Chemical Extraction of Uranium and Molybdenum from Vadose-Zone Soils and Aquifer Materials

Dam-to-Ditch Area, Cotter Uranium Mill, Cañon City, Colorado

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1.0 INTRODUCTION

This study was conducted to identify chemical reagents that can be used to effectively extract uranium (U) and molybdenum (Mo) from soils and subsurface geologic materials located in the Cotter Corporation (Cotter) Dam to Ditch Area (DDA). Uranium and Mo concentrations at several DDA groundwater locations exceed Colorado Groundwater Quality Standards (CGWQS) of 0.03 mg/L and 0.035 mg/L, respectively. As a result, an investigation was conducted in 2010 to delineate areas of impacted groundwater and to characterize potential sources of U and Mo to groundwater (HydroSolutions, 2010). Drill cuttings from investigative borings were subsequently used in a column study to characterize the mobility of U and Mo from DDA vadose-zone soils and subsurface materials.

Column leaching results showed that a portion of the total U and Mo in the DDA soils is readily released by either natural precipitation or local groundwater (AMEC, 2011a). Most columns produced initial leachate concentrations exceeding CGWQS for U and Mo, but with concentrations that decreased with increased leaching. Higher U and Mo concentrations were associated with weathered claystone (WCS) and overlying sands, silts, and clays (SSC), compared to the underlying claystone and sandstone. Mass balance calculations show that only a small fraction of the total U was released, while Mo was more soluble. Geochemical modeling results indicate that U and Mo exist as adsorbed species on soil mineral surfaces. Although the potential exists for natural leaching of elevated U and Mo concentrations from DDA soils, only a small fraction of the total mass is released by natural leaching (AMEC, 2011a). These findings suggest that leaching with a selective extraction solution more aggressive than water could be used to enhance the extraction of total U and Mo from DDA soils.

As part of the ongoing remedial investigations for the DDA, Cotter has considered implementing a field-scale *in situ* soil flushing test to evaluate U and Mo removal from the soils. This batch test study was originally designed to provide reagent recommendations for use in future field-scale pilot tests for removal of U and Mo from soils in the DDA. However, additional characterization of total U and Mo soil concentrations, in conjunction with the soil water balance, indicates there is no significant source of U or Mo in the DDA soils which could produce the observed concentrations in downgradient groundwater (AMEC, 2011b). The batch testing study was completed in anticipation that the results could be useful in the design of future remedial systems elsewhere at the site. The objectives of this report are to: (1) provide a literature summary of chemical reagents that have been used to effectively extract U from contaminated soils, and (2) identify chemical reagents that can be used to effectively extract U and Mo from soils and aquifer materials at the site.

2.0 Uranium Extraction From Soils

Chemical extraction of U from contaminated soils involves the conversion of U into a water soluble form, which is then extracted from the soil. Efficient U removal from soils can be achieved provided that the extraction solution enhances the solubility of U, and that the U exists predominantly in the oxidized state [U(VI)] (Gavrilescu et al., 2009).

2.1 Extraction Using Carbonate

One of the most commonly-used reagents for removal of U from contaminated soils is sodium bicarbonate ($NaHCO_3$). Sodium bicarbonate is also used in the mining industry to extract U from certain ores, because carbonate forms strong solution complexes with U:

$$UO_2^{2+}(aq) + 2HCO_3^-(aq) \leftrightarrow UO_2(CO_3)_2^{2-}(aq) + 2H^+(aq) \quad [1]$$

$$UO_2(CO_3)_2^{2-}(aq) + HCO_3(aq) \leftrightarrow UO_2(CO_3)_3^{4-}(aq) + H^+(aq) \quad [2]$$

Consequently, the formation of stable dissolved U-carbonate complexes enhances the solubility and subsequent removal of solid-phase U(VI) from contaminated soils. In a soil column leaching study, Mason et al. (1997) used 0.5 M $NaHCO_3$ to achieve 75 to 90% U removal efficiency, corresponding to the percentage of U in the oxidized form. Even though varying the solution ratios of HCO_3^-:CO_3^{2-} (1:0, 2:1, and 1:1) produced pH values of 8.3, 9.9, and 10.3, respectively, U removal efficiencies did not change significantly within the pH range of 8.3 to 10.3 (Mason et al., 1997).

Recognizing that bicarbonate extraction only dissolves the oxidized form of U [U(VI)], Mason et al. (1997) used an oxidizing agent (sodium peroxide, Na_2O_2) to further enhance U removal by oxidizing the reduced forms of U [U(IV)] present as solid UO_2 (Gavrilescu et al., 2009):

$$Na_2O_2 + 2H_2O(l) \rightarrow 2NaOH + H_2O_2 \quad [3]$$

$$UO_2(s) + H_2O_2 + 2H+ \rightarrow UO_2^{2+} + 2H_2O(l) \quad [4]$$

By incorporating solid Na_2O_2 into the contaminated soil prior to leaching, the U removal was enhanced by 20% compared to columns where Na_2O_2 was not added (Mason et al. 1997).

In a bench-scale experiment, Kulpa and Hughes (2001) demonstrated 90% removal of U from contaminated soils using a solution of 0.2 M $NaHCO_3$ and a retention time of 1.5 hours. Based on their bench-scale results, a pilot-scale and subsequent full-scale soil washing facility was designed which achieved U removal efficiencies of approximately 80 to 95%.

2.2 Extraction Using Citric Acid

Organic acids also have a tendency to form strong solution complexes with U, and hence can be used to mobilize U from contaminated soils. A number of studies have shown that citric acid is very effective in dissolving U, and that the removal efficiency generally improves with increasing citric acid concentration. For example, Francis and Dodge (1998) utilized citric acid extraction of U, in conjunction with both biodegradation and photodegradation, to remove U from contaminated soil. Sixty percent of the U was extracted using 0.2 M citric acid, while 80% of the U was extracted when using 0.4 M citric acid. Use of 0.6 M citric acid did not result in any further significant removal of U.

Batch experimentation by Kantar et al. (2006) shows that even low citric acid concentrations (0.001 M) can increase the extraction of U from contaminated soils by a factor of 3 times greater than distilled water. Citric acid was particularly effective in cases where U is associated with Fe-

oxide coatings on soil minerals. Kantar et al. (2006) also noted that greater solution:solid ratios and higher citric acid concentrations were required to achieve the same column removal efficiencies observed in batch tests. Citric acid has also been used to treat U-depleted contaminated soils with removal efficiencies ranging from 85 to 99% (Gavrilescu et al., 2009).

Citric acid is environmentally-compatible and the U-citrate complexes will biodegrade rapidly when the pH is maintained between 8 and 9. Once the extraction process is complete, however, biodegradation of residual U-citrate complexes does not promote additional U mobility from the treated soils (Gavrilescu et al., 2009).

