August 1997

**Idaho
National
Engineering
Laboratory**

Demonstration of Various Ion Exchange Sorbents for the Removal of Cesium and Strontium from TAN Groundwater

RECEIVED
NOV 05 1997
OSTI

**T. G. Garn
K. N. Brewer
R. D. Tillotson
T. A. Todd**

LOCKHEED MARTIN

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Demonstration of Various Ion Exchange Sorbents for the Removal of Cesium and Strontium from TAN Groundwater

**T. G. Garn
K. N. Brewer
R. D. Tillotson
T. A. Todd**

Published August 1997

**Idaho National Engineering and Environmental Laboratory
Waste Management Technologies
Lockheed Martin Idaho Technologies Company
Idaho Falls, Idaho 83415**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

**Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
Contract DE-AC07-94ID13223**

DISCLAIMER

**Portions of this document may be illegible
electronic image products. Images are
produced from the best available original
document.**

ABSTRACT

Groundwater remediation efforts are currently ongoing at the Test Area North (TAN) located at the Idaho Engineering and Environmental Laboratory (INEEL). These efforts are primarily directed towards the Technical Support Facility-05 (TSF-05) for the removal of volatile organic compounds (VOC's). The Groundwater Treatment Facility (GWTF), positioned near the TSF-05 injection well at TAN, was installed in 1994 to pump and treat the injection well groundwater. The GWTF was designed to be operated continuously at 50 gpm. Presently the GWTF operates in batch mode attributed to ^{137}Cs found at higher concentrations than expected. This presence of ^{137}Cs , along with the higher than expected concentration of suspended solids revealed a need for further testing and evaluation of the GWTF process.

Two independent experiments were conducted at the GWTF with actual groundwater pumped from TSF-25 and TSF-05 injection wells. One experiment used the 3M Company's web technology to remove Cs from the actual groundwater, while the second experiment contained a duplicate set of ion exchange columns in series. Each set having two columns, one to remove Cs, the other to remove Sr from the actual groundwater. A total of 5 Cs or Sr specific sorbents were tested in the column setups.

A total of eight batches of water were processed through the GWTF with the experimental setups in place, six from TSF-25 and two from TSF-05. Downtime occasionally occurred when high differential pressures prompted the high pressure shutoff switches to shut down the 3M experiment feed pump. A pre-filter change out was initiated when this occurred. Also, experimental setups were shut down for GWTF backwash and discharge operations.

Approximately 41,635 liters (11,000 gallons) of contaminated groundwater were pumped through the 3M system, which consisted of two pre-filters and a cartridge containing potassium cobalt hexacyanoferrate. The ^{137}Cs concentration of the groundwater entering the 3M experiment was as high as 1200 pCi/L. The effluent was analyzed for ^{137}Cs and never found to be higher than 14 pCi/L, well below the maximum contaminate level (MCL) of 119 pCi/L.

The initial ion exchange setups consisted of two columns each assembled in series with the Cs selective sorbent column placed upstream of the Sr sorbent column. The first setup employed Pellx-137[®] and Ionac C-250[®] while the second setup used SELION CsTreat[®] and AlliedSignal's sodium titanate. The first setup was later replaced with IONSIV IE-911[®] a crystalline silicotitanate (CST) sorbent after ~1500 bed volumes had been processed through the initial setup. The combined SELION CsTreat[®]/sodium titanate column setup had ~2400 bed volumes processed while the IONSIV IE-911[®] CST column had ~1400 bed volumes of water processed. Cs breakthrough was not observed in any of the setups. Partial Sr breakthrough was reached in the Ionac C-250[®] and sodium titanate columns.

The MCL for ^{90}Sr is 8 pCi/L. The Ionac C-250[®] column effluent sample indicated ^{90}Sr concentration was > 8 pCi/L after ~ 1100 bed volumes had been treated, and the CST column effluent sample indicated the ^{90}Sr concentration was > 8 pCi/L at 1120 bed volumes treated. The sodium titanate column never removed ^{90}Sr below the MCL. A combination of low Cs and Sr concentrations in the TSF-25 injection well groundwater and insufficient run time due to GWTF batch schedules, caused the column experiments to be terminated prior to complete breakthrough.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to the operations and management personnel of the GWTF (Groundwater Treatment Facility) for their cooperation and assistance with testing and operation of the experimental setups. Also, Harry Heidkamp and Gary Mecham provided invaluable support for the completion of these tests.

Many thanks to Jeff Laug and the Spectrochemical Analysis Group as well as Troy Tranter and the Radiochemical Analysis Group for the efficient and accurate sample analysis. Without the work and dedication of these people, this work could not have been performed.

Tom Kafka and Lloyd White of 3M Company made significant contributions to the success of this demonstration.

Special thanks is also extended to the following manufacturers for providing sorbents at no cost for use in this testing: Pell Resources, Inc., AlliedSignal Inc., SELION, Inc., and UOP, Inc.

CONTENTS

ABSTRACT	iii
ACKNOWLEDGMENTS	v
INTRODUCTION	1
PURPOSE AND SCOPE	2
BACKGROUND	2
EXPERIMENTAL	4
3M Web Experiment	4
Ion Exchange Experiment	6
RESULTS AND CONCLUSIONS	9
3M System Demonstrations	10
Ion Exchange System Demonstrations	12
RECOMMENDATIONS	17
REFERENCES	18
APPENDIX	19

FIGURES

Figure 1. 3M cartridge apparatus installed at the GWTF	3
Figure 2. Ion Exchange setup situated in the GWTF	4
Figure 3. Schematic of 3M experimental setup	4
Figure 4. Schematic of Ion Exchange setup	7
Figure 5. Differential pressure as a function of TSF-25 water processed for 0.1 μ m pre-filter .	10
Figure 6. Differential pressure as a function of TSF-05 water processed for 0.1 μ m pre-filter .	11
Figure 7. Measured activity of KCOHEX housing versus processed ground water	12
Figure 8. Cs breakthrough for Pellx-137 [®] column	13
Figure 9. Total Sr breakthrough for Ionac C-250 [®] column	14
Figure 10. Cs breakthrough curve for SELION CsTreat [®] column	14
Figure 11. Total Sr breakthrough curve for sodium titanate column	15
Figure 12. Cs, Sr, Ca, and Mg breakthrough curves for IONSIV IE-911 (CST) column	16

TABLES

Table 1. Equipment list for 3M experimental setup	5
Table 2. Equipment list for ion exchange experimental setups	7
Table 3. Column sorbent information for ion exchange experimental setups	8
Table 4. Average batch concentrations of analyzed elements for TSF-25 and TSF-05	9

Demonstration of Various Ion Exchange Sorbents for the Removal of Cesium and Strontium from TAN Groundwater

INTRODUCTION

The United States Department of Energy (DOE), United States Environmental Protection Agency (EPA), and the Idaho Department of Health and Welfare jointly signed a Record of Decision (ROD) in August 1995 for the cleanup of contaminated groundwater associated with the Technical Support Facility Injection Well (TSF-05) and Surrounding Groundwater Contamination Well (TSF-25), jointly referred to as Operable Unit (OU) 1-07B [1]. The contamination site is located at the Test Area North (TAN) facility at the Idaho National Engineering and Environmental Laboratory (INEEL). The contaminants of concern (COC's) identified at higher than acceptable levels were trichloroethane (TCE), cis- and trans-1, 2-dichloroethane (DCE), tetrachloroethane (PCE), and the radionuclides strontium-90, and cesium-137.

