidal material that is transporting this activity at the same rate as the migration of the groundwater through the column.
2. There is some, rather minor, retardation of iodine (Rs values previously measured to be 0.1 to 1.0 L/kg by batch tests).
3. There is a very strong retardation of strontium and cesium which corresponds to the high Rs values (4,800 to 38,000 L/kg, respectively) for these radionuclides.

5. ACKNOWLEDGMENTS

The authors wish to acknowledge the excellent technical assistance of F. Barrera and C. G. Westmoreland, who conducted most of the laboratory tests reported in this document, the Materials and Chemistry Technology Department, ORGDP, for x-ray diffraction analyses of the clay soils; the Micro Meritics Group of the same department for surface area and particle-size distribution analyses; the Analytical Chemistry Division, ORNL, for ICP and ion chromatographic analyses; and G. K. Jacobs for modeling uranium speciation by means of the MINTEQ program. Appreciation is also expressed to Debbie S. Brown, Donna R. Snow, and Martha M. Dawson for secretarial assistance in the preparation of this report.

6. REFERENCES

1. R. J. Serne and J. F. Relyea, *The Status of Radionuclide Sorption-Desorption for the WRIT Program*, PNL-39979, Pacific Northwest Laboratory, Richland, Wash., 1982.

2. Z. Borovec, "The Adsorption of Uranyl Species by Fine Clay," *Chem. Geol.* *32*, 45-58 (1981).

3. D. Langmuir, "Uranium Solution-Mineral Equilibria at Low Temperatures with Application to Sedimentary Ore Deposits," *Geochim. Cosmochim. Acta* *42*, 547-69 (1978).

4. C. F. Baes and R. E. Mesmer, "Uranium," Sect. 9.2 in *The Hydrolysis of Cations*, Wiley, New York, 1976, pp. 174-80.

5. R. J. Lemire and P. R. Tremaine, "Uranium and Plutonium Equilibria in Aqueous Solutions to 200°C," *J. Chem. Eng. Data* *25*, 361-70 (1980).

6. A. M. Giblin, B. D. Bates, and D. J. Swaine, "Laboratory Simulation Studies of Uranium Mobility in Mineral Waters," *Geochim. Cosmochim. Acta* *45*, 699-709 (1981).

7. L. L. Ames, J. E. McGarrah, B. A. Walker, and P. F. Salter, *Chem. Geol.* *35*, 205-25 (1982).

8. R. H. Ketelle, *Report on Preliminary Site Characterization of the West Chestnut Ridge Site*, Draft Report ORNL/NFW-82/21.

9. D. D. Huff, J. L. Elmore, and D. C. Farmer, *Hydrologic Study and Evaluation of the Ish Creek Watershed (West Chestnut Ridge Proposed Disposal Site)*, ORNL/TM-8960, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1983.

10. T. H. Sidall and R. S. Ondrejcin, *Behavior of Technetium in the Purex Process*, DP-364, Savannah River Laboratory, Aiken, S.C., 1959.

7. APPENDIXES

Appendix A.

SITE CHARACTERIZATION DATA

ORNL DWG 84-50

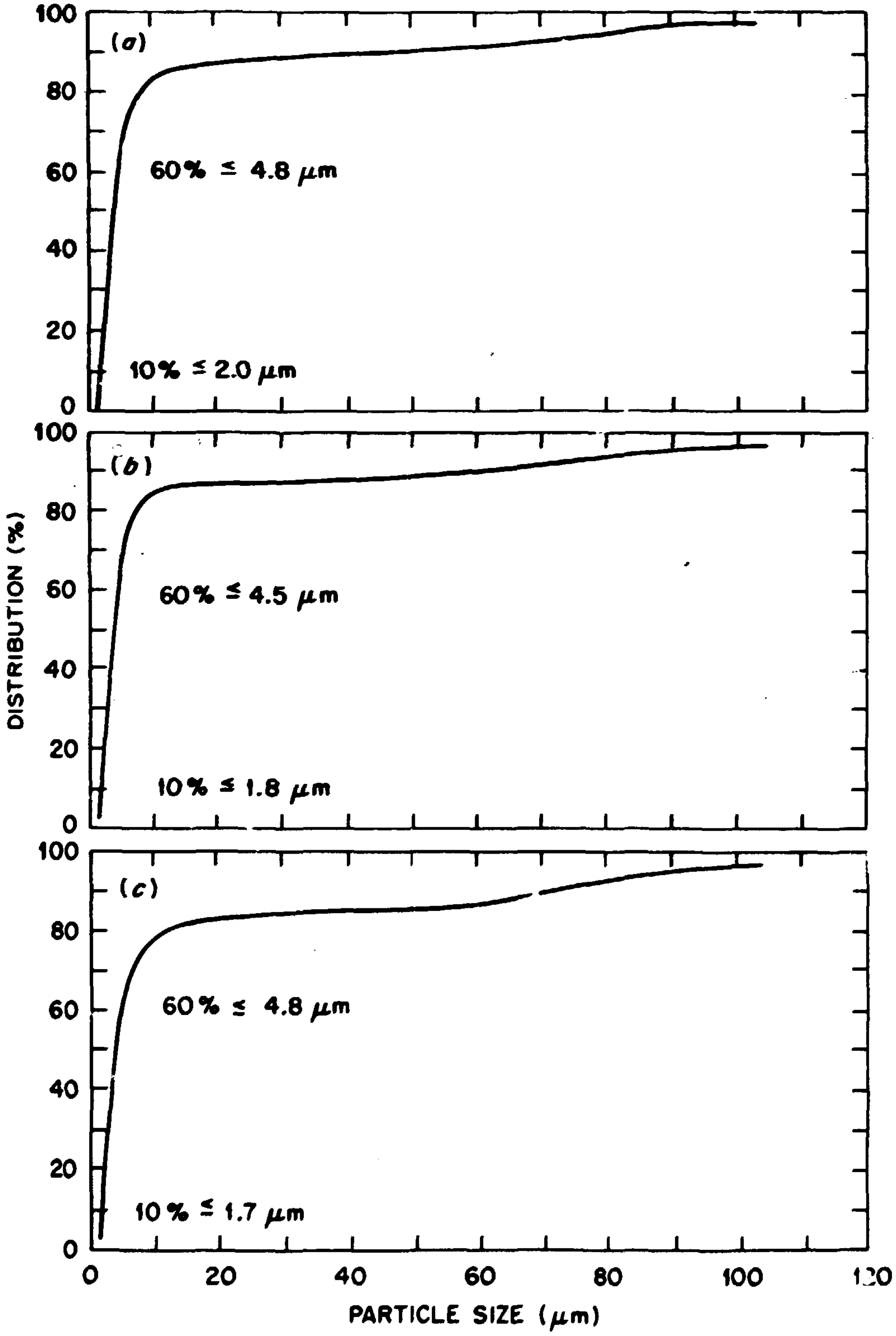


Fig. A-1. Particle-size distribution for soil samples from the West Chestnut Ridge site: (a) B1-10, (b) B1-30, and (c) B1-40.

ORNL DWG 84-51

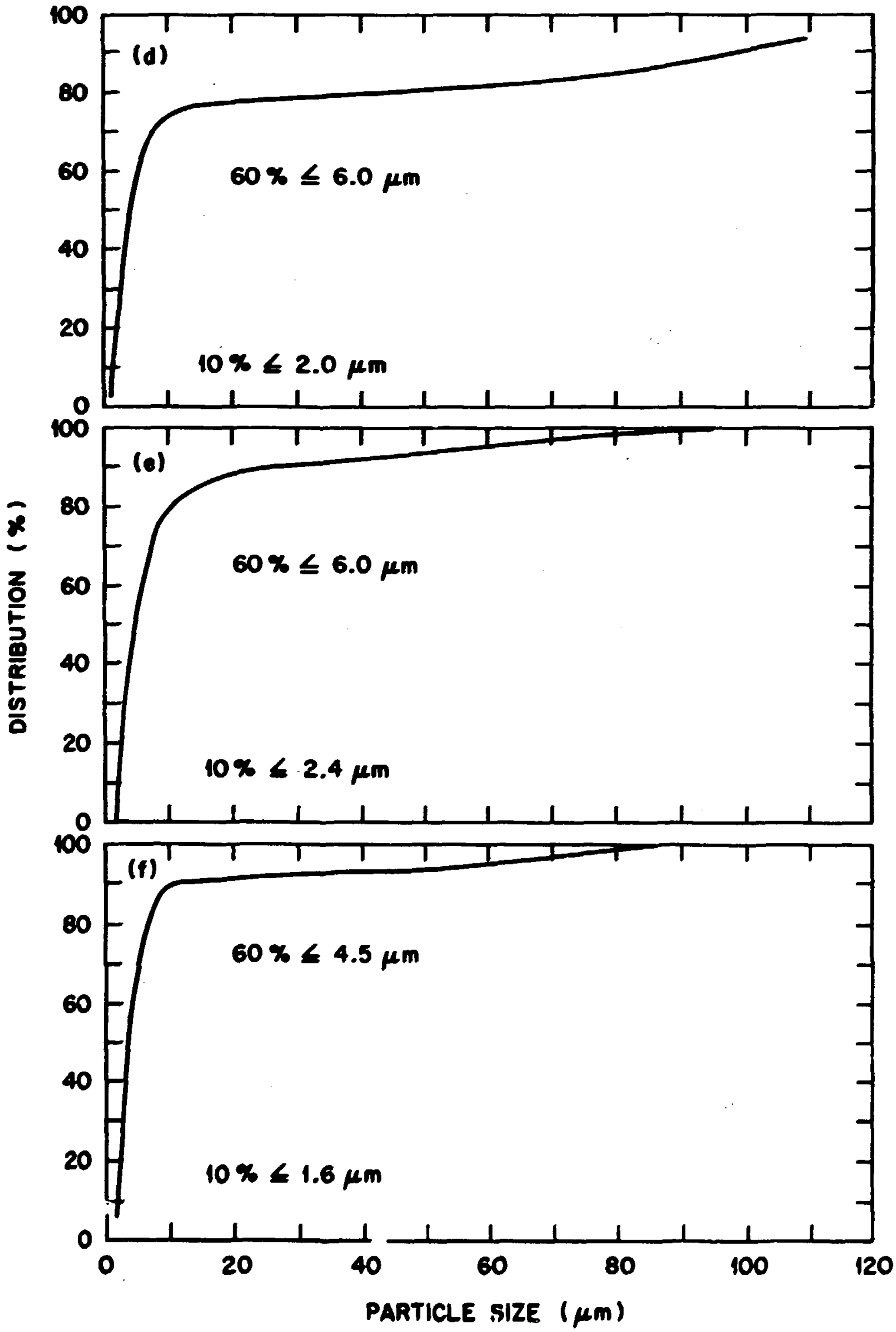


Fig. A-2. Particle-size distribution for soil samples from the West Chestnut Ridge site: (d) B2-20, (e) B2-30, and (f) B2-60.

Appendix B.

EXPERIMENTAL METHODS

B-1. EXPERIMENTAL PROCEDURE FOR THE DETERMINATION OF SORPTION ISOTHERMS (AMBIENT-pH METHOD)

To provide data for sorption isotherms, each test is conducted by contacting 1.0 g of soil with 10 mL of the synthetic groundwater in a polystyrene centrifuge tube for an initial period of 3 h to allow the soil and the groundwater to reach steady-state conditions. An argon atmosphere is maintained above the slurry to minimize any additional source of carbonate from CO_2 in the air from being introduced into the sample and to prevent air oxidation of reduced components. The appropriate metal-ion spike is added to the slurry to obtain the desired initial concentration. The concentration of the metal-ion stock solutions is chosen such that the addition of 0.1 mL to the 10 mL of the groundwater will give the desired initial concentration. The radioactive tracer activity is then added to the sample. The activity of the appropriate radionuclide stock solution is also adjusted to a level such that the addition of 0.1 mL of the solution to the 10 mL of the metal ion-spiked groundwater will give an initial counting level of approximately 100,000 cpm/mL. The sample is then placed on a shaker for 4 h. (Various contact times can be used in sorption rate studies.) After removal from the shaker, the solids are allowed to settle and the pH of the supernate is measured. If there is any significant departure from the predetermined experimental pH level (the natural pH established between the soil and the well water) being investigated, an adjustment is made at this point to bring the pH to the desired level. A 4-h period of recontacting is employed for any sample requiring pH adjustment.

After a sample has reached a stable pH level, it is placed in a Sorvall centrifuge and centrifuged at 5000 rpm for about 15 min. For the determination of the metal-ion concentration, 1.0 mL of the clear supernate is then removed and the alpha and gamma activities are determined by counting in a Packard Tri-Carb scintillation spectrometer and a Packard automatic gamma spectrometer, respectively. Appropriate standards and blanks are also counted.

B-2. DETERMINATION OF URANIUM DESORPTION RATIOS (Rd) FOR SOILS FROM THE CHESTNUT RIDGE SITES

1. Determine the uranium sorption isotherm in the usual manner; that is:

   a. Weigh 2.0 g of soil into a centrifuge tube. Record the weight of the tube and dry solids so that the amount of solution retained by the soil after centrifugation can be determined.

   b. Place 10.0 mL of groundwater in the tube with the 2.0 g of soil.

   c. Pipette 0.1 mL of the desired concentration of uranium stock solution into the tube.

   d. Pipette 0.2 mL of the ^{233}U tracer solution into the tube, displace air in tube by flushing with argon, and seal. Prepare a counting standard in the same manner; that is, place 0.2 mL of the ^{233}U tracer solution in 10.1 mL of groundwater to obtain a count rate with no solids present.

   e. Equlibrate on the shaker for 16 to 20 h.

   f. Centrifuge the sample, and pour the clear supernate into a small plastic bottle to save for analysis. Measure the pH of this supernate.

2. Then determine the uranium desorption isotherms in the following manner:

   g. Weigh the tube containing the wet soil. Record the weight in order to obtain a fairly accurate estimate of the amount of solution held by the soil.

h. Place 10.0 mL of fresh groundwater in the tube. Do not add any uranium or tracer. Flush with argon and seal.

i. Equilibrate on the shaker for 16 to 20 h.

j. Centrifuge the sample, and pour the clear supernate into a small plastic bottle to save for analysis. Measure the pH of this supernate.

k. Weigh the tube containing the wet soil. Record the weight in order to check on the amount of solution that is held up in the solid on the second contact.

l. Place 10.0 mL of fresh groundwater in the tube. Do not add any uranium or tracer. Flush with argon and seal.

m. Equilibrate on the shaker for 16 to 20 h.

n. Centrifuge the sample, and remove some of the supernate for alpha counting. Check the pH of the remaining supernate.

o. Place 1.0 mL of each of the three supernates in 10 mL of Insta Gel and count for alpha activity.

p. Calculate the sorption isotherm data in the usual manner. At that time, make a decision as to the significance of the solution holdup and determine whether it should be included in the calculations of the desorption isotherms. If the holdup is not considered significant, then the calculation will be the same as that for the initial sorption isotherm.

B-3. PROCEDURE FOR THE DETERMINATION OF SORPTION ISOTHERMS AT CONSTANT pH

Stock solution	Uranium[a] (mg/L)	^{233}U[a] (cpm/mL)	Total U (mg/L)	Total ^{233}U (cpm/mL)
1	0	1.0E7	1	1.0E5 (1)
2	500	1.0E7	6	1.0E5 (2)
3	1,000	1.0E7	11	2.0E5 (1)
4	2,500	1.0E7	32	2.0E5 (2)
5	5,000	1.0E7	62	3.0E5 (1)
6	10,000	1.0E7	133	3.0E5 (2)
7	25,000	1.0E7	313	4.0E5 (1)
8	50,000	1.0E7	634	4.0E5 (2)
9	100,000	1.0E7	1314	5.0E5 (1)
10	250,000	1.0E7	3135	5.0E5 (2)
11	500,000	1.0E7	6315	6.0E5 (1)

[a] If you take 1.0 mL of the uranium stock solution and add the amount of activity in approximately 0.1 mL to give the desired activity to the 1.1-mL stock solution sample which will be added to the 100 mL of groundwater, the total activity can be maintained at a minimum.

Solid: Soil composite from West Chestnut Ridge site

Titration procedure:

1. Weigh 10 g of soil sample into a titration vessel.

2. Measure 100 mL of synthetic groundwater into the titration vessel.

3. Adjust the pH of the slurry to 3.0.

4. Add uranium stock solution 1, and readjust the pH to the initial value. See that this pH is maintained by occasional adjustment during the titration.

5. Allow a 30-min equilibration period, and then sample the slurry. Take a 5-mL sample, centrifuge, take a 1.0-mL sample of the clear supernate for alpha liquid scintillation counting, and return the remaining 4 mL to the titration vessel.

6. Repeat step 4 with stock solution 3.

7. Repeat step 5.

8. Repeat step 4 with stock solution 5.

9. Repeat step 5.

10. Repeat step 4 with stock solution 7.

11. Repeat step 5.

12. Repeat step 4 with stock solution 9.

13. Repeat step 5.

14. Repeat step 4 with stock solution 11.

15. Repeat step 5.

16. With a new 100-mL volume of groundwater and 10 g of soil, repeat the above procedure using stock solutions 2, 4, 6, 8, and 10.

