PNL-10722
UC-510

Solid Waste Leach Characteristics and Contaminant-Sediment Interactions Volume 2: Contaminant Transport Under Unsaturated Moisture Contents

C. W. Lindenmeier
R. J. Serne
J. L. Conca
A. T. Owen
M. I. Wood

September 1995

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

Battelle

PNL-10722

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831;
prices available from (615) 576-8401.

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161

PNL-10722
UC-510

Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions
Volume 2: Contaminant Transport Under Unsaturated Moisture Contents

C. W. Lindenmeier
R. J. Serne
J. L. Conca
A. T. Owen
M. I. Wood

September 1995

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

35

Summary

The objectives of this report and subsequent volumes include describing progress on 1) development and optimization of experimental methods to quantify the release of contaminants from solid wastes and their subsequent interactions with unsaturated sediments, and 2) the creation of empirical data that become input parameters to performance assessment (PA) analyses for future Hanford Site disposal units and baseline risk assessments for inactive and existing solid waste disposal units.

For this report, efforts focussed on developing methodologies to evaluate contaminant transport in Trench 8 (W-5 Burial Ground) sediments under unsaturated (vadose zone) conditions. To accomplish this task, a series of flow-through column tests were run using standard saturated column systems, Wierenga unsaturated column systems (both commercial and modified), and the Unsaturated Flow Apparatus (UFA). The reactants investigated were ^{85}Sr, ^{236}U, and ^{238}U as reactive tracers, and tritium as a non-reactive tracer.

Results indicate that for moderately unsaturated conditions (volumetric water contents $>50\%$ of saturation), the Wierenga system performed reasonably well such that long water residence times (50-147 h) were achieved, and reasonably good steady-state flow conditions were maintained. The major drawbacks in using this system for reactive tracer work included 1) the inability to achieve reproducible and constant moisture content below 50% of saturation, 2) the four to six month time required to complete a single test, and 3) the propensity for mechanical failure resulting from laboratory power outages during the prolonged testing period.

When using the UFA, volumetric saturation levels of $\geq 25\%$ were easily achieved and duplicate tests could be run under the same moisture content conditions within a period of four to six weeks. Drawbacks to this system included 1) a limitation of 18-20 h maximum water residence time, and 2) a sample collection system which required completely stopping the system to collect each pore volume fraction.

Reactive-contaminant transport results indicate that uranium exhibits lower distribution coefficient (R_d) values as Trench 8 sediment becomes less saturated. For the saturated column tests, an R_d value for uranium of 2 mL/g was noted, whereas at 29% of saturation, results showed a value closer to 0.6 mL/g, indicating a 70% reduction. Though it has been traditional in Hanford Site PA calculations to assign an R_d value of 0.0 mL/g to uranium, test results indicate that sorption occurred under all test conditions. Results for strontium in a 0.038 M $CaCl_2$ solution also show a slight trend to lower R_d values as moisture content decreases. The average strontium R_d was 1.7 mL/g at saturation but dropped to 0.79 mL/g at 25% saturation, indicating a 54% reduction. Because current PA methodology groups R_d values into classes of 0, 1, 10, 100, and ≥ 1000, these results should have little impact on the current PA predictions for contaminant fate at the W-5 Burial Ground. That is, the uranium R_d class will remain at $R_d = 0$ regardless of the moisture content.

Though the PA calculations may be unaffected, these results do provide some interesting questions related to current assumptions on reactive tracer transport under unsaturated conditions. From the onset of the tests, it was presumed that the R_d would at the very least stay the same if not increase as the systems became more unsaturated. Having obtained results to the contrary, it is recommended that

further research into this area be performed in order to ensure that the results are not simply an artifact inherent within the test methods, or to identify some physicochemical phenomena not yet understood that may be contributing to early breakthrough under unsaturated conditions (e.g., differences in uranyl complexation resulting from changes in O_2/CO_2 fugacity as the gas phase changes during desaturation).

Acknowledgments

The authors thank the numerous analytical support persons who performed many of the analyses reported herein. Of special note were the efforts of E. J. Wyse and J. P. Bramson from Pacific Northwest Laboratory's (PNL's) Advanced Inorganic Analyses Section, and V. L. LeGore and D. S. Burke from PNL's Applied Geology and Geochemistry Group.

The authors acknowledge technical comments from K. J. Cantrell, D. I. Kaplan, and G. R. Holdren of PNL's Applied Geology and Geochemistry Group.

Finally, the authors acknowledge the fiscal support of Westinghouse Hanford Company Solid Waste Technology Group and the administrative support of G. M. Holter, R. C. Walling, and R. T. Tessier in the PNL Solid Waste Technology Support Project.

Contents

Summary iii

Acknowledgments v

1.0 Introduction 1.1
  1.1 Purpose and Objectives 1.1
  1.2 Test Methodologies and Contaminants 1.2
  1.3 Trench 8 Soil Characteristics 1.2

2.0 Development of Partially Saturated Soil Column Tests 2.1
  2.1 Overview of Application 2.2
  2.2 Wierenga Column Description/Methodology 2.4
  2.3 Saturated Column ^{238}U Test 1 . . . . 2.7
  2.4 Wierenga Column Tritium Test 2.7
  2.5 Wierenga Column ^{238}U Tests 2.7
  2.6 Residence Time Sensitive Saturated Column ^{238}U Tests 2.10
  2.7 Modified Wierenga Column ^{236}U Tests 2.14
  2.8 Modified Wierenga Column ^{85}Sr Tests 2.16

3.0 UFA Contaminant Transport Test 3.1
  3.1 Overview of Application 3.1
  3.2 UFA Description/Methodology 3.1
  3.3 UFA ^{238}U Tests 3.3
  3.4 UFA ^{236}U Tests 3.5
  3.5 UFA Tritium Tests 3.5
  3.6 UFA ^{85}Sr Tests 3.5

4.0 Conclusion 4.1

5.0 References 5.1

Figures

2.1 Wierenga Column Diagram 2.5
2.2 Comparison of UFA and Water Residence Methods 2.6
2.3 ^{238}U Saturated Column Test 1 . . . . . 2.8
2.4 Tritium Unsaturated Column Test 1 . . . . . 2.9
2.5 ^{238}U Unsaturated Column Test 1 . . . . . 2.11
2.6 ^{238}U Saturated Column Test 2D 2.12
2.7 ^{238}U Saturated Column Test 3D 2.12
2.8 ^{238}U Saturated Column Test 4D 2.13
2.9 ^{238}U Hanford Site Groundwater Dissolution Column Test 2.15
2.10 ^{238}U D1-H_2O Dissolution Column Test 1 . . . . . 2.15
2.11 ^{236}U Unsaturated Column Test 1 . . . . . 2.17
2.12 ^{236}U Unsaturated Column Test 2 . . . . . 2.17
2.13 ^{85}Sr Saturated Column Test 1 . . . . . 2.19
2.14 ^{85}Sr Saturated Column Test 2 . . . . . 2.19
2.15 ^{85}Sr Unsaturated Column Test 1 . . . . . 2.20
2.16 ^{85}Sr Unsaturated Column Test 2 . . . . . 2.20
3.1 UFA Rotor Diagram 3.2
3.2 ^{238}U Unsaturated UFA Test 1 . . . . . 3.4
3.3 ^{238}U Unsaturated UFA Test 2 . . . . . 3.4
3.4 ^{236}U Unsaturated UFA Test 1A 3.6
3.5 ^{236}U Unsaturated UFA Test 1C 3.6
3.6 Tritium Unsaturated UFA Test 1A 3.7
3.7 Tritium Unsaturated UFA Test 1C 3.7
3.8 ^{85}Sr Unsaturated UFA Test 1A 3.8
3.9 ^{85}Sr Unsaturated UFA Test 1C 3.8
4.1 Uranium Versus Percent Volumetric Saturation 4.2
4.2 Strontium Versus Percent Volumetric Saturation 4.4

Tables

4.1 Summation of R_f and R_d Values for Uranium 4.3
4.2 Summation of R_f and R_d Values for ^{85}Sr 4.3

1.0 Introduction

1.1 Purpose and Objectives

This report documents progress from fiscal year (FY) 92 through July, FY95 on waste-form release and contaminant/sediment adsorption properties germane to assessing performance/risk of past and future shallow land burial of defense wastes in Hanford Site sediments. The objectives of this report include describing progress on 1) development and optimization of experimental methods to quantify the release of contaminants from solid wastes and their subsequent interactions with unsaturated sediments, and 2) the creation of empirical data that become input parameters to performance assessment (PA) analyses for future Hanford Site disposal units and baseline risk assessments for inactive and existing solid waste disposal units.

To accomplish the task of developing methodologies to evaluate contaminant transport in Trench 8 (W-5 Burial Ground) sediments under unsaturated (vadose zone) conditions, a series of flow-through column tests was run using standard saturated column systems, Wierenga unsaturated column systems (both commercial and modified), and the Unsaturated Flow Apparatus (UFA). The reactants investigated were ^{85}Sr, ^{236}U, and ^{238}U as reactive tracers, and ^{3}H as a non-reactive tracer. Originally, the work was funded by two distinct projects, Hanford Site Performance Assessment (HSPA) and Solid Waste Technology Support (SWTS), both funded through Westinghouse Hanford Company (WHC). The HSPA project support ended in FY91.

Waste-form release and leachate-sediment interactions are generally quantified by a release rate and a distribution coefficient, respectively. Release rates are either a constant concentration (solubility-controlled release), a constant distribution coefficient (desorption-controlled release), an effective diffusion coefficient (diffusion-controlled release), or a strictly empirical release rate (e.g., fixed percent/yr). Contaminant-sediment interactions for dissolved species are generally reported as retardation factors (R_f values), defined as the velocity of the groundwater divided by the velocity of the reactive-contaminant, or as distribution coefficients (R_d values), defined as the concentration of reactive-contaminant in the solid phase divided by the concentration in the liquid phase. Until recently, quantification methods for R_f and R_d values have been generally derived from water saturated column or batch adsorption tests. Other more sophisticated and technically defensible adsorption models exist but require more detailed measurements than generally performed when collecting R_d values. As discussed in Serne and Wood (1990), such models are not considered practical or feasible in the context of current HSPA needs.

A specific objective of this work is to support a WHC solid waste performance assessment activity to simulate the performance of a newly proposed solid, low-level radioactive waste burial ground located in the currently operated W-5 Burial Ground in 200 West Area. In accordance with DOE Order 5820.2A, "Radioactive Waste Management," site-specific performance assessments must be performed. Key elements of the performance assessment include collection of site-specific geologic, hydrologic, and geochemical data, definition of natural processes and human-intrusion events, development of appropriate conceptual models, and conduct of computer simulations.

Within the SWTS project there is special interest with respect to the PA in optimizing experimental methodology and then collecting data that quantify the release of radionuclides and other contaminants from solid waste forms as discussed in Volume 1 of this series (Serne et al. 1993). Continuing this effort, the focus for this volume concerns the development of the ability to quantify subsequent transport of radionuclides and regulated chemicals through the vadose zone to the unconfined aquifer. One key goal was to investigate whether leach rates and sediment adsorption reactions are fundamentally different in unsaturated sediments than those within saturated systems. Most laboratory tests typically use saturated conditions because of the ease in which they can be performed and manipulated.

1.2 Test Methodologies and Contaminants

In FY92-FY95, the primary contaminants studied were Sr^{85} and uranium (VI) as both ^{236}U and ^{238}U. One Hanford Site sediment from the W-5 Burial Ground site (Trench 8 sediment) was used in partially saturated adsorption tests. The solutions used were Hanford groundwater for the uranium tests and 0.038 M $CaCl_2$ for the strontium tests. The test methodologies that were developed and evaluated for partially saturated conditions include:

- flow-through column tests of spiked groundwater through Trench 8 sediment under unsaturated conditions

- unsaturated flow centrifuge tests of spiked groundwater through Trench 8 sediment.

Two tests yet to be performed include:

- diffusion tests for selected contaminants solidified in grout placed in sediment under unsaturated conditions

- flow-through column and/or centrifuge tests of spiked waste forms embedded in sediment and leached with simulated pore water under unsaturated conditions.

Data collected from these tests will be used to determine the acceptability of only using results from simple saturated batch and column tests to support PA analyses being performed on the proposed W-5 Burial Ground expansion at the 200 West Area and the Environmental Restoration Disposal Facility (ERDF) on the Hanford Site.

1.3 Trench 8 Soil Characteristics

As described in Volume 1 (Serne et al. 1993), the <2-mm fraction of Trench 8 sediment used for tests consisted of 87% sand, 7% silt, and 6% clay-size fractions, having a particle density of 2.70 g/cm^3. The in situ sediment-size fractions were determined to be 9.7% gravel, 78.6% sand, 6.3% silt, and 5.4% clay. Amorphous hydrous oxide, organic, and carbonate contents for the <2-mm size fraction were reported as percent by weight as follows: SiO_2 at 0.03, Al_2O_3 at 0.30, Fe_2O_3 at 0.30, MnO_2 at 0.47, $CaCO_3$ at 2.00, and organic carbon as 0.19. Semiquantitative mineralogy of a <2-mm bulk sample showed values (in weight percent) of plagioclase as 26.1, quartz as 43.0, K-feldspar as 5.1, hornblende as 1.7, mica(biotite)/illite as 9.1, kaolinite/serpentine as 7.4, chlorite as 0.8, smectite as 3.3, vermiculite as 0.3, hydrous oxides as 1.1, and $CaCO_3$ as 2.0. Results from inductively coupled plasma-mass spectroscopy (ICP-MS) analysis of totally digested sediment showed uranium and strontium concentrations of 1.6 ppm and 395 ppm, respectively. Under natural conditions, the exchange sites for Trench 8 sediment were found to be loaded with 91.2% Ca, 8.4% Mg, 0% Na, and 0.4% K. The total cation exchange capacity was 5.2 ± 2.0 meq/100 g.

2.0 Development of Partially Saturated Soil Column Tests

Laboratory methods for the measurement of solute transport through unsaturated soils have generally employed specially designed soil columns that enable the user to create a steady-state, vertical water flux while maintaining a uniform water content throughout the column. The underlying principle for creating such conditions relies on Darcy's Law:

$$J_w = -K(\psi_m)\delta\psi/\delta z \tag{1}$$

where:

J_w = volume flux of water (m/sec)
ψ = water potential = matric (ψ_m) + gravitational (ψ_g) = m
$K(\psi_m)$ = conductivity as a function of matric potential = m/sec.

For laboratory tests, the goal is to create a unit gradient condition which is defined as when the matric potential is consistent throughout the vertical profile of the column and the flow of water is driven only by gravity. Under this condition, the gravitational potential at any position in the column is assumed to be equal to the distance from any point along the vertical axis of the column to a reference location used to define zero gravitational potential. The sign of the gravitational potential is determined by spatial selection of the reference location ($z = 0$) and the point in question ($z = L$). If the point in question is above the reference location, the gravitational potential is positive. If the point in question is below the reference location, the gravitational potential is negative.

By convention, water flow in the direction of increasing depth is considered positive flow. Within a column, if the top is labeled as $z = 0$ and the bottom as $z = L$, then the downward water flow would have a positive flux density with a negative gravitational potential. The gravitational gradient would then be expressed as:

$$\delta(\psi_g)/\delta z = -1. \tag{2}$$

Rewriting Darcy's law to include all components results in:

$$J_w = -K(\psi_m)[\delta(\psi_m + \psi_g)/\delta z]$$

and then to:

$$\begin{aligned} J_w &= -K(\psi_m)\delta\psi_m/\delta z - K(\psi_m)(\delta(\psi_g)/\delta z) \\ J_w &= -K(\psi_m)\delta\psi_m/\delta z + K(\psi_m)(1) \end{aligned} \tag{3}$$

where the matric component $-K(\psi_m)\delta\psi_m/\delta z$ is equal to zero when a uniform moisture content exists throughout the column, and the gravitational component previously expressed as $-K(\psi_m)\delta(\psi_g)/\delta z$ becomes the conductivity as a function of matric potential $K(\psi_m)(1)$. Thus, under unit gradient conditions:

$$J_w = K(\psi_m), \tag{4}$$

from which we are able to measure ψ_m using a tensiometer attached to the soil column.

2.1 Overview of Application

The objective for this research was to develop test methodologies that would investigate contaminant transport under partially saturated (vadose zone) conditions and to compare these results with results from classical methods used for the determination of contaminant transport under saturated conditions.

Prior to this work, most adsorption tests that measure R_d have been performed under saturated conditions. Typically, R_d values such as those presented in Volume 1 (Serne et al. 1993) are defined as the concentration of the reactive-contaminant in the solid phase divided by concentration of the reactive-contaminant in the liquid phase. As a comparison to column test methodologies presented in this report, R_d values from Volume 1 (uranium and ^{85}Sr) were measured in batch tests by placing 1 g of soil in contact with 30 mL of an aqueous solution spiked with the contaminant of interest. During the batch tests, small aliquots of solution were removed at different intervals and analyzed for the presence of the contaminant. The measured values for the contaminant of interest were then incorporated into the general expression:

$$R_d = (BV - E(V+X))/WE \qquad (5)$$

where B is the spike concentration in the influent blank, V is the volume of spiked groundwater added, E is the spike concentration in the effluent solution, X is the excess solution left from unspiked equilibration washes, and W is the weight of sediment (Relyea et al. 1980; Relyea 1982).

For this report, R_d values were determined by first running a soil column under saturated conditions in order to measure R_f which is defined as the pore velocity of water divided by the linear transport velocity of the reactive contaminant in solution (Bouwer 1991). Simply expressed as:

$$R_f = V_{gw}/V_{sp} \qquad (6)$$

where

V_{gw} = the velocity of groundwater
V_{sp} = the velocity of the species.

If none of a particular species is lost to the solid phase, then $R_d = 0$ and $R_f = 1$ for that species. R_f values for this report were determined using column breakthrough curves generated from continually injecting the contaminant into the column. The actual R_f value is the number of pore volumes having passed through the column at which the effluent/influent ratio reaches $C/C_o = 0.5$, where C = effluent and C_o = influent concentrations. Pore-volume calculations used in this report were equal to the volumetric water content of the column at any point in time. As an example, under completely saturated conditions, a pore volume is equal to the sediment porosity multiplied by the empty volume of the column. By convention, the continual injection test is assumed to yield the R_f value when the concentration of chemical in the effluent solution (C) is 50% of the concentration of the influent solution (C_o).

Having measured the R_f value (for a saturated condition), the R_d value can be determined by using the relationship:

$$R_f = 1+[(\rho b/n)*R_d] \tag{7}$$

where ρb is the bulk density of the dry sediment, n is the porosity, and R_d is the distribution coefficient. When using the above equation and solving for R_d:

$$R_d = (R_f\text{-}1)/(\rho b/n). \tag{8}$$

An R_d value can then be calculated from any saturated column test with a known ρb and n. For unsaturated conditions, the same equations (Equations 7 and 8) can be used if n is replaced by the volumetric water content (θ) which represents the actual content of water moving through the column and influencing the reacting chemical transport process (Bouwer 1991). Thus

$$R_f = 1+[(\rho b/\theta)*R_d] \tag{9}$$

$$R_d = (R_f\text{-}1)/(\rho b/\theta). \tag{10}$$

With respect to Equation (9), under unsaturated conditions, as θ decreases, R_f should theoretically increase for a given species. In other words, the residence time between the solute with respect to the solvent in a column test would be greater under unsaturated conditions relative to saturated conditions for the same period of time. When using θ in calculating R_d (Equation 10) under unsaturated conditions, all R_d values should be the same provided that breakthrough is independent of moisture content.

Past Pacific Northwest Laboratory (PNL) results from tests using saturated columns and batch adsorption procedures for Hanford Site sediments have provided rather good agreement when comparing calculated (from R_f tests) versus batch R_d values for a variety of contaminants (e.g., uranium and strontium), though there is general literature citations that report discrepancies among R_d values when comparing column and batch methods. Such differences may be because of the agitation during the batch method (not present in column method) which could result in the grinding and eventual dissolution of soil particles. This dissolution may lead to the formation of more surface area for adsorption, or the release of competing ions that could reduce adsorption. Sorption kinetics could also be a consideration for differences in column and batch tests. If the soil and solute contact time is too short in either of these tests, equilibrium will not be attained and thus the R_d value would be biased low (Relyea et al. 1980; Relyea 1982).

The inherent difficulties in performing saturated tests become compounded when trying to determine unsaturated R_d values. Currently, very few R_f or R_d values have been determined under unsaturated conditions. Such limitations for measuring an unsaturated R_d using batch tests are the inability to assure homogeneous mixing of the contaminant solution with sediment, and the difficulty in extracting solution for analysis at the end of the test.

2.2 Wierenga Column Description/Methodology

In order to measure unsaturated R_f values, Wierenga columns were initially selected based on their ability to conduct hydraulic conductivity studies on various sediments under unsaturated conditions. By design, these columns allow for the manipulation of θ, and by using Equation (10), it should theoretically be possible to calculate an unsaturated R_d.

Wierenga columns (Wierenga et al. 1986, 1989) are commercially available (Figure 2.1) and use a vacuum source and stainless steel bubble-pressure plates (commonly rated at 140 cm) at each end to create unsaturated moisture conditions within the soil. These columns have a volume of 589 cm^3 with a internal diameter of 5 cm and a chamber length of 30 cm. Each column has two tensiometer ports that also include bubble-pressure plates at the soil interface. Each tensiometer is located 5 cm from the column ends to allow measurement of the pore water matric potential and to monitor stability during operation.

The general procedure used for the tests required packing a preweighed column with oven-dried Trench 8 soil and slowly saturating it from bottom to top using a low velocity pump. After several pore volumes had passed through (requiring 4 to 5 days of operation), the column was then reweighed to calculate a saturated volumetric water content. Once saturated, the flow was reversed with the bottom effluent line connected to a fraction collector sealed inside a vacuum chamber.

To obtain an unsaturated condition, both vacuum pressure and influent velocity were adjusted until a reasonably unsaturated moisture content was achieved. The low velocity pumps selected for the tests were medical infusion pumps (3M AVI Micro 210A) with an adjustable range of 0.1 to 99 mL/h. When the system was stable (having no appreciable fluxuation in matric potential), a previously measured water potential versus water content curve for Trench 8 soil (see Figure 2.2) was used to estimate the sediment moisture content (Serne et al. 1993). Gravimetric measurements were then performed to verify the actual moisture content.

