Mobility of Uranium and Molybdenum from Subsurface Materials Dam-to-Ditch Area, Cotter Uranium Mill, Cañon City, Colorado

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1.0 INTRODUCTION

This report presents the results of a column leaching study that was designed to characterize uranium and molybdenum mobility from subsurface geologic materials in the Cotter Corporation (Cotter) Dam to Ditch Area (DDA) near Cañon City, Colorado. The DDA extends from the north side of the Soil Conservation Service (SCS) Dam, located near the northern boundary of the Cotter site, to the Deweese Dye Ditch, north of Well 006 (Figure 1). Both uranium and molybdenum concentrations in Well 006, and in other DDA groundwater locations, are present at levels that exceed Colorado Groundwater Quality Standards (CGWQS) of 0.030 mg/L and 0.035 mg/L, respectively. The elevated uranium and molybdenum within the DDA is believed to have originated from a combination of overland flow along the Sand Creek Drainage from the Cotter Mill, and to a lesser extent, from groundwater flowing beneath the SCS Dam (HydroSolutions, 2010).

A field investigation was conducted in August 2010 to better understand the areas of impacted groundwater in the DDA, and to characterize potential sources and pathways for migration of uranium and molybdenum to the north. The results from the 2010 investigation were used to update the existing Site Conceptual Model (SCM) with respect to the geologic, hydrologic, and water quality conditions within the DDA (HydroSolutions, 2010). In addition, geologic materials were collected from monitoring well borings for use in a column leaching study. The objective of the column study was to characterize the mobility of uranium and molybdenum from subsurface materials and to evaluate their potential as a source of elevated uranium and molybdenum to groundwater in the DDA. The information collected during the column study will also be used in support of potential future corrective actions for the DDA, if necessary.

2.0 DESIGN AND IMPLEMENTATION OF COLUMN LEACHING STUDY

This section describes the selection and characterization of the geologic materials, column construction and preparation, synthesis of leach solutions, and column leaching procedures.

2.1 Materials Selection and Characterization

In August 2010, thirteen borings were drilled in the DDA, and two borings were drilled offsite to the north of the DDA (Figure 1) with continuous sampling (Engineering Analytics, Inc. (EA), 2010). The borings ranged in depth from approximately 27.5 to 65 feet and contained unconsolidated brown to yellowish-brown sands, silts, clays (SSC) with some gravel in the upper 15 to 35 feet. The SSC were usually underlain by weathered claystone (WCS), which varied in thickness from about 1 to 10 feet. Unweathered claystone (CS) was encountered at five of the locations and ranged in thickness from <1 to approximately 20 feet. Borings that extended below the WCS and CS encountered a dense, gray to brown sandstone (SS) with occasional iron staining. The low moisture contents and an abundance of brownish-yellow coloration and iron staining indicated that oxidizing conditions predominate in the subsurface.

Due to the presence of oxidizing conditions, the drill cuttings did not require any specialized preservation techniques and were stored in clean cardboard core trays prior to preparation for column leaching.

Eight columns were prepared to represent various material types for leaching (Table 1). Each column contained a composite of similar geologic materials to obtain an adequate amount of material for leaching. Columns 1 through 3 were designed to evaluate uranium and molybdenum mobility from vadose zone materials (SSC); however, some WCS material was inadvertently combined with the SSC material during preparation of Column 3, and therefore Column 3 contained approximate equal amounts of SSC and WCS. The remaining columns were prepared to evaluate uranium and molybdenum leaching from WCS (Columns 4 and 5), CS (Column 6), and SS (Columns 7 and 8) materials that typically occur in the saturated zone (Table 1). A single sample (approximately 200 grams) of the homogenized material representing each column was collected and analyzed for total uranium and molybdenum content prior to leaching. Two additional columns (not included in Table 1) were also prepared using only clean silica sand to obtain column solution equipment blanks.

Two different leach solutions were used in the column study: (1) a meteoric water leach solution (MWLS) with pH adjustment to simulate percolation of natural precipitation through the vadose materials (Columns 1 through 3), and (2) a synthetic groundwater solution (GWS) to simulate interaction of Vermejo Formation groundwater with saturated-zone materials (Columns 4 through 8). Details regarding preparation of both solutions are described in Section 3.3. Use of synthetically-prepared leach solutions offers the advantage of being able to prepare large volumes of fresh, unimpacted leach solutions with consistent chemical composition.

2.2 Leach Column Design and Construction

The column design and operation guidelines were provided by AMEC Earth & Environmental (AMEC, 2010), and the columns were subsequently constructed and operated at the Cotter Uranium Mill Site in Cañon City, Colorado. A simple downflow, gravity-driven column design was utilized for the column leaching study (Figure 2). The columns were built using 54-inch (4.5-foot) lengths of Schedule 40 PVC pipe with a 6-inch inside diameter. All column parts were thoroughly cleaned before loading by washing with soap and water followed by rinsing with distilled water. The bottom of each column was equipped with a PVC base plate containing a piece of felt to prevent loss of solid materials from the columns during leaching. The base plate was equipped with a valve to control the discharge of column effluent. A 2-gallon (7.6 liter) plastic bucket equipped with a re-sealable lid (fitted with a threaded hose barb) was attached to discharge tubing running from the bottom of each column for sample collection.

2.3 Materials Preparation and Column Loading

The geologic samples specified in Table 1 were selected to provide representative materials for compositing, with a capacity to provide 3 feet of material per column based on knowledge of sample recovery (EA, 2010). The column tests were designed to provide adequate water-rock contact and flushing such that a relatively large number of pore volumes can be passed through the columns over a short time frame. Therefore, some degree of particle size reduction was required to increase the uniformity of surface area and the consistency of placement inside of the columns. The materials were first air-dried and the less-competent and unconsolidated materials were then passed through a vibrating screen to obtain a particle size of ≤ 0.50 inches. The remaining fraction was then passed through a mechanical jaw crusher, and the screening process was repeated to obtain the ≤0.50-inch fraction. This particle size meets the requirements for maximum particle diameter not to exceed 1/10 of the inside diameter of the column (ASTM, 2001). Prior to placement into the columns, each composite sample was thoroughly mixed to obtain a homogeneous sample.

Following particle size reduction and material homogenization, the columns were filled to a height of 3 feet with the appropriate sample (Table 1). A plastic 500 mL transfer container was used to weigh smaller portions of each sample while loading the columns in 4- to 6-inch lifts. Each lift was gently compacted by tapping on the sides of the column with a rubber mallet. This process was repeated for each column until a material height of 3 feet was obtained. The mass of each transfer was recorded and summed to determine the total mass of material in each column (Table 1). Approximately 2 to 4 inches of clean silica sand were placed both into the top of the column and above the PVC base plate to promote an even distribution of leaching solution. Equipment blank Columns 9 and 10 were constructed in a manner identical to Columns 1 through 8 (including silica sand), except for the addition of rock sample.

2.4 Pore Volume Calculation

Due to slight variations in bulk density between the different column materials (SSC, WC, CS, and SS), it was necessary to calculate their specific pore volume because the columns were leached on a pore-volume basis. Using the total air-dry mass of the material in each column, the bulk density of the material was calculated by dividing the sample mass (g) by its volume (16,672 cm^3 for 3 feet of material in a 6-inch diameter column) (Table 1). The porosity of the material in each column was then calculated using the following relationship:

$$f = 1 - (\rho_b / \rho_s) \qquad [1]$$

where: f = porosity
ρ_b = bulk density (g/cm^3)
ρ_s = particle density (estimated) = 2.65 g/cm^3.

The calculated porosity was then multiplied by the volume of material (16,672 cm^3 for 3 feet of material in a 6-inch diameter column) to obtain pore volume in units of cm^3 (mL). The calculated pore volumes ranged from 5,800 to 8,500 mL (5.8 - 8.5 liters or 1.5 - 2.3 gallons) (Table 1).

2.5 Leach Solution Preparation

Vadose zone columns (Columns 1 through 3) were leached using the meteoric water leach solution (MWLS) prepared from distilled water by adjusting the pH to 5.2 to simulate the pH of natural precipitation in the Cañon City area (NADP, 2010). The MWLS was prepared from a stock 60/40 weight percent mixture of H_2SO_4/HNO_3 in a manner consistent with the U.S. EPA Synthetic Precipitation Leaching Procedure (USEPA, 1994). Fresh MWLS was prepared from the stock solution prior to each leaching step. A subsample from each batch of MWLS was collected as a leachate blank for Columns 1 through 3, filtered through a 0.45 µm pore-size filter, and preserved with HNO_3 (pH <2) for analysis of dissolved uranium and molybdenum.