3.0 Molybdenum Extraction From Soils

Reported incidences of Mo contamination in soils are not as common when compared to U, and therefore less information exists regarding the effectiveness of soil flushing to remove Mo from soils. Under oxidizing soil conditions, dissolved molybdenum exists mainly as the molybdate ion (MoO_4^{2-}). Molybdate does not tend to form strong solution complexes with inorganic ions or organic acids, and is generally mobile in soils. In calcareous soils, dissolved Mo concentrations may be controlled by calcium molybdate (powellite, $CaMoO_4$). More commonly, Mo occurs as adsorbed molybdate on mineral surfaces. Molybdenum adsorption by soil minerals is generally greatest at low pH (3 to 5) but decreases rapidly with increasing pH, and with very little adsorption occurring above pH 7 (Goldberg et al., 1996).

The DDA column study (AMEC, 2011a) demonstrated that the soil leachates were undersaturated with respect to solid $CaMoO_4$, and that the majority of the Mo occurs as molybdate adsorbed to soil minerals. In addition, a larger fraction of the total Mo was leached from the soil when compared to U. Therefore, the batch testing methods used here are primarily designed to identify a candidate U extraction solution. It is assumed that adequate Mo removal efficiencies will also be achieved due to favorable mobility of Mo under oxidizing conditions.

4.0 LABORATORY LEACHING PROCEDURES

Two methods were utilized to identify potential chemical reagents that can be used to optimize removal of U (and Mo) from soils: (1) Supplemental column leaching and (2) laboratory batch testing.

4.1 Supplemental Column Leaching

In the recent DDA column leaching study, 10 pore volumes of either synthetic meteoric precipitation or groundwater were passed through columns containing representative vadose- and saturated-zone aquifer materials (AMEC, 2011a). Most of the columns produced leachates whose initial concentrations exceeded CGWQS for U (0.03 mg/L) and Mo (0.035 mg/L), but with concentrations that continued to decrease with increased leaching. Higher observed U and Mo leachate concentrations were typically associated with SSC and WCS from the vadose zone.

Carbonate is known to be an effective reagent for U extraction (Section 2.1). Columns 1, 4, and 5 were leached with four additional pore volumes of 0.5 M NaHCO3 as a preliminary test to

evaluate the effects of enhanced U leaching by complexation with carbonate. The results of mass balance calculations indicated that a significant fraction of the initial total U remained in the columns after 10 pore volumes, and that the U likely exists as adsorbed uranium(VI) (AMEC, 2011a). Supplemental leaching of the existing columns with carbonate solution should produce a concentration "spike" in the column effluents, provided that the residual U exists in the oxidized form. If no spikes are observed in the column effluents, this may indicate that much of the residual U is present in the reduced form.

4.2 Laboratory Batch Testing

Batch tests were designed to identify an efficient U and Mo extraction solution for vadose-zone soils and aquifer materials. Two of DDA materials previously evaluated in the column tests were used (AMEC, 2011a): (1) Unconsolidated sands, silts, and clays (SSC) and (2) weathered claystone (WCS). To improve uniformity of the results, the reactive fraction (<2-mm) was isolated by sieving and used for all tests. The samples were extracted using two concentrations of sodium bicarbonate (0.2 and 0.5 M) and citric acid (0.2 and 0.5 M). Treatments were repeated using an approximate 100:1 molar ratio of oxidant (Na_2O_2) to U (50 mg Na_2O_2). Each sample was also extracted using deionized H_2O (without oxidant) as a control for a total of 18 tests (Table 1). A solution:solid ratio of 5:1 was used, and all tests were run in triplicate.

Four subsamples of each material was analyzed for total U and Mo to characterize their initial total concentrations. The efficiency of U and Mo removal for each test was defined as the ratio of the U and Mo removed to their initial levels, expressed as a percentage. Detailed procedures for the laboratory batch tests are provided in Attachment A.

5.0 SUPPLEMENTAL COLUMN LEACHING RESULTS

In the previous DDA column leaching study, the SSC material (Column 1) displayed rinse-out behavior of U that decreased asymptotically to concentrations below 0.03 mg/L, whereas the WCS material (Columns 4 and 5) produced leachates with linear decreases in U concentration that remained above 0.03 mg/L up through 10 pore volumes (Figure 1). Leaching with an additional four pore volumes (pore volumes 11 to 14) using 0.5 M $NaHCO_3$ produced large increases in effluent U concentration, which also greatly exceeded the initial water-leachable concentrations obtained from pore volume 1 (Figure 1). The large U concentration increases obtained with supplemental leaching using $NaHCO_3$ result from the strong complexation of U with carbonate in solution (Section 2.1).

Table 1 Experimental Matrix for the Laboratory Batch Tests.

Test No.	Material [a]	Sample Mass(g)	Solution Volume (mL)	$NaHCO_3$ (M)	Citric Acid (M)	Na_2O_2	H_2O
1	SSC	50	250	0.2	----------	----------	----------
2	SSC	50	250	0.2	----------	50 mg	----------
3	SSC	50	250	0.5	----------	----------	----------
4	SSC	50	250	0.5	----------	50 mg	----------
5	SSC	50	250	----------	0.2	----------	----------
6	SSC	50	250	----------	0.2	50 mg	----------
7	SSC	50	250	----------	0.5	----------	----------
8	SSC	50	250	----------	0.5	50 mg	----------
9 (control)	SSC	50	250	----------	----------	----------	Deionized
10	WCS	50	250	0.2	----------	----------	----------
11	WCS	50	250	0.2	----------	50 mg	----------
12	WCS	50	250	0.5	----------	----------	----------
13	WCS	50	250	0.5	----------	50 mg	----------
14	WCS	50	250	----------	0.2	----------	----------
15	WCS	50	250	----------	0.2	50 mg	----------
16	WCS	50	250	----------	0.5	----------	----------
17	WCS	50	250	----------	0.5	50 mg	----------
18 (control)	WCS	50	250	----------	----------	----------	Deionized

[a] SSC = archived sands, silts, and clays used for Column 1. WCS = archived weathered claystone used for Column 4 (AMEC, 2011a).