17. Count all of the samples collected from the procedures listed above, and calculate uranium concentrations in the same manner as for other isotherms. The major difference here is that each added increment of stock solution increases the total activity of the solution as well as the total uranium concentration.

18. Repeat the entire procedure (steps 1-17) at pH 4.0.

19. Repeat the entire procedure (steps 1-17) at pH 5.0.

20. Repeat the entire procedure (steps 1-17) at pH 6.0.

21. Repeat the entire procedure (steps 1-17) at pH 7.0.

22. Repeat the entire procedure (steps 1-17) at pH 8.0.

B-4. COMPUTER PROGRAM FOR CALCULATING SORPTION OR DESORPTION ISOTHERMS

```
00010   PRINT "PROGRAM FOR CALCULATING ISOTHERM"
00020   PRINT "THIS PROGRAM REQUIRES THE FOLLOWING VARIABLES:"
00030   PRINT "(1) C, ACTIVITY OF INITIAL TRACER IN CTS/M/ML"
00040   PRINT "(2) VS, VOLUME OF SAMPLE AND (3) VRS, VOLUME OF RESIDUAL
        SOLUTION
"
00050   PRINT "(4) A, ACTIVITY OF FINAL SOLUTION IN CTS/MIN/ML"
00060   PRINT "(5) W, WEIGHT OF SAMPLES"
00070   PRINT "(6) M, CONCENTRATION OF INITIAL NUCLIDE IN MOLES/L"
00080   PRINT "(7) N, ANY ACTIVITY ADDED BY NUCLIDE"
00090   PRINT "TO END ENTRIES, GIVE 0 FOR ACTIVITY OF SAMPLE"
00100   Y$="N"
00110   DIM A(60),W(60),E(60),B(60),V(60),A1(60)
00115 DIM N(60)
00120   DIM G(60),H(60),J(60),K(60),R(60),V1(60)
00130   PRINT "STANDARD TRACER CTS/MIN/ML ";
00140   INPUT C
00150   I=1
00160   FOR I=1 TO 60
00170   PRINT "ACTIVITY OF SAMPLE IS (CPM/ML)";
00180   INPUT A(I)
00190   IF A(I)=0 THEN 300
00200   PRINT "ACTIVITY ADDED BY NUCLIDE IS ";
00210   INPUT N(I)
00220   PRINT "SAMPLE VOLUME, RESIDUAL VOLUME ARE (MLS)";
00230   INPUT V(I),E(I)
00240   PRINT "WEIGHT OF SAMPLE IS (GM)";
00250   INPUT W(I)
00260   PRINT "CONCENTRATION NUCLIDE IN MOLES/L IS ";
00270   INPUT B(I)
00280   NO=I
00290   NEXT I
00300   FOR I=1 TO NO
00310   V1=V(I)+E(I)
00320   C=N(I)+C
00330   H1=B(I)/C
00340   S=V(I)/V1
00350   S1=C*S
00360   R(I)=V1*(S1-A(I))/(A(I)*W(I))
00370   H(I)=A(I)*H1
00380   G(I)=R(I)*H(I)
00390   J(I)=.4343*LOG(G(I))
00400   K(I)=.4343*LOG(H(I))
00410 NEXT I
00420   PRINT
00430   PRINT "SAMPLE      CONC.      MASS        VOL.       RES.
"
00440   PRINT "CTS/MIN/ML  MOLES/L    GRAMS       MLS.       VOL.
"
00450   PRINT
```

```
00460   FOR I=1 TO NO
00465   PRINT A(I),B(I),W(I),V(I),E(I)
00480   NEXT I
00490   PRINT
00500   PRINT
00510   PRINT"AMOUNT     AMOUNT                                  D
"
00520   PRINT"ADSORBED    IN SOLUTION   LOG          LOG       OR R
S"
00530   PRINT"MOLS/KG     MOL/L         ADSORBED     SOL
OR RD"
00540   PRINT
00550   FOR I=1 TO NO
00555   PRINT G(I),H(I),J(I),K(I),R(I)
00570   NEXT I
00580   PRINT
00590   PRINT "DESORPTION (Y/N) ";
00600   INPUT Y$
00620   IF Y$="N" THEN 820
00630   FOR I=1 TO NO
00640   PRINT "NEW VOLUME IS ";
00650   INPUT V1(I)
00660   PRINT "NEW RESIDUAL VOLUME IS ";
00670   INPUT E(I)
00680   PRINT "NEW ACTIVITY OF SAMPLE IS ";
00690   INPUT A1(I)
00695   H1=B(I)/C
00700   A=R(I)*W(I)*A(I)
00710   A1=E(I)*A(I)
00720   S=A1(I)*(V(I)+E(I))
00730   R1=(A+A1-S)/W(I)
00740   R(I)=R1/A1(I)
00750   H(I)=A1(I)*H1
00760   G(I)=R(I)*H(I)
00770   J(I)=.4343*LOG(G(I))
00780   K(I)=.4343*LOG(H(I))
00790   A(I)=A1(I)
00800   NEXT I
00801   PRINT
00802   PRINT"SAMPLE      CONC.      MASS       VOL.     RES."
00803   PRINT"CTS/MIN/ML  MOLES/L    GRAMS      MLS.     VOL."
00804   PRINT
00805   FOR I=1 TO NO
00806   PRINT A1(I),B(I),W(I),V1(I),E(I)
00807   NEXT I
00810   GOTO 490
00820   END
```

Appendix C.

SORPTION RATE TEST DATA

Table C-1. Uranium sorption rate data for composite soil sample from the West Chestnut Ridge site

(Initial uranium concentration: 5 mg/L; constant pH of 7.0 maintained)

Contact time (h)	After contact				
	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0.16	3.0E-8	1.3E-4	-7.52	-3.89	4.4E3
0.30	2.0E-8	1.3E-4	-7.70	-3.89	6.6E3
1.0	4.4E-9	1.3E-4	-8.36	-3.89	3.0E4
2.0	8.1E-9	1.3E-4	-8.09	-3.89	1.6E4
4.0	2.5E-8	1.3E-4	-7.60	-3.89	5.1E3
8.0	8.7E-9	1.3E-4	-8.06	-3.89	1.5E4
24.0	2.2E-8	1.3E-4	-7.66	-3.89	5.9E3

Table C-2. Uranium sorption rate data for composite soil sample from the West Chestnut Ridge site

(Initial uranium concentration: 1000 mg/L; constant pH of 7.0 maintained)

Contact time (h)	After contact				
	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0.16	9.6E-5	4.1E-2	-4.02	-1.39	4.3E2
0.3	8.0E-5	4.1E-2	-4.10	-1.39	5.2E2
1.0	5.4E-5	4.1E-2	-4.27	-1.38	7.7E2
2.0	5.2E-5	4.1E-2	-4.28	-1.38	7.9E2
4.0	4.2E-5	4.1E-2	-4.38	-1.38	9.8E2
8.0	2.9E-5	4.1E-2	-4.54	-1.38	1.4E3
24.0	1.6E-5	4.1E-2	-4.80	-1.37	2.6E3
48.0	7.7E-6	4.1E-2	-5.11	-1.37	5.5E3

Table C-3. Uranium sorption/precipitation rate data for composite soil sample from the West Chestnut Ridge site

(Initial uranium concentration: 25,000 mg/L)

	After contact					
Contact time	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/Kg)
1 d	11.5	4.9E-7	6.4E-2	-6.31	-1.19	1.3E5
1 d	11.5	1.8E-7	6.4E-2	-6.74	-1.19	3.6E5
2 d	11.8	2.7E-7	6.4E-2	-6.57	-1.19	2.4E5
1 week	10.3	1.2E-8	6.7E-2	-7.92	-1.17	5.3E6
2 weeks	10.5	1.3E-7	6.4E-2	-6.87	-1.19	4.9E5
3 weeks	10.9	2.1E-7	6.6E-2	-6.68	-1.18	3.1E5

Table C-4. Uranium sorption rate data for composite soil sample from the West Chestnut Ridge site: effect of ionic strength

(Initial uranium concentration: 1000 mg/L; constant pH of 7.0 maintained; no NaCl present in the groundwater)

Contact time (h)	After contact				
	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0.16	9.6E-5	4.1E-2	-4.02	-1.39	4.3E2
0.3	8.0E-5	4.1E-2	-4.10	-1.39	5.2E2
1.0	5.4E-5	4.1E-2	-4.27	-1.38	7.7E2
2.0	5.2E-5	4.1E-2	-4.28	-1.38	7.9E2
4.0	4.2E-5	4.1E-2	-4.38	-1.38	9.8E2
8.0	2.9E-5	4.1E-2	-4.54	-1.38	1.4E3
24.0	1.6E-5	4.1E-2	-4.80	-1.37	2.6E3
48.0	7.7E-6	4.1E-2	-5.11	-1.37	5.5E3

Table C-5. Uranium sorption rate data for composite soil sample from the West Chestnut Ridge site: effect of ionic strength

(Initial uranium concentration: 1000 mg/L; constant pH of 7.0 maintained; concentration of NaCl in groundwater: 0.5 *M*)

Contact time (h)	After contact				
	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0.16	4.0E-5	4.2E-2	-4.40	-1.38	1.0E3
0.50	3.6E-5	4.2E-2	-4.44	-1.38	1.1E3
1.0	3.4E-5	4.2E-2	-4.47	-1.38	1.2E3
2.0	3.1E-5	4.2E-2	-4.51	-1.38	1.3E3
4.0	2.9E-5	4.2E-2	-4.54	-1.38	1.4E3
7.0	2.5E-5	4.2E-2	-4.60	-1.38	1.6E3
24.0	2.1E-5	4.2E-2	-4.68	-1.38	1.9E3
48.0	1.1E-5	4.2E-2	-4.96	-1.38	3.9E3

Table C-6. Europium sorption rate data for composite soil sample from the West Chestnut Ridge site

(Initial europium concentration: 5 mg/L; constant pH of 7.0 maintained)

Contact time (h)	After contact				
	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0.16	1.4E-8	4.1E-4	-7.85	-3.39	2.9E4
0.30	1.1E-8	4.1E-4	-7.96	-3.39	3.8E4
1.0	1.3E-8	4.1E-4	-7.87	-3.39	3.2E4
2.0	9.3E-9	4.1E-4	-8.03	-3.39	4.4E4
4.0	5.6E-9	4.1E-4	-8.25	-3.39	7.3E4
8.0	1.2E-8	4.1E-4	-7.92	-3.39	3.4E4
24.0	6.2E-9	4.1E-4	-8.21	-3.39	6.7E4
48.0	4.8E-9	4.1E-4	-8.32	-3.39	8.6E4

Appendix D.

UNBUFFERED AMBIENT-pH SORPTION TESTS

Table D-1. Uranium sorption isotherm data for West Chestnut Ridge core sample B1-10-B[a]

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	4.86	9.2x10^{-11}	1.3x10^{-7}	-10.04	-6.89	1.4x10^{3}
10	4.80	1.9x10^{-10}	2.3x10^{-7}	-9.74	-6.64	1.2x10^{3}
20	4.77	4.7x10^{-10}	4.4x10^{-7}	-9.33	-6.36	9.4x10^{2}
30	4.76	8.2x10^{-10}	6.5x10^{-7}	-9.09	-6.19	7.9x10^{2}
40	4.74	1.2x10^{-9}	8.4x10^{-7}	-8.94	-6.08	7.0x10^{2}
50	4.72	1.7x10^{-9}	1.1x10^{-6}	-8.76	-5.98	6.5x10^{2}
100	4.61	5.6x10^{-9}	2.0x10^{-6}	-8.25	-5.70	3.6x10^{2}
200	4.42	3.1x10^{-8}	4.0x10^{-6}	-7.51	-5.40	1.3x10^{2}
300	4.37	9.6x10^{-8}	5.7x10^{-6}	-7.02	-5.24	5.9x10^{1}
400	4.32	2.0x10^{-7}	7.3x10^{-6}	-6.69	-5.14	3.7x10^{1}
500	4.30	3.7x10^{-7}	8.6x10^{-6}	-6.43	-5.07	2.3x10^{1}
1000	4.48	5.6x10^{-7}	1.2x10^{-5}	-6.26	-4.92	2.1x10^{1}
5000	4.26	8.2x10^{-6}	3.0x10^{-5}	-5.00	-4.52	3.7
10000	4.24	1.8x10^{-5}	4.8x10^{-5}	-4.74	-4.32	2.7

[a] Core B1, 10-ft level; second section of Shelby tube sample.

Table D-2. Uranium sorption isotherm data for West Chestnut Ridge core sample B1-30-B[a]

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.00	$1.8\text{x}10^{-11}$	$1.3\text{x}10^{-7}$	-10.76	-6.88	$7.2\text{x}10^{3}$
10	5.90	$2.4\text{x}10^{-11}$	$2.4\text{x}10^{-7}$	-10.63	-6.63	$1.0\text{x}10^{4}$
20	5.85	$6.0\text{x}10^{-11}$	$4.5\text{x}10^{-7}$	-10.22	-6.36	$7.5\text{x}10^{3}$
30	5.84	$1.1\text{x}10^{-10}$	$6.6\text{x}10^{-7}$	-9.96	-6.18	$6.0\text{x}10^{3}$
40	5.72	$1.9\text{x}10^{-10}$	$8.7\text{x}10^{-7}$	-9.72	-6.07	$4.6\text{x}10^{3}$
50	5.71	$2.1\text{x}10^{-10}$	$1.1\text{x}10^{-6}$	-9.67	-5.97	$5.2\text{x}10^{3}$
100	5.57	$1.1\text{x}10^{-9}$	$2.1\text{x}10^{-6}$	-8.95	-5.51	$1.9\text{x}10^{3}$
200	5.40	$4.3\text{x}10^{-9}$	$4.2\text{x}10^{-6}$	-8.36	-5.38	$9.8\text{x}10^{2}$
300	5.36	$1.3\text{x}10^{-8}$	$6.3\text{x}10^{-6}$	-7.08	-5.20	$4.8\text{x}10^{2}$
400	5.19	$2.8\text{x}10^{-8}$	$8.3\text{x}10^{-6}$	-7.42	-5.08	$3.0\text{x}10^{2}$
500	5.00	$6.2\text{x}10^{-8}$	$1.0\text{x}10^{-5}$	-7.21	-4.99	$1.6\text{x}10^{2}$
1000	5.00	$1.2\text{x}10^{-7}$	$1.4\text{x}10^{-5}$	-6.93	-4.84	$1.2\text{x}10^{2}$
5000	5.07	$3.5\text{x}10^{-6}$	$5.4\text{x}10^{-5}$	-5.44	-4.26	$1.5\text{x}10^{1}$
10000	5.01	$2.9\text{x}10^{-6}$	$1.3\text{x}10^{-4}$	-5.54	-3.88	$4.5\text{x}10^{1}$

[a] Core B1, 30-ft level; second section of Shelby tube sample.

Table D-3. Uranium sorption isotherm data for West Chestnut Ridge core sample B1-40-B[a]

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.09	2.3×10^{-11}	1.3×10^{-7}	-10.65	-6.88	5.7×10^{3}
10	7.10	3.4×10^{-11}	2.4×10^{-7}	-10.41	-6.63	7.1×10^{3}
20	7.16	8.2×10^{-11}	4.5×10^{-7}	-10.08	-6.36	5.5×10^{3}
30	7.08	1.5×10^{-10}	6.6×10^{-7}	-9.83	-6.18	4.4×10^{3}
40	7.16	2.7×10^{-10}	8.7×10^{-7}	-9.56	-6.08	3.2×10^{3}
50	7.16	3.2×10^{-10}	1.1×10^{-6}	-9.50	-5.97	3.4×10^{3}
100	7.12	8.4×10^{-10}	2.1×10^{-6}	-9.08	-5.67	2.5×10^{3}
200	6.95	1.8×10^{-9}	4.2×10^{-6}	-8.74	-5.37	2.3×10^{3}
300	6.85	2.9×10^{-9}	6.3×10^{-6}	-8.54	-5.20	2.2×10^{3}
400	6.55	4.0×10^{-9}	8.4×10^{-6}	-8.40	-5.08	2.1×10^{3}
500	6.52	6.2×10^{-9}	1.5×10^{-5}	-8.21	-4.98	2.4×10^{3}
1000	5.88	6.5×10^{-9}	1.5×10^{-5}	-8.19	-4.84	2.3×10^{3}
5000	5.62	6.4×10^{-7}	1.4×10^{-4}	-6.20	-3.84	2.2×10^{2}
10000	5.60	2.4×10^{-6}	2.7×10^{-4}	-5.63	-3.56	1.1×10^{2}

[a] Core B1, 40-ft level; second section of Shelby tube sample.

