GEOCHEMISTRY REPORT
FOR
KAISER-TULSA
THORIUM REMEDIATION SITE

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for

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Executive Summary

The purpose of this report is to present results of geochemical studies conducted to date of the Kaiser-Tulsa thorium remediation site. The studies included chemical and mineralogic characterization of dross, chemical analyses of dross pore waters and selected ground waters, and measurements of thorium and radium radioactivities in dross, dross pore waters and selected ground waters. In addition, thorium and radium radioactivities were measured in dross and clays above and below the dross/clay interface beneath the retention pond and sorption coefficients were determined for thorium and radium in several sediment samples from downgradient locations.

Geochemical data indicate that the dross at the Kaiser-Tulsa site is primarily composed of hydrous magnesium oxides dominated by the mineral brucite. Surface and upgradient ground waters are primarily calcium bicarbonate waters with near-neutral pH. Retention pond water and pore waters in dross show high pH (9.2-9.8) and high Mg/Ca (>0.3) reflecting interaction with dross. Downgradient ground waters appear to contain excess chloride, magnesium and potassium leached from dross.

Filtered pore waters in dross contain little or no detectable thorium although they contain measurable concentrations of radium-228 (4.5-666 pCi/l), a daughter product of thorium-232 and radium-226 (4.5-25.8 pCi/l), a daughter product of thorium-230. Unfiltered dross porewaters contain higher concentrations of all isotopes, as expected. Filtered ground waters contain little or no detectable thorium and low concentrations of radium-228 (0.7-4.2 pCi/l). Unfiltered ground waters are similar to filtered ground waters in thorium and radium concentrations.

The concentrations of thorium and radium isotopes measured above and below the dross/clay interface indicate that these constituents have migrated less than 3 inches into the clay. The results of batch experiments indicate that the sorption coefficients for both thorium and radium are greater than 100 ml/g. Combined with the dross/clay interface data, the high sorption coefficients indicate that vertical transport of thorium and radium through the sediments at the site will be very slow under current conditions.

The source terms for soluble thorium isotopes in the dross will likely be considerably lower than 1 pCi/l. Although the potential for colloidal transport of thorium must be considered, the data obtained on the depth of penetration of thorium beneath the dross-clay interface suggest colloidal transport of thorium will likely not be a concern because the clay layer will greatly retard the transport of colloidal-sized particles. The source terms for radium isotopes are constrained by the adsorption of radium onto dross. Conservative assumptions were used to estimate an upper bound on the source term for radium-228 of 1,000 pCi/l. The upper bound on the future radium-226 source term is estimated at 2,000 pCi/l. The transport of these isotopes in the ground water flow system at the site will be greatly retarded by sorption reactions within the unconsolidated sedimentary units beneath and adjacent to the dross.

1. INTRODUCTION

This report discusses geochemical data that were obtained in relation to the Kaiser Aluminum thorium remediation site in Tulsa, Oklahoma. These data were obtained for site characterization purposes and to provide input for transport and dose assessment calculations. The data obtained include the following:

- Chemical and mineralogical composition of samples of dross (spent flux/slag)
- The concentrations of major chemical constituents in selected ground waters at the site
- The radioactivities of thorium and radium isotopes in selected ground waters at the site
- The radioactivities of thorium and radium isotopes in samples from the dross/clay interface
- Sorption coefficients for thorium and radium on samples of sediments from different geologic units at the site.

The data were obtained using written quality assurance procedures for sampling and analysis.

2. DROSS CHEMICAL AND MINERALOGIC COMPOSITION

The process of refining of magnesium-thorium alloys at the Kaiser-Tulsa plant was briefly described by Mr. Bobby Holmes (pers. comm., June 25, 1997). An iron pot was filled with approximately 4,000 lbs of scrap magnesium alloy. A refining flux was added and the mixture was heated with a gas-fired burner to melt the alloy (700-800°C). The mass in the pot was stirred and agitated during the refining process. The refining flux had a higher density than the magnesium metal and gradually settled to the bottom of the pot as the alloy was melted. The thorium in the alloy was extracted into the flux as it sank through the molten metal. The top surface of the molten metal in the pot was covered with a "cover" flux to keep the magnesium metal from burning in air. Once the refining process was considered complete, the molten magnesium metal was ladled out of the pot into molds. The flux remaining at the bottom of the pot was broken up and removed from the pot. Once removed from the pot, spent flux (i.e., dross) was transported to the area north of the plant.

According to company records, several flux compositions were used to refine magnesium scrap at the Tulsa plant. The available information is summarized in Table 1. According to Mr. Holmes, Flux 230 Blended was used in the greatest quantity.

TABLE 1

FLUX COMPOSITIONS

Component	230 Blended (wt.%)	220 Blended (wt. %)	234 Blended (wt. %)
Potassium Chloride (KCl)	55	57	25
Magnesium Chloride ($MgCl_2$)	34		50
Calcium Chloride ($CaCl_2$)		28	
Barium Chloride ($BaCl_2$)	9	12.5	
Calcium Fluoride (CaF_2)	2	2.5	5
Barium Fluoride (BaF_2)			20

Samples of dross from the site were analyzed to provide data on the current mineralogic and chemical compositions of this material. Such data are useful in developing an understanding of controls on local water chemistry and the leaching behavior of thorium and radium.

The mineralogic compositions of 2 dross samples were analyzed by Professor Mark Miller at the University of New Mexico using X-ray diffraction methods. One of these samples was obtained from a surface exposure directly adjacent to MWS-4 (Figure 1). The other sample was selected from borehole BH-101 (approximately 60 feet NE of MWD-4; Figure 1) because it showed a relatively high level of radioactivity among the samples measured during coring operations by ARS (1995). The X-ray diffraction method allows the identification of crystalline phases in powdered samples. The main mineral phases identified in these two samples are listed in Table 2.

TABLE 2

MINERALOGY OF DROSS

Major minerals:	Brucite - $Mg(OH)_2$
	Quartz - SiO_2
	$Mg_6Al_2(OH)_{18}\bullet 4.5H_2O$
Minor minerals:	Iowaite - $Mg_4Fe(OH)_8OCl\bullet xH_2O$
	Metal - Mg, Al

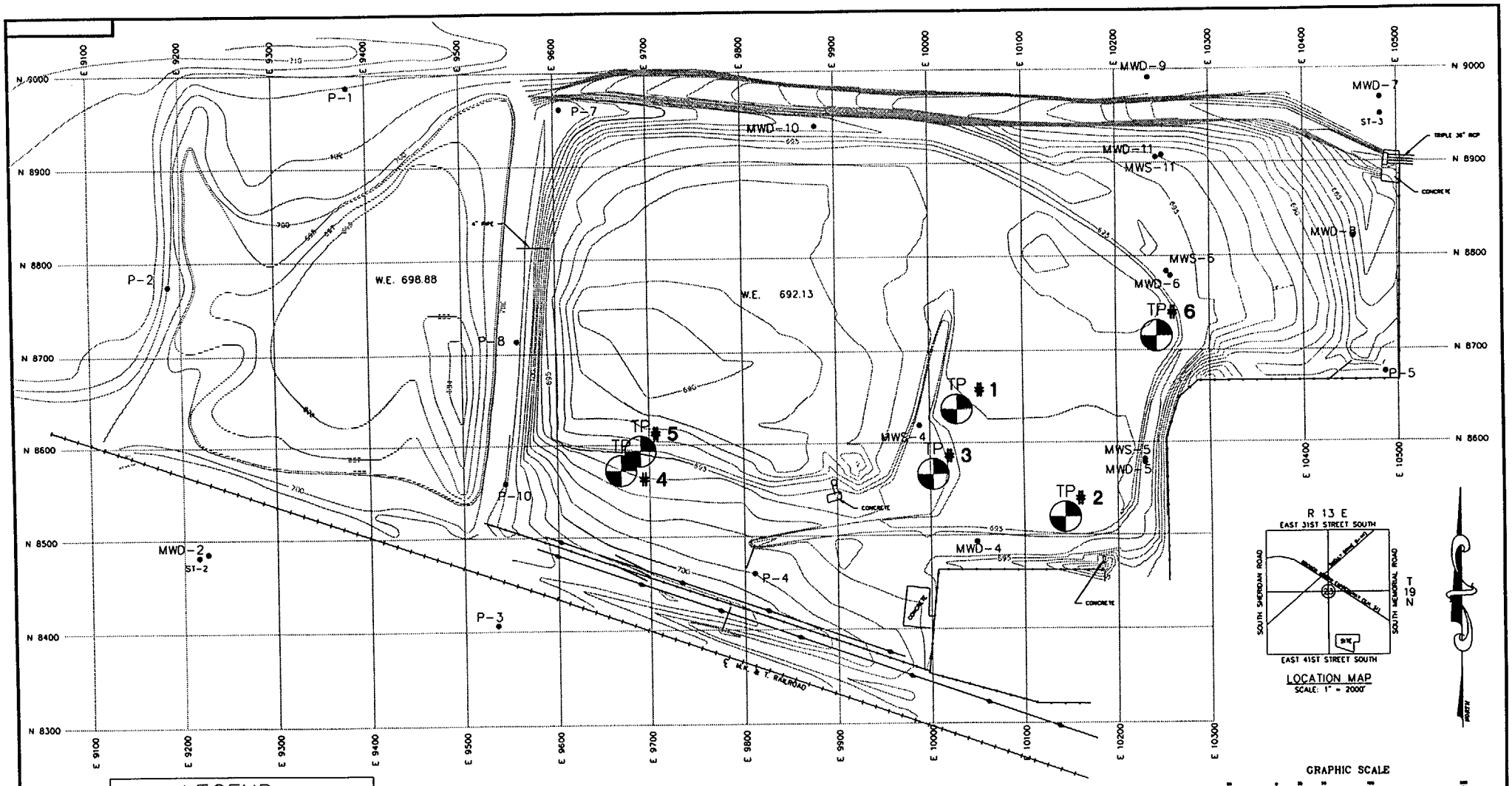
The data presented in Table 2 indicate the dross is composed of magnesium and aluminum hydroxides, quartz, magnesium and aluminum metal and the mineral iowaite. Silica may have been a component of the flux, an impurity in the magnesium alloy or a constituent of the soils where the dross was dumped. Whether iowaite was an original component of flux or formed after the dross was placed on the site is unknown. It is important to note that the X-ray diffraction analysis did not identify separate thorium phases eventhough one of the samples analyzed was selected because it was among those showing the highest radioactivity. This result could reflect either a low absolute concentration of thorium in the dross or a lack of crystallinity in the thorium phase(s), if present. The chemical composition of the dross sample from borehole BH-101 is given in Table 3.

TABLE 3

CHEMICAL COMPOSITION OF DROSS*

Compound	(wt %)	Compound	(wt.%)
SiO_2	6.05	MgO	49.04
TiO_2	0.11	CaO	0.16
Al_2O_3	6.53	Na_2O	0.15
Fe_2O_3	2.85	K_2O	0.10
FeO	N.D.	$H_2O(-)$	2.78
MnO	2.02	$H_2O(+)+CO_2$	30.80
		P_2O_5	<0.1
N.D. = Not Determined		Total	100.6

*Analysis by John Husler, University of New Mexico, Albuquerque, New Mexico.



GRAPHIC SCALE

(IN FEET)
1 inch = 80 ft.

LEGEND

TP # 5 — TEST PITS DUG AND REFILLED 10/14/97

GENERAL NOTES

REVISIONS

NO.	DESCRIPTION	BY	CHECKED	DATE	NO.	DESCRIPTION	BY	CHECKED	DATE

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

ENGINEERING – ENVIRONMENTAL – CONSTRUCTION

DRAWN: JDA	CHECKED BY: JT	MATERIALS BY:	ENGINEER: ALB
DATE: 6-7-99	DATE: 6-7-99	DATE:	DATE: 5-2-1997

TULSA REMEDIATION PROJECT
SAMPLE LOCATION MAP

APPROVED BY:	SCALE:	PROJECT NUMBER:	DRAWING NUMBER:	REV.:
DATE:	NTS	1556-003	FIGURE 1	

Based on the mineralogic composition reported in Table 2 and the chemical analysis reported in Table 3, brucite must be the major mineral constituent in this dross sample. The relatively high manganese (Mn) content reported in Table 3 may reflect an impurity in the iron pot used to melt the alloys or it may have been a minor component of the flux. Thorium is not reported in this analysis because it was not detected as a major constituent. When compared with the flux compositions presented in Table 1, this chemical analysis implies that significant quantities of potassium, barium, chloride and fluoride have been leached from this flux sample since it was deposited on the site.

3. WATER COMPOSITIONS AND RADIOACTIVITIES OF THORIUM AND RADIUM IN WATERS

3.1 Water Compositions

The major chemical constituents were analyzed in water samples from the fresh water pond, the retention pond and selected wells. In addition, pH and specific conductance were measured in the field in the two ponds and in most of the wells that contained water. The major constituent analyses are reported in Table 4. The laboratory data reports are included in the Appendix.

TABLE 4

CHEMICAL ANALYSES OF WATERS[1,2]

	Well P-1	Well P-2	Well P-8	Well P-5	Well MWS-5	Well MWD-5	Well MWD-8	Well ST-3	Retention Pond	Freshwater Pond
Ca	159	180	154	123	14.7	122	47.8	159	16.5	40.2
Mg	9.5	20	23.5	81.2	69.3	42.1	98.7	58.4	49.4	7.0
Na	19.4	32	23.8	60.6	29.0	48.7	25.3	1020	24.5	21.8
K	1.6	8.2	2.0	357	11.6	232	194	10.4	10.3	2.7
Fe	2.6	54.8	12.6	<0.1	0.8	0.2	1.9	0.4	<0.1	1.2
Ba	0.29	1.8	3.7	8.5	1.3	7.7	12.3	3.7	0.77	0.1
Cl	20.8	24.8	268	981	197	636	517	6720	57.6	13.9
SO_4	35.6	11.8	4.4	7.9	10	11.5	4.6	11.2	40.1	38.7
NO_3	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0	<2.0
HCO_3	414	533	213	254	128	12.1	228	139	112	113
CO_3	<1.0	<1.0	<1.0	<1.0	20.5	23.8	<1.0	<1.0	69.7	<1.0
PO_4	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
HS	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
pH	7.1	7.2	7.2	7.4	9.8	9.2	7.9	7.7	9.5	8.1
Ec	866	990	1250	3290	705	2240	2160	6280	585	352

[1]in mg/l except pH and Ec. Ec in µmho/cm.
[2]Well locations shown on Figure 1.

According to the data presented in the report "Hydrologic and Geologic Investigation of the Kaiser-Tulsa Facility" (A&M Engineering and Environmental Services, 1999), the freshwater pond and wells P-1, P-2 and P-8 are upgradient from dross while the retention pond and the other wells are either in dross or downgradient from dross. Compared to upgradient ground waters, downgradient ground waters have significantly higher concentrations of K, Mg, Ba and Cl. These higher concentrations most likely reflect leaching of these constituents from dross. Some waters also show pH > 9.0. This is characteristic of waters in equilibrium with magnesium hydroxide phases such as those contained in the dross (Table 2). The high chloride concentration found in downgradient well ST-3 is not associated with high K/Na and Mg/Ca. This water has either dissolved halite (NaCl) somewhere along its flowpath or if it originated in dross it may have had higher K/Na and Mg/Ca ratios and preferentially lost K and Mg through ion exchange reactions involving clay minerals present in the unconsolidated sediments below the dross.