Supplemental leaching of the DDA columns using $NaHCO_3$ also produced effluent concentration spikes for Mo (Figure 2). Increasing the total dissolved solids concentrations (and hence, both electrical conductivity and ionic strength) has not been shown to affect the extent of Mo adsorption (Goldberg, 2009). Rather, the increase in Mo concentrations upon the addition of $NaHCO_3$ could have resulted from: (1) desorption of adsorbed Mo from soil mineral surfaces promoted by the high pH (8.8 to 8.9) of the $NaHCO_3$ solution (Goldeberg et al., 1996), and/or (2) dissolution of powellite ($CaMoO_4$) promoted by the addition of bicarbonate and precipitation of calcite:

$$CaMoO_4(s) + 2Na^+(aq) + 2HCO_3^-(aq) = 2Na^+(aq) + MoO_4^{2-}(aq) + CaCO_3(s) + CO_2(g) + H_2O(l)$$

It is also important to note that the column percolation rates decreased following the addition of the $NaHCO_3$ solution. It was suspected that the reduction in percolation rates may be caused by the high sodium levels in the leaching solution which promotes the physical dispersion of clay minerals. Upon completion of the $NaHCO_3$ leaching, a pore volume of distilled H_2O was added to each column. The additional soil dispersion caused by the clean water resulted in surface sealing and a significant reduction in percolation rates in all columns.

6.0 LABORATORY BATCH TESTING RESULTS

In this section, the batch test results for extractable U and Mo using various extraction solutions for both the SSC and WCS materials are presented. The extractable U results for the SSC material (Figure 3) show that deionized H_2O was the least effective extractant, with only 0.41% of the total U removed. Sodium bicarbonate was more effective, resulting in 19 to 26% U removal, with approximately 5% greater U removal when using 0.5 M $NaHCO_3$ compared to 0.2 M $NaHCO_3$. Citric acid was the most effective in extracting U, with up to 42% removal obtained when using 0.2 M citric acid, but only about 35% removal with the higher (0.5 M) concentration. There were no notable increases in the amount of U extracted by these reagents with the addition of oxidant (Na_2O_2) indicating that the majority of the U in the SSC material exists as oxidized U(VI).

The extractable U results for the WCS material (Figure 4) produced similar trends with respect to extraction solution efficiency, but overall there was less U recovery for the WCS compared to the SSC material. The WCS extraction efficiency for U with H_2O was less than 1%. However, $NaHCO_3$ was much more effective and resulted in 15% to 17% U removal, with 2% greater U removal efficiency when using 0.5 M $NaHCO_3$ compared to 0.2 M $NaHCO_3$ (Figure 4). Citric acid was the most effective in extracting U from the WCS, with up to 21% removal obtained when using 0.2 M citric acid, but with lower removal efficiency (11% and 13%) when using the higher (0.5 M) concentration. There were also no major increases in the amount of U extracted by these reagents with the addition of oxidant (Na_2O_2), indicating that the majority of the U in the WCS material exists as oxidized U(VI).

The batch testing results indicate that Mo is more soluble compared to U in the SSC and WCS materials. The extractable Mo results for the SSC material (Figure 5) show that while deionized H_2O was least effective, 23% removal efficiency was obtained when using deionized H_2O alone. Sodium bicarbonate was more effective, resulting in 31% to 41% removal. Citric acid was the most effective in extracting Mo, with almost 50% removal from the SSC material in the presence or absence of oxidant (Figure 5). Citric acid does not form strong complexes with Mo, however, citric acid may increase the solubility of soil Mo by: (1) forming solution complexes with calcium and increasing the solubility of powellite ($CaMoO_4$), and/or (2) forming solution complexes with iron and increasing the solubility of Mo adsorbed to mineral iron hydroxide coatings.

Molybdenum extraction efficiencies for the WCS material were similar to those for the SSC when using the same extraction solutions (Figure 6). In the WCS, deionized H_2O removed 26% of the total Mo, while a larger proportion (29% to 39%) was extracted with $NaHCO_3$. As much as 42% to 44% of the total Mo was extracted from the WCS material when using citric acid, with no effect of oxidant on the amount of Mo extracted (Figure 6).

7.0 SUMMARY & CONCLUSIONS

Supplemental column leaching and laboratory batch testing of DDA soil materials has shown that both $NaHCO_3$ and citric acid can increase the extraction efficiency of U and Mo compared to H_2O alone. In summary, this study has shown that:

- Uranium in the soils is less soluble than Mo and therefore higher proportions of Mo (23% to 26%) were extracted using deionized H_2O compared to U (< 1%).

- Extraction with $NaHCO_3$ significantly increased the removal efficiency of U compared to H_2O in both the SSC and WCS materials. Increasing the concentration of $NaHCO_3$ from 0.2 M to 0.5 M also increased the amount of U extracted.

- Citric acid was most effective in extracting U at a concentration of 0.2 M due to the formation of strong U-citrate solution complexes. Less U was removed at higher citric acid concentrations (0.5 M), perhaps due to partial reduction of U(VI) to U(IV) with subsequent precipitation of UO_2.

- Citric acid was also most effective in extracting Mo at either concentration (0.2 or 0.5 M), most likely due to formation of calcium-citrate solution complexes which enhance the solubility of $CaMoO_4$ (powellite).

- The addition of an oxidant (Na_2O_2) did not increase the extraction efficiency of U in any of the tests, suggesting that U in the soils exists primarily as oxidized U(VI).

- Molybdenum removal efficiencies were similar for the SSC and WCS materials, while U removal efficiencies were lower for the WCS compared to the SSC.

Based on the batch leach testing results from this study, citric acid has been identified as the most suitable reagent for extracting both U and Mo from soils and similar geologic materials at the Cotter mill facility. While $NaHCO_3$ can be used to significantly enhance U removal from soils, $NaHCO_3$ is less effective than citric acid at equal concentrations, and using $NaHCO_3$ has the potential to cause soil infiltration problems due to the elevated sodium levels. To determine the optimum concentration of citric acid for use in field-scale pilot studies, It is recommended that additional batch tests first be conducted to determine U and Mo extraction efficiencies under a larger range of citric acid concentrations.