Table D-4. Uranium sorption isotherm data for West Chestnut Ridge core sample B2-20-B[a]

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.85	$2.0\mathrm{x}10^{-11}$	$1.3\mathrm{x}10^{-7}$	-10.69	-6.88	$6.5\mathrm{x}10^{3}$
10	5.80	$3.9\mathrm{x}10^{-11}$	$2.3\mathrm{x}10^{-7}$	-10.41	-6.63	$5.9\mathrm{x}10^{3}$
20	5.77	$1.1\mathrm{x}10^{-10}$	$4.5\mathrm{x}10^{-7}$	-9.95	-6.35	$4.1\mathrm{x}10^{3}$
30	5.69	$1.5\mathrm{x}10^{-10}$	$6.3\mathrm{x}10^{-7}$	-9.81	-6.20	$4.2\mathrm{x}10^{3}$
40	5.60	$3.0\mathrm{x}10^{-10}$	$8.6\mathrm{x}10^{-7}$	-9.52	-6.07	$2.9\mathrm{x}10^{3}$
50	5.60	$9.4\mathrm{x}10^{-10}$	$1.0\mathrm{x}10^{-6}$	-9.03	-5.98	$1.1\mathrm{x}10^{3}$
100	5.42	$1.9\mathrm{x}10^{-9}$	$2.0\mathrm{x}10^{-6}$	-8.73	-5.69	$1.1\mathrm{x}10^{3}$
200	5.10	$7.4\mathrm{x}10^{-9}$	$4.1\mathrm{x}10^{-6}$	-8.13	-5.38	$5.5\mathrm{x}10^{2}$
300	5.00	$1.8\mathrm{x}10^{-8}$	$5.7\mathrm{x}10^{-6}$	-7.76	-5.23	$3.2\mathrm{x}10^{2}$
400	4.90	$6.3\mathrm{x}10^{-8}$	$8.1\mathrm{x}10^{-6}$	-7.20	-5.09	$1.3\mathrm{x}10^{2}$
500	4.92	$7.9\mathrm{x}10^{-8}$	$1.0\mathrm{x}10^{-5}$	-7.10	-5.00	$1.3\mathrm{x}10^{2}$
1000	4.80	$6.2\mathrm{x}10^{-7}$	$1.7\mathrm{x}10^{-5}$	-6.21	-4.76	$2.7\mathrm{x}10^{1}$
5000	4.92	$4.9\mathrm{x}10^{-6}$	$4.2\mathrm{x}10^{-5}$	-5.31	-4.38	8.6
10000	4.80	$1.2\mathrm{x}10^{-5}$	$7.2\mathrm{x}10^{-5}$	-4.92	-4.14	6.0

[a] Core B2, 20-ft level; second section of Shelby tube sample.

Table D-5. Uranium sorption isotherm data for West Chestnut Ridge core sample B2-30-B[a]

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Ks (L/kg)
5	5.59	6.1×10^{-11}	1.3×10^{-7}	-10.21	-6.90	2.1×10^{3}
10	5.43	1.5×10^{-10}	2.3×10^{-7}	-9.81	-6.63	1.5×10^{3}
20	5.79	3.8×10^{-10}	4.3×10^{-7}	-9.43	-6.37	1.1×10^{3}
30	5.32	7.5×10^{-10}	6.3×10^{-7}	-9.12	-6.20	8.4×10^{2}
40	5.28	1.4×10^{-9}	8.6×10^{-7}	-8.84	-6.07	6.1×10^{2}
50	5.27	-	-	-	-	-
100	5.09	1.1×10^{-8}	2.0×10^{-6}	-7.94	-5.70	1.8×10^{2}
200	5.02	5.9×10^{-8}	3.9×10^{-6}	-7.23	-5.41	6.6×10^{1}
300	4.85	1.7×10^{-7}	5.3×10^{-6}	-6.77	-5.28	3.1×10^{1}
400	4.67	4.6×10^{-7}	6.0×10^{-6}	-6.33	-5.22	1.3×10^{1}
500	4.69	5.6×10^{-7}	7.6×10^{-6}	-6.25	-5.12	1.4×10^{1}
1000	4.61	2.1×10^{-6}	9.9×10^{-6}	-5.68	-5.00	4.7
5000	5.01	8.3×10^{-6}	2.5×10^{-5}	-5.08	-4.59	3.0
10000	4.82	9.5×10^{-6}	8.6×10^{-5}	-5.02	-4.07	9.0

[a] Core B2, 30-ft level; second section of Shelby tube sample.

Table D-6. Uranium sorption isotherm data for West Chestnut Ridge core sample B2-60-B[a]

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.43	$2.6\mathrm{x}10^{-11}$	$1.1\mathrm{x}10^{-7}$	-10.58	-6.90	$4.2\mathrm{x}10^{3}$
10	5.47	$5.7\mathrm{x}10^{-11}$	$2.3\mathrm{x}10^{-7}$	-10.25	-6.64	$4.0\mathrm{x}10^{3}$
20	5.42	$1.7\mathrm{x}10^{-10}$	$4.5\mathrm{x}10^{-7}$	-9.76	-6.35	$2.6\mathrm{x}10^{3}$
30	5.46	$3.2\mathrm{x}10^{-10}$	$6.4\mathrm{x}10^{-7}$	-9.50	-6.20	$2.0\mathrm{x}10^{3}$
40	5.41	$5.3\mathrm{x}10^{-10}$	$8.6\mathrm{x}10^{-7}$	-9.28	-6.06	$1.6\mathrm{x}10^{3}$
50	5.39	$7.2\mathrm{x}10^{-10}$	$1.0\mathrm{x}10^{-6}$	-9.14	-5.98	$1.4\mathrm{x}10^{3}$
100	5.27	$3.0\mathrm{x}10^{-9}$	$2.1\mathrm{x}10^{-6}$	-8.52	-5.68	$7.0\mathrm{x}10^{2}$
200	5.25	$1.0\mathrm{x}10^{-8}$	$4.1\mathrm{x}10^{-6}$	-7.98	-5.39	$4.1\mathrm{x}10^{2}$
300	5.10	$3.2\mathrm{x}10^{-8}$	$6.0\mathrm{x}10^{-6}$	-7.50	-5.22	$1.9\mathrm{x}10^{2}$
400	4.74	$8.4\mathrm{x}10^{-8}$	$8.0\mathrm{x}10^{-6}$	-7.07	-5.10	$9.5\mathrm{x}10^{1}$
500	4.80	$1.0\mathrm{x}10^{-7}$	$9.9\mathrm{x}10^{-6}$	-6.99	-5.00	$9.9\mathrm{x}10^{1}$
1000	4.68	$7.8\mathrm{x}10^{-6}$	$1.7\mathrm{x}10^{-6}$	-6.11	-4.77	$2.2\mathrm{x}10^{1}$
5000	4.84	$5.4\mathrm{x}10^{-6}$	$4.1\mathrm{x}10^{-5}$	-5.27	-4.39	7.6
10000	4.88	$1.2\mathrm{x}10^{-5}$	$7.5\mathrm{x}10^{-5}$	-4.93	-4.13	6.3

[a] Core B2, 60-ft level, second section of Shelby tube sample.

Table D-7. Uranium sorption isotherm data for West Chestnut Ridge core sample B1-10-B[a]

(Natural pH maintained)

Initial U conc. (mg/L)	After contact					
	pH[b]	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	4.86	$9.2x10^{-11}$	$1.3x10^{-7}$	-10.04	-6.89	$1.4x10^{3}$
10	4.80	$1.9x10^{-10}$	$2.3x10^{-7}$	-9.74	-6.64	$1.2x10^{3}$
20	4.77	$4.7x10^{-10}$	$4.4x10^{-7}$	-9.33	-6.36	$9.4x10^{2}$
30	4.76	$8.2x10^{-10}$	$6.5x10^{-7}$	-9.09	-6.19	$7.9x10^{2}$
40	4.74	$1.2x10^{-9}$	$8.4x10^{-7}$	-8.94	-6.08	$7.0x10^{2}$
50	4.72	$1.7x10^{-9}$	$1.1x10^{-6}$	-8.76	-5.98	$6.5x10^{2}$
100	4.61	$5.6x10^{-9}$	$2.0x10^{-6}$	-8.25	-5.70	$3.6x10^{2}$
200	4.42	$3.1x10^{-8}$	$4.0x10^{-6}$	-7.51	-5.40	$1.3x10^{2}$
300	4.37	$9.6x10^{-8}$	$5.7x10^{-6}$	-7.02	-5.24	$5.9x10^{1}$
400	4.32	$2.0x10^{-7}$	$7.3x10^{-6}$	-6.69	-5.14	$3.7x10^{1}$
500	4.30	$3.7x10^{-7}$	$8.6x10^{-6}$	-6.43	-5.07	$2.3x10^{1}$
1000	4.48	$5.6x10^{-7}$	$1.2x10^{-5}$	-6.26	-4.92	$2.1x10^{1}$
5000	4.26	$8.2x10^{-6}$	$3.0x10^{-5}$	-5.00	-4.52	3.7
10000	4.24	$1.8x10^{-5}$	$4.8x10^{-5}$	-4.74	-4.32	2.7

[a] Core B1, 10-ft level; second section of Shelby tube sample.
[b] Mean pH, 4.55 ± 0.23.

Table D-6. Uranium sorption isotherm data for West Chestnut Ridge core sample B1-10-B[a]

(Target pH = 5.3)

Initial U conc. (mg/L)	After contact					
	pH[b]	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.34	1.0×10^{-10}	1.0×10^{-7}	-10.00	-6.98	1.0×10^{3}
10	5.39	1.1×10^{-10}	2.1×10^{-7}	-9.97	-6.68	1.9×10^{3}
20	5.39	1.9×10^{-10}	4.1×10^{-7}	-9.72	-6.38	2.2×10^{3}
30	5.56	2.7×10^{-10}	6.1×10^{-7}	-9.56	-6.21	2.2×10^{3}
40	5.43	5.0×10^{-10}	8.4×10^{-7}	-9.30	-6.08	1.7×10^{3}
50	5.49	4.6×10^{-10}	1.0×10^{-6}	-9.34	-5.99	2.2×10^{3}
100	5.48	1.4×10^{-9}	2.0×10^{-6}	-8.85	-5.69	1.5×10^{3}
200	5.26	7.1×10^{-9}	4.0×10^{-6}	-8.16	-5.40	5.6×10^{2}
300	5.33	9.9×10^{-9}	6.1×10^{-6}	-8.00	-5.22	6.1×10^{2}
400	5.22	2.4×10^{-8}	8.0×10^{-6}	-7.62	-5.08	3.5×10^{2}
500	5.08	5.1×10^{-8}	9.8×10^{-6}	-7.30	-5.01	1.7×10^{3}
1000	4.97	3.1×10^{-7}	1.9×10^{-5}	-6.50	-4.72	6.1×10^{1}

[a] Core B1, 10-ft level; second section of Shelby tube sample.
[b] Mean pH, 5.33 ± 0.17.

Table D-9. Uranium sorption isotherm data for West Chestnut Ridge core sample B1-40-B[a]

(Target pH = 7.4)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.61	8.8×10^{-12}	1.07×10^{-7}	-11.06	-6.97	1.2×10^{4}
10	7.57	4.5×10^{-11}	2.1×10^{-7}	-10.36	-6.68	4.7×10^{3}
20	7.51	1.6×10^{-10}	4.3×10^{-7}	-9.79	-6.37	2.6×10^{3}
30	7.51	2.7×10^{-12}	6.7×10^{-7}	-9.56	-6.18	2.4×10^{3}
40	7.50	4.5×10^{-10}	8.3×10^{-7}	-9.36	-6.08	1.9×10^{3}
50	7.47	5.5×10^{-10}	1.0×10^{-6}	-9.26	-6.00	1.8×10^{3}
100	7.44	1.9×10^{-9}	2.0×10^{-6}	-8.71	-5.69	1.0×10^{3}
200	7.38	2.3×10^{-9}	4.1×10^{-6}	-8.65	-5.39	1.8×10^{2}
300	7.39	3.0×10^{-9}	6.3×10^{-6}	-8.53	-5.20	2.1×10^{3}
400	7.36	3.3×10^{-9}	8.1×10^{-6}	-8.48	-5.09	2.4×10^{3}
500	7.40	4.0×10^{-9}	1.1×10^{-5}	-8.40	-4.98	2.7×10^{3}
1000	7.36	5.9×10^{-9}	2.1×10^{-5}	-8.23	-4.67	3.6×10^{3}
		Initiation of Probable Precipitation				
5000	7.28	2.3×10^{-8}	9.8×10^{-5}	-7.63	-4.01	4.2×10^{3}
10000	7.32	1.2×10^{-8}	2.0×10^{-4}	-7.92	-3.70	1.7×10^{4}

[a] Core B1, 40-ft level; second section of Shelby tube sample.
[b] Mean pH, 7.44 ± 0.10.

Table D-10. Strontium sorption isotherm data for West Chestnut Ridge core sample B1-10-B[a]

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.28	5.1×10^{-10}	2.7×10^{-7}	-9.29	-6.56	5.3×10^{2}
10	5.16	1.7×10^{-9}	5.6×10^{-7}	-8.76	-6.26	3.3×10^{2}
20	4.84	6.6×10^{-9}	1.1×10^{-6}	-8.10	-5.96	1.7×10^{2}
30	4.59	1.4×10^{-8}	1.6×10^{-6}	-7.84	-5.79	1.1×10^{2}
40	4.52	2.7×10^{-8}	2.1×10^{-6}	-7.57	-5.63	7.7×10^{1}
50	4.32	4.1×10^{-8}	2.6×10^{-6}	-7.38	-5.58	6.3×10^{1}
100	4.13	1.7×10^{-7}	4.9×10^{-6}	-6.78	-5.31	2.9×10^{1}
200	4.02	5.9×10^{-7}	8.4×10^{-6}	-6.23	-5.08	1.4×10^{1}
300	4.00	1.2×10^{-6}	1.1×10^{-5}	-5.92	-4.96	9.2
400	4.02	1.9×10^{-6}	1.3×10^{-5}	-5.72	-4.89	6.8
500	4.00	2.6×10^{-6}	1.5×10^{-5}	-5.58	-4.84	5.8
1000	3.95	7.1×10^{-6}	2.1×10^{-5}	-5.15	-4.68	3.0
5000	3.80	4.7×10^{-5}	3.5×10^{-5}	-4.32	-4.46	7.4×10^{-1}
10000	3.72	9.6×10^{-5}	3.7×10^{-5}	-4.02	-4.43	3.9×10^{-1}

---

[a] Core B1, 10-ft level; second section of Shelby tube sample.

Table D-11. Strontium sorption isotherm data for West Chestnut Ridge core sample B1-30-B[a]

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.85	$1.8x10^{-10}$	$2.8x10^{-7}$	-9.74	-6.56	$1.6x10^{3}$
10	5.80	$4.6x10^{-10}$	$5.6x10^{-7}$	-9.34	-6.25	$1.2x10^{3}$
20	5.60	$1.5x10^{-9}$	$1.1x10^{-6}$	-8.83	-5.96	$7.3x10^{2}$
30	5.97	$3.3x10^{-9}$	$1.7x10^{-6}$	-8.49	-5.28	$5.2x10^{2}$
40	5.40	$5.8x10^{-9}$	$2.3x10^{-6}$	-8.23	-5.64	$4.0x10^{2}$
50	5.36	$8.6x10^{-9}$	$2.8x10^{-6}$	-8.07	-5.55	$3.3x10^{2}$
100	5.10	$3.6x10^{-8}$	$5.6x10^{-6}$	-7.45	-5.26	$1.6x10^{2}$
200	4.97	$1.5x10^{-7}$	$1.1x10^{-5}$	-6.83	-4.96	$7.3x10^{1}$
300	4.86	$3.2x10^{-7}$	$1.5x10^{-5}$	-6.49	-4.82	$4.7x10^{1}$
400	4.84	$5.5x10^{-7}$	$1.9x10^{-5}$	-6.26	-4.72	$3.5x10^{1}$
500	4.81	$8.6x10^{-7}$	$2.3x10^{-5}$	-6.07	-4.63	$2.7x10^{1}$
1000	4.76	$3.0x10^{-6}$	$4.2x10^{-5}$	-5.52	-4.38	$1.4x10^{1}$
5000	4.56	$3.7x10^{-5}$	$9.0x10^{-5}$	-4.43	-4.04	2.4
10000	4.48	$8.5x10^{-5}$	$9.8x10^{-5}$	-4.07	-4.01	1.2

[a] Core B1, 30-ft level; second section of Shelby tube sample.

