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Retention: Permanent

Laboratory Evaluation of I-129 and Tc-99 Removal at the F-Area Water Treatment Units

November 11, 2002

S. M. Serkiz
Waste Processing Technology,
SRTC, Building 773A

J. P. Kanzleiter
ER Engineering
Environmental Restoration Division, 704-22G

W.E. Stevens 11/21/02
Authorized Derivative Classifier

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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Authors

S. M. Serkiz
Westinghouse Savannah River Company

J. P. Kanzleiter
ER Engineering
Environmental Restoration Division

Laura McDowell-Boyer
Alara Environmental Analysis, Inc.

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Westinghouse Savannah River Company
Savannah River Site
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Authors

11/14/02

S. M. Serkiz, Waste Disposal & Environmental Development — Date

11/14/02

J. P. Kanzleiter — Date
ER Engineering – Environmental Restoration Division

Design Check

11/14/02

D. I. Kaplan, Waste Disposal & Environmental Development — Date
(per Manual E7, Procedure 2.40)

Approvals

11/19/02

B. T. Butcher, Level 4 Manager — Date
Waste Disposal & Environmental Development – SRTC

11/14/02

John Adams — Date
ER Engineering – Environmental Restoration Division

Table of Contents

1. Executive Summary 4
2. Introduction 4
3. Materials and Methods 7
4. Results 11
5. Conclusions and Recommendations 24
6. References 26
7. Figures 27
8. Appendix A (Email From Butcher 7/9/02) 36
9. Appendix B (Full ICP-ES Elemental Data) 1

List of Tables

Table 1 – Sorbent Materials Evaluated 8
Table 2 – Effluent Sampling and Analysis Schedule 10
Table 3 – Radiochemical Data for F WTU Feedwater (pCi/L) 12
Table 4 – Elemental Composition Data for F WTU Feedwater (mg/L) 12
Table 5 – Radiochemical Data Concept 1 (Silver Modified Carbons) 15
Table 6 – ICP-ES Silver and Uranium Data Concept 1 (Silver-Modified Carbons) 16
Table 7 – TCLP Silver Data for Silver Modified Carbons 17
Table 8 – Ag and U Post Column Test Data for Silver Modified Carbons 18
Table 9 – Radiochemical Data Concept 2 20
Table 10 – Radiochemical Data Concept 3 (Commercial Anion Resin) 22
Table 11 – ICP-ES Uranium Data SIR1200 23
Table 12 –U Post Column Test Data for Commercially Available Resins 24

List of Figures

Figure 1 – F WTU Process Schematic 27
Figure 2 – SEM of AgCl SIAC (2000X Magnification). 28
Figure 3 – EDX of AgCl SIAC. 28
Figure 4 – Schematic of Experimental Setup. 29
Figure 5 – Photograph of Experimental Setup. 30
Figure 6 – I-129 Effluent Activity for Concept 1 (Silver Modified Carbons). 31
Figure 7 – Tc-99 Effluent Activity for Concept 1 (Silver Modified Carbons). 32
Figure 8 – I-129 Effluent Activity for Concept 3 (Anion Resin). 33
Figure 9 – Tc-99 Effluent Activity for Concept 3 (Anion Resin). 34

1. Executive Summary

The current process configuration of the F-Groundwater Treatment Unit (F-WTU) is limited in its ability to remove I-129 from the feed water. Furthermore, because the disposal limits at SRS for I-129 bearing waste are low, disposal of both the spent ion exchange (IX) resin and filtercake from the clarification process has been a complex problem. The focus of this study was to investigate the effectiveness of a variety of sorption materials to remove problematic anions (e.g., I-129) present in feed water at the F-WTU. The results from this study suggest that the silver-modified carbons and the commercially available anion exchange resin, SIR-1200, were effective in removing I-129 from the feed water to low levels. Pilot or field testing at the F-WTU on a subset of these materials is recommended to confirm these findings and to evaluate the potential benefits for full-scale implementation.

2. Introduction

Removal of anions at the F- and H- Seepage Basins Groundwater Treatment Units (WTUs) has been problematic in terms of low decontamination factors (DFs) and rapid resin exhaustion. It is believed that these problems stem from the lack of target contaminant sorption specificity and, to a lesser extent, lack of resin exchange capacity. Currently anion exchange is performed as a polishing step after clarification (see Figure 1 for process schematic).

Additionally, because the SRS disposal limits for I-129 bearing waste are low, disposal of both the spent ion exchange (IX) resin and filtercake from the clarification process has also been problematic. Estimates based on disposal costs and waste production estimates from Butcher (2002) indicate that cost savings would be on the order of $7-8 M if filtercake and spent cation resins could be disposed of in slit trenches at SRS rather than at the Nevada Test Site. This, it is believed, could be accomplished if I-129 can be kept out of these wastes and/or if the I-129 is a sufficiently stable secondary waste to prevent I-129 leaching.

In the summer of 2001, work was initiated to evaluate alternative separation processes (moving anion exchange to the front end of the process) and materials (i.e., ion exchange resins and sorbents) for the removal of I-129 and Tc-99 in groundwater being treated at the F-Area Seepage Basins WTU. The general approach of this work was to evaluate a number of anion removal materials for their ability to remove and sequester I-129 and Tc-99 from actual F-Area WTU feedwater in a series of laboratory column experiments. The performance criteria for these materials are (1) selectivity of the sorbent for I-129 and Tc-99 (i.e., target contaminant DF); (2) capacity of the sorbent for the target contaminant(s) (i.e., contaminant breakthrough profile); (3) the ability of the sorbent to produce a stable secondary waste material; and (4) cost. These criteria were evaluated in three separate concepts:

- Silver-modified activated carbons,
- concurrent I-129/mercury removal, and
- screening of commercially available organic anion exchange resins.

These approaches are described in more detail below.

2.1. Concept 1 – Silver-Modified Activated Carbons

Recent work has been completed as a joint project between SRTC and Clemson University on the use of silver impregnated activated carbon (SIAC) sorption media for the removal of iodide from aqueous waste streams (Hoskins et al. 2002 and Cumbie, 2002). SIACs are granular activated carbons that have been impregnated with silver to form a composite reactive surface of silver and activated carbon. Silver can be impregnated in a variety of chemical forms with the most common being metallic silver [Ag(0)]. As described below, in addition to SIAC-Ag(0), advantageous solubility controls associated with silver chloride (AgCl) lead us to investigate this chemical form of silver impregnation in SIAC as the SIAC-AgCl composite material.

Note that the SIAC media is different than the activated carbon used at the WTUs by Adtechs during startup. The Adtechs' unmodified activated carbon material did not effectively remove the iodine, was prone to clogging due to inefficient operating conditions at that time, and was a source for biological growth. In order to elucidate the role of the activated carbon backbone on anion removal, we chose to include in the study the unmodified activated carbon material that was the precursor for two of the SIACs.

Costs for these SIAC materials ($3-$8/lb) are competitive with the Dowex-21K and SIR 1200 anion exchange resins used at the F WTU (approximately $4.6/lb and $3.7/Ib, respectively) and have the potential for a substantially increased operational life.

The work by Hoskins et al (2002) showed that SIAC impregnated with silver metal [SIAC-Ag(0)] exhibited high DFs for iodide removal over a wide range of chemical conditions. Furthermore, once this material was contacted with iodide, leaching of iodide from the secondary waste was not measurable (high K_d values). The SIAC-Ag(0) material, however, leached silver when iodide was absent from the aqueous waste stream and the pH was low. The low-pH conditions of feedwater at the F-Area WTU makes silver leaching from the SIAC-Ag(0) material a concern. While another approach for this material could be as a post-clarifier anion exchange step where the pH of the system is alkaline, this approach and the current WTU configuration would not keep I-129 out of the filtercake clarifier waste.

Work by Cumbie (2002) has shown that activated carbon can be impregnated with silver chloride (AgCl) rather than silver metal [Ag(0)] and that the SIAC-AgCl has the potential to overcome the problems of silver leaching observed for SIAC-Ag(0). These silver leaching observations are consistent with the solubility limit for the AgCl solid reported in the MINTEQA2 thermodynamic database (Allison, 1991) of K_{sp} = 1.8E-10 which corresponds to solubility of 1.44 ppm Ag in deionized water. The presence of naturally occurring chloride, however, will reduce the soluble silver level significantly. For example, at the average river water concentration for chloride of 5.6 mg/L (Stumm and Morgan, 1995) the solubility of Ag drops to 0.12 ppm. Additionally, if silver becomes soluble, the activated carbon has the potential of removing soluble silver through nonspecific sorption to the surface which will further reduce soluble silver concentrations.

The basic approach to testing silver modified carbons for I-129 removal was to develop, produce, and characterize SIAC based on a sparingly soluble AgCl chemistry and then evaluate these materials in the laboratory using actual F-Area WTU influent water in column tests. To assess the performance changes associated with the SIAC-AgCl approach, the base activated carbon (no silver) and SIAC-Ag(0) materials were also evaluated side-by-side using actual F-Area WTU influent water in column tests. In these tests, I-129 DF, sorption kinetics, and SIAC sorption capacity will all be measured. In order to evaluate secondary waste stability, both the starting SIACs and the SIACs after reaction with the F-Area feedwater were subjected to TCLP extractions and these extracts analyzed for silver content.

2.2. Concept 2 - Concurrent I-129/Mercury Removal

As in Concept 1, the second concept investigated in this study also takes advantage of the low solubility of transition metal-halide solids [in this case mercuric (Hg^{2+}) iodide]. Because Hg is a toxic metal and has a very low regulatory limit (2 ppb in groundwater), the addition of an engineered mercury containing sorbent was thought to be potentially unacceptable from a regulatory standpoint. Rather, because low levels of Hg are present in groundwater treated in the WTU, this concept involves the creation of a Hg containing resin in the WTU by sorption of Hg from contaminated groundwater onto a commercially available Hg specific resin during normal WTU operations. The hypothesis was that this *in situ* Hg-loaded resin would then act as sorbent capable of highly selective removal of I-129 as a mercuric iodide solid.

This hypothesis was developed based on recent data on the leaching of I-129 from spent Effluent Treatment Facility mercury-specific resin (GT-73) that showed concurrent loading of I-129 and mercury (Hg) (Kaplan et al, 1999). Furthermore, the leach rate of both I-129 and Hg from these resins was found to be exceedingly small. It was thought that iodine and mercury were removed from solution by the following mechanism: (1) Hg sorption to the Hg-specific resin and (2) reaction of the sorbed Hg with I-129 to form a sparingly soluble mercury iodine solid. For example, mercuric iodide [$Hg(II)I_2$ (s)] has a solubility product of 10E-28.62 (Lindsay, 1979). This solubility product corresponds to an equilibrium aqueous iodide concentration of 7.2E-5 ppm. If the conservative assumption were made that all iodide is in the isotope I-129, then this would correspond to an activity in solution of about 30 pC_i/L. Therefore, if solubility control of I-129 can be achieved by the mechanism described above, then this would ensure I-129 leachate concentrations from the resulting secondary waste below the South Carolina Department of Health and Environmental Control Underground Injection Control (UIC) Permit limit of 50 pC_i/L.

In a previous bench-scale study (Monson et al., 2000), GT-73, SR-4, and SIR-200 resins were the mercury specific ion exchange materials shown to be the most effective for removal of mercury from process water from the H-Area WTU. Based on this study and data collected from the ETF study, GT-73 was thought to be a good candidate for Hg removal and the production of a mercury containing sorbent. This concept was evaluated with GT-73 resin that was loaded with Hg as a mercuric nitrate prior to contacting with WTU feedwater and a second column of GT-73 resin that had not been exposed to mercury prior to contacting with WTU feedwater. These materials (GT-73 resin and GT-73 resin loaded with Hg) were tested in the laboratory using actual F-Area WTU influent water in column studies. These column studies were designed to provide data to estimate sorption capacity, competitive ion sorption, and operational life for these materials.

2.3. Concept 3 – Screening of Commercially Available Organic Anion Resins

The anion exchange resin previously employed at the F-WTU, Dowex-21K, is an expensive specialty anion exchange resin designed to remove uranium in the anionic form (carbonate complexes) in the uranium mining industry. Recently, a study conducted at the F-WTU (Kanzleiter, 2001) indicated that the SIR-1200 exhibited better performance when compared to the DOWEX-21K. The SIR-1200 has since replaced the DOWEX 21K at the F- and H-WTUs based on improved performance (i.e., higher DF and longer runtime) at a lower cost.

The current location for anion removal (i.e., I-129 and Tc-99) is after the clarifier where the pH has been raised to a value between 7 and 9. At these higher pH values, anion removal is less effective due to hydroxide anion competition for sorption onto the resin. This study examined the removal of anions from the WTU feedwater, at lower pH values (prior to pH adjustment), where anion removal should be more effective.