As discussed in more detail below, the transport behavior of thorium and radium at the site is controlled in part by the compositions of ground water in the flow system and in part by the mineral phases present in the system. In order to evaluate the potential future transport of these constituents, potential changes in the compositions of ground waters and minerals at the site must be evaluated. If the current ground water compositions are close to being in equilibrium with the minerals in the flow system, water compositions are unlikely to undergo much change in the future. On the other hand, if current ground waters are not in equilibrium with the minerals present in the flow system, changes in ground water compositions and/or minerals might occur in the future. A code that calculates the degree to which a given water composition is in equilibrium with minerals contained in its database was developed by Lawrence Livermore National Laboratory (Wolery, 1992). This code, named EQ3, uses thermodynamic data to calculate the saturation states of the minerals contained in its database. The database used for these calculations contains thermodynamic data for over 950 solution species and over 900 mineral phases.

Saturation is typically calculated in terms of a saturation index (SI). A value greater than zero indicates the water composition under consideration is saturated with the mineral of interest. An SI value greater than 1.0 indicates the water is supersaturated with this mineral. Non-silicate minerals that are close to saturation in several representative waters from the site are listed in Table 5. A mineral that is saturated in a water could theoretically precipitate from that water. Whether or not such precipitation occurs is a function of the nucleation and crystallization rates of the mineral phase. Minerals that nucleate and crystallize rapidly should be present in the system assuming the water in the system is saturated with them. Conversely, minerals that have slow nucleation and/or crystallization rates may not be evident in the system even though the waters may be supersaturated with these phases. Silicate and aluminosilicate minerals have been excluded from consideration in Table 5 because their rates of nucleation and crystallization are much slower than the minerals listed. Silicate minerals may nucleate and crystallize in the dross over a long time frame (e.g., hundreds to thousands of years) but are unlikely to have formed in significant quantities to date.

TABLE 5

SATURATION INDICES

Mineral	Mineral Composition	Saturation Index in Water from Retention Pond	MWS-5	MWD-8
Brucite	$Mg(OH)_2$	-0.2	0.5	-3.1
Magnesite	$MgCO_3$	1.5	1.6	0.3
Hydromagnesite	$Mg_5(CO_3)_4(OH)_2 \bullet 4H_2O$	0.5	1.6	-7.1
Calcite	$CaCO_3$	1.2	1.1	0.2
Aragonite	$CaCO_3$	1.1	1.0	0.1
Monohydrocalcite	$CaCO_3 \bullet H_2O$	0.4	0.3	-0.6
Huntite	$Mg_3Ca(CO_3)_4$	4.3	4.3	-0.3
Dolomite	$MgCa(CO_3)_2$	4.4	4.3	2.2
Dolomite (disordered)	$MgCa(CO_3)_2$	2.8	2.8	0.7
Witherite	$BaCO_3$	4.3	4.4	4.0
Alstonite	$CaBa(CO_3)_2$	2.5	1.8	0.5
Barytocalcite	$BaCa(CO_3)_2$	1.6	1.6	1.0
Barite	$BaSO_4$	0.9	0.5	1.0

As indicated in Table 5, brucite is not the most supersaturated magnesium phase in these three waters. Yet, it is the phase identified in the X-ray diffraction analysis. Apparently, the nucleation and/or crystallization rate of brucite is sufficiently fast and the rates for magnesite and hydromagnesite are sufficiently slow so that brucite is the phase that currently controls the magnesium concentration of the dross pore water and probably retention pond water as well. With time, brucite in the dross will be converted to carbonate minerals such as hydromagnesite or magnesite. This conversion would result from the attack of brucite by carbonic acid derived from the dissolution of atmospheric CO_2 in surface and pore waters at the site. Similar reactions take place in cement or concrete during which calcium hydroxide (portlandite) is converted to calcium carbonate. As brucite is converted to hydromagnesite and/or magnesite, the magnesium concentrations in ground water will decrease. In addition, the pH of ground waters will tend toward more neutral values (7.0). In well MW-8, brucite and hydromagnesite are sufficiently undersaturated so that they cannot control the magnesium concentration of the water in this well. The high Mg/Ca ratio in water from this well more likely reflects leaching of magnesium chloride phases originally in the dross.

Calcite and aragonite are saturated in all three of the waters whereas monohydrocalcite is only saturated in the retention pond water and in dross pore water. This suggests either calcite or aragonite may be controlling calcium concentrations in all three of these waters. The calculations also suggest that several calcium-magnesium carbonates are substantially supersaturated in these waters. However, these phases were not identified in the X-ray diffraction analysis, probably because they are very slow to nucleate and crystallize.

Various barium phases are also supersaturated in these waters. One or more of them may be present in the dross. However, the concentration of barium in the dross may be low enough so

that these phases would not be evident in the X-ray analysis even if they were present. The presence of barium phases in the dross could act to retard the release of radium isotopes from the dross because radium is coprecipitated with barium phases.

In summary, the EQ3 calculations suggest that the mineralogy of the dross will likely be converted from dominantly magnesium hydroxides (i.e., brucite) to magnesium carbonates with time. This change will result in the gradual lowering of magnesium concentrations and pH in downgradient ground waters. The on-site waters are currently saturated with calcite and aragonite and will likely remain that way in the future given that upgradient waters are high in calcium (Table 4). Dross pore waters and downgradient ground waters currently show potassium and chloride concentrations that are higher than concentrations in upgradient ground waters. Because the waters at the site are not currently saturated with salts that contain these constituents (e.g., KCl) and will not likely be so in the future, the concentrations of these constituents will decrease with time as a result of leaching and ion exchange reactions.

3.2 Thorium and Radium Radioactivities in Ground Waters

As part of site characterization, the radioactivities of thorium and radium isotopes were measured in water samples obtained from a limited set of wells on the Kaiser-Tulsa site. Thorium and radium activities were analyzed in both filtered and unfiltered samples.

For the filtered samples, the measured thorium activities were low (<2.0 pCi/l) for all isotopes as shown in Table 6. The reported analytical errors for many of the analyses were as large as or larger than the reported concentrations. Therefore, many of these samples have thorium concentrations that are not demonstrably greater than zero.

TABLE 6

Thorium and Radium Analyses of Filtered Ground Waters[1]
(pCi/l)

Location	Screened Unit[2]	^{232}Th	^{230}Th	^{228}Th	^{226}Ra	^{228}Ra
MWS-11	Dross	0.4±1.2	0.07±0.13	0.0±0.16	25.8±0.9	666±2.0
MWS-5	Dross±Unit#3	0.4±0.4	1.8±2.4	0.0±1.4	8.4±0.3	152±0.5
MWS-4	Fill+Dross	0.0±0.78	0.1±0.18	0.27±0.34	4.5±0.3	4.5±0.3
MWS-6	Unit #3	0.31±0.27	0.46±0.38	0.42±0.16	0.1±0.1	1.1±0.1
MWD-4	Unit #2/#1/sh	0.18±0.21	0.58±0.37	0.0±0.3	0.2±0.1	1.1±0.1
P-7	Unit #1/#2	0.06±0.08	0.06±0.12	0.49±0.17	0.1±0.1	0.7±0.1
MWD-7	Unit #1/#2	1.1±0.86	0.20±0.15	0.37±0.06	0.7±0.1	2.5±0.1
MWD-8	Unit #1/#2	0.0±0.4	0.48±0.56	1.0±0.3	0.5±0.2	4.2±0.1
MWD-5	Unit #1	0.3±0.3	1.6±0.8	0.0±0.17	0.9±0.2	0.9±0.1
MWD-6	Unit #1	0.23±0.27	0.1±0.17	0.59±0.13	0.1±0.1	1.0±0.1

[1]Waters sampled on October 15, 1997.
[2]See Hydrologic and Geologic Investigation of the Kaiser-Tulsa Facility (A&M Engineering and Environmental Services, 1999).

The ^{226}Ra activities were also low (<1.0 pCi/l) in all filtered water samples from wells screened below dross. Wells that produced filtered water with ^{226}Ra activities above the detection limits included MWD-4, MWD-5, MWD-7 and MWD-8. Water from well MWD-5 showed the highest ^{226}Ra activity at 0.9 pCi/l. Measured ^{228}Ra activities in filtered samples were ≤1.1 pCi/l in all wells screened below the dross except MWD-7 and MWD-8. Of the latter two wells, MWD-8 had the highest activity at 4.2 pCi/l. Filtered waters from the three wells screened in dross (MWS-4, MWS-5 and MWS-11) had significantly higher ^{226}Ra and ^{228}Ra activities. The highest activities (25.8 and 666 pCi/l, respectively) were found in well MWS-11 and the lowest activities (4.5 and 4.5, respectively) were found in MWS-4. The range in activities in waters from wells screened in dross probably reflects variations in the thorium and radium contents of dross at different locations on the site.

For unfiltered water samples, the measured thorium activities are zero within analytical error for most of the samples obtained from wells screened below the dross (Table 7). The sample from upgradient well P-7 showed activity slightly over the detection limit. Samples from wells screened in the dross (MWS-4, MWS-5, MWS-11) had activities well above the detection limit. For example, the ^{230}Th activity in the MWS-4 sample was 132 pCi/l. Considering that the filtered MWS-4 sample contained essentially no ^{230}Th activity, the measured thorium activities in the unfiltered samples must represent fine-grained particles (<0.45 μm) suspended in the waters.

TABLE 7

Thorium and Radium Analyses of Unfiltered Ground Waters[1]
(pCi/l)

Location	Screened Unit[2]	^{232}Th	^{230}Th	^{228}Th	^{226}Ra	^{228}Ra
MWS-11	Dross	31.9±7.5	73.3±10.1	18.4±3.0	21.1±2.0	450±1.5
MWS-5	Dross±Unit#3	26.0±4.3	104±7.7	27.2±1.5	22.4±0.9	265±1.6
MWS-4	Unit #1+Dross	24±9.1	132±17.8	28.8±4.1	10.6±0.3	146±2.1
MWS-6	Unit #3	0.0±0.38	0.21±0.57	0.0±0.42	0.4±0.2	1.8±0.1
MWD-4	Unit #2/#1/sh	0.35±0.49	0.18±0.35	0.53±0.49	0.2±0.1	1.1±0.1
P-7	Unit #1/#2	0.48±0.35	0.8±0.23	0.62±0.19	0.6±0.1	1.4±0.1
MWD-7	Unit #1/#2	0.04±0.46	0.0±0.49	0.0±0.56	0.8±0.1	2.7±0.1
MWD-8	Unit #1/#2	0.52±0.64	0.0±0.57	0.0±0.99	0.6±0.1	3.3±0.1
MWD-5	Unit #1	0.05±0.5	0.0±0.71	0.0±0.61	0.8±0.1	5.7±0.1
MWD-6	Unit #1	0.0±0.27	0.0±0.27	0.0±0.81	0.7±0.1	1.7±0.1

[1]Waters sampled on October 15, 1997.
[2]See Hydrologic and Geologic Investigation of the Kaiser-Tulsa Facility (A&M Engineering and Environmental Services, 1999).

Some of these waters also had measurable radium activities. The ^{226}Ra activities in unfiltered waters from wells screened below the dross were generally very low (<1.0 pCi/l) and similar to the value measured in water from the upgradient well P-7. In samples from wells screened in dross, ^{226}Ra activities were as high as 22.4 pCi/l (MWS-5). The ^{228}Ra activities were measurably above background in three wells screened below dross. These are MWD-5, MWD-7 and MWD-8. In each case, the measured values are less than 4 times the value measured in upgradient well P-7 (i.e., <6.0 pCi/l). In samples from wells MWD-7 and MWD-8, the filtered and unfiltered

samples have similar activities. However, the unfiltered sample from MWD-5 has almost 6 times as much ^{228}Ra activity as the filtered sample. Without additional information on the amount of solid material in each sample, it is difficult to evaluate the significance of these differences in radioactivity between filtered and unfiltered samples. In wells screened within dross, ^{228}Ra radioactivities are similar in the filtered and unfiltered samples. Interestingly, the unfiltered MWS-11 sample shows lower radioactivity (450 pCi/l) than the filtered sample (666 pCi/l). This most likely reflects absorption (i.e., attenuation) of radioactivity by the solids present in the unfiltered sample during the radiometric analysis.

4.0 THORIUM AND RADIUM TRANSPORT PARAMETERS

In order to calculate potential future radiological doses from radioactivity at potential exposure points within the site, data are required on the transport behavior of radium and thorium in water-bearing units beneath and adjacent to the dross. Two types of transport data were obtained in this study. One type consists of sorption coefficients (K_d) measured for thorium and radium in batch experiments involving representative unconsolidated sediments and pore waters. Sorption coefficients quantify the degree to which the solid materials in contact with ground water interact with and retard the migration of radioactive species. The other type of data obtained consists of measurements of thorium and radium in samples taken above and below the interface between dross and underlying unconsolidated sediment at several locations. These measurements indicate the extent to which thorium and radium have migrated from dross into the sediments beneath the dross over the time period the dross has been in place on the site.

4.1 Batch Experiments for Thorium and Radium Sorption Coefficients

A sorption coefficient is here defined as the exchangable concentration of an element on an unconsolidated sedimentary material divided by its concentration in a solution phase. This coefficient is typically measured in batch experiments in which a known quantity of unconsolidated sedimentary material (e.g., clay) is contacted with a known volume of liquid (i.e., ground water) that has been spiked with the constituents of interest (i.e., thorium or radium isotopes). This mixture is allowed to react for several days to weeks to allow the achievement of steady-state concentrations. The solution and sediment phases are subsequently separated and analyzed for the constituents of interest. In a series of experiments, different aliquots of the solution phase may be spiked with different concentrations of the constituents of interest to determine if the sorption coefficient value is dependent on radionuclide concentrations in solution. The duration of the experiments may be varied to determine how long it takes to achieve a steady state for the sorption reactions. A copy of the method used in these experiments (ASTM Designation D 4319-93 "Standard Test Method for Distribution Ratios by the Short-Term Batch Method") is included in the Appendix.

In this study, experiments to obtain sorption coefficients for radium and thorium were conducted with 5 different sediment samples and 4 different water compositions. Sediment and water samples were chosen based on location and availability. Sample A-13-1 was chosen to represent the clay layer beneath the dross in the retention pond. It was obtained at Test Pit #6 (Figure 1). Because a water sample was not available for the location from which this sample was collected, a water from downgradient well MW-8 (Figure 1) was used in the experiments with this sample. Sample MWD-5 (14-16 ft) was selected to represent Unit #2 on the southeast edge of the site. A water sample from MWS-5 was used with this sample. Sample MWD-10 (12-14 ft) was selected to represent Unit #2 below the northern berm of the retention pond while sample MWD-10 (17-18 ft) was selected to represent Unit #1 at this location. Water from MWD-10 was used in

experiments with both of these samples. The indurated shale beneath the surficial sediments was represented by a sample from well ST-3 (20-30 ft). Water from well ST-3 was used in experiments with this sample.

Based on the data presented in the Appendix, steady-state concentrations were established in the batch tests in a time period of less than 3 days, the shortest period measured. This suggests the kinetics of the sorption reactions are fast. Details of the experimental results are presented in the Appendix. The results of the batch sorption experiments are presented in Table 8. The sorption coefficients for both thorium and radium are relatively large. Sample A-13-1 shows the highest values for both coefficients. The values reported for the other samples show variability but no consistent trends. Basically, the sorption coefficient for radium shows a range of 100-160 ml/g and the coefficient for thorium shows a range of 135-400 ml/g.

The pH of the solutions in the batch experiments tended toward a value of 7.9-8.4 even though the pH of the original ground waters varied from 7.2 (MWD-10) to 9.7 (MWS-5). This reflects equilibration of the solutions with the soils and with the partial pressure of carbon dioxide in the atmosphere in Broken Arrow, OK. The pH values of ground waters at the site will likely be in the range from 7.2 to 8.4 in the future as magnesium hydroxide is converted to magnesium carbonate.