Table D-12. Strontium sorption isotherm data for West Chestnut Ridge core sample B1-40-B[a]

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.18	$1.2x10^{-9}$	$2.7x10^{-7}$	-8.92	-6.56	$2.3x10^{2}$
10	7.16	$2.4x10^{-9}$	$5.6x10^{-7}$	-8.61	-6.25	$2.3x10^{3}$
20	7.15	$5.3x10^{-9}$	$1.1x10^{-6}$	-8.27	-5.96	$2.1x10^{2}$
30	7.16	$8.6x10^{-9}$	$1.6x10^{-6}$	-8.07	-5.79	$1.9x10^{2}$
40	7.20	$1.3x10^{-8}$	$2.2x10^{-6}$	-7.89	-5.15	$1.7x10^{2}$
50	7.29	$1.7x10^{-8}$	$2.6x10^{-6}$	-7.77	-5.58	$1.5x10^{2}$
100	7.26	$5.0x10^{-8}$	$5.3x10^{-6}$	-7.30	-5.27	$1.1x10^{2}$
200	7.23	$1.5x10^{-7}$	$1.1x10^{-5}$	-6.81	-4.98	$7.3x10^{1}$
300	7.16	$3.0x10^{-7}$	$1.5x10^{-5}$	-6.52	-4.82	$5.0x10^{1}$
400	7.17	$5.3x10^{-7}$	$1.9x10^{-5}$	-6.28	-4.72	$3.6x10^{1}$
500	7.17	$7.7x10^{-7}$	$2.4x10^{-5}$	-6.11	-4.62	$3.1x10^{1}$
1000	7.06	$2.6x10^{-6}$	$4.3x10^{-5}$	-5.58	-4.37	$1.7x10^{1}$
5000	6.72	$3.4x10^{-5}$	$1.0x10^{-4}$	-4.47	-3.99	2.9
10000	6.77	$8.2x10^{-5}$	$1.2x10^{-4}$	-4.09	-3.94	1.5

[a] Core B1, 40-ft level; second section of Shelby tube sample.

Table D-13. Strontium sorption isotherm data for West Chestnut Ridge core sample B2-20-B[a]

Initial	After contact					
Sr conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.09	2.6×10^{-10}	2.8×10^{-7}	-9.58	-6.56	1.1×10^{3}
10	6.02	8.1×10^{-10}	5.6×10^{-7}	-9.09	-6.25	6.9×10^{2}
20	5.98	3.2×10^{-9}	1.1×10^{-6}	-8.49	-5.95	3.4×10^{2}
30	5.84	6.7×10^{-9}	1.7×10^{-6}	-8.17	-5.78	2.5×10^{2}
40	5.66	1.2×10^{-8}	2.2×10^{-6}	-7.94	-5.66	1.8×10^{2}
50	5.54	1.7×10^{-8}	2.7×10^{-6}	-7.76	-5.57	1.6×10^{2}
100	5.30	7.7×10^{-8}	5.2×10^{-6}	-7.12	-5.28	6.7×10^{1}
200	5.08	3.0×10^{-7}	9.9×10^{-6}	-6.53	-5.00	3.3×10^{1}
300	4.96	6.5×10^{-7}	1.4×10^{-5}	-6.19	-4.86	2.1×10^{1}
400	4.86	1.1×10^{-6}	1.7×10^{-5}	-5.96	-4.78	1.5×10^{1}
500	4.73	1.7×10^{-6}	1.9×10^{-5}	-5.78	-4.71	1.1×10^{1}
1000	4.60	5.2×10^{-5}	2.9×10^{-5}	-5.29	-4.53	5.6
5000	5.68	4.6×10^{-5}	4.1×10^{-5}	-4.43	-4.39	8.9×10^{-1}
10000	5.82	9.5×10^{-5}	3.9×10^{-5}	-4.02	-4.41	4.1×10^{-1}

[a] Core B2, 20-ft level; second section of Shelby tube sample.

Table D-14. Strontium sorption isotherm data for West Chestnut Ridge core sample B2-30-B[a]

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.85	$1.4x10^{-9}$	$2.8x10^{-7}$	-8.86	-6.55	$2.0x10^{2}$
10	5.89	$4.2x10^{-9}$	$5.5x10^{-7}$	-8.37	-6.26	$1.3x10^{2}$
20	5.74	$1.4x10^{-8}$	$1.0x10^{-6}$	-7.85	-5.98	$7.1x10^{1}$
30	5.74	$3.1x10^{-8}$	$1.6x10^{-6}$	-7.50	-5.81	$5.2x10^{1}$
40	5.68	$5.3x10^{-8}$	$1.9x10^{-6}$	-7.28	-5.71	$3.6x10^{1}$
50	5.63	$8.4x10^{-8}$	$2.4x10^{-6}$	-7.07	-5.61	$2.9x10^{1}$
100	5.46	$3.0x10^{-7}$	$4.2x10^{-6}$	-6.52	-5.37	$1.4x10^{1}$
200	5.39	$9.4x10^{-7}$	$6.4x10^{-6}$	-6.03	-5.19	6.8
300	5.30	$1.8x10^{-6}$	$7.8x10^{-6}$	-5.74	-5.11	4.3
400	5.23	$2.7x10^{-6}$	$9.1x10^{-6}$	-5.56	-5.04	3.4
500	5.19	$3.8x10^{-6}$	$2.9x10^{-6}$	-5.42	-5.05	$7.6x10^{-1}$
1000	4.63	$9.0x10^{-6}$	$1.1x10^{-6}$	-5.05	-4.97	$1.2x10^{-1}$
5000	5.92	$5.3x10^{-5}$	$6.0x10^{-6}$	-4.28	-5.23	$1.1x10^{-1}$
10000	5.98	$1.0x10^{-4}$	$2.4x10^{-6}$	-3.99	-5.63	$2.4x10^{-2}$

[a] Core B2, 30-ft level; second section of Shelby tube sample.

Table D-15. Strontium sorption isotherm data for West Chestnut Ridge core sample B2-60-B[a]

Initial	After contact					
Sr conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.00	5.9×10^{-10}	2.8×10^{-7}	-9.23	-6.55	4.7×10^{2}
10	6.00	1.5×10^{-9}	5.5×10^{-7}	-8.81	-6.26	3.7×10^{2}
20	5.91	4.1×10^{-9}	1.1×10^{-6}	-8.39	-5.97	2.7×10^{2}
30	5.65	8.1×10^{-9}	1.7×10^{-6}	-8.09	-5.78	2.1×10^{2}
40	5.63	1.4×10^{-8}	2.2×10^{-6}	-7.86	-5.65	1.6×10^{2}
50	5.60	2.0×10^{-8}	2.7×10^{-6}	-7.70	-5.57	1.4×10^{2}
100	5.57	7.6×10^{-8}	5.2×10^{-6}	-7.12	-5.29	6.8×10^{1}
200	5.52	2.9×10^{-7}	1.0×10^{-5}	-6.53	-5.00	3.4×10^{1}
300	5.34	6.1×10^{-7}	1.4×10^{-6}	-6.21	-4.85	2.3
400	5.16	1.0×10^{-6}	1.7×10^{-6}	-5.99	-4.76	1.7
500	5.05	1.6×10^{-6}	2.1×10^{-6}	-5.80	-4.68	1.3
1000	4.98	4.9×10^{-6}	3.0×10^{-6}	-5.31	-4.52	6.1×10^{-1}
5000	5.81	4.4×10^{-6}	5.3×10^{-6}	-4.36	-4.28	1.2
10000	5.92	9.4×10^{-5}	4.5×10^{-6}	-4.03	-4.35	4.8×10^{-2}

[a] Core B2, 60-ft level; second section of Shelby tube sample.

Table D-16. Cesium sorption isotherm data for West Chestnut Ridge core sample B1-10-B

Initial	After contact					
Cs conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	4.90	1.2E-10	1.9E-7	-9.94	-6.73	1.6E3
10	4.75	6.1E-10	3.6E-7	-9.21	-6.45	5.8E2
20	4.64	2.5E-9	7.4E-7	-8.60	-6.13	2.9E2
30	4.60	5.1E-9	1.1E-6	-8.29	-5.95	2.2E2
40	4.53	8.3E-9	1.4E-6	-8.08	-5.86	1.7E2
50	4.53	1.2E-8	1.8E-6	-7.92	-5.74	1.5E2
100	4.39	7.9E-8	7.0E-6	-7.10	-5.15	8.9E1
200	4.25	1.3E-7	6.8E-6	-6.89	-5.17	5.3E1
300	4.15	2.6E-7	9.7E-6	-6.59	-5.01	3.8E1
400	4.10	4.1E-7	1.3E-5	-6.38	-4.89	3.1E1
500	4.05	6.0E-7	1.5E-5	-6.22	-4.82	2.6E1
1000	3.88	2.0E-6	2.8E-5	-5.71	-4.55	1.4E1
5000	3.70	2.1E-5	7.5E-5	-4.68	-4.12	3.6E0
10000	3.75	5.1E-5	9.2E-5	-4.29	-4.03	1.8E0

Table D-17. Cesium sorption isotherm data for West Chestnut Ridge core sample B1-30-B

Initial	After contact					
Cs conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.69	3.2E-11	1.8E-7	-10.50	-6.74	5.7E3
10	5.68	1.9E-10	3.7E-7	-9.73	-6.43	1.5E3
20	5.39	7.7E-10	7.6E-7	-9.11	-6.12	9.9E2
30	5.35	1.7E-9	1.1E-6	-8.76	-5.95	6.4E2
40	5.26	2.9E-9	1.5E-6	-8.54	-5.82	5.3E2
50	5.19	3.6E-9	1.8E-6	-8.44	-5.74	5.0E2
100	5.15	1.1E-8	3.6E-6	-7.94	-5.45	3.1E2
200	4.96	3.5E-8	7.4E-6	-7.45	-5.13	2.1E2
300	4.91	6.8E-8	1.1E-5	-7.16	-4.97	1.6E2
400	4.85	9.9E-8	1.4E-5	-7.00	-4.86	1.4E2
500	4.80	1.4E-7	1.8E-5	-6.85	-4.75	1.3E2
1000	4.69	4.2E-7	3.5E-5	-6.38	-4.45	8.4E1
5000	4.36	1.2E-5	1.2E-4	-4.92	-3.91	1.0E1
10000	4.33	3.2E-5	1.9E-4	-4.50	-3.72	6.0E0

Table D-18. Cesium sorption isotherm data for West Chestnut Ridge core sample B1-40-B

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.18	1.6E-11	1.8E-7	-10.81	-6.74	1.1E4
10	7.15	1.0E-10	3.6E-7	-9.99	-6.45	3.5E3
20	7.15	5.3E-10	7.5E-7	-9.27	-6.13	1.4E3
30	7.16	1.2E-9	1.1E-6	-8.91	-5.97	8.8E2
40	7.16	1.9E-9	1.4E-6	-8.72	-5.84	7.5E2
50	7.18	2.5E-9	1.8E-6	-8.60	-5.75	7.2E2
100	7.12	8.0E-9	3.6E-6	-8.10	-5.45	4.4E2
200	7.12	2.7E-8	7.5E-6	-7.58	-5.12	2.8E2
300	7.11	5.3E-8	1.1E-5	-7.27	-4.97	2.0E2
400	7.07	7.9E-8	1.5E-5	-7.10	-4.83	1.9E2
500	7.04	1.2E-7	1.8E-5	-6.91	-4.75	1.4E2
1000	6.95	3.9E-7	3.4E-5	-6.41	-4.46	8.9E1
5000	6.59	9.7E-6	1.3E-4	-5.01	-3.88	1.4E1
10000	6.61	3.8E-5	1.6E-4	-4.42	-3.78	4.3E0

Table D-19. Cesium sorption isotherm data for West Chestnut Ridge core sample B2-20-B

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.35	2.2E-10	1.8E-7	-9.65	-6.74	8.1E2
10	5.13	7.0E-10	3.7E-7	-9.16	-6.44	5.3E2
20	5.09	2.1E-9	7.2E-7	-8.67	-6.14	3.4E2
30	5.01	4.4E-9	1.1E-6	-8.35	-5.96	2.5E2
40	4.90	6.4E-9	1.5E-6	-8.20	-5.83	2.3E2
50	4.94	9.3E-9	1.8E-6	-8.03	-5.74	2.0E2
100	4.81	2.8E-8	3.6E-6	-7.55	-5.44	1.3E2
200	4.70	7.7E-8	6.9E-6	-7.12	-5.16	9.0E1
300	4.61	1.5E-7	1.0E-5	-6.84	-5.00	6.9E1
400	4.53	2.6E-7	1.3E-5	-6.59	-4.88	5.1E1
500	4.44	3.9E-7	1.6E-5	-6.41	-4.79	4.2E1
1000	4.23	1.5E-6	2.9E-5	-5.84	-4.53	2.0E1
5000	4.00	2.3E-5	6.4E-5	-4.64	-4.19	2.8E0
10000	4.03	5.5E-5	7.3E-5	-4.26	-4.14	1.3E0

Table D-20. Cesium sorption isotherm data for West Chestnut Ridge core sample B2-30-B

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.58	1.7E-9	1.8E-7	-8.76	-6.74	1.1E2
10	5.55	4.4E-9	3.5E-7	-8.36	-6.46	7.8E1
20	5.58	1.2E-8	6.6E-7	-7.92	-6.18	5.4E1
30	5.45	2.3E-8	1.0E-6	-7.64	-5.99	4.5E1
40	5.37	3.3E-8	1.3E-6	-7.48	-5.88	4.0E1
50	5.32	4.4E-8	1.6E-6	-7.35	-5.79	3.7E1
100	5.33	1.2E-7	3.1E-6	-6.93	-5.51	2.6E1
200	5.10	3.5E-7	5.6E-6	-6.45	5.25	1.6E1
300	5.11	7.0E-7	7.7E-6	-6.16	-5.11	1.1E1
400	5.02	1.8E-6	6.0E-6	-5.75	-5.22	3.4E0
500	5.75	2.2E-6	7.6E-6	-5.65	-5.12	3.4E0
1000	4.98	4.6E-6	1.4E-5	-5.34	-4.85	3.1E0
5000	5.11	3.1E-5	2.2E-5	-4.51	-4.65	7.2E-1
10000	5.13	6.4E-5	2.0E-5	-4.19	-4.71	3.1E-1

Table D-21. Cesium sorption isotherm data for West Chestnut Ridge core sample B2-60-B

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.38	2.3E-10	1.8E-7	-9.64	-6.74	7.9E2
10	5.42	7.5E-10	3.6E-7	-9.12	-6.45	4.8E2
20	5.53	2.3E-9	7.3E-7	-8.64	-6.13	3.2E2
30	5.36	4.0E-9	1.1E-6	-8.40	-5.96	2.7E2
40	5.44	6.5E-9	1.5E-6	-8.19	-5.83	2.3E2
50	5.45	8.9E-9	1.8E-6	-8.05	-5.74	2.1E2
100	5.21	2.5E-8	3.6E-6	-7.60	-5.44	1.4E2
200	5.11	6.8E-8	7.0E-6	-7.17	-5.15	1.0E2
300	5.02	1.2E-7	1.0E-5	-6.92	-4.98	8.6E1
400	4.76	3.5E-7	1.3E-5	-6.45	-4.89	3.6E1
500	5.72	4.6E-7	1.6E-5	-6.33	-4.80	3.4E1
1000	4.76	9.3E-7	3.3E-5	-6.03	-4.49	3.5E1
5000	4.36	2.1E-5	7.8E-5	-4.69	-4.11	3.8E0
10000	4.38	5.2E-5	8.8E-5	-4.29	-4.06	1.7E0

Table D-22. Cobalt sorption isotherm data for West Chestnut Ridge core sample 31-10-B

Initial Co conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	4.68	2.6E-9	4.2E-7	-8.58	-6.38	1.6E2
10	4.50	9.6E-9	7.6E-7	-8.02	-6.12	7.9E1
20	4.33	3.8E-8	1.5E-6	-7.42	-5.84	3.9E1
30	4.25	8.2E-8	2.1E-6	-7.09	-5.68	2.6E1
40	4.22	1.4E-7	2.6E-6	-6.84	-5.59	1.8E1
50	4.26	2.2E-7	3.1E-6	-6.66	-5.51	1.4E1
100	4.13	7.0E-7	5.0E-6	-6.16	-5.30	7.2E0
200	4.04	1.9E-6	6.9E-6	-5.72	-5.16	3.6E0
300	3.99	3.1E-6	9.5E-6	-5.51	-5.02	3.1E0
400	3.98	4.9E-6	9.0E-6	-5.31	-5.05	1.8E0
500	3.97	6.4E-6	9.5E-6	-5.19	-5.02	1.5E0
1000	3.91	1.4E-5	1.4E-5	-4.86	-4.87	1.0E0
5000	3.83	7.9E-5	2.1E-6	-4.10	-5.55	3.5E-2
10000	4.06	1.4E-4	5.9E-5	-3.85	-4.23	4.2E-1

Table D-23. Cobalt sorption isotherm data for West Chestnut Ridge core sample B1-30-B

Initial	After contact					
Co conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.14	5.3E-10	4.1E-7	-9.28	-6.39	7.8E2
10	5.83	2.1E-9	8.5E-7	-8.67	-6.07	4.0E2
20	5.57	7.9E-9	1.6E-6	-8.10	-5.79	2.1E2
30	5.43	1.8E-8	2.4E-6	-7.74	-5.61	1.3E2
40	5.33	3.4E-8	3.2E-6	-7.47	-5.50	7.3E1
50	5.23	5.3E-8	3.9E-6	-7.28	-5.41	7.4E1
100	5.12	2.1E-7	7.5E-6	-6.67	-5.12	3.5E1
200	4.89	8.1E-7	1.3E-5	-6.09	-4.88	1.6E1
300	4.81	1.6E-6	1.7E-5	-5.78	-4.77	1.0E1
400	4.76	2.5E-6	2.1E-5	-5.60	-4.69	8.2E0
500	4.72	3.7E-6	2.3E-5	-5.43	-4.64	6.2E0
1000	4.62	1.0E-5	3.3E-5	-4.99	-4.48	3.3E0
5000	4.41	7.4E-5	3.3E-5	-4.13	-4.49	4.4E-1
10000	4.40	1.5E-4	2.4E-5	-3.83	-4.62	1.6E-1