One concern while packing each column was to prevent preferential channeling of the influent solution during operation. Typically in column tests, channeling results from the horizontal or radial layering of different particle sizes. Under saturated conditions, if the soil is not well sorted, the influent will move preferentially through areas of greater particle size with higher porosity. To achieve a uniform bulk density and to prevent stratified layers, columns were packed with a filling apparatus that consisted of a 66-cm long by 2.54-cm ID PVC pipe with one 4-mm mesh screen on the bottom end and another 4-mm screen, 10-cm from the bottom (Wierenga 1986). With the apparatus inserted into the column, soil was slowly poured into the pipe while tamping both the pipe and column at the same time. After filling, the column was reweighed to determine the bulk density and porosity.

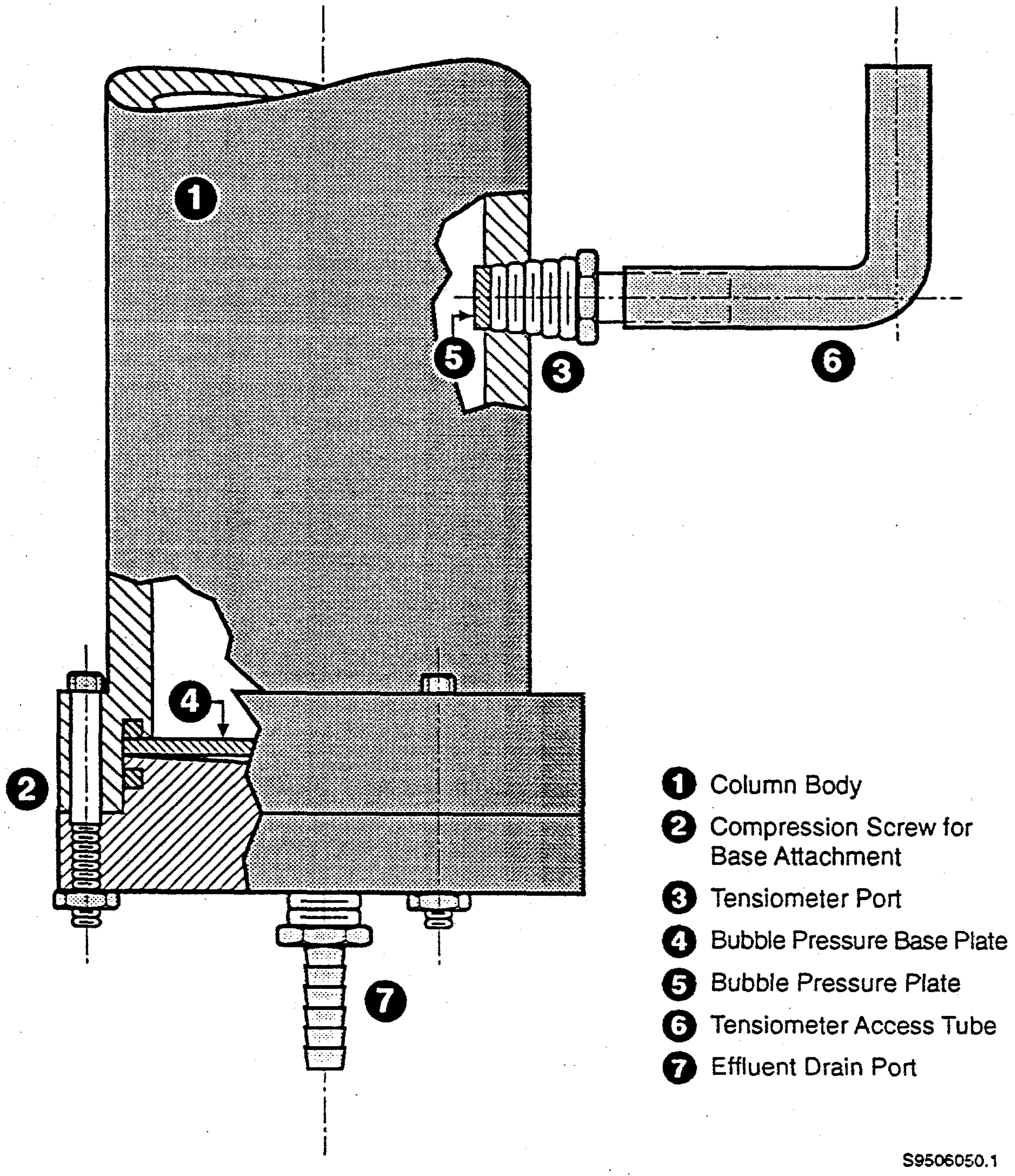

Figure 2.1. Wierenga Column Diagram

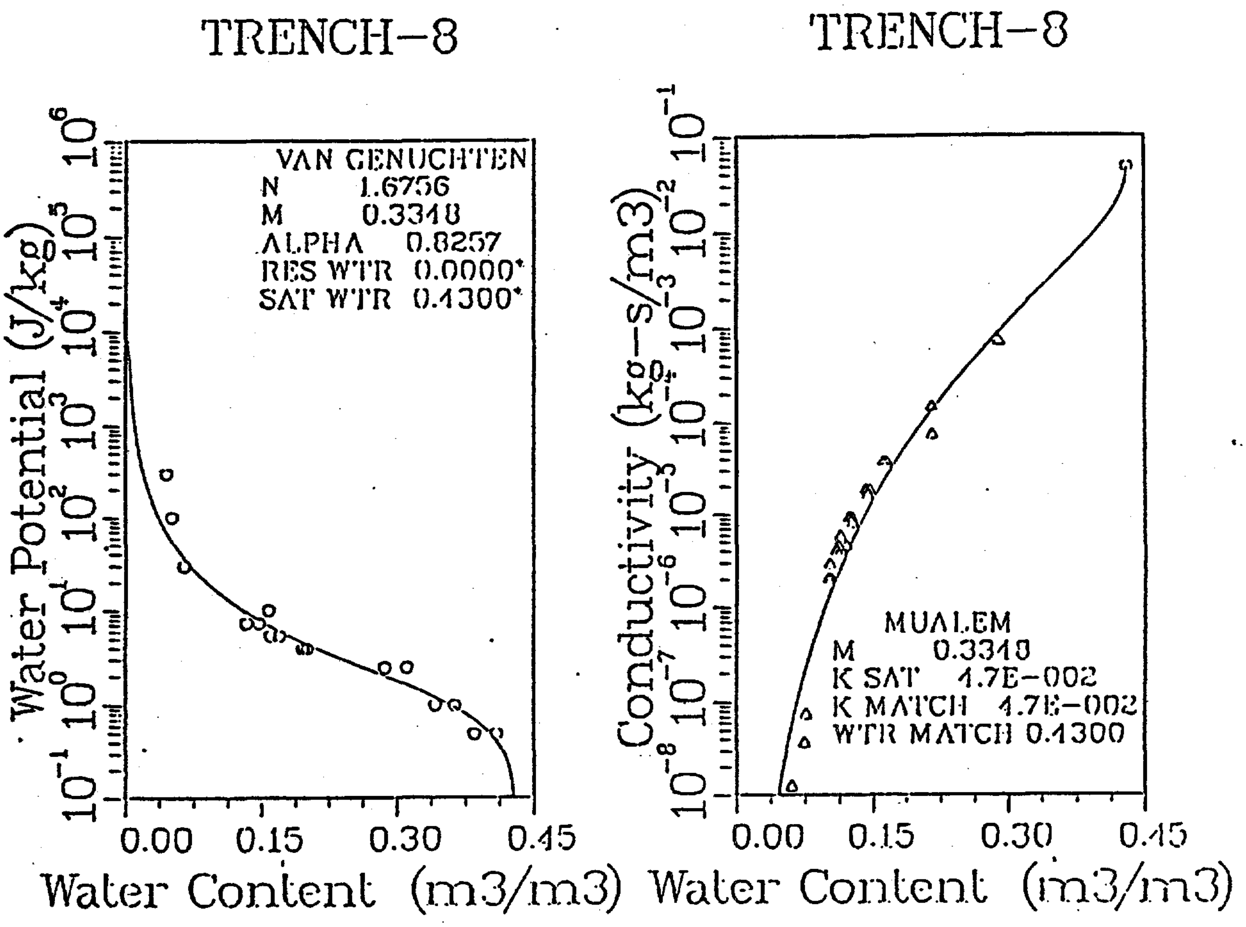

Figure 2.2. Comparison of UFA and Water Residence Methods (Serne et al. 1993)

Using the above method, the bulk density for a given column (grams of dry soil/column volume) in tests ranged from 1.65 to 1.75 g/cm^3. To determine the porosity and the pore volume of a given column, the particle density for Trench 8 soil measured in Volume 1 (Serne et al. 1993) at 2.7 g/cm^3 and the relationship:

$$n = 1 - \rho b/\rho p \qquad (11)$$

where n is the porosity, ρb is the bulk density and ρp is the particle density was used. The saturated pore volume was then determined by multiplying the porosity by the volume of the soil column. From Equation (11), the individual column porosities ranged from 35% to 39%, resulting in a pore volume range from 206 to 230 mL. It should be noted that the saturated volumetric water content (equivalent to porosity) calculations assumed that the airfilled porosity (pore space which never becomes saturated) was negligible.

In keeping with the objective to investigate contaminant transport in unsaturated sediments, Hanford groundwater was selected as the carrier matrix, and uranium was selected as the contaminant of choice since it is both a contaminant of concern at the Hanford Site and has low sorption properties. Previous batch adsorption tests using uranium (as UO_2^2+) with Trench 8 soil had provided an average R_d value of 2.3 ± 1.2 mL/g [see Table 30, Vol 1, (Serne et al. 1993)]. Using this number as a reference point with an average bulk density of 1.7 g/cm^3, an R_f range from 8 to 17.5 and thus a 50% breakthrough to occur at the same pore volumes was expected.

2.3 Saturated Column ^{238}U Test 1

Prior to starting the Wierenga unsaturated column tests, a saturated column test was run using Hanford Site groundwater spiked with 37.3 ppb uranium (as UO_2^{2+}) in order to establish a base line breakthrough curve for uranium (Figure 2.3). For this test, a Teflon column with screw cap fittings having a total volume of 154.5 cm^3 (diameter to length ratio of 1:3) was used. The operating parameters are listed in Table A.1 (Appendix A) which included a bulk density of 1.64 g/cm^3, a porosity of 40%, and an influent velocity of 5.0 mL/h. The column was initially equilibrated with unspiked Hanford groundwater by pumping 4 to 5 pore volumes through the system. The uranium spiked groundwater was then added to the system and the column was left running for over 60 pore volumes. Analysis of the data indicated breakthrough ($C/C_o = 0.5$) at 9 pore volume which was within the predicted R_f range.

2.4 Wierenga Column Tritium Test

For the initial Wierenga column test, the soil was packed as previously described to a bulk density of 1.76 g/cm^3, a porosity of 35%, a volumetric water content of 21% (59% saturation), and an influent velocity of 4.0 mL/h. As part of both the pretracer washing and desaturation process, approximately 5 to 6 pore volumes (saturated) of unspiked Hanford Site groundwater were required to pass through the column before reaching the steady-state 21% volumetric water content. Tritium spiked Hanford Site groundwater was then used (Figure 2.4 and Table A.2) to verify the operational integrity of the system. Analysis of the test results indicated a 50% C/C_o breakthrough was reached at 1.0 pore volume which was consistent with the anticipated tritium R_f value of 1 (R_d for tritium = 0).

2.5 Wierenga Column ^{238}U Tests

After flushing the same column (tritium column) with 5 pore volumes of uncontaminated groundwater at the end of the tritium injection, a second test using Hanford Site groundwater spiked with 39.7 ppb uranium as UO_2^{2+} was performed. For this test, the same pore water velocity was used as before, however a 1% increase in the volumetric water content was noted giving a final value of 22%. Predictions indicated that a 50% C/C_o breakthrough should have been reached between the sixth

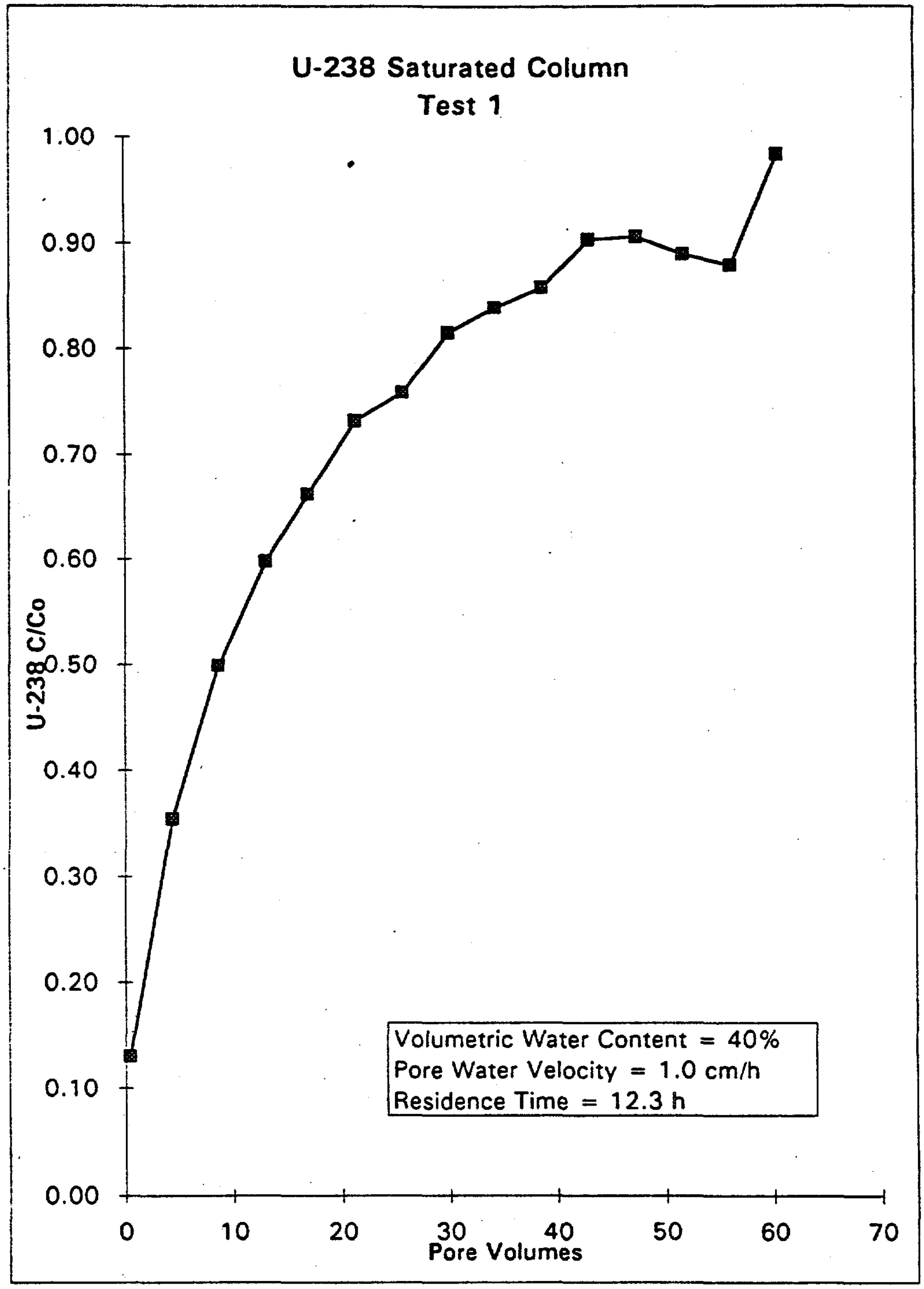

Figure 2.3. ^{238}U Saturated Column Test 1

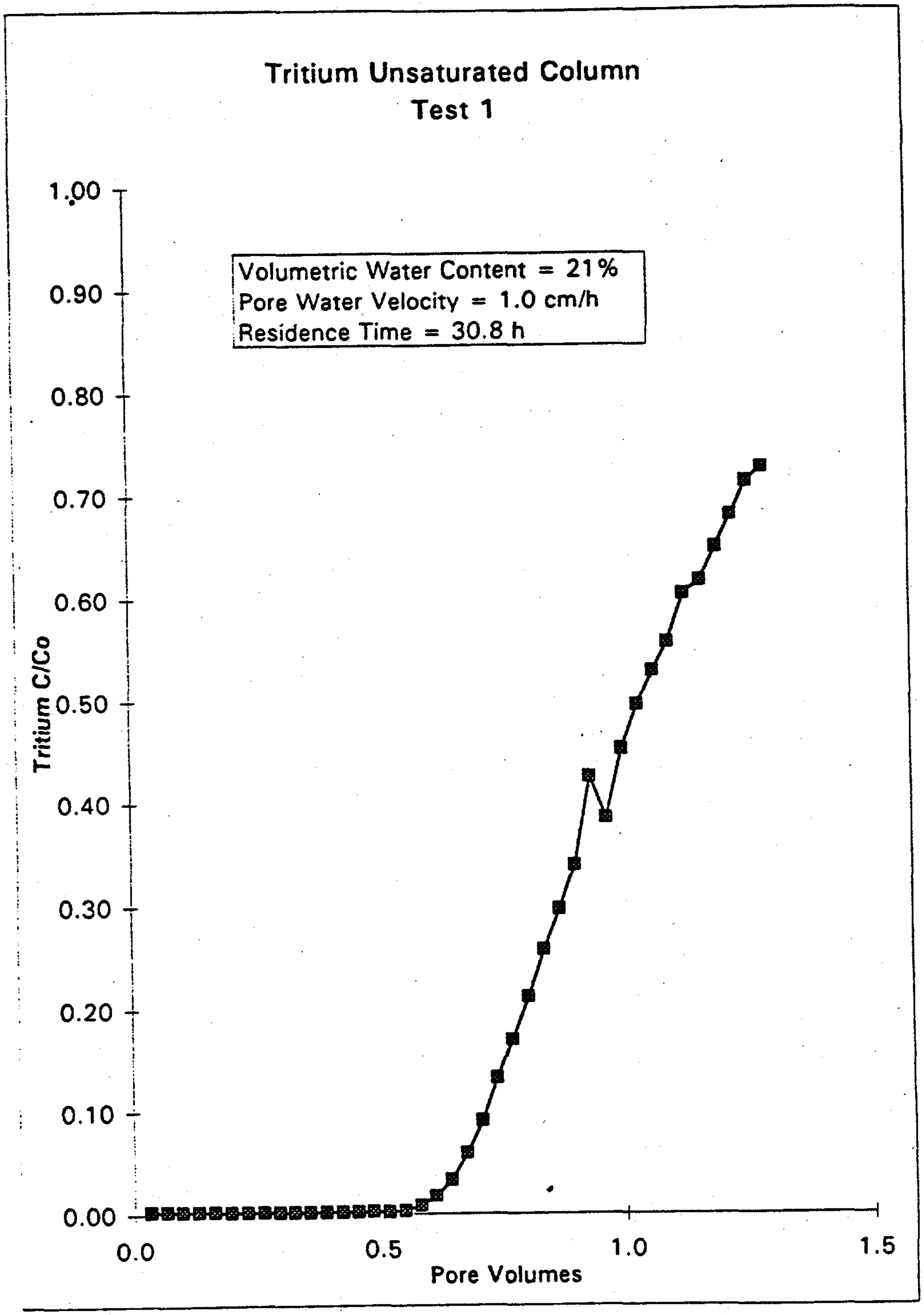

Figure 2.4. Tritium Unsaturated Column Test 1

and eighth pore volume, however the test was terminated prematurely after the sixth pore volume where a C/C_0 breakthrough of only 48% was observed (Figure 2.5 and Table A.3). In comparison to the saturated column, the results from this test were considered reasonable. However, there is some question related to premature leveling off of the breakthrough curve at the fifth and sixth pore volumes. Such curve flattening at this point is contrary to the smooth sigmoidal curve typically associated with breakthrough for continuous tracer injection.

Given the results of the first two Hanford Site groundwater tests (tritium and uranium), two more unsaturated uranium tests were conducted using the same procedure as previously described including a 5 to 6 pore volume equilibration flushing with clean HGW prior to tracer injection. Using separate columns, one attempt was made at reproducing the results noted in the first unsaturated uranium test, while the other column was run at dryer conditions (13% saturation). For uranium tests two and three, a total of 10 pore volumes of spiked groundwater were allowed to pass through prior to performing uranium analyses on selected effluent samples. However, during the four to six month test period, several events such as power outages, building vacuum failures, inadvertent shut down during routine building maintenance operations, and column O-ring and/or tensiometer septum deterioration occurred. Subsequently, these events resulted in severe fluctuations of vacuum pressure which in turn compromised the confidence of the ability to maintain steady state during their operation. When the analytical results for uranium concentrations in the effluent were obtained, they exhibited such wide scatter that both tests were terminated.

2.6 Residence Time Sensitive Saturated Column ^{238}U Tests

One possible explanation for the extremely scattered data in the last two Wierenga column uranium trials may be the result of the uranium sorption kinetics being influenced by the variability in residence time caused by the mechanical failures. To evaluate the potential influence of residence time, we ran three more saturated columns using residence times of 0.6, 5.9, and 60.7 h (Figures 2.6, 2.7, 2.8, and Tables A.4, A.5, A.6). Unlike the previous column tests (both saturated and unsaturated), these columns were not equilibrated with filtered groundwater, instead the uranium spiked groundwater was introduced into the system while the columns were still dry. The choice of dry soil was in part because of results from earlier UFA tests as discussed in Section 3.2, and to determine if uranium under prolonged residence times may leach from the initially dry soil. From these tests, R_f values of 2 for the 0.6 h (2D) and 12 for the 5.9 h (3D) runs were found, but no apparent breakthrough curve could be determined from the 60.7 h (4D) test.

Results from test 2D appeared consistent with the earlier run UFA tests (Figures 3.1, 3.2, and Tables A.15, A.16) where breakthrough occurred at 2 and 2.3 pore volumes under similar residence times (0.6 and 0.5 h, respectively). The results from test 3D also appeared consistent with the earlier pre-spike equilibrated saturated column (Figure 2.3, Table A.1) which was also run under a similar residence time. Comparison of these five tests would suggest that sorption kinetics of uranium can be resident time sensitive.