The Groundwater Treatment Facility (GWTF), at TAN was constructed as an interim action for groundwater remediation of the TSF-05 injection well. The GWTF was started in 1994 to pump and treat injection well water, primarily for the removal of TCE as the primary COC. The GWTF consists of several subsystems operated in series to remove various constituents from the water. These subsystems include: 1) filtration system for the removal of solids, oils, and greases; 2) an air stripper system for the removal of VOC's; and 3) two ion exchange columns (operated in series) containing the Ionac C-250[®] sorbent for the removal of ⁹⁰Sr. Initially the GWTF was designed to operate continuously at a rate of 50 gpm; however, decontamination of the water was insufficient due to presence of other contaminants (¹³⁷Cs) detected at higher concentrations than originally planned and it became apparent that additional capacity or alternative technologies were necessary for ¹³⁷Cs and potentially ⁹⁰Sr removal.

Continued treatability studies for the evaluation of candidate radionuclide removal technologies are mandated over a three year period following signing of the ROD. The agencies will then jointly decide on radionuclide reinjection performance standards based on the results of the radionuclide removal treatability studies and associated cost benefit analysis. The treatability studies discussed herein were intended to evaluate potential radionuclide removal technologies for partial fulfillment of the requirement mandated by the ROD.

The Separations Technology Development group at Lockheed Martin Idaho Technologies Company (LMITCO) has been evaluating several potential technologies for the removal of Cs and Sr from the TAN groundwater. One of the technologies tested was the 3M Company's web technology, which relies on ion specific sorbents immobilized in a web type matrix and

contained in a cartridge [2]. Other technologies evaluated were ion specific sorbents placed in ion exchange columns.

Bench scale setups were constructed at the Idaho Chemical Processing Plant (ICPP) and transported to the GWTF where they were connected directly into available process lines to enable actual contaminated groundwater to be fed directly to both the 3M cartridge apparatus and the ion exchange column experimental setups. The setups were installed downstream of the multi-media filter and air scrubber and upstream of the ion exchange columns to evaluate the technologies under the current GWTF operating configuration.

The GWTF was operating in batch mode at the time of this experiment. A typical batch would involve pumping contaminated groundwater from either TSF-05 or TSF-25 injection wells into a 20,000 gallon surge tank. The groundwater would be recirculated through the GWTF treatment process until sample analysis indicated the groundwater met specific criteria for reintroduction of the groundwater back into the environment. The experimental setups would be brought on line soon after a new batch was initiated, and shut down when a GWTF treated batch was discharged. The average time frame for a typical GWTF batch to reach completion was about three days.

PURPOSE AND SCOPE

The purpose of this study was to evaluate several potential ion exchange sorbents that may remove associated radionuclides from the contaminated groundwater wells TSF-25 and TSF-05. The ion exchange experiments were conducted on a bench scale using continuous flow columns packed with the appropriate sorbents. 3M web technology was also evaluated using a bench scale experimental setup with 0.1 μm and 2.0 μm pre-filters and a Cs specific potassium cobalt hexacyanoferrate (KCOHEX) cartridge purchased from the 3M company. These experiments were performed using actual groundwater pumped through the GWTF treatment process.

The scope of this work was limited to continuous bench scale testing of the following sorbents: Pellx-137®; Ionac C-250®; SELION-CsTreat®; AlliedSignal's sodium titanate; IONSIV IE-911 (CST); and the 3M Company's web technology using potassium cobalt hexacyanoferrate. The effects of particulates in the groundwater on pressure drops across the Cs specific (KCOHEX) cartridge were also monitored to determine the life expectancy of the cartridge and associated pre-filters.

BACKGROUND

Previously, a bench scale experiment was performed at the ICPP to test the effectiveness of the 3M web technology to remove Cs and Sr from TAN groundwater [2]. The water used in this experiment had been processed through the GWTF. The results of this test indicate that the ^{137}Cs

had been effectively removed after ~ 4730 liters (1250 gallons) of water had been processed through a 4 inch cartridge. Due to the solids having been removed by settling and multiple passes through the solids filtration systems at the GWTF, there was little concern of pre-filter plugging or high pressure drops accumulating across the Cs or Sr specific cartridges. However, the experiment herein was of some concern because the extent of solids removed from the groundwater was not to the same degree as the previous experiment. Water supplied to the 3M cartridge apparatus was downstream of the solids removal subsystem of the GWTF. Additional solids filtration was anticipated to extend the life of the Cs specific cartridge; thus, two pre-filters were installed in series upstream of the Cs cartridge. The first pre-filter removed particles above 2.0 μm followed by a second pre-filter removing particles above 0.1 μm . Figure 1 shows the actual cartridge apparatus installed at the GWTF.

Figure 1. 3M cartridge apparatus installed at the GWTF.

The Pellx-137[®] and SELION-CsTreat[®] sorbents used in this experiment were chosen based on recommendations received from GWTF personnel. SELION-CsTreat[®] was also chosen because the sorbent is potassium cobalt hexacyanoferrate which is the same type of sorbent used in the KCOHEX cartridge. Sodium titanate and IONSIV IE-911 CST sorbents were chosen based on technical information received from the respective manufacturers. The Ionac C-250[®] sorbent was included to provide a baseline value to predict performance of Sr specific sorbents when compared to GWTF removal data (Ionac C-250[®] is used in GWTF process).

The ion exchange setup was also constructed at ICPP with chosen Cs and Sr sorbents packed into columns and transported to GWTF. A second photograph shows the ion exchange setup at the GWTF (Figure 2).

Figure 2. Ion exchange setup situated in the GWTF.

EXPERIMENTAL

3M Web Experiment

The configuration of the 3M experimental setup is shown in Figure 3. Two identical trains were assembled in parallel. This setup enabled the isolation of one train's pre-filters or Cs specific cartridges for change out without shutting down the system.

Figure 3. Schematic of 3M experimental setup.

The experimental setup consisted of the equipment listed in Table 1 connected with appropriate tubing and Swagelok® fittings. The system was designed to operate at a flowrate of 3.8 liters per minute (1gpm) with a system pressure not to exceed 60 psig. The design consisted of two independently identical bridged trains. Each train consisted of three cartridge housings in series, including two pre-filters and a cesium specific unit. The cartridges were connected in series with 3/8" stainless steel tubing. A gear pump was installed at the headend of the setup to supply flow from the GWTF process lines to the equipment. A pressure switch was included to shut down the pump should the system pressure exceed 60 psi, an indication of filter plugging. For ease of installation and connection to the GWTF process, 3/8" flexible poly tubing was used to supply contaminated water to the setup and return it back to the GWTF process. The GWTF had an operating pressure of ~5 psig at the tie-in points of the experimental systems and as a result, check valves were installed on the return lines to prevent backflow from the GWTF to the setup through the return lines.

