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Elution Testing of Resorcinol-Formaldehyde Resins with AN-105 Simulant

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LEGAL NOTICE

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for W. Tamosaitis 2/6/04
ACCEPTED FOR
WTP PROJECT USE

February 2004

Test specification: 24590-PTF-RSP-RT-03-01, Revision 0
Test plan: TP-RPP-WTP-244, Rev. 0
R&T focus area: Pretreatment
Test Scoping Statement(s): A-202
Test Exception(s): 24590-WTP-TEF-RT-03-050

Battelle—Pacific Northwest Division
Richland, Washington 99352

COMPLETENESS OF TESTING

This report describes the results of work and testing specified by Test Specification 24590-PTF-RSP-RT-03-01, Revision 0 and Test Plan TP-RPP-WTP-244, Rev. 0. The work and any associated testing followed the quality assurance requirements outlined in the Test Specification/Plan. The descriptions provided in this test report are an accurate account of both the conduct of the work and the data collected. Test plan results are reported. Also reported are any unusual or anomalous occurrences that are different from expected results. The test results and this report have been reviewed and verified.

Approved:

Gordon H. Beeman, Manager — 2/5/04 — Date

WTP R&T Support Project

Summary

Battelle—Pacific Northwest Division (PNWD) is contracted to Bechtel National Inc. (BNI) on the River Protection Project-Waste Treatment Plant (RPP-WTP) project to perform research and development activities. Unit operations of the low-activity waste (LAW) treatment process include the separation of ^{137}Cs by ion exchange from the liquid portion of the waste. SuperLig® 644 (SL-644) was selected by the project as the baseline ion exchange resin to perform the ^{137}Cs separation. To provide an alternative to this sole-source resin supply, an alternative ion exchange resin, Resorcinol-Formaldehyde (RF), is being evaluated for Cs removal. The tests described in this report were undertaken to compare the elution behavior of two types of RF resin, ground gel and spherical.

Objectives

This investigation was conducted according to the test plan prepared by Burgeson (2003) in response to the test requirements for investigating RF as a potential alternative to cesium removal delineated by Thorson (2003a) in the supplemental Research and Technology Plan and the test exceptions initiated by Thorson (2003b). The research testing is identified in test scoping statement A-202. Table S.1 identifies the test objectives and provides a brief discussion of the test results. Additional discussion of the testing and results are provided later in this section.

Table S.1. Summary of Test Objectives and Results

Test Objective	Objective Met	Discussion
Examine elution conditions as a function of nitric acid concentration (0.5 to 1.5 M) and temperature (25 to 45°C) to achieve the required decontamination factor on subsequent load cycles while maintaining sufficient resin capacity to allow reasonable multi-cycle use of the resin.	Yes	Increasing temperature and increasing acid concentration both enhance cesium elution; however, increasing the temperature has the most significant impact on the elution profile. Increasing the acid concentration had a deleterious effect on the spent-resin K_ds. Based upon the results in this testing, the best elution was obtained at high temperature (45°C) and low acid strength (0.50 M HNO_3).
Confirm the testing results of Task A-222 using the RF spherical resin using 0.5 M HNO_3 at 25°C.	Yes	This work confirmed the excellent elution profile for the spherical RF resin. Indeed, the performance of spherical RF resin obtained in this work was even better than that reported by Fiskum et al. (2003). The spherical resin demonstrated superior elution characteristics compared to the ground-gel resin.
Determine equilibrium-distribution coefficients for spent resin to evaluate the effect of elution parameters on resin stability and performance and to predict equilibrium cesium content in polish-column conditions.	Yes	Increasing the elution temperature does not significantly impact the spent-resin K_ds; however, increasing the eluant acid concentration resulted in a lower spent-resin K_d. The spent-resin K_d values after elution with 1.5 M HNO_3 were 25% lower than the control batch contacts. The high-temperature spent-resin K_d values were ~4% higher than the control resin, which is within the experimental uncertainty.

Test Exceptions

The work details were modified in test exception 24590-WTP-TEF-RT-03-050. Table S.2 describes the test exceptions initiated by Thorson (2003b) for this test.

Table S.2. Test Exceptions

Test Exception	Discussion
Reduce the current planned 13 column runs all with ground-gel RF resin to three column runs with ground-gel RF resin and one column run with spherical RF resin.	The current test plan is designed to determine the optimum elution conditions for ground-gel Resorcinol Formaldehyde (RF) to meet cesium decontamination requirements on resin reuse. Preliminary results from RF testing to date have shown a spherical RF to have performance superior to the ground-gel RF. Consequently, there is a significant chance that ground-gel RF will not be selected for Stage 2 testing, and the required testing for this test plan could be reduced to only that needed to determine conditions for ground-gel RF disposal. This will determine if resin disposal issues eliminate ground-gel RF for consideration for Stage 2 testing.
Perform four elution tests where the temperature and eluant concentration are independently varied.	The experimental design for column elution will be performed with columns loaded to 10 µg/ml and eluted at 1.4 bed volumes per hour. The unique conditions of these elutions will be: a. 1.5 M HNO_3 with ground gel RF resin at 25°C b. 0.5 M HNO_3 with ground gel RF at 45°C c. 0.5 M HNO_3 with ground gel RF at 25°C d. 0.5M HNO_3 with spherical RF at 25°C.
Eliminate the confirmatory testing of Section 7.6 (Confirmatory Testing for Resin Reuse) and Section 7.7 (Elution Test for TCLP Metals).	The columns examining residual TCLP metals and confirmatory testing for resin reuse have been deferred to later testing (Phase 2 or 3).
Eliminate the prediction of column performance in Section 7.5 (Estimating Polishing Column Performance using Batch Equilibrium and Column Elution Results).	The resin-performance prediction for reuse in a polishing-column position has been deferred to later testing (Phase 2 or 3).

Results and Performance Against Success Criteria

As described by Thorson (2003a), the original test success criteria were identified by the RPP-WTP project to establish elution conditions that will achieve required decontamination of cesium on subsequent load runs while maintaining sufficient resin capacity to allow reasonable multi-cycle use of the resin. The test exception (Thorson 2003b) eliminated this success criterion and shifted the focus to the spent-resin analysis. Based upon the test exception, this testing would be considered successful if it were determined that the ground-gel RF would meet disposal requirements without the need to determine if ground-gel RF can be conditioned for successful reuse. This test criterion was satisfied, as demonstrated later in this summary.

Quality Requirements

PNWD implemented the RPP-WTP quality requirements in a quality assurance project plan (QAPjP) as approved by the RPP-WTP quality assurance (QA) organization. Testing and analytical activities were conducted in accordance with PNWD's quality assurance project plan, RPP-WTP-QAPjP, which invoked NQA-1-1989 Part I, "Basic and Supplementary Requirements," and NQA-2a-1990, Part 2.7. These quality requirements were implemented through PNWD's Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual.

PNWD addressed data-verification activities by conducting an independent technical review of the final data report in accordance with Procedure QA-RPP-WTP-604. This review verified that the reported results were traceable, that inferences and conclusions were soundly based, and that the reported work satisfied the Test Plan objectives.

Research and Technology Test Conditions

The test specification (Thorson 2003a) established extensive conditions to ensure that the results are valid for RPP-WTP project needs. Due to their extensive nature, the conditions are not repeated here, but they essentially constitute the test methodology described later in this summary. The conditions, as modified by the test exceptions and test plan (Burgeson 2003), were satisfied.

Simulant Use

The RPP-WTP project has a contractual requirement to compare the results of testing with simulants to the results from similar tests using actual waste. The tests described in this report used AN-105 simulated low activity waste (LAW). There are no actual waste-testing results available for the different types of RF resin; however, simulants should behave effectively similar to actual waste under elution conditions.

Test Methodology

Tests were performed using a simulated 241-AN-105 (AN-105) LAW. The simulated AN-105 LAW recipe was modified to provide an ion exchange feed that was 5 M in sodium. The simulated LAW was traced with ^{137}Cs so that process samples could be analyzed by gamma-energy analysis (GEA). A series of four independent ion exchange columns were used to perform simultaneous load and elution cycles using ground-gel and spherical RF resin. The resin bed was nominally 11 ml of RF resin expanded in 1.0 M NaOH.

The two RF resins were conditioned outside of the column with 0.5 M HNO_3 and 1.0 M NaOH before transfer to the column. The RF resins were cycled in the column through two shrink-swell cycles before initiating testing. The RF resins were processed with AN-105 simulant prepared at one cesium concentration, 10 µg/ml, to ≥90% cesium breakthrough. Each column then underwent feed displacement with 0.10 M NaOH, deionized (DI) water rinse, and then elution. The elution temperature and nitric acid concentration were independently varied to access the effect of temperature and eluant concentration on elution performance. The elution of the ground-gel resin was monitored for nominally 70 bed volumes (BVs) and the spherical resin for 40 BVs. Once the elutions were completed, the resins were rinsed with DI water, removed from the column, and dried at room temperature under nitrogen flow.

Batch contacts were performed under feed conditions and with AN-105 simulant at 10 µg/ml cesium. Batch contacts were performed to access resin degradation (comparing the results of conditioned resin with that of spent resin processed through a single load and elution cycle) and to access cesium capacity at low cesium concentrations. Batch contacts performed with AN-105 simulant used 0.50 g of resin and 50 ml of feed at a phase ratio of 100 and were contacted in a 60-ml polyethylene bottle for 48 hours.

Test Results

All four columns were loaded to ≥90% cesium breakthrough and then processed for elution testing. The total amount of cesium loaded on the spherical resin column was significantly lower (43%) than that of the ground-gel columns. One of the ground-gel columns loaded slightly less cesium (17%) than the other two resins based upon the amount of processed solution and the effluent composite cesium concentrations. This difference may be insignificant; however, there was likely a slight impact on the elution testing results caused by the lower amount of cesium loaded onto the reference column (25ºC 0.50 M HNO_3 elution).

There were no processing difficulties encountered while eluting the columns at either high temperature (45ºC) or high-acid concentration (1.5 M HNO_3). The best ground-gel elution-curve profile was obtained with the high-temperature elution test, 45ºC and 0.50 M HNO_3. The volume in which the peak cesium concentration in the eluant is reached is affected most by the HNO_3 concentration. It is the tailing that is most significantly impacted by the higher temperature and which provides the best elution profile. The high-strength acid elution peaked more quickly than the low-strength acid elutions (3 BVs versus 5 BVs) and initially dropped more quickly than the other elutions, but after 13 BVs, the concentration of cesium present in the high-strength acid eluant was equivalent to that of the high-temperature elution (C/C_0 = 0.017). After processing for 58 BVs, the high-strength acid C/C_0 was 1.3E-03, and the high-temperature elution C/C_0 was 7.5E-04, which is significantly lower than the high-strength acid value.

The ground-gel spent-resin analysis was used to determine which elution conditions are best for reducing the residual cesium on the resin. The lowest residual cesium on the ground-gel resin was obtained from the elution processing at high temperature (45ºC) and low acid strength (0.50 M HNO_3). The residual cesium, after eluting for 68 BV, 1.35 µg Cs/g dry spent resin (H-form), was at least 50% lower than that measured under high-strength acid or low-temperature elution conditions (3.0 and 3.2 µg Cs/g dry spent resin [H-form], respectively, eluted for 57 and 67 BV).

The spherical resin elution outperformed the ground-gel resin elutions. The spherical resin was eluted at the standard temperature and eluant concentration for 51 BV (25ºC and 0.50 M HNO_3); nonetheless, the elution profile and residual cesium values were far better than those obtained in each of the three ground-gel elution tests. The elution peak occurred at 5 BVs but continued to drop sharply, resulting in eluant solution concentration that was two orders of magnitude lower than that of the ground-gel resins when the elution began to tail. The elution tailing was approximately the same as that observed with the ground-gel resin. The spent-resin residual cesium concentration, 0.15 µg Cs/g dry spent resin (H-form), was at least an order of magnitude lower than that of the ground-gel resin eluted under the same conditions (25ºC and 0.50 M HNO_3), i.e., 3.16 µg Cs/g spent dry resin [H-form]).

The WTP design basis for resin disposal (60 µCi Cs/g resin) was calculated for the ground-gel resin and spherical resin, resulting in a target residual cesium concentration of 4.2 and 2.4 µg Cs/g dried resin, respectively. The spherical RF resin met this spent-resin value after elution with 5 BV of 0.50 M HNO_3. Two of the ground-gel RF elution conditions failed to reach the basis level after elution with ≥58 BV HNO_3. The ground-gel elution performed at elevated temperature (45°C) met the basis level after elution with 20 BV of 0.50 M HNO_3.

Discrepancies and Follow-on Tests

Both the spherical and ground-gel RF resins show strong promise as an alternative to the SL-644 resin. This work confirmed the excellent elution profile for the spherical RF resin. Therefore, further testing of an alternative ion exchange resin beyond the first stage detailed by Thorson et al (2003a) is highly recommended.

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Terms, Symbols, and Abbreviations

ASO	Analytical Service Operations
AV	apparatus volume
BNI	Bechtel National, Inc.
BV	bed volume
DI	distilled and deionized (water)
FMI	Fluid Metering, Incorporated
GEA	gamma-energy analysis
HLW	high-level waste
IC	ion chromatography
ICP-AES	inductively coupled plasma/atomic emission spectrometry
ICP-MS	inductively coupled plasma-mass spectrometry
ID	inner diameter
LAW	low-activity waste
L/D	ratio of bed height to bed diameter
LEPS	Low Energy Photon Spectroscopy
M&TE	measuring and test equipment
OD	outer diameter
PNWD	Battelle—Pacific Northwest Division
QA	quality assurance
QAPjP	quality assurance project plan
QC	quality control
RF	Resorcinol-Formaldehyde
RPD	relative percent difference of the standard deviation from the mean value
RPL	Radiochemical Processing Laboratory
RPP	River Protection Project
TIC	total inorganic carbon
TOC	total organic carbon
WTP	Waste Treatment Plant
WTPSP	Waste Treatment Plant Support Project

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1.0 Introduction

1.1 Background

Battelle—Pacific Northwest Division (PNWD) is contracted to Bechtel National Inc. (BNI) on the River Protection Project-Waste Treatment Plant (RPP-WTP) project to perform research and development activities. The purpose of the RPP-WTP project is to design, construct, and commission a plant to treat and immobilize high-level waste (HLW) and low-activity waste (LAW) stored in underground storage tanks at the Hanford Site. Unit operations of the LAW treatment process include the separation of ^{137}Cs by ion exchange from the liquid portion of the waste. SuperLig® 644 (SL-644) was selected by the project as the baseline ion exchange resin to perform the ^{137}Cs separation and is available from IBC Advanced Technologies, Inc., American Fork, Utah. To provide an alternative to this sole-source resin supply, an alternative ion exchange resin, Resorcinol-Formaldehyde (RF), is being evaluated for Cs removal. The tests described in this report were undertaken to compare the elution behavior of two types of RF resin—ground gel and spherical.

Staff at PNWD have conducted small-column load and elution testing of RF resin from different manufacturers. Both ground-gel resin and spherical resin performed well in the testing and were identified for further testing (Fiskum et al. 2003). These tests clearly identified spherical RF resin as having superior elution profiles. The tests described in this report were undertaken to verify the elution performance of the spherical resin in addition to examining the impact of temperature and eluant concentration on the elution behavior of the ground-gel RF resin.

1.2 Objectives

The primary objectives of this task were to:

- Examine elution conditions as a function of nitric acid concentration (0.5 to 1.5 M) and temperature (25 to 45^{o}C) to achieve the required decontamination factor on subsequent load cycles while maintaining sufficient resin capacity to allow reasonable multi-cycle use of the resin.

- Confirm the testing results of Task A-222 using the RF spherical resin using 0.5 M HNO_3 at 25^{o}C.

- Determine equilibrium-distribution coefficients for spent resin to evaluate the effect of elution parameters on resin stability and performance and to predict equilibrium cesium content in polish-column conditions.

1.3 Purpose

This report documents the testing, results, and analysis associated with the RF elution investigation. The purpose of the investigation was to provide information for an assessment of the best means of eluting the RF ion exchange resin. The report is intended to aid the RPP-WTP project in decisions regarding the design and operation of the cesium ion exchange system in the WTP.

1.4 Quality Assurance

1.4.1 Application of RPP-WTP Quality Assurance Requirements

PNWD implemented the RPP-WTP quality requirements by performing work in accordance with the PNWD Waste Treatment Plant Support Project quality assurance project plan (QAPjP) approved by the RPP-WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, and NQA-2a-1990, Part 2.7. These quality requirements were implemented through PNWD's *Waste Treatment Plant Support Project (WTPSP) Quality Assurance Requirements and Description Manual*. The analytical requirements were implemented through PNWD's *Conducting Analytical Work in Support of Regulatory Programs* through WTPSP's Statement of Work (WTPSP-SOW-005) with the Radiochemical Processing Laboratory Analytical Service Operations (RPL ASO).

A matrix that cross-references the NQA-1 and 2a requirements with the PNWD's procedures for this work is given by Burgeson (2003). It includes justification for those requirements not implemented.

1.4.2 Conduct of Experimental and Analytical Work

Experiments that were not method-specific were performed in accordance with PNWD's procedures QA-RPP-WTP-1101 "Scientific Investigations" and QA-RPP-WTP-1201 "Calibration Control System," assuring that sufficient data were taken with properly calibrated measuring and test equipment (M&TE) to obtain quality results.

As specified by Test Specification, 24590-PTF-TSP-RT-03-01, Rev. 0, Small Column Ion Exchange Testing of Resorcinol Formaldehyde Elution, BNI's QAPjP, PL-24590-QA00001, is not applicable since the work will not be performed in support of environmental/regulatory testing, and the data will not be used as such.

The applicable quality control (QC) parameters for chemical analysis are delineated by Burgeson (2003). Blank spike and/or laboratory control sample QC failures will result in re-analyzing the sample for the particular analyte for which the spike failed. Matrix spike and/or duplicate analysis QC failures will not result in reanalyzing the sample, but probable reasons for the failure will be discussed in the analytical report to be stored in the project files. A qualitative impact assessment of the failure on the results is discussed in the report.

Analytical processes were performed in accordance with the requirements in the PNWD's *Conducting Analytical Work in Support of Regulatory Programs* and WTPSP's Statement of Work (WTPSP-SOW-005) with the RPL ASO. Cesium-137 tracer used in the batch contacts and column tests was counted using a GEA system consisting of a multi-channel analyzer and a suitable detector, such as a high-purity germanium detector. Counting was performed according to the procedure *Gamma Energy Analysis (GEA) and Low Energy Photon Spectroscopy (LEPS)*, PNL-ALO-450, when activity concentrations are required for reporting. The procedure *Routine Research Operations*, RPL-OP-001, was used to control counting when relative activity concentrations (e.g., in calculating equilibrium-distribution coefficients and column-breakthrough profiles) was required for reporting. Absolute counting efficiency and energy calibration were not required since the analysis is comparative. The GEA instruments were monitored for consistent operation by counting cesium-137 control standards both before and after one day's analysis sequence. The instrument background was counted once per day the system was used.

Additional equipment that was used included a ruler, thermocouple, thermometer, clock, and balances. The thermometer for monitoring the batch-contact temperature, ruler, and timepiece are standard laboratory equipment for use as indicators only. The thermocouple was used to verify the water-bath temperature and resin-bed temperature and was calibrated by PNWD Instrumentation Services and Technology. Balances are calibrated annually by a certified contractor, QC Services, Portland, Oregon.

1.4.3 Internal Data Verification and Validation

PNWD addressed internal verification and validation activities by conducting an Independent Technical Review of the final data report in accordance with PNWD's procedure QA-RPP-WTP-604. This review verified that the reported results are traceable, that inferences and conclusions are soundly based, and the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's *WTPSP Quality Assurance Requirements and Description Manual*. The percent completeness for the analytes of interest were calculated and reported according to the formula:

$$\%C = \left(\frac{N_v}{N_p}\right) \times 100 \qquad (1.1)$$

where %C is the percentage completeness, N_p is the total number of planned measurements, and N_v is the number of valid measurements as defined by the project.

The percent completeness was 100%.

2.0 Experimental

This section describes the preparation and composition of the AN-105 tank simulant, the resin preconditioning, and the column preparation. It also covers the batch-distribution measurements and resin wet-sieving results. The column ion exchange test procedure and conditions are described.

2.1 AN-105 Simulant

Noah Technologies (San Antonio, TX) prepared 100 L of AN-105 tank-waste simulant according to specifications provided by PNWD. The AN-105 simulant recipe was reported by Eibling and Nash (2001), but was adjusted to provide a simulant that was 5 M in sodium and did not contain cesium. The simulant recipe is provided in Table 2.1. Noah analyzed the simulant for metals using inductively coupled plasma-atomic emission spectroscopy (ICP-AES), and the composition was verified before the simulant was shipped to PNWD. The simulant was a yellow-green color. Upon filtering, a black solids precipitate was collected, and the resulting simulant was bright yellow. The formation of a black precipitate was observed in other preparations as well (Arm et al. 2003) and is likely silver metal, a photodecomposition product of precipitated silver chloride.

Once received, the filtered simulant density was determined with a volumetric flask in duplicate (1.238±0.003 g/ml), and an aliquot of the simulant was analyzed for metals by ICP-AES, anions by ion chromatography (IC anions), total inorganic and total organic carbon (TIC/TOC) using both furnace and hot persulfate methods, and free hydroxide by titration. The results of the analyses are summarized in Table 3.1. Note that silver was not observed above the detection limit in the simulant analysis, which supports the above prediction that the black material was silver metal formed from the precipitation and photodecomposition of AgCl.