Table D-24. Cobalt sorption isotherm data for West Chestnut Ridge core sample B1-40-B

Initial Co conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/l)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.72	5.5E-11	4.3E-7	-10.26	-6.36	7.9E3
10	7.56	1.8E-10	8.6E-7	-9.74	-6.07	4.7E3
20	7.39	1.1E-9	1.7E-6	-8.98	-5.77	1.6E3
30	6.95	2.4E-9	2.4E-6	-8.63	-5.62	1.0E3
40	7.38	5.4E-9	3.4E-6	-8.27	-5.47	6.3E2
50	7.04	7.0E-9	4.1E-6	-8.05	-5.38	4.6E2
100	6.81	7.4E-8	8.1E-6	-7.13	-5.09	1.1E2
200	6.57	5.7E-7	1.4E-5	-6.25	-4.85	2.5E1
300	6.41	9.8E-7	2.0E-5	-6.01	-4.71	2.0E1
400	6.34	1.8E-6	2.4E-5	-5.74	-4.62	1.3E1
500	6.24	2.8E-6	2.8E-5	-5.56	-4.55	1.0E1
1000	6.02	8.7E-6	3.9E-5	-5.06	-4.41	4.5E0
5000	5.59	7.1E-5	4.7E-5	-4.15	-4.33	6.7E-1
10000	5.58	1.4E-4	4.5E-5	-3.84	-4.34	3.1E-1

Table D-25. Cobalt sorption isotherm data for West Chestnut Ridge core sample B2-20-B

Initial Co conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.00	1.3E-9	4.1E-7	-8.89	-6.39	3.2E2
10	4.88	5.1E-9	8.0E-7	-8.30	-6.10	1.6E2
20	4.87	1.8E-8	1.6E-6	-7.75	-5.80	8.8E1
30	4.70	8.7E-8	2.1E-6	-7.06	-5.68	2.4E1
40	4.59	7.0E-8	3.0E-6	-7.16	-5.53	4.3E1
50	4.57	1.1E-7	3.7E-6	-6.96	-5.43	3.4E1
100	4.27	4.4E-7	6.3E-6	-6.36	-5.20	1.4E1
200	4.42	1.3E-6	1.0E-5	-5.88	-4.98	8.0E0
300	4.23	2.8E-6	1.1E-5	-5.55	-4.96	3.9E0
400	4.21	3.9E-6	1.4E-5	-5.41	-4.86	3.6E0
500	4.26	5.3E-6	1.5E-5	-5.28	-4.83	2.8E0
1000	4.19	1.3E-5	2.1E-5	-4.90	-4.68	1.7E0
5000	4.02	7.5E-5	2.7E-5	-4.13	-4.57	3.6E-1
10000	4.00	1.3E-4	1.2E-4	-3.88	-3.91	9.1E-1

Table D-26. Cobalt sorption isotherm data for West Chestnut Ridge core sample B2-30-B

Initial Co conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.07	4.3E-9	3.9E-7	-8.37	-6.41	7.1E1
10	5.56	1.8E-8	7.5E-7	-7.75	-6.13	4.2E1
20	5.52	6.5E-8	1.3E-6	-7.19	-5.87	2.1E1
30	5.35	1.4E-7	1.9E-6	-6.87	-5.73	1.4E1
40	5.23	2.0E-7	2.3E-6	-6.69	-5.63	1.2E1
50	5.25	3.2E-7	2.6E-6	-6.50	-5.59	8.1E0
100	5.14	9.9E-7	3.3E-6	-6.00	-5.48	3.4E0
200	4.98	2.4E-6	4.6E-6	-5.62	-5.34	1.9E0
300	4.97	4.1E-6	4.6E-6	-5.39	-5.34	1.1E0
400	4.95	5.6E-6	5.4E-6	-5.25	-5.26	1.0E0
500	4.94	7.5E-6	4.0E-6	-5.12	-5.40	5.3E-1
1000	4.95	1.5E-5	5.8E-6	-4.81	-5.23	3.8E-1
5000	4.65	7.9E-5	6.7E-6	-4.10	-5.17	8.5E-2
10000	4.53	1.5E-4	7.8E-6	-3.82	-5.11	5.2E-2

Table D-27. Cobalt sorption isotherm data for West Chestnut Ridge core sample B2-60-B

Initial Co conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.18	1.5E-9	4.1E-7	-8.81	-6.39	2.7E2
10	5.95	5.1E-9	8.3E-7	-8.29	-6.08	1.6E2
20	5.50	1.9E-8	1.6E-6	-7.73	-5.80	8.4E1
30	5.42	4.0E-8	2.4E-6	-7.40	-5.63	6.0E1
40	5.26	7.0E-8	3.1E-6	-7.16	-5.51	4.4E1
50	5.19	1.1E-7	3.6E-6	-6.96	-5.44	3.3E1
100	4.98	4.0E-7	6.4E-6	-6.40	-5.19	1.6E1
200	4.83	1.1E-6	1.1E-5	-5.94	-4.95	9.8E0
300	4.75	2.4E-6	1.4E-5	-5.63	-4.87	5.8E0
400	4.68	3.4E-6	1.6E-5	-5.47	-4.79	4.7E0
500	4.62	5.1E-6	1.6E-5	-5.29	-4.79	3.2E0
1000	4.52	1.3E-5	2.0E-5	-4.90	-4.70	1.6E0
5000	4.29	7.5E-5	2.4E-5	-4.12	-4.62	3.2E-1
10000	4.18	1.6E-4	6.4E-5	-3.78	-4.20	3.7E-1

Table D-28. Europium sorption isotherm data for soil sample B2-60 from the West Chestnut Ridge site

Initial Eu conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.7	3.4E-9	2.1E-4	-8.47	-3.68	6.1E4
10	5.4	1.1E-8	3.7E-4	-7.96	-3.43	3.5E4
20	5.3	1.4E-8	6.9E-4	-7.85	-3.16	4.8E4
30	5.1	7.6E-8	1.0E-3	-7.12	-3.00	1.3E4
40	5.2	2.9E-7	1.3E-3	-6.54	-2.89	4.7E3
50	5.0	9.1E-8	1.7E-3	-7.04	-2.77	1.9E4
100	4.9	5.0E-7	3.2E-3	-6.30	-2.49	6.4E3
200	4.8	2.0E-6	6.5E-3	-5.70	-2.19	3.2E3
300	4.7	6.3E-6	9.9E-3	-5.20	-2.00	1.6E3
400	4.7	1.4E-5	1.3E-2	-4.85	-1.87	8.9E2
500	4.7	2.9E-5	1.6E-2	-4.54	-1.80	5.5E2
1000	4.7	4.5E-4	2.9E-2	-3.35	-1.54	6.4E1

Table D-29. Thorium sorption isotherm data for soil sample B2-60 from the West Chestnut Ridge site

Initial	After contact					
Th conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	4.9	1.2E-8	1.3E-4	-7.92	-3.89	1.1E4
10	4.8	3.8E-8	2.3E-4	-7.42	-3.64	6.1E3
20	4.4	1.3E-7	4.6E-4	-6.87	-3.34	3.6E3
30	4.1	2.2E-7	6.7E-4	-6.66	-3.17	3.0E3
40	3.8	8.7E-7	8.7E-4	-6.06	-3.06	1.0E3
50	3.5	3.9E-6	1.0E-3	-5.41	-3.80	2.8E2
100	2.6	2.1E-4	1.1E-3	-3.68	-2.96	5.4E0

Table D-30. Technetium sorption isotherm data for soil sample B2-60 from the West Chestnut Ridge site

Initial Tc conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
9.9E3	5.2	2.0E-4	2.8E-4	-3.70	-3.55	1.4E0
9.9E1	5.3	8.4E-7	8.5E-7	-6.08	-6.07	1.0E0
9.9E-1	5.3	7.6E-9	1.2E-8	-8.12	-7.92	1.6E0
9.9E-3	5.3	7.6E-11	1.2E-10	-10.12	-9.92	1.6E0

Table D-31. Effect of the presence of uranium on the sorption of technetium by soil sample B2-60 from the West Chestnut Ridge site

Initial Tc conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
9.9E-3	4.4	7.5E-11	1.3E-10	-10.13	-9.89	1.7E0

Table D-32. Iodine sorption isotherm data for West Chestnut Ridge core sample B1-10-B

Initial I conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.26	3.4×10^{-8}	2.1×10^{-8}	-7.46	-7.69	0.60
10	5.06	6.8×10^{-8}	4.7×10^{-8}	-7.17	-7.33	0.68
20	5.03	1.4×10^{-7}	9.3×10^{-8}	-6.87	-7.03	0.69
30	4.90	2.1×10^{-7}	1.6×10^{-7}	-6.69	-6.80	0.77
40	4.95	2.8×10^{-7}	1.3×10^{-7}	-6.55	-6.87	0.48
50	4.82	3.5×10^{-7}	1.8×10^{-7}	-6.46	-6.75	0.51
100	4.93	6.9×10^{-7}	4.5×10^{-7}	-6.16	-6.35	0.65
200	4.74	1.4×10^{-6}	7.8×10^{-7}	-5.86	-6.11	0.56
300	4.64	2.0×10^{-6}	1.4×10^{-6}	-6.69	-5.86	0.67
400	4.58	2.8×10^{-6}	1.4×10^{-6}	-5.55	-5.84	0.52
500	4.59	3.7×10^{-6}	1.4×10^{-6}	-5.44	-5.84	0.40
1000	4.57	7.4×10^{-6}	2.2×10^{-6}	-5.13	-5.65	0.30
5000	4.36	3.8×10^{-5}	3.9×10^{-6}	-4.42	-5.40	0.10
10000	4.25	7.2×10^{-5}	4.5×10^{-6}	-4.14	-5.34	0.06

Table D-33. Iodine sorption isotherm data for West Chestnut Ridge core sample B1-30-B

Initial	After contact					
I conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.33	3.9×10^{-8}	7.8×10^{-10}	-7.41	-9.11	0.02
10	5.35	7.5×10^{-8}	1.2×10^{-8}	-7.13	-7.94	0.15
20	5.31	1.5×10^{-7}	3.3×10^{-8}	-6.83	-7.48	0.22
30	5.38	2.2×10^{-7}	6.7×10^{-8}	-6.66	-7.17	0.31
40	5.39	3.0×10^{-7}	6.2×10^{-8}	-6.53	-7.21	0.21
50	5.36	3.7×10^{-7}	8.0×10^{-8}	-6.43	-7.10	0.21
100	5.27	7.2×10^{-7}	2.4×10^{-7}	-6.14	-6.62	0.33
200	5.21	1.4×10^{-6}	5.5×10^{-7}	-5.84	-6.26	0.38
300	5.14	2.2×10^{-6}	8.2×10^{-7}	-5.67	-6.09	0.38
400	5.15	2.9×10^{-6}	7.3×10^{-7}	-5.53	-6.14	0.25
500	5.16	3.6×10^{-6}	1.5×10^{-6}	-5.46	-5.82	0.42
1000	5.07	6.9×10^{-6}	3.9×10^{-6}	-5.16	-5.41	0.56
5000	5.20	3.5×10^{-6}	1.1×10^{-5}	-4.46	-4.95	0.32
10000	5.45	6.6×10^{-5}	2.4×10^{-5}	-4.18	-4.61	0.37

Table D-34. Iodine sorption isotherm data for West Chestnut Ridge core sample B1-40-B

Initial I conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.96	$3.8\text{x}10^{-8}$	$1.8\text{x}10^{-9}$	-7.42	-8.74	0.05
10	6.95	$7.7\text{x}10^{-8}$	$2.5\text{x}10^{-9}$	-7.11	-8.60	0.03
20	6.98	$1.5\text{x}10^{-7}$	$4.9\text{x}10^{-10}$	-6.81	-9.31	0.03
30	6.99	$2.3\text{x}10^{-7}$	$1.9\text{x}10^{-8}$	-6.64	-7.71	0.09
40	7.08	$3.0\text{x}10^{-7}$	$6.5\text{x}10^{-8}$	-6.52	-7.19	0.22
50	6.96	$3.9\text{x}10^{-7}$	$6.1\text{x}10^{-8}$	-6.41	-7.21	0.16
100	6.97	$8.0\text{x}10^{-7}$	$1.0\text{x}10^{-7}$	-6.10	-6.99	0.13
200	6.99	$1.6\text{x}10^{-6}$	$3.6\text{x}10^{-7}$	-5.80	-6.45	0.23
300	6.98	$2.4\text{x}10^{-6}$	$3.2\text{x}10^{-7}$	-5.62	-6.50	0.13
400	7.02	$3.2\text{x}10^{-6}$	$5.6\text{x}10^{-7}$	-5.50	-6.25	0.18
500	7.01	$3.9\text{x}10^{-6}$	$9.1\text{x}10^{-7}$	-5.41	-6.04	0.23
1000	7.01	$7.9\text{x}10^{-6}$	$1.5\text{x}10^{-6}$	-5.10	-5.82	0.19
5000	6.92	$3.7\text{x}10^{-6}$	$6.6\text{x}10^{-6}$	-4.43	-5.18	0.18
10000	6.88	$6.3\text{x}10^{-5}$	$5.6\text{x}10^{-5}$	-4.20	-4.26	0.88

Table D-35. Iodine sorption isotherm data for West Chestnut Ridge core sample B2-20-B

Initial I conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.87	$3.1x10^{-8}$	$3.9x10^{-8}$	-7.50	-7.42	1.21
10	5.87	$6.7x10^{-8}$	$5.5x10^{-8}$	-7.17	-7.26	0.81
20	5.71	$1.4x10^{-7}$	$8.5x10^{-8}$	-6.86	-7.07	0.62
30	5.60	$2.1x10^{-7}$	$1.2x10^{-7}$	-6.68	-6.92	0.58
40	5.58	$2.8x10^{-7}$	$1.6x10^{-7}$	-6.56	-6.80	0.57
50	5.52	$3.5x10^{-7}$	$1.8x10^{-7}$	-6.46	-6.74	0.52
100	5.37	$6.7x10^{-7}$	$5.0x10^{-7}$	-6.17	-6.30	0.74
200	5.28	$1.4x10^{-6}$	$5.8x10^{-7}$	-5.86	-6.24	0.41
300	5.18	$2.1x10^{-6}$	$9.8x10^{-7}$	-5.67	-6.01	0.46
400	5.13	$2.8x10^{-6}$	$1.3x10^{-6}$	-5.55	-5.87	0.48
500	4.72	$3.6x10^{-6}$	$1.1x10^{-6}$	-5.44	-5.96	0.30
1000	4.57	$7.2x10^{-6}$	$2.3x10^{-6}$	-5.14	-5.64	0.32
5000	4.37	$3.5x10^{-6}$	$9.0x10^{-6}$	-4.45	-5.05	0.26
10000	4.30	$6.8x10^{-5}$	$1.1x10^{-6}$	-4.17	-4.95	0.16

Table D-36. Iodine sorption isotherm data for West Chestnut Ridge core sample B2-30-B

Initial	After contact					
I conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.68	$3.7\text{x}10^{-8}$	$8.8\text{x}10^{-9}$	-7.44	-8.05	0.24
10	5.69	$7.3\text{x}10^{-8}$	$2.1\text{x}10^{-8}$	-7.14	-7.68	0.29
20	5.66	$1.4\text{x}10^{-7}$	$3.6\text{x}10^{-8}$	-6.84	-7.44	0.26
30	5.61	$2.1\text{x}10^{-7}$	$1.0\text{x}10^{-7}$	-6.68	-6.98	0.50
40	5.65	$2.9\text{x}10^{-7}$	$1.0\text{x}10^{-7}$	-6.64	-6.99	0.36
50	5.65	$3.4\text{x}10^{-7}$	$2.2\text{x}10^{-7}$	-6.47	-6.66	0.64
100	5.69	$7.0\text{x}10^{-7}$	$3.6\text{x}10^{-7}$	-6.16	-6.44	0.52
200	5.50	$1.5\text{x}10^{-6}$	$2.8\text{x}10^{-7}$	-5.83	-6.56	0.19
300	5.34	$2.2\text{x}10^{-6}$	$4.7\text{x}10^{-7}$	-5.65	-6.33	0.21
400	5.46	$3.0\text{x}10^{-6}$	$4.0\text{x}10^{-7}$	-5.53	-6.40	0.13
500	5.42	$3.7\text{x}10^{-6}$	$5.7\text{x}10^{-7}$	-5.43	-6.24	0.15
1000	5.41	$7.3\text{x}10^{-6}$	$1.7\text{x}10^{-6}$	-5.14	-5.77	0.23
5000	5.48	$3.5\text{x}10^{-6}$	$6.1\text{x}10^{-6}$	-4.45	-5.21	0.17
10000	5.57	$6.8\text{x}10^{-6}$	$6.0\text{x}10^{-6}$	-4.17	-5.22	0.88

Table D-37. Iodine sorption isotherm data for West Chestnut Ridge core sample B2-60-B

Initial	After contact					
I conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.66	3.5×10^{-8}	1.7×10^{-8}	-7.46	-7.78	0.48
10	5.39	7.5×10^{-8}	4.8×10^{-9}	-7.12	-8.32	0.06
20	5.32	1.4×10^{-7}	4.3×10^{-8}	-6.84	-7.37	0.30
30	5.22	2.3×10^{-7}	1.5×10^{-8}	-6.65	-7.81	0.07
40	5.21	3.0×10^{-7}	3.0×10^{-8}	-6.53	-7.52	0.10
50	5.19	3.8×10^{-7}	1.0×10^{-8}	-6.42	-7.98	0.03
100	5.11	6.9×10^{-7}	3.4×10^{-7}	-6.16	-6.46	0.50
200	5.10	1.4×10^{-6}	7.4×10^{-7}	-5.86	-6.13	0.54
300	5.04	2.2×10^{-6}	7.2×10^{-7}	-5.66	-6.14	0.33
400	4.97	3.0×10^{-6}	5.2×10^{-7}	-5.53	-6.29	0.17
500	4.94	3.0×10^{-6}	4.4×10^{-6}	-5.52	-5.36	1.44
1000	4.93	7.4×10^{-6}	1.2×10^{-6}	-5.13	-5.93	0.16
5000	4.92	3.6×10^{-5}	4.6×10^{-6}	-4.44	-5.34	0.13
10000	5.02	6.9×10^{-6}	5.6×10^{-6}	-4.16	-5.26	0.81

Appendix E.