To evaluate Concept 3, SIR-1200 and ResinTech's WBG-30, a high capacity, weak base granular anion exchange resin were tested in the laboratory using actual F-Area WTU influent water in column studies. These column studies were designed to provide data to estimate sorption capacity, competitive ion sorption, and operational life for these materials.

3. Materials and Methods

The materials and methods section describes the (1) development, pretreatment, and characterization of sorbent materials used in this study, (2) experimental protocols used in the column testing of sorbent materials with actual F Area WTU feedwater, and (3) analytical methods used in this testing.

3.1. Materials

Eight different sorbents were evaluated in this study and are listed in Table 1. For the silver-modified carbon studies, two commercially prepared bituminous coal based SIAC-Ag(0)s with different silver contents by weight [1.05% (TOG-NDS-20x50, Calgon Corporation) and 0.05% (Nusorb A 20x40, Nucon International, Inc.)] were used as starting materials for this study. These commercially available SIACs were reacted with hydrochloric acid to form SIAC-AgCl materials for further evaluation. The reaction conditions, time and acid concentration, were optimized using material characterization of the reacted material. Scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDX) were used to evaluate the solid phase. After reaction, the spent hydrochloric acid solution was analyzed for silver content. The details of these analyses and the development of reaction conditions are contained in Cumbie, 2002. The SEM and EDX show that this treatment process is capable of converting silver metal in the SIAC to silver chloride. Once the reaction conditions were optimized, larger batches of SIAC-AgCl materials were produced for this study. Representative SEM and EDX data of this material (1.05% Ag) are included as Figures 2 and 3 respectively.

For comparison purposes, the base activated carbon (containing no silver) used to produce the 1.05% SIAC-Ag(0), and the 1.05% SIAC-Ag(0) used to produce the SIAC-AgCl were evaluated against the SIAC-AgCl with 0.05 and 1.05 weight percent silver. For testing the concurrent removal of mercury and I-129, the mercury specific ion exchange resin, GT-73 was evaluated. This ion exchange resin was tested "as received" and after being loaded with mercury. For the mercury-loaded resin, the resin was pretreated with 100 pore volumes of 2 ppb mercuric nitrate ($Hg(NO_3)_2$) via a peristaltic pump at a flow rate of 2 ml per minute. The commercially available anion exchange resins, SIR-1200 and WBG-30, were tested as received.

Table 1 – Sorbent Materials Evaluated

Material	Source	Pretreatment	Sorbent Added to Column (g)
Base Activated Carbon (1.05% SIAC-Ag(0) precursor)	Calgon Corporation	None	11.12
SIAC-Ag(0) (1.05% Ag) (Sample TOG-NDS-20x50)	Calgon Corporation	None	12.42
SIAC-AgCl (0.05% Ag)	Treated in House	HCl Treatment of Nusorb A 20x40	12.25
SIAC-AgCl (1.05% Ag)	Treated in House	HCl Treatment of Calgon TOG-NDS-20x50	14.11
GT-73 Resin	Rohm & Haas	None	24.86
GT-73 Resin Hg Loaded	Treated in House	2 ppb $HgNO_3$ Treatment of Rohm & Haas GT-73 Resin	25.30
SIR-1200 Anion Resin	ResinTech	None	17.02
WBG-30 Anion Resin	ResinTech	None	14.02

3.2. Column Studies

All column testing was conducted using established test methods and the general approach contained in the following procedures.

- ASTM D 1782-91, "Test Methods for Operating Performance of Particulate Cation-Exchange Materials"
- ASTM D 2187-94, "Standard Test Methods for Physical and Chemical Properties of Particulate Ion Exchange Resins"

Because this study was designed for the rapid screening of the performance of a large number of resin materials rather than a detailed characterization of the materials, minor modifications to the ASTM procedures (column dimensions, mass of resin, and flow rate) were necessary.

A schematic of the experimental setup is presented in Figure 4 with photographs of the setup in Figure 5. The columns used in this study were constructed of glass and were 1.5 cm in diameter and 15 cm in height (i.e., a total column volume of 26.5 mL) and were obtained from the Kontes Glass Co. Eight glass columns were each filled to approximately three-quarters height and the weight recorded (see Table 1). The bedvolume of material is approximately 20 ml, and at an assumed porosity of 40 percent, one porevolume is about 8 mL. After the solid material was packed into each column, a plug of glass wool was inserted to fill the remaining space at the top of the column. Each column was then capped. A straight line from the feed water was used to evaluate the influent concentration (i.e., column blank).

Feed water from the F-Area WTU was used as influent solution for the column study. Personnel from the Environmental Restoration Department delivered two hundred liters of F-WTU feedwater, contained in eight 25-liter carboys, to SRTC for use in this study. Each of the columns were "pretreated" with one liter of feed water at a flow rate of 5.0 ml/min (approximately 50 bedvolumes) prior to chemical analyses. This "pretreatment" was completed in order to allow the columns to achieve steady state conditions prior to sampling. After preconditioning, the experiment was run continuously (24-hour a day basis) at an influent pumping rate of 5.0 ml/min. The column testing lasted about 2.8 days or a total effluent volume of about 20-L. At predetermined cumulative effluent volumes, samples were collected for analysis as outlined in Table 2.

The lab column study was conducted at a flow rate that results in approximately 15 bedvolumes per hour and 37.5 porevolumes per hour. This flow rate per bedvolume results in a contact time of 4 minute per bedvolume. In comparison, an anion exchange vessel at the F-WTU is normally filled with about 56 cubic feet (or 419 gallons) of resin. At a porosity of 40 percent, one porevolume is about 22.4 cubic feet or 168 gallons. The average flow rate through the vessel is approximately 40 GPM (or 2400 GPH) that results in approximately 5.7 bedvolumes per hour and 14.3 porevolumes per hour. The plant flow rate per bedvolume results in a contact time of about 10.5 minutes. The column study flow rate was about 2.6 times faster than those normally experienced for anion removal at the F WTU. I-129 breakthrough at the F-WTU has been estimated at approximately 600 bedvolumes (approximately 4.3 days of continuous operation under full-flow condition). The column study at 1050 bedvolumes equates to approximately 8 days of plant operations.

At the conclusion of the column study, solids from each sorbent were extracted and selected solids digested. Digestion was accomplished using an acid microwave process and was completed by the Analytical Development of SRTC. The liquid from the digestion process was analyzed by ion coupled emission spectrophotometry (ICP-ES) for RCRA Metals and uranium. Extraction was conducted using the USEPA's toxicity characteristic leaching procedure (TCLP) and the extract analyzed by cold vapor atomic absorption spectrophotometry for mercury and ICP-ES for RCRA metals and uranium.

Table 2 – Effluent Sampling and Analysis Schedule		
Effluent Volume (L)	Average Porevolume	Analysis
1 to 2	75	Iodine-129, ICP-ES Metals
2 to 3	125	Iodine-129, ICP-ES Metals
3 to 4	175	Iodine-129, ICP-ES Metals
4 to 6	250	Tc-99, Gross Alpha/Non-Volatile Beta, ICP-ES Metals
6 to 7	325	Iodine-129, ICP-ES Metals
7 to 8	375	Iodine-129, ICP-ES Metals
8 to 9	425	Iodine-129, ICP-ES Metals
9 to 11	500	Tc-99, Gross Alpha/Non-Volatile Beta, ICP-ES Metals
11 to 12	575	Iodine-129, ICP-ES Metals
12 to 14	650	Tc-99, Gross Alpha/Non-Volatile Beta, ICP-ES Metals
14 to 15	725	Iodine-129, ICP-ES Metals
15 to 17	800	Tc-99, Gross Alpha/Non-Volatile Beta, ICP-ES Metals
17 to 18	875	Iodine-129, ICP-ES Metals
18 to 20	950	Tc-99, Gross Alpha/Non-Volatile Beta, ICP-ES Metals
20 to 21	1025	Iodine-129, ICP-ES Metals

Note: All effluent samples from silver containing carbon columns were also analyzed for Ag and uranium by ICP-ES at the ADS of SRTC.

3.3. Analysis and QA/QC

GEL Laboratories of Charleston, SC analyzed effluent samples under contract AB80091N with WSRC. Details of analytical procedures and QA requirements for these analyses are contained in this contract. Standard QA practices were utilized to maximize usefulness of the experimental data. This included: a) use of an accredited analytical laboratory; b) routine submittal of experimental blanks; and c) submittal of experimental replicates. The SRTC Conduct of R&D Manual was employed for this work and a Hazard Screening Checklist was completed.

3.3.1. Radiochemical Analyses

GEL Laboratories conducted all radiochemical analyses (Tc-99, I-129, gross alpha and nonvolatile beta). Serkiz and Reboul (1999 Clearwell IX Study) reported that alpha emitters included U-238, U-234, Cm-244, Am-241, Th-230, and Ra-226 and the beta emitters included Sr-90, Y-90 (Y-90 is in secular equilibrium with Sr-90), and Ra-228, as well as potentially volatile C-14, Tc-99, and I-129.

3.3.2. Elemental Composition

At selected effluent volumes 30-mL aliquots were collected for elemental composition analysis by ICP-ES and mercury using cold vapor atomic absorption (AA) spectrophotometry by the ADS of SRTC. Samples were analyzed by ICP-ES without filtration and were acidified to a pH of approximately 1 with ultra-pure nitric acid prior to analysis. ICP-ES was used to analyze for major ion chemistry (e.g., Al, Si, Fe), RCRA metals, and uranium. Mercury was analyzed on unpreserved samples using cold vapor atomic absorption (AA) spectrophotometry.

Liquids from microwave dissolutions and TCLP extractions were analyzed by ICP-ES without preservation.

4. Results

This section describes the results of ion exchange optimization testing and is organized in four sections: feedwater characterization; Concept 1 - Silver Modified Activated Carbons; Concept 2 - Concurrent I-129/Mercury Removal; Concept 3 – Screening of Commercially Available Organic Anion Resins, and Solids Characterization.

4.1. F-WTU Feedwater Characterization

Samples of column influent were collected at predetermined volumes during column testing of sorbent materials and subsequently analyzed for I-129, Tc-99, gross alpha, and nonvolatile beta. For these samples, the average activities were determined to be 56 pCi/L for I-129, 64 pCi/L for Tc-99 , 380 pCi/L for gross alpha, and 680 pCi/L for nonvolatile beta. These radiochemical data are summarized in Table 3. Activity levels for the feedwater used in this study are similar, but consistently lower, than historical data in the Preliminary Engineering Report for the WTU and reported in Serkiz et al. 2000. This is thought to be due to the slow decline in concentrations since the beginning of remediation operations.

Silver and uranium data for column influent are summarized in Table 4. For silver the average concentration is about 9 ppb and for uranium about 1.6 ppm.

Table 3 - Radiochemical Data for F WTU Feedwater (pCi/L)

Bedvol. Effluent	I-129 (pCi/L)	Counting Error Std Dev	Tc-99 (pCi/L)	Countin g Error Std Dev	Gross Alpha (pCi/L)	Counting Error Std Dev	Nonvolatile Beta (pCi/L)	Counting Error Std Dev
75	54.8	4.35						
125	45.9	7.98						
175	58	10.1						
250			55	6.79	394	15.9	663	12.1
325	63.2	9.55						
375	56.4	7.2						
425	56.9	9.99						
500			50.4	5.88	322	13.2	685	12.9
575	58.6	3.81						
650			65.7	6.78	501	34.6	738	23.2
725	63.7	9.33						
800			81.2	8.49	371	14.1	617	12.3
875	56.1	9.03						
950			70.1	6.88	293	13.1	708	13.5
1025	47.4	7.44						
Average	56.1		64.48		376.2		682.2	
Std Dev	5.8		12.3		80.3		45.8	

Table 4 – Elemental Composition Data for F WTU Feedwater (mg/L)

Bedvol. Effluent	Ag	U
100	0.0021	1.714
150	0.0029	1.717
200	0.0018	1.700
250	0.0022	1.700
350	0.0036	1.697
400	0.0039	1.704
450	0.0040	1.715
500	0.0289	1.506
600	0.0160	1.520
650	0.0116	1.562
750	0.0106	1.518
800	0.0115	1.521
900	0.0130	1.516
950	0.0127	1.509
Average	0.0089	1.614
Std Dev	0.0076	0.097

4.2. Concept 1 - Silver Modified Activated Carbons

Effluent water quality data for these column studies are presented in Tables 5 and

6 for radiochemical and ICP-ES silver and uranium analyses respectively.