2.2 Feed Preparation

Immediately before each column run, the Noah AN-105 simulant was filtered in-house using a 0.45-µm Nylon filter and then spiked with a $CsNO_3$ solution prepared from ACS reagent grade $CsNO_3$ (99.99% purity) and deionized (DI) water. One cesium concentration, 10 µg/ml, was prepared for the column runs. The prepared feed solution was analyzed for ^{133}Cs by inductively coupled plasma-mass spectrometry (ICP-MS) to verify the final cesium concentration. The feed solution was spiked with a ^{137}Cs tracer at 0.10 µCi/ml. The radiotracer was added using a small volume (2000 µL) of 2.0 mCi/ml ^{137}Cs nitrate prepared in water added to 40 L of AN-105 simulant. The mole ratio of ^{133}Cs to ^{137}Cs in the feed preparations was 8.9×10^3, demonstrating that the contribution of the tracer to the total cesium was negligible. A 5-ml aliquot of the spiked feed typically provided 220,000 counts (peak area) in 5 minutes.

Table 2.1. AN-105 Simulant Recipe—Modified to 5 M Sodium Content

Species	Main Reagent Used	Formula	Formula Weight	Moles/L[(a)]	g to make 1 L
Metals					
Aluminum	Sodium aluminate	$NaAlO_2$	81.96	7.36E-01	60.32
Cadmium	Cadmium nitrate	$Cd(NO_3)_2{*}4\ H_2O$	308.5	1.47E-05	0.01
Calcium	Calcium nitrate	$Ca(NO_3)_2{*}4H_2O$	236.1	4.99E-04	0.12
Cesium	Cesium nitrate	$CsNO_3$	199	6.09E-05	0.02
Chromium	Sodium chromate	Na_2CrO_4	162	1.30E-02	5.05
Lead	Lead nitrate	$Pb(NO_3)_2$	331.2	1.28E-04	0.13
Magnesium	Magnesium nitrate	$Mg(NO_3)_2{*}6H_2O$	256.4	1.11E-04	0.03
Molybdenum	Potassium molybdate	K_2MoO_4	238.1	4.27E-04	0.10
Potassium	Potassium nitrate	KNO_3	101.1	9.51E-02	9.61
Selenium	Selenium dioxide	SeO_2	111.0	6.27E-06	0.07
Silicon	Sodium meta-silicate	$Na_2SiO_3{*}9H_2O$	284.1	3.76E-03	1.07
Silver	Silver nitrate	$AgNO_3$	169.9	7.56E-05	0.04
Sodium	Various	--	--	5.34E+00	--
Zinc	Zinc nitrate	$Zn(NO_3)_2{*}6H_2O$	297.5	7.72E-05	0.02
Cations					
Ammonium	Ammonium acetate	CH_3COONH_4	77.1	3.33E-03	0.26
Boron	Boric acid	H_3BO_3	61.8	2.36E-03	0.15
Anions					
Carbonate	Sodium carbonate	Na_2CO_3	106.0	1.04E-01	11.02
Chloride	Sodium chloride	$NaCl$	58.4	1.28E-01	7.48
Fluoride	Sodium fluoride	NaF	42.0	5.00E-03	0.21
Hydroxide	Sodium hydroxide	$NaOH$	40.0	1.72E+00	68.77
Nitrate	Sodium nitrate	$NaNO_3$	85.0	1.33E+00	113.02
Nitrite	Sodium nitrite	$NaNO_2$	69.0	1.21E+00	83.47
Phosphate	Sodium phosphate	$Na_2HPO_4{*}12H_2O$	380.1	3.00E-03	1.14
Sulfate	Sodium sulfate	Na_2SO_4	142.1	4.01E-03	0.57
Organic Compounds					
Glycolic acid	Glycolic acid[(b)]	$HOCH_2COOH$ 70%	76.0	1.09E-02	1.18
Acetate	Sodium and ammonium acetate	$CH_3COONa{*}3H_2O$	136.0	1.75E-02	2.38
Formate	Sodium formate	$HCOONa$	68.0	3.20E-02	2.18
Oxalate	Sodium oxalate	$Na_2C_2O_4$	134.0	3.47E-03	0.46

(a) Recipe from Eibling and Nash (2001), scaled down to 5 M Na.
(b) Mass of glycolic acid is measured in a 70-wt% aqueous solution. All other mass values are on a dry-mass basis.

2.2.1 RF Resin Receipt and Initial Handling

The spherical and ground-gel RF resins used in this testing were originally received and processed by PNWD under a separate task (A-222). This task tested RF resins prepared by different vendors. Under that task, each RF resin was assigned a unique identification number (#1 through #11) upon arrival at PNWD. The cross-reference to the identification number and actual resin supplier and manufacturing process is provided in a confidential letter to BNI.

Each RF resin was split and sub-sampled with the aid of an open-pan riffle sampler (Model H-3980, Humboldt Manufacturing, Co., Norridge, IL). Resins #2 and #5 were considered duplicates of one another since they were made by the same manufacturer under the same process conditions but several months apart. These two resins were combined after dry-sieving was complete. The combined resins were re-identified as #9, ground-gel RF resin. An aliquot of this #9 resin, 470 ml, was delivered for additional testing under this task directly after sub-sampling. The resin identified as #3, spherical RF resin, was pretreated under Task A-222 and underwent permeability testing under Task A-222, and then 167 ml of resin was delivered for additional testing under this task. The following sections provide a detailed processing history of each RF resin.

2.3 Spherical RF Resin History

The spherical RF resin was pretreated by cycling several times from the H-form to Na-form as described in Table 2.2. The resin was then dried under flowing N_2 at ambient temperature until it was free-flowing and had a nearly constant mass.

The pretreated spherical RF resin was then used in permeability process testing under Task A-222 (Fiskum et al. 2003). The permeability testing involved column processing of the resin. The H- form resin was slurried into a column and pretreated as follows: 3 apparatus volumes (AVs) DI water, 6 BVs 0.50 M HNO_3, 3 AVs DI water, and 6 BVs 1.0 M NaOH. Following the pretreatment, the resin was cycled four times through a load/displace/elute/regenerate cycle. Table 2.2 provides the entire processing history of the spherical RF resin before receipt for the testing reported in this document.

Before using the processed resin for column ion exchange testing, batch contacts were performed to determine if the resin cesium capacity had been affected by the column cycling. The batch contacts were conducted using H-form resin as described in Section 2.5. The K_d results were compared against those performed with an aliquot of the resin that had undergone preconditioning only. The resin performed well in the batch-contact test; the K_d value was not significantly impacted by the permeability testing. Table 2.3 reports the K_d values of the pretreated resin and the permeability-tested resin.

Table 2.2. Pretreatment and Permeability Process Testing of Spherical RF Resin

Process step	Solution	Total Volume		Flow Rate	
		BV	ml	BV/h	ml/min
Preconditioning (7/10/03)					
Water Rinse	DI water	7.21	134	2.59	0.801
Acid Wash	0.5 M HNO_3	6.06	112	2.64	0.814
Water Rinse	DI water	7.91	146	2.65	0.819
Pretreatment – 1 BV=274 ml, L/D 2.7					
Water Rinse	DI water	3	822	3	14
Acid Wash	0.5 M HNO_3	6	1,644	3	14
Water Rinse	DI water	3	822	3	14
Regeneration	1 M NaOH	6	1,644	3	14
Cycle 1					
Load	AP-101 Simulant	180	48,000	360	1600
Feed Displacement	0.1 M NaOH	3	822	3	14
Water Rinse	DI water	3	822	3	14
Elute	0.5 M HNO_3	12	3,288	6	27
Regeneration	1 M NaOH	526	144,000	360	1600
Cycle 2					
Load	AP-101 Simulant	180	48,000	360	1600
Feed Displacement	0.1 M NaOH	3	822	3	14
Water Rinse	DI water	3	822	3	14
Elute	0.5 M HNO_3	12	3,288	6	27
Regeneration	1 M NaOH	526	144,000	360	1600
Cycle 3					
Load	AP-101 Simulant	180	48,000	360	1600
Feed Displacement	0.1 M NaOH	3	822	3	14
Water Rinse	DI water	3	822	3	14
Elute	0.5 M HNO_3	12	3,288	6	27
Regeneration	1 M NaOH	526	144,000	360	1600
Cycle 4					
Load	AP-101 Simulant	180	48,000	360	1600
Feed Displacement	0.1 M NaOH	3	822	3	14
Water Rinse	DI water	3	822	3	14
Elute	0.5 M HNO_3	12	3,288	6	27
Regeneration	1 M NaOH	526	144,000	360	1600
Conversion of Resin to H Form (126 ml Resin)					
Water Rinse	DI water	3	378	NA	NA
Acid Wash	0.5 M HNO_3	3	378	NA	NA
Water Rinse 1	DI water	3	378	NA	NA
Water Rinse 2	DI water	3	378	NA	NA

Table 2.3. Comparison of Batch-Contact Results for Pretreated Spherical Resin and Processed Spherical Resin

RF Spherical Resin	Average Kd, ml/g	RPD, %	Final Solution, M Cs
Spherical resin, pretreated only	742	8	1.40E-04
Spherical resin, pretreated and permeability testing	764	3	8.72E-05
RPD = relative percent difference			

2.3.1 Ground-Gel RF Resin Conditioning

The resin identified as #9 in the A-222 testing was “as- received” resin that had been sub-sampled and delivered for process testing. The resin was soaked in a 3-fold excess volume of DI water (470 g of resin soaked in 1410 ml of water) for 10 minutes, the water was decanted, and the resin was soaked in a 3-fold excess of 0.50 M HNO_3 for 1 hour. The acid was decanted, the resin was soaked in a 3-fold excess of DI water for 10 minutes, and the water was decanted. The resin was contacted with 1.0 M NaOH for 2 hours, the base was decanted, and the resin was rinsed three times with a 3-fold excess of DI water. The final water-rinse solution had a pH of 11.5. The resin was contacted with a 3-fold excess of 0.50 M HNO_3 for 1 hour and then rinsed a final time with a 3-fold excess of DI water. The resin was dried under nitrogen until a free-flowing state was achieved. An aliquot of each resin was weighed out and stored under water with a nitrogen head-space. The remaining conditioned resin was stored in bulk in water, under nitrogen.

The F-factor was determined for the free-flowing, spherical, and ground-gel RF resins in duplicate using 0.50 g of resin, which were dried under vacuum at 50ºC to constant mass. The F-factor was calculated according to Equation 2.1.

$$F = \frac{M_v}{M_f} \qquad (2.1)$$

where F is the F-factor, M_v is the vacuum dried resin mass, and M_f is the nitrogen-dried free-flowing resin mass.

2.4 Ion Exchange Process Testing

Four columns were prepared and were processed in a single group. Each column system, which is mounted in a radiological fume hood, consists of a single small column containing the sorbent resin, a small metering pump, two valves, a pressure gauge, and a pressure-relief valve. The pump-inlet tube was manually switched between the waste feed and various process solutions. Both valves are three-way valves that can be turned to a flow position, a sample position, or a no-flow position. The first valve is placed at the outlet of the pump and is used to eliminate air from the system, purge the initial volume of the system, or isolate the columns from the pump. The second valve is located after the column and is used for obtaining samples.

The columns are Spectra Chrom™ chromatography columns made of glass with adjustable plungers on the bottom and the top. The inside diameter of the columns is 1.5 cm, which corresponds to a volume of 1.77 ml per cm of length. The columns are jacketed with a clear plastic to provide temperature regulation and a safety shield. Two water baths (Brinkmann and VWR International) were used to control the temperature during elution. The column connecting tubing is a polyfluorinated plastic with $^1/_8$-in. OD and $^1/_{16}$-in. ID. An Accu® piston pump (SciLog, Middleton, WI) equipped with a metering pump head (Fluid Metering, Inc. [FMI], Oyster Bay, NY) and a pump stroke-rate controller (0.025 ml/stroke) or an FMI QVG50 pump (FMI, Oyster Bay, NY) equipped with a ceramic and Kynar® coated low-flow piston pump heads were used to deliver solutions to the columns. The volume actually pumped through the system is determined using the effluent mass (including analytical samples) and the fluid density. The pressure-relief valve is set at 40 psi, which is below the maximum operating pressure for the columns.

The ground-gel RF resin performance was tested in a side-by-side comparison with the spherical RF resin. The free-flowing acid form of RF resins was sub-sampled to provide approximately 5.5 g of spherical RF resin and 5.1 g of ground-gel RF resin for each column. The actual H-form resin mass, on a dry-weight basis, loaded in the columns, was calculated according to Equation 2.2.

$$M_v = M_f * F \tag{2.2}$$

where M_v is the vacuum-dried resin mass in the resin bed, M_p is the nitrogen-dried free-flowing resin mass, and F is the water-loss factor dried at 50°C, determined from Equation 2.1. The Na mass basis was not calculated as part of this scope of work.

The resin identification and the corresponding column identification are provided in Table 2.4. The duplicate F-factors provided excellent precision, as determined from the standard deviation from the mean for each measurement.

Table 2.4. Resin Identification and Resin Mass in Column Ion Exchange Testing

Column Identification	Resin Identification	H-Form Resin Mass, g	Resin F-Factor	H- Form Resin Dry Basis Mass, g
Pink	Ground gel	5.0919	0.724 ±0.001	3.687 ±0.007
Yellow	Ground gel	5.0903	0.724 ±0.001	3.686 ±0.007
Blue	Spherical	5.5237	0.4896 ±0.0005	2.704 ±0.004
Green	Ground gel	5.0871	0.724 ±0.001	3.683 ±0.007

Before process testing, the weighed aliquot of each resin was loaded in the column and cycled through the H- and Na- resin forms. The mass of conditioned, free-flowing, RF resin transferred to each column is identified in Table 2.4. The storage water was decanted from the resin, and the resins were contacted with a 10-fold excess of 1.0 M NaOH for 2 hours. The sodium hydroxide solution was decanted, and the resin was slurried with DI water and immediately transferred to the column. The resin was rinsed with DI water and was cycled to the acid form using 0.50 M HNO_3 and back to the sodium-form using 1.0 M NaOH. The column pretreatment steps are summarized in Table 2.5 through Table 2.8.

Column processing was performed at ambient temperature for the loading, feed displacement, and water rinse. Table 2.5 through Table 2.8 show the experimental conditions for each processing step. Elution was performed either at ambient temperature or at 45°C. Ambient temperature during this run ranged from 24 to 25°C. A recirculating water bath was used to circulate heated water through the column jacket during elution to heat the resin bed to 45°C. Room-temperature 0.50 M HNO_3 was introduced into the equilibrated bed at a low flow rate (nominally 1.4 BV/h). Before performing the ion exchange column testing, a column was set up with a type-K thermocouple placed within the top ⅓ of the resin bed. The bed temperature was monitored in this column while 45°C water was cycled through the column jacket. The resin bed attained the desired temperature within 8 minutes and maintained that temperature throughout a mock elution, 45±1°C. Thus, the low flow rate provides enough time for the eluant to equilibrate without affecting the resin-bed temperature. The adjustable plungers at the top of each column were adjusted at each processing stage to minimize the volume of solution above each resin bed during processing (~2 ml).

Table 2.5. Experimental Conditions for Ground-Gel RF Resin Pink Column

Step	Reagent	Total Volume of Reagent		Flow Rate of Reagent		pH	Resin Height	Resin Volume	Volume Ratio to 1.0 M NaOH
		BV	ml	BV/h	ml/h				
Resin Pretreatment									
Water Wash	DI water	3	33	3	33		6.6	11.7	1.0
Acid Rinse	0.5 M HNO_3	6	66	3	33	--	5.0	8.8	0.76
Water Wash	DI water	6	66	3	33		5.1	9.0	0.77
Regeneration	1.0 M NaOH -1	1	16	1.5	16	2.8	5.3	9.4	0.80
	1.0 M NaOH -2	1	10	0.9	10	12.5	5.8	10.2	0.88
	1.0 M NaOH -3	1	11	1.0	11	13.1	6.1	10.8	0.92
	1.0 M NaOH -4	1	11	1.0	11	13.2	6.4	11.3	1.0
	1.0 M NaOH -5	1	11	1.0	11	13.2	6.6	11.7	1.0
	1.0 M NaOH -6	1	11	1.0	11	13.2	6.6	11.7	1.0
Ion Exchange Processing									
Load	AN-105 Simulant at 10 µg/ml ^{133}Cs	850	8,931	6	63		6.4	11.3	0.97
Feed Displacement	0.10 M NaOH	2.9	32	2.9	32	--	6.6	11.7	1.0
Water Rinse	DI water	2.6	28	2.6	28		6.5	11.5	0.98
Elute	0.5 M HNO_3, 25°C	67	741	1.4	15		4.4	7.8	0.67
Water Rinse	DI water	5.6	62	3.	37		4.9	8.7	0.74

The feed was introduced to each column from a single container shared with another column located in the same fumehood. The effluent was collected in a 4-L container that was then transferred to a 10-L container to form an effluent composite. Loading samples were collected three-daily except on weekends when the sampling frequency was reduced to twice-daily. The feed displacement and water-rinse samples were each collected as a single composite sample. During elution, individual samples were collected in either 0.5 or 1-BV increments. After collection, a 10-ml sample aliquot was sub-sampled for gamma counting.

The feed solutions were spiked with a ^{137}Cs tracer. The ^{137}Cs decay product ^{137m}Ba provides a strong gamma emission peak at 661 KeV ($t_{1/2}$ = 30 years). The $^{137}C/C_0$ ratio was determined for each loading sample by counting the gamma emission at 661 KeV with a portable gamma spectrometer equipped with a Ge flat-crystal detector. The elution samples were counted on a portable gamma spectrometer equipped with a well-type, sodium iodide detector. The loading samples were counted in a 5-ml configuration, and the elution samples were counted in a 10-ml configuration for comparative measurements (i.e., indication). The counting was performed at least 15 minutes after collecting each process sample to allow secular equilibrium to be reached. The C/C_0 ratios were determined by taking the ratio of the peak area of the original feed with the peak area of the loading or elution samples. The original feed sample was recounted periodically to determine the detector stability.

Table 2.6. Experimental Conditions for Ground-Gel RF Resin Yellow Column

Step	Reagent	Total Volume of Reagent		Flow Rate of Reagent		pH	Resin Height	Resin Volume	Volume Ratio to 1.0 M NaOH
		BV	ml	BV/h	ml/h				
Resin Pretreatment									
Water Wash	DI water	3	33	3	33	--	6.5	11.5	0.98
Acid Rinse	0.5 M HNO_3	6	66	3	33		5.2	9.2	0.79
Water Wash	DI water	6	66	3	33		5.2	9.2	0.79
Regeneration	1.0 M NaOH -1	1	15	1.4	15	2.70	5.3	9.4	0.80
	1.0 M NaOH -2	1	11	1.0	11	11.71	5.9	10.4	0.89
	1.0 M NaOH -3	1	10	0.9	10	12.89	6.3	11.1	0.95
	1.0 M NaOH -4	1	12	1.1	12	13.09	6.5	11.5	0.98
	1.0 M NaOH -5	1	11	1.0	11	13.14	6.6	11.7	1.0
	1.0 M NaOH -6	1	12	1.1	12	13.16	6.6	11.7	1.0
Ion Exchange Processing									
Load	AN-105 Simulant at 10 µg/ml ^{133}Cs	851	9,365	6	66	--	6.5	11.5	0.98
Feed Displacement	0.10 M NaOH	3.6	39	36	39		6.7	11.8	1.02
Water Rinse	DI water	3	33	3.0	33		6.6	11.7	1.0
Elute	1.5 M HNO_3, 25°C	57	630	1.2	13		5.0	8.8	0.76
Water Rinse	DI water	5	59	3	33		5.1	9.0	0.77

Table 2.7. Experimental Conditions for Spherical RF Resin Blue Column

Step	Reagent	Total Volume of Reagent		Flow Rate of Reagent		pH	Resin Height	Resin Volume	Volume Ratio to 1.0 M NaOH
		BV	ml	BV/h	ml/h				
Resin Pretreatment									
Water Wash	DI water	3	33	3	33	--	6.0	10.6	0.92
Acid Rinse	0.5 M HNO_3	6	66	3	33		5.2	9.2	0.80
Water Wash	DI water	6	66	3	33		5.1	9.0	0.78
Regeneration	1.0 M NaOH -1	1	9.8	0.9	10	3.11	5.2	9.2	0.80
	1.0 M NaOH -2	1	10.0	0.9	10	12.00	5.8	10.2	0.89
	1.0 M NaOH -3	1	10.7	1.0	11	12.96	6.2	11.0	0.95
	1.0 M NaOH -4	1	10.5	1.0	11	13.04	6.4	11.3	0.98
	1.0 M NaOH -5	1	10.6	1.0	11	13.07	6.5	11.5	1.0
	1.0 M NaOH -6	1	10.5	1.0	11	13.10	6.5	11.5	1.0
Ion Exchange Processing									
Load	AN-105 Simulant at 10 μg/ml ^{133}Cs	609	6,695	4.4	49	--	6.4	11.3	0.98
Feed Displacement	0.10 M NaOH	3.5	39	3.5	39		6.5	11.5	1.0
Water Rinse	DI water	3.4	38	3.4	38		6.3	11.1	0.97
Elute	0.5 M HNO_3, 25°C	51	560	1.4	15		5.1	9.0	0.78
Water Rinse	DI water	5.4	60	3.4	37		5.1	9.0	0.78

Table 2.8. Experimental Conditions for Ground-Gel RF Resin Green Column

Step	Reagent	Total Volume of Reagent		Flow Rate of Reagent		pH	Resin Height	Resin Volume	Volume Ratio to 1.0 M NaOH
		BV	ml	BV/h	ml/h				
Resin Pretreatment									
Water Wash	DI water	3	33	3	33	--	6.5	11.5	0.98
Acid Rinse	0.5 M HNO_3	6	66	3	33		5.3	9.4	0.80
Water Wash	DI water	6	66	3	33		5.2	9.2	0.79
Regeneration	1.0 M NaOH -1	1	13	1.2	13	3.01	5.2	9.2	0.79
	1.0 M NaOH -2	1	10	0.9	10	2.95	5.5	9.7	0.83
	1.0 M NaOH -3	1	10	0.9	10	12.55	6.0	10.6	0.91
	1.0 M NaOH -4	1	10	0.9	10	12.96	6.4	11.3	0.97
	1.0 M NaOH -5	1	10	0.9	10	13.02	6.5	11.5	0.98
	1.0 M NaOH -6	1	10	0.9	10	13.05	6.6	11.7	1.0
Ion Exchange Processing									
Load	AN-105 Simulant at 10 μg/ml ^{133}Cs	847	9,320	6.0	66	--	6.5	11.5	0.98
Feed Displacement	0.10 M NaOH	3.3	36	3.3	36		6.7	11.8	1.02
Water Rinse	DI water	3	33	3.0	33		6.6	11.7	1.0
Elute	0.5 M HNO_3, 45°C	68	744	1.4	15		4.6	8.1	0.70
Water Rinse	DI water	5	56	3.0	33		4.6	8.1	0.70

2.5 Batch-Distribution Measurement

Two types of batch-distribution measurements were performed in this testing: cesium-loading isotherms and spent-resin batch contacts. The loading-isotherm contacts were performed with conditioned RF resins in contact with AN-105 simulant with the cesium concentration ranging from 1.0E-06 M ^{133}Cs to ~1.0E-09 M ^{133}Cs. The spent-resin contacts were performed at 10 µg/ml cesium with each ion exchange-column resin after column processing was completed, as well as with non-processed, conditioned RF resin. These batch-distribution measurements were performed to determine the effect of the elution conditions on the resin performance.