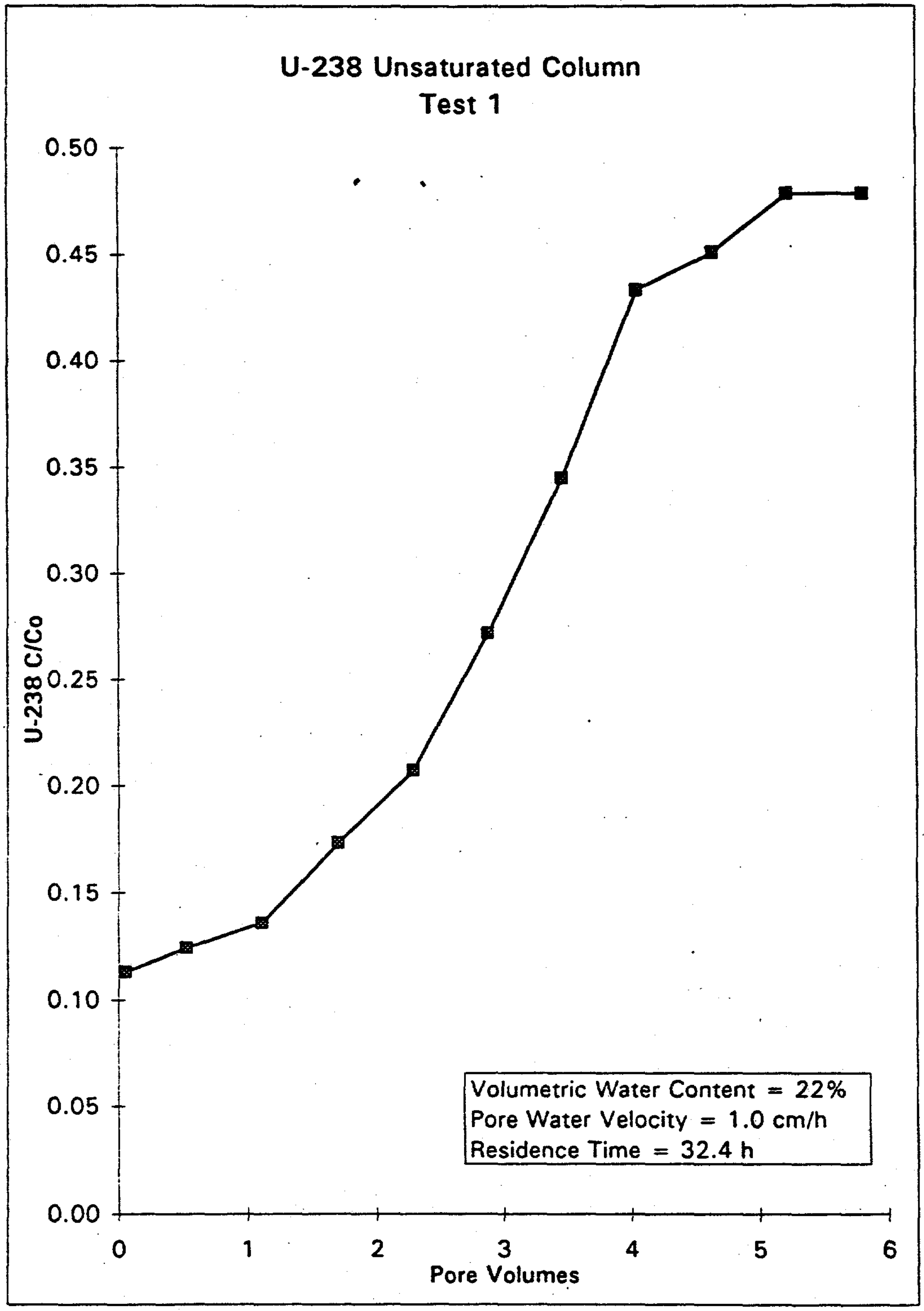

Figure 2.5. ^{238}U Unsaturated Column Test 1

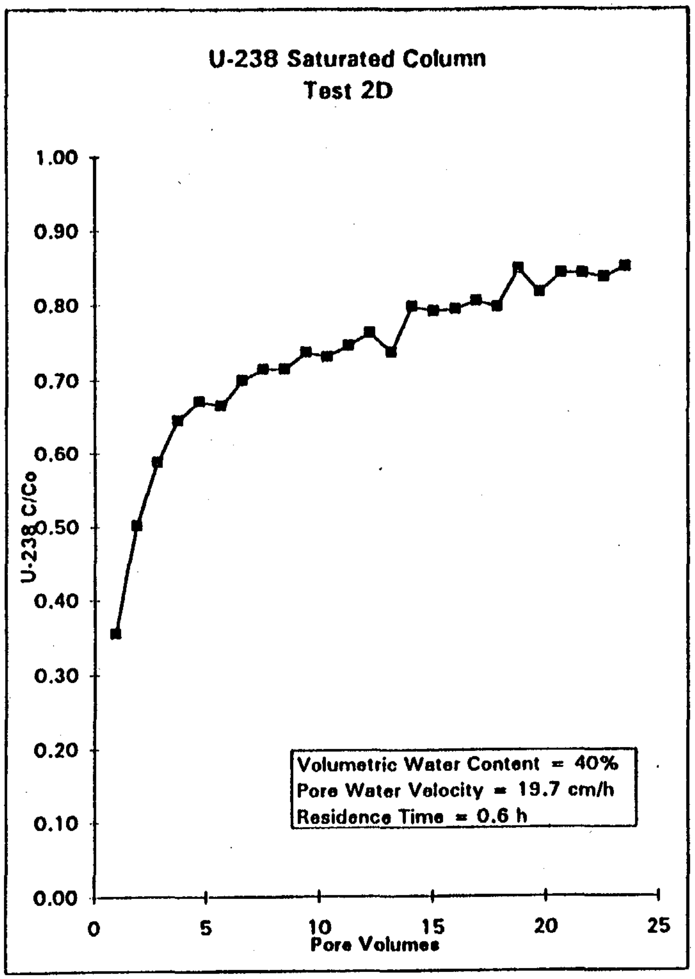

Figure 2.6. ^{238}U Saturated Column Test 2D

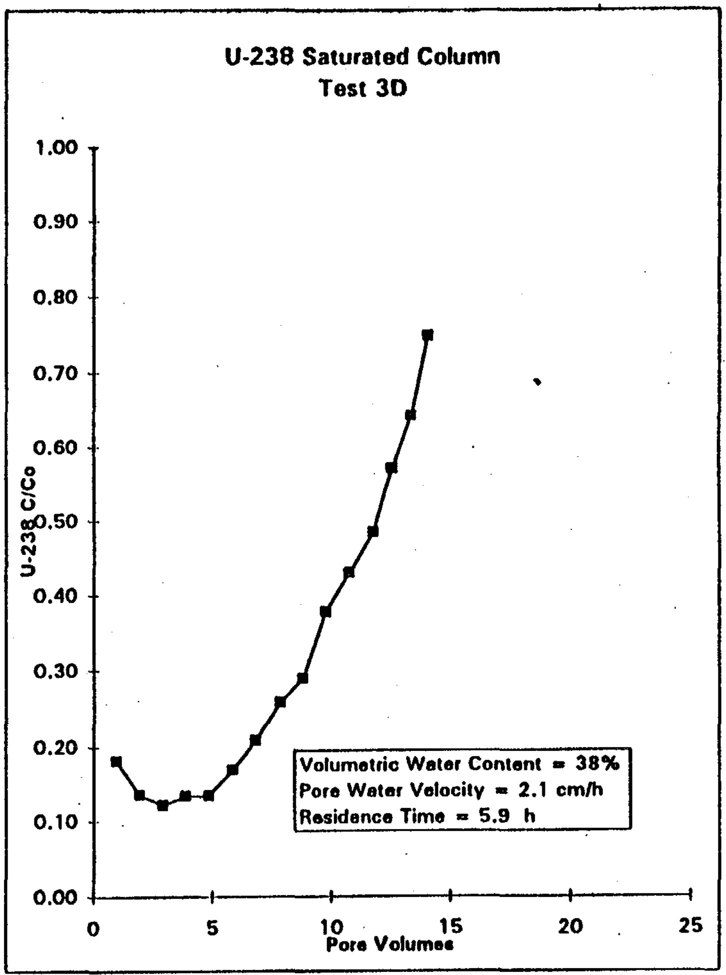

Figure 2.7. ^{238}U Saturated Column Test 3D

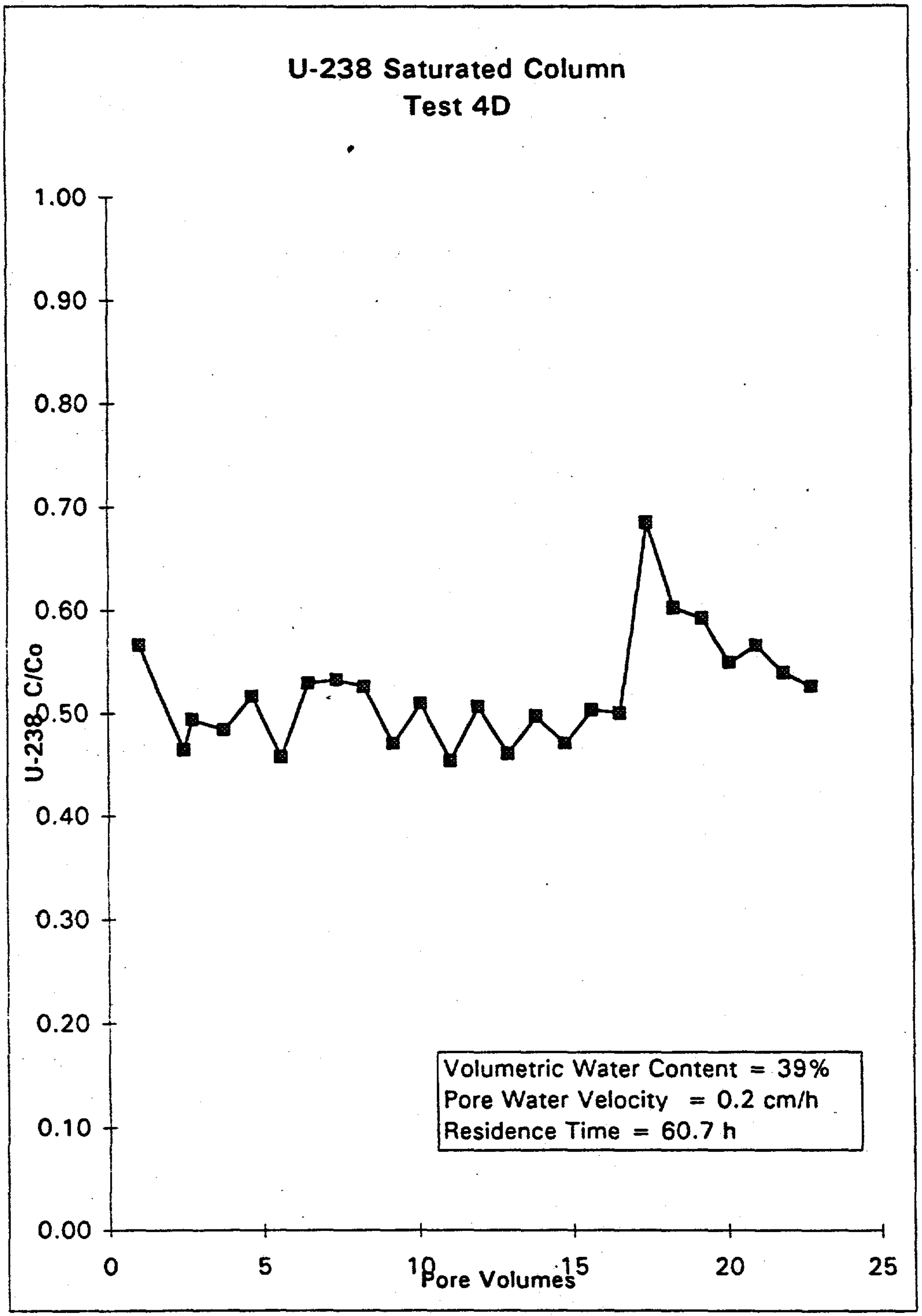

Figure 2.8. ^{238}U Saturated Column Test 4D

For the longest residence time test (4D), breakthrough occurred within the first pore volume, however the percent C/C_o never achieved a value greater than 60% before the test was terminated after 14 pore volumes. The results from this test in comparison to tests 2D and 3D appear rather inconsistent in both the early breakthrough and flattening of the curve at a value of 50%-60% C/C_o going beyond 14 pore volumes.

To further investigate the potential for natural uranium to leach from the Trench 8 sediment which naturally contains 1.5 μg/g uranium, two more saturated tests (using Teflon columns) were run with one using only Hanford Site groundwater having a natural uranium concentration of 5 μg/L, and the other using deionized/distilled water having no measurable amount of uranium. Both tests were allowed to run for 8 to 15 pore volumes with a pore volume residence time of 56 h each. Results (Figures 2.9, 2.10, and Tables A.7, A.8) clearly demonstrate uranium leaching out of the Trench 8 sediment in both tests. When using only groundwater, initial results indicate immediate leaching with values 2.25 to 1.5 times the natural background of the groundwater for the first 2 pore volumes. In addition, even after 16 pore volumes, the original background concentration wasn't achieved but instead continued to leach uranium at a concentration 25% greater than the natural groundwater starting solution. As for the DI H_2O test, there was a substantial initial leaching of 20 to 34 ppb for the first two pore volumes, but then an immediate drop to 0 ppb by the twelfth pore volume.

In consideration of the two desorption tests, the early breakthrough in the 60.7 h test may have involved a leaching phase during the initial contact of the spiked groundwater with the dry sediment. Changes in pore water chemistry during the rewetting of dried soil could be effecting the solubility of the uranium. For example, this rewetting process may temporarily increase the availability of carbonate and subsequently increase the initial solubility of uranium in the form of uranyl carbonates.

The flattening of the curve in test 4D at the 50%-60% C/C_o is somewhat more difficult to explain. Without having performed complete chemical analyses on any of the leachate fractions, a speculative explanation may be that following the initial leaching of some uranium from the soil, the extremely slow flow rate allowed for the readsorption of some of the initially removed uranium. Subsequently, test 4D may be representative of a desorption curve combined with an adsorption curve as a result of complex uranium sorption kinetics. It was clear from these tests however, that pre-flushing the columns is an essential step, especially when using low concentrations of reactants that are also inherently found in the soil.

2.7 Modified Wierenga Column ^{236}U Tests

Because of inherent problems with the standard Wierenga columns, the system was modified with the hope of improving the uranium breakthrough tests. Additionally, we spiked the Hanford Site groundwater with a ^{236}U tracer (not naturally found in the environment) at a concentration of 0.7 ppm in order to ignore potential leaching of natural uranium from the Trench 8 soil which was determined to contain 1.6 μg/g of natural uranium. The primary modifications to the standard Wierenga column included a reduction in volume from 589 to 154 cm^3 (but still maintaining the 1:6 diameter to length ratio), and replacing the two rubber septum covered tensiometer ports with a single self-sealing Nordel valve tensiometer port placed centrally in the column. Though reducing the number of tensiometer

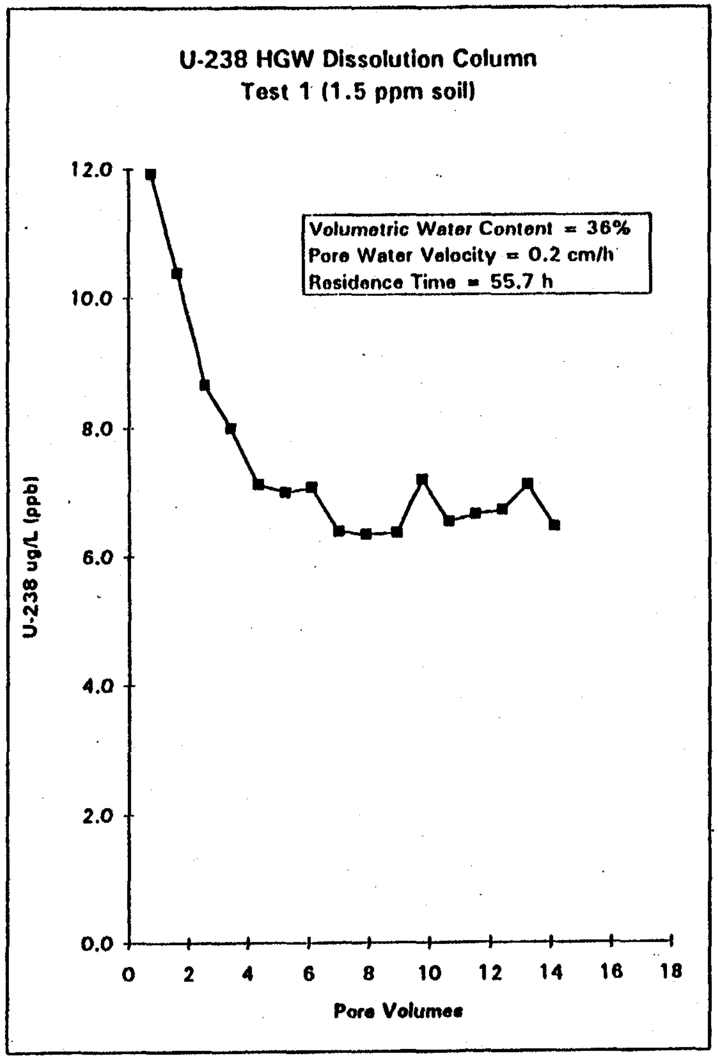

Figure 2.9. ^{238}U Hanford Site Groundwater Dissolution Column Test

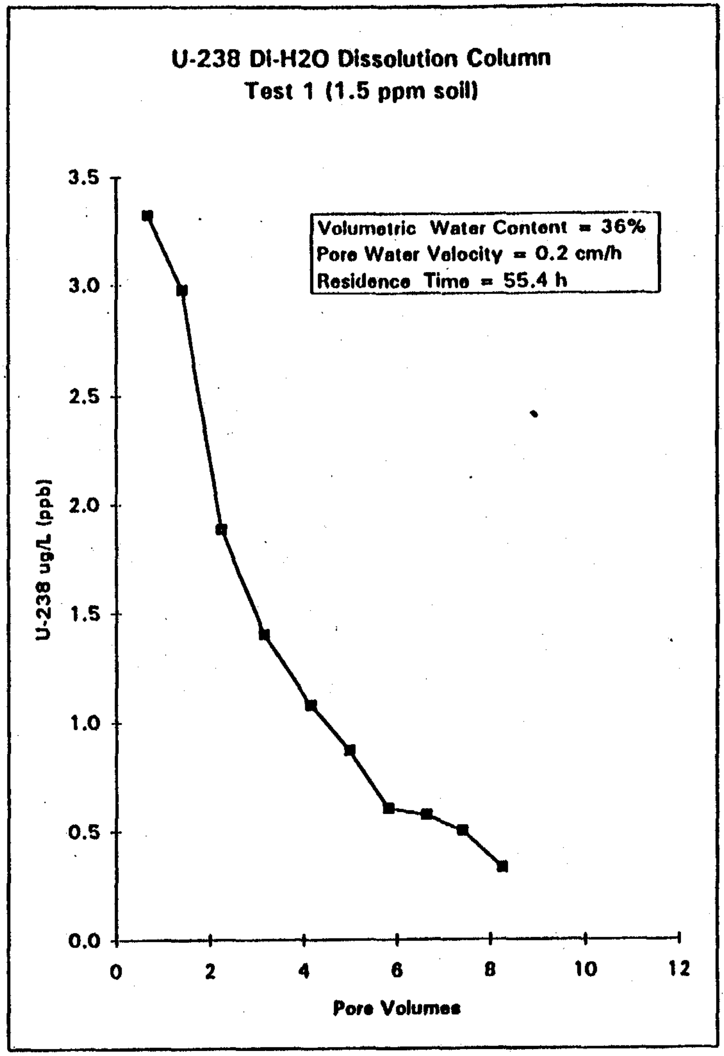

Figure 2.10. ^{238}U D1-H_2O Dissolution Column Test 1

ports affected the ability to determine steady state at both ends of the column, it was believed that such a modification would reduce the potential for air leakage over the prolonged period of a given test. Steady-state conditions for the modified columns were determined by using gravimetric measurements during the test along with careful monitoring of the central tensiometer port for changes in the matric potential.

With the newly modified Wierenga columns, two more uranium tests were performed using ^{236}U. For these tests, volumetric water contents of 25% and 17% were achieved which equates to 62% and 43% saturation, respectively. Both columns were run concurrently for at least 41 days at a flux of 0.5 mL/h until the tests were terminated abruptly during an unscheduled building power outage. Roughly 15 pore volumes were collected in the 25% test while a total of 23 pore volumes were collected in the 17% test. Breakthrough curves (Figures 2.11, 2.12, Tables A.9, A.10) show R_f values of approximately 8.1 and 11.2 or their calculated R_d values of 1.1 mL/g and 1.1 mL/g, respectively. In comparison to the expected saturated R_d value of 2.0 mL/g, these results suggest that the distribution coefficient calculated from the saturated test (Figure 2.3) is too large and over estimates the R_d for unsaturated tests by 45%.

2.8 Modified Wierenga Column ^{85}Sr Tests

Because of the leaching of natural uranium and non-equilibrium adsorption difficulties encountered during the uranium tests, ^{85}Sr was selected for testing because of its better characterized sorption properties. In previous saturated R_d batch tests using Trench 8 sediment and Hanford Site groundwater, the R_d for strontium was noted to have a value of 22.97 ± 2.69 mL/g. For these tests, an R_d value of 23 mL/g would take too long to complete a breakthrough curve within a reasonable amount of time, thus strontium sorption was artificially lowered. Using the results reported in Table 31 of Volume 1 (Serne et al. 1993), a 0.038 M $CaCl_2$ carrier solution for strontium was selected. This carrier solution produces an R_d value of 1.02 ± 0.64 when contacted with Trench 8 sediments.

For the ^{85}Sr tests, four columns were prepared of which two were used for unsaturated conditions (modified Wierenga) and two (standard Teflon) were run at saturated conditions. As with all other tests, oven dried Trench 8 soil was packed into the columns in the same manner as described in Section 2.1. The average bulk density for the two unsaturated columns was 1.5 g/cm^3 and the bulk density for the two saturated columns was 1.7 g/cm^3. The $CaCl_2$ solution was prepared by adding 55.49 g of $CaCl_2$ into 100 mL of DI H_2O which provided a 5 M stock solution. 30.4 mL of the stock solution was then added to DI H_2O to a final volume of 4.0 L resulting in a final concentration of 0.038 M $CaCl_2$. The last manipulation of this solution required the small addition of 0.1 M NaOH in order to adjust the pH to 8.3 (similar to groundwater).