The saturated zone columns (Columns 4 through 8) were leached using a synthetic Vermejo Formation groundwater solution (GWS), because adequate volumes of non-impacted Vermejo site groundwater were not available. The synthetic GWS was prepared to match the composition of groundwater measured in DDA Well 051 during October 2010 (data supplied by Cotter). The Vermejo GWS was prepared using distilled water and standard laboratory reagents ($CaSO_4$, Na_2SO_4, and $NaHCO_3$). The resulting GWS was a Na-HCO_3-type water with slightly-alkaline pH (8.1) and a total dissolved solids (TDS) concentration of 2,100 mg/L. Fresh GWS was prepared prior to each leaching step. A subsample from each batch of GWS was collected as a leachate blank for Columns 4 through 8, filtered through a 0.45 µm pore-size filter, and preserved with HNO_3 (pH <2) for analysis of dissolved uranium and molybdenum.

2.6 Column Leaching, Sampling, and Analysis

Prior to addition of Pore Volume (PV) 1, Columns 1 through 8 were moistened to field capacity using the appropriate leaching solution (Table 1). Solution was added to the top of each column in small increments to allow the solution to be fully-absorbed into the sample matrix, until discharge began to drip from the column outlet. Following the field capacity adjustment, leaching of PV 1 through 10 was initiated. Either the MWLS or GWS was added to the top of the respective column, which was then covered with plastic film containing a small hole to minimize evaporation and to reduce the potential for atmospheric contamination. The leach solutions were then allowed to pass through the columns by gravity until the columns ceased to drain. At the completion of each pore volume leach, a filtered (0.45 µm pore-size) sample was collected from the leachate collection reservoir, placed into a clean plastic sample bottle, and preserved using HNO_3 (pH <2). The leaching process was repeated to obtain a total of 10 pore volumes from Columns 1 through 10. The leachate samples were analyzed for dissolved uranium, molybdenum, major cations (Ca, Mg, Na, K), and major anions (Cl, SO_4, HCO_3).

2.7 Column Leachate and Solid Phase Evaluation

The concentrations of dissolved uranium and molybdenum measured in the column leachates were plotted as a function of pore volume to evaluate the leaching characteristics of the various materials (Table 1). If uranium or molybdenum were detected in the column blanks, the column leachate concentrations were corrected by subtracting the measured blank concentration from the appropriate pore volume. The cumulative mass of uranium and molybdenum leached from each column (on a mg/kg basis) was calculated from the effluent concentrations, pore volume, and mass of material in each column. The cumulative uranium and molybdenum masses were then compared to their total solid-phase concentrations to determine the fraction that was leached from the columns.

The uranium, molybdenum, and major ion concentration data from the column leachates were input to the geochemical speciation model PHREEQC (Parkhurst and Appelo, 1999), which was used to calculate saturation index values for a number of uranium- and molybdenum-bearing phases. Negative SI values indicate undersaturation, while positive SI values indicate oversaturation, with respect to a given mineral phase. An SI value of 0 indicates the solution and mineral phase are in equilibrium, and that the respective mineral phase may be important in controlling the solution chemistry.

3.0 COLUMN LEACHING STUDY RESULTS

This section describes the observed trends in uranium and molybdenum concentrations as a function of pore volume leached from the columns. Geochemical modeling results are also evaluated with respect to potential mineral phases that may act to control uranium and molybdenum concentrations in the leachates. The tabulated column effluent concentrations, mass balance calculations, and computed saturation index values are provided in Appendix A.

3.1 Uranium and Molybdenum Concentration Trends

The highest leachable uranium concentrations were associated with WCS material in Columns 4 and 5 (Table 1). The initially-elevated uranium concentrations in these column effluents decreased at similar rates with increased leaching, although uranium concentrations remained above the CGWQS of 0.03 mg/L after 10 pore volumes (Figure 3). Elevated uranium concentrations were also initially leached from the SSC material in Column 1, but the concentrations decreased more rapidly in comparison, and dropped below the CGWQS after 9 pore volumes. The uranium concentrations in the SSC effluent from Columns 2 and 3 were much lower in comparison, and both were below the CGWQS after 2 pore volumes (Figure 3).

The initial uranium concentrations in the CS and SS materials from Columns 6 and 7, respectively, were above the CGWQS, and remained relatively constant during the experiment after PV3 (Figure 4). The SS material from Column 8, collected from boring CC049 further to the

north (Table 1, Figure 1), also produced initial concentrations that exceeded the CGWQS, but which subsequently decreased to concentrations less than 0.03 mg/L after PV4. The relatively stable leachate uranium concentrations from the CS and SS (Figure 4), as compared to the rinse-out behavior observed for the SSC and WCS (Figure 3), indicates that a source of natural mineralization may be contributing to the leachable uranium from the CS and SS.

The column leachate concentration trends for molybdenum were similar to those for uranium. The initial (PV1) molybdenum concentrations in the SSC and WCS column leachates exceed the CGWQS of 0.035 mg/L and were comparable, with the exception of the SSC material from Column 1, where the initial molybdenum concentration was 0.84 mg/L (Figure 5). The molybdenum concentrations in all of the SSC and WCS column leachates remained above the CGWQS after 10 pore volumes, except for the SSC material from Column 3 (Figure 5). The initial leachate molybdenum concentrations from the CS and SS Columns 6 though 8 were also at or above the CGWQS of 0.035 mg/L, but were all reduced to levels below the CGWQS after PV 6 (Figure 5). Leachable molybdenum concentrations from the CS and SS materials (Figure 6) were lower than those from the SSC and WCS materials (Figure 6).

3.2 Solid Phase Evaluation

In the column solids, total uranium ranged from 2.8 to 7.4 mg/kg and total molybdenum ranged from 0.26 to 0.93 mg/kg (Table 2). A mass balance analysis of the column effluents (Appendix A, Tables A-2 and A-3) indicates that 0.54 to 9.9% of the total uranium and 16.1 to 259% of the total molybdenum were leached from the columns. The low percentage of uranium released from the columns indicates the majority of uranium in the aquifer materials is sparingly soluble. However, molybdenum appears to be more soluble than uranium based on greater cumulative leaching percentages for molybdenum. Calculated cumulative molybdenum values that exceed 100% (Table A-3) may be a result of variation in the molybdenum content of the materials.

The results of saturation index calculations indicate that the column leachates are highly undersaturated with respect to the common uranium minerals rutherfordine (UO_2CO_3), schoepite ($UO_2(OH)_2$), uraninite (UO_2), and amorphous UO_2 (Table A-2). Therefore, uranium in the aquifer materials probably exists as oxidized uranium (UO_2^{2+}) present as adsorbed species on mineral surfaces. The majority of the saturation index values for calcium molybdate ($CaMoO_4$), a mineral that commonly controls molybdenum concentrations in soils, also indicate undersaturation (Table A-3). Consequently, molybdenum in the column materials also probably exists as adsorbed molybdenum associated with mineral surfaces.

4.0 CONCLUSIONS

Column leaching results from vadose- and saturated-zone aquifer materials collected from the Dam to Ditch Area (DDA) north of the Cotter site indicate that a portion of the total uranium and molybdenum is readily released upon interaction with both natural precipitation and local

groundwater. Most columns produced leachates whose initial concentrations exceeded CGWQS for uranium and molybdenum, but with concentrations that continued to decrease with increased leaching. Higher uranium and molybdenum leachate concentrations were often associated with the vadose-zone SSC and WCS materials, compared to the underlying CS and SS materials, whose leachable uranium which may contain a component of natural mineralization. The results of mass balance calculations show that only a small fraction of the total uranium was released, whereas molybdenum was more soluble. Geochemical modeling indicated undersaturation with respect to the common uranium- and molybdenum-containing minerals in the column leachates, and therefore uranium and molybdenum likely exist as adsorbed species associated with mineral surfaces.