4.2.1. Effluent I-129 Data

Data for I-129 activity as a function of bedvolumes of effluent are presented graphically in Figure 6. The performance of the silver modified carbons with actual F WTU feedwater was very good with I-129 breakthrough (as defined by effluent activity of 50% of the feedwater activity) not being reached for any of these materials during the 1050 bedvolumes duration of this test. Furthermore, none of the column effluent I-129 activities were above the detection limit until after 725 bedvolumes and after this point effluent volume only slightly above the 10 pCi/L detection limit. At the last data point, the SIAC-AgCl 0.05% showed an increase in I-129 activity to about 20 pCi/L. It is important not to over interpret a single data point, but this may indicate that this material had expended its capacity for I-129 removal as it originally contained only $1/20^{th}$ of the silver in the 1.05% SIAC.

Contact times in the laboratory were similar to what would be expected for fesd water flow rates under normal plant operation and I-129 removal was achieved with the silver modified carbons, I-129 removal kinetics is not expected to be problematic under normal plant flow rate conditions.

In contrast to the silver-modified carbons, the base activated carbon showed breakthrough at about 600 bedvolumes.

4.2.2. Effluent Tc-99 Data

Data for Tc-99 activity as a function of bedvolumes of effluent are presented graphically in Figure 7. All carbon materials produced effluent below detection limit over the entire duration of the experiment. The exact mechanism for Tc removal is not known, but is thought to be nonspecific sorption to the activated carbon and/or a reduction of TcO_4^- anion to Tc^{+4} cation and subsequent precipitation of an insoluble $Tc(IV)O_2$ solid.

4.2.3. Effluent Gross Alpha/Nonvolatile Beta

Gross alpha and nonvolatile beta data do not exhibit any major trends for the carbon materials evaluated. The gross alpha data (see Table 5) show removal of alpha activity by up to a factor of 2 for the silver-modified carbons. These observations are consistent with elemental data for uranium (the major alpha contributor) where uranium DF values started at a value of greater than 3 and fell to minimum values of about 1.5 at the end of the experiment (see Table 6). Coupled with the isotope specific analyses for I-129 and Tc-99, this suggests that the silver modified materials are highly specific for the target anions (I-129 and Tc-99).

4.2.4. Effluent Silver Data

Hoskins et al. (2002) identified Ag leaching in the absence of iodide from SIAC-Ag(0) under acidic conditions. This was the motivation for producing and testing SIAC-AgCl materials.

Consistent with these previous observations, silver leaching from the SIAC-Ag(0) was significantly greater than that for SIAC-AgCl. In fact, effluent concentrations were as high as 13.9 mg/L, which is above the USEPA's TCLP leachate limit of 5 mg/L. Note that the TCLP extraction limit is for use with the acetic acid TCLP extraction in order to define RCRA hazardous material.

In comparison, the maximum silver concentrations observed in effluents from the SIAC-AgCl column effluents were 0.36 mg/L. Maximum concentrations were approximately equal for both the 0.05 and 1.05 percent SIAC-AgCl materials and these data suggest that silver was leached under a solubility control mechanism. For both of the SIAC-AgCl materials, silver concentrations in the effluent rose quickly to maximum concentrations in the first several hundred bedvolumes. In the case of the 1.05% SIAC-AgCl, the effluent silver concentration remained relatively constant near the maximum concentration through the remainder of the test. In contrast, the 0.05% SIAC quickly reached a maximum silver concentration and then rapidly declined. Because there was only about 6 mg silver in this column, it is thought that the reduction in silver in the effluent is due to a depletion of silver in the SIAC (note: 20 L at 0.3 mg/L would account for leaching of all the silver).

Table 5 – Radiochemical Data Concept 1 (Silver Modified Carbons)

	Feedwater		Base Activated Carbon		1.05% SIAC-Ag(0)		0.05% SIAC-AgCl		1.05% SIAC-AgCl	
Bedvol. Effluent	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**
75	54.8	4.35	0.823	2.50	1.28	1.32	0.0307	1.82	-0.429	1.29
125	45.9	7.98	5.95	3.19	-0.343	7.57	-0.655	1.74	0.288	0.926
175	58.0	10.1	9.28	2.01	-0.0777	0.446	0.713	0.626	-0.148	0.903
325	63.2	9.55	20.3	4.14	0.148	1.29	0.0973	0.963	1.41	1.69
375	56.4	7.2	15.7	4.71	-0.185	0.862	0.302	1.85	0.432	1.20
425	56.9	9.99	20.4	2.06	-0.0462	0.492	0.346	0.621	0.789	0.828
575	58.6	3.81	24.6	3.73	-0.187	0.828	2.00	1.37	0.504	1.34
725	63.7	9.33	33.1	4.93	0.657	1.43	0.0054	0.943	0.180	0.683
875	56.1	9.03	23.5	5.59	7.39	1.86	0.472	0.637	0.546	1.32
1025	47.4	7.44	25.1	5.22	-0.0859	1.60	17.0	4.31	7.42	4.98
Bedvol. Effluent	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**
250	55.0	6.79	3.05	3.02	0.587	2.77	0.855	2.75	-0.990	2.58
500	50.4	5.88	3.44	3.12	0.215	2.70	-0.420	2.58	-2.96	2.31
650	65.7	6.78	4.18	3.33	0.426	3.27	-1.57	2.72	-1.94	2.80
800	81.2	8.49	4.71	3.32	0.864	3.09	3.25	3.22	-3.59	12.8
950	70.1	6.88	5.99	3.38	-0.987	2.85	2.63	3.14	-2.89	2.57
Bedvol. Effluent	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**
250	394	15.9	379	31.9	232	6.86	248	12.8	207	6.26
500	322	13.2	436	43.2	299	14.8	282	13.1	244	12.8
650	501	34.6	344	13.6	272	12.4	305	15.0	235	12.6
800	371	14.1	230	12.3	308	14.9	275	13.2	274	12.8
950	293	13.1	288	13.1	318	14.5	318	13.9	296	13.0
Bedvol. Effluent	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**
250	663	12.1	742	34.1	664	7.29	579	11.3	638	7.10
500	685	12.9	826	46.2	634	12.0	706	13.5	557	11.1
650	738	23.2	719	13.2	648	12.8	618	11.9	510	10.7
800	617	12.3	529	10.9	648	12.1	546	13.2	535	12.8
950	708	13.5	706	13.5	608	11.6	581	11.3	674	13.1

Table 6 – ICP-ES Silver and Uranium Data Concept 1 (Silver-Modified Carbons)

	Feedwater		1.05% SIAC-Ag(0)			0.05% SIAC-AgCl			1.05% SIAC-AgCl		
Bedvol. Effluent	**Ag (mg/L)**	**U (mg/L)**	**Ag (mg/L)**	**U (mg/L)**	**U DF** (Unitless)	**Ag (mg/L)**	**U (mg/L)**	**U DF** (Unitless)	**Ag (mg/L)**	**U (mg/L)**	**U DF** (Unitless)
100	0.0021	1.714	0.073	<0.550	>3.12	0.052	<0.550	>3.12	0.036	<0.550	>3.12
150	0.0029	1.717	0.174	<0.550	>3.12	0.365	<0.550	>3.12	0.066	<0.550	>3.12
200	0.0018	1.700	1.42	<0.550	>3.09	0.321	<0.550	>3.09	0.279	<0.550	>3.09
250	0.0022	1.700	13.9	0.639	2.66	0.298	0.620	2.74	0.307	0.598	2.84
350	0.0036	1.697	13.4	0.719	2.36	0.274	0.637	2.66	0.314	0.622	2.73
400	0.0039	1.704	9.69	0.714	2.39	0.262	0.610	2.79	0.324	0.640	2.66
450	0.0040	1.715	5.63	0.751	2.28	0.266	0.713	2.41	0.336	0.682	2.51
500	0.0289	1.506	1.52	0.799	1.88	0.139	0.734	2.05	0.338	0.690	2.18
600	0.0160	1.520	0.855	0.787	1.93	0.079	0.746	2.04	0.338	0.887	1.71
650	0.0116	1.562	0.678	0.876	1.78	0.062	0.746	2.09	0.335	0.839	1.86
750	0.0106	1.518	0.657	0.861	1.76	0.041	0.660	2.30	0.355	0.931	1.63
800	0.0115	1.521	0.670	0.790	1.93	0.040	0.775	1.96	0.343	0.875	1.74
900	0.0130	1.516	0.596	0.836	1.81	0.040	0.792	1.91	0.338	0.987	1.54
950	0.0127	1.509	0.441	0.853	1.77	0.035	0.784	1.92	0.322	0.914	1.65
1050	NA	NA	0.358	0.840	1.79	0.014	0.814	1.84	NA	NA	

NA = Not Analyzed

Result exceeds 5 mg/L Ag TCLP Limit

4.2.5. Effluent Uranium Data

The UIC limit for uranium activity is 50 pCi/L and the post clarification anion exchange units serve to polish uranium not removed in the precipitation and clarification processes. Therefore, if the post-clarification anion exchange resin were removed in lieu of anion removal in the feedwater, meeting UIC limits for uranium could be problematic if the units received elevated levels of uranium and the feedwater anion exchange units did not remove uranium.

Elemental uranium data collected by ICP-ES for the feedwater and silver-modified carbon column effluent are presented in Table 6. Average feedwater concentrations are approximately 1.6 mg/L. There appears to be an inconsistency, however, between the gross alpha activities and elemental ICP-ES uranium data as 1.6 mg/L ^{238}U should have an alpha activity of 540 pCi/L and none of the gross alpha activities measured in the feedwater are that high (see Table 5). Even so, as long as the discrepancy between the two measurements is proportional, DF values can be calculated from the data. Average DF values, assuming all the gross alpha activity is attributable to uranium range from 1.3 to 1.5 whereas DF values calculated from elemental uranium data range from 2.3 to 2.5. In either case, the silver-modified carbons are likely removing some uranium and the mechanism is thought to be reduction of U(VI) to the generally less soluble and stronger sorbing U(IV) form.

With these DF values, we can calculate the maximum feed activities the F WTU can accommodate and still achieve the 50 pCi/L UIC injection limits. Assuming an RO-DF of 50 and a clarifier-DF of 10 (both from F WTU plant data), a DF of 1.3 corresponds to a maximum treatable feedwater activity of 1250 pCi/L and at a DF of 2.3 corresponds to 2400 pCi/L. Current feedwater activities at the F WTU are on the order of 600 pCi/L and, therefore, the placement of anion removal at the WTU feed location should still provide adequate uranium removal even with higher uranium activities in the feedwater.

4.2.6. Solids Analysis

TCLP was completed on both the original sorbent and after column testing (top 5th of column solid). Additionally, microwave dissolution of the top 5th of the column for the base carbon and the 0.05% SIAC-AgCl and individual analyses of five individual sections of the 1.05% SIAC-Ag(0) and 1.05% SIAC-AgCl was completed on solids after column testing. These results are summarized in Tables 7 and 8 for the TCLP and microwave dissolution, respectively.

Table 7 – TCLP Silver Data for Silver Modified Carbons

Material	Unreacted Sorbent TCLP Ag (mg/L)
0.05% SIAC-Ag(0)	NA
1.05% SIAC-Ag(0)	NA
0.05% SIAC (AgCl)	<0.3
1.05% SIAC (AgCl)	<0.3

Notes: NA = Not Analyzed; post column results are from the top 5th (outlet) of column

Table 8 – Ag and U Post Column Test Data for Silver Modified Carbons

Material	Sample Location	Ag TCLP Extract (mg/L)	Ag Digest (µg/g solid)	U TCLP Extract (mg/L)	U Digest (µg/g solid)
Base Carbon	Top 5th	0.219	24.2	<5.00	<439
1.05% SIAC-Ag(0)	Top 5th	10.2	2630	<5.00	<490
	2nd 5th	NA	2690	NA	<451
	3rd 5th	NA	2720	NA	<484
	4th 5th	NA	2200	NA	<482
	Bottom 5th	NA	2020	NA	<463
0.05% SIAC-AgCl	Top 5th	<0.05	54.4	<0.03	<215
1.05% SIAC-AgCl	Top 5th	0.113	956	<0.03	269
	2nd 5th	NA	428	NA	<489
	3rd 5th	NA	635	NA	<455
	4th 5th	NA	907	NA	<455
	Bottom 5th	NA	1100	NA	<484

NA = Not Analyzed
Result exceeds 5 mg/L Ag TCLP Limit

Of the modified carbons only one, the 1.05% SIAC-Ag(0) after the column testing, leached silver at concentrations greater than the silver TCLP limit of 5 mg/L. The digestion concentrations for silver were greatest in the SIAC-Ag(0) and were relatively constant over the length of the column. Due to problems with AgCl(s) digestion, the SIAC-AgCl sample is more difficult to accurately analyze. Therefore, differences observed between solids concentrations of the SIAC-Ag(0) and SIAC-AgCl may be due to problems in the digestion process rather than in actual silver concentration. The initial silver concentrations between these two materials have been reported to be within 10 percent (Cumbie, 2002) and higher column effluent concentrations of Ag were observed for the SIAC-Ag(0). The higher silver concentrations in the SIAC-Ag(0) are, therefore, not consistent with the other observations.