All four columns were then saturated with the 0.038 M $CaCl_2$ solution for 72 h at a flow rate of 10 mL/h. An estimated 10 to 11 pore volumes passed through each column during the equilibration period. Desaturation for the two modified Wierenga columns required 41 days to reach steady-state unit gradient conditions. The saturated columns were also allowed to operate at a reduced flow rate during the desaturation period. By the time the ^{85}Sr spike solution was introduced, 18 to 20 pore

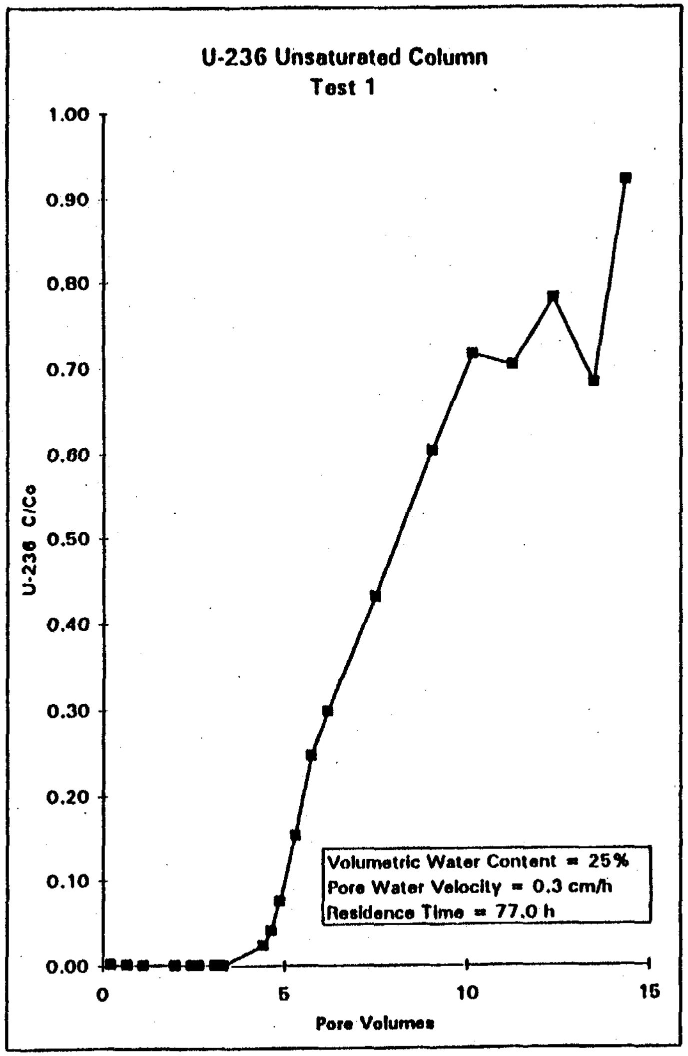

Figure 2.11. ^{236}U Unsaturated Column Test 1

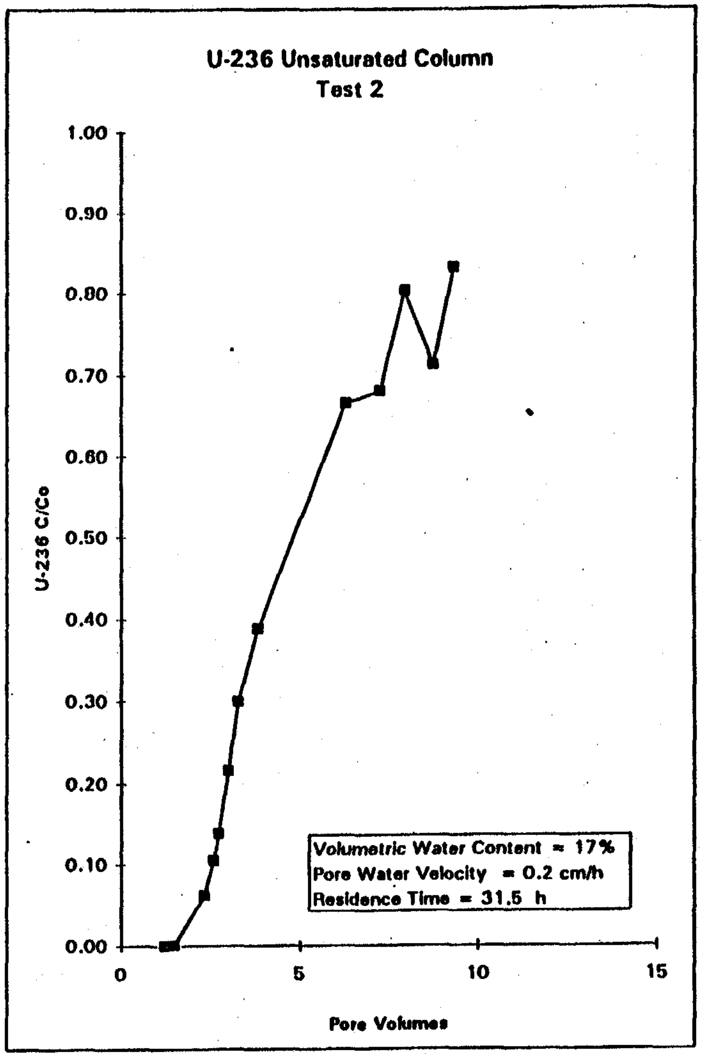

Figure 2.12. ^{236}U Unsaturated Column Test 2

volumes of unspiked solution had passed through each column. The final steady-state volumetric water content conditions for the four columns were 37% (two saturated), 31%, and 20%. 4 L of fresh 0.038 M $CaCl_2$ solution was prepared and pH adjusted as previously described. Approximately 250 uCi of ^{85}Sr was then added to the solution to give a final concentration of 0.016 uCi/mL. The ^{85}Sr solution was allowed to equilibrate for three days before being introduced into the columns. All four columns were allowed to run 22 days during which 15 pore volumes of spiked solution passed through the sediments.

Breakthrough curves for the four tests indicated R_f values of 9.1, 6.9, 10.8, and 8.3 for the two 37%, the 31%, and the 20% volumetric water contents, respectively (Figures 2.13, 2.14, 2.15, 2.16, and Tables A.11, A.12, A.13, A.14). For the two 37% saturated tests, pore water velocities 0.4 cm/h and 0.5 cm/h were used having residence times of 28.8 and 23.8 h. For the 31% test, a pore water velocity of 0.8 cm/h was used resulting in a residence time of 24 h. Finally, the 20% test operating at a pore water velocity of 1.2 cm/h resulted in a residence time of 16 h. Total mL for the pore volumes were again calculated as a function of the volumetric water content.

Results from these unsaturated column tests appear to give the same R_f value as the original saturated test (see Section 2.3) and are thus contrary to the expected higher R_f values for the unsaturated conditions predicted by Equation (9). If an average saturated R_f value of 8.0 is used in Equation (10), the resulting R_d value would be approximately 1.7 mL/g, and thus the R_f values for the 31% and 20% unsaturated tests given a constant R_d value should have been closer to values of 13 and 14, respectively, as opposed to the observed values of 10.8 and 8.3. The calculated R_d values from the unsaturated tests provide values of 2.0 mL/g for the 31% test (72% saturated), and 1.0 mL/g for the 20% test (47% saturated). In comparison, there appears to be no significant difference between the average saturated test R_d value of 1.7 mL/g and the 31% test value of 2.0 mL/g, however there appears to be a significant drop of 42% when the average saturated value is compared with the 1.0 mL/g R_d value calculated from the 20% test.

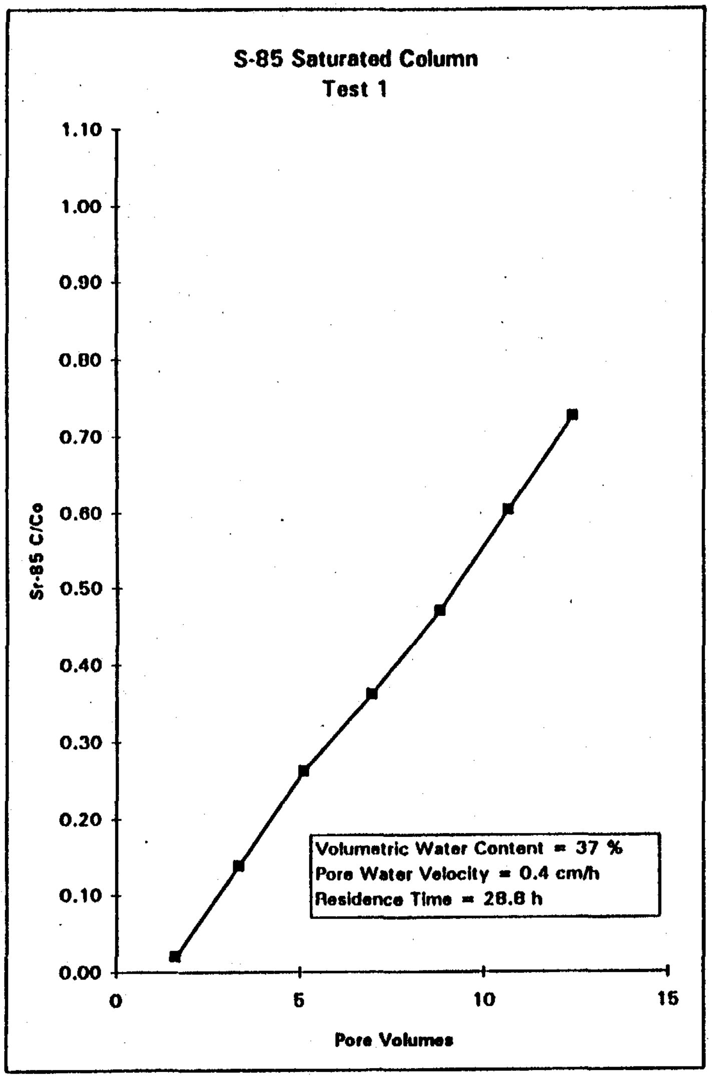

Figure 2.13. ^{85}Sr Saturated Column Test 1

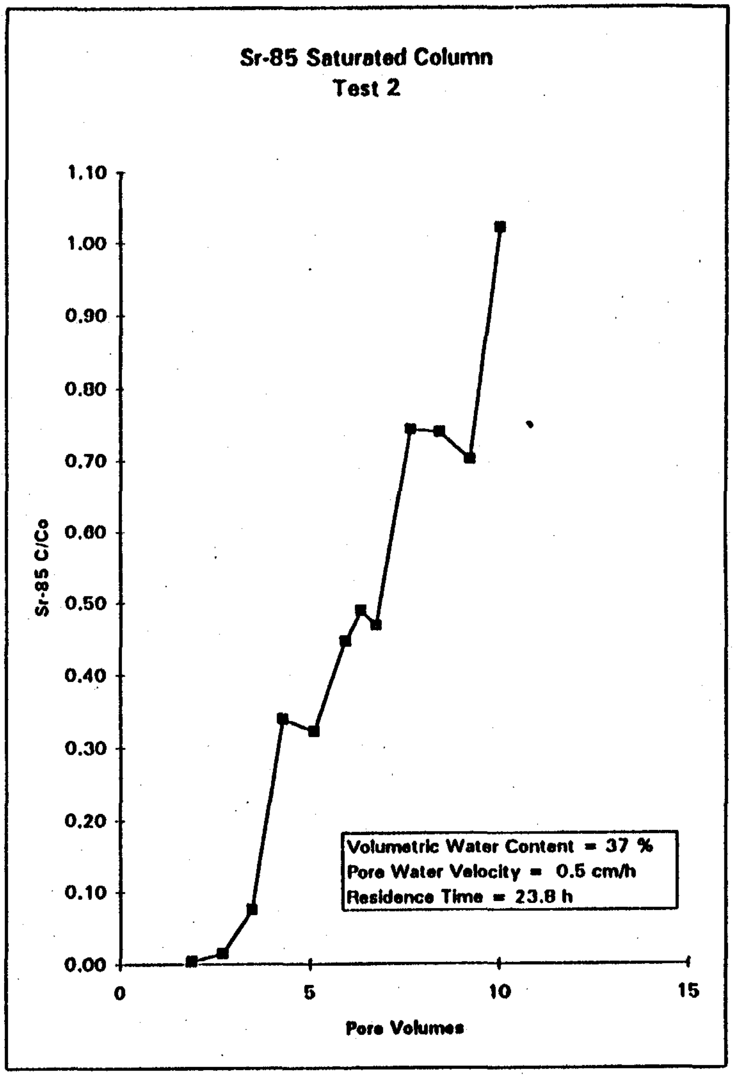

Figure 2.14. ^{85}Sr Saturated Column Test 2

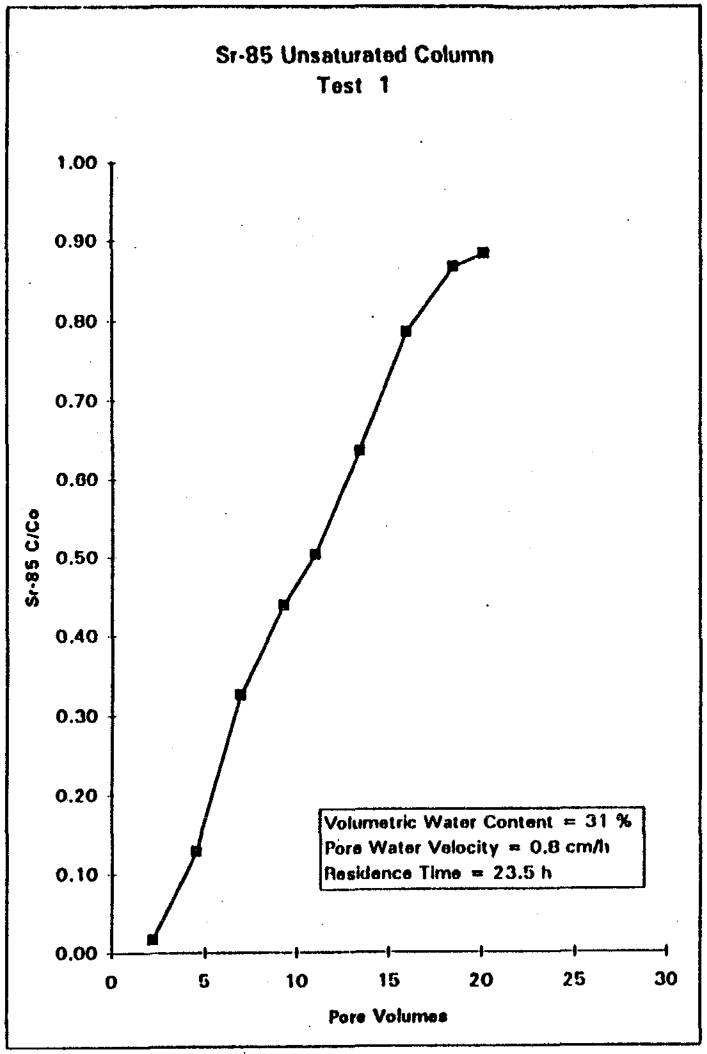

Figure 2.15. ^{85}Sr Unsaturated Column Test 1

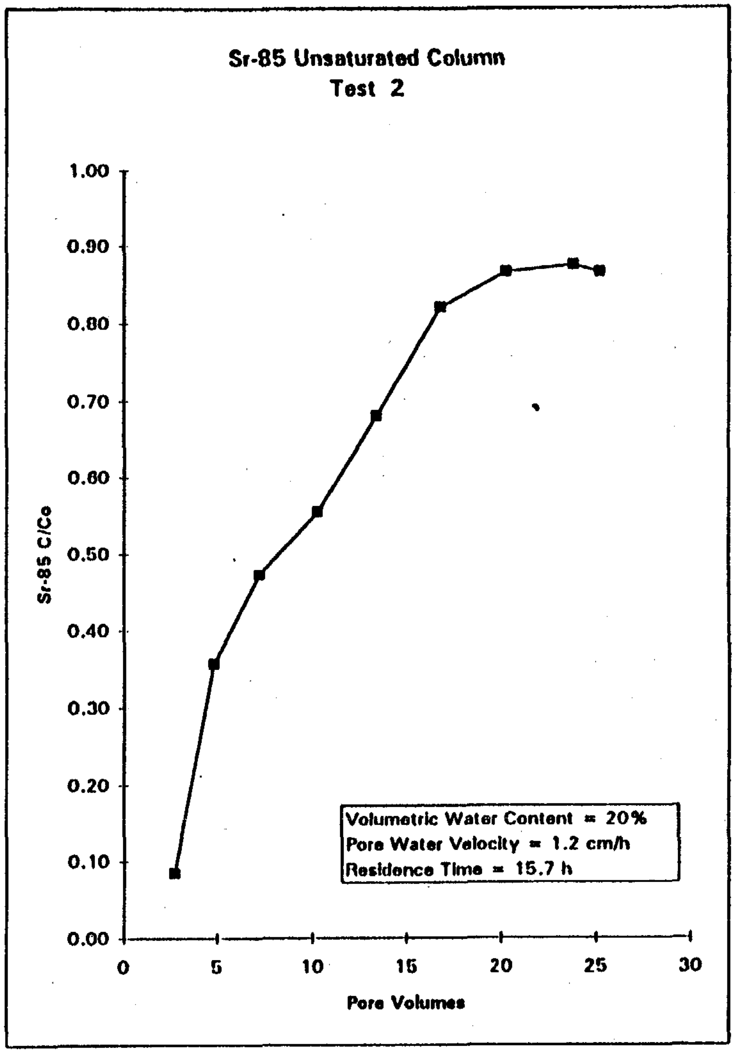

Figure 2.16. ^{85}Sr Unsaturated Column Test 2

3.0 UFA Contaminant Transport Test

A second method evaluated for creating partially saturated conditions used the UFA (Conca and Triay 1994). This instrument is able to create unsaturated conditions at steady state by regulating the combination of centripetal force applied to the sample holder (which in essence is a horizontal column) and the rate of flux of influent from an infusion pump.

3.1 Overview of Application

The operating principle behind the UFA is a derivation of Darcy's law which replaces the gravitational component with centrifugal force. This relationship can be expressed as:

$$J_w = -K(\psi_m)\ [\delta\psi/\delta r - \rho\omega^2 r] \qquad (12)$$

where:

J_w = the flux density into the sample
$K(\psi_m)$ = conductivity as a function of matric potential
r = the radius from the axis of rotation
ρ = fluid density
ω = rotational speed.

At speeds above about 400 rpm, provided that a sufficient flux density exists, $\delta\psi_m/\delta r <<< \rho\omega^2 r$ and the equation reduces to:

$$J_w = K(\psi_m)[\rho\omega^2 r]. \qquad (13)$$

As with the Wierenga columns, the key factor is creating a steady-state condition by which there is a uniform moisture content throughout the sample. Such conditions are usually determined by verifying the flux into the system is equal to the flux leaving the system, and the actual moisture content is determined gravimetrically as a function of position (e.g., thin slices of sediment) at the end of the test.

Using the same principle equations (Equations 6 and 9) as described in Section 2.1 where:

$$R_f = V_{gw}/V_{sp} = 1 + \rho R_d/\theta \qquad (14)$$

retardation factors again can be determined in flow through experiments by using the UFA.

3.2 UFA Description/Methodology

This instrument is essentially an ultra-centrifuge that allows fluid to be pumped into the system through a rotating seal on the rotor (Figure 3.1). As with the Wierenga columns, a non-pulsating, medical infusion pump is used to introduce the influent. Unlike the Wierenga columns, centripetal acceleration is used as the fluid driving force instead of gravity. Another important difference from the Wierenga columns is the ability to run duplicate tests. The UFA rotor's rotating seal is designed to

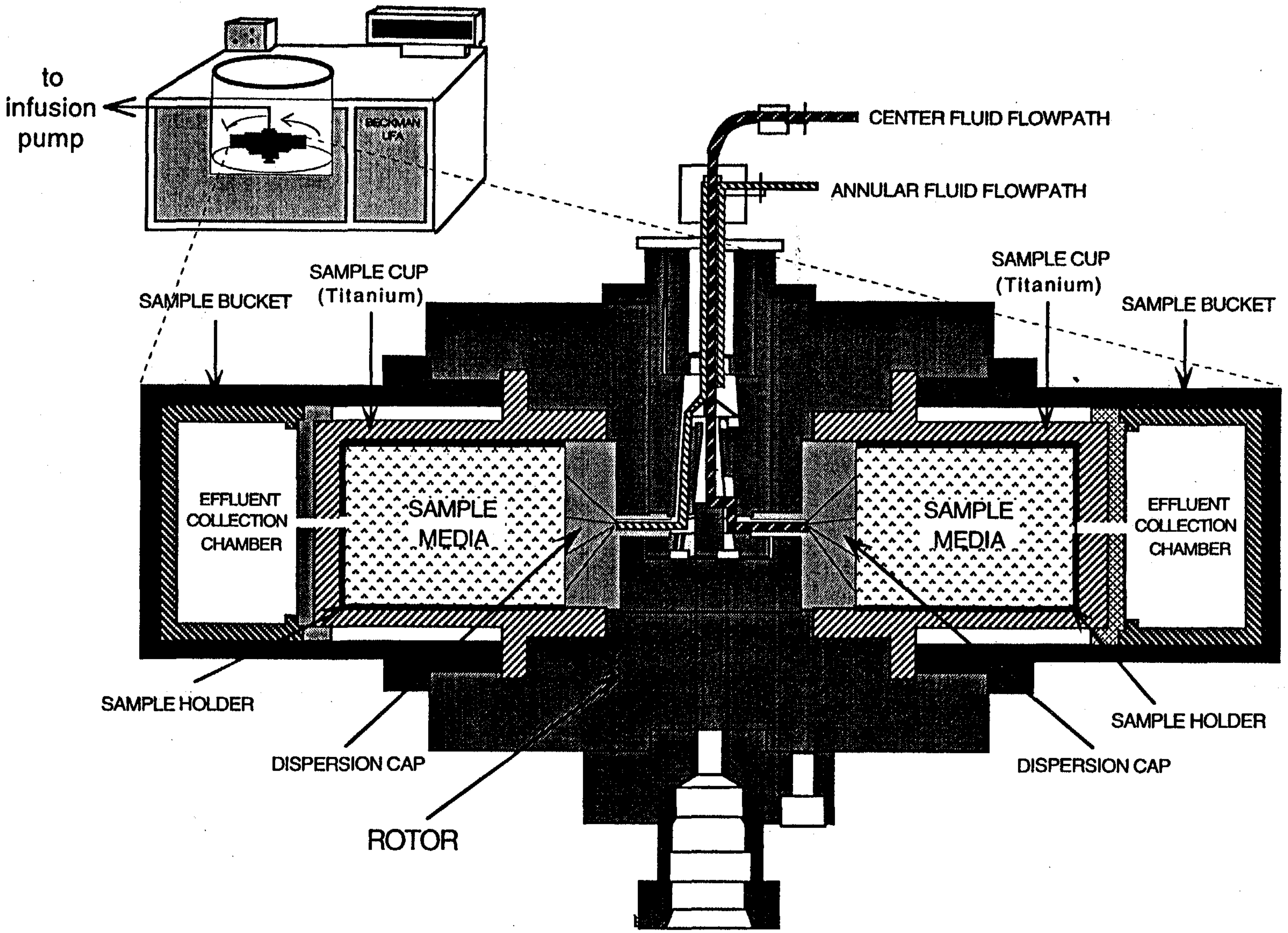

Figure 3.1. UFA Rotor Diagram

allow measured flow into two separate cells. These cells are distinguished by one receiving central flow which occurs as direct injection into the designated cell and the other receiving annular flow which is the secondary flow path running on the outside of the central injection tube. This secondary flow is directed to the appropriate port by a dispersion cone near the end of the central injection tube (Figure 3.1).