Table 1. Equipment and material list for the 3M experimental setup.

Equipment	Description	Purpose
Feed Pump	Tuthill magnetic drive variable speed gear pump, 120 gph, 120psig.	Supply contaminated water to the experimental setup.
Active Cartridge	10 inch 3M KCOHEX Cartridge	Cs-137 removal
Filter Housings	Filterite 10" VP series polypropylene filter housing.	House both 2.0µm and 0.1µm pre-filters for solids removal.
Pre-filters	3M 10 inch 2.0 µm pore size and Pall POSIDYNE® 222 style 0.1 µm pore size pre-filters.	Remove small particulates from groundwater before passing through Cs specific cartridge.
Safety Switch	Square D electrical cutout pressure switch.	Pressure cutout switch, pump shutdown if system pressure reaches 60 psig
Flow Totalizer	Great Plains Industries electronic digital flowmeter, 0.3-3 gpm	Monitor flowrate and record total flow through system.

Initially, contaminated water was pumped through a single train's set of pre-filters before passing through the Cs specific cartridge. Early into the testing, pressure readings indicated that the 0.1 µm pre-filter was plugging off due to solids present in the contaminated water. Because run time was limited, frequent change out of plugged pre-filters was a concern. The pre-filters from the other train were valved in so the contaminated water could be routed through both sets of pre-filters in parallel flow to increase run time between filter change outs. This configuration allowed a much larger volume of water to be pumped through the setup before 0.1 µm pre-filter change out was necessary.

One liter samples were pulled from three specific locations into polypropylene bottles. Feed samples were taken at the beginning of each new GWTF batch to determine the ¹³⁷Cs activity .

These samples were collected on the inlet line of the setup downstream of the feed pump. Samples were also periodically drawn after the pre-filters but before the Cs specific cartridge to determine if any activity was being removed with the solids captured by the pre-filters. A third sample was pulled from the line leaving the setup to determine the ^{137}Cs activity of the water after passing through the Cs specific cartridge. All samples were transported to the ICPP radiochemistry group for ^{137}Cs analysis. Cesium-137 activities were determined by gamma counting the one liter samples on a high purity p-type coaxial germanium detector having a relative efficiency of 80%. Sample analyses were evaluated to determine the removal efficiency of the Cs specific cartridge.

Pressure readings were taken frequently to monitor differential pressures occurring across associated filters. Differential pressure values were used to predict the plugging rate of all on-line pre-filters as well as detect excessive pressure buildup across the Cs specific cartridge which could potentially reduce Cs removal capabilities.

Radiation readings were taken intermittently on the Cs cartridge housing using a hand held radiation meter. The readings were utilized for safety and health purposes to protect employees from exposure to excessive radiation and ensure compliance with radiation safety standards and common work practices associated with the GWTF. The readings were also used to plot a curve associating Cs removal vs. throughput.

Flowrate and total flow values were recorded periodically to observe flowrate fluctuations and to record total flow through Cs specific cartridge.

At the completion of the testing, the experiment was dismantled and the potentially contaminated equipment was disposed of per TAN radiation safety personnel direction. All other equipment was decontaminated to undetectable levels and disposed of as cold waste.

Ion Exchange Experiment

The ion exchange experiments consisted of two columns in series. The systems were first assembled at the ICPP and then transported to the GWTF. Table 2 features the equipment list used for the ion exchange experiments. Two identical ion exchange experimental setups were used so that several sorbents could be tested in the brief GWTF operating window.

The ion exchange experimental setups were assembled using the above equipment with appropriate flexible tubing, stainless tubing, fittings, valves and pressure gauges. Figure 4 illustrates a simple schematic of the ion exchange column setups. The systems were designed to operate at a flowrate of 20 mL/min with a system pressure not to exceed 60 psig. The flowrate could be adjusted as process conditions changed using a variable speed controller to vary the feed pump output. Changing process conditions included pressure fluctuations, flowrate oscillations, and particle presence based on number of cycles treated for a given batch.

Table 2. Equipment and materials list for ion exchange experimental setups.

Equipment	Description	Purpose
Feed Pumps	Tuthill Magnetic Drive Gear Pump 1-120 mL/min at 120 psig	Pump contaminated groundwater from GWTF system through IX setups.
Sorbents	Pellx-137®, Ionac C-250®, SELION-CsTreat®, AlliedSignal sodium titanate, and Ionsiv IE-911 CST.	Removal of ^{137}Cs and/or ^{90}Sr .
Columns	Ace Glassware Chromatography Column i.d. 2.5 cm x h 30 cm with threaded ends.	Contain IX sorbents and allow contact with contaminated water.
Flow Indicator/Totalizer	McMillan Co. Model 220 with transducer. 13-100 mL/min	Indicate flowrate and record total flow through columns.
Pressure Switch	Square-D electrical cutout pressure switch, series H, type KM 38.	Shut down pumps should inlet pressure exceed 60 psig.

Figure 4. Schematic of ion exchange setup.

Column Preparation

The initial column system prepared at the ICPP was the Pellx-137® and Ionac C-250® system. The Cs specific Pellx-137® column was placed upstream of the Sr specific Ionac C-250® column to prevent ^{137}Cs from sorbing onto the Ionac C-250® sorbent, thus reducing its capacity for Sr. The Ionac C-250® sorbent will remove Sr and to some extent Cs. Cs may displace Sr from the resin, therefore, in an attempt to increase column efficiency, Cs was removed from the groundwater prior to introduction to the Ionac C-250® sorbent.

The Pellx-137[®] column was prepared by following the manufacturer's directions. The sorbent was first placed in a volumetric flask and washed with deionized water to remove dust. A column was then filled with deionized water to an appropriate level and a pre-weighed mass of sorbent was added to the column by allowing it to fall through the water and settle to the desired height. The glass column was lightly tapped to further pack the sorbent. Once the sorbent was appropriately packed, deionized water was pumped through the column until there was no evidence of dust particles present in the effluent stream. The same procedure was used for preparing the Ionac C-250[®] column.

A second setup was prepared using SELION CsTreat[®] and sodium titanate sorbents. Again the Cs specific SELION CsTreat[®] sorbent was placed first followed by the sodium titanate column. The column preparation procedure followed for the SELION CsTreat[®] was identical to the procedure used with the Pellx-137[®] and Ionac C-250[®] columns. The sodium titanate sorbent was received from the vendor in large pellet form. The particle size of the sodium titanate sorbent was reduced to improve sorption kinetics. A column diameter to particle size ratio of ≥ 20 is also recommended to minimize wall effects and prevent channeling [3]. The sorbent was ground and sieved to a mass mean diameter between 212 and 850 micron. Water was used to wash dust from particles accumulating during the grinding operation. The sorbent was then added to a water filled glass column and packed to the proper height and density.