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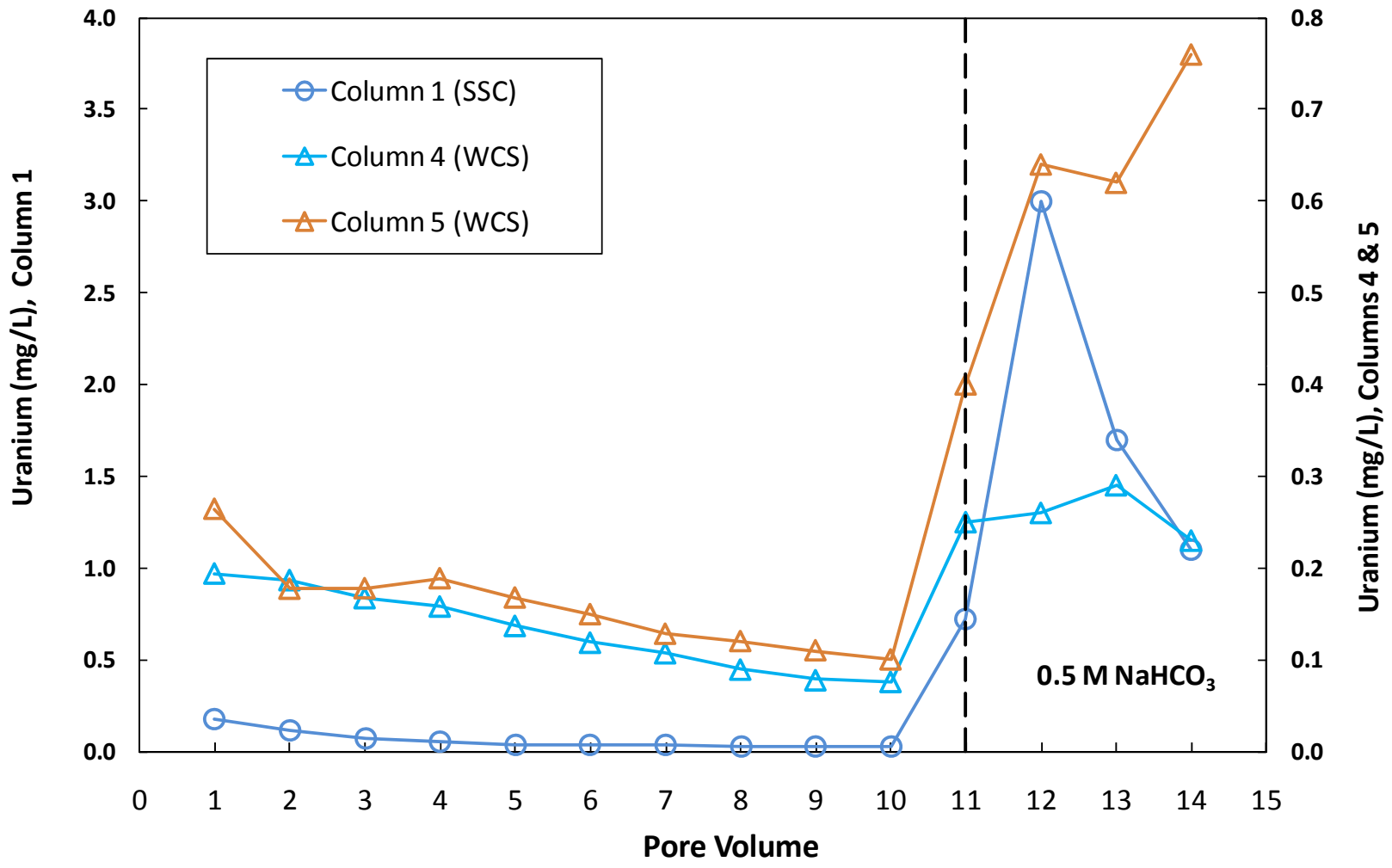
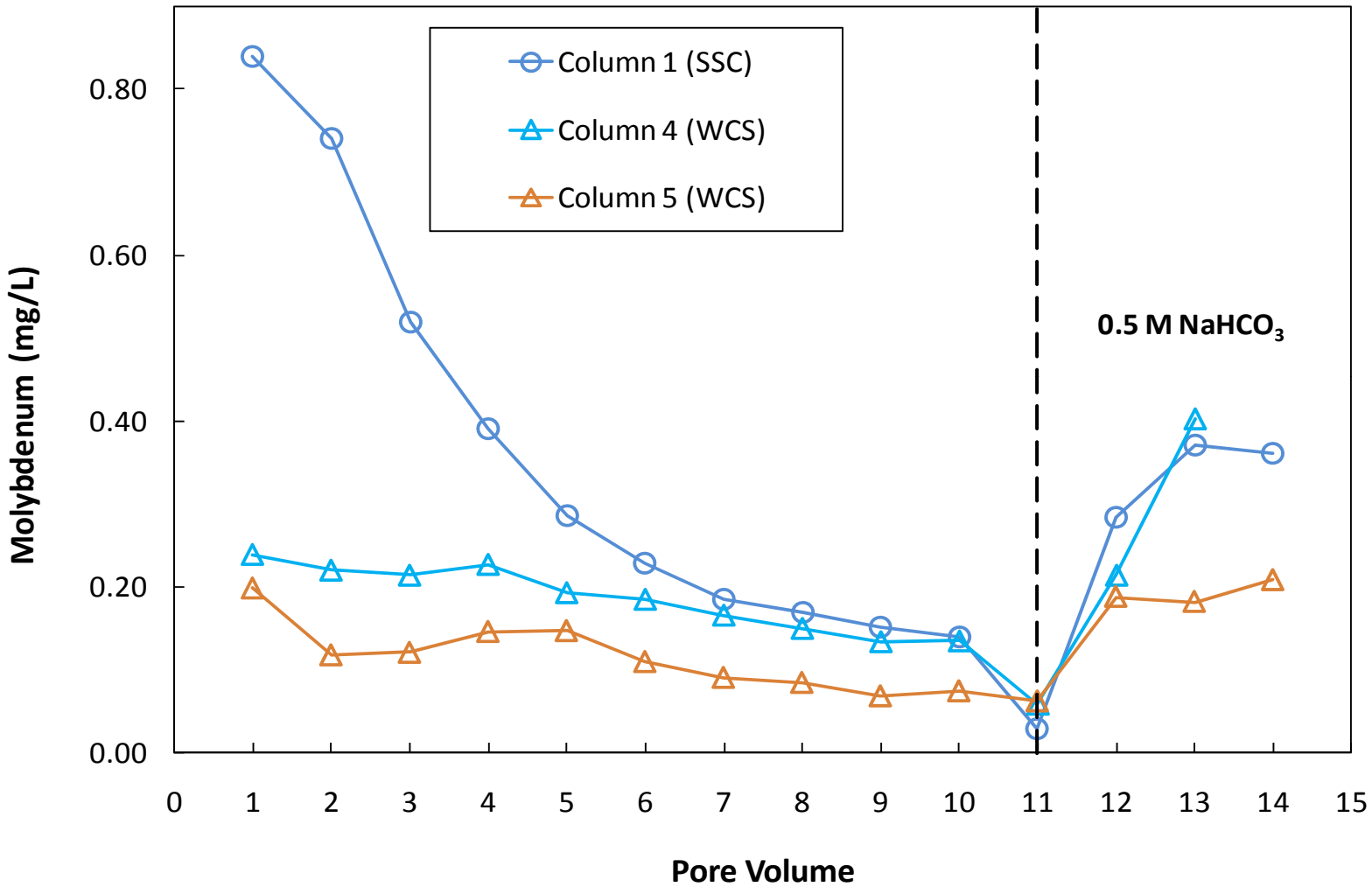
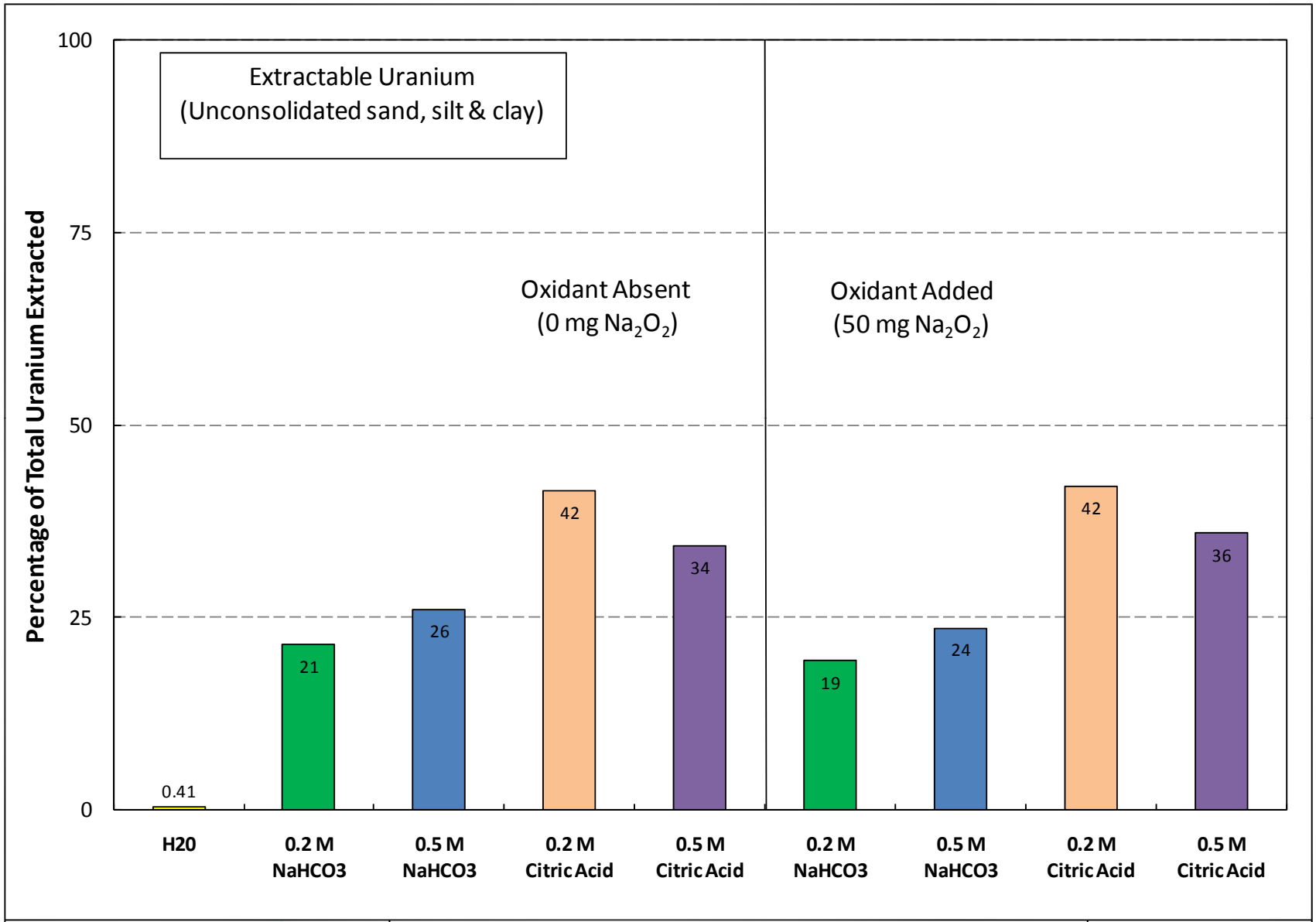
FIGURES