Creating an unsaturated condition at steady state in the UFA requires regulating the combination of centripetal force applied to the sample holders (which are in essence horizontal columns) and the rate of flux of influent from the infusion pump. Initially, it is helpful to determine the steady-state parameters for the target volumetric water content prior to the start of the test. Using a test sediment packed to a known bulk density, it is possible to perform simple hydraulic conductivity measurements at various unsaturated moisture conditions until the appropriate test parameters (rpm's and flow rates to achieve X% moisture content) have been identified. After the operating parameters have been determined, the test sediments can be replaced and the actual test is initiated. One major consideration while establishing the test parameters is to optimize the residence time of the influent with respect to the sorption kinetics of the contaminant in question. In essence, the primary goal for this methodology is to be able to complete the test in a reasonable amount of time in addition to ensuring enough contact time for a truly representative breakthrough curve to occur.

3.3 UFA ^{238}U Tests

In past UFA experiments reported in Volume 1 (Serne et al. 1993), initial retardation factors for Trench-8 soil with respect to cadmium, cobalt, chromium, cesium, iodine, molybdenum, neodymium, strontium, and uranium were determined using Hanford Site groundwater spiked with each element to approximately 25 ppb levels, at two levels of unsaturation: 30% volumetric water content (70% of saturation) and 10% volumetric water content (24% of saturation) using the UFA. Retardation factors for chromium, molybdenum, and iodine were near zero in the Trench 8 soil at both water contents, probably because they are present as the highly mobile species chromate, molybdate, and iodide, respectively. Retardation factors for cadmium, cobalt, cesium, and neodymium were >200, most likely because of strong surface sorption of their cationic species.

Only uranium in the initial UFA trials exhibited low retardation behavior and was amenable to study in reasonable time frames (days to a few weeks). Figures 3.2, 3.3, and Tables A.15, A.16 show breakthrough curves for uranium at two different water contents using Equation 14. In the test run at 30% volumetric water content, breakthrough occurred at 2.0 pore volumes whereas in the 10% test, breakthrough occurred at 2.3 pore volumes. Both these test were started with dry soil and run at exceptionally fast residence times (0.6 and 0.5 h, respectively). With these considerations and by comparison to the saturated uranium column test 2D (Figure 2.6) having a breakthrough at about 2 pore volumes with a residence time of 0.6 h, the overall early breakthrough results were most likely due to kinetics; that is equilibrium was not achieved.

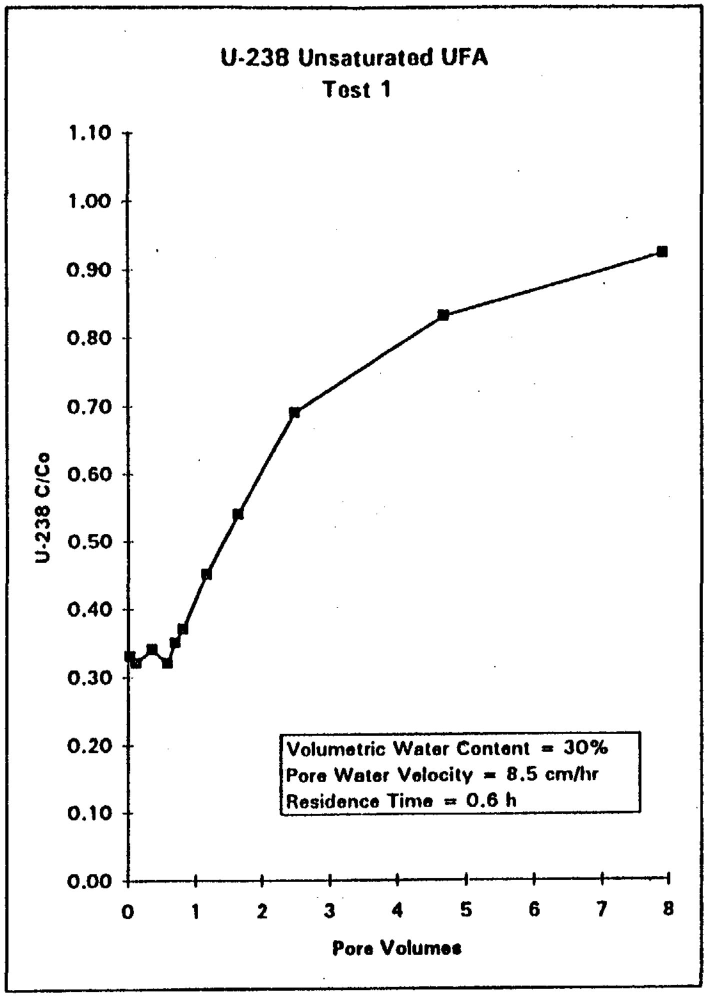

Figure 3.2. ^{238}U Unsaturated UFA Test 1

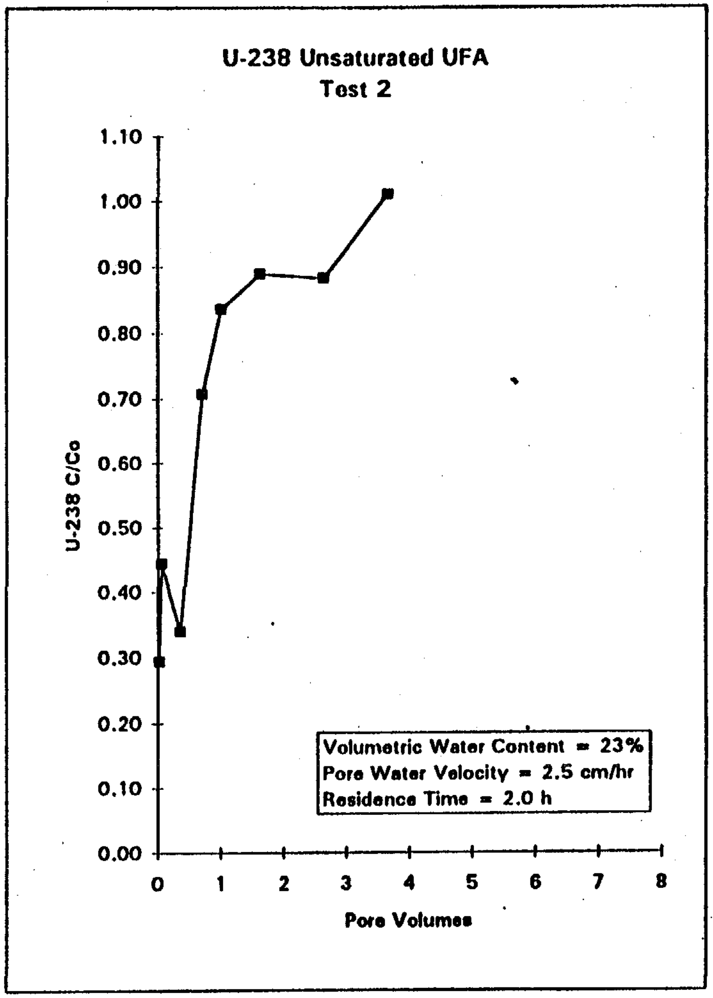

Figure 3.3. ^{238}U Unsaturated UFA Test 2

3.4 UFA ^{236}U Tests

As with the modified Wierenga tests, ^{236}U was selected as a reactant for two additional UFA tests. To reduce kinetic effects, pump flow rate and centrifuge speed were set to obtain the longest residence time possible while still allowing the simplification necessary for Equation (13) to be valid. For the two tests shown in Figures 3.4, 3.5, and Tables A.17, A.18, ^{236}U spiked groundwater at a concentration of 0.7 ppm was introduced into the system at a flux of 0.5 mL/h with a rotational speed of 1000 rpm resulting in a residence time between 20 and 21 h.

Breakthrough occurred at approximately 10.5 pore volumes for test A (annular injection to the sample holder) and just slightly less than 10 pore volumes for test C (center injection to the sample holder) which, for all practical purposes, would be considered reasonably good comparisons. It should be noted however, that a substantial amount of ^{236}U passed through test A within the initial pore volume then dropped almost to zero before increasing again. One explanation for this event could be that some leakage occurred due an initial O-ring misalignment outside of the inner sample cell sleeve and this leakage moved directly into the sample collection cup. Leakage bypass of the sample cell was later stopped once centripetal force reset the O-ring seal.

3.5 UFA Tritium Tests

Prior to the start of the unsaturated ^{85}Sr tests, a tritium tracer was used to ensure the operational integrity (e.g., proper O-ring alignment) of the UFA. As with all other ^{85}Sr tests, a 0.038 M solution of $CaCl_2$ was prepared, adjusted to a pH of 8.3, and then used to flush the two UFA cells for several pore volumes. Once a steady-state volumetric water content of 10% was achieved, a portion of the initial flush solution spiked with tritium was introduced into the system. Breakthrough curves for both cells are presented in Figures 3.6, 3.7, and Tables A.19, A.20. Results from these tests showed breakthrough at an R_f of slightly greater than 1 pore volume which indicated no preferential channeling or O-ring leakage in the system. At the completion of the tritium tests, the cells were allowed to continue to flush using unspiked $CaCl_2$ until no detectable tritium was present.

3.6 UFA ^{85}Sr Tests

Immediately following the tritium tests, two ^{85}Sr tests were initiated while the UFA was still operating at a 10% volumetric water content. Using the same 0.038 M $CaCl_2$ solution only now spiked with ^{85}Sr, the tests were initiated and allowed to run for 30 pore volumes. Results from these tests are presented in Figures 3.8, 3.9, and Tables A.21, A.22 and show R_f values of 13 and 14, respectively. Compared to R_d values of 1.4 to 1.8 mL/g from the saturated column tests, these latest UFA results yield R_d values of 0.7 to 0.8 under the unsaturated conditions used in these tests, which is a drop of 50% from the values based on the saturated column tests.