TABLE 8

SORPTION COEFFICIENTS[1]

SAMPLE	Geologic Unit	Th K_d (ml/g)	Ra K_d (ml/g)	pH[2]
A-13-1	#3	400	160	8.2
MWD-5 (14-16 ft)	#2	212	99	8.4
MWD-10 (12-14 ft)	#2	135	159	8.1
MWD-10 (17-18 ft)	#1	183	100	8.0
ST-3 (20-30 ft)	shale	139	155	7.9

[1]See Appendix for more detailed experimental results.
[2]Measured at end of experiment

4.2 Thorium and Radium Concentrations Above and Below the Dross/Sediment Interface

The sorption coefficients reported in the previous section are relatively large and imply that the migration rate of thorium and radium through sediments at the site will be very slow. To test this conclusion, thorium and radium activities were measured in samples of clay that were obtained from directly beneath dross at several onsite locations. Dross samples were also obtained at each location and measured for thorium and radium activities. The samples were obtained by digging trenches or pits with a backhoe. The locations are shown in Figure 1. Additional details concerning the excavations are included in the Appendix. Of the 6 locations at which sampling was attempted, the dross/clay interface was recovered at only 3 locations (locations #4, #5, and #6). At location #4 on dry ground, the dross/sediment interface was recovered from the side of the pit after removal of the immediate surface layer. The other two locations were in the retention pond. At the time of sampling, there was no standing water in the pond at these locations. The dross/sediment interface was recovered in the last bucket brought up after digging down through

the dross layer. In each case, great care was taken to remove potential contamination from the material in the bucket by scraping off a surficial layer before taking a sample. A summary of the results of the thorium and radium analyses of samples from the dross/sediment interface is presented in Table 9. The detailed laboratory results are presented in the Appendix.

The data presented in Table 9 indicate that the thorium and radium activities fall-off rapidly with distance below the dross/clay interface. The data for ^{232}Th in samples from site #6 are plotted in Figure 2. The data points are plotted as boxes to reflect the analytical uncertainties and the vertical interval represented by each sample. The steep fall-off in activities reflects the slowness with which thorium has been transported downward from the dross/clay interface into the clay over the last 20-30 years.

Although a representative background value has not been obtained for Unit #1 clays at the site, it does appear that the ^{232}Th activity for the deepest sample obtained at Site #6 may be above background based on a comparison with literature data. The 4.7 pCi/g reported in Table 9 for this sample corresponds to approximately 42 ppm Th. The average value for Th in shales is around 13 ppm (Adams and Weaver, 1958) although a value of 47 ppm was reported for one sample by these authors. The clay at Site #5 has a ^{232}Th activity of 1.0 pCi/g corresponding to approximately 9 ppm. Perhaps the deep sample at Site #6 was slightly contaminated by overlying clay and/or dross when it was extracted from the retention pond.

TABLE 9

Thorium and Radium Analyses of Samples at the Dross/Sediment Interface
(pCi/g)

Location[1]	^{232}Th	^{230}Th	^{228}Th	^{226}Ra	^{228}Ra
Site #4					
0-2" (dross; A-6)	158±5.3	492±9.4	175±12	1.2±1.5	31.9±0.2
0-2" (clay; A-7)	4.2±0.85	11.9±1.5	3.9±1.0	0.1±0.3	0.6±0.1
2-4" (clay; A-2)	19.7±5.2	35.1±7.5	18.2±4.1	0.5±0.9	1.0±0.1
23-25" (clay; A-3)	3.5±0.5	4.4±0.52	3.1±1.2	0.3±0.3	0.7±0.1
Site #5					
0-2" (dross; A-9)	55±5.2	207±10.1	63±17	4.1±3.0	32.9±0.3
0-2" (clay; A-8)	1.0±0.56	3.95±1.1	1.5±1.2	0.0±0.2	0.6±0.1
Site #6					
0-3" (dross; A-14)	71.3±14.9	250±27	69.2±11.6	1.7±0.4	21.4±0.1
0-1" (clay; A-12)	33.7±4.2	37.5±4.4	29±2.1	0.1±0.1	1.0±0.1
1-3" (clay; A-13)	9.7±2.3	14.4±2.8	10.1±2.3	0.4±0.4	1.3±0.1
2-4" (clay; A-17)	3.0±0.71	12.2±4.4	2.4±1.5	0.1±0.2	0.7±0.1
4-10" (clay; A-18)	4.7±0.86	18.8±1.7	4.2±1.3	0.2±0.2	0.7±0.1

[1]0" represents the dross/clay interface. Inches in dross are above the interface whereas inches in clay are below the interface.

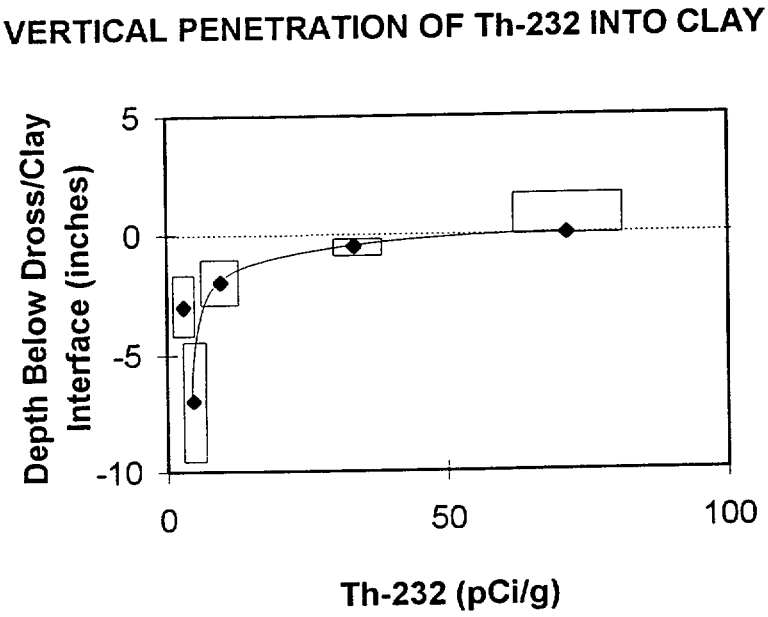


Figure 2. Plot of Th-232 activity in samples from clay layer beneath dross at locality #6. The boxes surrounding data points represent the vertical depth represented by each sample and estimates of analytical errors associated with the reported Th-232 activities.

5.0 DISCUSSION

The data presented in the previous sections contribute to the characterization of the site. However, they are particularly pertinent to the derivation of a source term and retardation coefficients for thorium and radium in transport calculations. Such transport calculations are required to estimate potential future exposure point concentrations which, in turn, are required to perform dose calculations.

5.1 Thorium and Radium Source Term

The radioactivities of thorium and radium isotopes measured in filtered samples from wells screened in dross represent a sampling of the distribution of pore water concentrations at the site. The available data suggest the maximum concentration of thorium in dross pore waters is less than 1.0 pCi/l. Because the reported thorium activities measured in these filtered waters are essentially at the limit of detection of the counting method used, the true activities in these waters could be much less than those reported in Table 6. A value of 1.0 pCi/l corresponds to approximately 3.8×10^{-8} M/l thorium in solution. This is well above the solubility of minerals such as thorianite (ThO_2) which would control thorium concentrations at approximately 10^{-14} M/l in dilute groundwaters under equilibrium conditions (Langmuir and Herman, 1980). Although slow nucleation and precipitation kinetics may allow for some degree of supersaturation of

minerals such as thorianite in the pore waters, this degree is unlikely to be six orders of magnitude. In addition, thorium is strongly sorbed. This further lowers the concentration in solution. As a result, the thorium activities reported for dross pore waters in Table 6 probably exceed the actual activities in solution by at least several orders of magnitude.

The fact that thorium activities are higher in unfiltered samples (Table 7) suggests the possibility that thorium may be transported in particulate form (i.e., colloidal transport). This possibility was also suggested by Langmuir and Herman (1980). The activities reported for ^{232}Th in unfiltered dross pore waters (Table 7) are equivalent to a concentration of approximately 10^{-6} M/l. Although particulate transport is a rather difficult mechanism to evaluate quantitatively, the data presented in Figure 2 suggest that if this mechanism is operative in dross, the clay layer largely inhibits particulate transport of thorium beneath the dross layer.

In summary, the soluble source term for thorium in dross will lie in a range from approximately 10^{-8} to 10^{-14} M/l. The particulate source term concentration in dross may be as high as 10^{-6} M/l. However, this concentration will likely be reduced to the 10^{-8} to 10^{-14} M/l level once percolating waters reach the clay layer beneath the dross.

Radium does not tend to be associated with particulate phases in the unfiltered ground waters as indicated by the similarity in radium concentrations in filtered and unfiltered waters (Tables 6 and 7). However, soluble radium concentrations (radioactivities) are potentially higher than those for thorium. For ^{228}Ra, the activities measured in filtered waters show a wide range from 4.5 to 666 pCi/l (Table 6). The overall distribution of ^{228}Ra activities in filtered dross pore waters may define a somewhat larger range. The activities of ^{226}Ra in dross pore waters are low at present (Table 6 and 7) but will eventually increase to levels corresponding to secular equilibrium with its ^{230}Th parent.

An estimate of the ^{228}Ra source term concentrations in dross can be derived using the following conservative assumptions:

- The range of ^{232}Th activities in dross defines the range of ^{228}Ra activities to be expected in dross at any time.
- All the ^{228}Ra present in dross at any time is available to the solution phase (i.e., dross pore waters).

The first assumption is conservative because with time ^{228}Ra will likely be leached preferentially to ^{232}Th and will generally not be in secular equilibrium with ^{232}Th. The second assumption is conservative because ^{228}Ra incorporated within the structure of dross grains will not always be available to the solution phase. Therefore, the assumption that all ^{228}Ra is available to the solution phase allows for the highest mobile concentrations.

With these assumptions, the ^{228}Ra activities to be expected in solution can be calculated from the range of ^{232}Th activities in the dross and the sorption coefficient as defined above. If we take an average value of 100 pCi/g for the ^{232}Th activity in dross (ARS, 1995) and assume the average activity of ^{228}Ra in dross has the same value, and further assume that the sorption coefficient for Ra in dross is similar to that in clay (approximately 100 ml/g; Table 8), the ^{228}Ra activity in dross pore water would be 1,000 pCi/l. This approximately 50% higher than the highest ^{228}Ra activity measured in dross pore water (666 pCi/l; Table 6). A similar calculation for ^{226}Ra based on current activities of ^{230}Th in dross (Table 9) suggests an upper limit to the future ^{226}Ra source term of 2,000 pCi/l.

5.2 Thorium and Radium Transport

The data presented in Section 4 provide evidence that thorium and radium have been transported over only very limited distances at the site to date. This is supported by the following:

- Thorium and radium have migrated vertically only inches beneath the dross/clay interface (Figure 2),
- Thorium and radium both have relatively large sorption coefficients on sediments from the site (Table 8),
- Thorium and radium concentrations are either below the limit of detection or extremely low in filtered ground waters from wells not screened in dross (Table 6).
- Thorium concentrations in filtered pore waters in dross are very low; less than the analytical error in the samples (Table 6).

6.0 CONCLUSIONS

The geochemical environment at the Kaiser-Tulsa dross disposal site is relatively benign with respect to the potential transport of thorium and radium in unconsolidated sedimentary units beneath and adjacent to the dross. Data on present-day thorium and radium concentrations in ground waters and in the clay beneath the dross-clay interface suggest that transport rates for these elements are very low. This is corroborated by the high values obtained for thorium and radium sorption coefficients in unconsolidated sediments from downgradient locations. The source terms for thorium isotopes in dross may be dominated by particulate transport. However, thorium transport by this mode will likely be greatly retarded by the clay layer present beneath the dross. The source terms for radium isotopes will be controlled largely by sorption reactions within the dross. The long-term ^{228}Ra and ^{226}Ra source terms are estimated at 1,000 pCi/l and 2,000 pCi/l, respectively. The migration rate of these isotopes will be greatly retarded by sorption reactions within the unconsolidated sedimentary units beneath and adjacent to the dross.

7.0 REFERENCES

Adams, J. A. S. and C. E. Weaver, 1958, Thorium-to-uranium ratios as indicators of sedimentary processes – an example of geochemical facies, Bull. Am. Assoc. Petrol. Geologists, v. 42, p. 387.

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Langmuir, D. and J. S. Herman, 1980, The mobility of thorium in natural waters at low temperatures, Geochem. Cosmochim Acta, v. 44, p. 1753-1766.

Wolery, T. J., 1992, EQ3NR, A Computer Program for Geochemical Aqueous Speciation-Solubility Calculations: Theoretical Manual, User's Guide, and Related Documentation (Version 7.0), UCRL-MA-110662-PT-III, Lawrence Livermore National Laboratory, Livermore, California.

APPENDIX

Letter from GCX Inc. to Henry Morton
Regarding Location of Samples of Dross/Clay Interface
and Results of Radiometric Analysis of Clay/Dross Samples,
Filtered and Unfiltered Ground Waters and Pore Waters
by Outreach Laboratories, Tulsa, OK.

GCX INC.
Geochemical/Geological Consultants
P.O. Box 87198-2427 • Albuquerque, New Mexico 87198 • (505) 256-3769

December 19, 1997

Henry Morton
10421 Masters Terrace
Potomac, Maryland 20854

Dear Henry,

The locations for the samples taken in October, 1997 for radionuclide analyses are described below. I have also attached some rough sketches of these sample locations and some sketches from A&M Engineering for samples they collected.

Location #4 (on dry ground):

Sample A-1	0-2 inches of clay below dross/clay interface (obtained with tube sampler)
A-2	2-4 inches of clay below sample A-1 (obtained with tube sampler)
A-3	clay 23-25 inches below dross/clay interface (obtained with tube sampler)
A-4	0-2 inches of dross above dross/clay interface (obtained with tube sampler)
A-5	2-5 inches of dross above Sample A-4 (obtained with tube sampler)
A-6	0-2 inches of dross above dross/clay interface (obtained with shovel)
A-7	0-2 inches of soil below dross/clay interface (obtained with shovel)

Location #5 (in pond):

Sample A-8	0-2 inches of clay below dross/clay interface (obtained with shovel)
A-9	0-2 inches of dross above dross/clay interface (obtained with shovel)

A-10 0-2 inches of clay below dross/clay interface (obtained with tube sampler)

A-11 0-2 inches of dross above dross/clay interface (obtained with tube sampler)

Location # 6 (in pond):

A-12 0-1 inches of clay below dross/clay interface (obtained with shovel)

A-13 1-3 inches of clay below Sample A-12 (obtained with shovel)

A-14 0-3 inches of dross above dross/clay interface (obtained with shovel)

Samples A-15 through A-19 collected by A&M Engineering (Murray McComas) near Location # 6 described by A&M as follows:

Sample A-15 0-4 inches of dross above dross/clay interface (obtained with tube sampler)

A-16 0-2 inches of clay below dross/clay interface (obtained with tube sampler)

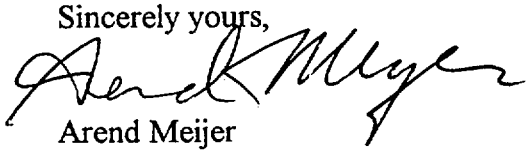
A-17 2-4 inches of clay below Sample A-16 (obtained with tube sampler)

A-18 4-10 inches of clay below Sample A-17 (obtained with tube sampler)

A-19-1 through A-19-7 See attached report from A&M Engineering

Please call if you have questions.