4.3. Concept 2 - Concurrent I-129/Mercury Removal

Effluent water quality data for these column studies are presented in Table 9 for radiochemical analyses.

4.3.1. Effluent I-129 Data

I-129 data for this concept indicate that there was no significant removal with either the GT-73 resin or GT-73 resin pretreated with mercuric nitrate. Because data on ETF GT-73 waste suggests an association between I-129 and Hg levels, it is thought that this reaction is kinetically very slow and that it is only over long time periods (timeframe of years) that the reaction between mercury and iodine becomes important.

4.3.2. Effluent Tc-99 Data

No significant Tc-99 reduction was observed for this concept.

4.3.3. Gross Alpha/Nonvolatile Beta

There is some gross alpha and nonvolatile beta removal although the decontamination factors are low. This is likely due to removal of cations contributing to total alpha (e.g., uranium) and beta (e.g., Sr).

4.3.4. Solids Analysis

Because this concept for anion removal was ineffective, no analysis of the solids data is included.

Table 9 – Radiochemical Data Concept 2

	Feedwater		GT-73		GT-73 Pretreated w/Hg	
Bedvol. Effluent	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**
75	54.8	4.35	46.9	7.58	52.7	5.76
125	45.9	7.98	54.6	5.14	49.4	8.64
175	58.0	10.1	54.9	5.19	53.3	8.6
325	63.2	9.55	50.0	8.50	49.1	9.91
375	56.4	7.20	58.3	9.08	56.9	5.76
425	56.9	9.99	65.6	11.3	46.8	8.73
575	58.6	3.81	62.4	9.04	59.0	8.99
725	63.7	9.33	56.6	4.27	56.7	9.06
875	56.1	9.03	59.7	4.23	60.8	10.1
1025	47.4	7.44	56.6	8.74	57.5	8.74
Bedvol. Effluent	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**
250	55.0	6.79	46.0	5.71	47.0	5.93
500	50.4	5.88	47.6	5.80	42.7	5.49
650	65.7	6.78	59.0	6.56	46.9	5.70
800	81.2	8.49	55.3	6.44	60.7	6.62
950	70.1	6.88	59.8	6.77	59.1	6.51
Bedvol. Effluent	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**
250	394	15.9	45.2	6.59	NA	NA
500	322	13.2	157	11.1	149	9.40
650	501	34.6	159	10.9	170	9.99
800	371	14.1	206	11.6	179	12.1
950	293	13.1	190	10.7	233	13.0
Bedvol. Effluent	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**
250	663	12.1	355	8.93	NA	NA
500	685	12.9	589	15.0	598	12.4
650	738	23.2	531	10.9	599	12.0
800	617	12.3	522	11.6	514	10.8
950	708	13.5	555	11.6	565	11.3

4.4. Concept 3 – Screening of Commercially Available Anion Resins

Effluent water quality data for these column studies are presented in Table 10 for radiochemical analyses. Because the WBG-30 resin was largely ineffective in the removal of I-129, further elemental analyses were only completed for the SIR-1200 column effluent. ICP-ES uranium column effluent data are summarized in Table 11.

As previously stated, the intent of this concept is to reduce anion exchange resin costs and to evaluate moving the location of anion removal to the beginning of the WTU process. The potential advantages of moving anion exchange to the head of the process are to reduce competitive anion effects associated with pH adjustment during the precipitation/flocculation and to reduce or eliminate I-129 from large volume waste streams (i.e., filtercake and post-clarification ion exchange resin).

4.4.1. Effluent I-129 Data

Data for I-129 as a function of bedvolumes of effluent are presented in Figure 8. These data show that the SIR-1200 resin was effective in removing I-129 from F WTU feedwater over the duration of testing. The DF for this resin is about 5 and is relatively constant over the test period. This DF is slightly lower than observed for the silver-modified carbons. The fact that breakthrough for this resin was not observed over the duration of the test suggests that the capacity for this resin was not exhausted.

I-129 DF values for WBG-30 were lower than the SIR-1200 ranging from about 3 to less than 2 and continually increased over the duration of the test.

4.4.2. Effluent Tc-99 Data

Data for Tc-99 as a function of bedvolumes of effluent are presented in Figure 9. As with I-129, the SIR-1200 performed better for Tc-99 removal than WBG-30 resin. DF values for SIR-1200 were on the order of 10 and did not increase significantly over the test.

Table 10 – Radiochemical Data Concept 3 (Commercial Anion Resin)

	Feedwater		SIR-1200		WBG-30	
Bedvol. Effluent	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**	**I-129 (pCi/L)**	**Std Dev**
75	54.8	4.35	5.37	2.29	21.7	3.55
125	45.9	7.98	9.41	3.13	17.4	3.57
175	58.0	10.1	10.0	2.58	27.9	4.90
325	63.2	9.55	7.90	3.65	26.5	5.61
375	56.4	7.20	10.1	2.87	28.4	4.44
425	56.9	9.99	7.27	2.48	29.8	5.39
575	58.6	3.81	9.80	2.41	28.4	5.55
725	63.7	9.33	10.9	3.19	38.8	7.03
875	56.1	9.03	9.89	2.34	41.2	3.70
1025	47.4	7.44	11.5	2.77	35.3	5.51
Bedvol. Effluent	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**	**Tc-99 (pCi/L)**	**Std Dev**
250	55.0	6.79	2.60	2.96	12.5	3.87
500	50.4	5.88	4.70	3.11	14.6	4.17
650	65.7	6.78	4.90	3.63	19.6	4.47
800	81.2	8.49	11.0	4.05	24.7	4.90
950	70.1	6.88	3.93	3.43	27.7	4.84
Bedvol. Effluent	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**	**Gross Alpha (pCi/L)**	**Std Dev**
250	394	15.9	351	15.4	133	8.97
500	322	13.2	343	13.6	118	8.44
650	501	34.6	350	13.7	161	10.6
800	371	14.1	333	13.8	212	11.1
950	293	13.1	338	13.6	256	12.8
Bedvol. Effluent	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**	**Nonvol. Beta (pCi/L)**	**Std Dev**
250	663	12.1	622	11.8	591	12.6
500	685	12.9	678	13.1	571	11.7
650	738	23.2	620	12.1	593	11.4
800	617	12.3	709	13.3	669	12.8
950	708	13.5	630	12.3	700	13.4

4.4.3. Gross Alpha/Nonvolatile Beta

Gross alpha and nonvolatile beta data do not exhibit any obvious systematic trends for the SIR-1200 anion resin. Coupled with the isotope specific analyses for I-129 and Tc-99, this suggests that this resin is highly specific for the target anions (I-129 and Tc-99). The WBG-30 resin initially removed alpha activity, but nonvolatile beta reduction was not observed.

4.4.4. Effluent Uranium Data

Uranium DF data for SIR-1200 are contained in Table 11. DF values are similar to those obtained for the silver-modified carbon with an average value of 2.0. Unfortunately, the first three samples of column effluent were lost when the project was suspended at the beginning of FY'02 and these samples would be expected to have higher DF values than those later in the column experiment. The loss of these samples is thought to have slightly lowered the average DF reported in this work. Even with a DF of 2, however, this DF is calculated to meet the 50 pCi/L UIC injection limit at an influent activity as high as 2100 pCi/L.

4.4.5. Solids Analysis

TCLP was completed after column testing (top 5th of column solid) and the extract analyzed for selected RCRA metals and uranium. Additionally, microwave dissolution of the top 5th of the column and these results are summarized in Table 12.

Table 11 – ICP-ES Uranium Data SIR1200

	Feedwater	SIR1200	
Bedvol. Effluent	**U (mg/L)**	**U (mg/L)**	**U DF (Unitless)**
100	1.714	NA	NA
150	1.717	NA	NA
200	1.700	NA	NA
250	1.700	0.746	2.28
350	1.697	0.736	2.31
400	1.704	0.754	2.26
450	1.715	0.706	2.43
500	1.506	1.309	1.15
600	1.520	0.730	2.08
650	1.562	0.725	2.15
750	1.518	0.792	1.92
800	1.521	0.730	2.08
900	1.516	0.795	1.91
950	1.509	0.789	1.91

NA = Not Analyzed

Table 12 –U Post Column Test Data for Commercially Available Resins

Material	Sample Location	U TCLP Extract (mg/L)	U Digest (µg/g solid)
SIR 1200	Top 5th	<0.77	<224
WBG-30	Top 5th	<0.77	395

5. Conclusions and Recommendations

This study examined the feasibility of anion exchange (I-129 and Tc-99 removal) on feedwater to the F-Area WTU. This approach represents a significant departure from the current process configuration in which anion exchange takes place after iron chloride addition, neutralization, and clarification.

The potential advantages of moving anion exchange to the head of the process are to reduce competitive anion effects associated with pH adjustment during the precipitation and flocculation processes and to reduce or eliminate I-129 from large volume waste streams (i.e., filtercake and post-clarification ion exchange resin).

At the F-Area WTU, process history shows anion breakthrough at approximately 600 bedvolumes of processed feedwater (approximately 4.3 days of continuous operation under full-flow conditions). In this laboratory study, breakthrough was not observed for any of the silver modified carbons as well as the SIR 1200 resin at 1050 bedvolumes (equivalent to approximately 8 days of plant operations). All silver-modified carbons and the commercially available SIR-1200 anion resin were effective in removal of I-129 and Tc-99 from the F-Area WTU feedwater. Within these effective materials, the silver modified carbons reduced I-129 to below detection limit over almost the entire duration of the test and exhibited DF values that were somewhat higher than the SIR-1200 resin. Both the silver modified carbons and SIR-1200 resin reduced Tc-99 in the feedwater to below detection limit (c. 8 pCi/L).

Although the uranium DF values for the silver-modified carbons and SIR-1200 were small, on the order of 2, this DF should be sufficient to achieve the UIC limits even without post-clarification uranium removal. Given the apparent inconsistency between the gross alpha and ICP-ES data, uranium DF values for these materials should be confirmed prior to any full-scale implementation.

TCLP testing indicates that the secondary waste for the AgCl-modified carbons and SIR-1200 resin would not be RCRA characteristically hazardous. The SIAC-Ag(0) material, however, exhibited elevated silver leaching and a silver TCLP extract concentration in excess of the 5 mg/L limit for a RCRA characteristic waste.

Because of the solubility control mechanism for AgI(s) for the AgCl-modified carbons, it is anticipated that I-129 leaching will be lower for these materials than for the SIR-1200. If these materials were put into use, then I-129 and Tc-99 leaching K_d values would need to be generated to confirm the leaching behavior of the secondary waste.

Concurrent removal of mercury and I-129 was ineffective for separation of I-129 from F WTU feedwater. It is thought that this reaction is kinetically very slow and that it is only over long time periods (timeframe of years) that the reaction between Hg and I becomes important.

Given the effectiveness of the silver-modified carbons and SIR-1200, pilot testing of a subset of these materials is recommended. Of these materials, the higher silver content (1.05% Ag) silver chloride carbon and SIR-1200 would be the logical choices. The SIR-1200 is commercially available whereas the silver chloride carbon would have to be produced by a specialty activated carbon manufacturer. During any pilot-scale testing, the following data should be collected:

- Complete breakthrough of I-129 and Tc-99;
- Uranium DF values;
- I-129, Tc-99, U, and RCRA metal leaching (both trench leachate and TCLP).