amec	SUPPLEMENTAL COLUMN LEACHING RESULTS FOR URANIUM IN UNCONSOLIDATED SANDS, SILTS & CLAYS (Column 1) AND WEATHERED CLAYSTONE (Columns 4 and 5)	Project No. DE10160100
		Figure 1



amec	SUPPLEMENTAL COLUMN LEACHING RESULTS FOR MOLYBDENUM IN UNCONSOLIDATED SANDS, SILTS & CLAYS (Column 1) AND WEATHERED CLAYSTONE (Columns 4 and 5)	Project No. DE10160100
		Figure 2



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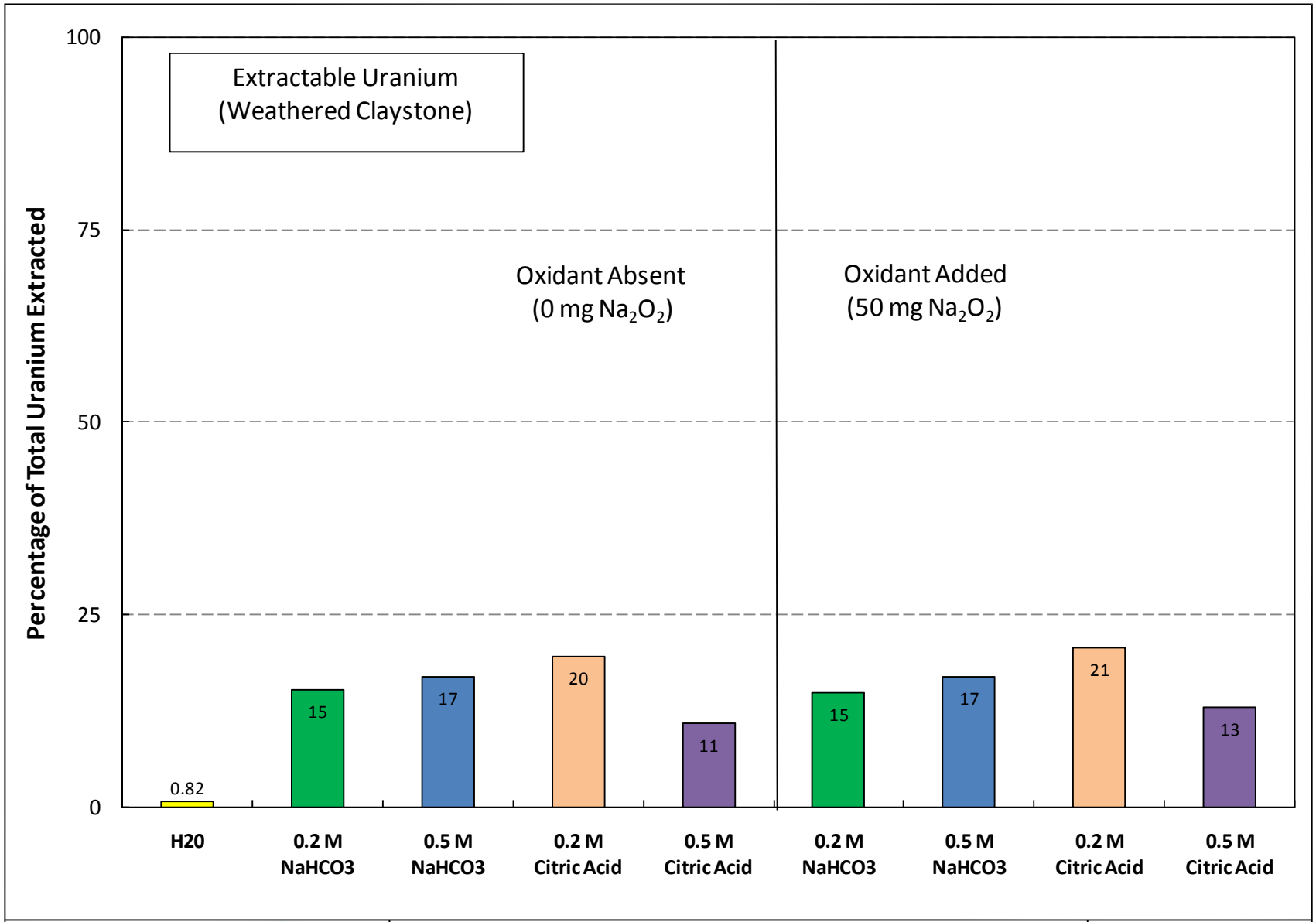
BATCH TEST RESULTS FOR URANIUM
IN UNCONSOLIDATED SAND, SILT & CLAY (COLUMN 1)