All Cs batch-distribution values (K_d) were determined by measuring the relative ^{137}Cs concentration before and after the batch contact. Initial ^{133}Cs concentrations were confirmed by ICP-MS. The batch-distribution coefficient, K_d (with units of ml/g), was determined using the following relationship:

$$K_d = \frac{(C_0 - C_1)}{C_1} * \frac{V}{M * F} \qquad (2.3)$$

where

- C_0 and C_1 = the initial and final ^{137}Cs solution counts, respectively
- V = the volume of the liquid sample (ml)
- M = the mass of resin used for the contact (g)
- F = the mass of a sample of dried resin divided by its mass before drying. The resin was sampled for F-factor determination at the same time resin samples for the batch contacts were measured to minimize mass changes due to changes in atmospheric humidity.

2.5.1 Feed-Side Batch-Distribution Measurements at Low Cesium Concentrations

AN-105 simulant at low cesium concentrations was used to access the batch-distribution coefficients (K_d values) of the SL-644 resin at polish-column conditions. Four initial cesium concentrations were used for the polish-column batch contacts. The initial cesium concentrations ranged from ~1.0E-06 M Cs to ~1.0E-09 M. The AN-105 simulant was spiked with a freshly made solution of $CsNO_3$ in water, and serial dilutions were performed to produce the lower concentrated cesium solutions. Each solution was then spiked with approximately 0.05 µCi/ml ^{137}Cs tracer ($CsNO_3$ in water). The mole ratio of ^{133}Cs to ^{137}Cs was 200 to 0.2; thus, the contribution of ^{137}Cs was included in the total cesium concentration.

The cesium-removal equilibrium was assessed concurrently with the isotherm contacts using separate solutions for each sampling event. Table 2.9 shows the conditions of the equilibrium and feed-side contacts. Two initial cesium concentrations, spanning the range of the isotherm batch-contact concentrations, were used to assess time to reach equilibrium. One concentration (1.02E-06 M) was contacted with the ground-gel RF resin and the other (1.04E-09) with the spherical RF resin. Previous work with SL-644 resin indicated that the relatively small cesium concentrations did not significantly impact the equilibrium time (Burgeson et al. 2003). However, this testing was using two types of RF resin, and the impact of cesium concentration on each resin was not known. Thus, the two resins were contacted with different initial cesium concentrations to ensure that adequate contact time was provided, just in case there was a more significant impact of cesium concentration on either of the two types of resin. The batch-distribution measurements of the equilibrium and polish-column condition were performed in the manner described below.

The batch contacts were conducted at a phase ratio of approximately 100:1 (liquid volume to resin mass), using both the ground-gel and spherical RF resins that had been preconditioned and dried under nitrogen. Fifty milliliters of AN-105 simulant were contacted with 0.50 g of exchanger in a 60-ml polyethylene bottle. The exchanger mass was determined to an accuracy of ±0.0001 g. The simulant volume was determined using the solution mass and density. The headspace was purged with nitrogen, and the caps were taped shut to retard air infusion. An orbital shaker (Labline 3520) was used to provide agitation at approximately 2300 rpm. The temperature was not controlled, and it varied between 23°C and 25°C over the course of the contacts. A single solution was used for each equilibrium condition; when the appropriate time was reached, a 5-ml sample aliquot was filtered using a 0.45-μm nylon syringe filter.

Table 2.9. Feed-Side Low Cesium Concentration Batch-Contact Conditions

Solution, Container	50-ml AN-105 Simulant, 60-ml Poly Bottle		
^{133}Cs Concentration	C1=1.02E-06 C2=5.15E-07 C3=1.03E-8and C4=1.04E-09 mole/L		
Tracer	0.06 μCi/ml ^{137}Cs in Water		
Resin/Form	RF resin #3 (spherical) and #9 (ground gel), Conditioned, Acid Form		
Container	60-ml Poly Bottle		
Headspace	Backfilled with Nitrogen		
Agitation	Orbital Shaker, Samples Upright		
Sample ID	**Contact Time, Hours**	**Sample ID**	**Contact Time, Hours**
RFGG-C1-EQ 1-5	8–54	RFSP-C4-EQ 1-5	3–46
RFGG C1-A-E	54	RFSP C1-A-E	46
RFGG C2- A-E	54	RFSP C1-A-E	46
RFGG C3-A-E	54	RFSP C1-A-E	46
RFGG C4-A-E	54	RFSP C1-A-E	46

2.5.2 Spent-Resin Batch-Distribution Measurements

After completing the column elution testing, the spent resin was dried under a stream of nitrogen and contacted with AN-105 simulant prepared with 10 μg/ml cesium. An aliquot of each dried spent resin was dried under vacuum to determine the F-factor for each column resin. The AN-105 simulant was spiked with a freshly made solution of $CsNO_3$ in water. The solution was then spiked with approximately 0.05 μCi/ml ^{137}Cs tracer (CsCl in 0.1 M HCl). The spent-resin batch-distribution measurements were performed in the manner described in Section 2.5.1.

3.0 Results

This section shows the composition of the feed and the batch-distribution measurements and presents the results of the feed-loading and parametric-elution tests.

3.1 AN-105 Feed Composition

Table 3.1 shows the composition of the AN-105 tank simulant used for the batch contacts and column ion exchange. All of the analytes observed by each analytical method—ICP-AES, titration, IC anions, and TIC/TOC—are presented. The total cation normality, 5.1 N, is less than the total anion normality, 5.8 N. This difference is approximately 15 percent and is slightly outside the analytical uncertainty.

Table 3.1. Composition of AN-105 Simulant

Analyte	Analytical Result	Method	Analyte	Analytical Result	Method
Carbon Results in µg C/ml					
TIC	1310	Hot Persulfate	TOC	880	Hot Persulfate
Inorganic Analysis Results in µg/ml					
Al	18,450	ICP-AES	Mo	43	ICP-AES
B	27	ICP-AES	Na	115,500	ICP-AES
Ca	<6	ICP-AES	P	94	ICP-AES
Cr	645	ICP-AES	Pb	<2.9	ICP-AES
K	3,460	ICP-AES	Si	[120]	ICP-AES
Mg	<3	ICP-AES			
Inorganic Anion Results in µg/ml					
Cl	3,820	IC Anions	NO_3	73,800	IC Anions
F	[126]	IC Anions	PO_4	1,355	IC Anions
NO_2	53,750	IC Anions	SO_4	390	IC Anions
Physical Properties Units as Reported; M is moles/L					
Hydroxide	1.52 M	Titration	Density	1.230 g/mL	Gravimetric

[ ] Analyte was detected within 10 times the instrument detection limit, and the uncertainty is estimated to exceed ±15%.
< Indicates the analyte was not observed above the instrument detection limit.

3.2 AN-105 Column Loading

Four columns were processed with AN-105 simulant prepared at 10 µg/ml cesium. The four columns were processed simultaneously in one set and were designated by color: pink, yellow, blue, and green. The columns were loaded to >90% breakthrough, based upon ^{137}Cs counting data. The loading flow rate (BV/h) was not a parameter in this testing. The flow rate was varied to accommodate available feed volume while trying to minimize the time needed to reach >90% breakthrough. The loading data are reported in Table 3.2.

Table 3.2. Loading Data for Spherical and Ground-Gel RF Columns

Pink Column	BV	C/Co, ^{137}Cs	Yellow Column	BV	C/Co, ^{137}Cs	Blue Column	BV	C/Co, ^{137}Cs	Green Column	BV	C/Co, ^{137}Cs
P-10-RF-L01	3	0.0006	Y-10-RF-L01	4.9	0.001	B-10-RF-L01	5	0.002	G-10-RF-L01	2	0.002
P-10-RF-L02	99	0.0052	Y-10-RF-L02	107	0.005	B-10-RF-L02	88	0.027	G-10-RF-L02	105	0.006
P-10-RF-L03	126	0.014	Y-10-RF-L03	137	0.017	B-10-RF-L03	108	0.048	G-10-RF-L03	133	0.015
P-10-RF-L04	151	0.028	Y-10-RF-L04	163	0.033	B-10-RF-L04	131	0.116	G-10-RF-L04	159	0.029
P-10-RF-L05	239	0.140	Y-10-RF-L05	238	0.094	B-10-RF-L05	222	0.551	G-10-RF-L05	246	0.129
P-10-RF-L06	315	0.277	Y-10-RF-L06	304	0.210	B-10-RF-L06	317	0.856	G-10-RF-L06	323	0.266
P-10-RF-L07	380	0.402	Y-10-RF-L07	364	0.343	B-10-RF-L07	386	0.880	G-10-RF-L07	389	0.394
P-10-RF-L08	458	0.537	Y-10-RF-L08	431	0.467	B-10-RF-L08	472	0.967	G-10-RF-L08	468	0.532
P-10-RF-L09	531	0.637	Y-10-RF-L09	496	0.582	B-10-RF-L09	555	1.001	G-10-RF-L09	541	0.687
P-10-RF-L10	558	0.683	Y-10-RF-L10	536	0.721	B-10-RF-L10	583	0.969	G-10-RF-L10	568	0.708
P-10-RF-L11	586	0.753	Y-10-RF-L11	567	0.761	B-10-RF-L11	592	1.000	G-10-RF-L11	595	0.750
P-10-RF-L12	681	0.803	Y-10-RF-L12	675	0.825	B-10-RF-L12	609	0.994	G-10-RF-L12	688	0.798
P-10-RF-L13	711	0.866	Y-10-RF-L13	705	0.872				G-10-RF-L13	716	0.840
P-10-RF-L14	741	0.881	Y-10-RF-L14	738	0.899				G-10-RF-L14	744	0.863
P-10-RF-L15	822	0.920	Y-10-RF-L15	824	0.919				G-10-RF-L15	820	0.893
P-10-RF-L16	850	0.940	Y-10-RF-L16	851	0.948				G-10-RF-L16	847	0.933

Figure 3.1 shows the loading curves for each column. The load data are plotted as % C/C_o versus the BVs of processed feed. The x-axis is a linear scale, and the y-axis is a log scale. The feed was first processed through the column system until the effluent was the same color as the initial feed, bright yellow. This took approximately 3 BVs. At this point, the first sample collected was considered to be 1 BV.

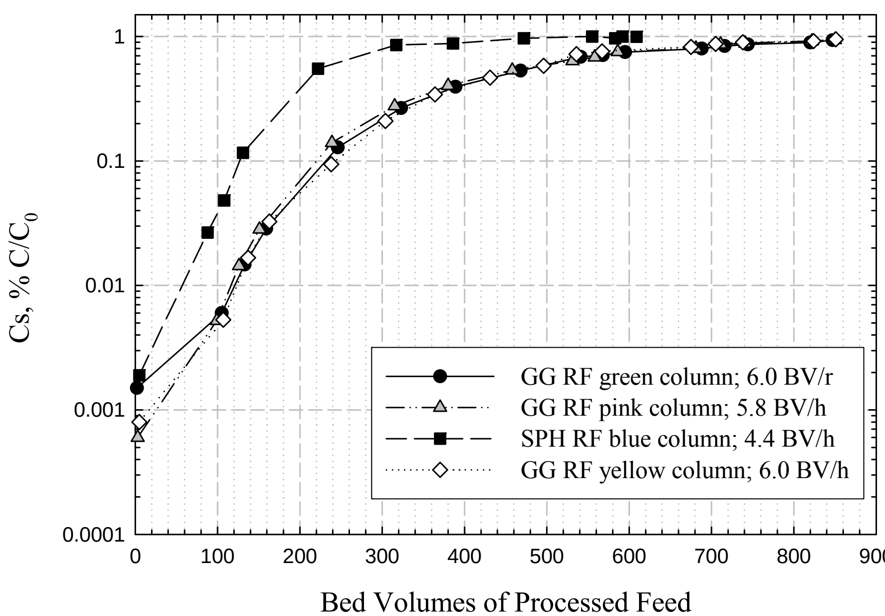

Figure 3.1. Loading Profile of Spherical and Ground-Gel RF SL-644 Resin, with 10 μg/ml AN-105 Simulant. Column diameter is 1.5 cm, and L/D is 4.

The target flow rate was 6 BV/h for all four columns to allow for a shorter loading duration; however, the attained flow rate for the blue column was significantly below 6 BV/h. The pump delivering the AN-105 simulant feed had been calibrated so the setting would deliver at the correct rate. Attempts to increase the flow rate resulted in a pressure buildup.

The amount of cesium loaded onto the resin was calculated according to Equation 3.1.

$$Cs_L = \sum_{i=0}^{i=N} \left[(1 - C/C_0)_i (C_{133})(\Delta V)_i \right] \tag{3.1}$$

where Cs_L = amount of cesium loaded onto the resin, μg
C = ^{137}Cs counts in each loading sample
C_0 = ^{137}Cs counts in the initial feed
C_{133} = initial feed ^{133}Cs concentration, μg/ml
ΔV = volume of feed processed between each sample (including sample volume), ml
N = number of samples collected during loading.

This calculation will have a significant error because it uses the summation of each loading sample count data and volume, each of which has errors associated with them. As a check of the calculated amount of cesium loaded onto the resin, the amount of cesium loaded onto the resin was calculated in a second manner using the amount of cesium processed through the column and the amount of cesium remaining in the effluent after processing. The amount of cesium processed through each column was calculated using the volume of processed feed, and the amount of cesium present in the effluent was calculated using the volume of effluent and the C/C_0 of the entire effluent composite. Equation 3.2 was applied to calculate the amount of loaded Cs in this manner.

$$Cs_R = \left[(Cs_F * V_F) - (C/C_{0Eff}) * V_{Eff} * Cs_F \right] \tag{3.2}$$

where Cs_R = amount of cesium retained by the resin, μg
Cs_F = initial feed ^{133}Cs concentration, μg/ml
V_F = volume of feed processed, ml
C/C_{0Eff} = ratio of effluent composite ^{137}Cs counts to initial feed ^{137}Cs counts
V_{Eff} = volume of effluent composite, ml.

As shown in Table 3.3, the two calculation methods yield very similar values for the amount of cesium loaded onto the resin, with the exception of the blue column, the spherical resin column. This discrepancy is likely due to taking inadequate samples during the steep-loading time period.

Table 3.3. Summary of Cesium Loading onto Spherical and Ground-Gel RF Resin

Column ID (resin type)	µg Cs Loaded on Resin per Equation 3.1	µg Cs Loaded on Resin per Equation 3.2	% Difference	Initial Mass Resin, Dry Basis	Cs loaded on Resin, mg/g Resin mg Cs
Pink, ground gel	45,620	42,230	7.4	3.6867	11.46
Yellow, ground gel	48,020	51,110	-6.4	3.6855	13.87
Blue, spherical	21,070	26,430	-25.5	2.7044	9.77
Green, ground gel	48,520	51,690	-6.5	3.6832	14.04

The data in Table 3.3 show that there was significantly less cesium loaded onto the spherical RF resin. Previous batch contact isotherm data[(a)] indicates that the spherical-resin capacity is greater than that of the ground-gel resin, especially at high cesium levels (300 µg/ml). The spherical RF resin capacity determined from the Fiskum loading curves at 50 µg/ml cesium, indicate that the spherical RF resin capacity was approximately 30% less than that of the ground-gel resin. Further, the Fiskum isotherm data indicates that the ratio between spherical RF to ground-gel RF cesium capacity decreases as the cesium concentration decreases. Thus, a 30% lower capacity at 50 µg/ml may be consistent with a 40 to 50% lower capacity at 10 µg/ml as indicated in Table 3.3.

Note that although the goal was to load each column to the same percentage of full capacity, the pink ground-gel RF column loaded less cesium than the other two ground-gel resin columns, from 5% to 17% lower, depending upon which calculated load value is used.

3.3 Column Elution

Once the column loading was completed, the feed was displaced with 3 BVs of 0.25 M NaOH, and the resin was rinsed with 3 BVs of DI water; then each column was processed for elution. Table 3.4 summarizes the elution experiments. Note that the BV of processed eluant is based upon the volume of the resin expanded in 1.0 M NaOH.

Table 3.4. Summary of Elution Experimental Conditions

Column Identification	Feed [Cs] (µg/ml)	Elution Temp (°C)	Nitric Conc. (M)	Elution Flow Rate (BV/h)	Total Elution Vol (BV)
Pink	10	25	0.50	1.4	67
Yellow	10	25	1.50	1.2	57
Blue	10	25	0.50	1.4	51
Green	10	45	0.50	1.4	68

The target elution volume was 70 BVs for the ground-gel resins and 50 BVs for the spherical resin. The flow rate for the yellow ground-gel column decreased steadily during processing, and the elution was inadvertently stopped short of the processing goal. It is readily apparent why there was a decrease in the flow rate during processing. Only 57 BVs of eluant were processed through the yellow column while the target was 70 BVs.

(a) Fiskum et al. draft report. 2003. *Comparison Testing of Multiple Resorcinol-Formaldehyde Resins for the River Protection Project—Waste Treatment Plant.* WTP-RPT-103, Rev. B, Battelle—Pacific Northwest Division, Richland, WA (see Table S4).

The elution conditions for the ground-gel resin examined the effect of temperature and eluant concentration on the elution of cesium from the resin. Figure 3.2 shows the ground-gel elution curves, and the corresponding elution data are presented in
Table 3.5.