Although the findings from this study indicate the potential for soils and aquifer materials to produce elevated uranium and molybdenum concentrations in DDA groundwater, only a small fraction of the total uranium and molybdenum is expected to be released by natural leaching. However, the results suggest that in situ leaching of the DDA materials with a selective extraction solution could be used to remove a larger fraction of the total uranium in fewer pore volumes. If Cotter plans to pursue field pilot testing for remediation of the DDA materials, it is recommended that additional batch-leaching tests first be conducted to assess the effectiveness of various extraction solutions in removing uranium and molybdenum from the DDA soils and aquifer materials.

5.0 REFERENCES

AMEC Earth & Environmental (AMEC). 2010. Scope of Work to Evaluate Leaching of Uranium and Molybdenum from Geologic Materials for the Dam to Ditch Area Investigation, Cotter Corporation Uranium Mill, Cañon City, Colorado. Prepared for Cotter Corporation, Cañon City, Colorado.

American Society for Testing and Materials (ASTM). 1995. Standard Test Method for Leaching Solid Material in a Column Apparatus. Designation: D 4874-95. ASTM, West Conshohocken, PA.

Engineering Analytics, Inc. 2010. Oversight of Soil Boring and Monitor Well Installation Activities, Dam to Ditch Area, Cañon City, CO.

HydroSolutions. 2010. Field Investigation Results, Dam to Ditch Area, Northeast of the Cañon City Milling Facility. November 30.

National Atmospheric Deposition Program (NADP). 2010. Hydrogen ion concentration as pH from measurements made at the Central Analytical Laboratory (2008). http://nadp.sws.uiuc.edu

Parkhurst, D.L. and C.A.J. Appelo. 1999. User's Guide to PHREEQC (Version 2) – A Computer Program for Speciation, Batch-Reaction, One-Dimensional Transport, and Inverse Geochemical Calculations. U.S.G.S. Water Resources Investigations Report 99-4259.

U.S. Environmental Protection Agency (USEPA). 1994. Method 1312: Synthetic Precipitation leaching Procedure. Test Methods for Evaluating Solid Waste (SW-846). http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1312.pdf

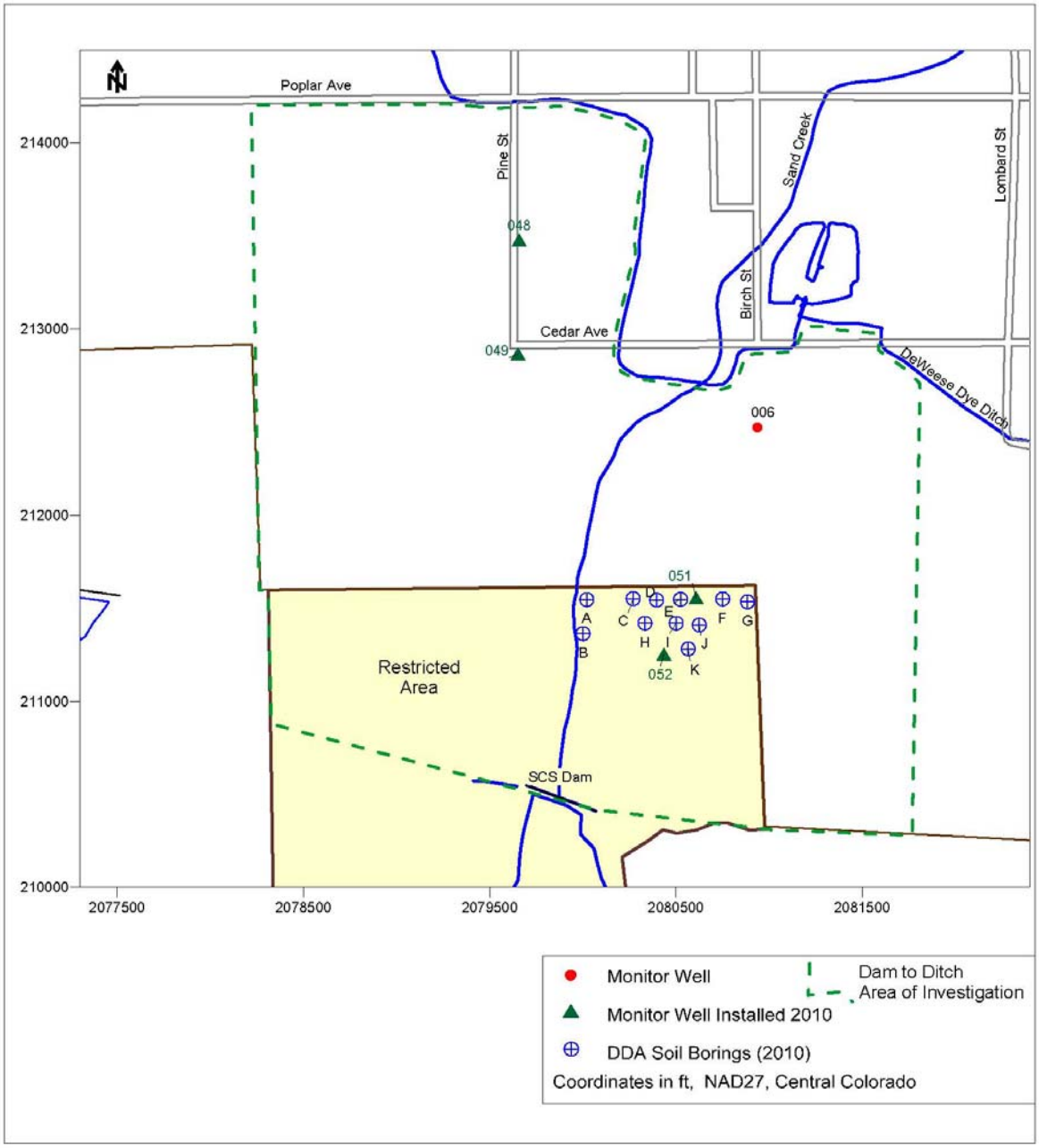
Table 1: Materials Selection and Laboratory Column Parameters

Column ID	Material Source Boring (interval, ft)	Simulated Zone	Material[1]	Leaching Solution[2]	Mass (kg)	Bulk Density[3] (g/cm^3)	Porosity[4] (%)	Pore Volume[3] (L)
1	SBE (0 –40)	Vadose	SSC	MWLS	28.8	1.73	35	5.83
2	SBA (0 -18) SBB (0 – 18)	Vadose	SSC	MWLS	25.9	1.55	42	7.00
3	SBC (0-24) SBD (0-29)	Vadose	WCS	MWLS	26.2	1.57	41	6.83
4	SBB (18.5 – 27) SBC (24.5 - 33.5) SBM (41.5 - 48)	Saturated	SSC	GWS	22.6	1.36	49	8.17
5	SBD (29.5 – 35) SBF (36.5 – 38.5) SBH (29 – 36.5) SBI (39 – 43) SBJ (32.5 – 36.5) SBK (20 – 23.5)	Saturated	WCS	GWS	21.5	1.29	51	8.50
6	SBA (24 – 29) SBC (35.5 – 43.5) SBI (39 – 43) SBL (43 – 59)	Saturated	WCS	GWS	23.0	1.38	48	8.00
7	SBB (29.5 – 33) SBF (38.5 – 41) SBJ (36.5 – 37) SBK (23.5 – 27.5) SBL (59 – 64)	Saturated	CS	GWS	24.5	1.47	45	7.50
8	CC049 (20 – 40)	Saturated	SS	GWS	23.0	1.38	48	8.00

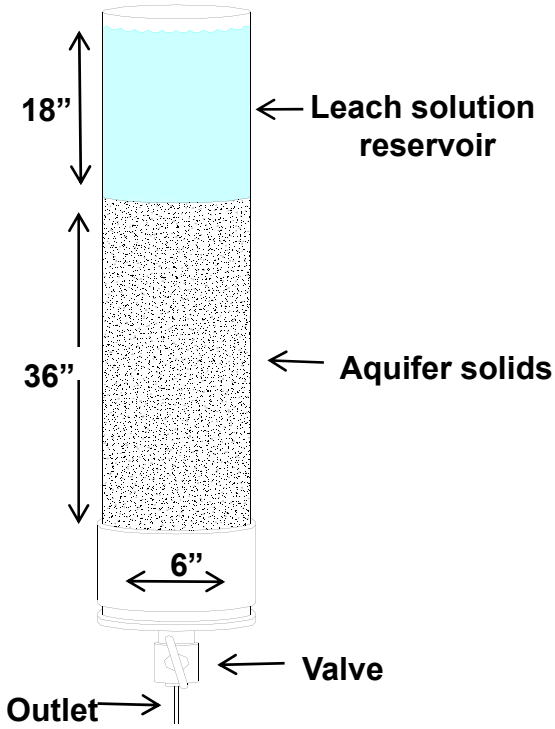
[1] SSC = unconsolidated sands, silts, and clays. WCS = weathered claystone. CS = claystone. SS = sandstone. [2] MWLS = meteoric water leach solution. GWS = groundwater solution. [3] Calculations based on 36 inches (91.4 cm) of material in a 6-inch (15.2 cm) diameter column (16,672 cm^3). [4] Calculation assumes particle density = 2.65 g/cm^3.