After limited data had been collected for the Pellx-137[®]/Ionac C-250[®] system it was replaced with a column containing the IONSIV IE-911 (CST) sorbent. This column was prepared using the same procedure previously described above for Pellx-137[®]. This column was installed unaccompanied by any other column and evaluated for both Cs and Sr removal. Table 3 describes the ion exchange sorbent information used in this experiment.

Table 3. Column sorbent information for ion exchange experimental setups.

Sorbent	Manufacturer	Composition	Height	Volume	Weight
Pellx-137	Pell Resources Inc.	Alumino-silicate	10"	120 mLs	~ 138 g
Ionac C-250	Sybron Chemical Inc.	Polystyrene-Sulfonate	10"	120 mLs	~ 125 g
SELION CsTreat	IVO Inc.	Potassium hexacyanocobalt(II)-Ferrate(II)	10"	120 mLs	~ 193 g
Sodium titanate	AlliedSignal Inc.	Sodium Titanium Oxide	10"	120 mLs	~ 108 g
IONSIV IE-911	UOP Inc.	Crystalline Silicotitanate	10"	120 mLs	~ 243 g

Samples were taken periodically from the column effluents. The samples were analyzed for calcium, magnesium, total Sr, ^{90}Sr , and ^{137}Cs . Total Sr, Ca, and Mg were analyzed by Inductively Coupled Plasma Emission Spectroscopy (ICP-ES) using a Jobin Yvon model 38 sequential Spectrometer. The atomic emission spectrum was generated by a plasma torch utilizing argon as the cooling gas. The samples were analyzed undiluted to obtain very low analytical detection limits. The analytical error associated with these analyses was $\pm 10\%$. The ^{137}Cs analytical method used was discussed earlier in this text. ^{90}Sr concentrations were obtained by using a ^{90}Sr specific method performed by the radiochemical group at the ICPP.

Radiation readings were also taken to monitor radiation fields associated with the extraction of radioactive elements onto the sorbents. These readings ensured the fields did not exceed the limits imposed by GWTF safety and health guidelines.

Flowrate and total flow values were recorded periodically to monitor changing flowrates introduced to the columns and calculate bed volumes of groundwater processed.

At the completion of the testing the setups were dismantled and disposed of under the direction of GWTF radiation control personnel.

RESULTS AND CONCLUSIONS

At the beginning of this testing it was unsure as to how long the experimental setups would be allowed to operate based on GWTF processing schedules and planned construction scheduled on GWTF process equipment. The GWTF was operating in batch mode with no final determination for converting to continuous operation. The experimental setups were operated as the GWTF was operating. Experimental setups were shut down for GWTF backwash and discharge operations.

A total of eight batches were processed through the GWTF with the experimental setups in place, six from TSF-25 and two from TSF-05. Table 4 illustrates a comparison of the average batch concentrations of elements between the TSF-25 and TSF-05 injection wells.

Table 4. Average batch concentrations of analyzed elements for TSF-25 and TSF-05.

Injection Well	Cs-137	Sr-90	Total Sr	Calcium	Magnesium
TSF-05	~ 1100 pCi/L	~ 232 pCi/L	~ 0.181 $\mu\text{g/mL}$	~ 13.4 $\mu\text{g/mL}$	~ 14.0 $\mu\text{g/mL}$
TSF-25	~ 520 pCi/L	~ 244 pCi/L	~ 0.269 $\mu\text{g/mL}$	~ 37.2 $\mu\text{g/mL}$	~ 14.7 $\mu\text{g/mL}$

3M System Demonstration

Pre-filter Operation

The initial operation of the 3M setup included the use of only one train of pre-filters and one Cs specific (KCOHEX) cartridge on line. After ~ 2080 liters (550 gallons) of TSF-25 water had been processed, a high pressure drop across the 0.1 μm pre-filter caused the high pressure safety switch to shut down the feed pump. The determination was made to operate with all four pre-filters on line with each set of pre-filters operating in parallel while still pumping the water through a single KCOHEX cartridge. This greatly increased run time. A total average of ~ 9460 liters (2500 gallons) could be processed before 0.1 μm pre-filter change out was necessary. Figure 5 illustrates the typical differential pressures observed versus throughput in gallons while the GWTF was treating TSF-25 water.

Figure 5. Differential Pressure as a function of TSF-25 water processed for 0.1 μm pre-filter.

The final two batches of this testing incorporated the use of TSF-05 water. This well water was known to exhibit higher concentrations of solids. Approximately 3780 liters (1000 gallons) of TSF-05 water could be processed before 0.1 μm pre-filter change out was performed (Figure 6). Sample results indicated that no ^{137}Cs was entrained in the solids removed by the pre-filters.

Figure 6. Differential pressure as a function of TSF-05 water processed for 0.1 μm pre-filter.

The 2.0 μm pre-filters never reached a differential pressure high enough to shut down the feed pump. 3M provided a new experimental 2.0 μm pre-filter for incorporation into the setup. The performance of this new filter was compared to an older model filter. Both filters performed well and can be used successfully for this type of application. The data indicate that the GWTF solids removal systems is efficiently removing solids above the 2.0 μm size range.

Cs Specific (KCOHEX) Cartridge Performance

Complete removal of ^{137}Cs from the contaminated groundwater was consistently observed throughout the 3M KCOHEX cartridge test. A total of $\sim 41,600$ liters (10,992 gallons) of water was processed. Samples indicated the effluent ^{137}Cs activity was at or below analytical detection limits of < 14 pCi/L. Consequently, ^{137}Cs capacity of the KCOHEX cartridge was high and breakthrough was never observed throughout the test. The total amount of ^{137}Cs contained on the cartridge at the completion of the testing was calculated to be approximately 25 μCi which is well below the expected capacity of the KCOHEX cartridge [4]. The high capacity of the KCOHEX cartridge indicates that the radiation level due to ^{137}Cs retention may be the limiting factor in changing the cartridge and not ^{137}Cs breakthrough. On the other hand, appropriate shielding may provide longer usage of the cartridge. Figure 7 illustrates a curve of β - λ activity measured at the cartridge housing versus processed volume of contaminated groundwater.

Figure 7. Measured β - λ activity at KCOHEX housing versus processed groundwater.

The pressure drop across this cartridge was 4 psig at the beginning of this test and never exceeded 9 psig throughout the entirety of this testing (see appendix for 3M pressure readings). These data indicate the solids were sufficiently removed upstream of the KCOHEX cartridge by the pre-filters and the performance of the KCOHEX cartridge was not challenged by the presence of solids.

Ion Exchange System Demonstrations

Pellx-137®, Ionac C-250® Column Setup

A total of ~ 174 liters or 1450 bed volumes (120 mLs/BV) of groundwater was processed through the Pellx-137®/ Ionac C-250® setup. Cesium-137 breakthrough was never reached throughout the experiment for the Pellx-137 column (Figure 8). Cesium-137 activity in the effluent stream never exceeded the analytical detection limit (13-25 pCi/L). Calcium and magnesium were not sorbed onto the Pellx-137® column.