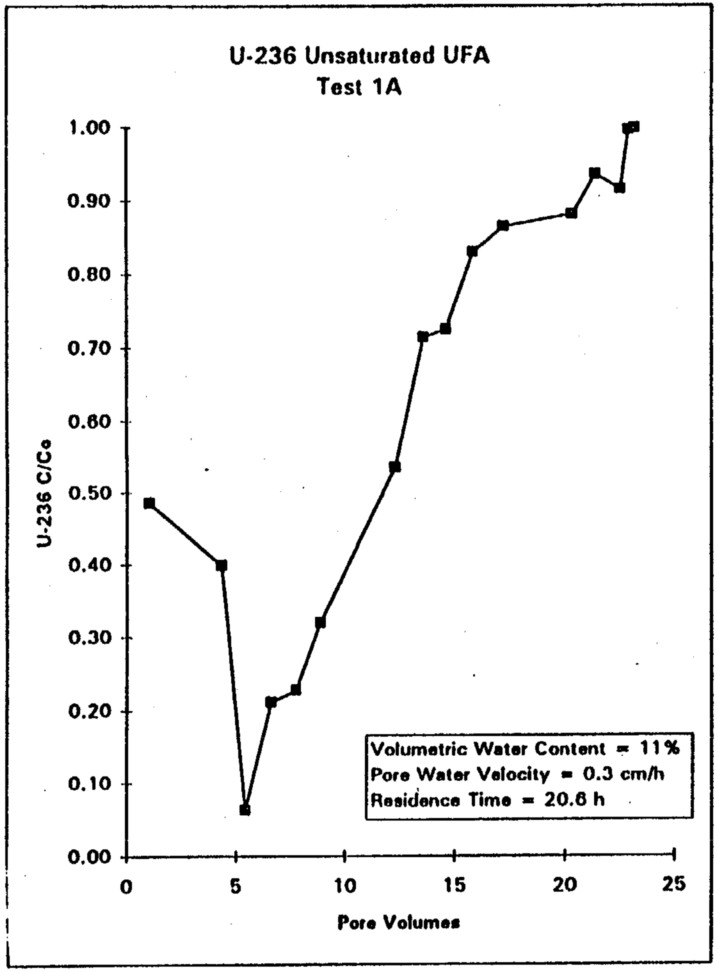

Figure 3.4. ^{236}U Unsaturated UFA Test 1A

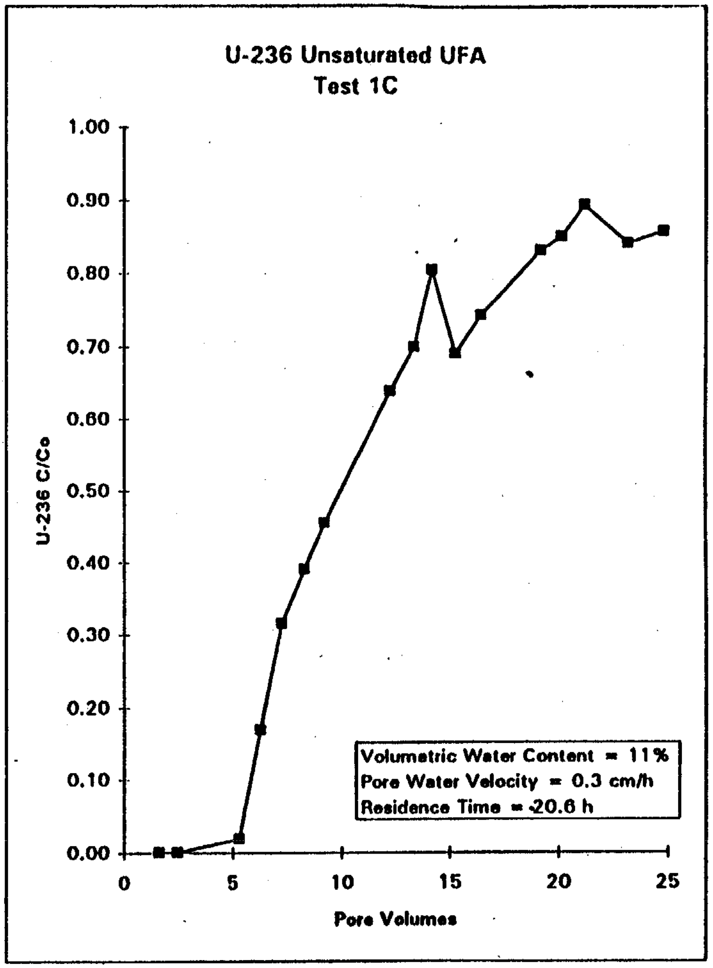

Figure 3.5. ^{236}U Unsaturated UFA Test 1C

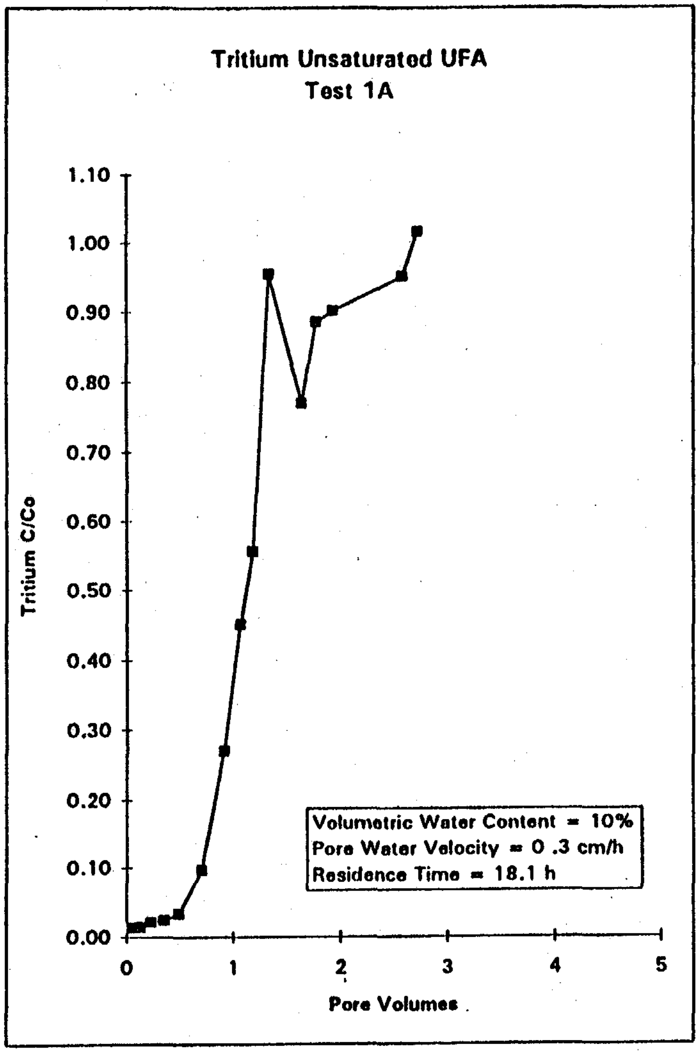

Figure 3.6. Tritium Unsaturated UFA Test 1A

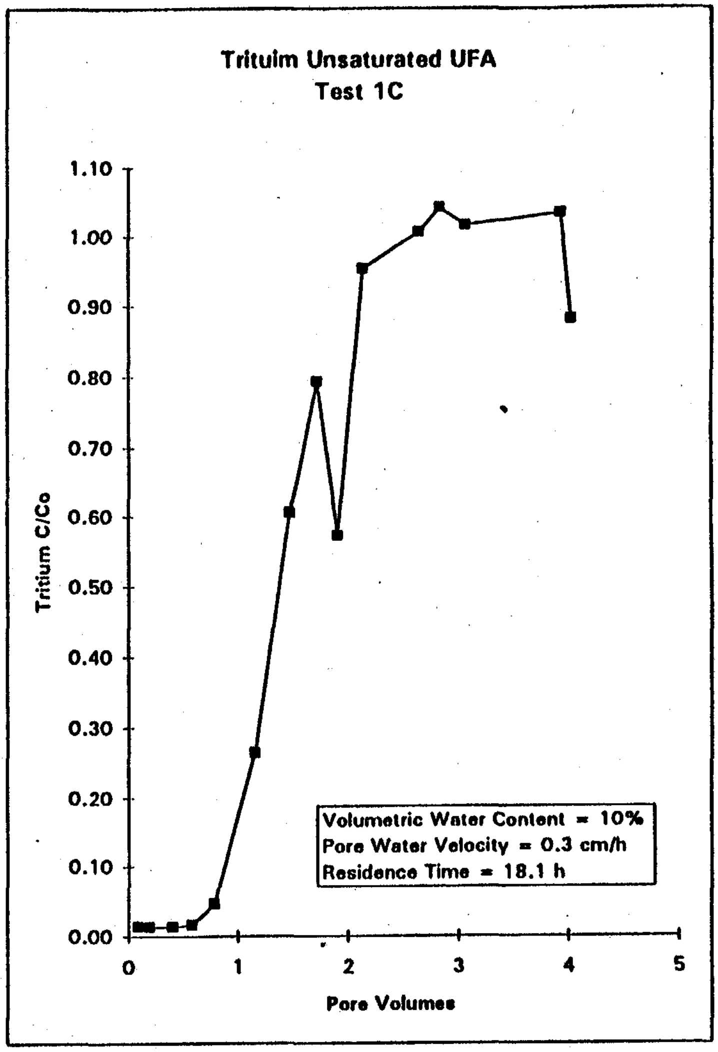

Figure 3.7. Tritium Unsaturated UFA Test 1C

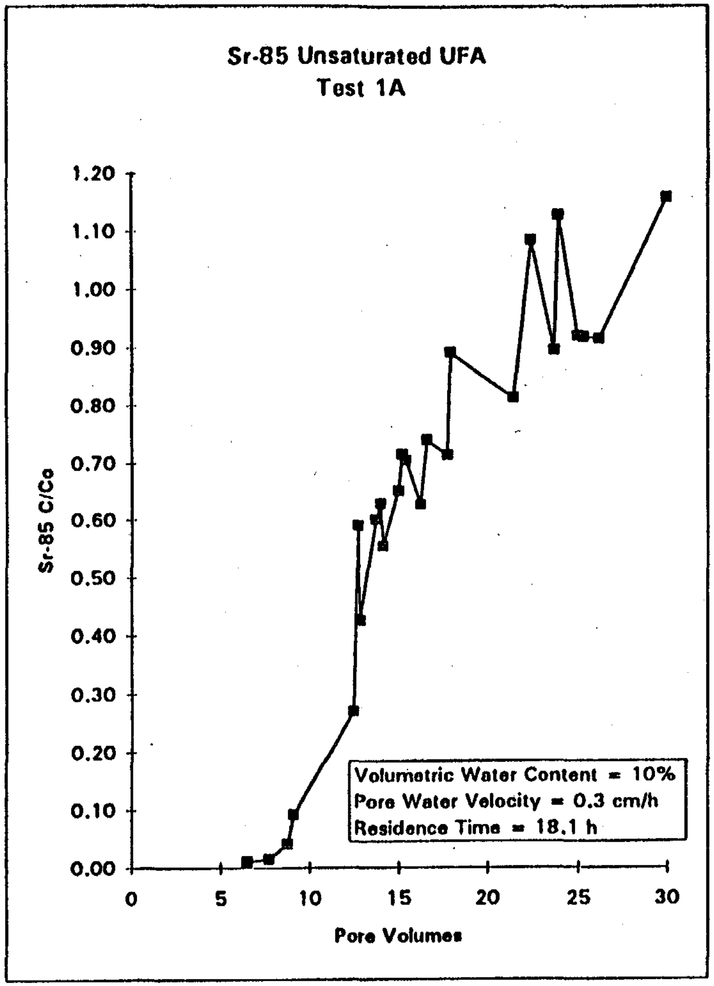

Figure 3.8. ^{85}Sr Unsaturated UFA Test 1A

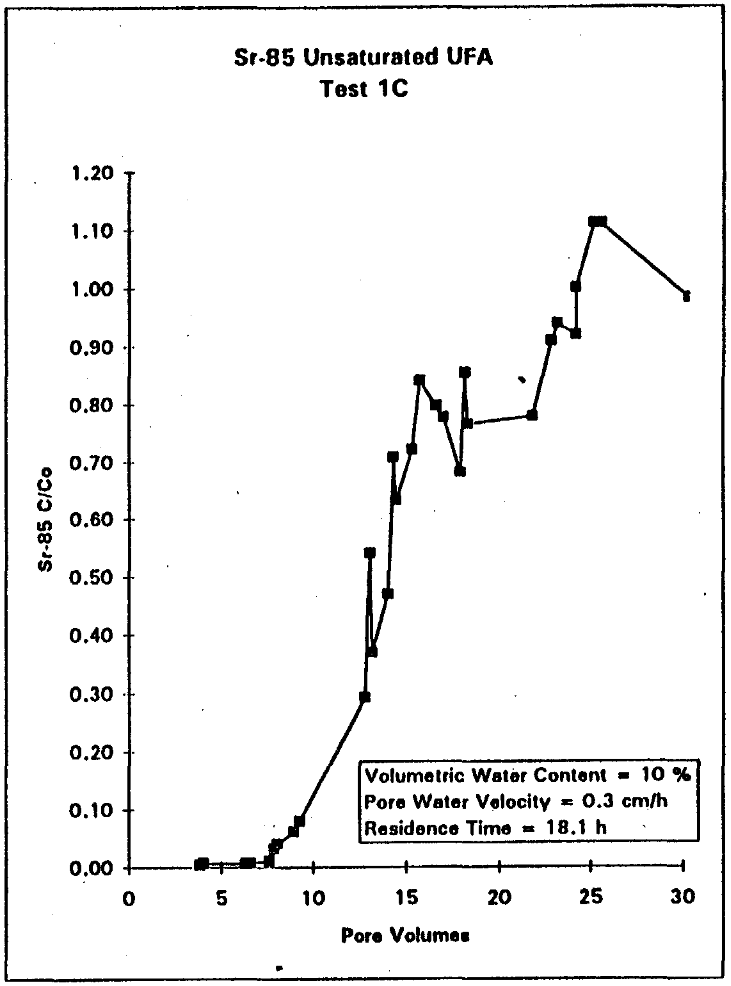

Figure 3.9. ^{85}Sr Unsaturated UFA Test 1C

4.0 Conclusion

The uranium breakthrough results are summarized in Table 4.1 for both ^{238}U and ^{236}U using either the modified Wierenga columns or the UFA systems. The results indicate that under increasingly unsaturated conditions, the R_d values appear to decrease. One possible explanation for this decrease may involve insufficient residence time in tests for the uranium to sorb onto the sediment. As a base line, Hanford Site groundwater and Trench 8 soil produced distribution coefficients for uranium under a batch test design of 1.9 ± 1.4 mL/g in 5 days of contact and a value of 2.4 ± 0.6 mL/g after 44 days of contact resulting in an average of 2.3 ± 1.2 mL/g (Serne et al. 1993). From the R_d values obtained with respect to residence time in the saturated uranium tests, the tests run at residence times of 12.3 and 5.9 h appear to support the batch test results with R_d values of 2.0 and 2.7 mL/g, respectively. The saturated uranium column test with a residence time of 0.6 h however, showed a substantially lower R_d of 0.5 suggesting that uranium sorption kinetics within the test design require a minimum residence time somewhere above 1 h and less than 6 h to give results consistent with batch tests. Consequently, Figure 4.1 which is derived from the volumetric water content (represented as percent saturation) and R_d data from Table 4.1 uses a 5.9 h residence time cut-off for plotting R_d versus percent saturation relationships. The percent volumetric water content values for Figure 4.1 were normalized to percent saturation by equating the calculated porosity to be 100% in terms of total possible saturation. Using the experimental volumetric water content divided by the total possible saturated volumetric water content, the percent saturation was determined.

Further analysis of the data from Table 4.1 indicates a higher degree of precision in R_d values obtained from the UFA tests (0.6 and 0.6 mL/g) and modified Wierenga columns (1.1 and 1.1 mL/g) than that of the standard Teflon column saturated tests (2.0 and 2.7 mL/g).

The same analysis of the strontium data in Table 4.2, also shows a trend for lower R_d values as water content decreases. This trend, however, is much less pronounced as shown in Figure 4.2. Under test conditions, it was assumed that an 18 h residence time was reasonably sufficient and thus, all of the tests were included in the generation of Figure 4.2. As with the uranium tests, it was apparent that a slightly higher degree of variability in calculated R_d values was encountered among our saturated and unsaturated column tests (1.4-1.8 mL/g and 1.0-2.0 mL/g, respectively) as compared to unsaturated UFA tests (0.7-0.8 mL/g).

In comparing both strontium and uranium breakthrough data, there appears reasonable evidence to suggest that soil moisture content may influence the distribution coefficient as calculated using the rather simplistic equation of $R_f = 1+((\rho b/\theta)*R_d)$. As data indicate, the R_d value becomes lower as a saturated system moves to a less saturated system. This phenomena is contrary to what would be expected in that breakthrough occurred much sooner than what has been hypothesized by others (Bouwer 1991; Jardine et al. 1993a,b). One of the most obvious explanations for our results could involve preferential flow through both the modified Wierenga and UFA systems. If such conditions were present, we would have expected early breakthrough when using our tritium tracers which was not observed. Another possible explanation could involve early breakthrough because of insufficient

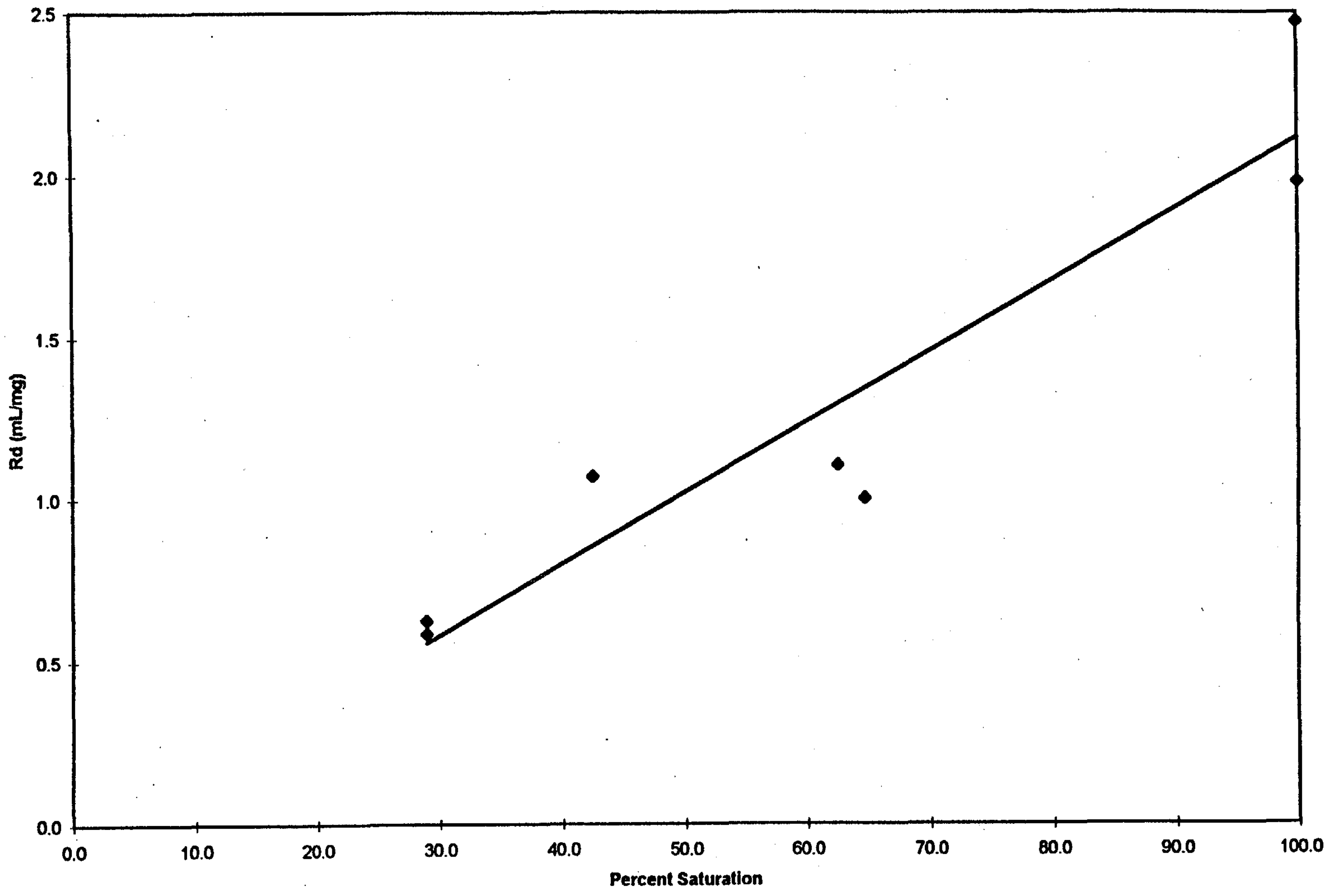

Figure 4.1. Uranium Versus Percent Volumetric Saturation

Table 4.1. Summation of R_f and R_d Values for Uranium

Test	Residence Time (h)	Pore Water Velocity (cm/h)	Volumetric Water Content	Saturated	R_f	R_d
^{238}U Sat-Col 1	12.4	1.0	40%	100%	9.0	2.0
^{238}U Sat-Col 2D(a)	0.6	19.7	40%	100%	1.9	0.5
^{238}U Sat-Col 3D	5.9	2.1	38%	100%	11.9	2.7
^{238}U Unsat-Col 1	32.4	0.2	22%	65%	9.0	1.0
^{238}U Unsat-UFA 1(a)	0.5	8.4	30%	70%	2.5	0.5
^{238}U Unsat-UFA 2(a)	0.6	10.0	10%	24%	2.5	0.2
^{236}U Unsat-Col 1	77.0	0.3	25%	63%	8.1	1.1
^{236}U Unsat-Col 2	31.5	0.4	17%	43%	11.2	1.1
^{236}U Unsat UFA 1A	20.6	0.3	11%	29%	10.5	0.6
^{236}U Unsat UFA 1C	20.6	0.3	11%	29%	9.9	0.6

(a) Indicates tests not used to generate Figure 4.1.

residence time for either the uranium or strontium. This explanation, however, would be inconsistent with the residence time data reported in Tables 4.1 and 4.2 from which the saturated tests generally had shorter residence times than our unsaturated tests. A third possibility may simply be that there is really no effect and that bias and/or variability among breakthrough curves are observed because of an insufficient amount of data or an unexamined artifact. A more speculative explanation for the earlier breakthrough curves under increasingly unsaturated conditions would suggest that as sediments become more unsaturated, less sediment sites are available for sorption. This assumption may support a gradient model such that under increasingly unsaturated conditions, flow becomes increasingly

Table 4.2. Summation of R_f and R_d Values for ^{85}Sr

Test	Residence Time (h)	Pore Water Velocity (cm/h)	Volumetric Water Content	Saturated	R_f	R_d
^{85}Sr Sat-Col 1	28.8	0.4	37%	100%	9.1	1.8
^{85}Sr Sat-Col 1	23.8	0.5	37%	100%	6.9	1.4
^{85}Sr Unsat-Col 1	23.5	0.8	31%	72%	10.8	2.0
^{85}Sr Unsat-Col 2	15.7	1.2	20%	47%	8.3	1.0
^{85}Sr Unsat-UFA 1A	18.0	0.3	10%	26%	13.2	0.7
^{85}Sr Unsat-UFA 1B	18.0	0.3	10%	26%	14.1	0.8

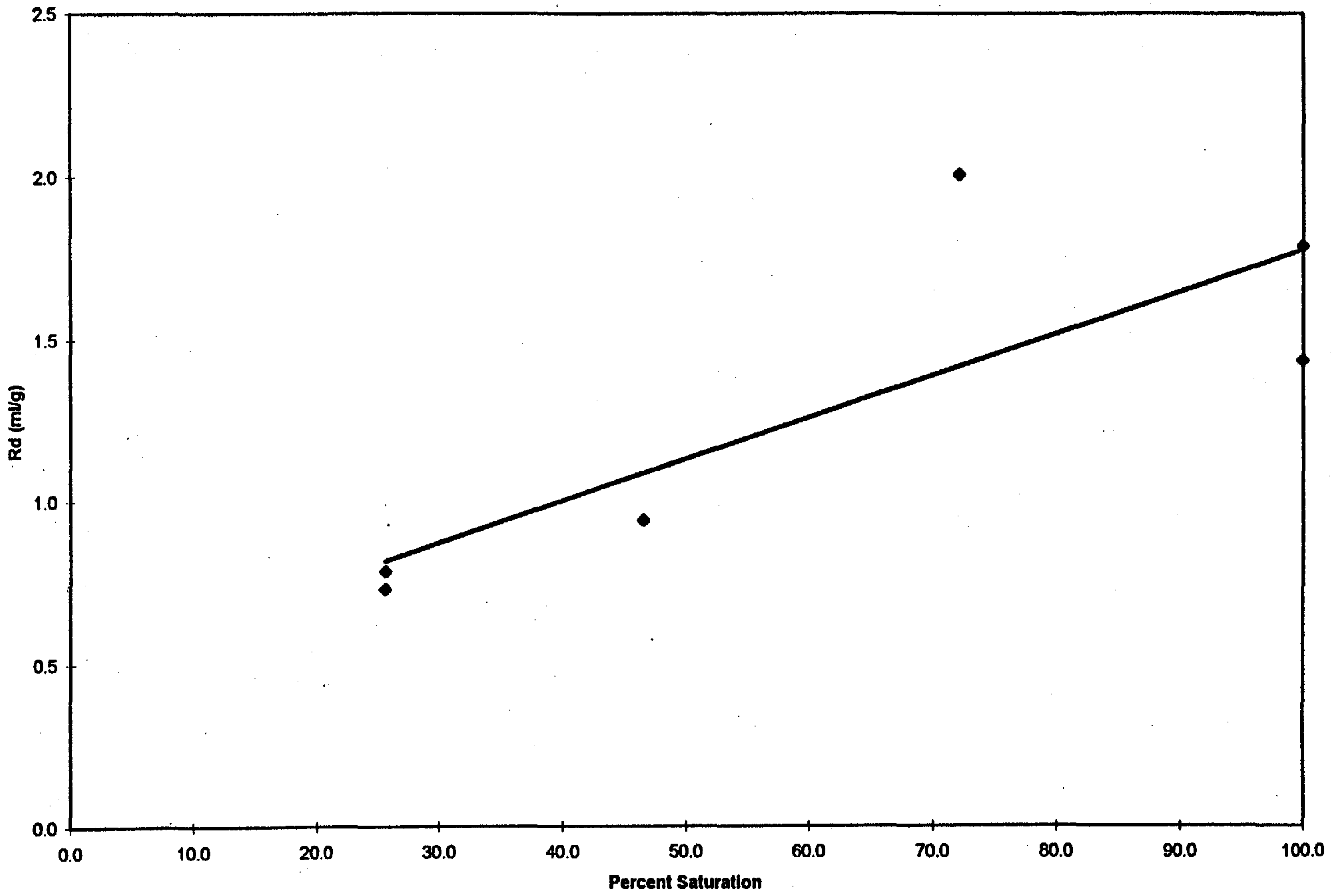

Figure 4.2. Strontium Versus Percent Volumetric Saturation

restricted to the meso and, finally, micro pores. Though simple diffusion through the assumed near surface film of water around all particles should allow for total surface contact over all sediment grains, solution and solutes may in fact be excluded from reaching micro fissures and point contacts within and among the grains.

With respect to the PA activities associated with the W-5 Burial Ground, the overall results do not appear to have any significant impact when considering distribution coefficients for various contaminants grouped into categories having R_d values of 0, 1, 10, 100, and ≥ 1000 mL/g. In the current PA calculations for the W-5 Burial Ground, the R_d input parameter for uranium is zero. This value appears conservative given that under the most rapid flow rates studied for either saturated or unsaturated conditions, R_d values were noted of 0.5 mL/g and 0.1 mL/g, respectively.

The effects of unsaturated moisture content on the adsorption of strontium in groundwater contacting Trench 8 sediment, which has had a reported value of R_d 22.97 ± 2.69 mL/g, no significant effect on PA calculations would be expected. That is, strontium will remain in the $R_d = 10$ category at all moisture contents that were studied. The R_d as a function of moisture content results however, do suggest that current efforts in understanding contaminant transport under unsaturated conditions is not yet complete and further research in this area should be continued.

5.0 References

Bouwer, H. 1991. "Simple Derivation of the Retardation Equation and Application to Preferential Flow and Macrodispersion." *Ground Water* 29:41-46.

Conca, J. L., and J. L. Triay. 1994. "Selenite Transport in Unsaturated Tuff from Yucca Mountain." In *Sixth International High Level Radioactive Waste Management Conference*, Las Vegas, Nevada.

Jardine, P. M., G. K. Jacobs, and J. D. O'Dell. 1993a. "Unsaturated Transport Processes in Undisturbed Heterogeneous Porous Media: II. Co-Contaminants." *Soil Sci. Soc. Am. J.* 57:954-962.

Jardine, P. M., G. K. Jacobs, and G. V. Wilson. 1993b. "Unsaturated Transport Processes in Undisturbed Heterogeneous Porous Media: I. Inorganic Contaminants." *Soil Sci. Soc. Am. J.* 57:945-953.

Relyea, J. F., R. J. Serne, and D. Rai. 1980. *Methods for Determining Radionuclide Retardation Factors: Status Report*. PNL-3349, Pacific Northwest Laboratory, Richland, Washington.

Relyea, J. F. 1982. "Theoretical and Experimental Considerations for the Use of the Column Method for Determining Retardation Factors." *Radioactive Waste Management* 3(2):115-130.

Serne, R. J., J. L. Conca, V. L. LeGore, K. J. Cantrell, C. W. Lindenmeier, J. A. Campbell, J. E. Amonette, and M. I. Wood. 1993. *Solid-Waste Leach Characteristics and Contaminant-Sediment Interactions Volume 1: Batch Leach and Adsorption Tests and Sediment Characterization*, PNL-8889. Pacific Northwest Laboratory, Richland, Washington.

Serne, R. J., and M. I. Wood. 1990. *Hanford Waste-Form Release and Sediment Interaction: A Status Report with Rationale and Recommendations for Additional Studies*. PNL-7927, Pacific Northwest Laboratory, Richland, Washington.

Wierenga, P. J., M. T. Van Genuchten. 1989. "Solute Transport Through Small and Large Unsaturated Soil Columns." *Ground Water* 27:35-42.

Wierenga, P. J., L. W. Gelhar, C. S. Simmons, G. W. Gee, and T. J. Nicholson. 1986. *Validation of Stochastic Flow and Transport Models for Unsaturated Soils: A Comprehensive Field Study*. PNL-5875, Pacific Northwest Laboratory, Richland, Washington.