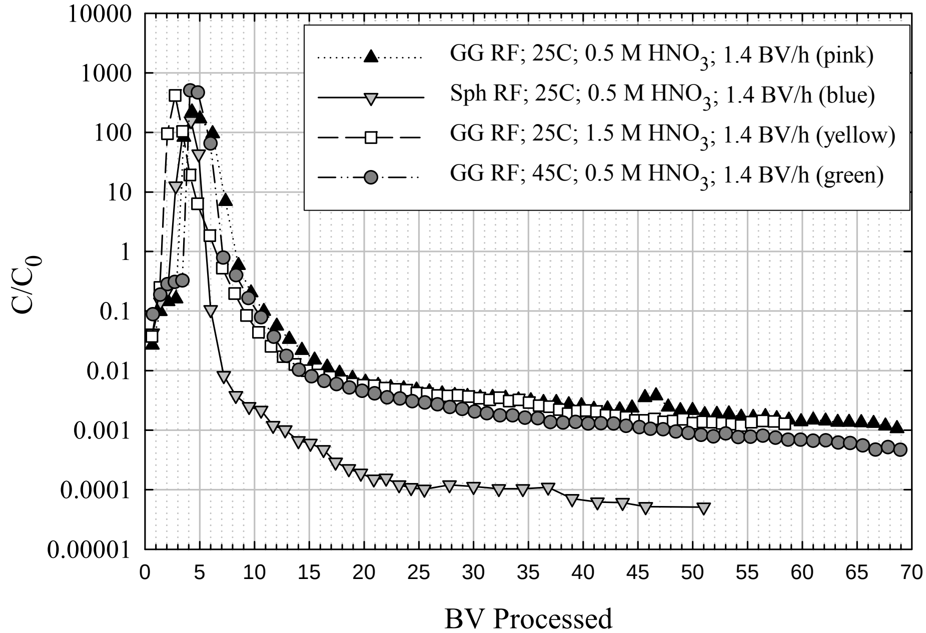

Figure 3.2. Elution Profile of Ground-Gel RF Resin as Temperature and Eluant Concentration Are Varied

Table 3.5. Elution Data for Ground-Gel Resin Loaded with 10 μg/ml Cesium in AN-105 Simulant

Sample	#BV Processed	C/Co	Sample	#BV Processed	C/Co	Sample	#BV Processed	C/Co
P-10-RF-E01	0.7	2.65E-02	Y-10-RF-E01	1.2	3.69E-02	G-10-RF-E01	0.7	8.71E-02
P-10-RF-E02	1.4	9.75E-02	Y-10-RF-E02	2.4	2.46E-01	G-10-RF-E02	1.4	1.85E-01
P-10-RF-E03	2.1	1.43E-01	Y-10-RF-E03	3.7	9.42E+01	G-10-RF-E03	2.0	2.79E-01
P-10-RF-E04	2.8	1.59E-01	Y-10-RF-E04	5.0	4.11E+02	G-10-RF-E04	2.7	3.03E-01
P-10-RF-E05	3.5	8.18E+01	Y-10-RF-E05	6.2	1.03E+02	G-10-RF-E05	3.4	3.21E-01
P-10-RF-E06	4.2	2.19E+02	Y-10-RF-E06	7.5	1.91E+01	G-10-RF-E06	4.0	5.01E+02
P-10-RF-E07	4.9	1.67E+02	Y-10-RF-E07	8.7	6.28E+00	G-10-RF-E07	4.7	4.59E+02
P-10-RF-E08	6.1	9.41E+01	Y-10-RF-E08	10	1.82E+00	G-10-RF-E08	5.9	6.41E+01
P-10-RF-E09	7.2	6.87E+00	Y-10-RF-E09	12	5.20E-01	G-10-RF-E09	7.0	7.79E-01
P-10-RF-E10	8.4	5.76E-01	Y-10-RF-E10	14	1.94E-01	G-10-RF-E10	8.2	3.93E-01
P-10-RF-E11	9.5	2.01E-01	Y-10-RF-E11	15	8.35E-02	G-10-RF-E11	9.3	1.63E-01
P-10-RF-E12	11	9.78E-02	Y-10-RF-E12	17	4.33E-02	G-10-RF-E12	10	7.75E-02
P-10-RF-E13	12	5.53E-02	Y-10-RF-E13	19	2.52E-02	G-10-RF-E13	12	3.63E-02
P-10-RF-E14	13	3.32E-02	Y-10-RF-E14	20	1.68E-02	G-10-RF-E14	13	1.73E-02
P-10-RF-E15	14	2.17E-02	Y-10-RF-E15	22	1.26E-02	G-10-RF-E15	14	1.02E-02
P-10-RF-E16	15	1.50E-02	Y-10-RF-E16	24	9.90E-03	G-10-RF-E16	15	7.89E-03
P-10-RF-E17	16	1.13E-02	Y-10-RF-E17	25	8.35E-03	G-10-RF-E17	16	6.62E-03
P-10-RF-E18	17	8.97E-03	Y-10-RF-E18	27	7.65E-03	G-10-RF-E18	17	5.85E-03
P-10-RF-E19	19	7.35E-03	Y-10-RF-E19	28	6.50E-03	G-10-RF-E19	18	5.13E-03

Table 3.5 (Contd)

Sample	#BV Processed	C/Co	Sample	#BV Processed	C/Co	Sample	#BV Processed	C/Co
P-10-RF-E20	20	6.31E-03	Y-10-RF-E20	30	5.91E-03	G-10-RF-E20	19	4.52E-03
P-10-RF-E21	21	5.61E-03	Y-10-RF-E21	31	5.64E-03	G-10-RF-E21	21	4.08E-03
P-10-RF-E22	22	5.13E-03	Y-10-RF-E22	33	5.51E-03	G-10-RF-E22	22	3.49E-03
P-10-RF-E23	23	4.94E-03	Y-10-RF-E23	34	5.06E-03	G-10-RF-E23	23	3.36E-03
P-10-RF-E24	24	4.68E-03	Y-10-RF-E24	36	4.79E-03	G-10-RF-E24	24	3.02E-03
P-10-RF-E25	25	4.37E-03	Y-10-RF-E25	37	4.63E-03	G-10-RF-E25	25	2.87E-03
P-10-RF-E26	27	4.05E-03	Y-10-RF-E26	39	4.16E-03	G-10-RF-E26	26	2.67E-03
P-10-RF-E27	28	3.81E-03	Y-10-RF-E27	40	4.04E-03	G-10-RF-E27	27	2.40E-03
P-10-RF-E28	29	3.65E-03	Y-10-RF-E28	42	3.78E-03	G-10-RF-E28	28	2.23E-03
P-10-RF-E29	30	3.48E-03	Y-10-RF-E29	43	3.71E-03	G-10-RF-E29	30	2.03E-03
P-10-RF-E30	31	3.52E-03	Y-10-RF-E30	45	3.80E-03	G-10-RF-E30	31	1.90E-03
P-10-RF-E31	32	3.42E-03	Y-10-RF-E31	46	3.63E-03	G-10-RF-E31	32	1.75E-03
P-10-RF-E32	33	3.19E-03	Y-10-RF-E32	47	3.41E-03	G-10-RF-E32	33	1.75E-03
P-10-RF-E33	35	3.10E-03	Y-10-RF-E33	49	3.18E-03	G-10-RF-E33	34	1.60E-03
P-10-RF-E34	36	2.88E-03	Y-10-RF-E34	50	3.46E-03	G-10-RF-E34	35	1.56E-03
P-10-RF-E35	37	2.91E-03	Y-10-RF-E35	52	3.05E-03	G-10-RF-E35	36	1.34E-03
P-10-RF-E36	38	2.66E-03	Y-10-RF-E36	53	3.18E-03	G-10-RF-E36	37	1.33E-03
P-10-RF-E37	39	2.56E-03	Y-10-RF-E37	54	2.87E-03	G-10-RF-E37	39	1.35E-03
P-10-RF-E38	40	2.24E-03	Y-10-RF-E38	56	2.55E-03	G-10-RF-E38	40	1.27E-03
P-10-RF-E39	41	2.26E-03	Y-10-RF-E39	57	2.46E-03	G-10-RF-E39	41	1.28E-03
P-10-RF-E40	43	2.17E-03	Y-10-RF-E40	59	2.20E-03	G-10-RF-E40	42	1.28E-03
P-10-RF-E41	44	2.35E-03	Y-10-RF-E41	60	1.88E-03	G-10-RF-E41	43	1.16E-03
P-10-RF-E42	45	3.50E-03	Y-10-RF-E42	61	2.06E-03	G-10-RF-E42	44	1.10E-03
P-10-RF-E43	46	3.74E-03	Y-10-RF-E43	62	2.12E-03	G-10-RF-E43	45	1.03E-03
P-10-RF-E44	47	2.43E-03	Y-10-RF-E44	64	2.03E-03	G-10-RF-E44	46	1.02E-03
P-10-RF-E45	48	2.12E-03	Y-10-RF-E45	65	1.76E-03	G-10-RF-E45	48	9.33E-04
P-10-RF-E46	49	2.13E-03	Y-10-RF-E46	67	1.73E-03	G-10-RF-E46	49	8.85E-04
P-10-RF-E47	50	1.82E-03	Y-10-RF-E47	68	1.62E-03	G-10-RF-E47	50	8.24E-04
P-10-RF-E48	51	1.84E-03	Y-10-RF-E48	70	1.45E-03	G-10-RF-E48	51	7.75E-04
P-10-RF-E49	52	1.87E-03	Y-10-RF-E49	71	1.44E-03	G-10-RF-E49	52	8.69E-04
P-10-RF-E50	53	1.64E-03	Y-10-RF-E50	73	1.53E-03	G-10-RF-E50	53	7.52E-04
P-10-RF-E51	54	1.62E-03	Y-10-RF-E51	74	1.36E-03	G-10-RF-E51	54	7.64E-04
P-10-RF-E52	56	1.68E-03	Y-10-RF-E52	76	1.40E-03	G-10-RF-E52	55	7.96E-04
P-10-RF-E53	57	1.55E-03	Y-10-RF-E53	77	1.50E-03	G-10-RF-E53	57	7.37E-04
P-10-RF-E54	58	1.47E-03	Y-10-RF-E54	79	1.29E-03	G-10-RF-E54	58	6.82E-04
P-10-RF-E55	59	1.37E-03	Y-10-RF-E55	80	1.37E-03	G-10-RF-E55	59	6.82E-04
P-10-RF-E56	60	1.48E-03	Y-10-RF-E56	81	1.34E-03	G-10-RF-E56	60	6.54E-04
P-10-RF-E57	61	1.41E-03	Y-10-RF-E57	83	1.29E-03	G-10-RF-E57	61	6.66E-04
P-10-RF-E58	62	1.34E-03	Y-10-RF-E58	84	1.25E-03	G-10-RF-E58	62	6.10E-04
P-10-RF-E59	63	1.35E-03	Y-10-RF-E59	86	1.19E-03	G-10-RF-E59	63	6.01E-04
P-10-RF-E60	64	1.32E-03	Y-10-RF-E60	87	1.34E-03	G-10-RF-E60	64	5.47E-04
P-10-RF-E61	65	1.28E-03	Y-10-RF-E61	88	1.41E-03	G-10-RF-E61	65	4.66E-04
P-10-RF-E62	66	1.16E-03	Y-10-RF-E62	90	1.38E-03	G-10-RF-E62	67	5.11E-04
P-10-RF-E63	67	1.06E-03	Y-10-RF-E63	91	1.26E-03	G-10-RF-E63	68	4.62E-04

The data from the pink column (25°C, 0.50 M HNO_3) and the yellow column (25°C, 1.50 M HNO_3) can be compared to examine the effect of increasing the eluant concentration. The elution concentration peaks more quickly at the higher eluant concentration. After peaking, the cesium concentration drops more rapidly at the higher acid concentration until approximately 22 BVs where both the 1.5 M and 0.5 M HNO_3 elution curves begin to merge. Previous work by Burgeson et al. (2003) reports a similar observation for PNWD testing of SL-644 resin: the major impact of increasing of HNO_3 concentration was on the shape and location of the elution peak. The impact of nitric acid concentration on the cesium elution is negligible after processing approximately 22 BVs of eluant. The higher nitric acid concentration results in an initial increase in the rate at which the cesium is eluted from the column, but the tailing of the elution curve at the higher acid concentration is more flat than that of a lower acid concentration elution curve. Thus, although the elution may peak more quickly at higher acid concentration, it does not necessarily translate into a more complete elution.

The data from the pink column (25ºC, 0.50 M HNO_3) and the green column (45ºC, 0.50 M HNO_3) can be compared to examine the impact of increasing the elution temperature. There is a sharpening of the elution peak at higher temperature, but the location of the elution peak is not affected by the increase in temperature. The cesium is eluted from the resin more quickly at the higher temperature, and this effect is continued throughout the elution, resulting in an increase in the amount of cesium eluted from the resin. Additionally, the better elution performance provides a decrease in the amount of eluant needed to reach a set elution goal.

The spherical resin (blue column) was eluted with 0.50 M HNO_3 at 25ºC and 1.4 BV/h. The goal of the spherical-resin testing was to confirm the elution performance with that observed by Fiskum et al. (2003), which also demonstrated far better elutability than the ground-gel RF resin. Figure 3.3 compares the elution profile from this work to that obtained by Fiskum and coworkers. The elution data are shown in Table 3.6. This work confirmed the excellent elution profile for the spherical RF resin. Indeed, the performance obtained in this work was even better than that reported by Fiskum and coworkers.

The elution reported in Fiskum et al. (2003) demonstrates a broader peak than the spherical-resin elution curve (blue column) from this testing. The Fiskum column was loaded using 50 µg/ml AZ-102 simulant, which processed ~146 mg of cesium compared to the loading from this testing, which used 10 µg/ml AN-105 simulant and processed ~67 mg of cesium. The Fiskum resin was loaded with ~132 mg Cs, which correlates to ~26.4 mg Cs/g dried H-from resin. This is approximately three-times that loaded on the blue column (9.8 mg Cs/g dried H-form resin). Thus, the broader elution curve and the higher tailing concentration are likely a result of the higher concentration of cesium present on the column during elution.

The spherical RF resin demonstrates excellent elution of cesium, resulting in eluate solutions that have C/C_0 values that are at least an order of magnitude below those of the ground-gel RF resins (starting from 7 BVs and continuing throughout elution). The elution of the spherical resin reaches C/C_0 <1% within 14 BVs.

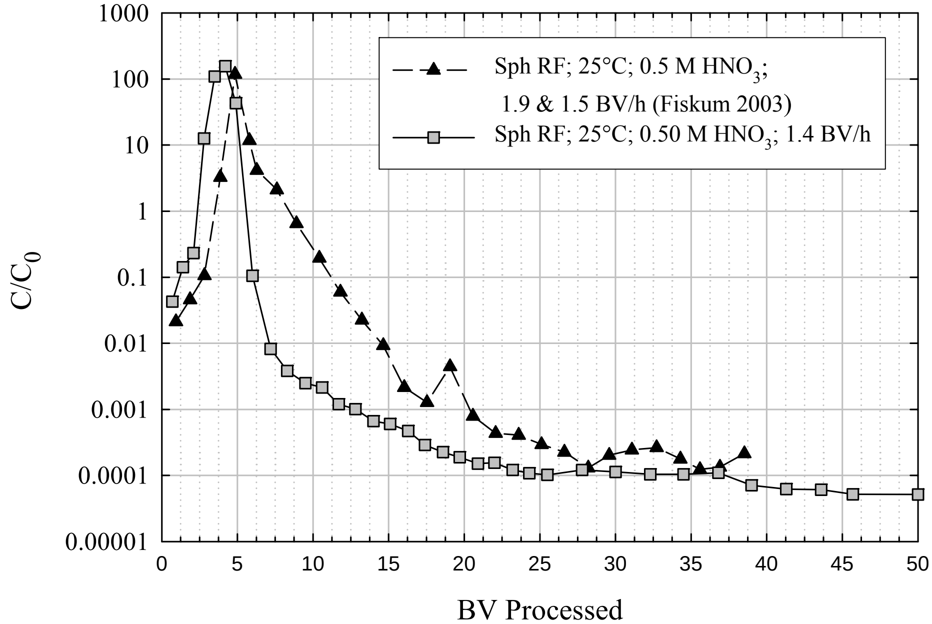

Figure 3.3. Elution Profile of Spherical RF Resin from this Testing Compared with the Elution Profile from Fiskum et al. (2003)

Table 3.6. Elution Data for Spherical Resin Loaded with 10 µg/ml Cesium in AN-105 Simulant and from Fiskum et al. 2003

Sample	#CV Processed	C/Co	Sample	#CV Processed	C/Co
B-10-RF-E01	0.7	0.043	Cycle 1-1	0.94	2.13E-02
B-10-RF-E02	1.4	0.142	Cycle 1-2	1.9	4.57E-02
B-10-RF-E03	2.1	0.232	Cycle 1-3	2.8	1.06E-01
B-10-RF-E04	2.8	12.58	Cycle 1-4	3.9	3.25E+00
B-10-RF-E05	3.5	109.08	Cycle 1-5	4.8	1.18E+02
B-10-RF-E06	4.2	156.36	Cycle 1-6	5.8	1.18E+01
B-10-RF-E07	4.9	43.14	Cycle 1-7	6.3	4.16E+00
B-10-RF-E08	6.0	0.105	Cycle 1-8	7.6	2.11E+00
B-10-RF-E09	7.2	8.24E-03	Cycle 1-9	8.9	6.49E-01
B-10-RF-E10	8.3	3.82E-03	Cycle 1-10	10	1.94E-01
B-10-RF-E11	9.5	2.49E-03	Cycle 1-11	12	5.97E-02
B-10-RF-E12	11	2.15E-03	Cycle 1-12	13	2.25E-02
B-10-RF-E13	12	1.20E-03	Cycle 1-13	15	9.24E-03
B-10-RF-E14	13	1.01E-03	Cycle 1-14	16	2.15E-03
B-10-RF-E15	14	6.65E-04	Cycle 1-15	18	1.27E-03
B-10-RF-E16	15	6.01E-04	Cycle 1-16	19	4.42E-03
B-10-RF-E17	16	4.71E-04	Cycle 1-17	21	7.90E-04
B-10-RF-E18	17	2.89E-04	Cycle 1-18	22	4.32E-04
B-10-RF-E19	19	2.25E-04	Cycle 1-19	24	4.07E-04
B-10-RF-E20	20	1.89E-04	Cycle 1-20	25	2.94E-04
B-10-RF-E21	21	1.51E-04	Cycle 1-21	27	2.25E-04
B-10-RF-E22	22	1.56E-04	Cycle 1-22	28	1.30E-04
B-10-RF-E23	23	1.21E-04	Cycle 1-23	30	2.02E-04
B-10-RF-E24	24	1.08E-04	Cycle 1-24	31	2.43E-04
B-10-RF-E25	25	8.53E-06	Cycle 1-25	33	2.64E-04
B-10-RF-E26	27	7.59E-05	Cycle 1-26	34	1.77E-04
B-10-RF-E27	28	6.41E-06	Cycle 1-27	36	1.23E-04
B-10-RF-E28	29	--	Cycle 1-28	37	1.34E-04
B-10-RF-E29	30	6.02E-06	Cycle 1-29	39	2.13E-04
B-10-RF-E30	31	--			
B-10-RF-E31	32	5.54E-06			
B-10-RF-E32	33	--			
B-10-RF-E33	35	5.53E-06			
B-10-RF-E34	36	--			
B-10-RF-E35	37	5.83E-06			
B-10-RF-E36	38	--			
B-10-RF-E37	39	3.75E-06			
B-10-RF-E38	40	--			
B-10-RF-E39	41	3.30E-06			
B-10-RF-E40	42	--			
B-10-RF-E41	44	3.23E-06			
B-10-RF-E42	45	--			
B-10-RF-E43	46	2.74E-06			
B-10-RF-E44	47	--			
B-10-RF-E45	48	--			
B-10-RF-E46	49	--			
B-10-RF-E47	50	2.59E-04			
B-10-RF-E48	51	1.25E-04			

-- indicates no data

3.4 System Recovery

The system recovery was determined for the loading and elution of each column. The data are shown in Table 3.7. The amount of cesium loaded onto the resin was calculated from the individual sample counting data as well as by the difference from the amount of feed processed and the amount of cesium remaining in the effluent composite. Both calculated values are presented in Table 3.3. The two calculation methods yielded similar values for the amount of cesium loaded onto the resin; the value determined using Equation 3.2 is reported in Table 3.7, since it represents the data with the least amount of experimental error.

The effluent composites were counted for ^{137}Cs, and the total ^{133}Cs eluted from each column was calculated from Equation 3.3.

$$Cs_{Elut} = (C/C_0) * (C_{133}) * (V) \tag{3.3}$$

where
Cs_{Elut} = total amount of cesium eluted from column, µg
C = ^{137}Cs counts in the eluate composite
C_0 = ^{137}Cs counts in the initial feed
C_{133} = initial feed ^{133}Cs concentration, µg/ml
V = volume of eluate composite, ml.

Table 3.7. Loading and Elution System Recovery

Column ID (resin)	µg Cs Loaded onto Column[(a)]	µg Cs Eluted from Column[(b)]	Recovery %
Pink, ground gel	42,200	51,300	121
Yellow, ground gel	51,100	50,300	98
Blue, spherical	26,400	22,700	86
Green, ground gel	51,700	49,100	95

(a) Determined from Equation 3.2 using effluent composite data.
(b) Determined from Equation 3.3 using eluate composite data.

The recovery represents the ratio of the amount of cesium loaded onto the resin versus the amount eluted from the resin. A recovery greater than 100% indicates that more cesium was eluted from the column than loaded. The system recovery of the pink ground-gel column results in ostensibly more cesium being eluted from the column than loaded onto the column, indicating that there is some uncertainty in the calculated amount of cesium loaded and eluted from the columns. These uncertainties give a good indication of the overall uncertainties in the experimental results. This testing is attempting to examine the impact of temperature and nitric acid concentration on the elution of cesium where the differences in the eluted cesium concentrations are sometimes very slight. This should be taken into consideration when drawing conclusions about the impact of the elution conditions on the elution of cesium from the RF ground-gel and spherical resins.

3.5 Resin Mass Change

After elution, each column resin was rinsed with 3 BVs of DI water. The resin was removed from the column and dried under nitrogen at ambient temperature until free-flowing. The resin was weighed, and an F-factor was measured for each resin. The mass change observed during the single load-elute cycle is reported in Table 3.8.

Table 3.8. Resin Mass Changes During Processing of RF Resin Through a Single Load and Elution Cycle. A negative mass change represents a mass loss.

Column Identification	Initial Resin Mass[(a)] (g)	Final Resin Mass[(a)] (g)	% Mass Change (g)	Feed [Cs] (μg/ml)	Elution Temp (°C)	Nitric Conc. (M)	Elution Flow Rate (BV/h)
Run 1 pink	3.6867	3.1664	-14	10	25	0.50	1.4
Run 1 yellow	3.6855	3.2113	-13	10	25	1.5	1.2
Run 1 blue	2.7044	2.7117	0	10	25	0.50	1.4
Run 1 green	3.6832	3.3267	-10	10	45	0.50	1.4

(a) Resin mass is in H-form, dried under nitrogen and corrected for F-factor.