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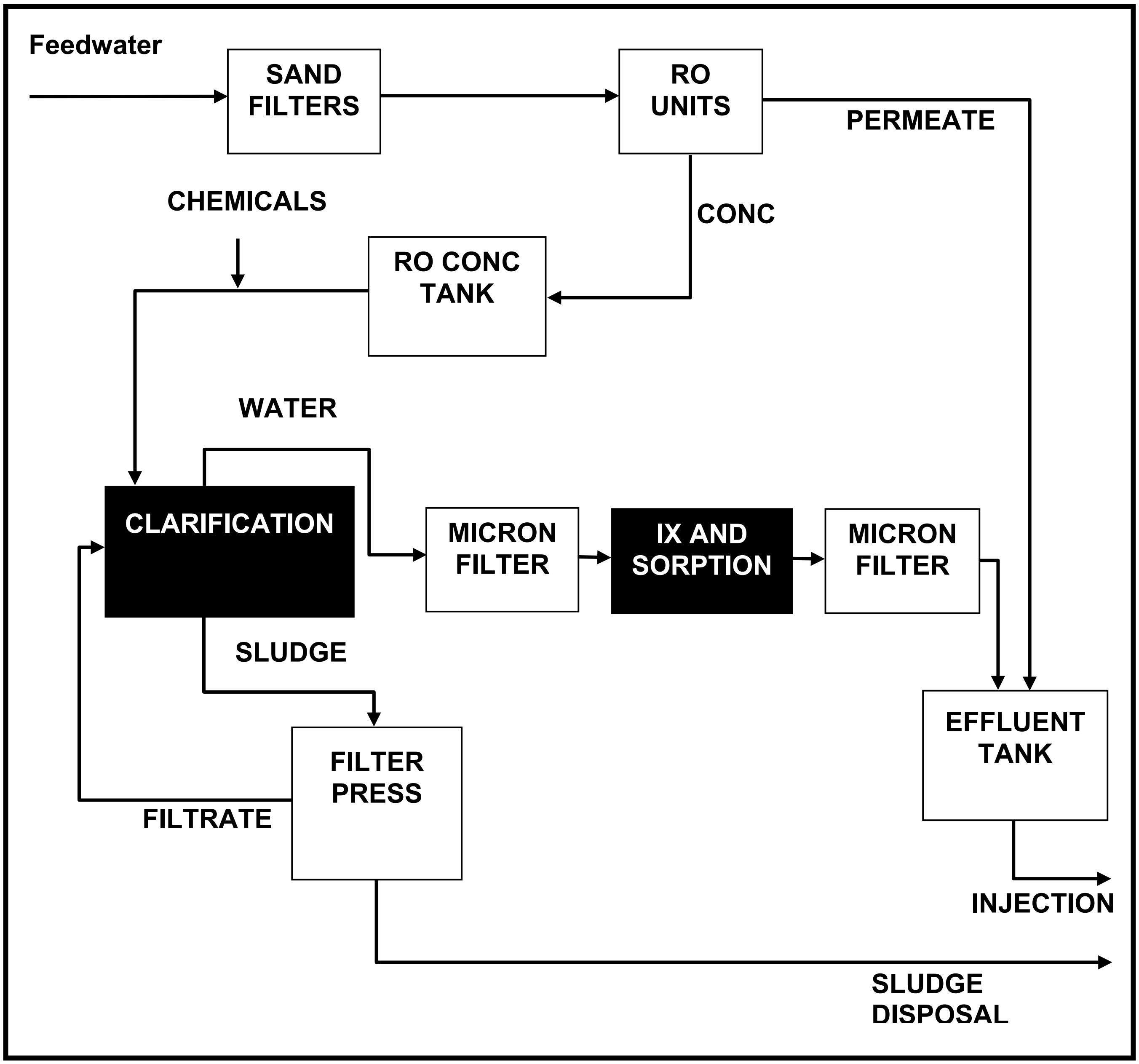
7. Figures

Figure 1 – F WTU Process Schematic



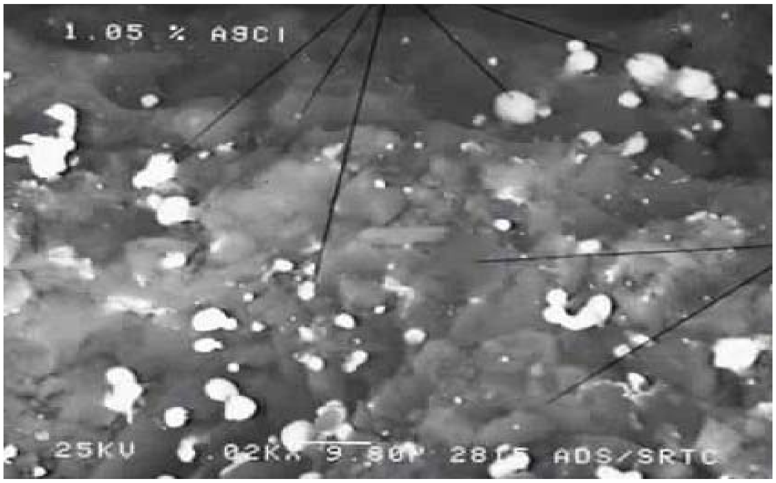


Figure 2 – SEM of AgCl SIAC (2000X Magnification).

Figure 3 – EDX of AgCl SIAC.

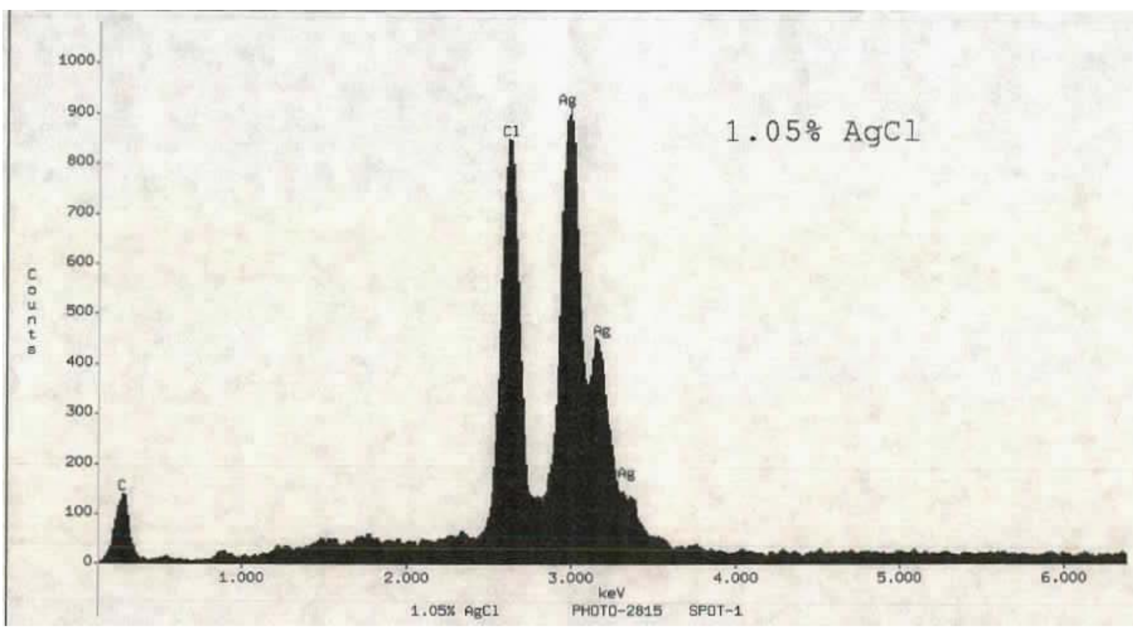


Figure 4 – Schematic of Experimental Setup.

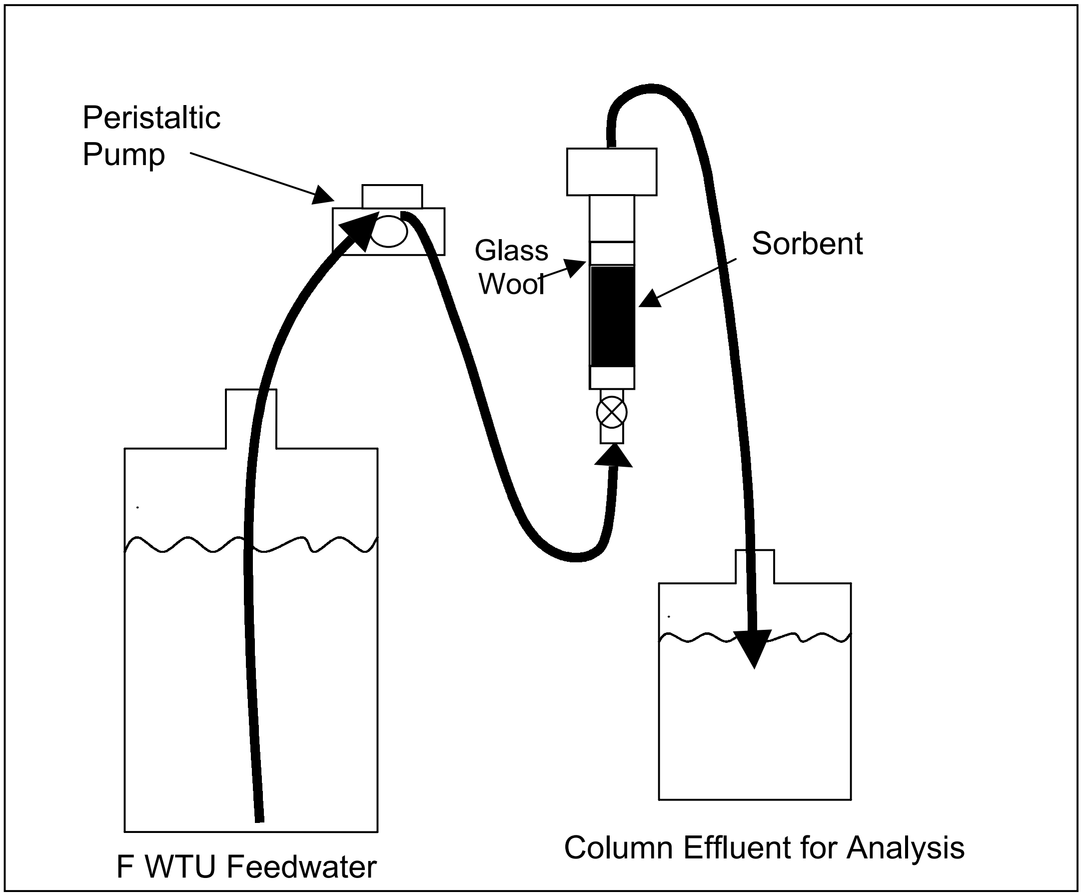


Figure 5 – Photographs of Experimental Setup.

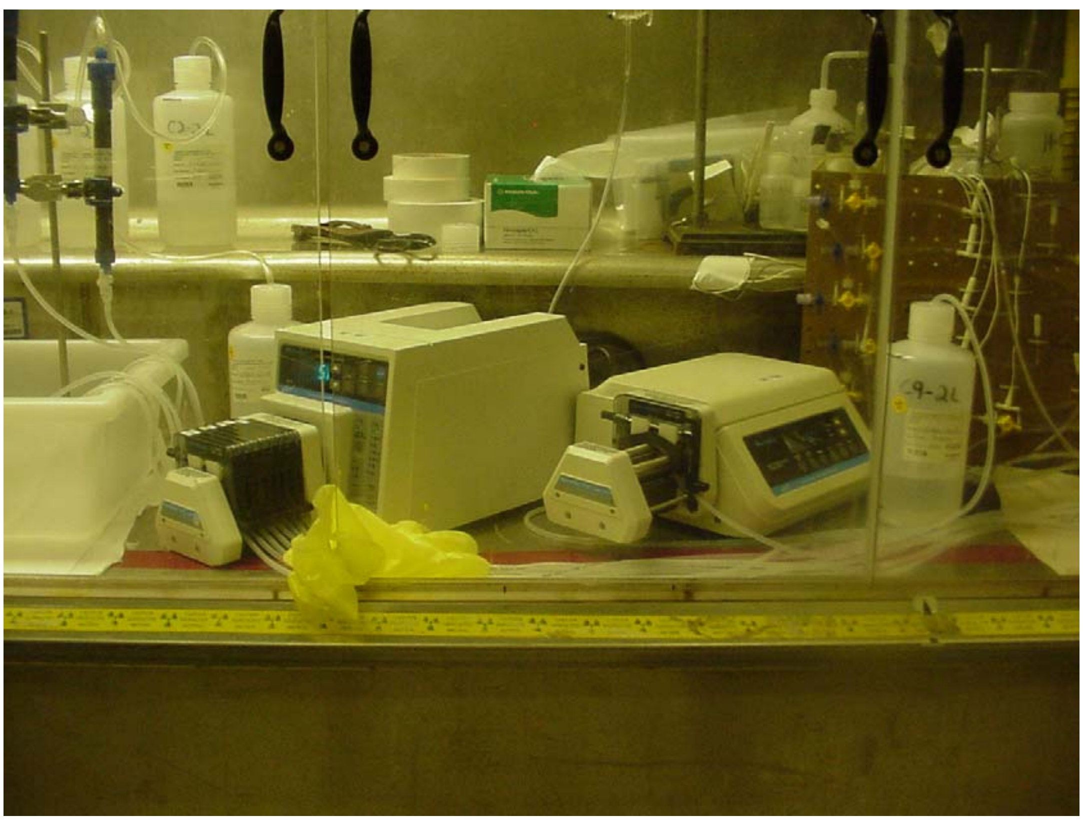


Figure 6 – I-129 Effluent Activity for Concept 1 (Silver Modified Carbons).