Appendix A

U-238 Saturated Column Test 1

U-238 Saturated Column		Column Volume (ml)	154.5
Test 1		Bulk Density (g/cm3)	1.64
Record Book 51472	page 123	Porosity	0.40
Starting Date	6/29/92	Sat. Pore Vol. (ml)	61.80
Ending Date	8/3/92	Soil Wet Wt. (g)	312.20
Influent = Uranium 238		Soil Dry Wt. (g)	253.4
Soil = Trench 8		Moisture Content (%)	23.20
Length (cm)	12.3	Volumetric Water Content (%)	38.06
Diameter (cm)	4	Unsat. Pore Volume (ml)	61.80
Influent Velocity (ml/h)	5	% of Saturation	100.00
Pore Water Velocity (cm/h)	1.00	Initial Concentration (ppb)	37.3
Residence Time (h)	12.27		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Total U-238 (ppb)	U-238 C/Co (ppb)
Co				37.30	0.14
SA-1	27.25	27.17	0	4.85	0.13
SA-10	26.75	271.70	4	13.20	0.35
SA-20	25.29	543.39	9	18.60	0.50
SA-30	26.81	815.09	13	22.30	0.60
SB-1	27.11	1059.61	17	24.70	0.66
SB-10	26.91	1331.31	21	27.30	0.73
SB-20	26.76	1603.00	26	28.30	0.76
SB-30	27.20	1874.70	30	30.40	0.82
SC-10	27.60	2146.39	34	31.30	0.84
SC-20	27.42	2418.09	39	32.00	0.86
SC-30	27.63	2689.78	43	33.70	0.90
SD-10	26.54	2961.48	47	33.80	0.91
SD-20	27.49	3233.17	52	33.20	0.89
SD-30	27.00	3504.87	56	32.80	0.88
SE-10	26.62	3776.56	61	36.70	0.98

Tritium Unsaturated Column Test 1

Tritium Unsaturated Column		Column Volume (ml)	589
Test 1		Bulk Density (g/cm3)	1.76
Record Book 51472	page 91	Porosity	0.35
Starting Date	11/25/91	Sat. Pore Vol. (ml)	207.38
Ending Date	11/27/91	Soil Wet Wt. (g)	1161.03
Influent = Hanford Ground Water		Soil Dry Wt. (g)	1038.01
spiked with H-3		Moisture Content (%)	11.85
Soil = Trench 8		Volumetric Water Content (%)	20.89
Length (cm)	30	Unsat. Pore Volume (ml)	123.02
Diameter (cm)	5	% of Saturation	59.32
Influent Velocity (ml/h)	4	Initial Concentration (counts)	209310
Pore Water Velocity (cm/h)	0.98		
Residence Time (h)	30.76		

Sample ID	Effluent Volume (ml)	Tritium CPM/ml Dil = 10X	Total Effluent (ml)	Pore Volumes (unsat)	C/Co o = 209310 CPM/ml
5	4.16	495	4	0.03	0.00
6	4.01	560	8	0.07	0.00
7	4.00	430	12	0.10	0.00
8	4.00	480	16	0.13	0.00
9	4.02	440	20	0.16	0.00
10	4.02	370	24	0.20	0.00
11	4.03	400	28	0.23	0.00
12	4.03	385	32	0.26	0.00
13	3.91	375	36	0.29	0.00
14	3.87	345	40	0.32	0.00
15	3.78	345	44	0.35	0.00
16	4.04	380	48	0.39	0.00
17	4.05	380	52	0.42	0.00
18	3.87	300	56	0.45	0.00
19	3.82	460	60	0.48	0.00
20	4.06	370	64	0.51	0.00
21	4.06	610	68	0.55	0.00
22	3.99	1655	72	0.58	0.01
23	3.80	3565	76	0.61	0.02
24	4.00	6935	80	0.64	0.03
25	4.09	12535	84	0.68	0.06
26	4.03	19100	88	0.71	0.09
27	3.85	27905	91	0.74	0.13
28	3.92	35565	95	0.77	0.17
29	4.11	44430	100	0.80	0.21
30	4.10	54005	104	0.84	0.26
31	4.04	62163	108	0.87	0.30
32	3.85	70902	112	0.90	0.34
33	4.13	88988	116	0.93	0.43
34	3.90	80581	120	0.97	0.38
35	4.13	94587	124	1.00	0.45
36	4.06	103625	128	1.03	0.50
37	3.86	110679	132	1.06	0.53
38	3.82	116661	135	1.09	0.56
39	4.16	126455	140	1.13	0.60
40	4.15	129143	144	1.16	0.62
41	4.06	135818	148	1.19	0.65
42	3.84	142365	152	1.23	0.68
43	3.85	149105	155	1.26	0.71
44	4.18	151934	160	1.29	0.73

U-238 Unsaturated Column		Column Volume (ml)	589
Test 1		Bulk Density (g/cm3)	1.76
Record Book 51472	page 91	Porosity	0.35
Starting Date	11/27/91	Sat. Pore Vol. (ml)	207.38
Ending Date	2/18/92	Soil Wet Wt. (g)	1167.43
Influent = Hanford Ground Water		Soil Dry Wt. (g)	1038.01
spiked with U-238		Moisture Content (%)	12.47
Soil = Trench 8		Volumetric Water Content (%)	21.97
Length (cm)	30	Unsat. Pore Volume (ml)	129.42
Diameter (cm)	5	% of Saturation	62.41
Influent Velocity (ml/h)	4	Initial Concentration (ppb)	39.7
Pore Water Velocity (cm/h)	0.93		
Residence Time (h)	32.36		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Pore Volume (sat)	Total U-238 (ppb)	U-238 C/Co (ppb)
Co					39.7	
1	10.75	10.75	0.08	0.05	4.49	0.11
10	10.91	105.81	0.17	0.53	4.94	0.12
20	11.03	223.37	0.25	1.12	5.41	0.14
30	11.31	340.93	0.34	1.70	6.88	0.17
40	11.23	458.49	0.43	2.29	8.24	0.21
50	11.69	576.06	0.52	2.88	10.80	0.27
60	11.88	693.62	0.61	3.47	13.70	0.35
70	12.21	811.18	0.70	4.06	17.20	0.43
80	12.19	928.75	0.80	4.64	17.90	0.45
90	12.58	1046.31	0.89	5.23	19.00	0.48
100	13.54	1163.87	1.00	5.82	19.00	0.48

U-238 Saturated Column Test 2D

U-238 Saturated Column		Column Volume (ml)	154.5
Test 2D		Bulk Density (g/cm3)	1.62
Record Book 53751	page 6	Porosity	0.40
Starting Date	3/25/93	Sat. Pore Vol. (ml)	61.80
Ending Date	3/28/93	Soil Wet Wt. (g)	312.78
Influent = U-238		Soil Dry Wt.(g)	250.98
Soil = Trench 8		Moisture Content (%)	24.62
Length (cm)	12.3	Volumetric Water Content (%)	40.00
Diameter (cm)	4	Unsat. Pore Volume (ml)	61.80
Influent Velocity (ml/h)	99.9	% of Saturation	100.00
Pore Water Velocity (cm/h)	19.74	Initial Concentration (ppb)	34.9
Residence Time (h)	0.62		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Total U-238 (ppb)	U-238 C/Co (ppb)
S1-2	28.89	57.53	0.93	12.4	0.3553
S1-4	28.87	115.22	1.86	17.5	0.5014
S1-6	28.92	173.07	2.80	20.5	0.5874
S1-8	29.00	231.02	3.27	22.5	0.6447
S1-10	29.04	289.01	4.68	23.4	0.6705
S1-12	29.08	347.16	5.62	23.2	0.6648
S1-14	29.07	405.29	6.56	24.4	0.6991
S1-16	29.15	463.55	7.50	24.9	0.7135
S1-18	29.14	521.80	8.44	24.9	0.7135
S1-20	29.16	580.11	9.39	25.7	0.7364
S1-22	29.03	638.19	10.33	25.5	0.7307
S1-24	29.13	696.44	11.27	26	0.7450
S1-26	29.15	754.71	12.21	26.6	0.7622
S1-28	29.12	813.00	13.16	25.7	0.7364
S1-30	29.17	871.31	14.10	27.8	0.7966
S1-32	28.93	929.08	15.50	27.6	0.7908
S1-34	29.01	987.03	15.97	27.7	0.7937
S1-36	28.96	1045.02	16.91	28.1	0.8052
S1-38	29.05	1103.08	17.85	27.8	0.7966
S1-40	29.04	1161.14	18.79	29.6	0.8481
S1-42	29.10	1219.33	19.73	28.5	0.8166
S1-44	29.11	1277.56	20.67	29.4	0.8424
S1-46	29.16	1335.84	21.62	29.4	0.8424
S1-48	29.15	1394.17	22.56	29.2	0.8367
S1-50	29.21	1452.59	23.50	29.7	0.8510

U-238 Saturated Column		Column Volume (ml)	154.5
Test 3D		Bulk Density (g/cm3)	1.68
Record Book 53751	page 8	Porosity	0.38
Starting Date	4/6/93	Sat. Pore Vol. (ml)	58.71
Ending Date	4/10/93	Soil Wet Wt. (g)	318.25
Influent = U-238		Soil Dry Wt. (g)	259.54
Soil = Trench 8		Moisture Content (%)	22.62
Length (cm)	12.3	Volumetric Water Content (%)	38.00
Diameter (cm)	4	Unsat. Pore Volume (ml)	58.71
Influent Velocity (ml/h)	10	% of Saturation	100.00
Pore Water Velocity (cm/h)	2.08	Initial Concentration (ppb)	34.9
Residence Time (h)	5.91		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Total U-238 (ppb)	U-238 C/Co (ppb)
S2-1	33.25	33.25	0.57	7.98	0.2287
S2-2	22.96	56.21	0.96	6.31	0.1808
S2-3	28.33	84.54	1.44	5.47	0.1567
S2-4	28.60	113.14	1.93	4.7	0.1347
S2-5	28.73	141.87	2.42	4.65	0.1332
S2-6	28.92	170.78	2.91	4.23	0.1212
S2-8	28.38	228.19	3.89	4.65	0.1332
S2-10	28.68	285.28	4.86	4.69	0.1344
S2-12	28.87	342.84	5.84	5.88	0.1685
S2-14	29.01	400.75	6.83	7.26	0.2080
S2-16	29.16	459.01	7.82	9.01	0.2582
S2-18	28.63	516.07	8.79	10.1	0.2894
S2-20	28.70	573.37	9.77	13.2	0.3782
S2-22	29.01	631.27	10.75	15	0.4298
S2-24	29.13	689.57	11.75	16.9	0.4842
S2-26	23.57	736.16	12.54	19.9	0.5702
S2-28	23.91	783.83	13.35	22.4	0.6418
S2-30	18.02	825.41	14.06	26.1	0.7479

U-238 Saturated Column Test 4D

U-238 Saturated Column		Column Volume (ml)	154.5
Test 4D		Bulk Density (g/cm3)	1.65
Record Book 53751	page 23	Porosity	0.39
Starting Date	4/16/93	Sat. Pore Vol. (ml)	60.26
Ending Date	5/20/93	Soil Wet Wt. (g)	315.59
Influent = U-238		Soil Dry Wt. (g)	255.33
Soil = Trench 8		Moisture Content (%)	23.60
Length (cm)	12.3	Volumetric Water Content (%)	39.00
Diameter (cm)	4	Unsat. Pore Volume (ml)	60.26
Influent Velocity (ml/h)	1.3	% of Saturation	100.00
Pore Water Velocity (cm/hr)	0.20	Initial Concentration (ppb)	30.2
Residence Time (hr)	60.65		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Total U-238 (ppb)	U-238 C/Co (ppb)
S3-2	29.53	61.79	1.03	17.1	0.5662
S3-4	54.94	147.73	2.45	14	0.4636
S3-6	31.79	164.84	2.74	14.9	0.4934
S3-8	31.04	226.53	3.76	14.6	0.4834
S3-10	25.44	282.90	4.69	15.6	0.5166
S3-12	27.55	337.13	5.59	13.8	0.4570
S3-14	26.28	391.20	6.49	16	0.5298
S3-16	27.03	445.72	7.40	16.1	0.5331
S3-18	26.37	499.60	8.29	15.9	0.5265
S3-20	28.15	555.20	9.21	14.2	0.4702
S3-22	27.56	610.03	10.12	15.4	0.5099
S3-24	28.47	666.13	11.05	13.7	0.4536
S3-26	28.37	722.79	11.99	15.3	0.5066
S3-28	28.39	779.66	12.94	13.9	0.4603
S3-30	27.59	835.42	13.86	15	0.4967
S3-32	28.04	891.43	14.79	14.2	0.4702
S3-34	26.44	943.25	15.65	15.2	0.5033
S3-36	27.54	997.79	16.56	15.1	0.5000
S3-38	25.50	1051.36	17.45	20.7	0.6854
S3-40	26.91	1104.68	18.33	18.2	0.6026
S3-42	26.36	1158.48	19.22	17.9	0.5927
S3-44	27.27	1212.48	20.12	16.6	0.5497
S3-46	25.66	1265.95	21.01	17.1	0.5662
S3-48	27.18	1319.60	21.90	16.3	0.5397
S3-50	27.61	1374.51	22.81	15.9	0.5265

U-238 HGW Dissolution Column Test 1

U-238 HGW Dissolution Column		Column Volume (ml)	154.5
Test 1		Bulk Density (g/cm3)	1.74
Record Book 53751	page 27	Porosity	0.36
Starting Date	3/1/94	Sat. Pore Vol. (ml)	55.68
Ending Date	4/3/94	Soil Wet Wt. (g)	324.48
Influent = Hanford Groundwater		Soil Dry Wt. (g)	268.8
Soil = Trench 8		Moisture Content (%)	20.71
Length (cm)	12.3	Volumetric Water Content (%)	36.04
Diameter (cm)	4	Unsat. Pore Volume (ml)	55.68
Influent Velocity (ml/h)	1	% of Saturation	100.00
Pore Water Velocity (cm/h)	0.22	Initial Concentration (ppb)	5.259
ResidenceTime (h)	55.70		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Total U-238 (ppb)	U-238 C/Co (ppb)
A-2	23.51	42.22	0.76	11.924	2.2674
A-4	24.93	91.77	1.65	10.372	1.9722
A-6	25.29	142.85	2.57	8.657	1.6461
A-8	24.52	190.93	3.43	7.998	1.5208
A-10	25.59	242.10	4.35	7.12	1.3539
A-12	25.50	292.24	5.25	6.993	1.3297
A-14	24.19	340.15	6.11	7.071	1.3446
A-16	25.36	390.66	7.02	6.391	1.2153
A-18	24.45	440.73	7.92	6.339	1.2054
A-20	30.67	496.73	8.92	6.363	1.2099
A-22	22.24	543.33	9.76	7.19	1.3672
A-24	25.35	592.85	10.65	6.544	1.2443
A-26	24.96	641.67	11.52	6.655	1.2654
A-28	25.27	691.06	12.41	6.721	1.278
A-30	23.26	736.74	13.23	7.114	1.3527
A-32	24.93	785.99	14.12	6.463	1.2289

U-238 Di-H2O Dissolution Column		Column Volume (ml)	154.5
Test 1		Bulk Density (g/cm3)	1.75
Record Book 53751	page 28	Porosity	0.36
Starting Date	2/18/94	Sat. Pore Vol. (ml)	55.32
Ending Date	3/25/94	Soil Wet Wt. (g)	325.08
Influent = DiH2O pH adjusted to 8.3		Soil Dry Wt. (g)	269.76
Soil = Trench 8		Moisture Content (%)	20.51
Length (cm)	12.3	Volumetric Water Content (%)	35.81
Diameter (cm)	4	Unsat. Pore Volume (ml)	55.32
Influent Velocity (ml/h)	1	% of Saturation	100.00
Pore Water Velocity (cm/h)	0.22	Initial Concentration (ppb)	0
Residence Time (h)	55.35		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	U-238 (ppb)
B-2	20.95	37.35	0.68	3.32
B-4	21.89	78.11	1.41	2.98
B-6	23.34	124.30	2.25	1.886
B-8	22.91	175.21	3.17	1.4
B-10	31.74	229.98	4.16	1.076
B-12	21.92	275.22	4.97	0.871
B-14	23.83	322.05	5.82	0.604
B-16	23.75	367.77	6.65	0.572
B-18	22.08	410.08	7.41	0.498
B-20	23.75	456.49	8.25	0.331

U-236 Unsaturated Column Test 1

U-236 Unsaturated Column		Column Volume (ml)		154.5
Test 1		Bulk Density (g/cm3)		1.62
Record Book 53751	page 42	Porosity		0.40
Starting Date	7/15/94	Sat. Pore Vol. (ml)		62.28
Ending Date	8/18/94	Soil Wet Wt. (g)		289.36
Influent = Hanford Groundwater		Soil Dry Wt. (g)		250.84
spiked with U-236		Moisture Content (%)		15.36
Soil = Trench 8		Volumetric Water Content (%)		24.93
Length (cm)	19.2	Unsat. Pore Volume (ml)		38.52
Diameter (cm)	3.2	*% of Saturation*		61.85
Influent Velocity (ml/h)	0.5	Initial Concentration (ppb)	697	968
Pore Water Velocity (cm/h)	0.25			
Residence Time (h)	77.00			

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Standard Effluent Volume	Pore Volume (unsat)	Pore Volume (sat)	Total U-236 (ppb)	U-236 C/Co (ppb)	Standard C/Co (ppb)
1-1	5.87	5.87	8.5	0.22	0.14	2.3	0.0033	0.0023
1-3	4.98	17.38	8.5	0.44	0.27	1.9	0.0027	0.0016
1-5	6.28	29.38	8.5	1.10	0.68	0.8	0.0011	0.0008
1-9	6.49	53.79	8.5	1.99	1.23	0.7	0.0010	0.0008
1-11	6.85	66.88	8.5	2.43	1.50	0.5	0.0007	0.0006
1-12	6.56	73.45	8.5	2.65	1.64	0.5	0.0007	0.0006
1-14	6.63	86.76	8.5	3.09	1.91	0.5	0.0007	0.0006
1-15	6.94	93.70	8.5	3.31	2.05	0.5	0.0007	0.0006
1-20	7.31	129.30	8.5	4.41	2.73	19.5	0.0280	0.0241
1-21	7.27	136.57	8.5	4.63	2.87	33.4	0.0479	0.0410
1-22	7.51	144.08	8.5	4. 85	3.00	59.8	0.0858	0.0758
1-24	7.72	159.30	8.5	5.30	3.28	117	0.1679	0.1525
1-26	7.90	175.00	8.5	5.74	3.55	185	0.2654	0.2466
1-28	8.07	190.84	8.5	6.18	3.82	219	0.3142	0.2985
1-34	4.55	217.70	8.5	7.50	4.64	561	0.8049	0.4312
1-41	5.60	253.72	8.5	9.05	5.60	638	0.9154	0.6034
1-46	5.78	281.70	8.5	10.15	6.28	734	1.0531	0.7167
1-51	6.22	311.82	8.5	11.25	6.96	670	0.9613	0.7036
1-56	6.41	344.06	8.5	12.36	7.64	723	1.0373	0.7821
1-61	6.71	378.59	8.5	13.46	8.33	603	0.8651	0.6833
1-65	7.69	408.23	8.5	14.34	8.87	711	1.0201	0.9225
1-68	4.64	427.82	8.5	15.01	9.28	679	0.9742	0.5317

U-236 Unsaturated Column Test 2

U-236 Unsaturated Column		Column Volume (ml)		154.5
Test 2		Bulk Density (g/cm3)		1.63
Record Book 53751	page 40	Porosity		0.40
Starting Date	7/15/94	Sat. Pore Vol. (ml)		62.14
Ending Date	8/18/94	Soil Wet Wt. (g)		277.94
Influent = Hanford Groundwater		Soil Dry Wt. (g)		251.21
spiked with U-236		Moisture Content (%)		10.64
Soil = Trench 8		Volumetric Water Content (%)		17.30
Length (cm)	5.87	Unsat. Pore Volume (ml)		26.73
Diameter (cm)	4.44	% of Saturation		43.01
Influent Velocity (ml/h)	0.5	Initial Concentration (ppb)	697	968
Pore Water Velocity (cm/h)	0.19			
Residence Time (h)	31.45			

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Standard Effluent Volume	Pore Volume (unsat)	Pore Volume (sat)	Total U-236 (ppb)	U-236 C/Co (ppb)	Standard C/Co (ppb)
2-9	3.73	17.62	8.5	2.54	1.09	0.5	0.0007	0.0003
2-11	4.68	25.92	8.5	3.50	1.50	0.601	0.0009	0.0005
2-17	5.62	54.85	8.5	5.41	2.33	65.1	0.0934	0.0617
2-19	5.69	66.29	8.5	6.04	2.60	109	0.1564	0.1047
2-20	5.87	72.16	8.5	6.36	2.74	139	0.1994	0.1378
2-22	6.65	84.82	8.5	7.00	3.01	192	0.2755	0.2155
2-24	6.93	98.42	8.5	7.63	3.28	256	0.3673	0.2996
2-28	7.71	127.90	8.5	8.90	3.83	298	0.4275	0.3879
2-46	3.86	159.56	8.5	14.63	6.29	1020	1.4634	0.6649
2-53	5.04	190.26	8.5	16.85	7.25	800	1.1478	0.6805
2-58	5.84	217.91	8.5	18.44	7.93	814	1.1679	0.8022
2-64	6.20	255.55	8.5	20.35	8.75	681	0.9770	0.7121
2-68	7.38	283.92	8.5	21.62	9.30	667	0.9570	0.8309
2-71	4.38	303.20	8.5	22.58	9.71	699	1.0029	0.5170

Sr-85 Saturated Column Test 1

Sr-85 Saturated Column		Column Volume (ml)	154.5
Test 1		Bulk Density (g/cm3)	1.71
Record Book 53751	page 20	Porosity	0.37
Starting Date	7/29/93	Sat. Pore Vol. (ml)	56.47
Ending Date	8/23/93	Soil Wet Wt. (g)	319.93
Influent = 0.038 M CaCl2 spiked		Soil Dry Wt. (g)	263.46
with Sr-85		Moisture Content (%)	21.43
Soil = Trench 8		Volumetric Water Content (%)	36.55
Length (cm)	12.3	Unsat. Pore Volume (ml)	56.47
Diameter (cm)	4	% of Saturation	100.00
Influent Velocity (ml/h)	2	Initial Concentration (counts)	0.01608
Pore Water Velocity (cm/h)	0.43		
Residence Time (h)	28.83		
Efficency (dpm/count)	2.82	dpm/ u ci	2220000

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Counts	Sr-85 u ci / ml	Sr C/Co
C-10	9.47	89.83	1.59	502.30	0.0003	0.0198
C-20	9.82	187.86	3.33	3489.10	0.0022	0.1378
C-30	9.84	288.32	5.11	6653.30	0.0042	0.2628
C-40	10.04	392.23	6.95	9146.10	0.0058	0.3613
C-50	10.32	496.78	8.80	11885.8	0.0075	0.4695
C-60	9.84	602.62	10.67	15257.5	0.0097	0.6026
C-70	9.86	700.67	12.41	18374.4	0.0117	0.7258
C-79	10.60	793.64	14.05	19651	0.0125	0.7762

Sr-85 Saturated Column Test 2

Sr-85 Saturated Column		Column Volume (ml)	154.5
Test 2		Bulk Density (g/cm3)	1.72
Record Book 53751	page 58	Porosity	0.37
Starting Date	12/15/94	Sat. Pore Vol. (ml)	56.80
Ending Date	1/6/95	Soil Wet Wt.(g)	322.07
Influent = 0.038 M CaCl2 spiked		Soil Dry Wt. (g)	264.99
with Sr-85		Moisture Content (%)	21.54
Soil = Trench 8		Volumetric Water Content (%)	36.94
Length (cm)	12.3	Unsat. Pore Volume (ml)	56.80
Diameter (cm)	4	% of Saturation	100.00
Influent Velocity (ml/h)	2.4	Initial Concentration (counts)	20.37
Pore Water Velocity (cm/h)	0.52		
Residence Time (h)	23.79		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (sat)	Sr-85 uci/L Counts	Sr-85 C/Co
D-4	9.36	56.12	0.98	0.00	0
D-8	16.55	107.88	1.89	0.07	0.35
D-12	11.54	154.14	2.70	0.30	1.45
D-16	11.53	198.75	3.48	1.53	7.52
D-20	11.34	244.90	4.29	6.91	33.94
D-22	11.72	268.26	4.70	4.45	21.86
D-24	11.51	291.31	5.10	6.57	32.26
D-28	11.54	338.11	5.92	9.09	44.61
D-30	11.52	361.06	6.33	9.96	48.89
D-32	11.89	384.75	6.74	9.55	46.89
D-36	16.58	436.20	7.64	15.13	74.24
D-40	11.52	480.67	8.42	15.05	73.88
D-44	11.56	526.09	9.22	14.29	70.16
D-48	11.24	571.52	10.01	20.79	102.04

Sr-85 Unsaturated Column Test 1

Sr-85 Unsaturated Column		Column Volume (ml)	154.5
Test 1		Bulk Density (g/cm3)	1.55
Record Book 53751	page 21	Porosity	0.43
Starting Date	9/1/93	Sat. Pore Vol. (ml)	66.18
Ending Date	9/22/93	Soil Wet Wt. (g)	287.33
Influent = 0.038 M CaCl2 spiked		Soil Dry Wt. (g)	240.24
with Sr-85		Moisture Content (%)	19.60
Soil = Trench 8		Volumetric Water Content (%)	30.48
Length (cm)	19.2	Unsat. Pore Volume (ml)	47.09
Diameter (cm)	3.2	% of Saturation	71.16
Influent Velocity (ml/h)	2	Initial Concentration (counts)	0.01608
Pore Water Velocity (cm/h)	0.82		
Residence Time (h)	23.53		
Efficency (dpm/count)	2.82	dpm/ u ci	2220000