The data indicate that approximately 10% of the ground-gel RF resin was lost during processing, while essentially none of the spherical resin was lost during processing.

3.6 Residual Cesium on Resin

The resins recovered from the columns were analyzed for ^{137}Cs by GEA. The ^{137}Cs was introduced as a tracer for ^{133}Cs; thus, a sample of the initial feed control was also submitted for analysis. The spent-resin ^{133}Cs concentration (μg ^{133}Cs/g dry spent resin) was determined from Equation 3.4.

$$R_{Cs} = \left[(A/A_0)\times\left(C_F * 2ml\right)\right]/(M * F) \tag{3.4}$$

where
R_{Cs} = spent resin residual cesium concentration, μg Cs/g vacuum-dried resin
A = ^{137}Cs activity on entire spent resin sample, μCi ^{137}Cs in sample
A_0 = ^{137}Cs activity in 2 ml of initial feed, μCi ^{137}Cs in solution
C_F = ^{133}Cs concentration in initial feed, μg/ml
M = mass of spent resin, g
F = spent resin F-factor (g dry resin/g free-flowing mass).

Table 3.9 reports the spent resin ^{133}Cs concentration for each column. The spherical resin testing results from Fiskum et al. (2003) are also shown in the table.

Table 3.9. RF Spent Resin Residual Cesium Concentration

Column ID	μg ^{133}Cs/g Spent Resin[(a)]	Elution Conditions Temp, °C	[HNO_3], M	Flow Rate, BV/h	BV Processed
Run 1 Pink , 10 μg/ml Cs in AN-105	3.16	25	0.50	1.4	67
Run 1 Yellow, 10 μg/ml Cs in AN-105	2.99	25	1.5	1.2	57
Run 1 Blue, 10 μg/ml Cs in AN-105	0.15	25	0.50	1.4	51
Run 1 Green, 10 μg/ml Cs in AN-105	1.35	45	0.50	1.4	68
Fiskum, 50 μg/ml Cs in AZ-102[(b)]	0.34	25	0.50	1.4/1.5	39

(a) Spent resin mass, H-form, dry-weight basis (applied F-factor of 1.0, 1.0, 0.98 and 0.92, respectively).
(b) Fiskum et al. (2003).

The spent resin ^{133}Cs content correlates directly with the elution graphs; the lower the solution C/C_0 ratio during elution, the lower the measured, spent-resin, residual ^{133}Cs concentration. Here, one can draw unambiguous conclusions on the impact of elution conditions on the final spent-resin cesium concentration. Changing the acid concentration from 0.50 M to 1.50 M HNO_3 does not significantly impact the final ground-gel resin cesium concentration (3.16 µg/g versus 2.99 µg/g, 5% decrease). Changing the elution temperature from 25ºC to 45ºC has a significant impact on the residual cesium; the concentration changes from 3.16 µg/g to 1.35 µg/g, a 60% decrease. The data also clearly indicate that the spherical RF resin can be eluted far more readily than the ground-gel RF resin.

The WTP design basis for spent resin is 60 µCi/g resin[(a)] based upon data from Arm et al. (2003). This value is based upon the air-dried, H-form SL-644 resin. This value, based on processing with SL-644 resin with a bulk density of 0.66 g/ml, corresponds to a ^{137}Cs concentration per unit volume basis of 40 µCi/ml. This volume-basis activity limit is the primary driver for WTP spent resin handling. In conjunction with the ^{137}Cs isotopic fraction, this volume-basis limit can be used to determine allowable total Cs concentrations on the spent resins (mass basis). The Envelope A tank wastes, represented by AN-105 simulant, contain nominally 25% ^{137}Cs. The total residual Cs concentration limits for the RF resins after processing Envelope A tank wastes can be calculated according to Equation 3.5.

$$C = \frac{L_m}{\delta * B * SpA} \tag{3.5}$$

where C = total cesium concentration limit, µg/g H-form
L_m = ^{137}Cs concentration limit, 40 µCi/ml H-form resin
δ = bulk dry resin density (g/ml H-form resin, Fiskum et al 2003)[b]
B = ^{137}Cs isotopic fraction (0.25 µg ^{137}Cs/ µg Cs)
SpA = specific activity of ^{137}Cs (86.8 µCi/µg ^{137}Cs).

a Meeting minutes prepared by John Olson for Bechtel National, Inc., CCN 055152. April 24, 2003. "Determine the Baseline Spent Resin Cesium Concentration." Richland, WA.

b Spent resin bulk density values were not available. As-received bulk density values were used as a rough estimate of the spent resin bulk density

After processing Envelope A tank waste, the mass-basis limit for total Cs on spent SL-644 is calculated to be 2.8 μg/g. The corresponding limit for spherical RF Resin is 4.2 μg/g and for ground-gel RF Resin it is 2.4 μg/g. The comparisons are on an equal curie per unit volume basis.

To ensure that the residual cesium is always below the design specification, a value equal to one-half of the design basis has been selected for comparison with the measured spent-resin residual cesium. The resin residual cesium concentrations at one-half the design basis are 2.1 μg Cs/g resin for spherical RF resin and 1.2 μg Cs/g resin for ground-gel RF resin. As can be seen from Table 3.9, only the spherical RF resin elution provided residual cesium concentration that would meet one-half of the WTP design basis. The RF ground-gel elution performed at 45°C using 68 BV of 0.50 M HNO_3 provided a residual cesium concentration that was at 56% of the design basis limit.

3.7 Residual Cesium on Resin During Elution

The spent-resin ^{133}Cs concentration was used in conjunction with each elution solution C/C_0 value to determine the amount of ^{133}Cs present on the resin during elution. The data are reported as μg cesium per g of dry spent resin (H-form). Figure 3.4 shows the residual ^{133}Cs on the resin during elution for each of the four columns processed. The data and the calculation are shown in the appendices. These plots more readily show the impact of changing temperature and eluant concentration on the resin residual cesium concentration. The information in Figure 3.4 can be used to determine the concentration of cesium remaining on the resin at any point during elution as well as to determine the impact of the elution parameters on elution of cesium from the resin.

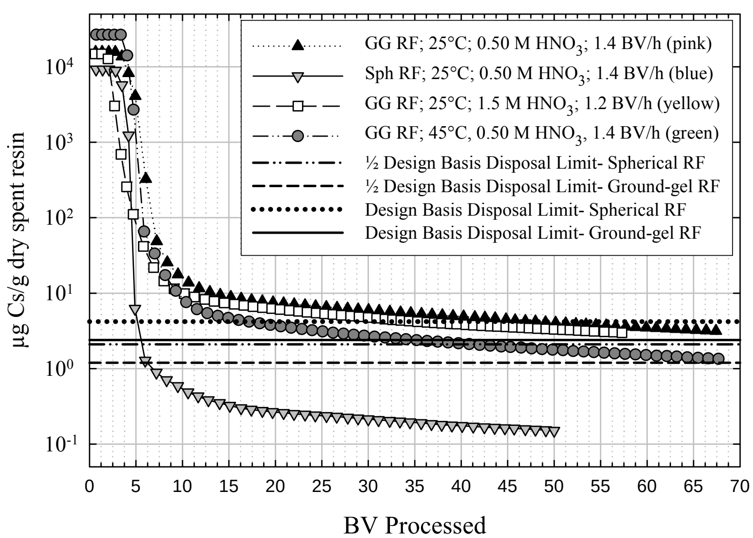

Figure 3.4. Residual Cesium on RF Resin for Columns Loaded with 10 μg/ml Cs in AN-105 Simulant

The data presented in Figure 3.4 demonstrate the impact of changing acid concentration and elution temperature on the elution of cesium. The trends are the same as discussed in Section 3.3. The increase in eluant concentration from 0.50 M to 1.5 M HNO_3 (pink and yellow columns, respectively) results in slightly more cesium being eluted from the resin and also results in an initially sharper elution of cesium. Increasing the temperature from 25ºC to 45ºC (pink and green columns, respectively) results in the greatest amount of cesium being eluted from the resin. The increased temperature also results in a much sharper initial elution of cesium, providing the overall lowest amount of residual cesium throughout the entire elution. These results suggest that low acid concentration and high elution temperatures would provide the best overall resin-elution conditions, based upon the range of conditions examined in this testing.

The spent-resin concentration required to meet one-half of the WTP design basis for spent-resin disposal (identified in Section 3.6) is shown in Figure 3.4; the ground-gel resin value is shown as a bold dashed line, and the spherical resin value is shown as a bold dash-dot line. The WTP design basis value for both resins is also shown: the ground-gel resin is shown as a bold line, and the spherical is shown as a bold dotted line. Figure 3.4 indicates that the spherical RF resin would meet one-half the WTP design basis for resin disposal after processing 5 BVs of eluant. After processing for 68 BV, the ground-gel elution performed at 45°C using 0.50 M HNO_3 (green column) was at 56% of the design basis limit, just exceeding the 50% value. The other two ground-gel elution conditions did not result in a spent-resin residual cesium concentration that would meet one-half of the WTP design basis for resin disposal. When compared against the full WTP design-basis value for resin disposal, the spherical resin meets the value within 5 BV of processed eluant. The ground-gel elution condition performed at 45°C using 0.50 M HNO_3 (green column) meets the value after 20 BV of processed eluant. The other two ground-gel elution conditions did not meet the specified value after ≥58 BVs of processed eluant.

3.8 Batch Distribution

This section reports the batch-distribution measurement with ground-gel and spherical RF preconditioned resins under polish-column conditions and with spent resin. Simultaneously, batch contacts were performed to determine the equilibrium time under the polish-column conditions

3.8.1 Equilibrium Evaluation at Low Initial Cesium-Feed Concentration

The equilibrium contact time for the ground-gel and spherical RF resins was evaluated for the low initial cesium feed concentration, i.e., polish-column conditions. Each resin was evaluated at a different initial cesium concentration; the two concentrations bracket the concentration range of interest. Five separate contacts were performed with each solution to allow a total of five equilibrium samples. Each solution was sub-sampled only once, with the exception of one equilibrium contact, which was sampled in duplicate. Table 3.10 shows the results of the low cesium equilibrium batch contacts.

Table 3.10. Equilibrium Batch-Distribution Values at Low Cesium Concentrations

Ground-Gel RF Resin Initial Cesium Concentration 1E-06 mole/L			Spherical RF Resin Initial Cesium Concentration 1E-09 mole/L		
Contact Time, h	K_d, ml/g	Final Solution Cs Molarity	Contact Time, h	K_d, ml/g	Final Solution Cs Molarity
8.2	2260	7.9E-08	3.2	890	2.0E-10
24	3970	4.7E-08	19	2050	1.0E-10
30	4370	4.2E-08	25	1960	1.1E-10
48	4950	3.7E-08	43	1760	1.2E-10
48 dup	4770	3.9E-08	43 dup	1810	1.2E-10
53	5990	3.1E-08	46	1720	1.2E-10

The data in Table 3.10 are plotted in Figure 3.5. After determining that the batch-contact values for the ground-gel resin were leveling off (48 hours), the loading isotherm and spent-resin batch contacts were permitted to continue for an additional 5 hours and then removed (53 hours). The delay in removing the batch contacts was caused by a technical delay in measuring the 43-hour sample aliquot. Note that the equilibrium sample collected at 53 hours shows a large increase in the cesium uptake, indicating that equilibrium may not have been reached. This seems unlikely since previous testing by Fiskum et al. (2003) showed that the ground-gel RF resin came to equilibration after 10 hours. The initial cesium concentrations were much higher in that testing, but lower cesium concentrations have been shown to equilibrate faster than the higher ones in previous testing with SL-644 resin (Burgeson et al. 2003). The spherical RF resin was clearly equilibrated after 43 hours, and the loading isotherm and spent-resin batch contacts were removed after 46 hours. Again, this delay was caused by unavoidable delays in analyzing the 43-hour sample aliquot.

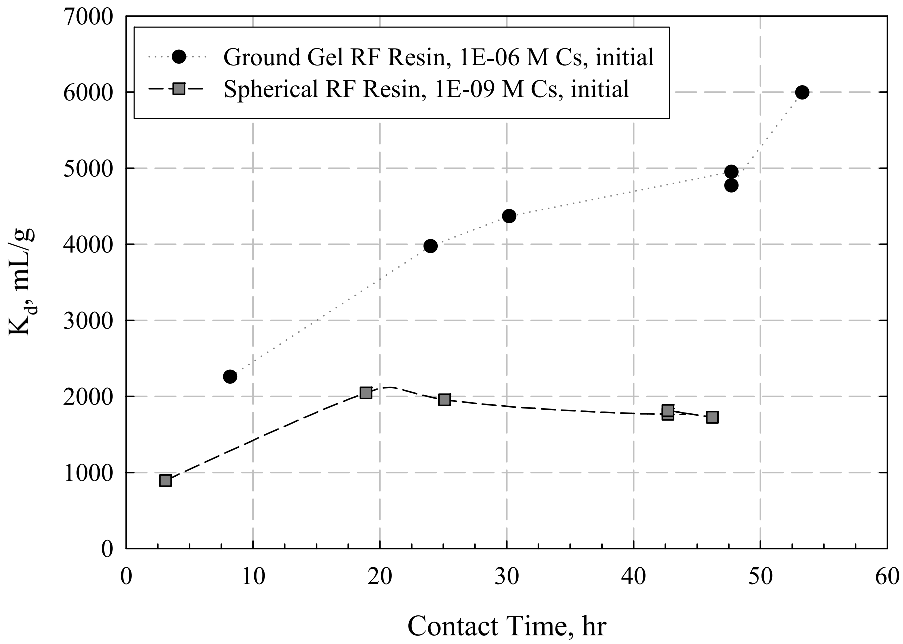

Figure 3.5. Low Cesium Equilibrium Determination

3.8.2 Batch-Distribution Isotherms

The loading behavior of ground-gel and spherical RF resin was assessed at low cesium concentrations in AN-105 simulant. The low concentrations of cesium were prepared by serial dilution, and the feed ^{133}Cs concentrations were verified by ICP-MS analysis. Cesium-137 was added as a tracer. The mole ratio of ^{133}Cs to ^{137}Cs ranged from 200 to 0.2. Thus, the contribution of ^{137}Cs was included in the calculations. Note that the lowest two batch-contact concentration targets were slightly exceeded once the contribution of ^{137}Cs was factored into the total cesium concentration. The K_d values were calculated using Equation 2.1. The spherical and ground-gel contact results are shown in Table 3.11 and Table 3.12, respectively. The final solution cesium concentration was determined according to Equation 3.2, and the resin cesium concentration was calculated from Equation 3.6.

$$R_{Cs} = \frac{\left[(Cs_{133}) - (C/C_0)_{final} * V_{sol} * Cs_{133}\right]}{M * F} \quad (3.6)$$

where R_{Cs} = total cesium concentration remaining on the resin, µmol/g
Cs_{133} = initial feed ^{133}Cs concentration, µmol/ml
V_{sol} = batch-contact volume, ml
$C/C_{0\,final}$ = ratio of final contact solution's ^{137}Cs counts to the initial solution's ^{137}Cs counts
M = mass of "air-dried"resin, g
F = mass of a sample of dried resin divided by its mass before drying.

Table 3.11. Ground-Gel RF Batch-Contact Results with Low Cesium Concentrations in AN-105 Simulant

Sample ID[(a)]	K_d, ml/g	Equilibrium Cesium Concentration		Sample ID[(a)]	K_d, ml/g	Equilibrium Cesium Concentration	
		Final Solution, M	Mole[(b)] Cs/g Resin			Final Solution, M	Mole[(b)] Cs/g Resin
Feed C1-A	3,940	3.32E-08	1.31E-07	Feed C3-A	4,220	4.95E-10	2.03E-09
Feed C1-B	3,910	3.53E-08	1.38E-07	Feed C3-B	4,360	4.66E-10	2.04E-09
Feed C1-C	3,680	3.64E-08	1.34E-07	Feed C3-C	4,220	4.69E-10	1.98E-09
Feed C1-D	3,860	3.47E-08	1.34E-07	Feed C3-D	3,940	5.32E-10	2.10E-09
Feed C1-E	4,440	3.09E-08	1.35E-07	Feed C3-E	4,360	4.65E-10	2.03E-09
Average	3,970 ± 280	3.41E-07	1.34E-07	Average	4,220 ±170	4.86E-10	2.03E-09
Feed C2-A	4,250	1.66E-08	6.92E-08	Feed C4-A	4,160	1.90E-10	7.77E-10
Feed C2-B	4,420	1.54E-08	6.76E-08	Feed C4-B	3,890	1.99E-10	7.74E-10
Feed C2-C	4,510	1.48E-08	6.68E-08	Feed C4-C	3,810	2.10E-10	7.86E-10
Feed C2-D	4,400	1.54E-08	6.73E-08	Feed C4-D	4,060	1.94E-10	7.77E-10
Feed C2-E	4,070	1.73E-08	6.96E-08	Feed C4-E	4,170	1.91E-10	7.81E-10
Average	4,330 ±180	1.59E-08	6.81E-08	Average	4,020 ±160	1.97E-10	7.78E-10

(a) Initial cesium concentration C1 = 1.02E-06, C2 = 5.20E-07, C3 = 1.54E-08, C4 = 6.09E-09.
(b) Resin mass is dry-weight basis, H-form.

Table 3.12. Spherical RF Batch-Contact Results with Low Cesium Concentrations in AN-105 Simulant

Sample ID[(a)]	K_d, ml/g	Equilibrium Cesium Concentration		Sample ID[(a)]	K_d, ml/g	Equilibrium Cesium Concentration	
		Final Solution, M	Mole[(b)] Cs/g Resin			Final Solution, M	Mole[(b)] Cs/g Resin
Feed C1-A	1,260	1.29E-07	1.62E-07	Feed C3-A	1,250	1.98E-09	2.50E-09
Feed C1-B	1,180	1.37E-07	1.68E-07	Feed C3-B	1,260	1.92E-09	2.46E-09
Feed C1-C	1,250	1.29E-07	1.67E-07	Feed C3-C	1,220	2.09E-09	2.62E-09
Feed C1-D	1,290	1.29E-07	1.70E-07	Feed C3-D	1,320	1.89E-09	2.55E-09
Feed C1-E	1,300	1.23E-07	1.67E-07	Feed C3-E	1,330	1.86E-09	2.55E-09
Average	1,260 ± 60	1.30E-07	1.67E-07	Average	1,280 ± 50	1.95E-09	2.53E-09
Feed C2-A	1,320	6.48E-08	8.79E-08	Feed C4-A	1,310	7.45E-10	9.81E-10
Feed C2-B	1,460	6.33E-08	9.42E-08	Feed C4-B	1,330	7.83E-10	1.07E-09
Feed C2-C	1,360	6.37E-08	8.72E-08	Feed C4-C	1,170	8.29E-10	1.00E-09
Feed C2-D	1,370	6.69E-08	9.43E-08	Feed C4-D	1,270	7.76E-10	9.96E-10
Feed C2-E	1,320	6.39E-08	8.55E-08	Feed C4-E	1,260	8.23E-10	1.07E-09
Average	1,360 ± 60	6.45E-08	8.98E-08	Average	1,270 ± 60	7.91E-10	1.02E-09

(a) Initial cesium concentration C1 = 1.02E-06, C2 = 5.20E-07, C3 = 1.54E-08, C4 = 6.09E-09.
(b) Resin mass is dry-weight basis, H-form. Divide value by F-factor (0.5565 to convert to vacuum dried resin mass.

The loading isotherm for the ground-gel and spherical-resin contacts is shown in Figure 3.6. The equilibrium concentration of cesium on the resin is displayed as the y-axis in mole Cs/g resin. All resin masses were based on the dry-weight, H-form, spent resin. The contacts were performed with five replicates at each concentration. The variability of the five measurements provides a measure of the uncertainty; these error bars are included in the plots. The error estimate based on propagation of the uncertainty in each individual measurement was determined for one data point in each plot. The error propagation for the largest spherical resin data point (1.30E-07 M Cs, 1.67E-07 mole Cs/g resin was ±1.94E-09 M Cs and ±1.41E-09 mole Cs/g resin. The propagation for the lowest ground-gel resin data point (7.78E-10 mole Cs/g resin, 1.97E-10 M Cs) was ±3.97E-11 mole Cs/g and ±3.97E-12 M Cs. These propagated errors are not shown in Figure 3.6.