URANIUM SORPTION/DESORPTION DATA

Table E-1. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B1-40

Initial	After contact					
U conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.1	2.7E-8	1.3E-4	-7.57	-3.89	4.7E3
10	7.2	5.1E-8	2.8E-4	-7.29	-3.55	4.7E3
20	7.1	1.1E-7	4.5E-4	-6.96	-3.35	4.0E3
30	7.1	1.8E-7	6.4E-4	-6.74	-3.19	3.5E3
40	7.1	2.7E-7	8.4E-4	-6.57	-3.08	3.2E3
50	7.1	3.8E-7	1.1E-3	-6.42	-2.96	2.8E3
100	7.0	8.5E-7	2.1E-3	-6.07	-2.68	2.5E3
200	6.9	1.9E-6	4.2E-3	-5.72	-2.38	2.2E3
300	6.8	2.6E-6	6.3E-3	-5.59	-2.20	2.5E3
400	6.5	3.7E-6	8.1E-3	-5.43	-2.09	2.2E3
500	6.1	1.3E-5	1.0E-2	-4.89	-2.00	7.8E2
1000	5.1	2.7E-4	2.0E-2	-3.57	-1.70	8.3E1
5000	3.9	1.5E-2	2.7E-2	-1.82	-1.57	1.8E0
10000	3.4	3.1E-2	3.7E-2	-1.51	-1.43	1.2E0

Table E-2. Uranium desorption (No. 1) isotherm data for soil from West Chestnut Ridge boring B1-40

Initial U conc. (mg/L)	After contact 1					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.1	2.2E-8	1.0E-4	-7.65	-3.98	4.7E3
10	7.2	4.6E-8	2.2E-4	-7.34	-3.66	4.7E3
20	7.1	1.1E-7	4.3E-4	-6.97	-3.36	4.0E3
30	7.1	1.8E-7	6.3E-4	-6.74	-3.20	3.5E3
40	7.1	2.6E-7	8.3E-4	-6.58	-3.08	3.2E3
50	7.1	3.8E-7	1.1E-3	-6.42	-2.97	2.8E3
100	7.0	8.6E-7	2.1E-3	-6.06	-2.68	2.5E3
200	6.9	1.9E-6	4.2E-3	-5.72	-2.37	2.2E3
300	6.8	2.6E-6	6.4E-3	-5.58	-2.19	2.5E3
400	6.5	3.8E-6	8.3E-3	-5.42	-2.08	2.2E3
500	6.1	1.3E-5	1.0E-2	-4.88	-1.98	7.8E2
1000	5.0	2.4E-4	2.0E-2	-3.62	-1.70	8.2E1
5000	3.9	1.6E-2	1.7E-2	-1.80	-1.76	1.1E0
10000	3.4	3.4E-2	1.7E-2	-1.46	-1.76	4.9E-1

Table E-3. Uranium desorption (No.2) isotherm data for soil from West Chestnut Ridge boring B1-40

Initial U conc. (mg/L)	After contact 2					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.3	1.9E-8	1.0E-4	-7.72	-3.98	5.4E3
10	7.5	4.6E-8	2.2E-4	-7.34	-3.67	4.7E3
20	7.3	1.1E-7	4.3E-4	-6.96	-3.37	4.0E3
30	7.3	1.8E-7	6.3E-4	-6.74	-3.20	3.5E3
40	7.3	3.0E-7	8.3E-4	-6.52	-3.08	2.8E3
50	7.3	4.1E-7	1.1E-3	-6.39	-2.97	2.6E3
100	7.2	9.0E-7	2.1E-3	-6.05	-2.68	2.3E3
200	7.2	2.1E-6	4.2E-3	-5.68	-2.37	2.0E3
300	7.1	3.3E-6	6.4E-3	-5.48	-2.19	1.9E3
400	7.0	3.6E-6	8.2E-3	-5.44	-2.08	2.3E3
500	6.8	5.2E-6	1.0E-2	-5.29	-1.98	2.0E3
1000	5.7	5.9E-5	2.0E-2	-4.23	-1.70	3.4E2
5000	4.1	1.9E-3	1.6E-2	-2.71	-1.80	8.1E0
10000	3.7	4.5E-3	1.1E-2	-2.34	-1.97	2.4E0

Table E-4. Uranium desorption (No. 3) isotherm data for soil from West Chestnut Ridge boring B1-40

Initial U conc. (mg/L)	After contact 3					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.5	3.7E-8	1.0E-4	-7.43	-3.98	2.8E3
10	7.4	6.8E-8	2.2E-4	-7.16	-3.67	3.1E3
20	7.2	1.6E-7	4.3E-4	-6.80	-3.37	2.7E3
30	7.2	3.4E-7	6.3E-4	-6.47	-3.20	1.8E3
40	7.2	5.3E-7	8.3E-4	-6.27	-3.08	1.6E3
50	7.2	8.0E-7	1.1E-3	-6.10	-2.97	1.3E3
100	7.1	1.7E-6	2.1E-3	-5.76	-2.68	1.2E3
200	7.1	3.3E-6	4.2E-3	-5.49	-2.38	1.3E3
300	7.0	5.3E-6	6.4E-3	-5.27	-2.19	1.2E3
400	6.9	7.1E-6	8.2E-3	-5.15	-2.09	1.2E3
500	6.5	5.7E-6	1.0E-2	-5.24	-1.99	1.8E3
1000	5.6	2.3E-5	2.0E-2	-4.64	-1.71	8.7E2
5000	4.3	4.6E-4	1.5E-2	-3.34	-1.83	3.2E1
10000	3.9	7.7E-4	9.3E-3	-3.11	-2.03	1.1E1

Table E-5. Uranium desorption (No. 4) isotherm data for soil from West Chestnut Ridge boring B1-40

Initial	After contact 4					
U conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.9	2.7E-8	1.0E-4	-7.57	-3.99	3.9E3
10	8.0	6.9E-8	2.2E-4	-7.16	-3.67	3.1E3
20	8.0	1.5E-7	4.3E-4	-6.83	-3.37	2.9E3
30	7.9	3.1E-7	6.2E-4	-6.50	-3.20	2.0E3
40	7.9	5.0E-7	8.3E-4	-6.30	-3.08	1.7E3
50	7.9	5.9E-7	1.1E-3	-6.23	-2.97	1.8E3
100	7.9	1.5E-6	2.1E-3	-5.83	-2.68	1.4E3
200	7.9	4.1E-6	4.2E-3	-5.38	-2.38	1.0E3
300	7.8	5.0E-6	6.4E-3	-5.30	-2.20	1.3E3
400	7.7	6.9E-6	8.2E-3	-5.16	-2.09	1.2E3
500	7.4	6.3E-6	1.0E-2	-5.20	-1.99	1.6E3
1000	6.4	1.5E-5	1.9E-2	-4.84	-1.71	1.3E3
5000	5.0	2.1E-4	1.4E-2	-3.68	-1.86	6.5E1
10000	4.5	2.8E-4	8.1E-3	-3.55	-2.09	2.8E1

Appendix F

URANIUM SORPTION ISOTHERM DATA FOR DOLOMITIC ROCK SAMPLE

Table F-1. Uranium sorption isotherm data for dolomitic rock sample from borehole B-7 (75- to 130-ft depth) at the West Chestnut Ridge site

(Particle size of rock sample: -4 +12 mesh; natural pH maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	9.6	3.9E-7	3.8E-5	-6.41	-4.42	9.6E1
5	9.3	1.3E-6	2.0E-4	-5.89	-3.70	1.5E2
10	9.6	4.0E-6	4.3E-4	-5.40	-3.37	1.1E2
25	9.0	8.4E-6	1.2E-3	-5.08	-2.92	1.4E2
50	9.3	1.4E-5	2.5E-3	-4.85	-2.60	1.8E2
100	8.8	3.5E-5	5.4E-3	-4.46	-2.27	1.5E2
250	8.8	1.4E-5	1.3E-2	-4.85	-1.89	9.6E2
500	6.3	3.0E-4	2.5E-2	-3.52	-1.60	8.4E1
1000	6.9	8.0E-5	5.8E-2	-4.10	-1.24	7.2E2

Table F-2. Uranium sorption isotherm data for dolomitic rock sample from borehole B-7 (75- to 130-ft depth) at the West Chestnut Ridge site

(Particle size of rock sample: -4 +12 mesh; constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	2.6E-7	4.0E-5	-6.58	-4.40	1.5E2
5	7.0	1.8E-6	1.9E-4	-5.74	-3.72	1.0E2
10	7.0	2.9E-6	4.4E-4	-5.54	-3.36	1.5E2
25	7.0	1.3E-5	1.1E-3	-4.89	-2.96	8.5E1
50	7.0	2.4E-5	2.4E-3	-4.62	-2.62	9.9E1
100	7.0	6.5E-5	5.1E-3	-4.19	-2.29	7.7E1
250	7.0	1.5E-4	1.2E-2	-3.82	-1.92	8.2E1
500	7.0	3.4E-4	2.5E-2	-3.47	-1.60	7.1E1
1000	7.0	6.9E-4	5.2E-2	-3.16	-1.28	7.6E1

Appendix G.

CONSTANT-pH SORPTION TEST DATA

Table G-1. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 3.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	3.0	1.8E-6	2.4E-5	-5.74	-4.62	1.3E1
5	3.0	1.3E-5	1.3E-4	-4.89	-3.89	1.0E1
10	3.0	2.9E-5	1.7E-4	-4.54	-3.77	6.0E0
25	3.0	8.3E-5	5.3E-4	-4.08	-3.28	6.4E0
50	3.0	1.7E-4	9.2E-4	-3.77	-3.04	5.4E0
100	3.0	3.7E-4	2.0E-3	-3.43	-2.70	5.3E0
250	3.0	9.3E-4	3.9E-3	-3.03	-2.41	4.2E0
500	3.0	2.1E-3	6.3E-3	-2.68	-2.20	3.1E0
1000	3.0	4.5E-3	1.1E-2	-2.35	-1.96	2.4E0

Table G-2. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 4.0 maintained)

Initial U conc. (mg/L)	After contact pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	4.0	8.0E-7	3.4E-5	-6.10	-4.47	4.2E1
5	4.0	5.2E-6	2.0E-4	-5.28	-3.70	3.8E1
10	4.0	1.1E-5	3.5E-4	-4.96	-3.46	3.1E1
25	4.0	3.5E-5	1.0E-3	-4.46	-3.00	2.8E1
50	4.0	6.6E-5	2.0E-3	-4.18	-2.70	3.0E1
100	4.0	1.6E-4	4.1E-3	-3.80	-2.39	2.6E1
250	4.0	5.2E-4	8.2E-3	-3.28	-2.09	1.6E1
500	4.0	1.5E-3	1.2E-2	-2.82	-1.92	7.8E0
1000	4.0	3.7E-3	1.9E-2	-2.43	-1.72	5.1E0

Table G-3. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 5.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	5.0	6.0E-8	4.1E-5	-7.22	-4.39	7.0E2
5	5.0	3.9E-7	2.5E-4	-6.41	-3.60	6.4E2
10	5.0	1.1E-6	4.6E-4	-5.96	-3.34	4.0E2
25	5.0	3.4E-6	1.3E-3	-5.47	-2.89	4.0E2
50	5.0	9.9E-6	2.6E-3	-5.00	-2.59	2.6E2
100	5.0	3.2E-5	5.4E-3	-4.49	-2.27	1.7E2
250	5.0	1.7E-4	1.2E-2	-3.77	-1.92	7.1E1
500	5.0	7.3E-4	2.0E-2	-3.14	-1.70	2.7E1
1000	5.0	2.4E-3	3.4E-2	-2.62	-1.47	1.3E1

Table G-4. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 6.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	6.0	2.5E-9	4.2E-5	-8.60	-4.38	1.7E4
5	6.0	1.9E-8	2.5E-4	-7.72	-3.60	1.4E4
10	6.0	5.9E-8	4.7E-4	-7.23	-3.33	8.0E3
25	6.0	1.8E-7	1.4E-3	-6.74	-2.85	7.5E3
50	6.0	3.9E-7	2.7E-3	-6.41	-2.57	6.8E3
100	6.0	3.0E-6	5.7E-3	-5.52	-2.24	1.9E3
250	6.0	3.0E-5	1.3E-2	-4.52	-1.89	4.4E2
500	6.0	1.5E-4	2.6E-2	-3.82	-1.59	1.8E2
1000	6.0	5.4E-4	5.2E-2	-3.27	-1.28	9.6E1

Table G-5. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	7.0	1.8E-9	4.2E-5	-8.74	-4.38	2.3E4
5	7.0	1.5E-8	2.5E-4	-7.82	-3.60	1.7E4
10	7.0	4.5E-8	4.7E-4	-7.35	-3.33	1.0E4
25	7.0	1.7E-7	1.4E-3	-6.77	-2.85	8.1E3
50	7.0	2.9E-7	2.7E-3	-6.54	-2.57	9.1E3
100	7.0	1.6E-6	5.8E-3	-5.80	-2.24	3.7E3
250	7.0	5.3E-6	1.3E-2	-5.28	-1.87	2.6E3
500	7.0	1.0E-5	2.8E-2	-5.00	-1.55	2.6E3
1000	7.0	5.4E-5	5.7E-2	-4.27	-1.24	1.0E3

Table G-6. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 8.0 maintained)

Initial	After contact					
U conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	8.0	5.9E-9	4.2E-5	-8.23	-4.38	7.1E3
5	8.0	1.3E-7	2.5E-4	-6.89	-3.60	1.9E3
10	8.0	6.6E-8	4.7E-4	-7.18	-3.33	7.1E3
25	8.0	2.3E-7	1.4E-3	-6.64	-2.85	5.9E3
50	8.0	2.8E-7	2.7E-3	-6.55	-2.57	9.4E3
100	8.0	8.6E-7	5.8E-3	-6.06	-2.24	6.7E3
250	8.0	2.3E-6	1.4E-2	-5.64	-1.85	6.0E3
500	8.0	5.4E-6	2.8E-2	-5.28	-1.55	5.3E3
1000	8.0	2.7E-5	5.7E-2	-4.57	-1.24	2.1E3

Table G-7. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of increased uranium concentration on solubility limit

Initial	After contact					
U conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	1.8E-9	4.2E-5	-8.74	-4.38	2.3E4
5	7.0	1.5E-8	2.5E-4	-7.82	-3.60	1.7E4
10	7.0	4.5E-8	4.7E-4	-7.35	-3.33	1.0E4
25	7.0	1.7E-7	1.4E-3	-6.77	-2.85	8.1E3
50	7.0	2.9E-7	2.7E-3	-6.54	-2.57	9.1E3
100	7.0	1.6E-6	5.8E-3	-5.80	-2.24	3.7E3
250	7.0	5.3E-6	1.3E-2	-5.28	-1.87	2.6E3
500	7.0	1.0E-5	2.8E-2	-5.00	-1.55	2.6E3
1000	7.0	5.4E-5	5.7E-2	-4.27	-1.24	1.0E3
500	7.0	2.1E-6	2.1E-2	-5.68	-1.68	1.0E4
1000	7.0	1.5E-5	6.3E-2	-4.82	-1.20	4.1E3
2000	7.0	9.9E-6	1.5E-1	-5.00	-0.82	1.5E4
5000	7.0	1.1E-5	3.7E-1	-4.96	-0.43	3.3E4
10000	7.0	1.4E-5	8.2E-1	-4.85	-0.09	6.1E4
25000	7.0	2.6E-4	2.0E-0	-3.59	0.30	7.9E3
25000[a]	7.0	6.4E-6	2.0E-0	-5.19	0.30	3.2E5

[a] Sample contacted for 24 h.