Interestingly, the Pellx-137® column effluent sample contained more Sr than the feed sample of the water entering the column. Figure 8 shows the C/Co value for Sr ranging between 1.4 and 1.8. These data would indicate strontium contamination from the Pellx-137®. This is understandable because Pellx-137® is a naturally occurring zeolite which may sorb stable Sr from natural groundwater. A laboratory experiment was performed to confirm this postulation. A simple batch contact with 0.5 grams of Pellx-137® and 10 mLs deionized water was conducted. A blank contact (10mLs of the same water, but no Pellx-137®) was filtered through a 0.45 μ m acrodisk to ensure Sr contamination was not present in the water or materials used in this test. The Pellx-137® contact was mixed for two minutes on a vortex mixer, centrifuged, and filtered through a 0.45 μ m acrodisk filter. A sample of the filtered blank and Pellx-137® contact were

sent for total Sr analysis. The results indicated that no Sr was present in the water before contact, however, after contacting with the Pellx-137[®] sorbent, there was a measurable quantity of Sr present (0.0489 $\mu\text{g/mL}$). This was interesting to note, however, it is important to remember that Pellx-137[®] is marketed explicitly as a Cs specific sorbent.

Figure 8. Cs-137 breakthrough for Pellx-137[®] column.

Calcium and magnesium reached 10% breakthrough in the Ionac column at ~ 1200 and ~ 1000 bed volumes respectively, while 10% Sr breakthrough occurred at ~ 1350 bed volumes (Figure 9). These data indicate calcium and magnesium will sorb onto Ionac C-250[®], thus decreasing the resin's capacity for Sr. Column effluent samples indicated ⁹⁰Sr concentrations exceeded the MCL of 8 pCi/L after ~ 1100 bed volumes of groundwater was processed. However the fact that calcium and magnesium did breakthrough before Sr indicates this material is more specific for Sr than calcium or magnesium. It should be noted that all water tested in this experiment was pumped from TAN injection well TSF-25 which has higher calcium and Sr concentrations than TSF-05 (see Table 4). Later Sr breakthrough would be expected with TSF-05 water.

Figure 9. Total Sr breakthrough for Ionac C-250® column.

SELION CsTreat®, AlliedSignal Sodium Titanate Column Setup

A total of ~ 290 liters or 2400 bed volumes (120 mLs/BV) of groundwater was pumped through the SELION CsTreat®/sodium titanate column setup. 1900 bed volumes were processed as the GWTF treated TSF-25 injection well groundwater and 500 bed volumes processed as the GWTF treated TSF-05 injection well groundwater. Cesium-137 breakthrough was not reached throughout the experiment in the SELION CsTreat® column. Concentration ratios C/C_o for Ca, Mg, and total Sr were ~ 1.0, indicating these elements did not sorb onto the SELION CsTreat® column (Figure 10). Column effluent sample analyses indicated Cs concentrations never exceeded the MCL of 119 pCi/L throughout the experiment.

Figure 10. Cs-137 breakthrough curve for SELION Cs-Treat® column.

The sodium titanate column did not efficiently remove Sr from the contaminated groundwater. Sample analyses from the effluent stream indicated ^{90}Sr concentrations were never below the MCL of 8 pCi/L and ranged between 32-85 pCi/L. It appears as though Sr has reached ~ 50% breakthrough after processing ~ 2100 bed volumes. Calcium and magnesium breakthrough appears to occur much earlier with the sodium titanate sorbent than with the Ionac C-250® sorbent, which would seem to indicate sodium titanate is more specific for Sr than Ionac C-250®. However, there does not appear to be significant bed volume differences between these two sorbents at 10% breakthrough. A graph showing a breakthrough curve for total Sr, Ca, and Mg is shown in Figure 11.

Figure 11. Total Sr breakthrough curve for sodium titanate column.

IONSIV IE-911 (CST) Column Setup.

A total of ~ 135 liters or 1120 bed volumes (120 mLs/BV) were pumped through the CST sorbent column. Approximately 770 bed volumes were pumped through the column as the GWTF processed the TSF-25 injection well groundwater and 350 bed volumes of TSF-05 injection well groundwater treated by the GWTF was pumped through the column. The CST column efficiently sorbed Cs and Sr from the contaminated groundwater, Cs breakthrough was not observed throughout the experiment. Cesium concentration never exceeded the MCL of 119 pCi/L in the effluent samples throughout the experiment. Strontium breakthrough was not observed during the test, however, one data point at 850 bed volumes indicates Sr may have reached breakthrough. This data point is believed to be erroneous because the following data point indicated no Sr was present in the effluent..

Calcium reached 50% breakthrough at ~ 750 bed volumes and Mg reached 100% breakthrough at ~ 240 bed volumes. These breakthrough values indicate the CST sorbent has a higher selectivity for Cs and Sr than for Ca or Mg. Sr breakthrough does not appear to be influenced to the same extent by Ca and Mg in the CST column as compared to the Ionac C-250®

and sodium titanate sorbents. Figure 12 illustrates the breakthrough curves obtained with the CST column for the species of interest i.e. Ca, Mg, Cs, and Sr.

Figure 12. Cs, Sr, Ca, and Mg breakthrough curves for the CST column.

It should be noted that a chosen flowrate of 20 mLs/min (10 BV/hr), based on residence time calculations, was used for all the ion exchange column experiments. Due to the presence of process fluctuations, it was virtually impossible to maintain a consistent flowrate. This inconsistency resulted in residence times varying from 10 to 20 BV/hr.

The Sr values used to reflect breakthrough curves for the previous ion exchange column tests utilized total Sr data received from the ICP sample analysis method. The method used to analyze for total Sr was found to be more accurate than the method used to determine ^{90}Sr activity. This inaccuracy is based on the low concentrations of ^{90}Sr found in the GWTF contaminated groundwater.

RECOMMENDATIONS

The following studies are recommended:

Further testing of the Cs selective sorbents is warranted. Capacities and removal efficiencies are uncertain due to limited bed volumes processed.

Further testing is also recommended using the IE-911® (CST) sorbent for Sr removal. Again, capacities and removal efficiencies are unclear due to limited bed volumes processed.

A large-scale removal system using 3M's Cs specific KCOHEX cartridge is recommended.