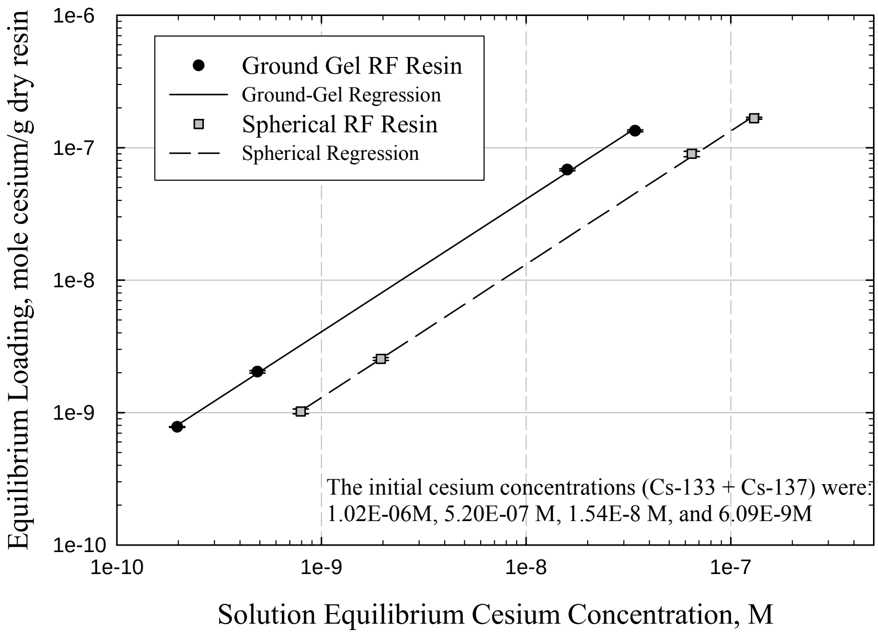

Figure 3.6. Cesium Loading Isotherm for Low-Level Cesium in AN-105 Simulant-with Error Bars

The slopes of both isotherms are the same (slope = 1.00), but the curves are offset. The offset of the curves is anticipated based upon the resin-loading observation; the capacity of the spherical resin is much lower than that of the ground-gel resin.

3.8.3 Batch-Distribution Measurements on Spent Resin

The impact of the elution conditions on the resin capacity was assessed by performing batch contacts on the ground-gel and spherical spent resins. These results are compared against the batch-contact results of the conditioned, but not processed, ground-gel and spherical resins. After completion of elution, the spent resin was collected from each column run, rinsed with DI water, and dried at ambient temperature under nitrogen until free-flowing. Aliquots of the spent resin were contacted with AN-105 simulant containing 10 µg/ml cesium. The results of the batch contacts are shown in Table 3.13. The spent-resin results shown are the average of four replicates, and the control results are the average of seven replicates. The variability of the measurements provides a measure of the uncertainty; these values are included in the table.

Table 3.13. Spent-Resin Batch-Contact Results

Column ID	Average K_d	Deviation from Average	Percent Change from Control[a]	Resin	Elution Conditions		
					Temp., °C	$[HNO_3]$, M	Flow Rate, BV/h
Pink	3,830	120	4.6	Ground gel	25	0.50	1.4
Yellow	2,830	130	-23	Ground gel	25	1.5	1.2
Blue	1,030	46	23	Spherical	25	0.50	1.4
Green	3,790	100	3.6	Ground gel	45	0.50	1.4
Control	3,660	130	--	Ground gel			
Control	840	40	--	Spherical			

(a) Determined as [(result-control)/control]*100 -- indicates no information reported.

The column processing appears to have enhanced the cesium uptake with the spherical resin, and the K_ds showed a significant increase (23%) from the control to the processed resin. It is not clear why the spherical resin would show enhanced cesium capacity after processing; possibly this enhanced behavior is due to increasing the accessibility of some of the active sites after processing through additional shrink-swell cycles. The spent spherical resin underwent two shrink-swell cycles more than the control resin. However, the spherical resin underwent considerable cycling before the load and elution testing described in this report; the resin underwent eight shrink-swell cycles; thus, it is surprising that another two cycles impacted the resin capacity so strongly.

The ground-gel resin cesium uptake was not significantly impacted by the column processing or elution conditions, with the exception of the resin eluted at a high-acid concentration. The spent resin from the yellow column was eluted with 1.5 M HNO_3. This resin showed a 23% loss of cesium capacity, which may be attributed to degradation of the resin while in contact with the high HNO_3 concentration.

4.0 Conclusions

4.1 Experimental Testing Observations

- The spherical RF resin has a lower cesium capacity than the ground-gel RF resin, as indicated by the difference in the amount of cesium loaded during nearly identical processing conditions. The spherical resin loaded ~43% less cesium than the ground-gel RF resin. This is consistent with the results reported by Fiskum et al. (2003), which showed that the spherical resin loaded ~30% less cesium than the ground-gel resin. However, it should be noted that even with the decreased loading in the RF-spherical beads, the Cs loading would meet the baseline WTP design specification.

- Although the goal was to load each column to the same C/C_0 level, the pink ground-gel RF column loaded less cesium than the other two ground-gel resin columns, from 5% to 17% lower, depending upon how the load value is calculated.

- The spherical resin demonstrated superior elution characteristics compared to the ground-gel resin. The elution profile is much sharper than any of the elution conditions tested with the ground-gel resin. The cesium was eluted much more quickly than the ground-gel resins; after the initial elution peak, the eluant cesium concentrations for the spherical resin were nearly two orders of magnitude lower than the ground-gel eluants.

- The WTP design basis for resin disposal (60 μCi Cs/g resin) was calculated for the ground-gel resin (25% ^{137}Cs, 0.76 g/ml bulk density), resulting in a target residual cesium concentration of 2.4 μg Cs/g dried resin. Two of the ground-gel RF elution conditions failed to reach either the basis level or ½ the basis level after elution with ≥58 BV HNO_3. The ground-gel elution performed with 0.50 M HNO_3 at 45°C met the basis level after elution with 20 BV but did not meet the ½ basis level after elution with 68 BV.

- The WTP design basis for resin disposal (60 μCi Cs/g resin) was calculated for the spherical (25% ^{137}Cs, 0.43 g/ml bulk density), resulting in a target residual cesium concentration of 2.4 μg Cs/g dried resin. The spherical RF resin met both this basis level and ½ the basis level after elution with 5 BV of 0.50 M HNO_3 at 25°C.

- Increasing temperature and increasing acid concentration both enhance cesium elution; however, increasing the temperature has the most significant impact on the elution profile. Increasing the acid concentration had deleterious effect on the spent resin K_ds. Thus, based upon the results in this testing, the best elution was obtained at high temperature (45ºC) and low acid strength (0.50 M HNO_3). Additional testing would be necessary to determine if lower acid strength, lower flow rates, and higher temperatures would result in even more enhanced elution from the ground-gel and spherical RF resins.

- The spherical resin demonstrated the lowest residual cesium concentration at 0.15 μg Cs/g dry spent resin (H-form). This value is an order of magnitude lower than the spent-resin concentration of any of the ground-gel resins.

- The lowest residual cesium on the ground-gel resin was obtained from the elution processing at high temperature (45ºC) and low acid strength (0.50 M HNO_3). The residual cesium, 1.35 µg Cs/g dry spent resin (H-form), was at least 50% lower than that measured under high-acid or low-temperature elution conditions (3.0 and 3.2 µg Cs/g dry spent resin [H-form], respectively).

- Increasing the elution temperature does not significantly impact the resin cesium capacity; however, increasing the eluant acid concentration may have a significant impact on the subsequent cesium capacity. The spent-resin K_d values after elution with 1.5 M HNO_3 were 23% lower than the control batch contacts; however, the spent resin exhibited the same mass loss as that observed under more moderate processing conditions. The high-temperature spent-resin Kd values were ~4% higher than the control resin, which is within the experimental uncertainty.

5.0 References

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Appendix A

Target AN-105 Simulant Composition Versus Actual Measured Composition

Appendix A: Target AN-105 Simulant Composition Versus Actual Measured Composition

Analyte	Target, mole/L	Analysis, mole/L	% of target	Analysis Method
Ag	7.07E-05	< 5.8E-06	< 8	ICP/AES
Al	6.88E-01	6.82E-01	99	ICP/AES
B	2.21E-03	2.53E-03	114	ICP/AES
Ca	4.67E-04	< 1.4E-04	< 30	ICP/AES
Cd	1.37E-05	[1.5E-05]	110	ICP/AES
Cr	1.21E-02	1.24E-02	103	ICP/AES
K	8.97E-02	8.95E-02	100	ICP/AES
Mg	1.04E-04	< 1.3E-04	< 125	ICP/AES
Mo	4.00E-04	4.51E-04	113	ICP/AES
Na	4.99E+00	5.00E+00	100	ICP/AES
P	2.81E-03	3.03E-03	108	ICP/AES
Pb	1.20E-04	< 1.4E-05	< 12	ICP/AES
Se	5.87E-06	[1.0E-05]	174	ICP/AES
Si	3.15E-03	[4.3E-03]	136	ICP/AES
Zn	7.23E-05	[2.6E-05]	36	ICP/AES
Cl^-	1.20E-01	1.12E-01	94	IC Anions
F^-	4.68E-03	[7.5E-03]	160	IC Anions
NO_2^-	1.13E+00	1.19E+00	105	IC Anions
NO_3^-	1.44E+00	1.15E+00	80	IC Anions
OH^-	1.61E+00	1.52E+00	94	IC Anions
PO_4^{3-}	2.81E-03	1.38E-02	491	IC Anions
SO_4^{2-}	3.75E-03	4.23E-03	113	IC Anions
TIC	Not calculated	4.86E-01	--	Hot persulfate
TOC	Not calculated	1.25E-01	--	Hot persulfate
free OH^-	1.60E+00	1.52E+00	95	Titration
Density	1.2 to 1.4 g/ml	1.235	--	Gravimetry
-- Indicates the value could not be calculated.				

Appendix B

Column-Run Spreadsheets

Appendix B: Column-Run Spreadsheets

Loading

Feed = AN-105 Simulant at 10 ppm Cs
Resin = GG RF, Lot 6
Supernate Density = 1.234
Flow Rate = approx 60 mL/hr or ~6.0 CV/hr

Pink Bed volume = 11 mL
Start Date and Time = 9/4/2003 2:25 PM
End Date and Time = 9/10/2003 11:42 AM

Table B.1. Cs Loading of Pink Column- 10 μg/L Cs with RF GG Resin

Sample	Source Column	Elapsed Time at Start, hh:mm	Sample Collected at __, for 10 minutes	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Eff. Bottle Tare (g)	Eff. Bottle Mass (g)	Mass Processed, g	Est. Effluent Vol	Est. Flow Rate	#CV Processed
P-10-RF-L01	Pink	0:20	9/4/2003 2:45 PM	17.2860	30.7011	13.4151	369.4	396.1	26.7	21.6	97.5	3
P-10-RF-L02	Pink	16:35	9/5/2003 7:00 AM	17.4349	30.7621	13.3272	369.4	1681.0	1311.6	1062.9	65.4	99
P-10-RF-L03	Pink	21:15	9/5/2003 11:40 AM	17.1945	30.4363	13.2418	369.4	2039.5	1670.1	1353.4	65.2	126
P-10-RF-L04	Pink	25:35	9/5/2003 4:00 PM	17.0093	30.3582	13.3489	369.4	2370.5	2001.1	1621.6	65.1	151
P-10-RF-L05	Pink	40:32	9/6/2003 6:57 AM	16.8994	30.3541	13.4547	369.4	3550.2	3180.8	2577.6	64.9	239
P-10-RF-L06	Pink	52:35	9/6/2003 7:00 PM	16.9444	30.6791	13.7347	370.1	1314.3	4125.0	3342.8	65.8	315
P-10-RF-L07	Pink	63:43	9/7/2003 6:08 AM	17.0709	30.4462	13.3753	370.1	2188.6	4999.3	4051.3	65.6	380
P-10-RF-L08	Pink	75:45	9/7/2003 6:10 PM	17.0178	30.3721	13.3543	368.7	1316.7	5947.3	4819.5	66.5	458
P-10-RF-L09	Pink	88:20	9/8/2003 6:45 AM	17.0371	30.2341	13.1970	368.7	2299.8	6930.4	5616.2	66.2	531
P-10-RF-L10	Pink	92:57	9/8/2003 11:22 AM	17.0342	30.2024	13.1682	368.7	2652.0	7282.6	5901.6	66.1	558
P-10-RF-L11	Pink	97:43	9/8/2003 4:08 PM	17.2270	30.4623	13.2353	368.7	3015.4	7646.0	6196.1	66.0	586
P-10-RF-L12	Pink	112:12	9/9/2003 6:37 AM	17.0362	30.2046	13.1684	369.1	1501.4	8778.3	7113.7	66.8	681
P-10-RF-L13	Pink	117:14	9/9/2003 11:39 AM	17.0424	30.3831	13.3407	369.1	1887.2	9164.1	7426.3	66.7	711
P-10-RF-L14	Pink	122:25	9/9/2003 4:50 PM	16.9665	30.1632	13.1967	369.1	2283.8	9560.7	7747.7	66.6	741
P-10-RF-L15	Pink	136:13	9/10/2003 6:38 AM	17.4582	30.8264	13.3682	369.1	3367.8	10644.7	8626.2	66.3	822
P-10-RF-L16	Pink	141:07	9/10/2003 11:32 AM	17.3730	30.6481	13.2751	369.1	3744.0	11020.9	8931.0	66.3	850

Table B.1 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, ml	count time, sec	gross counts	Net counts	back ground	Total Counts	Control Counts	counts /ml sample	control counts/ ml	C/Co, Cs137	%C/Co, Cs137
P-10-RF-L01	9/10/2003	10:20 AM	P5mLL01	5.0	302.8	110	106	81	25	43923	5	8785	0.0006	0.1%
P-10-RF-L02	9/10/2003	10:15 AM	P5mLL02	5.0	302.9	314	309	81	228	43923	46	8785	0.0052	0.5%
P-10-RF-L03	9/10/2003	10:10 AM	P5mLL03	5.0	302.9	751	713	81	632	43923	126	8785	0.0144	1.4%
P-10-RF-L04	9/10/2003	10:00 AM	P5mLL04	5.0	303.0	1363	1324	81	1243	43923	249	8785	0.0283	2.8%
P-10-RF-L05	9/10/2003	9:55 AM	P5mLL05	5.0	303.9	6457	6234	81	6153	43923	1231	8785	0.1401	14.0%
P-10-RF-L06	9/10/2003	9:10 AM	P5mLL06	5.0	304.9	12622	12228	81	12147	43923	2429	8785	0.2766	27.7%
P-10-RF-L07	9/10/2003	9:05 AM	P5mLL07	5.0	305.9	18305	17757	81	17676	43923	3535	8785	0.4024	40.2%
P-10-RF-L08	9/10/2003	9:00 AM	P5mLL08	5.0	306.9	24394	23650	81	23569	43923	4714	8785	0.5366	53.7%
P-10-RF-L09	9/10/2003	8:50 AM	P5mLL09	5.0	307.8	29097	28041	81	27960	43923	5592	8785	0.6366	63.7%
P-10-RF-L10	9/10/2003	8:30 AM	P5mLL10	5.0	308.0	31100	30080	81	29999	43923	6000	8785	0.6830	68.3%
P-10-RF-L11	9/9/2003	11:15 AM	P5mLL11	5.0	308.6	33267	32306	77	32229	42810	6446	8562	0.7528	75.3%
P-10-RF-L12	9/9/2003	10:30 AM	P5mLL12	5.0	308.9	35379	34467	77	34390	42810	6878	8562	0.8033	80.3%
P-10-RF-L13	9/9/2003	12:00 PM	P5mLL13	5.0	309.3	38254	37162	77	37085	42810	7417	8562	0.8663	86.6%
P-10-RF-L14	9/10/2003	8:15 AM	P5mLL14	5.0	309.5	40120	38785	81	38704	43923	7741	8785	0.8812	88.1%
P-10-RF-L15	9/10/2003	7:30 AM	P5mLL15	5.0	309.8	41738	40471	81	40390	43923	8078	8785	0.9196	92.0%
P-10-RF-L16	9/10/2003	12:05 PM	P5mLL16	5.0	310.1	43123	41380	81	41299	43923	8260	8785	0.9403	94.0%

Loading

Feed = AN-105 Simulant at 10 ppm Cs
Resin = GG RF, Lot 6
Supernate Density = 1.234
Flow Rate = approx 60 mL/hr or ~6.0 CV/hr

Yellow Bed volume = 11 mL
Start Date and Time = 9/4/2003 2:15 PM
End Date and Time = 9/10/2003 11:42 AM

Table B.2. Cs Loading of Yellow Column—10 μg/L Cs with RF GG Resin

Sample	Source Column	Elapsed Time at Start, hh:mm	Sample Collected at __, for 10 minutes	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Eff. Bottle Tare (g)	Eff. Bottle Mass (g)	Mass Processed, g	Est. Effluent Vol	Est. Flow Rate	#CV Processed
Y-10-RF-L01	yellow	0:20	9/4/2003 2:45 PM	17.4684	34.1370	16.6686	423.7	473.6	66.6	53.9	200	4.9
Y-10-RF-L02	yellow	16:35	9/5/2003 7:00 AM	17.4182	31.7339	14.3157	423.7	1847.8	1455.1	1179	88	107
Y-10-RF-L03	yellow	20:35	9/5/2003 11:00 AM	17.4067	31.6579	14.2512	423.7	2234.7	1856.2	1504	90	137
Y-10-RF-L04	yellow	25:35	9/5/2003 4:00 PM	17.4659	31.5523	14.0864	423.7	2579.2	2214.8	1795	87	163
Y-10-RF-L05	yellow	40:32	9/6/2003 6:57 AM	17.6909	29.5281	11.8372	423.7	3580.1	3227.6	2616	80	238
Y-10-RF-L06	yellow	52:35	9/6/2003 7:00 PM	17.4570	30.6643	13.2073	424.0	1236.2	4124.1	3342	78	304
Y-10-RF-L07	yellow	63:43	9/7/2003 6:08 AM	17.4349	29.9651	12.5302	424.0	2034.2	4934.7	3999	77	364
Y-10-RF-L08	yellow	75:45	9/7/2003 6:10 PM	17.4213	30.0163	12.5950	424.1	1229.7	5849.7	4740	77	431
Y-10-RF-L09	yellow	88:20	9/8/2003 6:45 AM	17.4324	29.5599	12.1275	424.1	2096.1	6728.3	5452	76	496
Y-10-RF-L10	yellow	92:57	9/8/2003 11:22 AM	17.3305	37.7983	20.4678	424.1	2628.7	7281.3	5901	78	536
Y-10-RF-L11	yellow	97:43	9/8/2003 4:08 PM	17.4093	32.2689	14.8596	424.1	3031.6	7699.1	6239	79	567
Y-10-RF-L12	yellow	112:12	9/9/2003 6:37 AM	17.4858	32.4540	14.9682	423.8	1715.3	9162.5	7425	82	675
Y-10-RF-L13	yellow	117:14	9/9/2003 11:39 AM	17.4838	32.3805	14.8967	423.8	2106.6	9568.7	7754	82	705
Y-10-RF-L14	yellow	122:25	9/9/2003 4:50 PM	17.3097	31.9419	14.6322	423.8	2546.9	10023.6	8123	82	738
Y-10-RF-L15	yellow	136:13	9/10/2003 6:38 AM	17.2298	31.1040	13.8742	423.8	3697.8	11188.4	9067	82	824
Y-10-RF-L16	yellow	141:07	9/10/2003 11:32 AM	17.4216	31.1531	13.7315	423.8	4049.6	11554.0	9363	82	851

Table B.2 (Contd)

Sample	Count date	Count start time	file name	Volume Counted	count time, sec	gross counts	Net counts	back ground	Total Counts	Control Counts	counts /ml sample	control counts/ ml	C/Co, Cs137	%C/Co, Cs137
Y-10-RF-L01	9/10/2003	10:30 AM	Y5mLL01	5.0	303	128	115	81	34	43923	6.8	8785	0.001	0.08%
Y-10-RF-L02	9/10/2003	10:40 AM	Y5mLL02	5.0	303	330	314	81	233	43923	47	8785	0.005	0.53%
Y-10-RF-L03	9/10/2003	10:45 AM	Y5mLL03	5.0	303	830	814	81	733	43923	147	8785	0.017	1.67%
Y-10-RF-L04	9/10/2003	10:50 AM	Y5mLL04	5.0	303	1582	1513	81	1432	43923	286	8785	0.033	3.3%
Y-10-RF-L05	9/10/2003	11:00 AM	Y5mLL05	5.0	303	4422	4212	81	4131	43923	826	8785	0.094	9.4%
Y-10-RF-L06	9/10/2003	11:15 AM	Y5mLL06	5.0	304	9592	9292	81	9211	43923	1842	8785	0.210	21.0%
Y-10-RF-L07	9/10/2003	11:20 AM	Y5mLL07	5.0	305	15595	15133	81	15052	43923	3010	8785	0.343	34.3%
Y-10-RF-L08	9/10/2003	11:30 AM	Y5mLL08	5.0	306	21431	20595	81	20514	43923	4103	8785	0.467	46.7%
Y-10-RF-L09	9/10/2003	11:40 AM	Y5mLL09	5.0	307	26720	25633	81	25552	43923	5110	8785	0.582	58.2%
Y-10-RF-L10	9/10/2003	8:40 AM	Y5mLL10	5.0	308	32831	31744	81	31663	43923	6333	8785	0.721	72.1%
Y-10-RF-L11	9/9/2003	11:20 AM	Y5mLL11	5.0	309	33609	32648	77	32571	42810	6514	8562	0.761	76.1%
Y-10-RF-L12	9/9/2003	10:40 AM	Y5mLL12	5.0	309	36308	35386	77	35309	42810	7062	8562	0.825	82.5%
Y-10-RF-L13	9/9/2003	12:05 PM	Y5mLL13	5.0	309	38443	37389	77	37312	42810	7462	8562	0.872	87.2%
Y-10-RF-L14	9/10/2003	8:25 AM	Y5mLL14	5.0	310	40890	39581	81	39500	43923	7900	8785	0.899	89.9%
Y-10-RF-L15	9/10/2003	7:45 AM	Y5mLL15	5.0	310	41719	40429	81	40348	43923	8070	8785	0.919	91.9%
Y-10-RF-L16	9/10/2003	11:55 AM	Y5mLL16	5.0	310	43459	41727	81	41646	43923	8329	8785	0.948	94.8%