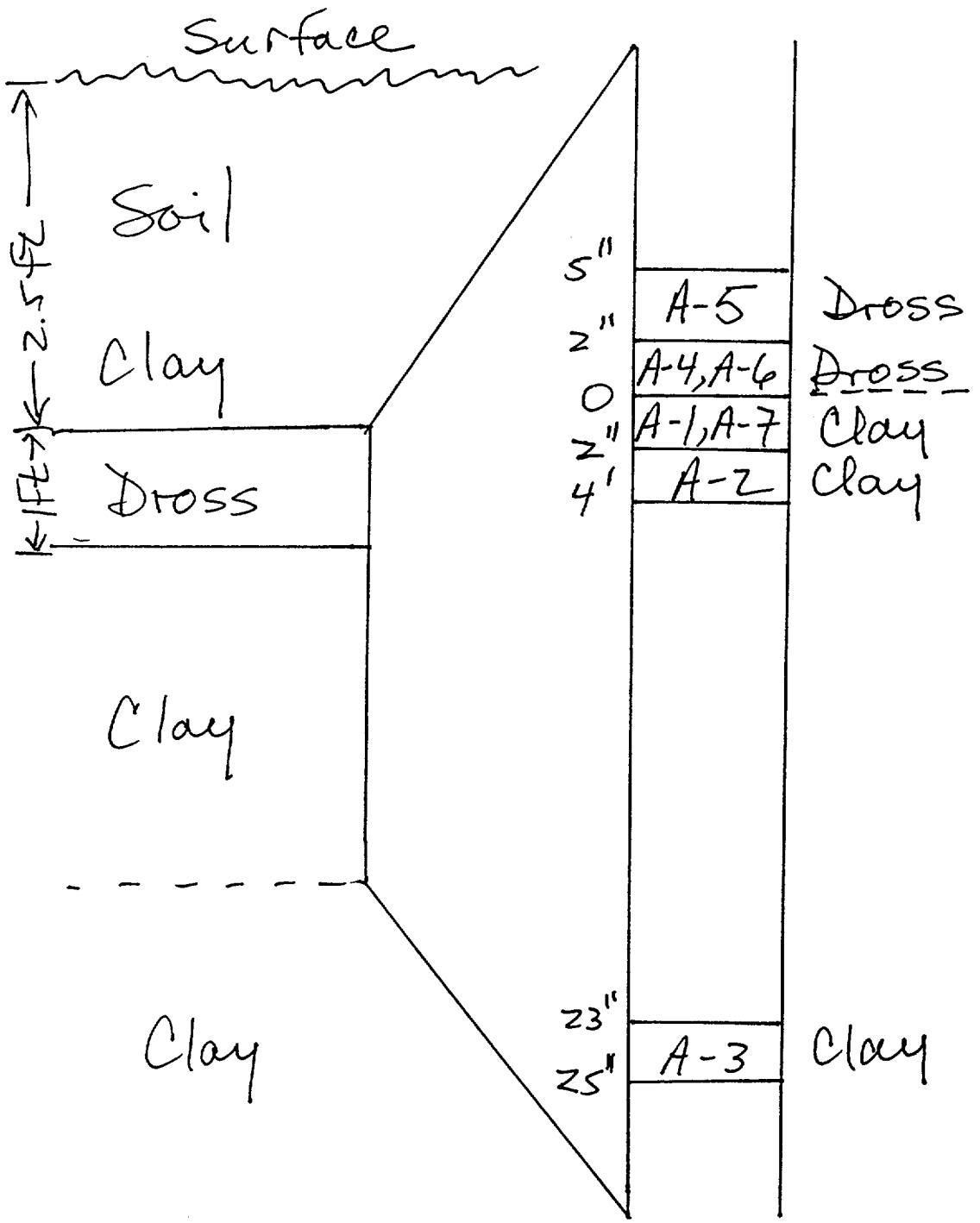
Sincerely yours,



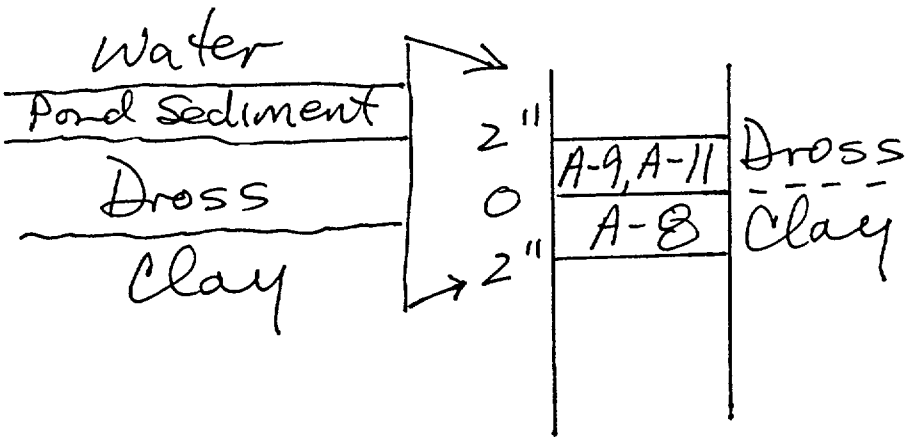
Arend Meijer
Geochemist
GCX Inc.

cc: Bobby Holmes
Rick Kuhlthau
Doug Kent
Henry Morton
Ed Chojnicki
Jerry Boller

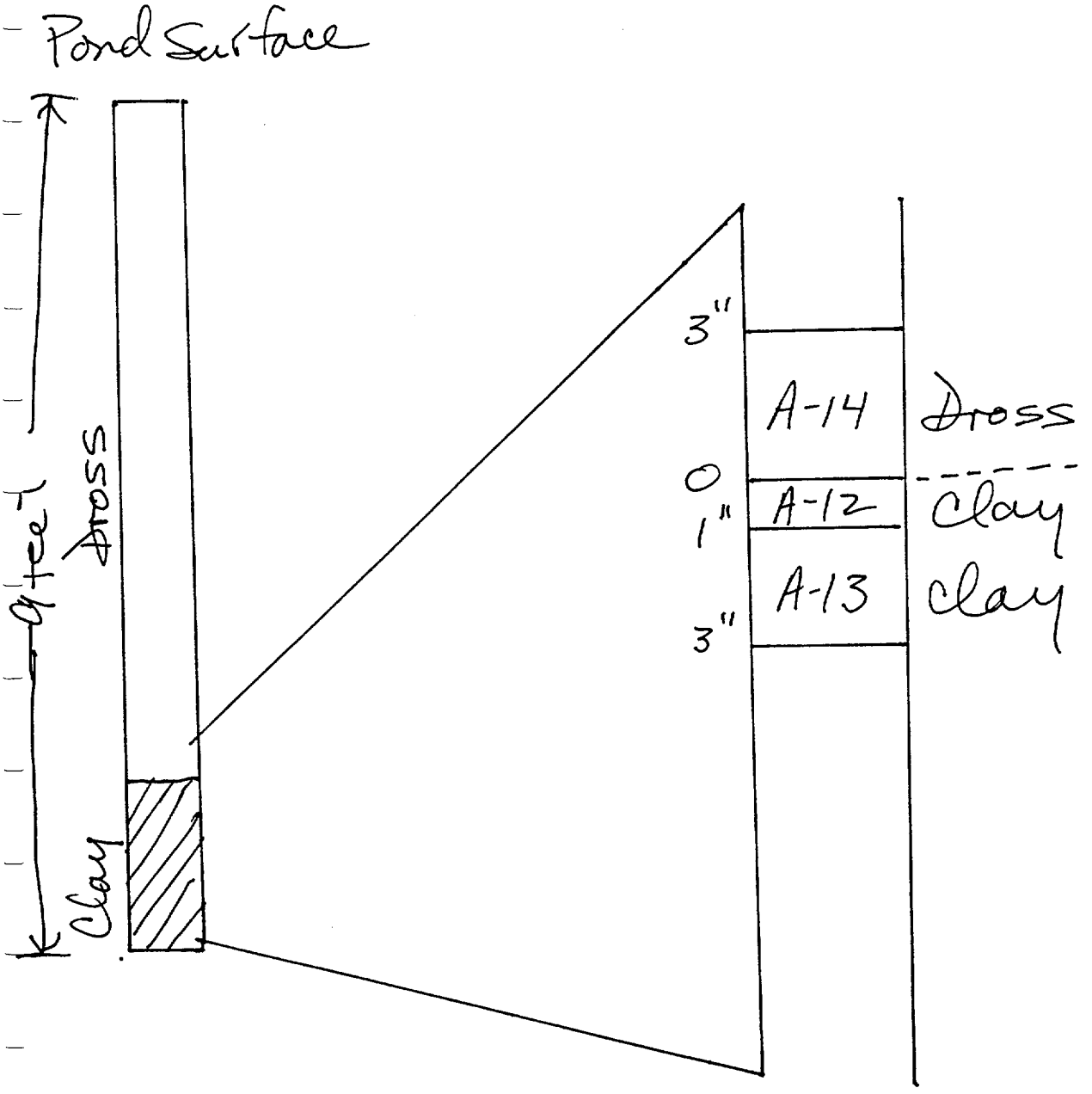
LOCATION #4
(On Dry Ground)



LOCATION #5
(In Pond)



LOCATION #6
(In Dessicated Pond)



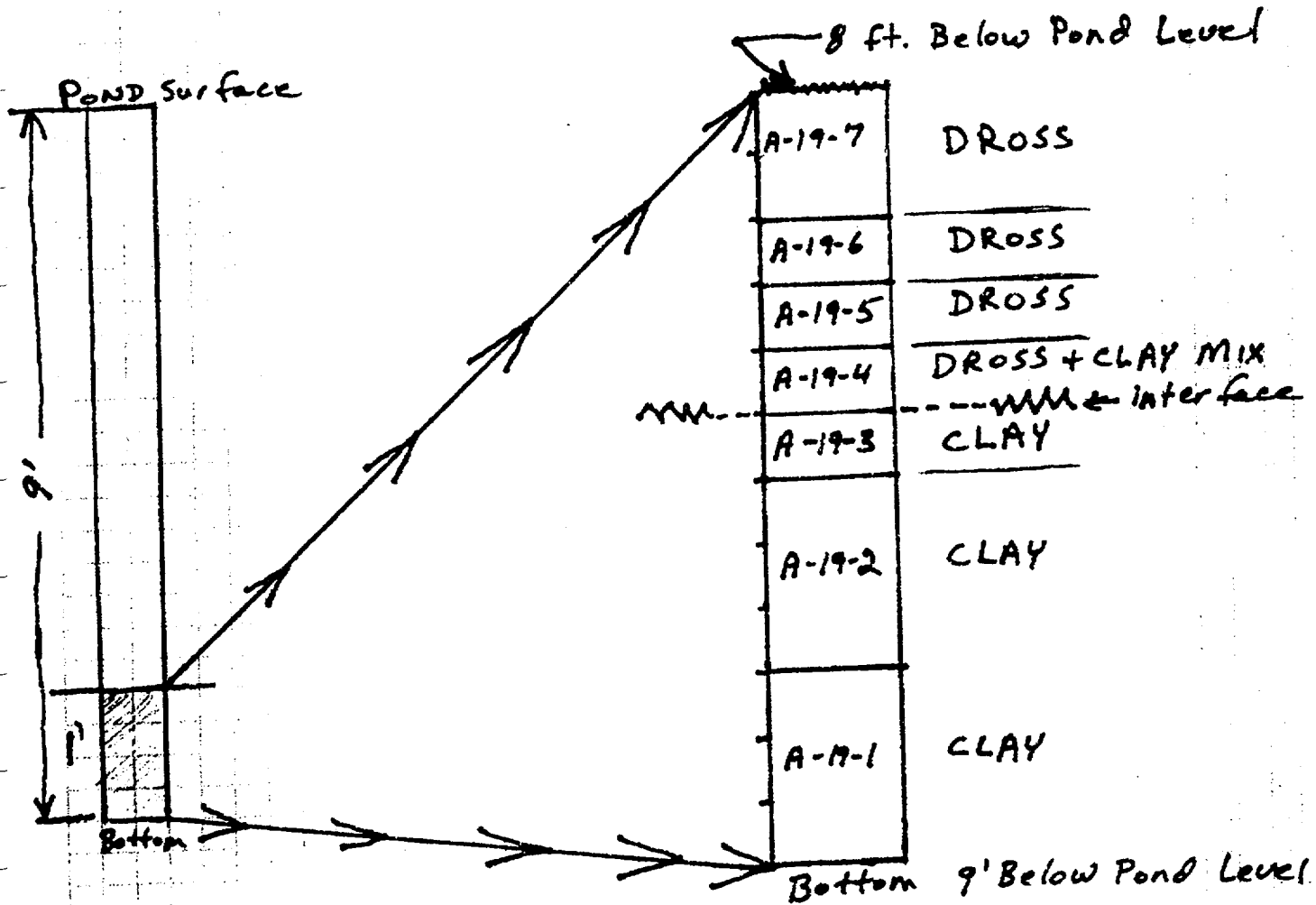
A & M ENGINEERING AND
ENVIRONMENTAL SERVICES, INC.
10010 East 16th Street
Tulsa, Oklahoma 74128-4813
Tel: (918) 665-6575 • Fax: (918) 665-6576

SHEET NO. 1 OF 1

PROJECT TITLE

CALCULATED BY DATE 10-20-97

SUBJECT Core Sample A-19 JOB NO. 1556-010



Samples Collected 10-20-97

OUTREACH LABORATORY

REACHING BEYOND THE STANDARD!!!