Table 2: Solid-Phase Uranium and Molybdenum Concentrations for the Column Materials

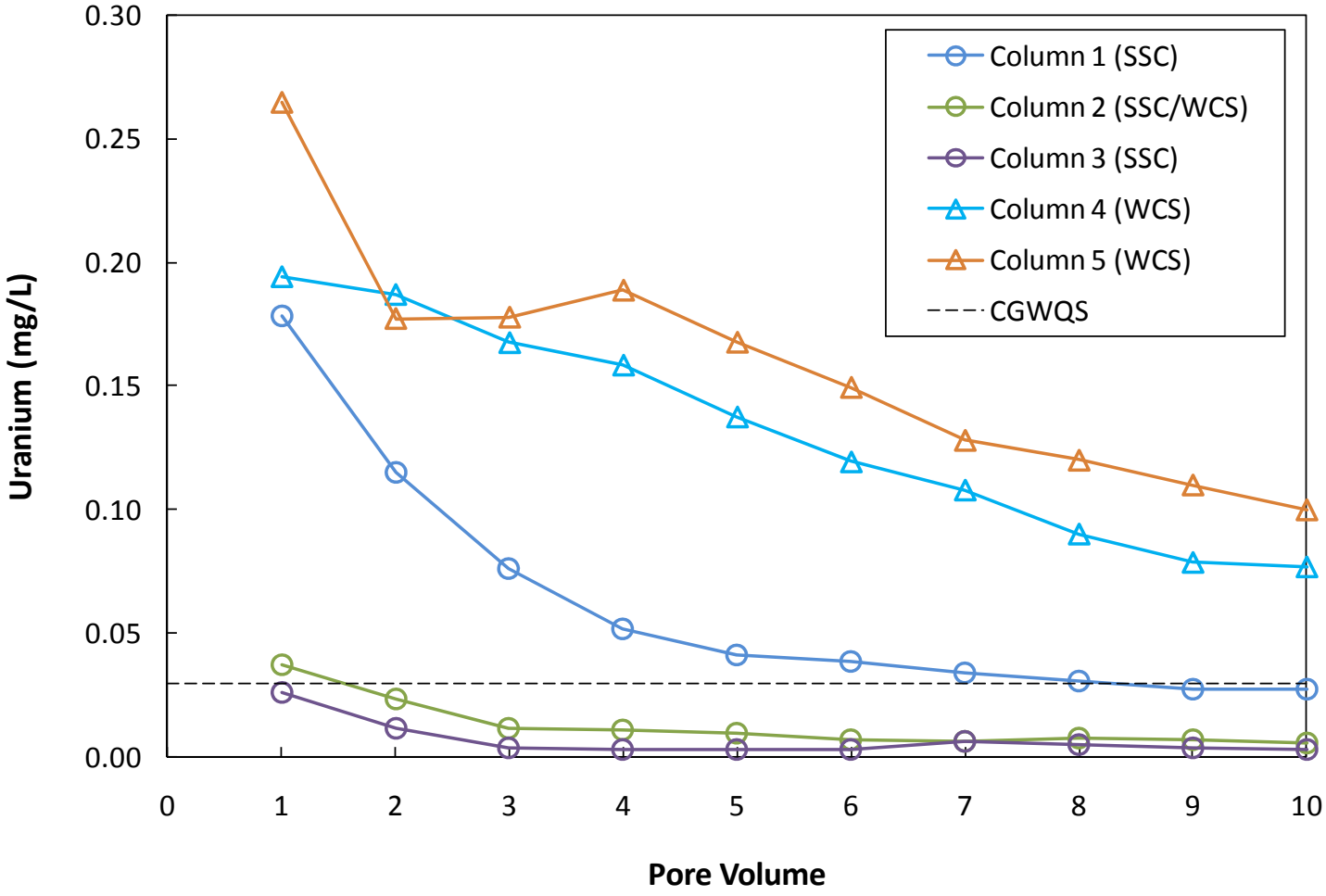
Column ID	Material	Uranium (mg/kg)	Molybdenum (mg/kg)
1	SSC	4.4	0.42
2	SSC/WCS	3.9	0.40
3	SSC	3.3	0.31
4	WCS	4.8	0.26
5	WCS	7.4	0.93
6	CS	4.6	0.49
7	SS	3.6	0.75
8	SS	2.8	0.35



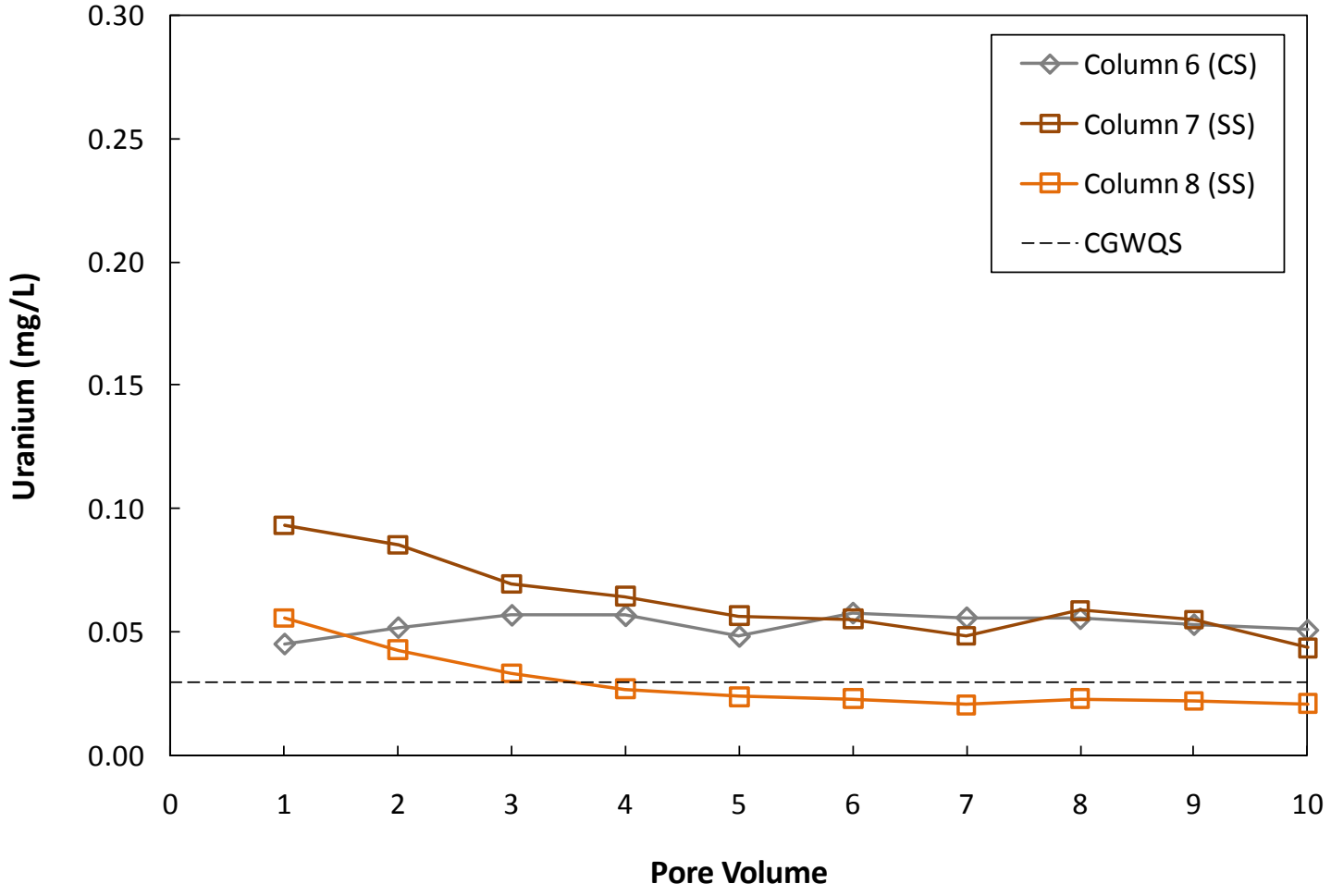
amec	DAM TO DITCH INVESTIGATION AREA SHOWING AUGUST 2010 BOREHOLE LOCATIONS	Project No. DE10160100
		Figure 1