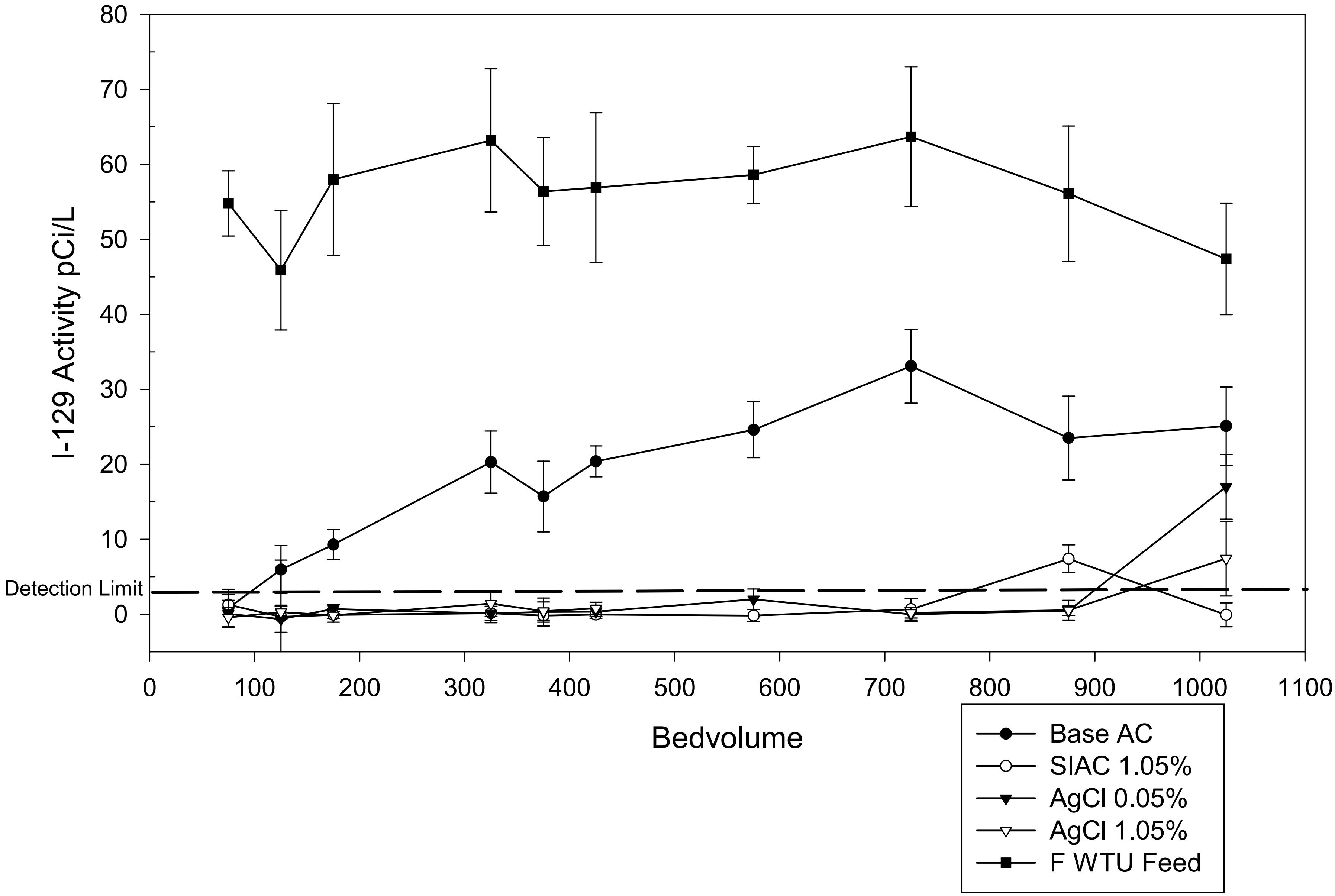


Figure 7 – Tc-99 Effluent Activity for Concept 1 (Silver Modified Carbons).

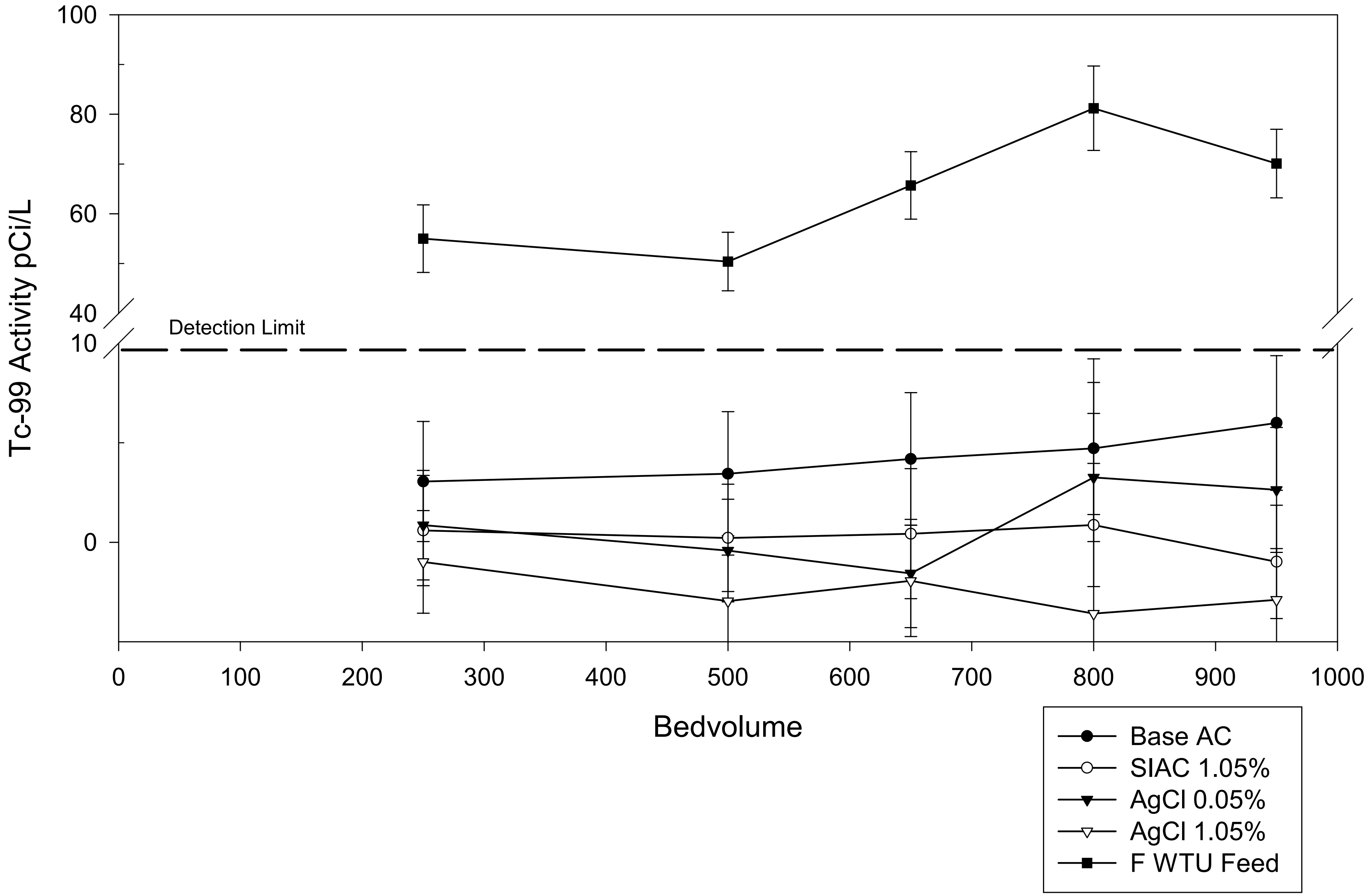
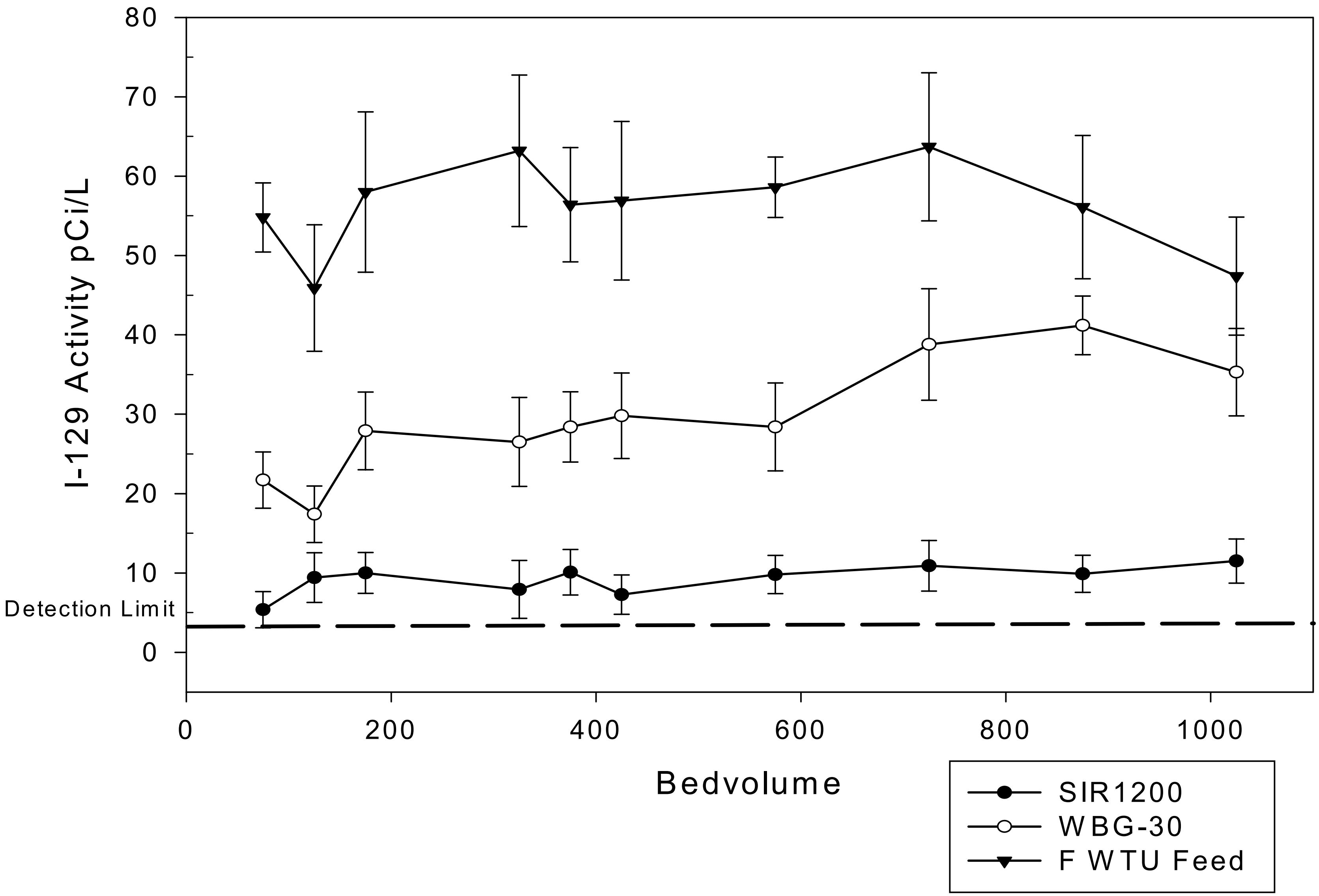


Figure 8 – I-129 Effluent Activity for Concept 3 (Anion Resin).