Fax No: (918) 251-0008

Telephone No: (918) 251-2515

Fax No: 505-255-1815

Date: 11/26/97

To: Arend Meijer

From: Ron Erdson

Total Number of Pages, including Cover Sheet: 5

Message: waters and soils from Kaiser (Tulsa)

OUTREACH LABORATORY

ANALYTICAL REPORT

PROJECT NO: 970771
CLIENT: Kaiser
DATE SUBMITTED: 15-Oct-97
DATE REPORTED: 28-Nov-97

Sample ID	Date Sampled	Matrix	Th-232 pCi/g			MDA	Th-230 pCi/g			MDA	Th-228 pCi/g			MDA	Ra226 pCi/g			MDA	Ra228 pCi/g			MDA
A-2	10/14/97	Soil	19.7	+/-	5.2	0.5	35.1	+/-	7.5	0.5	18.2	+/-	4.1	0.5	0.5	+/-	0.9	0.1	1.0	+/-	0.1	0.1
A-3	10/14/97	Soil	3.5	+/-	0.47	0.5	4.4	+/-	0.52	0.5	3.1	+/-	1.2	0.5	0.3	+/-	0.3	0.1	0.7	+/-	0.1	0.1
A-6	10/14/97	~~Soil~~ Dross	158	+/-	5.3	0.5	492.0	+/-	9.4	0.5	175	+/-	12.1	0.5	1.2	+/-	1.5	0.1	31.9	+/-	0.2	0.1
A-7	10/14/97	Soil	4.2	+/-	0.85	0.5	11.9	+/-	1.5	0.5	3.9	+/-	1.0	0.5	0.1	+/-	0.3	0.1	0.6	+/-	0.1	0.1
A-8	10/14/97	Soil	1.0	+/-	0.56	0.5	3.95	+/-	1.1	0.5	1.5	+/-	1.2	0.5	0.0	+/-	0.2	0.1	0.6	+/-	0.1	0.1
A-9	10/14/97	~~Soil~~ Dross	55	+/-	5.2	0.5	207	+/-	10.1	0.5	63	+/-	17.0	0.5	4.1	+/-	3.0	0.1	32.9	+/-	0.3	0.1
A-12	10/14/97	Soil	33.7	+/-	4.2	0.5	37.5	+/-	4.4	0.5	29	+/-	2.1	0.5	0.1	+/-	0.1	0.1	1.0	+/-	0.1	0.1
A-13	10/14/97	Soil	9.7	+/-	2.3	0.5	14.4	+/-	2.8	0.5	10.1	+/-	2.3	0.5	0.4	+/-	0.4	0.1	1.3	+/-	0.1	0.1
A-14	10/14/97	~~Soil~~ Dross	71.3	+/-	14.9	0.5	250	+/-	27	0.5	69.2	+/-	11.6	0.5	1.7	+/-	0.4	0.1	21.4	+/-	0.1	0.1

Quality Control	Th-232 Result	%	Th-228 Result	%	Th-230 Result	%	Ra-226 Result	%	Ra-228 Result	%
Blank	.7 +/- .5		.6 +/- .3		.7 +/- .5		.0 +/- .3		.8 +/- .1	
LCS Lab Control Sample		91		89		93		92.6		89.1
Dup		11.3		6.7		9.4	.2 +/- .4	40		5.8
							.1 +/- .3			
MS Matrix Spike		107		101		92.0		90.4		114

Laboratory Approvals:

QA/QC Officer

Laboratory Director

OUTREACH LABORATORY

ANALYTICAL REPORT

PROJECT NO: 970774
CLIENT: Kaiser
DATE SUBMITTED: 16-Oct-97
DATE REPORTED: 26-Nov-97

Sample ID	Date Sampled	Matrix	Th-232 pCi/g		MDA	Th-230 pCi/g		MDA	Th-228 pCi/g		MDA	Ra226 pCi/g		MDA	Ra228 pCi/g		MDA
A-17	10/15/97	Soil	3.0	+/- 0.71	0.5	12.2	+/- 4.4	0.5	2.4	+/- 1.5	0.5	0.1	+/- 0.2	0.1	0.7	+/- 0.1	0.1
A-18	10/15/97	Soil	4.7	+/- 0.86	0.5	18.8	+/- 1.70	0.5	4.2	+/- 1.3	0.5	0.2	+/- 0.2	0.1	0.7	+/- 0.1	0.1

Quality Control	Th-232 Result	%	Th-228 Result	%	Th-230 Result	%	Ra-226 Result	%	Ra-228 Result	%
Blank	.7 +/- .5		.6 +/- .3		.7 +/- .5		.0 +/- .3		.8 +/- .1	
LCS		91		89		93		92.6		89.1
Dup		11.3		6.7		9.4	.2 +/- .4	40		5.8
MS		107		101		92.0	.1 +/- .3	90.4		114

Laboratory Approvals:

QA/QC Officer

Laboratory Director

OUTREACH LABORATORY

ANALYTICAL REPORT

PROJECT NO: 970773
CLIENT: Kaiser
DATE SUBMITTED: 16-Oct-97
DATE REPORTED: 26-Nov-97

FILTERED

Sample ID	Date Sampled	Matrix	Th-232 pCi/g	MDA	Th-230 pCi/g	MDA	Th-228 pCi/g	MDA	Ra226 pCi/g	MDA	Ra228 pCi/g	MDA
MWD-6-2	10/15/97	Water	0.23 +/- 0.27	0.2	0.1 +/- 0.17	0.4	0.59 +/- 0.13	0.3	0.1 +/- 0.1	0.1	1.0 +/- 0.1	0.1
MWS-6-2	10/15/97	Water	0.31 +/- 0.27	0.2	0.46 +/- 0.38	0.4	0.42 +/- 0.16	0.3	0.1 +/- 0.1	0.1	1.1 +/- 0.1	0.1
MWD-4-2	10/15/97	Water	0.18 +/- 0.21	0.2	0.58 +/- 0.37	0.4	0 +/- 0.17	0.3	0.2 +/- 0.1	0.1	1.1 +/- 0.1	0.1
P-7-2	10/15/97	Water	0.06 +/- 0.08	0.2	0.06 +/- 0.12	0.4	0.49 +/- 0.17	0.3	0.1 +/- 0.1	0.1	0.7 +/- 0.1	0.1
MW-7-2	10/15/97	Water	1.1 +/- 0.86	0.2	0.20 +/- 0.15	0.4	0.37 +/- 0.05	0.3	0.7 +/- 0.1	0.1	2.5 +/- 0.1	0.1
MWD-8-2	10/15/97	Water	0 +/- 0.4	0.2	0.48 +/- 0.56	0.4	1.0 +/- 0.30	0.3	0.5 +/- 0.2	0.1	4.2 +/- 0.1	0.1
MWS-11	10/15/97	Water	0.4 +/- 1.2	0.2	0.07 +/- 0.13	0.4	0 +/- 0.16	0.3	25.8 +/- 0.9	0.1	666 +/- 2.0	0.1
MWS-5-2	10/15/97	Water	0.4 +/- 0.4	0.2	1.8 +/- 2.4	0.4	0 +/- 1.4	0.3	8.4 +/- 0.3	0.1	152 +/- 0.5	0.1
MWD-5-2	10/15/97	Water	0.3 +/- 0.3	0.2	1.6 +/- 0.8	0.4	0 +/- 0.17	0.3	0.9 +/- 0.2	0.1	0.9 +/- 0.1	0.1
MWS-4-2	10/15/97	Water	0 +/- 0.78	0.2	0.1 +/- 0.18	0.4	0.27 +/- 0.34	0.3	4.5 +/- 0.3	0.1	4.5 +/- 0.3	0.1

Quality Control	Th-232 Result	%	Th-230 Result	%	Th-228 Result	%	Ra-226 Result	%	Ra-228 Result	%
Blank	0 +/- .2		.2 +/- .5		.1 +/- .4		.1 +/- .1		.7 +/- .1	
LCS		101		96		111		108		90.2
Dup		NC		NC		NC	.7 +/- .1	90.9		5.7
MS		97		89		100	.1 +/- .1	85.2		80.4

Laboratory Approvals:

QA/QC Officer

Laboratory Director

OUTREACH LABORATORY

ANALYTICAL REPORT

Unfiltered

PROJECT NO: 970773
CLIENT: Kaiser
DATE SUBMITTED: 16-Oct-97
DATE REPORTED: 26-Nov-97

TOTAL

Sample ID	Date Sampled	Matrix	Th-232 pCi/g	MDA	Th-230 pCi/g	MDA	Th-228 pCi/g	MDA	Ra226 pCi/g	MDA	Ra228 pCi/g	MDA
MWD-6-1	10/15/97	Water	0 +/- 0.27	0.2	0.0 +/- 0.27	0.4	0 +/- 0.81	0.3	0.7 +/- 0.1	0.1	1.7 +/- 0.1	0.1
MWS-6-1	10/15/97	Water	0 +/- 0.38	0.2	0.21 +/- 0.57	0.4	0 +/- 0.42	0.3	0.4 +/- 0.2	0.1	1.8 +/- 0.1	0.1
MWD-4-1	10/15/97	Water	0.35 +/- 0.49	0.2	0.18 +/- 0.35	0.4	0.53 +/- 0.49	0.3	0.2 +/- 0.1	0.1	1.1 +/- 0.1	0.1
P-7-1	10/15/97	Water	0.48 +/- 0.35	0.2	0.8 +/- 0.23	0.4	0.62 +/- 0.19	0.3	0.6 +/- 0.1	0.1	1.4 +/- 0.1	0.1
MW-7-1	10/15/97	Water	0.04 +/- 0.46	0.2	0 +/- 0.49	0.4	0 +/- 0.56	0.3	0.8 +/- 0.1	0.1	2.7 +/- 0.1	0.1
MWD-8-1	10/15/97	Water	0.52 +/- 0.64	0.2	0 +/- 0.57	0.4	0.0 +/- 0.99	0.3	0.6 +/- 0.1	0.1	3.3 +/- 0.1	0.1
MWS-11	10/15/97	Water	31.9 +/- 7.5	0.2	73.3 +/- 10.1	0.4	18.4 +/- 3.0	0.3	21.1 +/- 2.0	0.1	450 +/- 1.5	0.1
MWS-5-1	10/15/97	Water	26.0 +/- 4.3	0.2	104 +/- 7.7	0.4	27.2 +/- 1.5	0.3	22.4 +/- 0.9	0.1	265 +/- 1.6	0.1
MWD-5-1	10/15/97	Water	0.05 +/- 0.5	0.2	0 +/- 0.71	0.4	0 +/- 0.61	0.3	0.8 +/- 0.1	0.1	5.7 +/- 0.1	0.1
MWS-4-1	10/15/97	Water	24 +/- 9.1	0.2	132 +/- 17.8	0.4	28.8 +/- 4.10	0.3	10.6 +/- 0.3	0.1	146 +/- 2.1	0.1

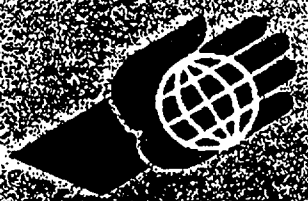
Quality Control	Th-232 Result	%	Th-230 Result	%	Th-228 Result	%	Ra-226 Result	%	Ra-228 Result	%
Blank	0 +/- .2		.2 +/- .5		.1 +/- .4		.1 +/- .1		.7 +/- .1	
LCS		101		96		111		108		90.2
Dup		NC		NC		NC	.7 +/- .1	90.9		5.7
MS		97		89		100	.1 +/- .1	85.2		80.4

Laboratory Approvals:

QA/QC Officer

Laboratory Director

FAX from Outreach Laboratories, Tulsa, OK
to Arend Meijer GCX Inc.
Regarding Results of Kd Measurements



Outreach Laboratory
3111 Long Aspen
Broken Arrow, OK 74012
918-251-2515
FAX 251-0008

Reaching Beyond the Standard

Fax No: (918) 251-0008

Telephone No: (918) 251-2515

Fax No:_____

Date: 11/10/98

To: Arend Meijer

From: Ron Eydelson

Total Number of Pages, including Cover Sheet: 16

Message:

Kd's

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_S	V_S	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 65301 Ra226

107.2 / 2.52	X / X	20 = 4.939	172.26	3 day
69.6 / 1.96	X / X	20 = 4.916	144.88	7 day
123 / 2.98	X / X	20 = 4.955	166.60	14 day
		average	161.25	

Sheet1

ACTIVITY SOLUTION A_s pCi	VOLUME SOLUTION V_s ml	ACTIVITY MINERAL A_M pCi	WEIGHT MINERAL W_M g

calculation

$$\frac{A_M}{A_s} \times \frac{V_s}{W_M} = K_d$$

sample: 65302 Ra226

92.6 / 3.9	X / X	20 = 4.922	96.48	3 day
104 / 3.92	X / X	20 = 4.919	107.87	7 day
105 / 4.44	X / X	20 = 5.139	92.04	14 day
		average	98.795	

Sheet1

ACTIVITY SOLUTION A_S pCi	VOLUME SOLUTION V_S ml	ACTIVITY MINERAL A_M pCi	WEIGHT MINERAL W_M g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 65303 Ra226

$\frac{115}{2.7} \frac{X}{X}$	20 = 5.144	185.60	3 day
$\frac{90.6}{2.4} \frac{X}{X}$	20 = 4.951	152.49	7 day
$\frac{103}{2.76} \frac{X}{X}$	20 = 5.106	146.18	14 day
	average	154.757	

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_s	V_s	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_s}{A_s \times W_M} = K_d$$

sample: 65301 Th230

77.1 / 1	X / X	20 / 5.049	=	305.41	3 day
95.4 / 0.9	X / X	20 / 4.926	=	430.37	7 day
95.4 / 0.8	X / X	20 / 5.032	=	473.97	14 day
			average	403.25	

Sheet1

ACTIVITY SOLUTION A_S pCi	VOLUME SOLUTION V_S ml	ACTIVITY MINERAL A_M pCi	WEIGHT MINERAL W_M g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 65302 Th230

72 / 2	X / X	20 = 4.955	145.31	3 day
72.8 / 1.2	X / X	20 = 4.907	247.27	7 day
73.2 / 1.2	X / X	20 = 5.017	243.17	14 day
		average	211.916	

Sheet1

ACTIVITY SOLUTION A_S pCi	VOLUME SOLUTION V_S ml	ACTIVITY MINERAL A_M pCi	WEIGHT MINERAL W_M g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 65303 Th230

100.8 / 2.4	X / X	20 = 5.144	163.30	3 day
86.4 / 2.8	X / X	20 = 4.951	124.65	7 day
75.6 / 2.3	X / X	20 = 5.106	128.75	14 day
		average	138.899	

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

TULSA, OKLAHOMA

ENGINEERING - ENVIRONMENTAL - CONSTRUCTION

10010 E. 16th Street - TULSA, OKLAHOMA 74128-4813

TEL: (918)665-8575 FAX: (918)665-8576 E-Mail: aandm@galstar.com

SAMPLING FIRM	CLIENT CONTACT	PHONE NUMBER
A&M	Murray McLamore	665-6575

PROJECT NUMBER	PROJECT NAME
	KAISER

SAMPLERS: (Signature)

STA. NO	DATE	TIME	COMP.	GRAB	STATION LOCATION	MATRIX	NO. OF CONTAINERS	RUSH ? YES	RUSH ? NO	ANALYTICAL TESTS REQUIRED: Vol. Formaldehyde (Modified)	REMARKS
	7-21-98	1:	X	X	KA-13-1	SOIL	1			✓	Call Arand Maijor
	7-21-98		X		MWD-5 14-16ft	SOIL	1			✓	to confirm. No
	7-21-98		X		ST-3 20-30ft	SOIL	1			✓	MWD-11 soil samples
											were found.