Table G-8. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 3.0 maintained)

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	3.0	5.1E-6	6.4E-5	-5.29	-4.19	1.3E1
5	3.0	2.8E-5	2.9E-4	-4.55	-3.54	1.0E1
10	3.0	8.8E-5	7.3E-4	-4.06	-3.14	8.3E0
25	3.0	2.9E-4	2.1E-3	-3.54	-2.68	7.0E0
50	3.0	8.5E-4	4.1E-3	-3.07	-2.39	4.8E0
100	3.0	2.1E-3	9.1E-3	-2.68	-2.04	4.3E0
250	3.0	5.7E-3	1.8E-2	-2.24	-1.74	3.2E0
500	3.0	1.4E-2	3.2E-2	-1.85	-1.49	2.2E0
1000	3.0	3.5E-2	4.8E-2	-1.46	-1.32	1.4E0
5000	3.0	1.1E-1	9.0E-2	-0.96	-1.05	8.3E1
10000	3.0	2.4E-1	3.8E-1	-0.62	-0.42	1.6E0
25000	3.0	4.6E-1	2.5E-0	-0.34	0.40	5.5E0

Table G-9. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 4.0 maintained)

Initial	After contact				
Sr conc. (mg/L)	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	2.6E-6	8.9E-5	-5.59	-4.05	3.4E1
5	1.8E-5	4.0E-4	-4.74	-3.40	2.2E1
10	6.3E-5	1.0E-3	-4.20	-3.00	1.6E1
25	2.3E-4	2.8E-3	-3.64	-2.55	1.2E1
50	6.8E-4	6.2E-3	-3.17	-2.20	9.1E0
100	1.8E-3	1.3E-2	-2.74	-1.89	7.2E0
250	5.1E-3	2.7E-2	-2.29	-1.57	5.3E0
500	1.3E-2	4.8E-2	-1.89	-1.32	3.6E0
1000	3.3E-2	8.1E-2	-1.48	-1.09	2.5E0
5000	1.0E-1	1.9E-1	-1.00	-0.72	1.9E0
10000	2.2E-1	6.6E-1	-0.66	-0.18	2.9E0
25000	4.4E-1	3.0E-0	-0.36	0.48	6.9E0

Table G-10. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 5.0 maintained)

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	5.0	3.5E-7	1.1E-4	-6.45	-3.96	3.1E2
5	5.0	2.3E-6	5.5E-4	-5.64	-3.26	2.4E2
10	5.0	8.9E-6	1.5E-3	-5.05	-2.82	1.7E2
25	5.0	3.8E-5	4.7E-3	-4.42	-2.33	1.2E2
50	5.0	1.5E-4	1.1E-2	-3.82	-1.96	7.4E1
100	5.0	5.8E-4	2.5E-2	-3.24	-1.60	4.3E1
250	5.0	2.5E-3	5.3E-2	-2.60	-1.28	2.1E1
500	5.0	9.4E-3	8.7E-2	-2.03	-1.06	9.0E0
1000	5.0	2.8E-2	1.3E-1	-1.55	-0.89	4.6E0
5000	5.0	9.8E-2	2.0E-1	-1.01	-0.70	2.0E0
10000	5.0	2.2E-1	5.4E-1	-0.66	-0.27	2.4E0
25000	5.0	4.4E-1	2.9E-0	-0.36	0.46	6.5E0

Table G-11. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 6.0 maintained)

Initial Sr conc. (mg/L)	After contact Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	2.4E-8	1.2E-4	-7.62	-3.92	4.8E3
5	1.5E-7	5.9E-4	-6.82	-3.23	3.8E3
10	9.5E-7	1.7E-3	-6.02	-2.77	1.7E3
25	2.0E-5	5.0E-3	-4.70	-2.30	2.6E2
50	1.1E-4	1.2E-2	-3.96	-1.92	1.1E2
100	5.7E-4	2.7E-2	-3.24	-1.57	4.7E1
250	2.5E-3	5.5E-2	-2.59	-1.26	2.1E1
500	9.5E-3	9.0E-2	-2.02	-1.05	9.5E0
1000	2.7E-2	1.4E-1	-1.57	-0.85	5.2E0
5000	9.6E-2	2.5E-1	-1.02	-0.60	2.6E0
10000	2.2E-1	7.1E-1	-0.66	-0.15	3.3E0
25000	4.3E-1	3.2E-0	-0.37	0.51	7.5E0

Table G-12. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 7.0 maintained)

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	9.8E-8	1.1E-4	-7.01	-3.96	1.1E3
5	7.0	2.4E-7	5.7E-4	-6.62	-3.24	2.3E3
10	7.0	3.8E-7	1.6E-3	-6.42	-2.80	4.2E3
25	7.0	3.5E-6	5.0E-3	-5.46	-2.30	1.4E3
50	7.0	4.3E-5	1.2E-2	-4.37	-1.92	2.9E2
100	7.0	3.3E-4	2.8E-2	-3.48	-1.55	8.5E1
250	7.0	2.0E-3	5.7E-2	-2.70	-1.24	2.8E1
500	7.0	8.8E-3	9.1E-2	-2.06	-1.04	1.0E1
1000	7.0	2.7E-2	1.3E-1	-1.57	-0.89	4.8E0
5000	7.0	9.9E-2	1.8E-1	-1.00	-0.74	1.9E0
10000	7.0	2.3E-1	5.5E-1	-0.64	-0.26	2.4E0
25000	7.0	4.4E-1	2.8E-0	-0.36	0.45	6.3E0

Table G-13. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 8.0 maintained)

Initial	After contact				
Sr conc. (mg/L)	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
0	2.1E-7	1.1E-4	-6.68	-3.96	5.5E2
5	1.1E-6	5.8E-4	-5.96	-3.24	5.0E2
10	3.4E-6	1.6E-3	-5.47	-2.80	4.8E2
25	6.2E-6	5.2E-3	-5.21	-2.28	8.3E2
50	8.1E-6	1.3E-2	-5.09	-1.89	1.7E3
100	1.0E-4	3.2E-2	-4.00	-1.49	3.1E2
250	1.3E-3	7.0E-2	-2.89	-1.15	5.4E1
500	7.3E-3	1.2E-1	-2.14	-0.92	1.6E1
1000	2.4E-2	1.8E-1	-1.62	-0.74	7.7E0
5000	8.9E-2	3.3E-1	-1.05	-0.48	3.7E0
10000	2.0E-1	8.7E-1	-0.70	-0.06	4.3E0
25000	4.1E-1	3.6E-0	-0.39	0.56	8.7E0

Table G-14. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of 0.05 *M* sulfate in the groundwater

(Constant pH of 7.0 maintained)

Initial Sr conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	5.8E-6	5.6E-5	-5.24	-4.25	9.7E0
5	7.0	3.0E-5	2.7E-4	-4.52	-3.57	9.2E0
10	7.0	8.6E-5	7.5E-4	-4.07	-3.12	8.7E0
25	7.0	2.4E-4	2.3E-3	-3.57	-2.64	8.5E0
50	7.0	7.0E-4	5.7E-3	-3.15	-2.24	8.1E0
100	7.0	1.6E-3	1.5E-2	-2.80	-1.82	9.1E0
250	7.0	2.3E-3	5.5E-2	-2.64	-1.26	2.4E1
500	7.0	1.1E-3	1.7E-1	-2.96	-0.77	1.5E2
1000	7.0	6.5E-4	4.2E-1	-3.19	-0.38	6.5E2
5000	7.0	4.0E-4	1.3E-0	-3.40	0.11	3.3E3
10000	7.0	1.9E-2	4.3E-0	-1.72	0.63	2.3E2
25000	7.0	6.4E-2	8.4E-0	-1.19	0.92	1.3E2

Table G-15. Strontium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of 0.5 M sulfate in the groundwater

(Constant pH of 7.0 maintained)

Initial	After contact					
Sr conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	9.9E-6	1.5E-5	-5.00	-4.82	1.5E0
5	7.0	5.1E-5	6.4E-5	-4.29	-4.19	1.3E0
10	7.0	1.4E-4	1.5E-4	-3.85	-3.82	1.1E0
25	7.0	4.5E-4	4.3E-4	-3.35	-3.37	9.7E1
50	7.0	1.2E-3	9.7E-4	-2.92	-3.01	8.4E1
100	7.0	2.8E-3	2.2E-3	-2.55	-2.66	8.1E1
250	7.0	6.0E-3	1.6E-2	-2.22	-1.80	2.6E0
500	7.0	4.1E-3	1.4E-1	-2.39	-0.85	3.5E1
1000	7.0	2.8E-3	4.0E-1	-2.55	-0.40	1.4E2
5000	7.0	1.6E-3	1.3E-0	-2.80	0.11	1.2E3
10000	7.0	1.1E-3	3.3E-0	-2.96	0.52	2.9E3
25000	7.0	2.1E-3	9.3E-0	-2.68	0.97	4.5E3

Table G-16. Cesium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 3.0 maintained)

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	3.0	9.5E-9	3.8E-5	-8.02	-4.42	4.0E3
5	3.0	2.9E-6	4.3E-4	-5.54	-3.37	1.5E2
10	3.0	1.6E-5	1.1E-3	-4.80	-2.96	6.9E1
25	3.0	6.3E-5	3.0E-3	-4.20	-2.52	4.7E1
50	3.0	2.0E-4	7.1E-3	-3.70	-2.15	3.6E1
100	3.0	5.5E-4	1.6E-2	-3.26	-1.80	3.0E1
250	3.0	1.7E-3	3.8E-2	-2.77	-1.42	2.2E1
500	3.0	5.0E-3	7.8E-2	-2.30	-1.11	1.6E1
1000	3.0	1.5E-2	1.4E-1	-1.82	-0.85	9.4E0
5000	3.0	5.8E-2	2.6E-1	-1.24	-0.59	4.6E0
10000	3.0	1.4E-1	6.4E-1	-0.85	-0.19	4.7E0
25000	3.0	2.6E-1	2.4E-0	-0.59	0.38	9.1E0

Table G-17. Cesium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 4.0 maintained)

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	4.0	1.1E-8	3.8E-5	-7.96	-4.42	3.5E3
5	4.0	2.0E-6	4.4E-4	-5.70	-3.36	2.2E2
10	4.0	1.0E-5	1.1E-3	-5.00	-2.96	1.1E2
25	4.0	4.4E-5	3.2E-3	-4.37	-2.49	7.3E1
50	4.0	1.4E-4	7.7E-3	-3.85	-2.11	5.5E1
100	4.0	4.0E-4	1.8E-2	-3.40	-1.74	4.5E1
250	4.0	1.3E-3	4.2E-2	-2.87	-1.38	3.1E1
500	4.0	4.5E-3	8.4E-2	-2.35	-1.08	1.9E1
1000	4.0	1.4E-2	1.5E-1	-1.85	-0.82	1.1E1
5000	4.0	5.6E-2	2.8E-1	-1.25	-0.55	5.1E0
10000	4.0	1.3E-1	6.8E-1	-0.89	-0.17	5.1E0
25000	4.0	2.6E-1	2.4E-0	-0.59	0.38	9.5E0

Table G-18. Cesium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 5.0 maintained)

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	5.0	3.0E-9	3.8E-5	-8.52	-4.42	1.3E4
5	5.0	9.9E-7	4.5E-4	-6.00	-3.35	4.5E2
10	5.0	5.7E-6	1.2E-3	-5.24	-2.92	2.1E2
25	5.0	2.5E-5	3.4E-3	-4.60	-2.47	1.3E2
50	5.0	8.4E-4	8.3E-3	-4.08	-2.01	1.0E2
100	5.0	2.5E-4	2.0E-2	-3.60	-1.70	7.9E1
250	5.0	9.3E-4	4.6E-2	-3.03	-1.34	5.0E1
500	5.0	3.4E-3	9.5E-2	-2.47	-1.02	2.7E1
1000	5.0	1.3E-2	1.6E-1	-1.89	-0.80	1.2E1
5000	5.0	5.6E-2	2.8E-1	-1.25	-0.55	4.9E0
10000	5.0	1.3E-1	6.6E-1	-0.89	-0.18	4.9E0
25000	5.0	2.6E-1	2.4E-0	-0.59	0.38	9.5E0

Table G-19. Cesium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 6.0 maintained)

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	6.0	5.0E-9	3.8E-5	-8.30	-4.42	7.5E3
5	6.0	1.6E-7	4.6E-4	-6.80	-3.34	2.8E3
10	6.0	8.3E-7	1.2E-3	-6.08	-2.92	1.5E3
25	6.0	5.1E-6	3.6E-3	-5.29	-2.44	7.0E2
50	6.0	2.6E-5	8.9E-3	-4.59	-2.05	3.5E2
100	6.0	1.2E-4	2.1E-2	-3.92	-1.68	1.8E2
250	6.0	6.2E-4	5.0E-2	-3.21	-1.30	8.0E1
500	6.0	3.0E-3	1.0E-1	-2.52	-1.00	3.4E1
1000	6.0	1.2E-2	1.7E-1	-1.92	-0.77	1.3E1
5000	6.0	5.5E-2	3.0E-1	-1.26	-0.52	5.4E0
10000	6.0	1.3E-1	7.2E-1	-0.89	-0.14	5.5E0
25000	6.0	2.5E-1	2.6E-0	-0.60	0.41	1.0E1

Table G-20. Cesium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 7.0 maintained)

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	1.6E-8	3.7E-5	-7.80	-4.43	2.3E3
5	7.0	1.6E-7	4.6E-4	-6.80	-3.38	2.9E3
10	7.0	7.1E-7	1.2E-3	-6.15	-2.92	1.7E3
25	7.0	2.5E-6	3.6E-3	-5.60	-2.44	1.4E3
50	7.0	1.0E-5	9.1E-3	-5.00	-2.04	8.3E2
100	7.0	6.3E-5	2.2E-2	-4.20	-1.66	3.4E2
250	7.0	4.3E-4	5.2E-2	-3.37	-1.28	1.2E2
500	7.0	2.4E-3	1.1E-1	-2.62	-0.96	4.5E1
1000	7.0	1.1E-2	1.8E-1	-1.96	-0.74	1.7E1
5000	7.0	5.3E-2	3.2E-1	-1.28	-0.50	6.1E0
10000	7.0	1.3E-1	7.4E-1	-0.89	-0.13	5.7E0
25000	7.0	2.5E-1	2.6E-0	-0.60	0.41	1.0E1

Table G-21. Cesium sorption isotherm data for composite soil sample from the West Chestnut Ridge site

(Constant pH of 8.0 maintained)

Initial Cs conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	8.0	6.5E-8	3.7E-5	-7.19	-4.43	5.7E2
5	8.0	8.0E-7	4.5E-4	-6.10	-3.35	5.7E2
10	8.0	2.3E-6	1.2E-3	-5.64	-2.92	5.4E2
25	8.0	7.7E-6	3.6E-3	-5.11	-2.44	4.6E2
50	8.0	1.9E-5	9.0E-3	-4.72	-2.05	4.8E2
100	8.0	3.2E-5	2.2E-2	-4.49	-1.66	6.8E2
250	8.0	2.5E-4	5.4E-2	-3.60	-1.27	2.2E2
500	8.0	1.8E-3	1.1E-1	-2.74	-0.96	6.1E1
1000	8.0	9.8E-3	2.0E-1	-2.01	-0.70	2.0E1
5000	8.0	5.1E-2	3.4E-1	-1.29	-0.47	6.5E0
10000	8.0	1.3E-1	7.5E-1	-0.89	-0.12	5.9E0
25000	8.0	2.5E-1	2.6E-0	-0.60	0.41	1.0E1

Table G-22. Curium-244 sorption isotherm data for composite soil sample from the West Chestnut Ridge site

Initial	After contact					
Cm conc (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
4E-4	3.0	1.4E-11	1.6E-8	-10.85	-7.80	1.2E3
8E-4	3.0	4.5E-11	3.3E-8	-10.35	-7.48	7.4E2
2E-3	3.0	1.7E-10	8.4E-8	-9.77	-7.07	4.8E2
4E-3	3.0	5.4E-10	1.7E-7	-9.27	-6.77	3.3E2
4E-4	4.0	2.7E-12	1.6E-8	-11.57	-7.80	6.2E3
8E-4	4.0	8.5E-12	3.3E-8	-11.07	-7.48	4.0E3
2E-3	4.0	3.4E-11	8.6E-8	-10.47	-7.06	2.5E3
4E-3	4.0	1.1E-10	1.8E-7	-9.96	-6.74	1.6E3
4E-4	5.0	4.5E-13	1.6E-8	-12.35	-7.80	3.7E4
8E-4	5.0	8.1E-13	3.3E-8	-12.09	-7.48	4.1E4
2E-3	5.0	3.3E-12	8.6E-8	-11.48	-7.06	2.6E4
4E-3	5.0	1.3E-11	1.8E-7	-10.88	-6.74	1.3E4
4E-4	6.0	6.5E-13	1.7E-8	-12.19	-7.76	2.6E4
8E-4	6.0	1.7E-13	3.3E-8	-12.77	-7.48	1.9E4
2E-3	6.0	2.7E-12	8.6E-8	-11.57	-7.07	3.2E4
4E-3	6.0	4.3E-12	1.8E-7	-11.37	-6.74	4.1E4
4E-4	7.0	1.3E-11	1.6E-8	-10.89	-7.80	1.2E3
8E-4	7.0	7.1E-12	3.3E-8	-11.15	-7.48	4.7E3
2E-3	7.0	1.7E-11	8.6E-8	-10.77	-7.07	5.2E3
4E-3	7.0	1.5E-11	1.8E-7	-10.82	-6.74	1.2E4
4E-4	8.0	1.0E-11	1.6E-8	-11.00	-7.80	1.6E3
8E-4	8.0	2.5E-11	3.3E-8	-10.60	-7.48	1.3E3
2E-3	8.0	3.0E-12	8.6E-8	-11.52	-7.07	2.9E4
4E-3	8.0	2.9E-12	1.8E-7	-11.54	-6.74	6.3E4

Appendix H.