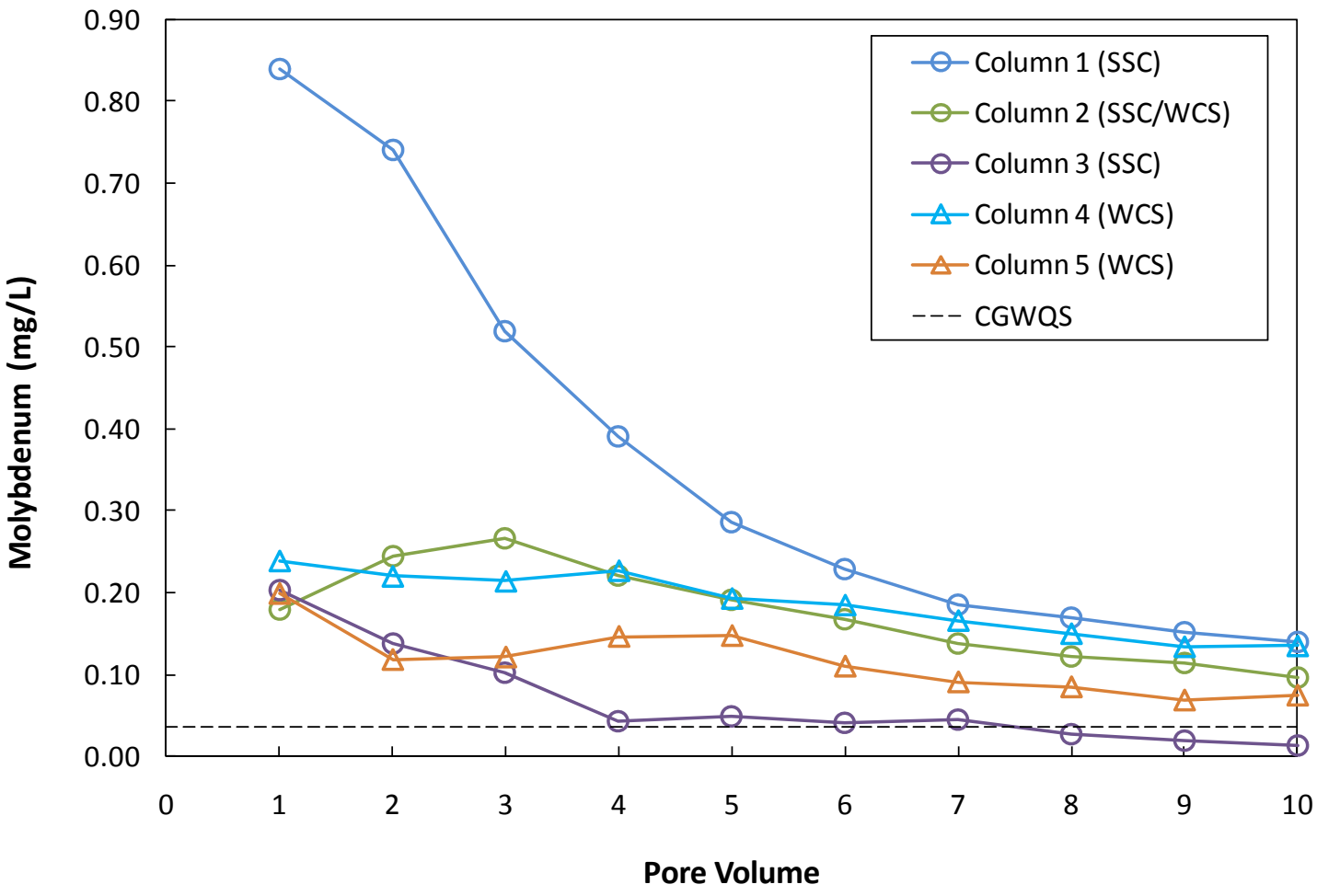
amec	COTTER DDA INVESTIGATION COLUMN DESIGN AND SETUP ASSEMBLY	Project No. DE10160100 Figure 2



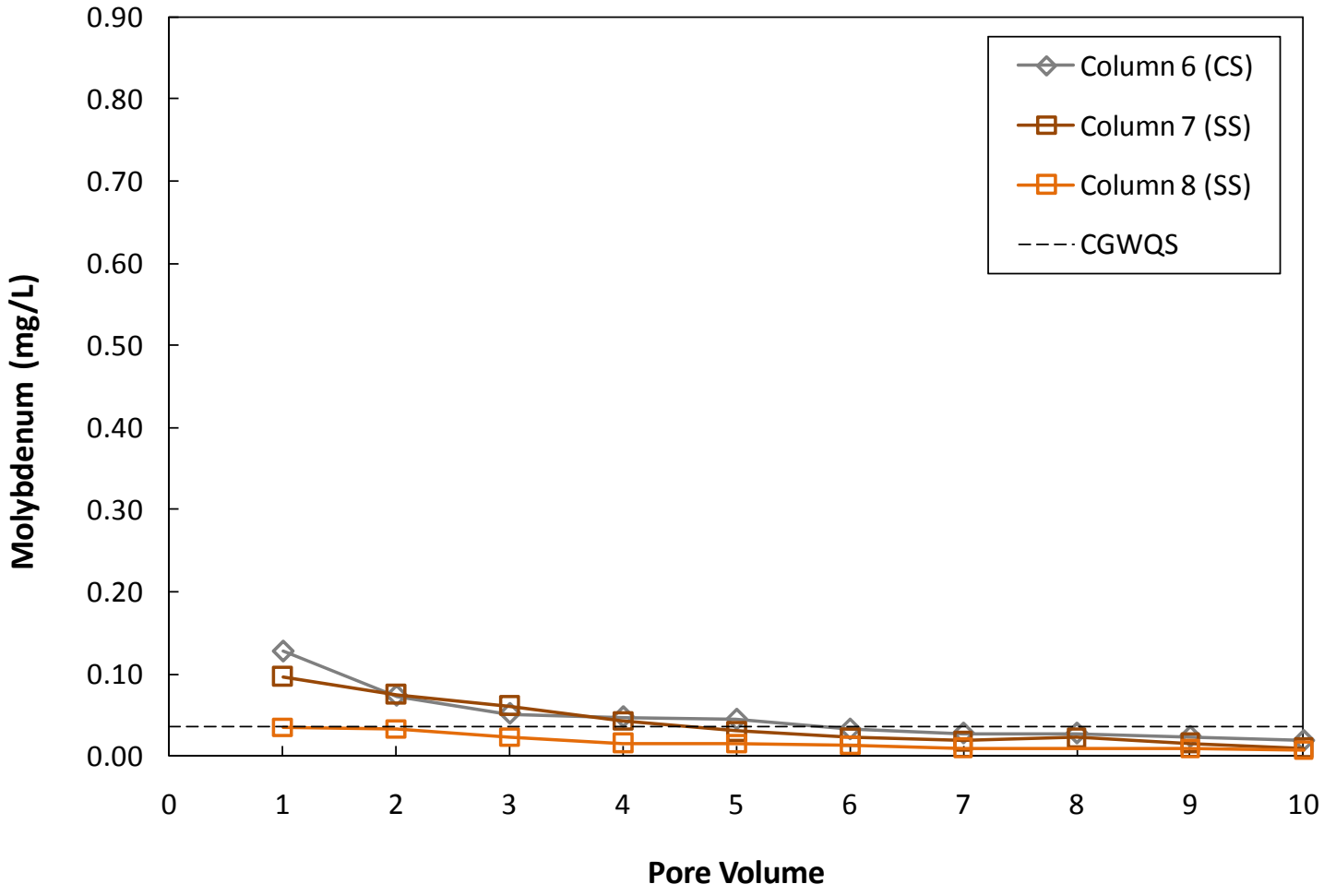
amec	URANIUM COLUMN LEACHING RESULTS FOR UNCONSOLIDATED SANDS, SILTS & CLAYS (SSC) AND WEATHERED CLAYSTONE (WCS)	Project No. DE10160100
		Figure 3



amec	URANIUM COLUMN LEACHING RESULTS FOR CLAYSTONE (CS) AND SANDSTONE (SS)	Project No. DE10160100
		Figure 4



amec	MOLYBDENUM COLUMN LEACHING RESULTS FOR UNCONSOLIDATED SANDS, SILTS & CLAYS (SSC) AND WEATHERED CLAYSTONE (WCS)	Project No. DE10160100
		Figure 5



amec	MOLYBDENUM COLUMN LEACHING RESULTS FOR CLAYSTONE (CS) AND SANDSTONE (SS)	Project No. DE10160100
		Figure 6

Appendix A:

Tabulated Column Data, Mass Balance Calculations, and Saturation Index Values

Table A1: Column Effluent Chemistry.