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
	7/21/98	17:00	
RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)

REMARKS:

CHAIN.DWG

990652

Outreach Laboratory
311 North Aspen
Broken Arrow, Ok 74012
(918) 251-2515
FAX (918) 251-0008

PROJECT NO: 980676
CLIENT: Kaiser Aluminum
CLIENT PROJECT#: KD
DATE SUBMITTED: 28-Jul-98
DATE REPORTED: 2-Nov-98
PAGE: 1 of 1

Sample ID	Date	Method	K_d ML/G Ra226	K_d ML/G Th230	Lab No.
MW-10 12-14 FT	7/21/98	ASTM D4319	159	135	67601
MW-10 17-18 FT	7/21/98	ASTM D4319	100	183	67602

Laboratory Approvals:

QA/QC Officer

Laboratory Director

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_S	V_S	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M}{A_S} \times \frac{V_S}{W_M} = K_d$$

sample: blank Ra226

0.2 / 65	X / X	20 / 1 =	0.06	3 day
0.3 / 54	X / X	20 / 1 =	0.11	7 day
0.3 / 57.3	X / X	20 / 1 =	0.10	14 day
		average	0.092	

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_S	V_S	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 67601 Ra226

38.1 / 0.84	X / X	20 / 4.939	=	183.67	3 day
30.4 / 0.95	X / X	20 / 4.916	=	130.19	7 day
49.1 / 1.21	X / X	20 / 4.955	=	183.79	14 day
			average	159.21	

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_S	V_S	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 67602 Ra226

50.9 / 2	X / X	20 / 4.922	=	103.41	3 day
50 / 2.35	X / X	20 / 4.919	=	86.51	7 day
47.9 / 1.66	X / X	20 / 5.139	=	110.96	14 day
			average	100.295	

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_S	V_S	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: blank Th

0.5 / 97.5	X / X	20 / 1 =	0.10	3 day
0.6 / 94.2	X / X	20 / 1 =	0.13	7 day
0.7 / 96.2	X / X	20 / 1 =	0.15	14 day
		average	0.125	

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_s	V_s	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_s}{A_s \times W_M} = K_d$$

sample: 67601 Th230

76 / 1.6	X / X	20 / 4.933	=	192.58	3 day
76.5 / 3	X / X	20 / 4.916	=	103.74	7 day
81 / 3	X / X	20 / 4.951	=	109.07	14 day
			average	135.13	

Sheet1

ACTIVITY SOLUTION	VOLUME SOLUTION	ACTIVITY MINERAL	WEIGHT MINERAL
A_S	V_S	A_M	W_M
pCi	ml	pCi	g

calculation

$$\frac{A_M \times V_S}{A_S \times W_M} = K_d$$

sample: 67602 Th230

103 / 2	X / X	20 / 5.104 =	201.80	3 day
98 / 2	X / X	20 / 5.087 =	192.65	7 day
98 / 2.5	X / X	20 / 5.075 =	154.48	14 day
		average	182.978	

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

TULSA, OKLAHOMA

ENGINEERING - ENVIRONMENTAL - CONSTRUCTION

10010 E. 16th Street - TULSA, OKLAHOMA 74128-4813

TEL: (918)665-8575 FAX: (918)665-6576 E-Mail: aandm@galstar.com

SAMPLING FIRM: A&M | CLIENT CONTACT: Irfan Samar | PHONE NUMBER: 665-6575

PROJECT NUMBER | PROJECT NAME: Kaiser

SAMPLERS: (Signature)

STA. NO	DATE	TIME	COMP.	GRAB	STATION LOCATION	MATRIX	NO. OF CONTAINERS	RUSH ? YES	RUSH ? NO	ANALYTICAL TESTS REQUIRED 1,2	REMARKS
1	7-28-98	3:00	X		MWD-10 12-14Ft	SOIL	1			✓	
2	7-28-98	3:00	X		MWD-10 17-18 Ft	SOIL	1			✓	
3	7-28-98	3:30		X	MWD-10	water SOIL	2			✓	

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
	7/28/98	4:50	Raymond Thomas
RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
REMARKS:			

CHAIN.DWG

980676

Letter from Dr. Murray McComas, A&M Engineering, Tulsa, OK to Arend Meijer, GCX Inc. Regarding Results of Water Analyses

A & M ENGINEERING
AND
ENVIRONMENTAL SERVICES, INC.
TULSA, OKLAHOMA
ENGINEERING - ENVIRONMENTAL - CONSTRUCTION
3840 SOUTH 103rd EAST AVENUE - TULSA, OKLAHOMA 74146
TEL (918)665-6575 FAX (918)665-6576

SAMPLING FIRM	CLIENT CONTACT	PHONE NUMBER
A&M Engineering	Murray McLemore	665-6575

PROJECT NUMBER	PROJECT NAME
1556	KAISER ALUM

SAMPLERS: (Signature)

STA. NO	DATE	TIME	COMP	GRAB	STATION LOCATION	MATRIX	NO. OF CONTAINERS	RUSH ? YES	RUSH ? NO	Brine Analysis	Total Dissolved Solids	Barium	Sulfide	REMARKS
	5/12/97	3:37			P-2	WATER	4			✓	✓	✓	✓	
		10:51			P-8		4			✓	✓	✓	✓	
		12:39			MWD-5		4			✓	✓	✓	✓	
		11:42			P-5		4			✓	✓	✓	✓	
		12:12			MW-8		4			✓	✓	✓	✓	
		2:33			ST-3		4			✓	✓	✓	✓	
					~~EQUIP BLANK~~		1			✓	✓	✓	✓	Canceled Per Client
					~~FIELD BLANK~~		1			✓	✓	✓	✓	" " "
					DUPLICITE	↓	1			✓	✓	✓	✓	" " ↓
	5/12	12:48			Retention Pond		4			✓	✓	✓	✓	Added Per Client
	5/12	11:28			Fresh Water Pond		4			✓	✓	✓	✓	" " "
							~~5~~ 4 MVB 5/13/97							MVB 5/13/97

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
[signature]	5/12/97	5:15	

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
	5/12/97	1715	[signature]

REMARKS:

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

TULSA, OKLAHOMA
ENGINEERING - ENVIRONMENTAL - CONSTRUCTION
3840 SOUTH 103rd EAST AVENUE - TULSA, OKLAHOMA 74146
TEL (918)665-6575 FAX (918)665-6578

SAMPLING FIRM	CLIENT CONTACT	PHONE NUMBER
A&M	Murray McComas	665-6575

PROJECT NUMBER	PROJECT NAME
1556	KAISER ALUM

SAMPLERS: (Signature) Patrick Clark

STA. NO	DATE	TIME	COMP.	GRAB	STATION LOCATION	MATRIX	NO. OF CONTAINERS	RUSH ? YES	RUSH ? NO	Brine Analysis	Total Plumbate	Bauxite	Sulfide	REMARKS
	5/13/97			✓	MW5-5	WATER	4			✓	✓	✓	✓	
	5/13/97	12:00		✓	P-1	WATER	4			✓	✓	✓	✓	
	5/13/97			✓	ST-3	WATER	1				✓			
	5/13/97			✓	EQUIP BLANK	WATER	4			✓	✓	✓	✓	
	5/13/97			✓	FIELD BLANK	WATER	4			✓	✓	✓	✓	
	5/13/97			✓	DUPLICATE	WATER	4			✓	✓	✓	✓	

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)
Patrick Clark	5/14/97	1440	

RELINQUISHED BY: (Signature)	DATE	TIME	RECEIVED BY: (Signature)

REMARKS:

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: Field Blank
Project ID: KAISER AL SITE
SWLO ID: 29344.05
Report: 29344.05 -M

Collected: 05/13/1997
Received: 05/14/1997
Report Date: 06/03/1997
Last Modified: 06/03/1997
Page: 1
Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	ND	05/22/97		**
Magnesium		.25	mg/l	ND	05/22/97		**
Sodium		.15	mg/l	ND	05/22/97		**
Iron		.1	mg/l	.144	05/22/97		**
Potassium		.3	mg/l	ND	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	ND	05/23/97		**
T. Hardness as CaCO3			mg/l	ND	05/29/97		**
Total Dissolved Sol.		10	mg/l	ND	05/23/97		**
Chloride		2	mg/l	ND	05/16/97		**
Sulfate		2	mg/l	ND	05/16/97		**
Nitrate		2	mg/l	ND	05/16/97		**
pH		.1	S.U.	5.88	05/14/97		**
Spec. Conductance		.1	umho/cm	1.4	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		2.0	mg/l	ND	05/16/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	ND	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
B = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1983

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: Equip Blank
Project ID: KAISER AL SITE
SWLO ID: 29344.04
Report: 29344.04 -M

Collected: 05/13/1997
Received: 05/14/1997
Report Date: 06/03/1997
Last Modified: 06/03/1997
Page: 1
Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	ND	05/22/97		**
Magnesium		.25	mg/l	ND	05/22/97		**
Sodium		.15	mg/l	ND	05/22/97		**
Iron		.1	mg/l	ND	05/22/97		**
Potassium		.3	mg/l	ND	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	ND	05/23/97		**
T. Hardness as CaCO3			mg/l	ND	05/29/97		**
Total Dissolved Sol.		10	mg/l	ND	05/23/97		**
Chloride		2	mg/l	ND	05/16/97		**
Sulfate		2	mg/l	ND	05/16/97		**
Nitrate		2	mg/l	ND	05/16/97		**
pH		.1	S.U.	5.75	05/14/97		**
Spec. Conductance		.1	umho/cm	2.6	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	ND	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
= ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
= UNABLE TO QUANTITTATE DUE TO MATRIX INTERFERENCE
nA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW - EPA METHODOLOGY, "SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: P-1 Project ID: KAISER AL SITE

SWLO ID: 29344.02 Report: 29344.02 -M

Collected: 05/13/1997
Received: 05/14/1997
Report Date: 06/03/1997 Page: 1
Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	159	05/22/97		**
Magnesium		.25	mg/l	9.49	05/22/97		**
Sodium		.15	mg/l	19.4	05/22/97		**
Iron		.1	mg/l	2.56	05/22/97		**
Potassium		.3	mg/l	1.57	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	414	05/23/97		**
T. Hardness as CaCO3			mg/l	436	05/29/97		**
Total Dissolved Sol.		10	mg/l	511	05/23/97		**
Chloride		2	mg/l	20.8	05/29/97		**
Sulfate		2	mg/l	35.6	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		.1	S.U.	7.07	05/14/97		**
Spec. Conductance		.1	umho/cm	866	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/28/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	288	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
F = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
N/A = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: Duplicate P-1 Project ID: KAISER AL SITE

SWLO ID: 29344.06 Report: 29344.06 -M

Collected: 05/13/1997
Received: 05/14/1997
Report Date: 06/03/1997
Last Modified: 06/03/1997
Page: 1
Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	161	05/22/97		**
Magnesium		.25	mg/l	9.58	05/22/97		**
Sodium		.15	mg/l	19.5	05/22/97		**
Iron		.1	mg/l	2.23	05/22/97		**
Potassium		.3	mg/l	1.41	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	414	05/23/97		**
T. Hardness as CaCO3			mg/l	442	05/29/97		**
Total Dissolved Sol.		10	mg/l	515	05/23/97		**
Chloride		2	mg/l	20.9	05/19/97		**
Sulfate		2	mg/l	35.9	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		.1	S.U.	7.07	05/14/97		**
Spec. Conductance		-1	umho/cm	866	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	288	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
H = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
I = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

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SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: P-2 Project ID: KAISER AL SITE

SWLO ID: 29326.01 Report: 29326.01 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	180	05/22/97		**
Magnesium		.25	mg/l	20	05/22/97		**
Sodium		.15	mg/l	32	05/22/97		**
Iron		.1	mg/l	54.6	05/22/97		**
Potassium		.3	mg/l	8.2	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	533	05/23/97		**
T. Hardness as CaCO3			mg/l	542	05/29/97		**
Total Dissolved Sol.		100	mg/l	630	05/23/97		**
Chloride		2	mg/l	24.8	05/19/97		**
Sulfate		2	mg/l	11.8	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		0.10	S.U.	7.2	05/14/97		**
Spec. Conductance		0.1	umho/cm	990	05/27/97		**
TOTAL PHOS.		0.10	mg/l	0.21	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/16/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	1820	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
! = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
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Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

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SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: P-5 Project ID: KAISER AL SITE

SWLO ID: 29326.04 Report: 29326.04 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
			*** INORGANICS ***				
BRINE PACKAGE							
Calcium		.25	mg/l	123	05/22/97		**
Magnesium		.25	mg/l	81.2	05/22/97		**
Sodium		.15	mg/l	60.6	05/22/97		**
Iron		.1	mg/l	ND	05/22/97		**
Potassium		.3	mg/l	357	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	254	05/23/97		**
T. Hardness as CaCO3			mg/l	640	05/29/97		**
Total Dissolved Sol.		10	mg/l	1730	05/23/97		**
Chloride		2	mg/l	981	05/16/97		**
Sulfate		2	mg/l	7.9	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		0.1	S.U.	7.37	05/14/97		**
Spec. Conductance		0.1	umho/cm	3290	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
			*** METALS ***				
BARIUM		2	ug/l	8530	05/22/97	SW 6010	

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NA = NOT APPLICABLE

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Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
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SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: P-8 Project ID: KAISER AL SITE

SWLO ID: 29326.02 Report: 29326.02 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
*** INORGANICS ***							
BRINE PACKAGE							
Calcium		.25	mg/l	154	05/22/97		**
Magnesium		.25	mg/l	23.5	05/22/97		**
Sodium		.15	mg/l	23.8	05/22/97		**
Iron		.1	mg/l	12.60	05/22/97		**
Potassium		.3	mg/l	2.04	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	213	05/23/97		**
T. Hardness as CaCO3			mg/l	481	05/29/97		**
Total Dissolved Sol.		40	mg/l	840	05/23/97		**
Chloride		2	mg/l	268	05/19/97		**
Sulfate		2	mg/l	4.4	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		0.10	S.U.	7.24	05/14/97		**
Spec. Conductance		0.10	umho/cm	1250	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/16/97	SW 9030	
*** METALS ***							
BARIUM		2	ug/l	3650	05/22/97	SW 6010	

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Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1983

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SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: MWS-5 Project ID: KAISER AL SITE

SWLO ID: 29344.01 Report: 29344.01 -M

Collected: 05/13/1997 Report Date: 06/03/1997 Page: 1
Received: 05/14/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	14.7	05/22/97		**
Magnesium		.25	mg/l	69.3	05/22/97		**
Sodium		.15	mg/l	29.0	05/22/97		**
Iron		.1	mg/l	.8	05/22/97		**
Potassium		.3	mg/l	11.6	05/22/97		**
Carbonate Alkalinity		1	mg/l	20.5	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	128	05/23/97		**
T. Hardness as CaCO3			mg/l	321	05/29/97		**
Total Dissolved Sol.		10	mg/l	343	05/23/97		**
Chloride		2	mg/l	197	05/19/97		**
Sulfate		2	mg/l	10	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		.1	S.U.	9.84	05/14/97		**
Spec. Conductance		.1	umho/cm	705	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	1260	05/22/97	SW 6010	

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Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
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SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: MWD-5 Project ID: KAISER AL SITE

SWLO ID: 29326.03 Report: 29326.03 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
			*** INORGANICS ***				
BRINE PACKAGE							
Calcium		.25	mg/l	122	05/22/97		**
Magnesium		.25	mg/l	42.1	05/22/97		**
Sodium		.15	mg/l	48.7	05/22/97		**
Iron		.1	mg/l	0.166	05/22/97		**
Potassium		.3	mg/l	232	05/22/97		**
Carbonate Alkalinity		1	mg/l	23.6	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	12.1	05/23/97		**
T. Hardness as CaCO3			mg/l	478	05/29/97		**
Total Dissolved Sol.		10	mg/l	1150	05/23/97		**
Chloride		1	mg/l	636	05/19/97		**
Sulfate		2	mg/l	11.5	05/16/97		**
Nitrate		2	mg/l	ND	05/16/97		**
pH		0.10	S.U.	9.15	05/14/97		**
Spec. Conductance		0.10	umho/cm	2240	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
			*** METALS ***				
BARIUM		2	ug/l	7670	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
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NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
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SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: MW-8 Project ID: KAISER AL SITE

SWLO ID: 29326.05 Report: 29326.05 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	47.8	05/22/97		**
Magnesium		.25	mg/l	98.7	05/22/97		**
Sodium		.15	mg/l	25.3	05/22/97		**
Iron		.1	mg/l	1.87	05/22/97		**
Potassium		.3	mg/l	194	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	228	05/23/97		**
T. Hardness as CaCO3			mg/l	524	05/29/97		**
Total Dissolved Sol.		10	mg/l	1130	05/23/97		**
Chloride		2	mg/l	517	05/19/97		**
Sulfate		2	mg/l	4.6	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		.1	S.U.	7.91	05/14/97		**
Spec. Conductance		.1	umho/cm	2160	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	12300	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
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Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
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SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: ST-3 Project ID: KAISER AL SITE

SWLO ID: 29326.06 Report: 29326.06 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
			*** INORGANICS ***				
BRINE PACKAGE							
Calcium		.25	mg/l	159	05/22/97		**
Magnesium		.25	mg/l	58.4	05/22/97		**
Sodium		.15	mg/l	1020	05/22/97		**
Iron		.1	mg/l	.384	05/22/97		**
Potassium		.3	mg/l	10.4	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	139	05/23/97		**
T. Hardness as CaCO3			mg/l	627	05/29/97		**
Total Dissolved Sol.		10	mg/l	13500	05/23/97		**
Chloride		2	mg/l	6720	05/16/97		**
Sulfate		2	mg/l	11.2	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		.1	S.U.	7.72	05/14/97		**
Spec. Conductance		.1	umho/cm	6280	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
			*** METALS ***				
BARIUM		2	ug/l	3710	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
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SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: ST-3 Project ID: KAISER AL SITE

SWLO ID: 29344.03 Report: 29344.03

Collected: 05/13/1997 Report Date: 06/03/1997 Page: 1
Received: 05/14/1997 Last Modified: Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE
*** INORGANICS ***						
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
* = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
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A = NOT APPLICABLE
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SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1700 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: RETENTION POND Project ID: KAISER AL SITE

SWLO ID: 29326.07 Report: 29326.07 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	16.5	05/22/97		**
Magnesium		.25	mg/l	49.4	05/22/97		**
Sodium		.15	mg/l	24.5	05/22/97		**
Iron		.1	mg/l	ND	05/22/97		**
Potassium		.3	mg/l	10.3	05/22/97		**
Carbonate Alkalinity		1	mg/l	69.7	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	112	05/23/97		**
T. Hardness as CaCO3			mg/l	244	05/29/97		**
Total Dissolved Sol.		10	mg/l	360	05/23/97		**
Chloride		2	mg/l	57.6	05/19/97		**
Sulfate		2	mg/l	40.1	05/19/97		**
Nitrate		2	mg/l	ND	05/19/97		**
pH		.1	S.U.	9.53	05/14/97		**
Spec. Conductance		.1	umho/cm	585	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	765	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
= ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
= UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
= NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1983

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

SOUTHWEST LABORATORY OF OKLAHOMA, INC.