DATA DESCRIBING THE EFFECT OF ORGANIC COMPLEXING AGENTS ON THE SORPTION OF URANIUM ON WEST CHESTNUT RIDGE SOIL

Table H-1. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of EDTA

(No EDTA present in the groundwater; constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	1.8E-9	4.2E-5	-8.74	-4.38	2.3E4
5	7.0	1.5E-8	2.5E-4	-7.82	-3.60	1.7E4
10	7.0	4.5E-8	4.7E-4	-7.35	-3.33	1.0E4
25	7.0	1.7E-7	1.4E-3	-6.77	-2.85	8.1E3
50	7.0	2.9E-7	2.7E-3	-6.54	-2.57	9.1E3
100	7.0	1.6E-6	5.8E-3	-5.80	-2.24	3.7E3
250	7.0	5.3E-6	1.3E-2	-5.28	-1.87	2.6E3
500	7.0	1.0E-5	2.8E-2	-5.00	-1.55	2.6E3
1000	7.0	5.4E-5	5.7E-2	-4.27	-1.24	1.0E3

Table H-2. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of EDTA

(Concentration of EDTA in groundwater: 0.01 M; constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	6.7E-8	4.1E-5	-7.17	-4.39	6.2E2
500	7.0	5.1E-7	2.5E-4	-6.29	-3.60	4.9E2
1,000	7.0	1.0E-6	4.6E-4	-6.00	-3.34	4.4E2
2,500	7.0	3.8E-6	1.3E-3	-5.42	-2.89	3.5E2
5,000	7.0	9.3E-6	2.6E-3	-5.03	-2.59	2.8E2
10,000	7.0	2.7E-5	5.5E-3	-4.57	-2.26	2.2E2
25,000	7.0	7.9E-5	1.3E-2	-4.10	-1.89	1.6E2
50,000	7.0	2.0E-4	2.7E-2	-3.70	-1.57	1.3E2
100,000	7.0	5.0E-4	5.3E-2	-3.30	-1.28	1.1E2

Table H-3. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of EDTA

(Concentration of EDTA in groundwater; 0.05 M; constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	1.2E-7	4.1E-5	-6.92	-4.39	3.3E2
500	7.0	1.2E-6	2.4E-4	-5.92	-3.62	2.1E2
1,000	7.0	1.9E-6	4.5E-4	-5.72	-3.35	2.4E2
2,500	7.0	8.0E-6	1.3E-3	-5.07	-2.87	1.6E2
5,000	7.0	1.5E-5	2.5E-3	-4.82	-2.60	1.7E2
10,000	7.0	4.4E-5	5.3E-3	-4.36	-2.27	1.2E2
25,000	7.0	9.9E-5	1.3E-2	-4.00	-1.87	1.3E2
50,000	7.0	2.7E-4	2.5E-2	-3.57	-1.60	9.1E1
100,000	7.0	5.2E-4	5.2E-2	-3.28	-1.28	1.0E2

Table H-4. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of citric acid

(No citric acid present in the groundwater;
constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	1.8E-9	4.2E-5	-8.74	-4.38	2.3E4
5	7.0	1.5E-8	2.5E-4	-7.82	-3.60	1.7E4
10	7.0	4.5E-8	4.7E-4	-7.35	-3.33	1.0E4
25	7.0	1.7E-7	1.4E-3	-6.77	-2.85	8.1E3
50	7.0	2.9E-7	2.7E-3	-6.54	-2.57	9.1E3
100	7.0	1.6E-6	5.8E-3	-5.80	-2.24	3.7E3
250	7.0	5.3E-6	1.3E-2	-5.28	-1.87	2.6E3
500	7.0	1.0E-5	2.8E-2	-5.00	-1.55	2.6E3
1000	7.0	5.4E-5	5.7E-2	-4.27	-1.24	1.0E3

Table H-5. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of citric acid

(Concentration of citric acid in groundwater: 0.01 M; constant pH of 7.0 maintained)

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	4.5E-7	3.8E-5	-6.35	-4.42	8.4E1
5	7.0	2.6E-6	2.3E-4	-5.59	-3.64	8.8E1
10	7.0	5.1E-6	4.2E-4	-5.29	-3.38	8.1E1
25	7.0	1.5E-5	1.2E-3	-4.82	-2.92	8.4E1
50	7.0	2.9E-5	2.4E-3	-4.54	-2.62	8.2E1
100	7.0	6.1E-5	5.1E-3	-4.21	-2.29	8.5E1
250	7.0	1.5E-4	1.2E-2	-3.82	-1.92	8.2E1
500	7.0	3.0E-4	2.5E-2	-3.52	-1.60	8.3E1
1000	7.0	6.3E-4	5.1E-2	-3.20	-1.29	8.1E1

Table H-6. Uranium sorption isotherm data for composite soil sample from the West Chestnut Ridge site: effect of the presence of citric acid

(Concentration of citric acid in groundwater: 0.05 *M*; constant pH of 7.0 maintained)

Initial U conc (mg, L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
1	7.0	—	—	—	—	—
5	7.0	3.0E-6	2.2E-4	-5.52	-3.66	7.5E1
10	7.0	4.6E-6	4.2E-4	-5.34	-3.38	9.2E1
25	7.0	1.6E-5	1.2E-3	-4.79	-2.92	7.5E1
50	7.0	2.6E-5	2.4E-3	-4.58	-2.62	9.2E1
100	7.0	6.7E-5	5.1E-3	-4.17	-2.29	7.6E1
250	7.0	1.3E-4	1.2E-2	-3.88	-1.92	9.2E1
500	7.0	3.2E-4	2.4E-2	-3.50	-1.62	7.7E1
1000	7.0	5.6E-4	5.2E-2	-3.25	-1.28	9.2E1

Appendix I.

EFFECT OF Y-12 TRENCH WATER ON THE SORPTION OF URANIUM ON WEST CHESTNUT RIDGE SOIL

Table I-1. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B1-40 in contact with Y-12 BCV-C-20 trench water

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	7.2	4.8E-6	1.1E-4	-5.32	-3.96	2.1E1
10	7.3	9.1E-6	1.9E-4	-5.04	-3.72	2.0E1
20	7.3	1.8E-5	3.5E-4	-4.74	-3.46	1.9E1
30	7.3	3.0E-5	4.9E-4	-4.52	-3.31	1.6E1
40	7.2	3.9E-5	6.6E-4	-4.41	-3.18	1.6E1
50	7.2	5.3E-5	7.7E-4	-4.28	-3.11	1.4E1
100	7.1	1.1E-4	1.5E-3	-3.96	-2.82	1.3E1
200	6.9	2.1E-4	3.0E-3	-3.68	-2.52	1.4E1
300	6.8	2.7E-4	4.9E-3	-3.57	-2.31	1.8E1
400	6.7	2.4E-4	7.1E-3	-3.62	-2.15	2.9E1
500	6.4	1.3E-4	9.5E-3	-3.89	-2.02	7.3E1
1000	5.5	1.2E-4	2.0E-2	-3.92	-1.70	1.6E2

Table I-2. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B2-60 in contact with synthetic groundwater (B1-40 + water) only

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.43	2.6E-8	1.1E-4	-7.58	-3.90	4.2E3
10	5.47	5.7E-8	2.3E-4	-7.25	-3.64	4.0E3
20	5.42	1.7E-7	4.5E-4	-6.76	-3.35	2.6E3
30	5.46	3.2E-7	6.4E-4	-6.50	-3.20	2.0E3
40	5.41	5.3E-7	8.6E-4	-6.28	-3.06	1.6E3
50	5.39	7.2E-7	1.0E-3	-6.14	-2.98	1.4E3
100	5.27	3.0E-6	2.1E-3	-5.52	-2.68	7.0E2
200	5.25	1.0E-5	4.1E-3	-4.98	-2.39	4.1E2
300	5.10	3.2E-5	6.0E-3	-4.50	-2.22	1.9E2
400	4.74	8.4E-5	8.0E-3	-4.07	-2.10	9.5E1
500	4.80	1.0E-4	9.9E-3	-3.99	-2.00	9.9E1
1000	4.68	7.8E-3	1.7E-3	-3.11	-1.77	2.2E1
5000	4.84	5.4E-3	4.1E-2	-2.27	-1.39	7.6E0
10000	4.88	1.2E-2	7.5E-2	-1.93	-1.13	6.3E0

Table I-3. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B2-60 in contact with synthetic groundwater (B1-40 + water) spiked with 200 mg sulfate per liter

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.5	6.2E-8	1.3E-4	-7.21	-3.89	2.1E3
10	5.4	1.3E-7	2.3E-4	-6.89	-3.64	1.8E3
20	5.4	3.0E-7	4.3E-4	-6.52	-3.37	1.4E3
30	5.4	6.0E-7	6.4E-4	-6.22	-3.19	1.1E3
40	5.3	9.6E-7	8.5E-4	-6.02	-3.07	8.9E2
50	5.3	1.3E-6	1.0E-3	-5.89	-3.00	7.6E2
100	5.2	5.0E-6	2.1E-3	-5.30	-2.68	4.2E2
200	5.1	2.3E-5	4.1E-3	-4.64	-2.39	1.8E2
300	5.0	6.0E-5	5.8E-3	-4.22	-2.24	9.6E1
400	4.9	1.3E-4	7.5E-3	-3.87	-2.12	5.7E1
500	4.6	3.8E-4	8.3E-3	-3.42	-2.08	2.1E1
1000	4.3	1.8E-3	1.1E-2	-2.74	-1.96	6.3E0

Table I-4. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B2-60 in contact with synthetic groundwater (B1-40 + water) spiked with 100 mg chloride per liter

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.1	6.6E-8	1.3E-4	-7.18	-3.89	1.9E3
10	5.2	1.5E-7	2.2E-4	-6.82	-3.66	1.5E3
20	5.2	4.0E-7	4.4E-4	-6.40	-3.36	1.1E3
30	5.2	6.6E-7	6.3E-4	-6.18	-3.20	9.5E2
40	5.2	1.1E-6	8.5E-4	-5.96	-3.07	7.7E2
50	5.2	1.6E-6	1.1E-3	-5.80	-2.96	6.7E2
100	5.1	5.4E-6	2.1E-3	-5.27	-2.68	3.9E2
200	4.9	2.1E-5	4.0E-3	-4.68	-2.40	1.9E2
300	4.8	6.0E-5	6.0E-3	-4.22	-2.22	1.0E2
400	4.8	1.3E-4	7.6E-3	-3.89	-2.12	6.0E1
500	4.5	3.6E-4	8.4E-3	-3.44	-2.08	2.3E1
1000	4.3	1.8E-3	1.1E-2	-2.74	-1.96	6.1E0

Table I-5. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B2-60 in contact with synthetic groundwater (B1-40 + water) spiked with 10 mg fluoride per liter

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.7	4.2E-8	1.3E-4	-7.38	-3.89	3.1E3
10	5.7	8.1E-8	2.3E-4	-7.09	-3.64	2.8E3
20	5.6	1.7E-7	4.3E-4	-6.77	-3.37	2.4E3
30	5.6	3.9E-7	6.3E-4	-6.41	-3.20	1.6E3
40	5.5	6.0E-7	8.4E-4	-6.22	-3.08	1.4E3
50	5.5	8.0E-7	1.0E-3	-6.10	-3.00	1.3E3
100	5.3	3.4E-6	2.1E-3	-5.47	-2.68	6.1E2
200	5.1	1.4E-5	4.1E-3	-4.85	-2.39	2.9E2
300	5.0	4.3E-5	5.9E-3	-4.37	-2.23	1.4E2
400	4.9	9.9E-5	7.8E-3	-4.00	-2.12	7.7E1
500	4.6	3.0E-4	8.7E-3	-3.52	-2.06	2.8E1
1000	4.3	1.6E-3	1.2E-2	-2.80	-1.92	7.6E0

Table I-6. Uranium sorption isotherm data for soil from
West Chestnut Ridge boring B2-60 in contact with
synthetic groundwater (BJ-40 + water)
spiked with 100 mg nitrate per liter

Initial	After contact					
U conc. (mg/L)	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	5.3	6.3E-8	1.3E-4	-7.20	-3.89	2.0E3
10	5.3	1.4E-7	2.3E-4	-6.85	-3.64	1.6E3
20	5.3	3.6E-7	4.4E-4	-6.44	-3.36	1.2E3
30	5.2	6.4E-7	6.3E-4	-6.19	-3.20	9.8E2
40	5.2	1.1E-6	8.6E-4	-5.96	-3.07	8.0E2
50	5.2	1.5E-6	1.0E-3	-5.82	-3.00	6.8E2
100	5.2	5.3E-6	2.0E-3	-5.28	-2.70	3.8E2
200	5.1	2.1E-5	4.0E-3	-4.68	-2.40	1.9E2
300	4.9	6.1E-5	5.8E-3	-4.21	-2.24	9.5E1
400	4.8	1.4E-4	7.6E-3	-3.85	-2.12	5.5E1
500	4.5	3.7E-4	8.3E-3	-3.43	-2.08	2.2E1
1000	4.2	1.9E-3	1.1E-2	-2.72	-1.96	5.9E0

Table I-7. Uranium sorption isotherm data for soil from West Chestnut Ridge boring B2-60 in contact with synthetic groundwater (B1-40 + water) spiked with 50 mg carbonate per liter

Initial U conc. (mg/L)	After contact					
	pH	Solution (mol/L)	Adsorbed (mol/kg)	Solution (log mol/L)	Adsorbed (log mol/kg)	Rs (L/kg)
5	6.4	3.0E-8	1.3E-4	-7.52	-3.89	4.4E3
10	6.4	5.2E-8	2.3E-4	-7.28	-3.64	4.4E3
20	6.3	1.4E-7	4.4E-4	-6.85	-3.36	3.2E3
30	6.3	2.7E-7	6.5E-4	-6.57	-3.19	2.4E3
40	6.2	3.9E-7	8.3E-4	-6.41	-3.08	2.1E3
50	6.2	5.8E-7	1.0E-3	-6.24	-3.00	1.8E3
100	6.0	1.8E-6	2.1E-3	-5.74	-2.68	1.1E3
200	5.7	6.4E-6	4.0E-3	-5.19	-2.40	6.2E2
300	5.5	1.8E-5	6.2E-3	-4.74	-2.21	3.5E2
400	5.3	4.0E-5	8.1E-3	-4.40	-2.09	2.0E2
500	4.8	1.8E-4	9.6E-3	-3.74	-2.02	5.2E1
1000	4.5	1.2E-3	1.4E-2	-2.92	-1.85	1.1E1

ORNL-6061
Dist. Category UC-70B

INTERNAL DISTRIBUTION

1. J. K. Bailey
2. W. D. Arnold
3. C. F. Baes III
4-13. L. D. Bates
14. T. R. Butz
15. J. B. Cannon
16. R. O. Chester
17. J. H. Coobs
18. L. R. Dole
19. D. E. Fields
20. B. A. Hannaford
21. F. J. Homan
22. D. D. Huff
23. G. K. Jacobs
24-28. A. D. Kelmers
29. J. H. Kessler
30-31. R. H. Ketelle
32. E. M. King
33. D. C. Kocher
34. D. W. Lee
35. S. Y. Lee
36. T. F. Lomenick
37. L. W. Long
38. R. E. Meyer
39. L. J. Mezga
40-41. F. G. Pin
42-43. W. W. Pitt
44. P. M. Pritz
45. T. H. Row
46-50. F. G. Seeley
51-52. M. G. Stewart
53. S. H. Stow
54. L. E. Stratton
55. R. E. Thomas
56. S. D. Van Hoesen
57-58. S. K. Whatley
59. R. G. Wymer
60. Central Research Library
61. ORNL-Y-12 Technical Library
Document Reference Section
62-63. Laboratory Records
64. Laboratory Records, ORNL R.C.
65. ORNL Patent Section

EXTERNAL DISTRIBUTION

66. Office of Assistant Manager, Energy Research and Development,
DOE-ORO, P. O. Box E, Oak Ridge, TN 37831
67-68. D. R. Brown, DOE-ORO, P. O. Box E, Oak Ridge, TN 37831
69. C. Luner, Argonne National Laboratory, 9700 South Cass Ave.,
Argonne, IL 60439
70-433. Given distribution as shown in TIC-4500 under Low-Level
Radioactive Waste Management category