Column	Pore Volume	Sulfate	Chloride	Alkalinity	Potassium	Magnesium	Calcium	Sodium	Uranium	Molybdenum	pH
1	1	----- [1]	-----	-----	6.1	132.7	472.7	751.9	0.178	0.840	-----
1	2	1200	<3.1	78	5.1	51.2	216.6	279.5	0.115	0.740	8.11
1	3	710	<3.1	76	2.2	33.2	159.2	153.1	0.076	0.520	7.98
1	4	380	<3.1	146	0.5	19.2	103.1	87.3	0.052	0.390	8.01
1	5	260	<3.1	146	3.1	17.4	87.8	34.8	0.041	0.286	8.05
1	6	230	<3.1	120	2.4	16.0	83.5	19.7	0.039	0.228	8.15
1	7	140	<3.1	122	3.4	13.9	81.8	17.1	0.034	0.186	8.04
1	8	130	<3.1	121	4.0	12.4	76.4	13.5	0.031	0.169	7.98
1	9	120	4.0	92	3.4	11.9	72.8	12.0	0.027	0.152	7.96
1	10	130	<3.1	122	2.6	11.3	73.4	9.4	0.027	0.139	8.33
2	1	1100	100	171	6.2	52.2	290.8	219.4	0.037	0.180	7.98
2	2	250	<3.1	121	4.4	11.5	77.7	101.0	0.024	0.245	8.22
2	3	130	<3.1	87	5.4	7.7	53.6	70.7	0.011	0.267	8.08
2	4	62	<3.1	146	7.8	6.0	47.0	58.9	0.011	0.221	8.26
2	5	74	<3.1	109	0.5	6.3	46.0	50.6	0.010	0.191	8.11
2	6	55	3.5	96	0.3	4.5	35.9	33.7	0.007	0.167	8.08
2	7	1200	<3.1	366	1.8	4.5	34.0	19.4	0.006	0.137	7.91
2	8	51	<3.1	120	2.4	4.8	30.1	13.9	0.008	0.121	7.91
2	9	51	<3.1	90	2.0	5.0	29.9	12.8	0.007	0.114	8.26
2	10	58	<3.1	120	3.6	4.5	38.6	15.6	0.006	0.096	8.04
3	1	270	16	102	7.1	14.4	80.1	141.6	0.026	0.203	-----
3	2	54	< 3.1	99	4.0	3.7	28.8	74.5	0.012	0.137	-----
3	3	32	< 3.1	83	4.0	2.9	24.9	59.6	0.004	0.102	7.34
3	4	25	<3.1	146	4.4	2.1	22.5	44.2	0.003	0.043	8.03
3	5	20	<3.1	106	3.2	2.4	26.3	36.6	0.003	0.049	8.09
3	6	16	<3.1	78	10.0	2.6	25.4	29.9	0.003	0.040	8.02
3	7	36	<3.1	146	2.5	3.5	29.0	23.8	0.006	0.044	8.14
3	8	12	<3.1	122	0.8	2.8	24.1	18.3	0.005	0.027	8.04
3	9	25	<3.1	72	0.9	2.7	23.5	14.2	0.004	0.018	7.90
3	10	24	<3.1	90	0.9	2.6	23.6	12.7	0.003	0.014	7.78
4	1	1600	20	342	7.4	75.6	307.3	370.2	0.194	0.239	7.92
4	2	1300	<3.1	354	8.8	63.8	253.7	382.6	0.187	0.220	8.06
4	3	1200	<3.1	378	7.8	58.8	235.8	391.1	0.168	0.214	8.20
4	4	1200	<3.1	378	9.3	56.8	210.1	412.5	0.159	0.227	8.22
4	5	1200	3.5	354	7.4	53.2	207.0	420.8	0.138	0.193	8.09
4	6	1200	<3.1	476	8.0	50.3	201.2	428.5	0.119	0.185	8.25
4	7	1200	<3.1	354	8.5	50.5	195.2	476.9	0.108	0.166	8.10
4	8	1200	<3.1	366	11.6	45.3	179.0	455.5	0.090	0.150	8.21
4	9	1200	<3.1	354	8.0	45.4	164.0	505.4	0.079	0.134	7.99

Column	Pore Volume	Sulfate	Chloride	Alkalinity	Potassium	Magnesium	Calcium	Sodium	Uranium	Molybdenum	pH
4	10	1200	<3.1	366	8.2	42.6	160.0	495.5	0.077	0.135	7.98
5	1	1600	30	366	5.1	67.6	229.7	530.2	0.264	0.198	8.08
5	2	1400	<3.1	415	5.2	52.5	186.0	493.1	0.177	0.118	8.38
5	3	1300	3.5	439	8.2	49.0	172.4	531.3	0.178	0.121	8.37
5	4	1300	<3.1	427	6.6	46.7	155.3	492.9	0.189	0.146	8.36
5	5	1300	<3.1	403	7.9	47.1	161.9	509.3	0.168	0.147	8.32
5	6	1200	<3.1	378	5.7	45.3	163.9	508.5	0.149	0.110	8.37
5	7	1200	<3.1	366	6.9	45.2	152.8	530.7	0.128	0.091	8.33
5	8	1300	<3.1	415	5.6	42.5	149.0	505.3	0.120	0.085	8.22
5	9	1300	<3.1	415	6.9	43.1	142.7	543.1	0.110	0.069	8.22
5	10	1200	<3.1	403	5.8	41.2	138.6	531.2	0.100	0.075	8.26
6	1	1700	7.5	232	14.1	44.0	256.1	427.3	0.045	0.127	7.92
6	2	1300	<3.1	293	12.8	34.0	197.1	406.7	0.052	0.073	8.21
6	3	1300	<3.1	317	17.3	35.7	199.8	458.9	0.057	0.051	8.31
6	4	1300	<3.1	305	16.7	33.8	175.9	459.3	0.057	0.047	8.07
6	5	1200	<3.1	305	15.6	32.8	174.0	447.8	0.048	0.044	8.29
6	6	1200	<3.1	305	13.2	32.5	165.8	468.5	0.058	0.032	8.04
6	7	1200	<3.1	293	15.8	32.8	159.2	481.6	0.056	0.027	8.26
6	8	1700	<3.1	244	17.3	34.6	153.7	516.0	0.056	0.027	8.01
6	9	1200	<3.1	256	14.9	32.3	155.0	497.4	0.053	0.023	8.00
6	10	1200	<3.1	281	14.6	31.9	146.6	500.4	0.051	0.018	8.00
7	1	1600	5.5	329	12.5	50.1	240.3	505.3	0.093	0.097	7.98
7	2	1500	<3.1	317	10.3	41.9	181.7	510.3	0.085	0.075	-----
7	3	1300	<3.1	317	10.4	34.6	162.5	465.2	0.070	0.061	8.07
7	4	1200	<3.1	342	7.1	30.6	137.0	458.9	0.065	0.043	7.98
7	5	1200	<3.1	366	7.0	30.0	136.0	492.9	0.057	0.030	8.20
7	6	1200	<3.1	342	9.9	29.8	143.3	538.5	0.055	0.023	8.12
7	7	1200	<3.1	342	9.6	30.2	133.1	559.6	0.048	0.018	8.11
7	8	1200	<3.1	342	9.3	29.1	138.8	503.9	0.059	0.022	8.10
7	9	1200	<3.1	342	7.1	29.0	138.6	524.3	0.055	0.016	8.16
7	10	1200	<3.1	342	7.6	28.7	138.9	565.9	0.044	0.010	8.11
8	1	1900	48	415	3.7	38.3	119.4	807.3	0.056	0.035	8.20
8	2	1400	4.0	378	2.5	23.8	79.8	619.9	0.043	0.033	8.29
8	3	1400	<3.1	427	1.6	21.6	89.5	538.5	0.033	0.023	8.23
8	4	1200	<3.1	390	2.0	19.7	103.6	540.4	0.027	0.016	8.12
8	5	1100	<3.1	366	1.8	18.1	105.1	536.7	0.024	0.015	8.13
8	6	1200	<3.1	390	2.7	18.3	129.5	574.9	0.023	0.013	8.28
8	7	1200	<3.1	390	1.3	16.1	113.0	522.6	0.021	0.010	8.18
8	8	1200	<3.1	390	2.9	16.5	130.1	548.2	0.023	0.008	8.35
8	9	1200	<3.1	366	4.0	16.7	131.2	561.9	0.022	0.009	8.34
8	10	1200	<3.1	329	4.7	17.2	129.4	607.4	0.021	0.007	8.15

[1] Inadequate sample volume for analysis.