Project No. DE10160100

Figure 3



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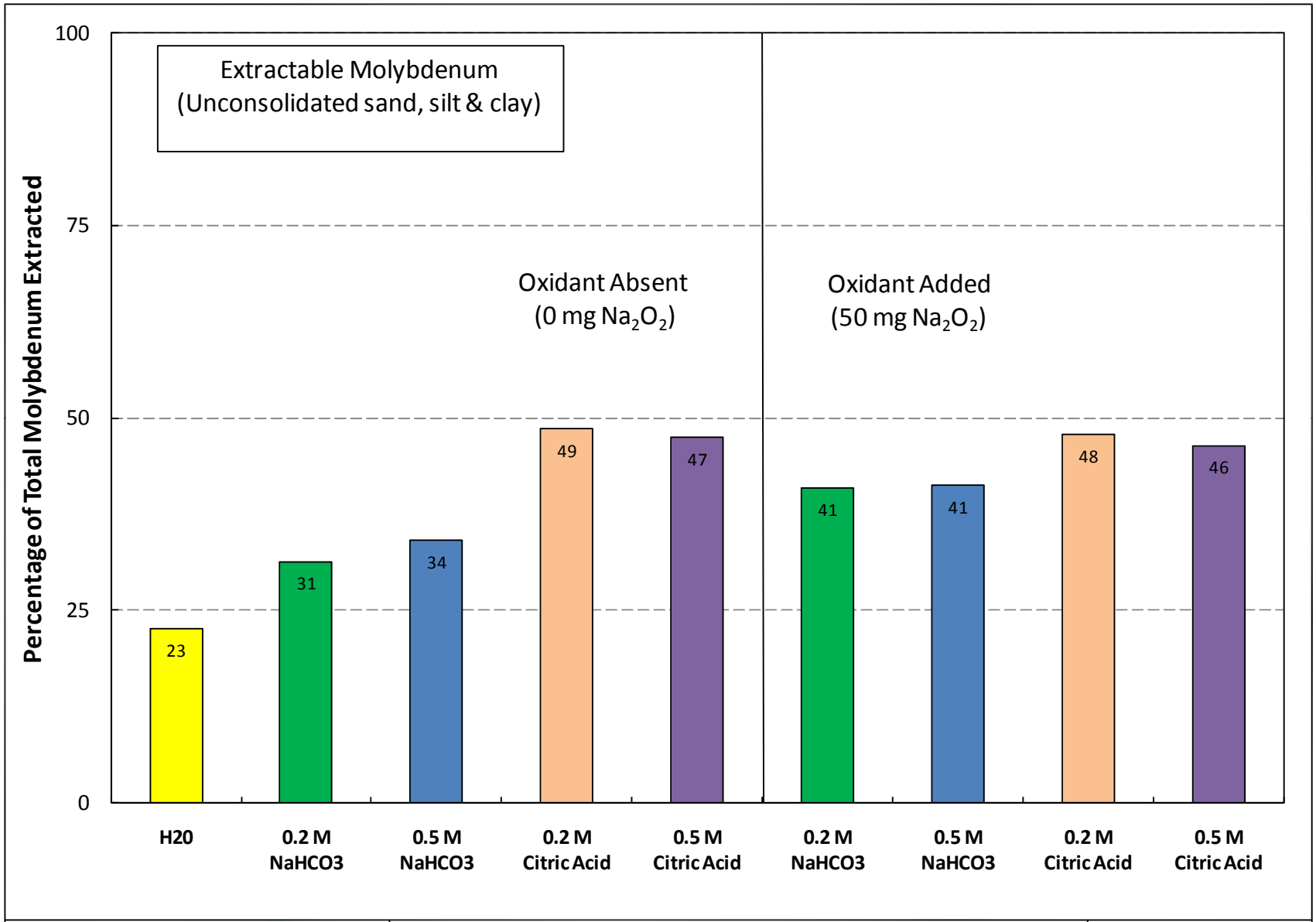
BATCH TEST RESULTS FOR URANIUM
IN WEATHERED CLAYSTONE (COLUMN 4)