REFERENCES

1. Environmental Impact Statement, Record of Decision., "Declaration for the Technical Support Facility Injection Well (TSF-05) and Surrounding Groundwater Contamination (TSF-23) and Miscellaneous No Action Sites Final Remediation Action", August 4, 1995
2. Herbst, R. S., Brewer, K. N., and Todd, T. A., "Decontamination of TAN Injection Well Water using 3M Web Technology", INEL-95/0589, November 1995
3. Kurath, D. E., et.al., "Experimental Data and Analysis to Support the Design of an Ion Exchange Process for the Treatment of Hanford Tank Waste Supernatant Liquids", PNL-10187, December 1994
4. Hobart, S. A., Hyman, M., "Demonstration of Radionuclides Removal at the 105-N Basin Using the 3M System", BHI-00759, March 1996

Appendix: Experimental Data

Pressure Readings and Sample Analyses for 3M Experimental Setup

Date	Time	Trial #	GPM	GALLONS	P1	P2-A or B	P3-A or B	P4	DP 2 micron	DP 0.1 micron	DP Co	Cs-137 Activity			Sr-90 Analyses	
												pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
			Flowrate	Total Flow								Feed	Cs Inlet	Effluent	Feed	Cs Inlet
8/21/96	15:25	B	1	0	24	14	16	12	10	2	4	678				
8/21/96	16:35	B	1	71	29	17	16	12	12	7	4					
8/22/96	8:25	A	1	565	29	22	15	13	7	7	2			<21.7		
8/22/96	10:00	A	1	660	33	27	16	12	6	11	4					
8/22/96	13:38	A	0.97	871	38	30	14	12	8	16	2					
8/22/96	15:52	A	0.94	998	44	36	18	12	8	18	6	532		<18.9	221	
8/26/96	13:30	A	1	1012	34	25	21	15	9	4	6					
8/26/96	14:30	A	1	1047	31	22	18	11	9	4	7	548		<11.7	211	
8/26/96	16:24	A	1	1124	35	26	18	12	9	8	6					
8/26/96	16:40	A	1	1136	23	20	18	12	3	2	6					
8/26/96	16:40	B	1	1136	23	21	18	12	2	3	6					
8/27/96	8:10	A	0.96	2049	33	30	18	12	3	12	6		422			233
8/27/96	8:10	B	0.96	2049	33	32	18	12	1	14	6		422	<14.2		233
8/27/96	10:15	A	1	2167	38	34	20	14	4	14	6	373			232	
8/27/96	10:15	B	1	2167	38	36	20	14	2	16	6	373			232	
8/28/96	10:30	A	1	2343	38	35	20	12	3	15	8					
8/28/96	10:30	B	1	2343	38	37	20	12	1	17	8					
8/28/96	13:45	A	1	2547	48	44	20	12	4	24	8		449			226
8/28/96	13:45	B	1	2547	48	46	20	12	2	26	8		449	<14.1		226
8/28/96	15:22	A	0.99	2639	51	47	19	12	4	28	7					
8/28/96	15:22	B	0.99	2639	51	49	19	12	2	30	7					
8/28/96	15:55	A	1	2650	23	20	19	12	3	1	7					
8/28/96	15:55	B	1	2650	23	22	19	12	1	3	7					
8/29/96	8:35	A	0.97	3640	30	26	20	12	4	6	8		345			202
8/29/96	8:35	B	0.97	3640	30	28	20	12	2	8	8		345	<14		202
8/29/96	10:25	A	1	3812	33	29	21	14	4	8	7					
8/29/96	10:25	B	1	3812	33	30	21	14	3	9	7					
8/29/96	12:55	A	0.99	3892	34	30	20	12	4	10	8					
8/29/96	12:55	B	0.99	3892	34	31	20	12	3	11	8					
9/3/96	11:25	A	1.01	3908	33	29	21	13	4	8	8	489			306	
9/3/96	11:25	B	1.01	3908	33	30	21	13	3	9	8	489			306	
9/3/96	15:00	A	0.99	4133	35	31	20	11	4	11	9		430			225
9/3/96	15:00	B	0.99	4133	35	32	20	11	3	12	9		430	<13.5		225
9/3/96	16:40	A	0.99	4197	34	30	20	12	4	10	8					
9/3/96	16:40	B	0.99	4197	34	31	20	12	3	11	8					
9/4/96	8:05	A	0.93	5090	57	53	19	12	4	34	7					
9/4/96	8:05	B	0.93	5090	57	52	19	12	5	33	7			<13.4		
9/4/96	9:10	A	1	5133	26	22	20	12	4	2	8					
9/4/96	9:10	B	1	5133	26	22	20	12	4	2	8					
9/4/96	9:55	A	1	5176	26	22	20	12	4	2	8					
9/4/96	9:55	B	1	5176	26	22	20	12	4	2	8					
9/4/96	13:05	A	1	5366	28	24	20	13	4	4	7					
9/4/96	13:05	B	1	5366	28	24	20	13	4	4	7					
9/4/96	15:00	A	1	5479	29	24	20	12	5	4	8					
9/4/96	15:00	B	1	5479	29	24	20	12	5	4	8					
9/9/96	11:40	A	0.99	5493	28	22	20	12	6	2	8	505			221	
9/9/96	11:40	B	0.99	5493	28	24	20	12	4	4	8	505			221	
9/9/96	14:45	A	1	5683	31	26	21	12	5	5	9		426			218
9/9/96	14:45	B	1	5683	31	26	21	12	5	5	9		426	<14.7		218
9/9/96	16:35	A	1	5762	30	26	20	12	4	6	8					
9/9/96	16:35	B	1	5762	30	26	20	12	4	6	8					
9/10/96	8:35	A	0.99	6723	39	33	20	12	6	13	8					
9/10/96	8:35	B	0.99	6723	39	30	20	12	9	10	8			<13.9		
9/10/96	10:20	A	0.99	6826	41	34	22	14	7	12	8	606	583.8			232
9/10/96	10:20	B	0.99	6826	41	32	22	14	9	10	8	606	583.8			232
9/10/96	13:00	A	0.99	6982	42	36	21	12	6	15	9					
9/12/96	10:05	A	1	7051	40	34	21	12	6	13	9					
9/12/96	10:05	B	1	7051	40	31	21	12	9	10	9					
9/12/96	14:10	A	0.99	7294	43	38	20	12	5	18	8					
9/12/96	14:10	B	0.99	7294	43	33	20	12	10	13	8			<14.6		
9/12/96	16:12	A	1	7416	45	40	21	12	5	19	9					
9/12/96	16:12	B	1	7416	45	34	21	12	11	13	9					
9/16/96	8:22	A	0.99	7430	42	35	21	12	7	14	9					
9/16/96	8:22	B	0.99	7430	42	33	21	12	9	12	9					
9/16/96	14:00	A	0.99	7765	51	45	21	12	6	24	9		302.7			181
9/16/96	14:00	B	0.99	7765	51	39	21	12	12	18	9		302.7	<15		181
9/16/96	16:28	A	1	7884	31	22	21	13	9	1	8					
9/16/96	16:28	B	1	7884	31	23	21	13	8	2	8					
9/17/96	8:18	A	1	8832	40	32	21	12	8	11	9					
9/17/96	8:18	B	1	8832	40	27	21	12	13	6	9					
9/17/96	14:20	A	0.99	9190	44	37	22	14	7	15	8					
9/17/96	14:20	B	0.99	9190	44	30	22	14	14	8	8					
9/30/96	8:55	A	1.01	9238	34	29	23	14	5	6	9	<13.5?				
9/30/96	8:55	B	1.01	9238	34	30	23	14	4	7	9	<13.5?				
9/30/96	13:35	A	1	9517	41	34	23	14	7	11	9					
9/30/96	13:35	B	1	9517	41	34	23	14	7	11	9			<12.8		
10/1/96	14:50	A	0.97	9665	44	37	21	12	7	16	9	1117				
10/1/96	14:50	B	0.97	9665	44	37	21	12	7	16	9	1117				
10/1/96	16:30	A	0.97	9733	45	38	21	12	7	17	9					
10/1/96	16:30	B	0.97	9733	45	38	21	12	7	17	9					
10/2/96	9:45	A	1	9935	30	22	22	13	8	0	9					
10/2/96	9:45	B	1	9935	30	24	22	13	6	2	9				<5.86	
10/2/96	15:30	A	0.97	10240	35	26	21	12	9	5	9					
10/2/96	15:30	B	0.97	10240	35	29	21	12	6	8	9					
10/3/96	10:20	A	0.95	10932	55	45	21	13	10	24	8					
10/3/96	10:20	B	0.95	10932	55	50	21	13	5	29	8					