Table A2: Uranium Mass Balance Calculations and PHREEQC Saturation Index Calculations

											Saturation Indices				
Column ID	Pore Volume	ReportedResult	Blank Corrected	Pore Volume	Material Mass	U Mass	U Leached	Cum. U Leached	U Soil	U Leached	Rutherfordine	Schoepite	UO_2(am)	$UO_2(OH)_2$(beta)	Uraninite
		mg/L	mg/L	L	kg	mg	mg/kg	mg/kg	mg/kg	% of Total	UO_2CO_3	UO2(OH)2	UO_2	$UO_2(OH)_2$	UO_2
Column 1	1	0.1900	0.1780	5.83	28.8	1.038	0.0360				----- [1]	-----	-----	-----	-----
	2	0.1200	0.1148			0.669	0.0232				-4.6	-3.6	-13.6	-3.3	-8.0
	3	0.0847	0.0761			0.444	0.0154				-4.3	-3.5	-13.2	-3.1	-7.6
	4	0.0563	0.0516			0.301	0.0104				-4.9	-4.3	-14.1	-3.9	-8.5
	5	0.0447	0.0410			0.239	0.0083				-4.9	-4.4	-14.2	-4.0	-8.6
	6	0.0419	0.0388			0.226	0.0079				-4.9	-4.2	-14.2	-3.8	-8.6
	7	0.0357	0.0341			0.199	0.0069				-4.8	-4.2	-14.0	-3.8	-8.4
	8	0.0305	0.0305			0.178	0.0062				-4.7	-4.1	-13.8	-3.8	-8.2
	9	0.0274	0.0274			0.160	0.0055				-4.6	-3.9	-13.5	-3.5	-7.9
	10	0.0273	0.0273			0.159	0.0055	0.125	4.4	2.9	-5.3	-4.4	-14.8	-4.0	-9.2
Column 2	1	0.0497	0.0374	7	25.9	0.262	0.0101				-5.5	-5.0	-14.7	-4.6	-9.1
	2	0.0288	0.0236			0.165	0.0064				-5.3	-4.5	-14.7	-4.1	-9.1
	3	0.0200	0.0114			0.080	0.0031				-5.1	-4.3	-14.2	-3.9	-8.6
	4	0.0157	0.0110			0.077	0.0030				-5.7	-4.9	-15.2	-4.6	-9.6
	5	0.0134	0.0097			0.068	0.0026				-5.3	-4.5	-14.5	-4.2	-8.9
	6	0.0100	0.0069			0.048	0.0019				-5.3	-4.5	-14.4	-4.1	-8.8
	7	0.0076	0.0060			0.042	0.0016				-6.7	-6.6	-16.2	-6.3	-10.6
	8	0.0075	0.0075			0.053	0.0020				-5.1	-4.6	-14.2	-4.2	-8.6
	9	0.0069	0.0069			0.048	0.0019				-5.5	-4.5	-14.7	-4.1	-9.1
	10	0.0058	0.0058			0.041	0.0016	0.03	3.9	0.87	-5.4	-4.8	-14.6	-4.4	-9.0
Column 3	1	0.0381	0.0258	6.83	26.2	0.176	0.0067				-4.7	-4.1	-13.6	-3.7	-8.0
	2	0.0167	0.0115			0.079	0.0030				-4.8	-4.3	-13.8	-3.9	-8.2
	3	0.0122	0.0036			0.025	0.0009				-4.5	-4.4	-12.8	-4.0	-7.2
	4	0.0075	0.0028			0.019	0.0007				-5.8	-5.3	-15.1	-4.9	-9.5
	5	0.0066	0.0029			0.020	0.0008				-5.7	-5.0	-14.9	-4.6	-9.3
	6	0.0063	0.0032			0.022	0.0008				-5.4	-4.6	-14.4	-4.2	-8.8
	7	0.0076	0.0060			0.041	0.0016				-5.7	-5.1	-15.1	-4.7	-9.5
	8	0.0052	0.0052			0.036	0.0014				-5.5	-4.9	-14.7	-4.5	-9.1
	9	0.0040	0.0040			0.027	0.0010				-5.0	-4.3	-13.9	-4.0	-8.3
	10	0.0032	0.0032			0.022	0.0008	0.0178	3.3	0.54	-5.1	-4.7	-14.0	-4.3	-8.3
Column 4	1	0.2000	0.1944	8.17	22.6	1.588	0.0703				-5.5	-5.3	-14.9	-5.0	-9.3
	2	0.1900	0.1872			1.529	0.0677				-5.7	-5.4	-15.3	-5.0	-9.7
	3	0.1700	0.1677			1.370	0.0606				-6.0	-5.6	-15.8	-5.3	-10.2
	4	0.1600	0.1586			1.296	0.0573				-6.1	-5.7	-15.8	-5.3	-10.2
	5	0.1400	0.1376			1.124	0.0497				-5.8	-5.6	-15.5	-5.2	-9.9
	6	0.1200	0.1194			0.975	0.0432				-6.5	-6.1	-16.4	-5.8	-10.8
	7	0.1100	0.1080			0.882	0.0390				-6.0	-5.7	-15.6	-5.3	-10.0
	8	0.0902	0.0902			0.737	0.0326				-6.3	-5.9	-16.0	-5.5	-10.4
	9	0.0787	0.0787			0.643	0.0285				-5.9	-5.7	-15.4	-5.4	-9.8
	10	0.0769	0.0769			0.628	0.0278	0.477	4.8	9.9	-5.9	-5.8	-15.5	-5.4	-9.9
Column 5	1	0.2700	0.2644	8.5	21.5	2.247	0.1045				-5.7	-5.5	-15.4	-5.1	-9.8
	2	0.1800	0.1772			1.506	0.0701				-6.5	-6.0	-16.5	-5.6	-10.8
	3	0.1800	0.1777			1.510	0.0703				-6.5	-6.0	-16.5	-5.6	-10.9
	4	0.1900	0.1886			1.603	0.0746				-6.4	-5.9	-16.4	-5.6	-10.8
	5	0.1700	0.1676			1.425	0.0663				-6.3	-5.9	-16.2	-5.5	-10.6
	6	0.1500	0.1494			1.270	0.0591				-6.4	-5.9	-16.3	-5.5	-10.7
	7	0.1300	0.1280			1.088	0.0506				-6.4	-5.9	-16.2	-5.5	-10.6
	8	0.1200	0.1200			1.020	0.0474				-6.3	-6.0	-16.1	-5.6	-10.5
	9	0.1100	0.1100			0.935	0.0435				-6.4	-6.0	-16.2	-5.7	-10.6
	10	0.1000	0.1000			0.850	0.0395	0.626	7.4	8.5	-6.4	-6.0	-16.3	-5.7	-10.7
Column 6	1	0.0509	0.0453	8	23	0.3624	0.0158				-5.8	-5.5	-15.1	-5.1	-9.4
	2	0.0548	0.0520			0.4160	0.0181				-6.3	-5.8	-16.0	-5.5	-10.4
	3	0.0593	0.0570			0.4560	0.0198				-6.6	-6.0	-16.3	-5.6	-10.7
	4	0.0582	0.0568			0.4544	0.0198				-6.1	-5.8	-15.6	-5.4	-10.0
	5	0.0508	0.0484			0.3872	0.0168				-6.5	-6.0	-16.3	-5.6	-10.7