Loading

Feed = AN-105 Simulant at 10 ppm Cs
Resin = Spherical RF, Resin #3
Supernate Density = 1.234
Flow Rate = approx 60 mL/hr or ~6.0 CV/hr

Blue Bed volume = 11 mL
Start Date and Time = 9/4/2003 2:38 PM
End Date and Time = 9/10/2003 12:05 PM

Table B.3. Cs Loading of Blue Column—10 μg/L Cs with RF Spherical Resin

Sample	Source Column	Elapsed Time at Start, hh:mm	Sample Collected at __, for 10 minutes	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Eff. Bottle Tare (g)	Eff. Bottle Mass (g)	Mass Processed, g	Est. Effluent Vol	Est. Flow Rate	#CV Processed
B-10-RF-L01	Blue	0:07	9/4/2003 2:45 PM	17.2498	32.8505	15.6007	432.4	440.9	63.8	52	--	4.7
B-10-RF-L02	Blue	16:22	9/5/2003 7:00 AM	17.4466	28.4234	10.9768	432.4	1557.6	1191.5	966	73	87.8
B-10-RF-L03	Blue	21:02	9/5/2003 11:40 AM	17.4268	26.4394	9.0126	432.4	1824.5	1467.4	1189	70	108.1
B-10-RF-L04	Blue	25:22	9/5/2003 4:00 PM	17.4000	29.3061	11.9061	432.4	2117.3	1772.1	1436	70	130.6
B-10-RF-L05	Blue	40:19	9/6/2003 6:57 AM	17.1562	29.3111	12.1549	432.4	3350.9	3017.9	2446	75	222.3
B-10-RF-L06	Blue	52:22	9/6/2003 7:00 PM	17.1463	34.6216	17.4753	434.3	1601.4	4301.8	3486	82	316.9
B-10-RF-L07	Blue	63:30	9/7/2003 6:08 AM	17.2977	31.9630	14.6653	434.3	2529.2	5244.3	4250	83	386.3
B-10-RF-L08	Blue	75:32	9/7/2003 6:10 PM	17.1862	31.1638	13.9776	433.7	1454.2	6410.2	5195	85	472.2
B-10-RF-L09	Blue	88:07	9/8/2003 6:45 AM	17.2044	32.4294	15.2250	433.7	2556.4	7527.6	6100	85	554.6
B-10-RF-L10	Blue	92:44	9/8/2003 11:22 AM	17.4621	31.2802	13.8181	433.7	2924.0	7909.1	6409	85	582.7
B-10-RF-L11	Blue	95:44	9/9/2003 4:50 PM	17.4031	23.7525	6.3494	433.7	3043.5	8034.9	6511.3	83.9	591.9
B-10-RF-L12	Blue	137:12	9/10/2003 7:50 AM	17.2097	25.5754	8.3657	433.7	471.3	8261.7	6695.1	73.0	608.6

Sample	Count date	Count start time	file name	Volume Conted, ml	count time, sec	gross counts	Net counts	back ground	Total Counts	Control Counts	counts /ml sample	control counts/ ml	C/Co, Cs-137	%C/Co, Cs-137
B-10-RF-L01	9/10/2003	8:40 PM	B5mLL01	5.0000	302.3	166	163	81	82	43928	16	8786	0.002	0.2%
B-10-RF-L02	9/10/2003	9:05 PM	B5mLL02	5.0	301.9	1388	1329	161	1168	43928	234	8786	0.027	2.7%
B-10-RF-L03	9/10/2003	9:25 PM	B5mLL03	5.0	302.1	2338	2279	161	2118	43928	424	8786	0.048	4.8%
B-10-RF-L04	9/10/2003	10:05 PM	B5mLL04	5.0	302.6	5482	5268	161	5107	43928	1021	8786	0.116	11.6%
B-10-RF-L05	9/10/2003	10:20 PM	B5mLL05	5.0	306.0	25364	24385	161	24224	43928	4845	8786	0.551	55.1%
B-10-RF-L06	9/10/2003	10:40 PM	B5mLL06	5.0	308.4	39361	37630	12	37618	43928	7524	8786	0.856	85.6%
B-10-RF-L07	9/10/2003	11:00 PM	B5mLL07	5.0	308.5	40131	38662	12	38650	43928	7730	8786	0.880	88.0%
B-10-RF-L08	9/8/2003	12:00 PM	B5mlL08	5.0	310.2	43745	42406	108	42298	43736	8460	8747	0.967	96.7%
B-10-RF-L09	9/8/2003	11:55 AM	B5mlL09	5.0	310.5	45202	43903	108	43795	43736	8759	8747	1.001	100.1%
B-10-RF-L10	9/8/2003	11:50 AM	B5mlL10	5.0	310.1	43780	42476	108	42368	43736	8474	8747	0.969	96.9%
B-10-RF-L11	9/10/2003	11:15 PM	B5mLL11	5.0	309.4	45948	43947	12	43935	43928	8787	8786	1.000	100.0%
B-10-RF-L12	9/10/2003	12:20 PM	B5mLL12	5.0	310.4	45707	43761	81	43680	43928	8736	8786	0.994	99.4%

Loading

Feed = AN-105 Simulant at 10 ppm Cs
Resin = GG RF, Lot 6
Supernate Density = 1.234
Flow Rate = approx 60 mL/hr or ~6.0 CV/hr

Green Bed volume = 11 mL
Start Date and Time = 9/4/2003 2:38 PM
End Date and Time = 9/10/2003 11:42 AM

Table B.4. Cs Loading of Green Column—10 μg/L Cs with RF GG Resin

Sample	Source Column	Elapsed Time at Start, hh:mm	Projected Date/Time	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Eff. Bottle Tare (g)	Eff. Bottle Mass (g)	Mass Processed, g	Est. Effluent Vol	Est. Flow Rate	#CV Processed
G-10-RF-L01	Green	0:07	9/4/2003 2:45 PM	17.1270	34.4510	17.3240	444.7	454.9	28	22	191	2
G-10-RF-L02	Green	16:22	9/5/2003 7:00 AM	17.2474	30.9364	13.6890	444.7	1837.3	1424	1154	70	105
G-10-RF-L03	Green	20:22	9/5/2003 11:00 AM	17.2564	30.8370	13.5806	444.7	2205.3	1805	1463	72	133
G-10-RF-L04	Green	25:22	9/5/2003 4:00 PM	17.2590	30.8730	13.6140	444.7	2542.5	2156	1747	69	159
G-10-RF-L05	Green	40:19	9/6/2003 6:57 AM	17.5467	31.0353	13.4886	444.7	3713.1	3340	2707	67	246
G-10-RF-L06	Green	52:22	9/6/2003 7:00 PM	17.1158	31.1981	14.0823	444.1	1401.9	4384	3552	68	323
G-10-RF-L07	Green	63:30	9/7/2003 6:08 AM	17.3633	30.8600	13.4967	444.1	2289.3	5285	4282	67	389
G-10-RF-L08	Green	75:32	9/7/2003 6:10 PM	17.2525	30.7071	13.4546	444.1	1395.8	6349	5145	68	468
G-10-RF-L09	Green	88:07	9/8/2003 6:45 AM	17.2288	30.2816	13.0528	444.1	2381.2	7347	5954	68	541
G-10-RF-L10	Green	92:44	9/8/2003 11:22 AM	17.4133	30.3491	12.9358	444.1	2727.0	7706	6245	67	568
G-10-RF-L11	Green	97:30	9/8/2003 4:08 PM	17.2801	30.1903	12.9102	444.1	3082.0	8074	6543	67	595
G-10-RF-L12	Green	111:59	9/9/2003 6:37 AM	17.1880	29.7439	12.5559	444.1	1538.0	9332	7563	68	688
G-10-RF-L13	Green	117:01	9/9/2003 11:39 AM	17.2223	29.8485	12.6262	444.1	1905.8	9713	7871	67	716
G-10-RF-L14	Green	122:12	9/9/2003 4:50 PM	17.0984	29.7618	12.6634	444.1	2283.3	10103	8187	67	744
G-10-RF-L15	Green	136:00	9/10/2003 6:38 AM	17.1763	29.6047	12.4284	444.1	3305.2	11137	9025	66	820
G-10-RF-L16	Green	140:54	9/10/2003 11:32 AM	17.2330	29.7500	12.5170	444.1	3655.9	11500	9320	66	847

Table B.4 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, ml	count time, sec	gross counts	Net counts	back ground	Total Counts	Control Counts	counts /ml sample	control counts/ ml	C/Co, Cs-137	%C/Co, Cs-137
G-10-RF-L01	9/10/2003	1/0/1900	G5mLL01	5.0	302	152	149	81	68	43928	13.6	8786	0.002	0.2%
G-10-RF-L02	9/10/2003	8:20 PM	G5mLL02	5.0	302	349	345	81	264	43928	52.8	8786	0.006	0.6%
G-10-RF-L03	9/10/2003	8:10 PM	G5mLL03	5.0	302	730	727	81	646	43928	129.2	8786	0.015	1.5%
G-10-RF-L04	9/10/2003	2:45 PM	G5mLL04	5.0	302	1396	1339	81	1258	43928	251.6	8786	0.029	2.9%
G-10-RF-L05	9/10/2003	2:20 PM	G5mLL05	5.0	303	5949	5730	81	5649	43928	1129.8	8786	0.129	12.9%
G-10-RF-L06	9/10/2003	2:00 PM	G5mLL06	5.0	304	12183	11770	81	11689	43928	2337.8	8786	0.266	26.6%
G-10-RF-L07	9/10/2003	1:50 PM	G5mLL07	5.0	305	17980	17370	81	17289	43928	3457.8	8786	0.394	39.4%
G-10-RF-L08	9/10/2003	1:40 PM	G5mLL08	5.0	307	24408	23452	81	23371	43928	4674.2	8786	0.532	53.2%
G-10-RF-L09	9/10/2003	1:35 PM	G5mLL09	5.0	307	31332	30239	81	30158	43928	6031.6	8786	0.687	68.7%
G-10-RF-L10	9/10/2003	1:25 PM	G5mLL10	5.0	307	32359	31195	81	31114	43928	6222.8	8786	0.708	70.8%
G-10-RF-L11	9/9/2003	10:55 AM	G5mLL11	5.0	308	33166	32298	77	32221	42988	6444.2	8598	0.750	75.0%
G-10-RF-L12	9/9/2003	10:45 AM	G5mLL12	5.0	309	35277	34371	77	34294	42988	6858.8	8598	0.798	79.8%
G-10-RF-L13	9/9/2003	12:10 PM	G5mLL13	5.0	309	37243	36191	77	36114	42988	7222.8	8598	0.840	84.0%
G-10-RF-L14	9/10/2003	8:00 AM	G5mLL14	5.0	309	39458	38004	81	37923	43928	7584.6	8786	0.863	86.3%
G-10-RF-L15	9/10/2003	7:55 AM	G5mLL15	5.0	310	40641	39320	81	39239	43928	7847.8	8786	0.893	89.3%
G-10-RF-L16	9/10/2003	12:10 PM	G5mLL16	5.0	310	42856	41071	81	40990	43928	8198.0	8786	0.933	93.3%

Wash & Rinse

Feed = Wash - 0.1 M NaOH, Rinse - water
Resin = RF GG, Lot 6
Bed Volume = 11 mL
NaOH density = 1.008 g/mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/10/03 1:15 PM
End Date and Time = 9/10/03 3:25 PM

Table B.5. Data Collection During 0.10 M NaOH Feed Displacement and Water Rinse of Pink Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Vol. (mL)	Collection Time, minutes	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)
P-10-RF-FD	Pink	3	1:00	9/10/2003 1:15 PM	11	20	1:15 PM	2:15 PM	14.6447	39.5315	24.8868
P-10-RF-WR1	Pink	3	1:00	9/10/2003 2:25 PM	11	20	2:25 PM	3:25 PM	14.6724	34.0381	19.3657

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ g sample	counts/ g control	C/Co, Cs-137
P-10-RF-FD	9/11/2003	12:18 AM	P10RFFD	305.7	23763	22888	161	22876	43928	0.5208	919	8786	0.105
P-10-RF-WR1	10/2/2003	9:15 AM	P5mLWR1	302.4	1437	1375	39	1161	42745	0.0272	60	8549	0.007

Wash & Rinse

Feed = Wash - 0.1 M NaOH, Rinse - water
Resin = RF GG, Lot 6
Bed Volume = 11 mL
NaOH density = 1.008 g/mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/10/03 1:15 PM
End Date and Time = 9/10/03 3:25 PM

Table B.6. Data Collection During 0.10 M NaOH Feed Displacement and Water Rinse of Pink Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Vol. (mL)	Collection Time, minutes	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)
Y-10-RF-FD	Yellow	3	1:00	9/10/2003 1:15 PM	11	20	1:15 PM	2:15 PM	14.4551	38.8280	24.3729
Y-10-RF-WR1	Yellow	3	1:00	9/10/2003 2:25 PM	11	20	2:25 PM	3:25 PM	14.5541	33.8841	19.3300

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ g sample	counts/ g control	C/Co, Cs-137
Y-10-RF-FD	9/11/2003	12:55 AM	Y10RFFD	306.5	28689	27741	176	27729	43928	0.6312	1138	8786	0.129
Y-10-RF-WR1	10/2/2003	9:30 AM	Y5mLWR1	302.4	1692	1614	43	1400	42745	0.0328	72	8549	0.008

Wash & Rinse

Feed = Wash - 0.1 M NaOH, Rinse - water
Resin = Spherical RF, Resin #3
Bed Volume = 11 mL
NaOH density = 1.008 g/mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/10/03 1:15 PM
End Date and Time = 9/10/03 3:25 PM

Table B.7. Data Collection During 0.10 M NaOH Feed Displacement and Water Rinse of Blue Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Vol. (mL)	Collection Time, minutes	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)
B-10-RF-FD	Blue	3	1:00	9/10/2003 1:15 PM	11	20	1:15 PM	2:15 PM	14.5501	48.3814	33.8313
B-10-RF-WR1	Blue	3	1:00	9/10/2003 2:25 PM	11	20	2:25 PM	3:25 PM	14.5303	38.1863	23.6560

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ g sample	counts/ g control	C/Co, Cs-137
B-10-RF-FD	9/11/2003	1:38 AM	B10RFFD	305.6	22985	22149	158	22137	43928	0.5039	654	8786	0.074
B-10-RF-WR1	10/2/2003	9:55 AM	B5mLWR1	302.5	1939	1855	46	1641	42545	0.0386	69	8509	0.008

Wash & Rinse

Feed = Wash - 0.1 M NaOH, Rinse - water
Resin = RF GG, Lot 6
Bed Volume = 11 mL
NaOH density = 1.008 g/mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/10/03 1:15 PM
End Date and Time = 9/10/03 3:25 PM

Table B.8. Data Collection During 0.10 M NaOH Feed Displacement and Water Rinse of Green Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Vol. (mL)	Collection Time, minutes	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial + Cap Mass (g)	Sample Mass (g)
G-10-RF-FD	Green	3	1:00	9/10/2003 1:15 PM	11	20	1:15 PM	2:15 PM	14.4579	44.7115	30.2536
G-10-RF-WR1	Green	3	1:00	9/10/2003 2:25 PM	11	20	2:25 PM	3:25 PM	14.5706	33.0269	18.4563

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ g sample	counts/ g control	C/Co, Cs-137
G-10-RF-FD	9/11/2003	1:12 AM	G10RFFD	306.7	29719	28682	179	28670	43928	0.6527	948	8786	0.108
G-10-RF-WR1	10/2/2003	10:10 AM	G5mLWR1	302.4	1831	1747	45	1533	42545	0.0360	83	8509	0.010

Elution

Feed = 0.5 M HNO_3 at 25°C
Resin = GG RF, Lot 6
Bed Volume = 11 mL
Density 0.5 M HNO_3 = 1.014 g/mL

Flow Rate = approx 15.4 mL/hr or 1.4 CV/hr
Start Date and Time = 9/10/03 4:30 PM
End Date and Time = 9/12/03 6:40 PM

Table B.9. Data Collection for Cs Elution of Pink Column—10 ppm Cs Feed—25ºC, 0.50 M HNO_3, and 1.4 BV/h Elution

Sample	Source	Elapsed Time at Start, hh:mm	Projected Date/Time	Vial + Cap Mass (g)	Sampling Start Time	Sampling End Time	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Volume, mL	#CV processed
P-10-RF-E01	Pink	0:00	9/10/03 10:30 AM	7.4958	5:00 PM	11:53 AM	14.8131	7.3173	7.2163	0.66
P-10-RF-E02	Pink	0:30	9/10/03 5:00 PM	7.5268	5:30 PM	12:38 PM	15.4432	7.9164	7.8071	1.37
P-10-RF-E03	Pink	1:00	9/10/03 5:30 PM	7.4350	6:00 PM	10:26 AM	15.3128	7.8778	7.7690	2.07
P-10-RF-E04	Pink	1:30	9/10/03 6:00 PM	7.4401	6:30 PM	10:33 AM	15.3080	7.8679	7.7593	2.78
P-10-RF-E05	Pink	2:00	9/10/03 6:30 PM	7.4338	7:00 PM	10:24 AM	15.3341	7.9003	7.7912	3.49
P-10-RF-E06	Pink	2:30	9/10/03 7:00 PM	7.5240	7:30 PM	12:34 PM	15.5303	8.0063	7.8958	4.20
P-10-RF-E07	Pink	3:00	9/10/03 7:30 PM	7.4320	8:00 PM	10:22 AM	15.3777	7.9457	7.8360	4.92
P-10-RF-E08	Pink	3:30	9/10/03 8:00 PM	7.5332	8:50 PM	12:47 PM	20.3501	12.8169	12.6399	6.06
P-10-RF-E09	Pink	4:20	9/10/03 8:50 PM	7.5286	9:40 PM	12:41 PM	20.4454	12.9168	12.7385	7.22
P-10-RF-E10	Pink	5:10	9/10/03 9:40 PM	7.4451	10:30 PM	10:40 AM	20.3365	12.8914	12.7134	8.38
P-10-RF-E11	Pink	6:00	9/10/03 10:30 PM	7.4868	11:20 PM	11:41 AM	20.1023	12.6155	12.4413	9.51
P-10-RF-E12	Pink	6:50	9/10/03 11:20 PM	7.5093	12:10 AM	12:13 PM	20.2622	12.7529	12.5768	10.65
P-10-RF-E13	Pink	7:40	9/11/03 12:10 AM	6.9043	1:00 AM	9:42 PM	19.7023	12.7980	12.6213	11.80
P-10-RF-E14	Pink	8:30	9/11/03 1:00 AM	7.5343	1:50 AM	12:49 PM	20.2301	12.6958	12.5205	12.94
P-10-RF-E15	Pink	9:20	9/11/03 1:50 AM	7.4924	2:40 AM	11:49 AM	20.1450	12.6526	12.4779	14.07
P-10-RF-E16	Pink	10:10	9/11/03 2:40 AM	7.3562	3:30 AM	8:32 AM	19.9333	12.5771	12.4035	15.20
P-10-RF-E17	Pink	11:00	9/11/03 3:30 AM	7.3078	4:20 AM	7:23 AM	19.9260	12.6182	12.4440	16.33
P-10-RF-E18	Pink	11:50	9/11/03 4:20 AM	7.4150	5:10 AM	9:57 AM	19.7941	12.3791	12.2082	17.44
P-10-RF-E19	Pink	12:40	9/11/03 5:10 AM	7.3826	6:00 AM	9:10 AM	20.3204	12.9378	12.7592	18.60
P-10-RF-E20	Pink	13:30	9/11/03 6:00 AM	7.4192	6:50 AM	10:03 AM	20.2208	12.8016	12.6249	19.75
P-10-RF-E21	Pink	14:20	9/11/03 6:50 AM	7.3881	7:40 AM	9:18 AM	20.1541	12.7660	12.5897	20.89
P-10-RF-E22	Pink	15:10	9/11/03 7:40 AM	7.4307	8:30 AM	10:20 AM	20.1223	12.6916	12.5164	22.03
P-10-RF-E23	Pink	16:00	9/11/03 8:30 AM	7.4909	9:20 AM	11:46 AM	20.4636	12.9727	12.7936	23.19
P-10-RF-E24	Pink	16:50	9/11/03 9:20 AM	7.3794	10:10 AM	9:06 AM	20.1768	12.7974	12.6207	24.34
P-10-RF-E25	Pink	17:40	9/11/03 10:10 AM	7.4443	11:00 AM	10:39 AM	20.2705	12.8262	12.6491	25.49
P-10-RF-E26	Pink	18:30	9/11/03 11:00 AM	7.4044	11:50 AM	9:42 AM	20.1781	12.7737	12.5973	26.64
P-10-RF-E27	Pink	19:20	9/11/03 11:50 AM	7.4059	12:40 PM	9:44 AM	20.1026	12.6967	12.5214	27.78
P-10-RF-E28	Pink	20:10	9/11/03 12:40 PM	7.4277	1:30 PM	10:15 AM	20.0581	12.6304	12.4560	28.91
P-10-RF-E29	Pink	21:00	9/11/03 1:30 PM	7.4565	2:20 PM	10:57 AM	20.1228	12.6663	12.4914	30.04
P-10-RF-E30	Pink	21:50	9/11/03 2:20 PM	7.5492	3:10 PM	1:10 PM	19.9851	12.4359	12.2642	31.16
P-10-RF-E31	Pink	22:40	9/11/03 3:10 PM	7.4750	4:00 PM	11:24 AM	20.4666	12.9916	12.8122	32.32
P-10-RF-E32	Pink	23:30	9/11/03 4:00 PM	7.3926	4:50 PM	9:25 AM	20.1456	12.7530	12.5769	33.47
P-10-RF-E33	Pink	0:20	9/11/03 4:50 PM	7.6221	5:40 PM	2:55 PM	20.0457	12.4236	12.2521	34.58
P-10-RF-E34	Pink	1:10	9/11/03 5:40 PM	7.4409	6:30 PM	10:34 AM	20.1206	12.6797	12.5046	35.72
P-10-RF-E35	Pink	2:00	9/11/03 6:30 PM	7.3961	7:20 PM	9:30 AM	20.1401	12.7440	12.5680	36.86