Readings for Ion Exchange Experimental Setups

Setup 1 = Column A is Pelix-137; Column B is Ionac-250												
Setup 2 = Column A is SELION Cs-Treat; Column B is Sodium Titanate							Cs-137 Activity			Sr Analyses		
		mL/min					pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
Date	Time	Setup #	Flowrate	Bed Volume	Inlet Pressure	DP across setup	Feed	Column A Eff.	Column B Eff.	Feed	Column A Eff.	Column B Eff.
8/21/96	15:45	1	20	0	19	15	678			251		
8/21/96	15:45	2	20	0	22	18	678			251		
8/21/96	16:37	1	20	9	20	16						
8/21/96	16:37	2	22	9	24	20						
8/22/96	8:30	1	44	331	14	9			<24.8			4.26
8/22/96	8:30	2	19	149	32	27			<24.3			17.1
8/22/96	10:00	1	26	349	20	16						
8/22/96	10:00	2	23	166	33	29						
8/22/96	13:45	1	20	396	17	12						
8/22/96	13:45	2	19	211	30	25						
8/22/96	15:50	1	20	418	18	13	532		<16.6	221		1.81
8/22/96	15:50	2	21	233	33	28	532		<20.3	221		12.6
8/26/96	13:45	1	20	419	25	19						
8/26/96	13:45	2	20	235	30	24						
8/26/96	14:30	1	20	419	18	13	548		<13.1	211		4.09
8/26/96	14:30	2	20	235	24	19	548		<12.9	211		17.6
8/26/96	16:40	1	20	441	20	16						
8/26/96	16:40	2	21	257	24	20						
8/27/96	8:00	1	46	734	26	23		<13.1			67.4	
8/27/96	8:00	2	16	412	27	24		<13.2			8.88	
8/27/96	10:20	1	21	758	20	15	373		<13.6	232		6.05
8/27/96	10:20	2	21	437	30	25	373		<13.3	232		207
8/28/96	10:30	1	20	790	18	14						
8/28/96	10:30	2	20	467	30	26						
8/28/96	13:48	1	28	827	20	16			<13			2.71
8/28/96	13:48	2	21	506	30	24			<13.8			15.9
8/28/96	16:00	1	20	850	17	13						
8/28/96	16:00	2	20	529	28	24						
8/29/96	8:40	1	23	1036	18	14		<13.6			61.9	
8/29/96	8:40	2	22	738	34	30		<13.2			204	
8/29/96	10:30	1	21	1055	18	13			<13.4			3.93
8/29/96	10:30	2	20	756	26	21			<13.8			28.8
8/29/96	13:00	1	20	1081	16	11						
8/29/96	13:00	2	20	781	26	21						
9/3/96	11:30	1	20	1084	20	16	489			306		
9/3/96	11:30	2	20	784	30	26	489			306		
9/3/96	15:10	1	21	1129	18	14			<14.6			13
9/3/96	15:10	2	28	833	34	30			<15.4			26.8
9/3/96	16:45	1	20	1140	14	9						
9/3/96	16:45	2	21	844	28	23						
9/4/96	8:08	1	31	1386	22	17		<14.4			83	
9/4/96	8:08	2	27	1040	36	31		<14.2			226	
9/4/96	10:00	1	20	1405	18	13			<13			10.4
9/4/96	10:00	2	20	1059	30	25			<14.3			39.9
9/4/96	13:10	1	21	1438	17	11						
9/4/96	13:10	2	20	1091	27	21						
9/4/96	15:05	1	20	1456	14	9						
9/4/96	15:05	2	20	1110	28	23						

Readings for Ion Exchange Experimental Setups (cont.)

Setup 1 = Column B is CST												
Setup 2 = Column A is SELION Cs-Treat; Column B is Sodium Titanate							Cs-137 Activity			Sr Analyses		
Date	Time	Setup #	mL/min	Bed Volume	Inlet Pressure	DP across setup	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L	pCi/L
							Feed	Column A Eff.	Column B Eff.	Feed	Column A Eff.	Column B Eff.
9/9/96	11:42	1	20	1	18	14	505			221		
9/9/96	11:42	2	20	1112	32	28	505			221		
9/9/96	14:50	1	33	54	21	18			<14.6			1.67
9/9/96	14:50	2	23	1149	31	28			<14.6			32.9
9/9/96	16:37	1	19	68	16	11						
9/9/96	16:37	2	20	1164	31	26						
9/10/96	8:40	1	30	240	20	15	606		<15.2	256		3.94
9/10/96	8:40	2	29	1392	38	33	606		<16	256		32.2
9/10/96	10:25	1	20	259	19	13						
9/10/96	10:25	2	20	1411	32	26		<15.3			231	
9/10/96	13:05	1	21	285	20	15						
9/10/96	13:05	2	20	1440	32	27						
9/12/96	10:07	1	20	297	20	16						
9/12/96	10:07	2	21	1453	36	32						
9/12/96	14:12	1	27	345	20	15			<14			3.75
9/12/96	14:12	2	19	1495	31	26			<16.1			55.5
9/12/96	16:15	1	20	367	17	12						
9/12/96	16:15	2	20	1516	31	26						
9/16/96	8:25	1	20	369	20	15						
9/16/96	8:25	2	20	1518	37	32						
9/16/96	14:05	1	22	437	20	16			<14			9.42
9/16/96	14:05	2	22	1583	34	30		<14.3	<14.8		241	56.1
9/16/96	16:30	1	20	459	19	14						
9/16/96	16:30	2	20	1603	35	30						
9/17/96	8:20	1	33	676	20	15						
9/17/96	8:20	2	32	1835	43	38						
9/17/96	14:25	1	36	760	24	19						
9/17/96	14:25	2	26	1904	40	35						
9/30/96	9:00	1	21	768	20	15	<13.5?			273?		
9/30/96	9:00	2	22	1913	39	34	<13.5?			273?		
9/30/96	13:40	1	39	844	24	18			<12.2			331
9/30/96	13:40	2	29	1975	42	36			<14.1			1.77
10/1/96	14:52	1	20	866	18	14	1117			190		
10/1/96	14:52	2	17	1999	38	34	1117	<12.5		190	107	
10/1/96	16:35	1	20	880	18	13						
10/1/96	16:35	2	20	2012	52	47						
10/2/96	9:15	1	20	1120	18	13			<5.97			1.57
10/2/96	9:15	2	19	2051	25	20		<6.22	<5.82		342	84.8
10/2/96	15:32	1	23	1179	19	14						
10/2/96	15:32	2	19	2107	28	23						
10/3/96	10:25	1	38	1413	24	19						
10/3/96	10:25	2	39	2385	34	29						