Project No. DE10160100

Figure 4



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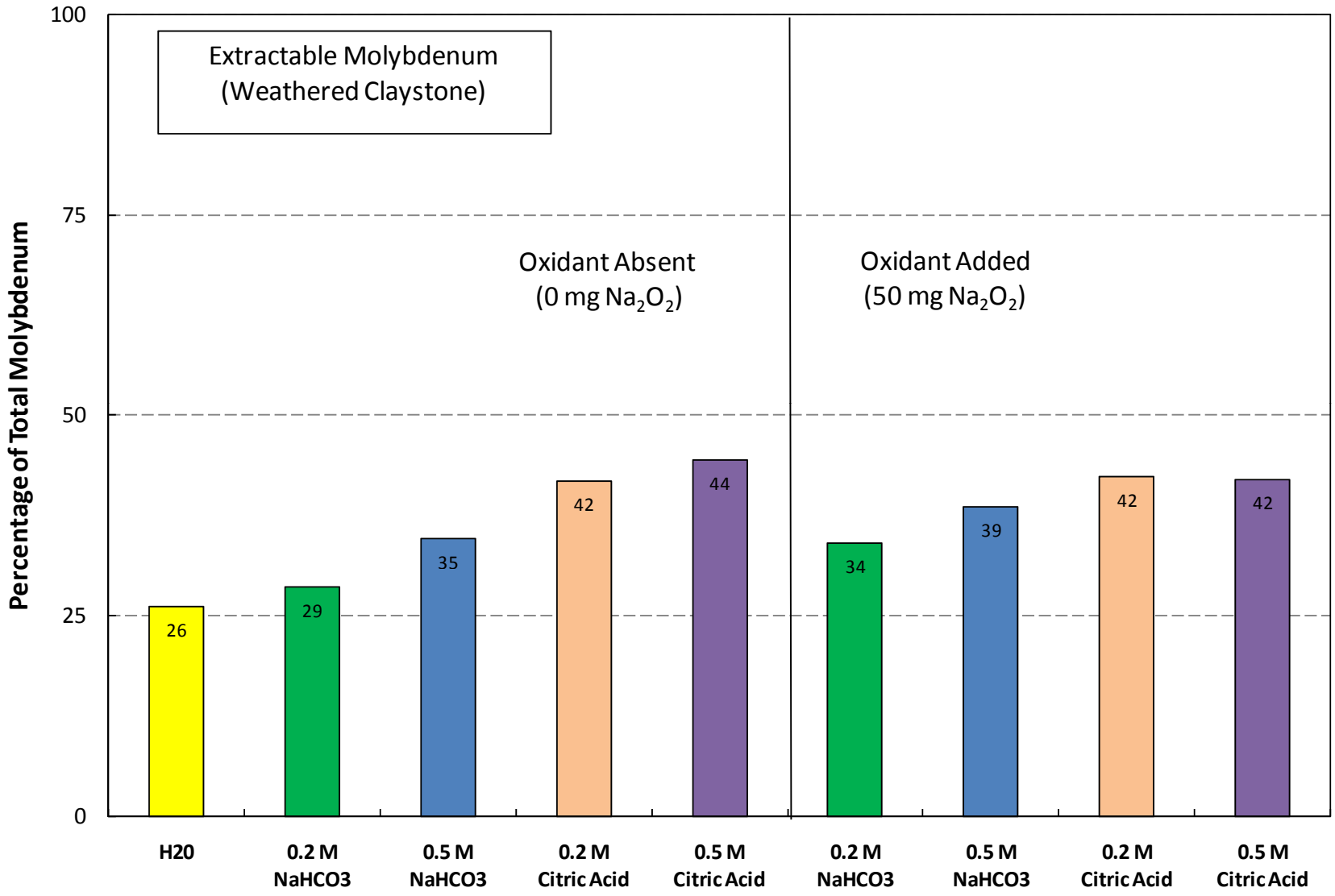
BATCH TEST RESULTS FOR MOLYBDENUM
IN UNCONSOLIDATED SAND, SILT & CLAY (COLUMN 1)

Project No. DE10160100

Figure 5



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BATCH TEST RESULTS FOR MOLYBDENUM
IN WEATHERED CLAYSTONE (COLUMN 4)

Project No. DE10160100

Figure 6

ATTACHMENT A

DETAILED BATCH TESTING PROCEDURES

Laboratory Batch Testing Procedures
Uranium and Molybdenum Extraction from Dam-to-Ditch Area Soils

Laboratory Materials

• Archived soils used for Columns 1 and 4	• Oscillating table shaker
• 2-mm (10 mesh) sieve	• Balance, spatula, weighing vessel
• 27- Nalgene wide mouth extraction bottles (250 mL or 8-oz)	• Filtering apparatus and 0.45 micron pore size filtration membranes
• 60 – small clean sample bottles for collection of filtered batch test leachates (100 to 200 mL)	• Labware cleaning supplies (soap, brushes)
• Sodium peroxide (Na_2O_2) (several grams)	• Clean plastic beakers for solution transfer
• Sodium bicarbonate ($NaHCO_3$) (approx. 200 g) to prepare 2 L of 0.2 and 0.5 M solution	• 250 to 500-mL graduated cylinder
• Citric Acid ($C_6H_8O_7$) (approx. 250 g) to prepare 2 L of 0.2 and 0.5 M solution	• Plastic storage bags (quart or gallon size), Sharpee, clear tape
• Distilled or deionized (DI) water	

Procedures

1. Prepare approximately 2 kg of fresh, air-dried material previously used for Column 1 (C1) by sieving to pass a 2-mm (10 mesh) screen. Place the sieved soil into a plastic Ziploc bag and thoroughly homogenize. Remove four separate 10 g subsamples using a small spatula, place into an appropriate sample container, and submit each sample to the laboratory for analysis of total uranium and molybdenum.

2. Prepare 27 Nalgene extraction bottles (250-mL capacity) by thoroughly cleaning the bottles and caps with warm soapy water and brushes (even if new). Rinse both bottles and caps thoroughly with tap water to remove soap, followed by rinsing a minimum of three times with DI water. Allow the bottles to dry upside down and replace the caps during storage.

3. Using DI water, prepare 2 Liters each of the respective $NaHCO_3$ and citric acid solutions:

    a. 0.2 M $NaHCO_3$: dissolve 16.8 g $NaHCO_3$ per Liter (33.6 g for 2 Liters).

    b. 0.5 M $NaHCO_3$: dissolve 42.0 g $NaHCO_3$ per Liter (84.0 g for 2 Liters).

    c. 0.2 M citric acid: dissolve 38.4 g per Liter or 76.8 g for 2 Liters (42.1 g per Liter or 84.2 g per 2 Liters, respectively, if using citric acid monohydrate).

    d. 0.5 M citric acid: dissolve 96.1 g per Liter or 192 g for 2 Liters (105 g per Liter or 210 g per 2 Liters, respectively, if using citric acid monohydrate).

4. Filter 100 mL of each solution through a 0.45 micron pore-size filter and into a small clean plastic sample bottle, acidify using nitric acid (HNO_3). Submit to the laboratory for analysis of dissolved uranium and molybdenum.

5. Label the 27 clean Nalgene extraction bottles for Tests 1 through 9 specified in Table 1. (triplicates should be labeled 1a, 1b, 1c, 2a, 2b, 2c, etc.). Place clear tape over the labels to prevent them from wearing off during the extraction process.