1706 W. ALBANY SUITE C BROKEN ARROW, OK 74012-1421 (918) 251-2858

Client Name: A & M ENGINEERING & ENVIRONMENTAL SERVICES
3840 S 103RD E AVE SUITE 227
TULSA, OK 74146

Client ID: FRESH WATER POND Project ID: KAISER AL SITE

SWLO ID: 29326.08 Report: 29326.08 -M

Collected: 05/12/1997 Report Date: 06/03/1997 Page: 1
Received: 05/13/1997 Last Modified: 06/03/1997 Matrix: Water-Rad

TEST	DATE EXTRACTED	DETECTION LIMIT	UNITS	RESULTS	DATE ANALYZED	METHOD REFERENCE	
		*** INORGANICS ***					
BRINE PACKAGE							
Calcium		.25	mg/l	40.2	05/22/97		**
Magnesium		.25	mg/l	7.01	05/22/97		**
Sodium		.15	mg/l	21.8	05/22/97		**
Iron		.1	mg/l	1.18	05/22/97		**
Potassium		.3	mg/l	2.74	05/22/97		**
Carbonate Alkalinity		1	mg/l	ND	05/23/97		**
Bi-Carb. Alkalinity		20	mg/l	113	05/23/97		**
T. Hardness as CaCO3			mg/l	129	05/23/97		**
Total Dissolved Sol.		10	mg/l	208	05/23/97		**
Chloride		2	mg/l	13.9	05/16/97		**
Sulfate		2	mg/l	38.7	05/16/97		**
Nitrate		2	mg/l	ND	05/16/97		**
pH		.1	S.U.	8.13	05/14/97		**
Spec. Conductance		.1	umho/cm	352	05/27/97		**
TOTAL PHOS.		0.10	mg/l	ND	05/22/97	EPA 365.2	
TOTAL SULFIDE		1.0	mg/l	ND	05/18/97	SW 9030	
		*** METALS ***					
BARIUM		2	ug/l	110	05/22/97	SW 6010	

ND = NOT DETECTED ABOVE QUANTITATION LIMIT
I = ANALYTE DETECTED IN BLANK AS WELL AS SAMPLE
J = UNABLE TO QUANTITATE DUE TO MATRIX INTERFERENCE
NA = NOT APPLICABLE
Methodology: SM = STANDARD METHODS, 16th EDITION, 1985
EPA = #EPA600/4-79-020, MARCH 1985

* = SURROGATE RECOVERY OUTSIDE OF QC LIMITS
D = SURROGATES DILUTED OUT
J = ESTIMATED VALUE: CONCENTRATION BELOW LIMIT OF QUANTITATION

SW = EPA METHODOLOGY, "#SW846", THIRD EDITION, NOVEMBER 1986

A & M ENGINEERING AND ENVIRONMENTAL SERVICES, INC.
3840 S. 103RD E. AVENUE
TULSA, OK 74146-2419
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(918) 665-6575 - FAX (918) 665-6576

June 6, 1997

Dr. Arend Meijer
GCX Inc.
Box 82427
Albuquerque, New Mexico 87198

RE: Water Analyses from Tulsa Remediation Project

Dear Arend:

I have enclosed FAX copies of the water analyses. I held off sending them in hopes that I would get hard copies before today. Anyway, this gives you something to start with. I am basically pleased with the data and think they will be helpful in the model.

Very truly yours,

Murray R. McComas PhD
Vice President

Enclosures

cc: Bobby Holmes
Ed Chojnicki
Rick Kuhlthau
Jerry Boller
Henry Morton
Al Gutterman

Xerox Copy of ASTM Designation: D 4319-93
Standard Test Method for
Distribution Ratios by the Short-Term Batch Method

Designation: D 4319 - 93

Standard Test Method for Distribution Ratios by the Short-Term Batch Method[1]

This standard is issued under the fixed designation D 4319; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

As an aqueous fluid migrates through geologic media, certain reactions occur that are dependent upon the chemistry of the fluid itself and upon the chemistry and geochemistry of other fluids and solid phases with which it comes in contact. These geochemical interactions determine the relative rates at which chemical species in the migrating fluid (such as ions) travel with respect to the advancing front of water. Processes of potential importance in retarding the flow of chemical species in the migrating fluid (movement of species at velocities less than the ground-water velocity) include ion exchange, adsorption, complex formation, precipitation (or coprecipitation, for example Ba^{++} and Ra^{++} co-precipitating as the sulfate), oxidation-reduction reactions, and precipitate filtration. This test method applies to situations in which only sorptive processes (adsorption and ion exchange) are operable for the species of interest, however, and is restricted to granular porous media.

It is difficult to derive generalized equations to depict ion exchange-adsorption reactions in the geological environment. Instead, a parameter known as the *distribution coefficient* (K_d) has been used to quantify certain of these sorption reactions for the purpose of modeling (usually, but not solely, applied to ionic species). The distribution coefficient is used to assess the degree to which a chemical species will be removed from solution as the fluid migrates through the geologic media; that is, the distribution coefficient provides an indication of how rapidly an ion can move relative to the rate of ground-water movement under the geochemical conditions tested.

This test method is for the laboratory determination of the *distribution ratio* (R_d), which may be used by qualified experts for estimating the value of the distribution coefficient for given underground geochemical conditions based on a knowledge and understanding of important site-specific factors. It is beyond the scope of this test method to define the expert qualifications required, or to justify the application of laboratory data for modeling or predictive purposes. Rather, this test method is considered as simply a measurement technique for determining the distribution ratio or degree of partitioning between liquid and solid, under a certain set of laboratory conditions, for the species of interest.

Justification for the distribution coefficient concept is generally acknowledged to be based on expediency in modeling-averaging the effects of attenuation reactions. In reference to partitioning in soils, equilibrium is assumed although it is known that this may not be a valid assumption in many cases. Equilibrium implies that (*1*) a reaction can be described by an equation and the free energy change of the reaction, within a specific system, is zero, and (*2*) any change in the equilibrium conditions (*T*, *P*, concentration, etc.) will result in immediate reaction toward equilibrium (the concept is based upon reversibility of reactions). Measured partitioning factors may include adsorption, coprecipitation, and filtration processes that cannot be described easily by equations and, furthermore, these solute removal mechanisms may not instantaneously respond to changes in prevailing conditions. Validity of the distribution coefficient concept for a given set of geochemical conditions should not be assumed initially, but rather should be determined for each situation.

This is a short-term test and the attainment of equilibrium in this laboratory test is not presumed, although this may be so for certain systems (for example, strictly interlayer ion exchange reactions of clays). Consistent with general usage, the result of this test could be referred to as "distribution coefficient" or as "distribution ratio;" in the strictest sense, however, the term "distribution ratio" is preferable in that the attainment of equilibrium is not implied.

The distribution ratio (R_d) for a specific chemical species may be defined as the ratio of the mass

[1] This test method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.14 on Geotechnics of Waste Management.

Current edition approved April 15, 1993. Published August 1993.

sorbed onto a solid phase to the mass remaining in solution, which can be expressed as:

$$R_d = \frac{\text{(mass of solute on the solid phase per unit mass of solid phase)}}{\text{(mass of solute in solution per unit volume of the liquid phase)}}$$

The usual units of R_d are mL/g (obtained by dividing g solute/g solid by g solute/mL solution, using concentrations obtained in accordance with this test method).

Major difficulties exist in the interpretation, application, and meaning of laboratory-determined distribution ratio values relative to a real system of aqueous fluid migrating through geologic media.[2] Typically, only reactions between migrating solutions and solid phases are quantified. In general, geochemical reactions that can result from interaction of the migrating fluid with another aqueous phase of a differing chemistry have not been adequately considered (interactions with other liquids can profoundly change the solution chemistry). Additionally, as noted above, the distribution coefficient or K_d concept implies an equilibrium condition for given reactions, which may not realistically apply in the natural situation because of the time-dependence or kinetics of specific reactions involved. Also, migrating solutions always follow the more permeable paths of least resistance, such as joints and fractures, and larger sediment grain zones. This tends to allow less time for reactions to occur and less sediment surface exposure to the migrating solution, and may preclude the attainment of local chemical equilibrium. Thus, the distribution coefficient or K_d concept is only directly applicable to problems involving contaminant migration in granular porous material.

Sorption phenomena are also strongly dependent upon the thermodynamic activity of the species of interest in solution (chemical potential). Therefore, experiments performed using only one activity or concentration of a particular chemical species may not be representative of actual in situ conditions or of other conditions of primary interest. Similarly, unless experimental techniques consider all ionic species anticipated to be present in a migrating solution, adequate attention is not directed to competing ion and ion complexation effects, which may strongly influence the R_d for a particular species.

Many "sorption" ion complexation effects are strongly influenced, if not controlled, by conditions of pH and Eh. Therefore, in situ conditions of pH and redox potential should be considered in determinations of R_d. To the extent possible, these pH and Eh conditions should be determined for field locations and must be approximated (for transition elements) in the laboratory procedure.

Other in situ conditions (for example, ionic strength, anoxic conditions, or temperature) could likewise have considerable effect on the R_d and need to be considered for each situation. Additionally, site-specific materials must be used in the measurement of R_d. This is because the determined R_d values are dependent upon rock and soil properties such as the mineralogy (surface charge and energy), particle size distribution (surface area), and biological conditions (for example, bacterial growth and organic matter). Special precautions may be necessary to assure that the site-specific materials are not significantly changed prior to laboratory testing.

The choice of fluid composition for the test may be difficult for certain contaminant transport studies. In field situations, the contaminant solution moves from the source through the porous medium. As it moves, it displaces the original ground water, with some mixing caused by dispersion. If the contaminant of interest has an R_d of any significant magnitude, the front of the zone containing this containment will be considerably retarded. This means that the porous medium encountered by the contaminant has had many pore volumes of the contaminant source water pass through it. The exchange sites achieve a different population status and this new population status can control the partitioning that occurs when the retarded contaminant reaches the point of interest. It is recommended that ground water representative of the test zone be used as contact liquid in this test; concentrations of potential contaminants of interest used in the contact liquid should be judiciously chosen. For studies of interactions with intrusion waters, the site-specific ground water may be substituted by liquids of other compositions.

The distribution ratio for a given chemical species generally assumes a different value when any of the above conditions are altered. Clearly, a very thorough understanding of distribution coefficients and the site-specific conditions that determine their values is required if one is to confidently apply the K_d concept (and the measured R_d values) to migration evaluation and prediction.

The adoption of a standard method for determining distribution ratios, R_d, especially applicable for ionic species, is important in that it will provide a common basis for comparison of

[2] Coles, D. G., and Ramspott, L. D., "Migration of Ruthenium-106 in a Nevada Test Site Aquifer: Discrepancy Between Field and Laboratory Results," *Science*, Vol. 215, pp. 1235–1237, March 5, 1982.

experimental results (particularly for near-similar conditions).

The most convenient method of determining R_d is probably the *batch method* (this test method), in which concentrations of the chemical species in solid and liquid phases, which are in contact with one another, are measured with time. Other methods include the dynamic test or column flow-through method using (*1*) continuous input and (*2*) pulsed input, the in situ dual tracer test, and the thin-layer chromatography (TLC) test.

In summary, this distribution ratio, R_d, is affected by many variables, all of which may not be adequately controlled or measured by the batch method determination. The application of experimentally determined R_d values for predictive purposes (assuming a functional relationship such as $R_d = K_d$) must be done judiciously by qualified experts with a knowledge and understanding of the important site-specific factors. However, when properly combined with knowledge of the behavior of chemical species under varying physicochemical conditions of the geomedia and the migrating fluid, distribution coefficients (ratios) can be used for assessing the rate of migration of chemical species through a saturated geomedium.

1. Scope

1.1 This test method covers the determination of distribution ratios of chemical species for site-specific geological media by a batch sorption technique. It is a short-term laboratory method primarily intended for ionic species subject to migration in granular porous material, and the application of the results to long-term field behavior is not known. Distribution ratios for radionuclides in selected geomedia are commonly determined for the purpose of assessing potential migratory behavior at waste repositories. This test method is also applicable to studies of intrusion waters and for parametric studies of the effects of variables and of mechanisms which determine the measured distribution ratios.

1.2 The values stated in acceptable metric units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 422 Test Method for Particle-Size Analysis of Soils[3]

D 2217 Practice for Wet Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[3]

D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[3]

D 3370 Practices for Sampling Water[4]

3. Terminology

3.1 *Description of Terms Specific to This Standard:*

3.1.1 *distribution coefficient, K_d*—is identically defined as R_d for equilibrium conditions and for ion exchange-adsorption reactions only. To apply R_d values to field situations, an assumption such that $R_d = K_d$ is necessary. The validity of such an assumption can only be determined by informed experts making a judgment (albeit uncertain) based on a detailed study of the specific site.

3.1.2 *distribution ratio, R_d*—the ratio of the concentration of the species sorbed on the soil or other geomedia, divided by its concentration in solution under steady-state conditions, as follows:

$$R_d = \frac{\text{(mass of solute on the solid phase per unit mass of solid phase)}}{\text{(mass of solute in solution per unit volume of the liquid phase)}}$$

by steady-state conditions it is meant that the R_d values obtained for three different samples exposed to the contact liquid for periods ranging from 3 to at least 14 days, other conditions remaining constant, shall differ by not more than the expected precision for this test method.

The dimensions of the expression for R_d reduce to cubic length per mass (L^3/M). It is convenient to express R_d in units of millilitres (or cubic centimetres) of solution per gram of geomedia.

3.1.3 *species*—a distinct chemical entity (such as an ion) in which the constituent atoms are in specified oxidation states.

4. Significance and Use

4.1 The distribution ratio, R_d, is an experimentally determined parameter representing the distribution of a chemical species between a given fluid and a geomedium sample under certain conditions, including the attainment of a steady state. Based on a knowledge and understanding of the important site-specific factors, R_d values may be used by qualified experts for estimating the value of the distribution coefficient, K_d, for a given set of underground geochemical conditions. The K_d concept is used in mass transport modeling, for example, to assess the degree to which an ionic species will be removed from solution as the solution migrates through the geosphere. For applications other than transport modeling, batch R_d measurements also may be used, for example, for parametric studies of the effects of variables and of mechanisms related to the interactions of fluids with geomedia.