Sample Results for TAN 3M Experimental Setups

na= sample analysis not requested						
Sample Format: 3MX-2 is cartridge effluent and 3MX-2in is cartridge inlet						
	analysis method	Gamma Scan	Sr Specific method	ICP	ICP	ICP
Sample	Total Flow (L)	Cs-137 pCi/L	Sr-90 pCi/L	Total Sr ug/mL	Calcium ug/mL	Magnesium ug/mL
Batch 1 feed 1	0	678	251	0.235	14	15.1
Batch 1 feed 2	3777	532	221	0.288	40.5	15
Batch 2 feed 1	3963	548	211	0.304	42.4	15.3
Batch 3 feed 1	8202	373	232	0.278	40.9	14.5
Batch 4 feed 1	14792	489	306	0.254	30.2	14.9
Batch 5 feed 1	20791	505	221	0.228	27.6	13.5
Batch 6 feed 1	25836	606	256	0.291	41.7	14.9
Batch 7 feed 1	34966	<13.5?	273	0.043	7.26	9.055
Batch 8 feed 1	36582	1117	190	0.181	13.43	13.95
3M1-2	2139	<21.7	na	na	na	na
3M2-2	3777	<18.9	na	na	na	na
3M3-2	3963	<11.7	na	na	na	na
3M4-2	7755	<14.2	na	na	na	na
3M5-2	9640	<14.1	na	na	na	na
3M6-2	13777	<14	na	na	na	na
3M7-2	15643	<13.5	228	na	na	na
3M8-2	19266	<13.4	233	na	na	na
3M9-2	21510	<14.7	na	na	na	na
3M10-2	25447	<13.9	na	na	na	na
3M11-2	27608	<14.6	na	na	na	na
3M12-2	29391	<15	na	na	na	na
3M13-2	36022	<12.8	na	na	na	na
3M14-2	37604	<5.86	na	na	na	na
3M1-2in	7755	422	233	na	na	na
3M2-2in	9640	449	226	na	na	na
3M3-2in	13777	345	202	na	na	na
3M4-2in	15643	430	225	na	na	na
3M5-2in	21510	426	218	na	na	na
3M6-2in	25836	538.8	232	na	na	na
3M7-2in	29391	302.7	181	na	na	na

Sample results for TAN IX Experimental Setups

Sample Format: 1B is Ionac, 2B is Sodium Titanate, 1A is Pelix, 2A is CsTreat, and IXX-1 is CST Column effluent						
	analysis method	Gamma Scan	Sr Specific method	ICP	ICP	ICP
Sample	Bed Volume	Cs-137 pCi/L	Sr-90 pCi/L	Total Sr ug/mL	Calcium ug/mL	Magnesium ug/mL
Batch 1 feed 1	0	678	251	0.235	14	15.1
Batch 1 feed 2	418	532	221	0.288	40.5	15
Batch 2 feed 1	419	548	211	0.304	42.4	15.3
Batch 3 feed 1	758	373	232	0.278	40.9	14.5
Batch 4 feed 1	1084	489	306	0.254	30.2	14.9
Batch 5 feed 1	1112	505	221	0.228	27.6	13.5
Batch 6 feed 1	1392	606	256	0.291	41.7	14.9
Batch 7 feed 1	1912	<13.5?	273	0.043	7.26	9.055
Batch 8 feed 1	1999	1117	190	0.181	13.43	13.95
IX1-1B	331	<24.8	4.26	0.00848	0.219	0.0384
IX1-2B	149	<24.3	17.1	0.0225	3.39	1.14
IX2-1B	418	<16.6	1.81	<0.0004	0.0154	<0.001
IX2-2B	233	<20.3	12.6	0.00929	2.33	0.768
IX3-1B	419	<13.1	4.09	0.00636	<0.009	<0.001
IX3-2B	235	<12.9	17.6	0.0146	2.43	0.779
IX4-1B	758	<13.6	6.05	<0.0004	0.305	0.21
IX4-2B	437	<13.3	207?	0.0106	1.63	0.546
IX5-1B	827	<13	2.71	<0.0004	0.0891	2.66
IX5-2B	506	<13.8	15.9	0.012	1.91	11
IX6-1B	1055	<13.4	3.93	<0.0004	2.38	38
IX6-2B	756	<13.8	28.8	0.0355	28.9	16.9
IX7-1B	1129	<14.6	13	<0.0004	4.99	34.2
IX7-2B	833	<15.4	26.8	0.018	29.1	15.4
IX8-1B	1405	<13	10.4	0.058	35.7	14.7
IX8-2B	1059	<14.3	39.9	0.028	35.6	13.7
IX9-2B	1149	<14.6	32.9	0.019	36.4	14
IX10-2B	1392	<16	32.2	0.061	40.7	14.8
IX11-2B	1495	<16.1	55.5	0.057	39.4	14.8
IX12-2B	1583	<14.8	56.1	0.06	39	15.3
IX13-2B	1975	<14.1	1.77	0.109	46.59	17.57
IX14-2B	2051	<5.82	84.8	0.1165	43.24	17.85
IX1-1A	734	<13.1	67.4	0.461	40.3	14.8
IX1-2A	412	<13.2	8.88	0.276	41.9	14.8
IX2-1A	1036	<13.6	61.9	0.485	41.9	15.1
IX2-2A	738	<13.2	204	0.294	41.8	15.1
IX3-1A	1386	<14.4	83	0.414	35.1	14.2
IX3-2A	1040	<14.2	226	0.249	42.2	14.1
IX4-2A	1411	<15.3	231	0.297	41.5	14.4
IX5-2A	1583	<14.3	241	0.275	40.7	14.5
IX6-2A	1999	<12.5	107	0.081	12.83	18.81
IX7-2A	2051	<6.22	342	0.2745	43.88	17.13
IX1-1	54	<14.6	1.67	<0.0004	0.0188	10
IX2-1	240	<15.2	3.94	<0.0004	5.8	14.4
IX3-1	345	<14	3.75	<0.0004	13.1	13.6
IX4-1	437	<14	9.42	<0.0004	18	14.2
IX5-1	844	<12.2	331	0.007	32.59	17.52
IX6-1	1120	<5.97	1.57	<.00325	36.29	16.39