	6	0.0585	0.0579			0.4632	0.0201				-6.0	-5.7	-15.5	-5.3	-9.9
	7	0.0580	0.0560			0.4480	0.0195				-6.4	-5.8	-16.1	-5.5	-10.5
	8	0.0556	0.0556			0.4448	0.0193				-5.9	-5.6	-15.3	-5.2	-9.7
	9	0.0532	0.0532			0.4256	0.0185				-5.8	-5.5	-15.2	-5.1	-9.6
	10	0.0509	0.0509			0.4072	0.0177	0.185	4.6	4.0	-5.9	-5.6	-15.3	-5.2	-9.7
Column 7	1	0.0990	0.0934	7.5	24.5	0.7005	0.0286				-5.9	-5.7	-15.4	-5.3	-9.8
	2	0.0881	0.0853			0.6398	0.0261				-5.9	-5.7	-15.4	-5.3	-9.8
	3	0.0718	0.0695			0.5213	0.0213				-6.0	-5.7	-15.6	-5.3	-10.0
	4	0.0659	0.0645			0.4838	0.0197				-5.9	-5.7	-15.4	-5.4	-9.8
	5	0.0591	0.0567			0.4253	0.0174				-6.5	-6.1	-16.2	-5.7	-10.6
	6	0.0559	0.0553			0.4148	0.0169				-6.3	-6.0	-15.9	-5.6	-10.3
	7	0.0504	0.0484			0.3630	0.0148				-6.3	-6.0	-16.0	-5.6	-10.4
	8	0.0588	0.0588			0.4410	0.0180				-6.2	-5.9	-15.8	-5.5	-10.2
	9	0.0550	0.0550			0.4125	0.0168				-6.3	-6.0	-16.0	-5.6	-10.4
	10	0.0436	0.0436			0.3270	0.0133	0.193	3.6	5.4	-6.4	-6.1	-16.0	-5.7	-10.4
Column 8	1	0.0613	0.0557	8	23	0.4456	0.0194				-6.9	-6.6	-16.7	-6.2	-11.1
	2	0.0456	0.0428			0.3424	0.0149				-6.9	-6.4	-16.7	-6.1	-11.1
	3	0.0357	0.0334			0.2672	0.0116				-7.0	-6.6	-16.8	-6.3	-11.2
	4	0.0283	0.0269			0.2152	0.0094				-6.7	-6.4	-16.4	-6.1	-10.8
	5	0.0264	0.0240			0.1920	0.0083				-6.7	-6.4	-16.4	-6.0	-10.8
	6	0.0237	0.0231			0.1848	0.0080				-7.1	-6.7	-16.9	-6.3	-11.3
	7	0.0227	0.0207			0.1656	0.0072				-6.9	-6.6	-16.7	-6.2	-11.1
	8	0.0231	0.0231			0.1848	0.0080				-7.2	-6.7	-17.1	-6.3	-11.5
	9	0.0221	0.0221			0.1768	0.0077				-7.1	-6.6	-17.0	-6.2	-11.4
	10	0.0211	0.0211			0.1688	0.00734	0.102	2.8	3.6	-6.7	-6.4	-16.4	-6.0	-10.8

Table A3: Molybdenum Mass Balance Calculations and PHREEQC Saturation Index Calculations

Column ID	Pore Volume	Reported Result mg/L	Pore Volume L	Material Mass kg	Mo Mass mg	Mo Leached mg/kg	Cum. Mo Leached mg/kg	Mo Soil mg/kg	Mo Leached % of Total	Saturation Index Calcium Molybdate $CaMoO_4$
Column 1	1	0.84	5.83	28.8	4.90	0.170				0.11
	2	0.74			4.31	0.150				-0.23
	3	0.52			3.03	0.105				-0.38
	4	0.39			2.27	0.079				-0.57
	5	0.286			1.67	0.058				-0.71
	6	0.228			1.33	0.046				-0.80
	7	0.186			1.08	0.038				-0.85
	8	0.169			0.99	0.034				-0.91
	9	0.152			0.89	0.031				-0.96
	10	0.139			0.81	0.028	0.739	0.420	175.9	-1.01
Column 2	1	0.18	7	25.9	1.26	0.049				-0.70
	2	0.245			1.72	0.066				-0.83
	3	0.267			1.87	0.072				-0.86
	4	0.221			1.55	0.060				-0.96
	5	0.191			1.34	0.052				-1.02
	6	0.167			1.17	0.045				-1.15
	7	0.137			0.96	0.037				-1.79
	8	0.121			0.85	0.033				-1.35
	9	0.114			0.80	0.031				-1.37
	10	0.096			0.67	0.026	0.470	0.400	117.5	-1.36
Column 3	1	0.203	6.83	26.2	1.39	0.053				-0.92
	2	0.137			0.94	0.036				-1.34
	3	0.102			0.70	0.027				-1.50
	4	0.043			0.29	0.011				-1.92
	5	0.049			0.33	0.013				-1.78
	6	0.04			0.27	0.010				-1.86
	7	0.044			0.30	0.011				-1.81
	8	0.027			0.18	0.007				-2.05
	9	0.018			0.12	0.005				-2.23
	10	0.014			0.10	0.004	0.176	0.310	56.9	-2.34
Column 4	1	0.239	8.17	22.6	1.95	0.086				-0.67
	2	0.22			1.80	0.080				-0.74
	3	0.214			1.75	0.077				-0.77
	4	0.227			1.85	0.082				-0.79
	5	0.193			1.58	0.070				-0.87
	6	0.185			1.51	0.067				-0.91
	7	0.166			1.36	0.060				-0.96
	8	0.15			1.23	0.054				-1.05
	9	0.134			1.09	0.048				-1.13
	10	0.135			1.10	0.049	0.673	0.260	259.0	-1.14
Column 5	1	0.198	8.5	21.5	1.68	0.078				-0.89
	2	0.118			1.00	0.047				-1.18
	3	0.121			1.03	0.048				-1.19
	4	0.146			1.24	0.058				-1.15
	5	0.147			1.25	0.058				-1.13
	6	0.11			0.94	0.043				-1.23
	7	0.091			0.77	0.036				-1.34
	8	0.085			0.72	0.034				-1.40
	9	0.069			0.59	0.027				-1.51

Column ID	Pore Volume	Reported Result	Pore Volume	Material Mass	Mo Mass	Mo Leached	Cum. Mo Leached	Mo Soil	Mo Leached	Calcium Molybdate
	10	0.075			0.64	0.030	0.459	0.930	49.3	-1.47
Column 6	1	0.127	8	23	1.02	0.044				-1.03
	2	0.073			0.58	0.025				-1.33
	3	0.051			0.41	0.018				-1.48
	4	0.047			0.38	0.016				-1.57
	5	0.044			0.35	0.015				-1.59
	6	0.032			0.26	0.011				-1.74
	7	0.027			0.22	0.009				-1.84
	8	0.027			0.22	0.009				-1.94
	9	0.023			0.18	0.008				-1.92
	10	0.018			0.14	0.006	0.163	0.490	33.3	-2.05
Column 7	1	0.097	7.5	24.5	0.73	0.030				-1.17
	2	0.075			0.56	0.023				-1.39
	3	0.061			0.46	0.019				-1.49
	4	0.043			0.32	0.013				-1.70
	5	0.03			0.23	0.009				-1.87
	6	0.023			0.17	0.007				-1.96
	7	0.018			0.14	0.006				-2.10
	8	0.022			0.17	0.007				-1.99
	9	0.016			0.12	0.005				-2.13
	10	0.01			0.08	0.003	0.121	0.750	16.1	-2.34
Column 8	1	0.035	8	23	0.28	0.0122				-1.99
	2	0.033			0.264	0.0115				-2.11
	3	0.023			0.184	0.0080				-2.21
	4	0.016			0.128	0.0056				-2.27
	5	0.015			0.12	0.0052				-2.26
	6	0.013			0.104	0.0045				-2.26
	7	0.01			0.08	0.0035				-2.43
	8	0.008			0.064	0.0028				-2.47
	9	0.009			0.072	0.0031				-2.41
	10	0.007			0.056	0.0024	0.059	0.350	16.8	-2.53