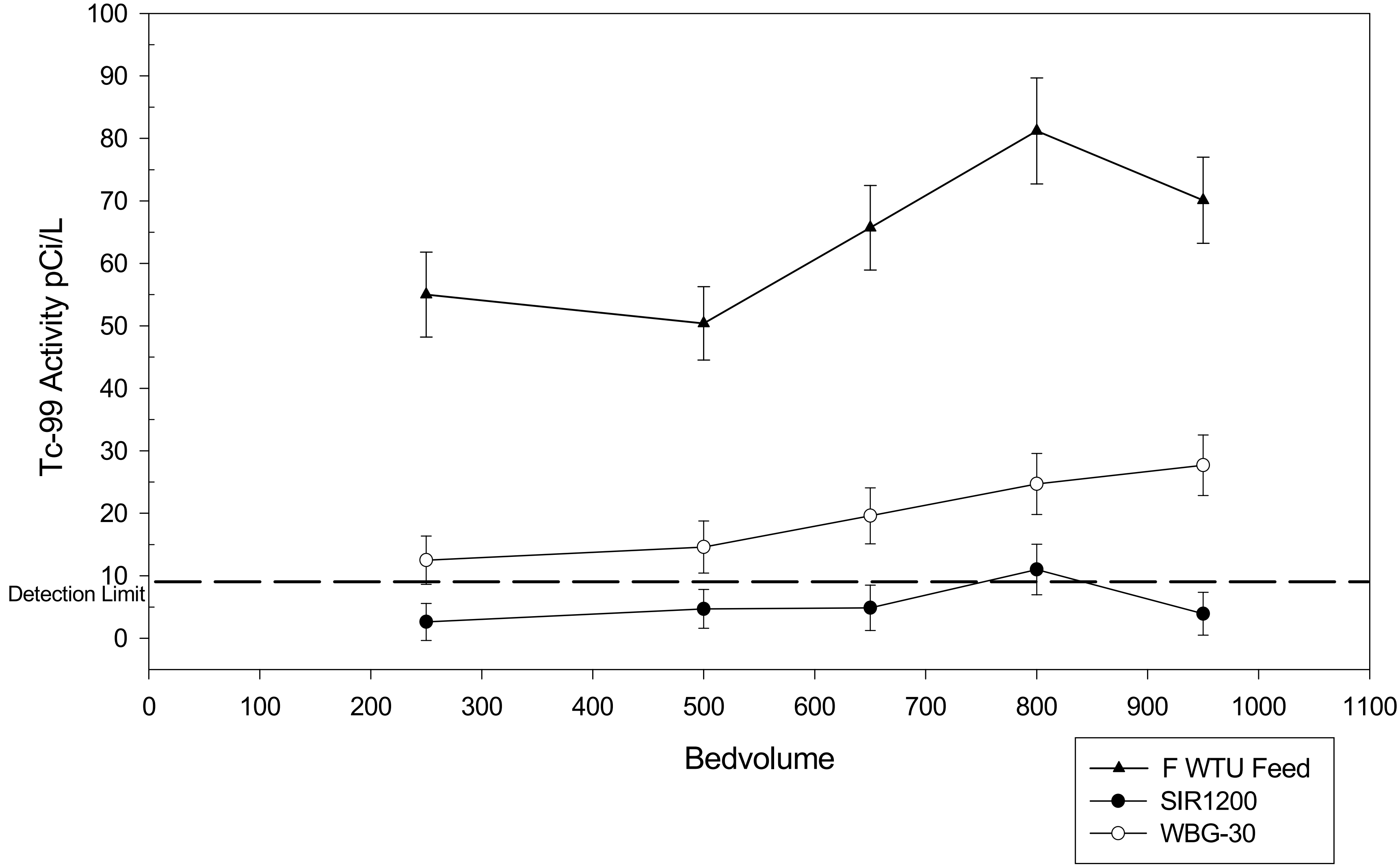


Figure 9 – Tc-99 Effluent Activity for Concept 3 (Anion Resin).

Appendix A (Email From Butcher 7/9/02)

Good morning Steve. Sorry about the late night call. Here are the disposal costs and waste volumes:

Disposal Costs

Trench	\$ 106 / m^3
LAWV	\$1161 / m^3
Offsite	\$1400 / m^3

Disposal Volumes (10 year forecast)*

ETF:	Carbon	150 m^3	(suitable only for vault disposal due to tritium)
	GT-73 Resin	15 m^3	
FWTU:	Filtercake	3570 m^3	
	CG8	1100 m^3	
	Dowex	520 m^3	
	Carbon	4 m^3	
HWTU:	CG8	390 m^3	
	Dowex	231 m^3	
	Filtercake	22 m^3	
	Carbon	4 m^3	

* Source: Memo, Hudson to Sauls, 9/5/01.

Appendix B

Full ICP-ES Elemental Data

Feedwater

Lab ID		C9-1L	C9-2L	C9-3L	C9-4L	C9-6L	C9-7L	C9-8L	C9-9L	C9-11L	C9-12L	C9-14L	C9-15L	C9-17L	C9-18L
ADS ID		300168981	300168982	300168983	300168984	300168985	300168986	300168987	300168988	300168989	300168990	300168991	300168992	300168993	300168994
Effluent Vol. (L)	MDL (ppm)	1	2	3	4	6	7	8	9	11	12	14	15	17	18
Bedvolmes		100	150	200	250	350	400	450	500	600	650	750	800	900	950
Ag	0.008	0.0021	0.0029	0.0018	0.0022	0.0036	0.0039	0.0040	0.0289	0.0160	0.0116	0.0106	0.0115	0.0130	0.0127
Al	0.057	14.5991	14.7596	14.5146	14.5575	14.5646	14.5292	14.5349	14.2055	14.0910	14.0663	14.0941	14.0446	14.1510	14.2002
B	0.028	0.0042	0.0045	0.0033	0.0056	0.0045	0.0039	0.0007	0.0020	-0.0010	0.0031	-0.0011	0.0022	0.0012	0.0022
Ba	0.019	0.2394	0.2433	0.2375	0.2387	0.2374	0.2389	0.2381	0.2824	0.2650	0.2586	0.2550	0.2582	0.2621	0.2617
Ca	0.023	8.2482	8.2621	8.1880	8.1291	8.1234	8.1742	8.2584	8.8090	8.8110	8.9740	8.7351	8.8640	8.8567	8.8907
Cd	0.0042	0.0074	0.0061	0.0072	0.0065	0.0070	0.0072	0.0072	0.0072	0.0080	0.0073	0.0069	0.0073	0.0063	0.0077
Cr	0.006	0.1950	0.2066	0.1889	0.1866	0.1900	0.2041	0.2090	0.4423	0.3190	0.2784	0.2682	0.2838	0.2938	0.2852
Cu	0.0048	-0.0030	-0.0047	-0.0042	-0.0043	-0.0038	-0.0046	-0.0041	-0.0045	-0.0030	-0.0049	-0.0036	-0.0035	-0.0033	-0.0037
Fe	0.0036	0.0470	0.0440	0.0425	0.0408	0.0390	0.0381	0.0386	0.0390	0.0390	0.0391	0.0393	0.0394	0.0399	0.0395
K	0.938	0.0069	0.0052	0.0033	0.0018	0.0022	0.0057	0.0016	0.0017	0.0030	0.0027	0.0013	0.0013	0.0012	0.0015
La	0.0072	0.0238	0.0251	0.0228	0.0232	0.0236	0.0254	0.0257	0.0571	0.0420	0.0351	0.0339	0.0348	0.0375	0.0366
Li	0.043	0.6700	0.9788	0.9231	0.9665	0.7386	0.8364	0.8562	0.7439	0.6870	0.6008	0.6073	0.7671	1.1096	1.1090
Mg	0.0053	0.0344	0.0353	0.0323	0.0326	0.0330	0.0334	0.0359	0.0727	0.0530	0.0459	0.0474	0.0471	0.0489	0.0488
Mn	0.0008	-0.0013	0.0002	-0.0016	-0.0016	0.0013	0.0014	0.0026	0.0555	0.0300	0.0185	0.0179	0.0196	0.0222	0.0206
Mo	0.053	3.3820	3.4371	3.3885	3.3938	3.4056	3.4207	3.4306	3.6643	3.6140	3.5609	3.5381	3.5747	3.5981	3.6106
Na	0.022	1.3824	1.4042	1.3834	1.3807	1.3820	1.3862	1.3907	1.4742	1.4610	1.4428	1.4367	1.4475	1.4592	1.4676
Ni	0.0135	0.0266	0.0283	0.0213	0.0248	0.0200	0.0238	0.0089	0.1150	0.0660	0.0638	0.0510	0.0536	0.0792	0.0703
P	0.069	33.0950	33.3369	32.9096	32.7341	32.6474	32.5840	32.5405	33.9413	34.0810	34.4469	34.8240	34.7788	34.9878	35.3079
Pb	0.0319	0.0274	0.0272	0.0253	0.0232	0.0254	0.0251	0.0265	0.0189	0.0280	0.0267	0.0176	0.0259	0.0264	0.0278
Sb	0.378	-0.0662	-0.0469	-0.0475	-0.0306	-0.0862	-0.0866	-0.0724	-0.0818	-0.0760	-0.0598	-0.1106	-0.0777	-0.0835	-0.0752
Si	0.0167	0.0002	0.0027	-0.0086	0.0017	0.0022	0.0110	0.0003	0.0122	0.0040	0.0065	-0.0056	0.0051	-0.0157	0.0007
Sn	0.045	0.0676	0.0518	0.0547	0.0512	0.0596	0.0596	0.0643	0.1483	0.0980	0.1014	0.0712	0.0904	0.1020	0.1013
Sr	0.0076	19.5011	19.7698	19.4737	19.4459	19.4529	19.5205	19.5413	20.9839	20.5740	20.3219	20.2970	20.4456	20.5894	20.6873
Ti	0.0077	0.0692	0.0791	0.0569	0.0514	0.0734	0.0658	0.0590	0.2366	0.1460	0.1302	0.1380	0.1287	0.1416	0.1343
U	0.5	1.7143	1.7172	1.6996	1.7000	1.6974	1.7040	1.7145	1.5063	1.5200	1.5617	1.5183	1.5207	1.5161	1.5088
Zn	0.0032	-0.0027	-0.0024	-0.0029	-0.0024	-0.0030	-0.0027	-0.0029	-0.0017	-0.0030	-0.0032	-0.0029	-0.0026	-0.0031	-0.0029
Zr	0.0228	0.7484	0.7920	0.7413	0.7451	0.7739	0.7725	0.7619	1.1254	0.9200	0.8516	0.8486	0.8636	0.8836	0.8821

1.05 % SIAC-Ag(0) Effluent

Lab ID		C2-1L	C2-2L	C2-3L	C2-4L	C2-6L	C2-7L	C2-8L	C2-9L	C2-11L	C2-12L	C2-14L	C2-15L	C2-17L	C2-18L
ADS ID		300169011	300169012	300169013	300169014	300169015	300169016	300169017	300169018	300169019	300169020	300169021	300169022	300169023	300169024
Effluent Vol.	MDL (ppm)	1	2	3	4	6	7	8	9	11	12	14	15	17	18
Bedvolmes		100	150	200	250	350	400	450	500	600	650	750	800	900	950
Ag	0.008	0.073	0.174	1.42	13.9	13.4	9.69	5.63	1.52	0.855	0.678	0.657	0.670	0.596	0.441
Al	0.057	1.69	9.41	12.9	15.1	15.4	15.5	15.8	15.8	16.0	16.0	15.7	15.4	15.1	14.7
B	0.028	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031
Ba	0.019	0.186	0.265	0.258	0.249	0.245	0.242	0.246	0.243	0.238	0.247	0.243	0.238	0.244	0.242
Ca	0.023	10.6	9.68	8.93	8.79	8.72	8.75	8.82	8.75	8.78	8.65	8.80	8.61	8.62	8.61
Cd	0.0042	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	0.006	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Cu	0.0048	0.016	0.016	0.022	0.027	0.029	0.031	0.034	0.035	0.036	0.035	0.036	0.036	0.035	0.036
Fe	0.0036	0.057	0.098	0.033	0.026	0.039	0.040	0.043	0.046	0.051	0.056	0.056	0.051	0.045	0.035
K	0.938	4.03	<1.03	<1.03	<1.03	<1.03	<1.03	1.04	1.09	1.11	1.31	1.12	1.03	1.21	<1.03
La	0.0072	0.046	0.047	0.055	0.054	0.055	0.050	0.054	0.052	0.049	0.057	0.054	0.051	0.055	0.051
Li	0.043	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Mg	0.0053	3.88	3.66	3.63	3.64	3.60	3.56	3.58	3.57	3.54	3.61	3.61	3.55	3.57	3.59
Mn	0.0008	1.80	1.75	1.54	1.48	1.45	1.44	1.44	1.43	1.42	1.44	1.44	1.42	1.43	1.43
Mo	0.053	0.106	<0.058	0.077	0.106	0.119	0.096	0.100	0.110	0.104	0.097	0.110	0.079	0.084	0.106
Na	0.022	36.4	34.2	32.8	33.2	33.1	33.4	33.5	33.1	33.6	32.5	33.2	32.9	32.9	32.7
Ni	0.0135	0.026	0.032	0.033	0.025	0.032	0.029	0.032	0.030	0.032	0.032	0.031	0.021	0.027	0.028
P	0.069	0.114	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076
Pb	0.0319	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
Sb	0.378	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416
Si	0.0167	16.7	19.0	20.2	21.0	21.0	20.9	21.1	21.1	21.1	21.2	21.3	20.9	20.9	20.8
Sn	0.045	0.250	0.215	0.251	0.272	0.263	0.243	0.272	0.253	0.255	0.286	0.275	0.239	0.273	0.278
Sr	0.0076	1.79	1.64	1.48	1.45	1.46	1.45	1.44	1.44	1.44	1.45	1.43	1.44	1.41	1.40
Ti	0.0077	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
U	0.5	<0.550	<0.550	<0.550	0.639	0.719	0.714	0.751	0.799	0.787	0.876	0.861	0.790	0.836	0.853
Zn	0.0032	0.005	0.030	0.029	0.021	0.021	0.019	0.022	0.021	0.024	0.026	0.021	0.018	0.019	0.022
Zr	0.0228	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025