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Pore Volume (sat)	Counts	Sr-85 u ci / ml	Sr C/Co
A-10	10.90	104.20	2.21	1.57	413.40	0.0003	0.0163
A-20	10.83	213.37	4.53	3.22	3226.00	0.0020	0.1274
A-30	11.08	325.62	6.91	4.92	8234.00	0.0052	0.3252
A-40	11.39	438.29	9.31	6.62	11093.60	0.0070	0.4382
A-50	11.45	518.28	11.01	7.83	12745.40	0.0081	0.5034
A-60	10.21	632.08	13.42	9.55	16091.20	0.0102	0.6356
A-70	11.55	750.18	15.93	11.34	19874.10	0.0126	0.7850
A-80	12.17	868.03	18.43	13.12	21939.10	0.0139	0.8666
A-87	6.97	945.47	20.08	14.29	22351.70	0.0142	0.8829

Sr-85 Unsaturated Column Test 2

Sr-85 Unsaturated Column		Column Volume (ml)	154.5
Test 2		Bulk Density (g/cm3)	1.54
Record Book 53751	page 20	Porosity	0.43
Starting Date	9/1/93	Sat. Pore Vol. (ml)	66.22
Ending Date	9/22/93	Soil Wet Wt.(g)	269.85
Influent = 0.038 M CaCl2		Soil Dry Wt.(g)	238.39
spiked with Sr-85		Moisture Content (%)	13.20
Soil = Trench 8		Volumetric Water Content (%)	20.36
Length (cm)	19.2	Unsat. Pore Volume (ml)	31.46
Diameter (cm)	3.2	% of Saturation	47.51
Influent Velocity (ml/h)	2	Initial Concentration (counts)	0.01608
Pore Water Velocity (cm/h)	1.22		
Residence Time (h)	15.72		
Efficency (dpm/count)	2.82	dpm/ u ci	2220000

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Pore Volume (sat)	Counts	Sr-85 u ci / ml	Sr C/Co
B-10	8.74	85.19	2.71	1.29	2153.00	0.0014	0.0850
B-20	9.05	151.61	4.82	2.29	9032.40	0.0057	0.3568
B-30	9.43	227.16	7.22	3.43	11947.3	0.0076	0.4719
B-40	9.78	322.86	10.26	4.88	14042.1	0.0089	0.5546
B-50	10.21	422.80	13.44	6.38	17233.3	0.0109	0.6807
B-60	10.50	527.95	16.78	7.97	20790.5	0.0132	0.8212
B-70	11.26	637.28	20.26	9.62	21928.7	0.0139	0.8661
B-80	11.26	749.01	23.81	11.31	22151.9	0.0141	0.8750
B-84	6.31	791.85	25.17	11.96	21932.5	0.0139	0.8663

U-238 Unsaturated UFA		Column Volume (ml)	40.2
Test 1		Bulk Density (g/cm3)	1.55
Record Book N/A		Porosity	0.43
Starting Date		Sat. Pore Vol. (ml)	17.29
Ending Date		Soil Wet Wt. (g)	N/A
Influent = Hanford Ground Water		Soil Dry Wt. (g)	N/A
spiked with U-238		Moisture Content (%)	N/A
Soil = Trench 8		Volumetric Water Content (%)	30.00
Length (cm)	5	Unsat. Pore Volume (ml)	12.06
Diameter (cm)	3.5	% of Saturation	69.74
Influent Velocity (ml/h)	25	Initial Concentration (ppb)	28.03
Pore Water Velocity (cm/h)	8.42		
Residence Time (h)	0.59		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	1/2 Sample Effluent (ml)	Pore Volume (unsat)	Total U-238 (ppb)	U-238 C/Co (ppb)
Co					28.03	
1	1.05	1.05	0.52	0.04	9.25	0.33
2	2.00	3.05	2.05	0.17	9.03	0.32
4	2.00	7.05	6.05	0.50	9.53	0.34
6	2.00	11.05	10.05	0.83	8.96	0.32
7	2.00	13.05	12.05	1.00	9.88	0.35
8	2.00	15.00	14.00	1.16	10.04	0.37
11	2.00	21.00	20.00	1.66	12.6	0.45
15	2.00	29.00	28.00	2.32	15.1	0.54
21	7.00	46.00	42.50	3.52	19.2	0.69
25	10.00	85.00	80.00	6.63		0.83
30	11.00	141.00	135.50	11.24	25.7	0.92
40	10.00	286.00	281.00	23.30	26.4	0.95
41			398.55	33.05		0.97

U-238 Unsaturated UFA Test 2

U-238 Unsaturated UFA		Column Volume (ml)	40.2
Test 2		Bulk Density (g/cm3)	1.57
Record Book N/A		Porosity	0.42
Starting Date N/A		Sat. Pore Vol. (ml)	16.88
Ending Date N/A		Soil Wet Wt. (g)	N/A
Influent = Hanford Ground Water		Soil Dry Wt. (g)	N/A
spiked with U-238		Moisture Content (%)	N/A
Soil = Trench 8		Volumetric Water Content (%)	10.00
Length (cm)	5	Unsat. Pore Volume (ml)	4.02
Diameter (cm)	3.5	% of Saturation	23.82
Influent Velocity (ml/h)	10	Initial Concentration (ppb)	27.9
Pore Water Velocity (cm/h)	10.11		
Residence Time (h)	0.50		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	1/2 Sample Effluent (ml)	Pore Volume (unsat)	Total U-238 (ppb)	U-238 C/Co (ppb)
Co					27.9	
1	0.93	0.93	0.47	0.12	8.20	0.29
2	2.07	3.00	1.00	0.25	12.40	0.44
4	4.00	8.07	6.07	1.51	13.20	0.34
8	2.00	18.07	17.07	4.25	23.30	0.84
11	9.00	32.07	27.57	6.86	24.80	0.89
14	5.00	47.07	44.57	11.09	24.60	0.88
17	9.00	66.07	61.57	15.32	29.20	1.01

U-236 Unsaturated UFA Test 1

U-236 Unsaturated UFA		Column Volume (ml)	90.88
Test 1		Bulk Density (g/cm3)	1.67
Record Book 53751	page 49	Porosity	0.38
Starting Date	8/4/94	Sat. Pore Vol. (ml)	34.97
Ending Date	8/26/94	Soil Wet Wt. (g)	162.36
Influent = Hanford Groundwater		Soil Dry Wt. (g)	152.08
spiked with U-236		Moisture Content (%)	6.76
Soil = Trench 8		Volumetric Water Content (%)	11.31
Length (cm)	5.87	Unsat. Pore Volume (ml)	10.28
Diameter (cm)	4.44	% of Saturation	29.40
Influent Velocity (ml/h)	0.5	Initial Concentration (ppb)	697
Pore Water Velocity (cm/h)	0.29		
Residence Time (h)	20.56		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Pore Volume (sat)	Total U-236 (ppb)	U-236 C/Co (ppb)
A-2	10.71	10.71	1.04	0.31	339	0.48637
A-3	33.77	44.48	4.33	1.27	278	0.3989
A-4	11.40	55.88	5.44	1.60	43.8	0.0628
A-5	12.06	67.94	6.61	1.94	147	0.2109
A-6	12.02	79.96	7.78	2.29	159	0.2281
A-7	11.49	91.45	8.90	2.62	223	0.3199
A-8	35.30	126.75	12.33	3.62	373	0.5352
A-9	12.89	139.64	13.58	3.99	497	0.7131
A-10	10.86	150.50	14.64	4.30	505	0.7245
A-11	12.21	162.71	15.83	4.65	578	0.8293
A-12	14.45	177.16	17.23	5.07	602	0.8637
A-13	31.80	208.96	20.33	5.98	614	0.8809
A-14	10.92	219.88	21.39	6.29	652	0.9354
A-15	11.86	231.74	22.54	6.63	638	0.9154
A-16	3.56	235.30	22.89	6.73	694	0.9957
A-17	2.66	237.96	23.15	6.81	696	0.9986

U-236 Unsaturated UFA		Column Volume (ml)	90.88
Test 2		Bulk Density (g/cm3)	1.67
Record Book 53751	page 49	Porosity	0.38
Starting Date	8/4/94	Sat. Pore Vol. (ml)	34.97
Ending Date	8/26/94	Soil Wet Wt. (g)	163.63
Influent = Hanford Groundwater		Soil Dry Wt. (g)	152.27
spiked with U-236		Moisture Content (%)	6.76
Soil = Trench 8		Volumetric Water Content (%)	11.31
Length (cm)	5.87	Unsat. Pore Volume (ml)	10.28
Diameter (cm)	4.44	% of Saturation	29.40
Influent Velocity (ml/h)	0.5	Initial Concentration (ppb)	697
Pore Water Velocity (cm/h)	0.29		
Residence Time (h)	20.56		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Pore Volume (sat)	Total U-236 (ppb)	U-236 C/Co (ppb)
C-1	16.38	16.38	1.59	0.47	0.8	0.0011
C-2	9.04	25.42	2.47	0.73	0.7	0.0010
C-3	29.09	54.51	5.30	1.56	13.4	0.0192
C-4	9.97	64.48	6.27	1.84	118	0.1693
C-5	10.00	74.48	7.25	2.13	220	0.3156
C-6	10.71	85.19	8.29	2.44	272	0.3902
C-7	9.50	94.69	9.21	2.71	317	0.4548
C-8	31.19	125.88	12.25	3.60	445	0.6385
C-9	11.44	137.32	13.36	3.93	487	0.6987
C-10	8.49	145.81	14.18	4.17	560	0.8034
C-11	10.78	156.59	15.23	4.48	481	0.6901
C-12	12.27	168.86	16.43	4.83	517	0.7418
C-13	28.08	196.94	19.16	5.63	578	0.8293
C-14	9.83	206.77	20.11	5.91	591	0.8479
C-15	10.65	217.42	21.15	6.22	621	0.8910
C-16	20.53	237.95	23.15	6.80	585	0.8393
C-17	17.06	255.01	24.81	7.29	596	0.8551

Tritium Unsaturated UFA		Column Volume (ml)	90.88
Test 1		Bulk Density (g/cm3)	1.67
Record Book 53751	page 68	Porosity	0.39
Starting Date	2/13/95	Sat. Pore Vol. (ml)	35.44
Ending Date	2/16/95	Soil Wet Wt. (g)	161
Influent = 0.038 M CaCl2 spiked		Soil Dry Wt. (g)	151.96
with H-3		Moisture Content (%)	5.95
Soil = Trench 8		Volumetric Water Content (%)	9.95
Length (cm)	5.87	Unsat. Pore Volume (ml)	9.04
Diameter (cm)	4.44	% of Saturation	25.51
Influent Velocity (ml/h)	0.5	Initial Concentration (counts)	3453.1
Pore Water Velocity (cm/h)	0.32		
Residence Time (h)	18.08		

Sample ID	Effluent Volume (ml)	Total Effluent vol	Pore Volume (unsat)	H3 u ci / L Counts	% of A0 H3 C/Co
A-1	0.57	0.57	0.06	45.23	0.01
A-2	0.61	1.18	0.13	48.03	0.01
A-3	0.93	2.11	0.23	74.57	0.02
A-4	1.11	3.22	0.36	82.13	0.02
A-5	1.21	4.43	0.49	115.37	0.03
A-6	1.96	6.39	0.71	332.93	0.10
A-7	1.84	8.23	0.91	934.05	0.27
A-8	1.38	9.61	1.06	1556.74	0.45
A-9	1.02	10.63	1.18	1917.14	0.56
A-10	1.43	12.06	1.33	3291.48	0.95
A-11	2.76	14.82	1.64	2655.79	0.77
A-12	1.25	16.07	1.78	3054.55	0.88
A-13	1.40	17.47	1.93	3109.85	0.90
A-14	5.89	23.36	2.58	3279.03	0.95
A-15	1.20	24.56	2.72	3503.1	1.01

Tritium Unsaturated UFA Test 2

Tritium Unsaturated UFA		Column Volume (ml)	90.88
Test 2		Bulk Density (g/cm3)	1.67
Record Book 53751	page 68	Porosity	0.39
Starting Date	2/13/95	Sat. Pore Vol. (ml)	35.44
Ending Date	2/16/95	Soil Wet Wt. (g)	161
Influent = 0.038 M CaCl2 spiked		Soil Dry Wt. (g)	151.95
with H-3		Moisture Content (%)	5.95
Soil = Trench 8		Volumetric Water Content (%)	9.95
Length (cm)	5.87	Unsat. Pore Volume (ml)	9.04
Diameter (cm)	4.44	% of Saturation	25.51
Influent Velocity (ml/h)	0.5	Initial Concentration (counts)	3453.1
Pore Water Velocity (cm/h)	0.32		
Residence Time (h)	18.08		

Sample ID	Effluent Volume (ml)	Total Effluent vol	Pore Volumes (unsat)	H3 u ci / L Counts	% of A0 H3 C/Co
C-1	0.81	0.57	0.09	47.30	0.01
C-2	0.91	1.72	0.19	45.73	0.01
C-3	1.95	3.67	0.41	45.50	0.01
C-4	1.57	5.24	0.58	53.80	0.02
C-5	1.88	7.12	0.79	160.80	0.05
C-6	3.30	10.42	1.15	912.18	0.26
C-7	2.90	13.32	1.47	2091.46	0.61
C-8	2.23	15.55	1.72	2737.30	0.79
C-9	1.67	17.22	1.90	1979.02	0.57
C-10	2.07	19.29	2.13	3291.78	0.95
C-11	4.52	23.81	2.63	3473.10	1.01
C-12	1.73	25.54	2.83	3596.43	1.04
C-13	2.06	27.60	3.05	3509.82	1.02
C-14	7.89	35.49	3.93	3572.14	1.03
C-15	0.86	36.35	4.02	3048.79	0.88

Sr-85 Unsaturated UFA		Column Volume (ml)	90.88
Test 1		Bulk Density (g/cm3)	1.67
Record Book 53751	page 68	Porosity	0.39
Starting Date	2/24/95	Sat. Pore Vol. (ml)	35.44
Ending Date	3/20/95	Soil Wet Wt. (g)	161
Influent = 0.038 M CaCl2 spiked		Soil Dry Wt. (g)	151.96
with Sr-85		Moisture Content (%)	5.95
Soil = Trench 8		Volumetric Water Content (%)	9.95
Length (cm)	5.87	Unsat. Pore Volume (ml)	9.04
Diameter (cm)	4.44	% of Saturation	25.51
Influent Velocity (ml/h)	0.5	Initial Concentration (counts)	0.01198
Pore Water Velocity (cm/h)	0.32		
Residence Time (h)	18.08		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Sr85 u ci / ml Counts	Sr 85 C/Co
A-9	1.98	58.54	6.48	1.23E-04	0.01
A-11	2.10	69.76	7.72	1.80E-04	0.02
A-13	7.93	79.30	8.77	4.98E-04	0.04
A-14	2.88	82.18	9.09	1.09E-03	0.09
A-15	30.49	112.67	12.46	3.24E-03	0.27
A-16	2.15	114.82	12.70	7.04E-03	0.59
A-17	1.34	116.16	12.85	5.10E-03	0.43
A-18	7.67	123.83	13.70	7.18E-03	0.60
A-19	2.21	126.04	13.94	7.51E-03	0.63
A-20	1.22	127.26	14.08	6.61E-03	0.55
A-21	7.93	135.19	14.95	7.78E-03	0.65
A-22	2.05	137.24	15.18	8.54E-03	0.71
A-23	1.66	138.90	15.37	8.42E-03	0.70
A-24	7.66	146.56	16.21	7.49E-03	0.63
A-25	3.22	149.78	16.57	8.84E-03	0.74
A-27	2.11	160.19	17.72	8.53E-03	0.71
A-28	1.32	161.51	17.87	1.06E-02	0.89
A-29	32.13	193.64	21.42	9.72E-03	0.81
A-30	8.50	202.14	22.36	1.30E-02	1.08
A-32	8.93	214.01	23.67	1.07E-02	0.89
A-33	2.17	216.18	23.91	1.35E-02	1.12
A-34	9.24	225.42	24.94	1.10E-02	0.92
A-35	3.13	228.55	25.28	1.10E-02	0.92
A-36	7.87	236.42	26.15	1.09E-02	0.91

Sr-85 Unsaturated UFA Test 2

Sr-85 Unsaturated UFA		Column Volume (ml)	90.88
Test 2		Bulk Density (g/cm3)	1.67
Record Book 53751	page 68	Porosity	0.39
Starting Date	2/24/95	Sat. Pore Vol. (ml)	35.44
Ending Date	3/20/95	Soil Wet Wt. (g)	161
Influent = 0.038 M $CaCl_2$ spiked		Soil Dry Wt. (g)	151.95
with Sr-85		Moisture Content (%)	5.95
Soil = Trench 8		Volumetric Water Content (%)	9.95
Length (cm)	5.87	Unsat. Pore Volume (ml)	9.04
Diameter (cm)	4.44	% of Saturation	25.51
Influent Velocity (ml/h)	0.5	Initial Concentration (counts)	0.01198
Pore Water Velocity (cm/h)	0.32		
Residence Time (h)	18.08		

Sample ID	Effluent Volume (ml)	Total Effluent (ml)	Pore Volume (unsat)	Sr85 u ci / ml Counts	Sr 85 C/Co
C-2	32.34	34.64	3.83	5.43E-05	0.00
C-3	1.86	36.50	4.04	9.35E-05	0.01
C-8	8.32	57.45	6.36	7.54E-05	0.01
C-9	1.83	59.28	6.56	8.51E-05	0.01
C-10	9.45	68.73	7.60	1.40E-04	0.01
C-11	2.51	71.24	7.88	3.80E-04	0.03
C-12	1.59	72.83	8.06	4.79E-04	0.04
C-13	7.93	80.76	8.93	7.34E-04	0.06
C-14	3.05	83.81	9.27	9.56E-04	0.08
C-15	31.81	115.62	12.79	3.50E-03	0.29
C-16	2.34	117.96	13.05	6.45E-03	0.54
C-17	1.27	119.23	13.19	4.42E-03	0.37
C-18	7.64	126.87	14.03	5.61E-03	0.47
C-19	2.47	129.34	14.31	8.47E-03	0.71
C-20	1.36	130.70	14.46	7.57E-03	0.63
C-21	7.97	138.67	15.34	8.64E-03	0.72
C-23	1.43	142.34	15.75	1.01E-02	0.84
C-24	7.97	150.31	16.63	9.55E-03	0.80
C-25	3.50	153.81	17.01	9.31E-03	0.78
C-26	8.12	161.93	17.91	8.16E-03	0.68
C-27	2.25	164.18	18.16	1.02E-02	0.85
C-28	1.37	165.55	18.31	9.17E-03	0.77
C-29	32.07	197.62	21.86	9.33E-03	0.78
C-30	8.78	206.40	22.83	1.09E-02	0.91
C-31	3.00	209.40	23.16	1.13E-02	0.94
C-32	9.18	218.58	24.18	1.10E-02	0.92
C-33	0.00	218.58	24.18	1.20E-02	1.00
C-34	9.00	227.58	25.17	1.33E-02	1.11
C-35	3.40	230.98	25.55	1.33E-02	1.11
C-38	32.78	273.96	30.31	1.18E-02	0.98

PNL-10722
UC-510

Distribution

No. of
Copies

J. A. Coleman, NE-24
DOE Office of Remedial
Action and Waste Technology
19901 Germantown Road
Germantown, MD 20545

3 Westinghouse Savannah River
Company
Savannah River Site
Aiken, SC 29808-001
Attn: C. A. Langton
R. M. Wallace
E. Wilhite

2 Brookhaven National Laboratory
Upton, NY 19973
Attn: M. Fuhrmann
T. M. Sullivan

3 Nuclear Regulatory Commission
Office of Nuclear Regulatory
Research
Washington, DC 20555
Attn: J. W. Bradbury
E. O'Donnell
P. R. Reed

4 Oak Ridge National Laboratory
P. O. Box X
Oak Ridge, TN 37831
Attn: T. M. Gilliam
H. W. Godbee
E. McDaniel
T. L. Sams

2 EG&G
P. O. Box 1625
Idaho Falls, ID 83415
Attn: J. McConnell
R. Rogers

No. of
Copies

T. L. Jones
New Mexico State University
Dept. of Agronomy
Agriculture Building
Room 254
Los Cruces, NM 88003-003

FOREIGN

A. Atkinson
Atomic Energy Research
Establishment
Harvell
Didcot
Oxfordshire OX 11 ORA
UNITED KINGDOM

L. P. Buckley
Atomic Energy of Canada Ltd.
Chalk River, Ontario K0J 1J0
CANADA

R. Dayal
Ontario Hydro
800 Kipling Ave.
Toronto, Ontario M8Z 5S4
CANADA

J. H. Rowat
Atomic Energy of Canada Ltd.
Chalk River Laboratories
Mail Station 15
Chalk River, Ontario
CANADA K0J 1J0

No. of Copies		
ONSITE		
3	**DOE Richland Operations Office**	
	E. A. Bracken	A5-19
	R. D. Freeberg	A5-19
	R. F. Guercia	S7-55
13	**Westinghouse Hanford Company**	
	K. C. Burgard	G6-13
	K. L. Hladek	T4-02
	F. N. Hodges	G1-40
	F. M. Mann	H0-36
	J. W. Shade	H5-27
	J. C. Sonnichsen	H6-23
	M. I. Wood (5)	T4-02
	G. F. Williamson	G6-13
	Washington State University-Tri-Cities	
	J. A. Conca	H2-52

No. of Copies		
34	**Pacific Northwest Laboratory**	
	K. J. Cantrell	K6-81
	M. J. Fayer	K9-33
	G. W. Gee	K9-33
	G. R. Holdren	K6-81
	D. I. Kaplan	K6-81
	C. T. Kincaid	K9-33
	K. M. Krupka	K6-81
	G. V. Last	K9-48
	V. L. Legore	P8-37
	C. W. Lindenmeier (5)	K6-81
	P.F.C. Martin	P8-37
	W. J. Martin	K1-19
	S. V. Mattigod	K6-81
	R. J. Serne (10)	K6-81
	G. A. Whyatt	P7-19
	Information Release Office (7)	K1-06