5. Apparatus

5.1 *Laboratory Ware* (plastic bottles, centrifuge tubes, open dishes, pipets, graduates), cleaned in a manner consistent with the analyses to be performed and the required precision. Where plateout may have significant effect on the measurement, certain porous plastics should be avoided and

[3] *Annual Book of ASTM Standards*, Vol. 04.08.

[4] *Annual Book of ASTM Standards*, Vol. 11.01.

ıe use of FEP TFE-fluorocarbon containers is recommended.

5.2 *Centrifuge*, capable of attaining 1400 g, or filtering pparatus.

5.3 *Laboratory Shaker/Rotator*, ultrasonic cleaner (optional).

5.4 *Environmental Monitoring Instruments*, a pH meter, lectrometer and electrodes for Eh determination, conductance apparatus, and thermometer.

5.5 *Analytical Balance*.

5.6 *Appropriate Equipment*, necessary to maintain in situ onditions within the laboratory.

5.7 *Analytical Instrumentation*, appropriate for determination of the concentration of major constituents (cations nd anions) and of the species of interest (for which R_d is eing determined) in the contact solutions (and, optionally, in the geomedia samples).

6. Sampling

6.1 The samples of soil, rock, or sediment shall be considered to be representative of the stratum from which it was obtained by an appropriately accepted or standard procedure and based on expert judgment.

6.2 The sample shall be carefully identified as to origin in accordance with Practice D 2488.

6.3 A geological description shall be given of the core material used for the distribution ratio measurement, including particle-size analysis (Method D 422) for unconsolidated material, depth of sample, and boring location.

6.4 Sampling of representative ground water in the test zone for use as the contact liquid in this test method shall be accomplished in accordance with Practices D 3370, using sampling devices that will not change the quality or environmental conditions of the waters to be tested. Recommended methods include the use of Kemmerer samplers or inert gas pressure lifts (provided this does not alter the ground-water sample by stripping out carbon dioxide and raising the pH, for example) or submersible diaphragm-type pumps. Proper precautions should be taken to preserve the integrity of in situ conditions of the sampled water, and in particular to protect against oxidation-reduction, exposure to light for extended periods, and temperature variation.

NOTE 1—It is recognized that sampling is likely to be a major problem. Materials (or fractures) that the contaminants pass through are likely to be the most difficult part of the geologic section to sample. In addition, proper sampling entails determining the path of ground-water flow so that the critical materials can be sampled. This determination is seldom accomplished in sufficient detail in normal geologic site exploration programs, and, if it is attempted in some cases, the exploration program may become unacceptably expensive. Specific guidelines are beyond the scope of this test method, however, it is recommended that geologic and water sampling procedures be carefully considered by the personnel involved in the site examination.

7. Procedure

7.1 This test method can be applied directly to consolidated core material samples or to disaggregated portions of the core material samples. For the applications intended for this test method, however, disaggregation of the samples is the recommended procedure. Disaggregate the sampled soil and friable core materials (this may be done by ultrasonic method although it should be noted that the effect of ultrasonics on the microstructure of geological material may lead to higher sorption values in certain cases). If a sufficiently large-sized sample is available, separate 200-g portions through a "nonbias" riffle splitter. Crush competent sedimentary rock materials to a desired particle size or equivalent soil texture anticipated to result from natural weathering processes (this is because surface area is controlled by sample particle size).

NOTE 2—A significant source of error may be introduced by disaggregating the sample in a batch test in that (*a*) disaggregation can mask a preferred flow path (either horizontal or vertical), (*b*) disaggregation can destroy the effect of preferred flow paths caused by fractures or perhaps thin sand stringers, and (*c*) disaggregation will tend to increase the available surface area of the geologic materials. It is for the purpose of achieving uniformity of application, however, that disaggregation is recommended for this test method. It should be realized by persons applying results from this method that inclusion of the disaggregating operations may for these reasons tend to maximize the values of the distribution coefficients (ratios) obtained from this test method.

7.2 In some cases, it may be desirable to remove organic material from the geomedium (soil specimen) for comparative purposes. If this is so indicated, remove the organic material from the composite sample mixtures for selected samples by treatment with concentrated hydrogen peroxide (30 % H_2O_2), using the procedure given in "Soil Chemical Analysis."[5] In such a case, make duplicate runs using samples both with and without pretreatment to remove organics. It should be noted, however, that treatment with concentrated hydrogen peroxide could cause other changes in the geomedium, for example, dissolution of hydrous metal oxides that may be important adsorbents.

7.3 Using standard analytical procedures, characterize the geologic specimen (without pretreatment and, if so done, with the pretreatment to eliminate organics) as considered appropriate. The analyses may include percent chemical composition of anhydrous oxides (for example, SiO_2, FeO, MnO, CaO, Na_2O, etc.), hydrous oxides (for example, Fe, Mn, and Al hydrous oxides), and minerals that are present, and carbonate content, surface area (m^2/g), and cation and anion exchange capacity (at specified pHs). Similarly, characterize the contact liquid obtained from the test zone as appropriate for interpreting the results. Chemical analysis of the liquid should include macro constituents (for example, Na^+, Ca^{++}, K^+, Mg^{++}, Cl^-, $HCO_3^-/CO_3^=$, SiO_2, etc.) and redox-active and hydrolyzable species such as Fe and Mn ions. Likewise, determine the pH and Eh of the contact liquid, as well as the concentration (if present) of the chemical species of interest. Specific instructions for the Eh determination are not part of this test method, however, use of a referenced technique is advised (such as a platinum versus standard calomel electrode measurement). If the species of interest may exist in the contact liquid in a variety of valence or chemical states (for example, with studies of actinides), a method of determining speciation should be applied.

7.4 Pass each of the soil and rock (core sediments) fractions again through a "nonbias" riffle splitter and place

[5] Jackson, M., *Soil Chemical Analysis*, Prentice Hall, Englewood Cliffs, NJ, 1954.

weigh everything

four 5- to 25-g portions (record weight to nearest 0.1 g) in centrifuge tubes or bottles.

NOTE 3—Unless it is decided that the samples may be allowed to dry by exposure to the open air, record a moisture weight (for comparative purposes, a moisture content determination should be done with a separate sample). Some soils never dry in nature, and characteristics may be greatly altered when dried. This is especially true for originally anoxic sediments. If the samples are not to be allowed to dry before testing, follow Practice D 2217 (Procedure B) for maintaining a moisture content equal to or greater than the natural moisture content. In all cases, the contact liquid used in this test is the sampled ground water from the site test zone.

7.5 If a radiotracer or spiked stable tracer determination of the distribution ratio is desired, pretreat the composite samples with exact solution (contact liquid) used in the determination but without the tracer present. This solution will be either the site-specific ground water or a selected intrusion water. Wash the composite soil and rock samples four times with the pretreatment solution. For the first three washes, stir the mixtures of soil and rock and pretreatment solution several times over a 15-min period, allow to settle, centrifuge at 1000 g or more for 5 min, and decant off the wash. Apply the fourth wash for at least 24 h with occasional stirring, and again separate the wash from the composite sample by centrifugation and decantation as before.

7.6 It may be advisable to pre-equilibrate the treatment solution (contact liquid) with the geomedia prior to the start of this test method. Proceed as in 7.5, using the fourth wash after centrifugation and decantation as the treatment solution. Unless otherwise noted, add 20 to 100 mL (exact value should be equal to four times the weight in g of the geomedia) to each 100 to 250 mL centrifuge tube or bottle, and thoroughly mix the contents by stirring action. Prior to contact, the treatment solution should contain the species of interest at a known concentration prepared by the addition of chemically pure reagents to the site-specific ground-water sample. (The species of interest may be at trace concentration; if it is a radioactive or stable tracer added to the treatment solution, the elemental concentration as well as the isotopic concentration must be known.) If tracers are used, first equilibrate the tracer with the ground-water (or intrusion-water) sample by allowing to stand overnight and then filter using a ≤0.45 μm pore size membrane filter. Following this step, analyze the contact solution and add to the soil and rock composite samples as indicated above. Measure the pH of the soil/rock-solution system; if the pH has changed or if other than the natural pH is desired, adjust by addition of *N* NaOH solution or HCl, or by an appropriate buffer. The in situ Eh should be maintained, if necessary, under an inert atmosphere.

NOTE 4—Experiments have shown that R_d will vary depending on the solution-to-geomedium ratio used in the test. If other ratios are indicated (which would more closely approximate the normal field situation), duplicate runs should be made, however, the ratio prescribed here should also be run as the reference case. Because R_d varies with the solution/medium ratio, it is strongly recommended that this measurement include determination of the isotherm by making several runs with different ratios of solution-to-geomedium than specified above.

NOTE 5—Some analytical techniques may require larger volumes of sample fluid. Increased volume can be obtained by compositing samples or by scale-up using larger centrifuge tubes.

7.7 Determine the specific conductance of each solution and report in units of micromhos per centimetre at 20°C.

7.8 Run each set of samples at least in triplicate to demonstrate that steady state is attained in this short-term test. Stir the contents of each contact tube, then gently shake all of the soil/rock solution mixtures on a laboratory shaker/rotator for a minimum of 6 h for every 3-day portion of the contact period. The contact periods shall be for a minimum of 3 days, and the longest shall extend to 14 days or longer. The contact periods shall differ by at least a 3-day period. During the latter 1 or 2 days of the contact period, allow all mixtures to stand and settle. If the variation of R_d with exposure time for these three or more contact periods is greater than the precision expected for this experiment, then the determination should be repeated for longer times until such a consistency is obtained. This is taken to be an indication that steady state has been established. In cases where the steady-state situation is not achieved, the extension of R_d values to the prediction of migratory behavior becomes of dubious value and requires clear reference to the inexactness of the application.

7.9 Measure and report the pH and Eh of all mixtures (in many investigations, pH and Eh will not vary greatly, so it might not be necessary to measure them on all samples).

7.10 Centrifuge each mixture for 20 min at a minimum setting of 1400 g. Controlled temperature centrifugation may be advised, particularly in the case of experiments run below ambient temperature. Carefully separate the phases. For the supernatant, the concentration of the species of interest can be directly determined using the appropriate standard analytical method.

7.11 If filtering is necessary or if desired for comparative purposes, use polycarbonate member filters (0.002 to 0.02 μm pore size), or the equivalent. Pretreat the filter disc by passing through it approximately 50 mL of 1.0 *N* HCl, followed by 50 mL of distilled water, by gravity flow or suction to near dryness. Check the possibility of sorption of tracers onto the filter by a standard "double filter" technique using the original contact solution.

7.12 Filter the supernate from each soil/rock-solution

TABLE 1 Example Calculation Sheet

The distribution ratio is given by:

$$R_d = \frac{(F_m)(V_s)}{(F_s)(W_m)}$$

where:

R_d = distribution ratio, mL/g,

F_s = fraction of total activity in solution, which equals the total concentration in solution, assuming the activity coefficients of a given ion were the same before and after steady state was attained in contact of the solution with the soil/rock materials (that is, the ionic strength is unchanged). Making this assumption, F_s is found by dividing the concentration of the ion *after* the solution has come to "equilibrium" (reaches steady state) with the soil/rock fraction by the concentration (of same units) of the ion *before* the solution was allowed to come to equilibrium with the soil fraction,

F_m = fraction of activity sorbed onto the mineral or solid residue (correcting for the natural content of the species of interest initially present), or, making the same assumption as to activity coefficients,

$$F_m = 1 - F_s$$

V_s = volume of solution "equilibrated" with W_m, mL, and

W_m = weight of mineral or solid residue, g.

In the case of a radioactive species of interest, where the radioactivities of the solution and solid residue are determined, the distribution coefficient is given by:

$$R_d = \frac{(A_m)(V_s)}{(A_s)(W_m)}$$

where:

A_m = activity of the mineral or solid residue, mCi, and

A_s = activity of the solution "equilibrated" with W_m, mCi.

TABLE 2 Example Report Sheet

Tabulated Results for Distribution Ratio Determination of Sample Number _____:
Contact liquid: Site-Specific Ground Water _____ Other (intrusion) Water _____ initial pH _____ initial Eh _____; method of determining Eh _____
final pH _____ final Eh _____ temperature _____°C specific conductance _____ μmhos/cm solid-to-liquid ratio _____ g/mL
contact time _____ da equilibrating atmosphere _____ air _____ other (specify) contact solution filtered after centrifugation? _____ yes
_____ no disaggregated? _____ yes _____ no particle size _____ mm H_2O_2 treatment to remove organics? _____ yes
_____ no calculated dry weight of solid _____ g volume of contact liquid _____ mL species of interest _____ method of analyzing for species of interest

(use separate sheet if necessary)

Site description, sampling methodology and core material description, analysis of core materials and of site-specific ground water or other contact liquid:

ATTACH SHEET

Species (Ion) of Interest	Initial Conc. in Solid (units)	Initial Conc. in Solution (units)	$F_s F_m R_d$	(mL/g)

mixture by gravity flow or suction to near dryness. Determine the concentration and speciation (chemical state), if it is variable, of the species of interest in this solution by the appropriate standard analytical method. Make a blank determination using the equivalent procedure outlined here (7.6 through 7.12, except do not add the soil/rock sample) with treatment solution only. The use of tracers involves particular attention to corrections for blanks and potential plateout of the tracer on container walls, filters, and other surfaces as well as other losses. For example, it should be ascertained that loss of tracer to the blank vial walls is the same as for the walls of the sample vial, etc.

7.13 If necessary or if desired for comparative purposes or for a mass-balance determination, determine the concentration of the species of interest for each filtered solid residue. In this case, note the necessity of removing the residual solution from the solid phase, or correcting for it, particularly for solids with low R_d values. If this determination is made, a correction is required for the amount (if any) of the species of interest to be found naturally present in the soil/rock sample. Provided a satisfactory analysis is accomplished for the species concentration in the soil/rock residue, calculate R_d by dividing this value (g solute per g solid residue) by the final concentration in the contact solution (g solute per mL solution), assuming the filter did not remove tracer from the solution. An alternative method is to compute R_d as shown on the Example Calculation Sheet (Table 1).

8. Precision and Bias

8.1 The accuracy of this test is operator-dependent and is a function of the care exercised in performing the steps and systematic repetition of the procedures used. Subcommittee D18.14 is seeking pertinent data from users of this test method on precision and bias.

8.2 *Within Laboratory Precision*—Precision results (repeatability) for distribution ratios by short-term batch method for Cd, Hg, Se, and Sr have been reported by Del Debbie and Thomas[6], and are found to be in the range of 1 % to 7 %. Fuhrman[7], et al. reported R_d values for Cs with a precision (repeatability) of 4 %.

8.3 *Multi-Laboratory Precision*—Precision of distribution ratio by short-term batch method between different laboratories has not been determined yet. Subcommittee D18.14 is seeking pertinent data from users of this test method on reproducibility conditions.

8.4 *Bias*—Since there is no accepted reference material suitable for determining the bias for the procedure in Test Method D 4319, Distribution Ratios by the Short-Term Batch Method, bias has not been determined.

9. Keywords

9.1 adsorption; attenuation; batch sorption; distribution ratio; geochemical; ground water; ion exchange capacity; liquid migration; modeling; short-term batch

[6] Del Debbie, J.A., and Thomas, T.R., *Hazardous Properties of Radionuclides and Hazardous Chemical Species in Soils at the Idaho Processing Plant*, WICNO-1068, Westinghouse Idaho Nuclear Company, Inc., Idaho Falls, ID, October, 1989.

[7] Fuhrman, M., Pietrzak, R., and Colombo, P., "Distribution Ratios of Cs-13 in Sediments from the Black Sea," *Draft Report. Department of Nuclear Energy*, Brookhaven National Laboratory, Upton, NY, December, 1990.