0.05 % SIAC-AgCl Effluent

Lab ID		C3-1L	C3-2L	C3-3L	C3-4L	C3-6L	C3-7L	C3-8L	C3-9L	C3-11L	C3-12L	C3-14L	C3-15L	C3-17L	C3-18L
ADS ID		300169026	300169027	300169028	300169029	300169030	300169031	300169032	300169033	300169034	300169035	300169036	300169037	300169038	300169039
Effluent Vol.	MDL (ppm)	1	2	3	4	6	7	8	9	11	12	14	15	17	18
Bedvolumes		100	150	200	250	350	400	450	500	600	650	750	800	900	950
Ag	0.008	0.052	0.365	0.321	0.298	0.274	0.262	0.266	0.139	0.079	0.062	0.041	0.040	0.040	0.035
Al	0.057	10.6	14.6	14.8	14.8	14.7	14.5	14.5	14.5	14.5	14.5	14.4	14.6	14.6	14.5
B	0.028	0.295	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031
Ba	0.019	0.313	0.276	0.236	0.240	0.232	0.224	0.234	0.232	0.236	0.233	0.223	0.230	0.235	0.235
Ca	0.023	10.5	8.53	8.42	8.37	8.31	8.33	8.44	8.51	8.45	8.51	8.50	8.49	8.58	8.53
Cd	0.0042	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	0.006	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Cu	0.0048	0.020	0.027	0.029	0.031	0.032	0.032	0.033	0.034	0.032	0.034	0.033	0.034	0.033	0.035
Fe	0.0036	0.021	0.028	0.020	0.016	0.015	0.014	0.014	0.012	0.013	0.012	0.008	0.009	0.007	0.007
K	0.938	1.25	<1.03	<1.03	<1.03	1.06	1.15	<1.03	1.60	<1.03	<1.03	<1.03	1.24	<1.03	1.49
La	0.0072	0.063	0.054	0.037	0.045	0.043	0.040	0.047	0.047	0.046	0.048	0.038	0.047	0.049	0.049
Li	0.043	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047	<0.047
Mg	0.0053	3.85	3.55	3.39	3.48	3.46	3.42	3.49	3.47	3.53	3.51	3.44	3.49	3.55	3.54
Mn	0.0008	1.35	1.42	1.37	1.39	1.38	1.37	1.39	1.39	1.40	1.40	1.39	1.40	1.42	1.41
Mo	0.053	0.089	0.088	<0.058	0.059	0.068	0.071	0.089	0.075	0.076	0.073	0.072	0.076	0.095	0.080
Na	0.022	34.9	33.4	34.1	33.3	33.2	33.4	33.6	33.9	33.3	33.7	34.1	33.8	33.9	33.5
Ni	0.0135	0.054	0.035	0.027	0.028	0.031	0.022	0.022	0.026	0.022	0.024	0.022	0.028	0.029	0.028
P	0.069	1.54	<0.076	0.142	0.191	0.164	0.153	0.094	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076
Pb	0.0319	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
Sb	0.378	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416
Si	0.0167	20.3	20.3	19.7	20.0	19.9	19.7	20.1	20.1	20.3	20.2	20.0	20.1	20.5	20.4
Sn	0.045	0.191	0.216	0.133	0.179	0.180	0.162	0.212	0.208	0.208	0.209	0.188	0.242	0.269	0.252
Sr	0.0076	2.03	1.55	1.53	1.50	1.51	1.51	1.48	1.49	1.48	1.46	1.48	1.47	1.47	1.48
Ti	0.0077	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
U	0.5	<0.550	<0.550	<0.550	0.620	0.637	0.610	0.713	0.734	0.746	0.746	0.660	0.775	0.792	0.784
Zn	0.0032	0.026	0.024	0.019	0.019	0.018	0.017	0.020	0.019	0.023	0.022	0.016	0.017	0.018	0.019
Zr	0.0228	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025

1.05 % SIAC-AgCl Effluent

Lab ID		C4-1L	C4-2L	C4-3L	C4-4L	C4-6L	C4-7L	C4-8L	C4-9L	C4-11L	C4-12L	C4-14L	C4-15L	C4-17L	C4-18L
ADS ID		300168906	300168907	300168908	300168909	300168910	300168911	300168912	300168913	300168914	300168915	300168916	300168917	300168918	300168919
Effluent Vol.	MDL (ppm)	1	2	3	4	6	7	8	9	11	12	14	15	17	18
Bedvolumes		100	150	200	250	350	400	450	500	600	650	750	800	900	950
Ag	0.008	0.036	0.066	0.279	0.307	0.314	0.324	0.336	0.338	0.338	0.335	0.355	0.343	0.338	0.322
Al	0.057	13.3	13.9	14.2	14.1	14.2	14.2	14.2	14.2	14.3	14.2	14.3	14.1	14.3	14.2
B	0.028	0.032	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031	<0.031
Ba	0.019	0.236	0.244	0.244	0.247	0.244	0.246	0.248	0.246	0.251	0.249	0.253	0.248	0.258	0.253
Ca	0.023	7.91	8.06	8.06	7.97	7.99	8.02	8.04	8.09	8.30	8.23	8.30	8.21	8.36	8.39
Cd	0.0042	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cr	0.006	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Cu	0.0048	0.028	0.028	0.032	0.035	0.036	0.037	0.038	0.038	0.042	0.042	0.043	0.044	0.044	0.043
Fe	0.0036	0.083	0.030	0.036	0.030	0.027	0.028	0.029	0.026	0.024	0.023	0.022	0.019	0.018	0.016
K	0.938	<0.026	<0.026	0.030	0.033	0.029	0.030	0.034	0.031	0.038	0.037	0.039	0.037	0.044	0.040
La	0.0072	<1.03	<1.03	<1.03	<1.03	<1.03	<1.03	1.10	<1.03	<1.03	<1.03	<1.03	<1.03	<1.03	<1.03
Li	0.043	0.033	0.034	0.038	0.036	0.034	0.035	0.039	0.036	0.042	0.039	0.042	0.039	0.039	0.040
Mg	0.0053	3.42	3.46	3.48	3.51	3.47	3.48	3.49	3.50	3.48	3.47	3.51	3.46	3.55	3.51
Mn	0.0008	1.36	1.39	1.40	1.41	1.39	1.40	1.40	1.40	1.39	1.38	1.39	1.37	1.40	1.39
Mo	0.053	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058	<0.058
Na	0.022	32.3	32.7	32.8	32.2	32.4	32.6	32.6	32.7	33.7	33.4	33.6	33.4	33.6	33.7
N	0.0135	0.028	0.022	0.021	0.027	0.018	0.020	0.019	0.022	0.020	0.017	0.020	0.027	0.015	0.029
P	0.069	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076
Pb	0.0319	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035	<0.035
Sb	0.378	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416	<0.416
Si	0.0167	20.0	20.0	20.1	20.3	20.1	20.1	20.2	20.2	20.2	20.1	20.3	20.0	20.5	20.3
Sn	0.045	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.071	0.066	0.066	0.062	0.060	<0.050
Sr	0.0076	1.39	1.40	1.39	1.38	1.39	1.39	1.39	1.37	1.31	1.29	1.30	1.29	1.30	1.29
Ti	0.0077	0.009	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
U	0.5	<0.550	<0.550	<0.550	0.598	0.622	0.640	0.682	0.690	0.887	0.839	0.931	0.875	0.987	0.914
Zn	0.0032	0.044	0.042	0.040	0.040	0.038	0.039	0.042	0.042	0.047	0.044	0.040	0.040	0.042	0.045
Zr	0.0228	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	0.027	<0.025	0.029	0.026

SIR-1200 Effluent

Lab ID		C7-1L	C7-2L	C7-3L	C7-4L	C7-6L	C7-7L	C7-8L	C7-9L	C7-11L	C7-12L	C7-14L	C7-15L	C7-17L	C7-18L
ADS ID		300168951	300168952	300168953	300168954	300168955	300168956	300168957	300168958	300168959	300168960	300168961	300168962	300168963	300168964
Effluent Vol.	MDL (ppm)	1	2	3	4	6	7	8	9	11	12	14	15	17	18
Bedvolmes		100	150	200	250	350	400	450	500	600	650	750	800	900	950
Ag	0.005	NA	NA	NA	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100	0.0100
Al	0.015	NA	NA	NA	15.9070	15.8800	15.9460	15.8310	15.6710	15.7330	15.2730	15.2810	15.3240	15.3990	15.3430
B	0.003	NA	NA	NA	0.0060	0.0060	0.0060	0.0060	0.0060	0.0060	0.0010	0.0060	0.0060	0.0060	0.0060
Ba	0.003	NA	NA	NA	0.2540	0.2540	0.2550	0.2540	0.2510	0.2520	0.2470	0.2470	0.2480	0.2490	0.2470
Ca	0.001	NA	NA	NA	8.7130	8.6800	8.6980	8.6490	8.5530	8.5450	8.4860	8.5260	8.5560	8.6390	8.5610
Cd	0.002	NA	NA	NA	0.0070	0.0110	0.0090	0.0090	0.0070	0.0080	0.0070	0.0070	0.0100	0.0070	0.0070
Co	0.003	NA	NA	NA	0.0880	0.0900	0.0890	0.0920	0.0810	0.0820	0.0850	0.0840	0.0910	0.0940	0.0930
Cr	0.009	NA	NA	NA	0.0180	0.0180	0.0180	0.0180	0.0180	0.0180	0.0110	0.0180	0.0180	0.0180	0.0180
Cu	0.003	NA	NA	NA	0.0230	0.0240	0.0230	0.0230	0.0220	0.0220	0.0220	0.0220	0.0240	0.0230	0.0230
Fe	0.004	NA	NA	NA	0.0160	0.0210	0.0110	0.0130	0.0110	0.0110	0.0130	0.0120	0.0150	0.0100	0.0130
La	0.010	NA	NA	NA	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200	0.0290	0.0310	0.0240	0.0310	0.0200
Li	0.003	NA	NA	NA	0.0070	0.0080	0.0070	0.0070	0.0060	0.0070	0.0070	0.0060	0.0080	0.0070	0.0070
Mg	0.001	NA	NA	NA	3.6960	3.6960	3.7130	3.6920	3.6440	3.6690	3.6250	3.6160	3.6540	3.6500	3.6240
Mn	0.001	NA	NA	NA	1.5010	1.5010	1.5060	1.4990	1.4780	1.4850	1.4510	1.4480	1.4620	1.4670	1.4570
Mo	0.003	NA	NA	NA	0.0060	0.0090	0.0060	0.0090	0.0060	0.0090	0.0030	0.0060	0.0120	0.0120	0.0130
Na	0.015	NA	NA	NA	33.3550	33.1720	33.4840	33.3750	33.2630	33.3130	32.4850	32.6640	32.2900	32.6510	32.6480
Ni	0.009	NA	NA	NA	0.0270	0.0280	0.0250	0.0250	0.0260	0.0300	0.0370	0.0420	0.0510	0.0440	0.0480
P	0.035	NA	NA	NA	0.0700	0.0700	0.0700	0.0700	0.0700	0.0700	0.0190	0.0700	0.0700	0.0700	0.0700
Pb	0.046	NA	NA	NA	0.0920	0.0920	0.0920	0.0920	0.0920	0.0920	0.0230	0.0920	0.0920	0.0920	0.0930
Si	0.015	NA	NA	NA	20.4670	20.3840	20.4780	20.3940	20.2230	20.2980	19.9550	19.9720	19.9810	20.0750	20.0140
Sn	0.016	NA	NA	NA	0.0340	0.0320	0.0320	0.0320	0.0320	0.0610	0.0100	0.0320	0.0320	0.0320	0.0320
Sr	0.001	NA	NA	NA	0.0440	0.0440	0.0440	0.0440	0.0430	0.0440	0.0430	0.0430	0.0430	0.0430	0.0430
Ti	0.001	NA	NA	NA	0.0330	0.0330	0.0320	0.0320	0.0310	0.0320	0.0320	0.0310	0.0340	0.0340	0.0350
U	0.077	NA	NA	NA	0.7460	0.7360	0.7540	0.7060	1.3090	0.7300	0.7250	0.7920	0.7300	0.7950	0.7890
V	0.003	NA	NA	NA	0.0060	0.0070	0.0060	0.0060	0.0060	0.0060	0.0040	0.0060	0.0070	0.0070	0.0060
Zn	0.003	NA	NA	NA	0.0430	0.0410	0.0390	0.0420	0.0410	0.0440	0.0490	0.0430	0.0440	0.0550	0.0440
Zr	0.003	NA	NA	NA	0.0360	0.0390	0.0360	0.0350	0.0310	0.0340	0.0350	0.0350	0.0390	0.0370	0.0360

NA = No Analysis

(red) Less than MDL