6. Weigh exactly 50.0 g of the prepared soil from Step 1 into each of the 27 extraction bottles.

7. Add 50 mg of solid Na_2O_2 reagent to the 12 extraction bottles labeled 2a,b,c; 4a,b,c; 6a,b,c; and 8a,b,c (Table 1).

8. Add 250 mL of the appropriate extraction solution to the extraction bottles according to Table 1. Rinse all glassware and plastic ware with DI water in between the various extraction solutions.

9. Cap all bottles tightly and place them on their sides into the oscillating table shaker such that the bottles oscillate end-to-end. At a minimum, the shaker should be set at a speed in which the soil and solution are continuously agitated with no observed settling of the sediment in the bottles. Shake the bottles for 8 hrs, remove from the shaker, and allow to settle while standing upright.

10. Filter a minimum of 100 mL of each supernatant solution through a 0.45 micron pore size filter and into a small clean plastic sample bottle (sample bottles should be cleaned by brushing with warm soapy tap water, followed by thorough rinsing with tap water, acid washing with 0.10 M HCl, and rinsing a minimum of three times with DI water). A fresh filter membrane should be used for each sample. Preserve the sample accordingly using a minimal amount of nitric acid (HNO_3) to achieve a pH less than 2 and submit to the laboratory for analysis of dissolved uranium and molybdenum.

11. Repeat Steps 1 through 10 using fresh material that was previously used to prepare Column 4 (AMEC, 2011a).

ATTACHMENT B

BATCH TESTING RESULTS AND CALCULATIONS

B1: Calculations for Extractable Uranium.

Test No.	Material	Sample Mass	Solution Volume	A	B	C	Mean	Method Blank	Solution Blank	Corrected Mean	Extractable U	Total U	Uranium Extracted
		(g)	(mL)	---------- mg/L ----------							(mg/kg)		(%)
1	C1	50	250	0.27	0.28	0.25	0.267	0.00019	<0.001	0.266	1.3	6.2	21
2	C1	50	250	0.23	0.23	0.26	0.240	0.00019	<0.001	0.240	1.2	6.2	19
3	C1	50	250	0.32	0.32	0.33	0.323	0.00019	<0.001	0.323	1.6	6.2	26
4	C1	50	250	0.28	0.30	0.30	0.293	0.00019	<0.001	0.293	1.5	6.2	24
5	C1	50	250	0.57	0.50	0.48	0.517	0.00019	0.002	0.515	2.6	6.2	42
6	C1	50	250	0.53	0.57	0.47	0.523	0.00019	0.002	0.521	2.6	6.2	42
7	C1	50	250	0.49	0.50	0.49	0.493	0.00019	0.068	0.425	2.1	6.2	34
8	C1	50	250	0.54	0.53	0.47	0.513	<RDL	0.068	0.445	2.2	6.2	36
9 (Control)	C1	50	250	0.0057	0.005	0.0047	0.005	<RDL	<RDL	0.005	0.026	6.2	0.41
10	C4	50	250	0.14	0.15	0.14	0.143	<RDL	<0.001	0.143	0.72	4.7	15
11	C4	50	250	0.14	0.14	0.14	0.140	<RDL	<0.001	0.140	0.70	4.7	15
12	C4	50	250	0.16	0.16	0.16	0.160	<RDL	<0.001	0.160	0.80	4.7	17
13	C4	50	250	0.16	0.16	0.16	0.160	<RDL	<0.001	0.160	0.80	4.7	17
14	C4	50	250	0.18	0.20	0.18	0.187	<RDL	0.002	0.185	0.92	4.7	20
15	C4	50	250	0.20	0.19	0.20	0.197	<RDL	0.002	0.195	0.97	4.7	21
16	C4	50	250	0.17	0.17	0.17	0.170	<RDL	0.068	0.102	0.51	4.7	11
17	C4	50	250	0.19	0.19	0.19	0.190	<RDL	0.068	0.122	0.61	4.7	13
18 (Control)	C4	50	250	0.0088	0.0074	0.0068	0.008	<RDL	<RDL	0.008	0.038	4.7	0.82

B2: Calculations for Extractable Molybdenum.

Test No.	Material	Sample Mass	Solution Volume	A	B	C	Mean	Method Blank	Solution Blank	Corrected Mean	Extractable Mo	Total Mo	Mo Extracted
		(g)	(mL)	---------- mg/L ----------							(mg/kg)		(%)
1	SSC	50	250	0.139	0.147	0.130	0.139	0.0007	<0.001	0.138	0.690	2.2	31
2	SSC	50	250	0.176	0.186	0.180	0.181	0.0007	<0.001	0.180	0.900	2.2	41
3	SSC	50	250	0.149	0.152	0.151	0.151	0.0007	<0.001	0.150	0.750	2.2	34
4	SSC	50	250	0.174	0.182	0.190	0.182	0.0007	<0.001	0.181	0.907	2.2	41
5	SSC	50	250	0.223	0.221	0.199	0.214	0.0007	<0.001	0.214	1.07	2.2	49
6	SSC	50	250	0.215	0.211	0.208	0.211	0.0007	<0.001	0.211	1.05	2.2	48
7	SSC	50	250	0.212	0.217	0.200	0.210	0.0007	<0.001	0.209	1.04	2.2	47
8	SSC	50	250	0.207	0.203	0.204	0.205	0.0004	<0.001	0.204	1.02	2.2	46
9 (Control)	SSC	50	250	0.106	0.099	0.095	0.100	0.0004	0.0004	0.100	0.498	2.2	23
10	WCS	50	250	0.178	0.180	0.174	0.177	0.0004	<0.001	0.177	0.885	3.1	29
11	WCS	50	250	0.210	0.216	0.208	0.211	0.0004	<0.001	0.211	1.05	3.1	34
12	WCS	50	250	0.214	0.213	0.217	0.215	0.0004	<0.001	0.214	1.07	3.1	35
13	WCS	50	250	0.235	0.241	0.243	0.240	0.0004	<0.001	0.239	1.20	3.1	39
14	WCS	50	250	0.259	0.267	0.252	0.259	0.0004	<0.001	0.259	1.29	3.1	42
15	WCS	50	250	0.270	0.261	0.257	0.263	0.0004	<0.001	0.262	1.31	3.1	42
16	WCS	50	250	0.280	0.277	0.270	0.276	0.0004	<0.001	0.275	1.38	3.1	44
17	WCS	50	250	0.256	0.263	0.262	0.260	<RDL	<0.001	0.260	1.30	3.1	42
18 (Control)	WCS	50	250	0.170	0.156	0.160	0.162	<RDL	<RDL	0.162	0.810	3.1	26