Table B.9 (Contd)

Sample	Source	Elapsed Time at Start, hh:mm	Projected Date/Time	Vial + Cap Mass (g)	Sampling Start Time	Sampling End Time	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Volume, mL	#CV processed
P-10-RF-E36	Pink	2:50	9/11/03 7:20 PM	7.4261	8:10 PM	10:13 AM	19.9066	12.4805	12.3082	37.98
P-10-RF-E37	Pink	3:40	9/11/03 8:10 PM	6.9099	9:00 PM	9:50 PM	19.6181	12.7082	12.5327	39.12
P-10-RF-E38	Pink	4:30	9/11/03 9:00 PM	7.4270	9:50 PM	10:14 AM	20.0003	12.5733	12.3997	40.25
P-10-RF-E39	Pink	5:20	9/11/03 9:50 PM	6.9280	10:40 PM	10:16 PM	20.3961	13.4681	13.2821	41.45
P-10-RF-E40	Pink	6:10	9/11/03 10:40 PM	7.3723	11:30 PM	8:56 AM	19.6480	12.2757	12.1062	42.55
P-10-RF-E41	Pink	7:00	9/11/03 11:30 PM	7.3364	12:20 AM	8:04 AM	19.6204	12.2840	12.1144	43.65
P-10-RF-E42	Pink	7:50	9/12/03 12:20 AM	7.5127	1:10 AM	12:18 PM	20.4510	12.9383	12.7597	44.81
P-10-RF-E43	Pink	8:40	9/12/03 1:10 AM	7.3565	2:00 AM	8:33 AM	18.3374	10.9809	10.8293	45.80
P-10-RF-E44	Pink	9:30	9/12/03 2:00 AM	7.3354	2:50 AM	8:02 AM	19.5025	12.1671	11.9991	46.89
P-10-RF-E45	Pink	10:20	9/12/03 2:50 AM	7.3339	3:40 AM	8:00 AM	19.5413	12.2074	12.0389	47.98
P-10-RF-E46	Pink	11:10	9/12/03 3:40 AM	7.4550	4:30 AM	10:55 AM	19.5971	12.1421	11.9745	49.07
P-10-RF-E47	Pink	12:00	9/12/03 4:30 AM	6.8780	5:20 AM	9:04 PM	19.0491	12.1711	12.0031	50.16
P-10-RF-E48	Pink	12:50	9/12/03 5:20 AM	7.4634	6:10 AM	11:07 AM	19.5681	12.1047	11.9376	51.25
P-10-RF-E49	Pink	13:40	9/12/03 6:10 AM	6.8914	7:00 AM	9:23 PM	18.9912	12.0998	11.9327	52.33
P-10-RF-E50	Pink	14:30	9/12/03 7:00 AM	6.8957	7:50 AM	9:29 PM	18.9639	12.0682	11.9016	53.42
P-10-RF-E51	Pink	15:20	9/12/03 7:50 AM	7.4224	8:40 AM	10:08 AM	19.4988	12.0764	11.9097	54.50
P-10-RF-E52	Pink	16:10	9/12/03 8:40 AM	7.4609	9:30 AM	11:03 AM	19.5928	12.1319	11.9644	55.59
P-10-RF-E53	Pink	17:00	9/12/03 9:30 AM	7.4317	10:20 AM	10:21 AM	19.0060	11.5743	11.4145	56.62
P-10-RF-E54	Pink	17:50	9/12/03 10:20 AM	7.4410	11:10 AM	10:35 AM	19.5535	12.1125	11.9453	57.71
P-10-RF-E55	Pink	18:40	9/12/03 11:10 AM	7.4208	12:00 PM	10:05 AM	19.5174	12.0966	11.9296	58.79
P-10-RF-E56	Pink	19:30	9/12/03 12:00 PM	7.5534	12:50 PM	1:16 PM	19.7222	12.1688	12.0008	59.89
P-10-RF-E57	Pink	20:20	9/12/03 12:50 PM	7.5240	1:40 PM	12:34 PM	19.8363	12.3123	12.1423	60.99
P-10-RF-E58	Pink	21:10	9/12/03 1:40 PM	7.4460	2:30 PM	10:42 AM	19.5820	12.1360	11.9684	62.08
P-10-RF-E59	Pink	22:00	9/12/03 2:30 PM	7.4337	3:20 PM	10:24 AM	18.7381	11.3044	11.1483	63.09
P-10-RF-E60	Pink	22:50	9/12/03 3:20 PM	7.5450	4:10 PM	1:04 PM	19.7622	12.2172	12.0485	64.19
P-10-RF-E61	Pink	23:40	9/12/03 4:10 PM	7.4964	5:00 PM	11:54 AM	19.8259	12.3295	12.1593	65.29
P-10-RF-E62	Pink	0:30	9/12/03 5:00 PM	7.6381	5:50 PM	3:18 PM	19.5510	11.9129	11.7484	66.36
P-10-RF-E63	Pink	1:20	9/12/03 5:50 PM	7.4004	6:40 PM	9:36 AM	18.9527	11.5523	11.3928	67.40

Table B.9 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, ml	count time, sec	gross counts	Net counts	back ground	Tot cts-bck	control counts	C/Co
P-10-RF-E01	9/11/03	10:05 AM	P10RFE01	7.3173	302.32	42193	38,862	0	38862	1,465,371	2.65E-02
P-10-RF-E02	9/22/03	10:20 AM	P10RFE02	7.9164	305.86	151925	142,917	0	142917	1,465,371	9.75E-02
P-10-RF-E03	9/18/03	2:37 PM	P10RFE03	7.8778	308.08	223232	209,160	0	209160	1,465,371	1.43E-01
P-10-RF-E04	9/18/03	2:44 PM	P10RFE04	7.8679	309	250006	233,367	0	233367	1,465,371	1.59E-01
P-10-RF-E05	9/19/03	10:15 AM	P10RFE05	7.9003	301.64	24051	223,770,124	0	223770123.6	2,734,884	8.18E+01
P-10-RF-E06	9/19/03	10:21 AM	P10RFE06	8.0063	302.88	61035	598,647,449	0	598647449	2,734,884	2.19E+02
P-10-RF-E07	9/19/03	10:28 AM	P10RFE07	7.9457	302.46	48914	457,837,100	0	457837099.8	2,734,884	1.67E+02
P-10-RF-E08	9/19/03	10:37 AM	P10RFE08	10.0	301.84	28747	257,458,454	0	257458454.3	2,734,884	9.41E+01
P-10-RF-E09	9/19/03	10:43 AM	P10RFE09	10.0	307.2	193014	18,799,287	0	18799286.87	2,734,884	6.87E+00
P-10-RF-E10	9/19/03	10:59 AM	P10RFE10	10.0	301.44	16723	1,574,530	0	1574530.04	2,734,884	5.76E-01
P-10-RF-E11	9/15/03	7:30 AM	P10RFE11	10.0	321.22	592313	548,476	0	548476	2,734,884	2.01E-01
P-10-RF-E12	9/15/03	7:50 AM	P10RFE12	10.0	310.68	290661	267,476	0	267476	2,734,884	9.78E-02
P-10-RF-E13	9/15/03	7:59 AM	P10RFE13	10.0	306.32	163285	151,202	0	151202	2,734,884	5.53E-02
P-10-RF-E14	9/15/03	8:06 AM	P10RFE14	10.0	304.18	99418	90,879	0	90879	2,734,884	3.32E-02
P-10-RF-E15	9/15/03	8:12 AM	P10RFE15	10.0	303.04	64804	59,412	0	59412	2,734,884	2.17E-02
P-10-RF-E16	9/15/03	8:56 AM	P10RFE16	10.0	302.4	45320	40,908	0	40908	2,734,884	1.50E-02
P-10-RF-E17	9/15/03	9:02 AM	P10RFE17	10.0	302.04	33747	30,995	0	30995	2,734,884	1.13E-02
P-10-RF-E18	9/15/03	9:09 AM	P10RFE18	10.0	301.82	21175	24,530	0	24530	2,734,884	8.97E-03
P-10-RF-E19	9/15/03	9:15 AM	P10RFE19	10.0	301.68	22574	20,115	0	20115	2,734,884	7.35E-03
P-10-RF-E20	9/15/03	9:24 AM	P10RFE20	10.0	301.58	19604	17,252	0	17252	2,734,884	6.31E-03
P-10-RF-E21	9/15/03	9:30 AM	P10RFE21	10.0	301.58	17731	15,341	0	15341	2,734,884	5.61E-03
P-10-RF-E22	9/15/03	9:37 AM	P10RFE22	10.0	301.48	16159	14,025	0	14025	2,734,884	5.13E-03
P-10-RF-E23	9/15/03	9:45 AM	P10RFE23	10.0	301.44	15180	13,519	0	13519	2,734,884	4.94E-03
P-10-RF-E24	9/15/03	9:58 AM	P10RFE24	10.0	301.4	14138	12,799	0	12799	2,734,884	4.68E-03
P-10-RF-E25	9/15/03	10:04 AM	P10RFE25	10.0	301.38	13589	11,959	0	11959	2,734,884	4.37E-03
P-10-RF-E26	9/15/03	10:12 AM	P10RFE26	10.0	301.36	12661	11,070	0	11070	2,734,884	4.05E-03
P-10-RF-E27	9/15/03	10:18 AM	P10RFE27	10.0	301.32	12020	10,426	0	10426	2,734,884	3.81E-03
P-10-RF-E28	9/15/03	10:24 AM	P10RFE28	10.0	301.32	11517	9,995	0	9995	2,734,884	3.65E-03
P-10-RF-E29	9/15/03	10:38 AM	P10RFE29	10.0	301.32	11182	9,514	0	9514	2,734,884	3.48E-03
P-10-RF-E30	9/15/03	10:45 AM	P10RFE30	10.0	301.32	11246	9,616	0	9616	2,734,884	3.52E-03
P-10-RF-E31	9/18/03	3:23 PM	P10RFE31	10.0	301.18	10311	9,364	0	9364	2,734,884	3.42E-03
P-10-RF-E32	9/18/03	3:30 PM	P10RFE32	10.0	301.16	9858	8,732	0	8732	2,734,884	3.19E-03
P-10-RF-E33	9/18/03	3:36 PM	P10RFE33	10.0	301.16	9755	8,488	0	8488	2,734,884	3.10E-03
P-10-RF-E34	9/18/03	3:44 PM	P10RFE34	10.0	301.14	9085	7,889	0	7889	2,734,884	2.88E-03
P-10-RF-E35	9/18/03	3:51 PM	P10RFE35	10.0	301.1	8678	7,948	0	7948	2,734,884	2.91E-03
P-10-RF-E36	9/18/03	3:57 PM	P10RFE36	10.0	301.1	8145	7,274	0	7274	2,734,884	2.66E-03
P-10-RF-E37	9/18/03	4:05 PM	P10RFE37	10.0	301.08	8009	6,997	0	6997	2,734,884	2.56E-03
P-10-RF-E38	9/18/03	4:11 PM	P10RFE38	10.0	301.06	7102	6,123	0	6123	2,734,884	2.24E-03
P-10-RF-E39	9/18/03	4:18 PM	P10RFE39	10.0	301.06	7012	6,178	0	6178	2,734,884	2.26E-03
P-10-RF-E40	9/18/03	4:26 PM	P10RFE40	10.0	903.2	20915	18,019	0	18019	8,298,693	2.17E-03

Table B.9 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, ml	count time, sec	gross counts	Net counts	back ground	Tot cts-bck	control counts	C/Co
P-10-RF-E41	9/18/03	4:42 PM	P10RFE41	10.0	903.24	22433	19,465	0	19465	8,298,693	2.35E-03
P-10-RF-E42	9/18/03	5:00 PM	P10RFE42	10.0	903.62	32557	29,047	0	29047	8,298,693	3.50E-03
P-10-RF-E43	9/19/03	7:49 AM	P10RFE43	10.0	903.7	35467	31,052	0	31052	8,298,693	3.74E-03
P-10-RF-E44	9/19/03	8:05 AM	P10RFE44	10.0	903.32	23647	20,135	0	20135	8,298,693	2.43E-03
P-10-RF-E45	9/19/03	8:34 AM	P10RFE45	10.0	903.24	20679	17,564	0	17564	8,298,693	2.12E-03
P-10-RF-E46	9/19/03	8:51 AM	P10RFE46	10.0	903.24	20316	17,709	0	17709	8,298,693	2.13E-03
P-10-RF-E47	9/19/03	9:07 AM	P10RFE47	10.0	903.18	18766	15,111	0	15111	8,298,693	1.82E-03
P-10-RF-E48	9/19/03	9:23 AM	P10RFE48	10.0	903.18	18358	15,243	0	15243	8,298,693	1.84E-03
P-10-RF-E49	9/19/03	9:39 AM	P10RFE49	10.0	903.16	18456	15,524	0	15524	8,298,693	1.87E-03
P-10-RF-E50	9/19/03	9:55 AM	P10RFE50	10.0	903.18	16791	13,605	0	13605	8,298,693	1.64E-03
P-10-RF-E51	9/22/03	10:14 AM	P10RFE51	10.0	903.34	17431	13,414	0	13414	8,298,693	1.62E-03
P-10-RF-E52	9/25/03	11:40 AM	P10RFE52	10.0	903.52	16712	13,925	0	13925	8,298,693	1.68E-03
P-10-RF-E53	9/25/03	11:24 AM	P10RFE53	10.0	903.44	16113	12,822	0	12822	8,298,693	1.55E-03
P-10-RF-E54	9/25/03	11:08 AM	P10RFE54	10.0	903.46	15619	12,216	0	12216	8,298,693	1.47E-03
P-10-RF-E55	9/25/03	10:51 AM	P10RFE55	10.0	903.5	15046	11,390	0	11390	8,298,693	1.37E-03
P-10-RF-E56	9/25/03	10:36 AM	P10RFE56	10.0	903.42	15151	12,253	0	12253	8,298,693	1.48E-03
P-10-RF-E57	9/25/03	10:20 AM	P10RFE57	10.0	903.42	14461	11,710	0	11710	8,298,693	1.41E-03
P-10-RF-E58	9/25/03	9:56 AM	P10RFE58	10.0	903.38	13941	11,117	0	11117	8,298,693	1.34E-03
P-10-RF-E59	9/25/03	9:41 AM	P10RFE59	10.0	903.4	13827	11,185	0	11185	8,298,693	1.35E-03
P-10-RF-E60	9/24/03	12:42 PM	P10RFE60	10.0	903.44	13843	10,947	0	10947	8,298,693	1.32E-03
P-10-RF-E61	9/25/03	9:24 AM	P10RFE61	10.0	903.38	12977	10,624	0	10624	8,298,693	1.28E-03
P-10-RF-E62	9/25/03	9:02 AM	P10RFE62	10.0	903.32	12312	9,633	0	9633	8,298,693	1.16E-03
P-10-RF-E63	9/24/03	12:59 PM	P10RFE63	10.0	903.42	12045	8,787	0	8787	8,298,693	1.06E-03

Elution

Feed = 1.5 M HNO_3 at 25°C
Resin = GG RF, Lot 6
Bed Volume = 11 mL
Density 1.5 M HNO_3 = 1.043 g/mL

Flow Rate = approx 15.4 mL/hr or 1.4 CV/hr
Start Date and Time = 9/10/03 4:30 PM
End Date and Time = 9/12/03 6:40 PM

Table B.10. Data Collection for Cs Elution of Yellow Column—10-ppm Cs Feed—25ºC, 1.50 M HNO_3, and 1.4 BV/h Elution

Sample	Source Column	Elapsed Time at Start, hh:mm	Projected Date/Time	Vial + Cap Mass (g)	Sampling Start Time	Sampling End Time	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Volume, mL	#CV processed
Y-10-RF-E01	Yellow	0:00	9/10/03 4:30 PM	6.9323	4:30 PM	5:00 PM	14.0408	7.1085	6.8	0.6
Y-10-RF-E02	Yellow	0:30	9/10/03 5:00 PM	6.9617	5:00 PM	5:30 PM	15.3152	8.3535	8.0	1.3
Y-10-RF-E03	Yellow	1:00	9/10/03 5:30 PM	7.4712	5:30 PM	6:00 PM	15.1503	7.6791	7.4	2.0
Y-10-RF-E04	Yellow	1:30	9/10/03 6:00 PM	7.3811	6:00 PM	6:30 PM	15.2514	7.8703	7.5	2.7
Y-10-RF-E05	Yellow	2:00	9/10/03 6:30 PM	7.4954	6:30 PM	7:00 PM	15.1060	7.6106	7.3	3.4
Y-10-RF-E06	Yellow	2:30	9/10/03 7:00 PM	7.4753	7:00 PM	7:30 PM	15.0913	7.6160	7.3	4.0
Y-10-RF-E07	Yellow	3:00	9/10/03 7:30 PM	7.5178	7:30 PM	8:00 PM	15.2335	7.7157	7.4	4.7
Y-10-RF-E08	Yellow	3:30	9/10/03 8:00 PM	6.9891	8:00 PM	8:50 PM	19.7624	12.7733	12.2	5.8
Y-10-RF-E09	Yellow	4:20	9/10/03 8:50 PM	7.4038	8:50 PM	9:40 PM	20.1316	12.7278	12.2	6.9
Y-10-RF-E10	Yellow	5:10	9/10/03 9:40 PM	6.9592	9:40 PM	10:30 PM	19.6434	12.6842	12.2	8.0
Y-10-RF-E11	Yellow	6:00	9/10/03 10:30 PM	7.4267	10:30 PM	11:20 PM	19.7219	12.2952	11.8	9.1
Y-10-RF-E12	Yellow	6:50	9/10/03 11:20 PM	7.5340	11:20 PM	12:10 AM	19.8753	12.3413	11.8	10.2
Y-10-RF-E13	Yellow	7:40	9/11/03 12:10 AM	7.4527	12:10 AM	1:00 AM	20.2466	12.7939	12.3	11.3
Y-10-RF-E14	Yellow	8:30	9/11/03 1:00 AM	7.5148	1:00 AM	1:50 AM	20.0985	12.5837	12.1	12.4
Y-10-RF-E15	Yellow	9:20	9/11/03 1:50 AM	7.5413	1:50 AM	2:40 AM	19.6502	12.1089	11.6	13.4
Y-10-RF-E16	Yellow	10:10	9/11/03 2:40 AM	7.4273	2:40 AM	3:30 AM	19.4950	12.0677	11.6	14.5
Y-10-RF-E17	Yellow	11:00	9/11/03 3:30 AM	7.5120	3:30 AM	4:20 AM	19.6041	12.0921	11.6	15.6
Y-10-RF-E18	Yellow	11:50	9/11/03 4:20 AM	7.4322	4:20 AM	5:10 AM	19.1255	11.6933	11.2	16.6
Y-10-RF-E19	Yellow	12:40	9/11/03 5:10 AM	7.4392	5:10 AM	6:00 AM	19.4594	12.0202	11.5	17.6
Y-10-RF-E20	Yellow	13:30	9/11/03 6:00 AM	7.5433	6:00 AM	6:50 AM	18.9915	11.4482	11.0	18.6
Y-10-RF-E21	Yellow	14:20	9/11/03 6:50 AM	7.4970	6:50 AM	7:40 AM	18.4472	10.9502	10.5	19.6
Y-10-RF-E22	Yellow	15:10	9/11/03 7:40 AM	7.4620	7:40 AM	8:30 AM	18.6491	11.1871	10.7	20.5
Y-10-RF-E23	Yellow	16:00	9/11/03 8:30 AM	7.3600	8:30 AM	9:20 AM	18.5539	11.1939	10.7	21.5
Y-10-RF-E24	Yellow	16:50	9/11/03 9:20 AM	7.4147	9:20 AM	10:10 AM	18.3158	10.9011	10.5	22.5
Y-10-RF-E25	Yellow	17:40	9/11/03 10:10 AM	7.4165	10:10 AM	11:00 AM	18.4156	10.9991	10.5	23.4
Y-10-RF-E26	Yellow	18:30	9/11/03 11:00 AM	7.4029	11:00 AM	11:50 AM	18.1676	10.7647	10.3	24.4
Y-10-RF-E27	Yellow	19:20	9/11/03 11:50 AM	7.6250	11:50 AM	12:40 PM	18.3705	10.7455	10.3	25.3
Y-10-RF-E28	Yellow	20:10	9/11/03 12:40 PM	7.5449	12:40 PM	1:30 PM	18.1529	10.6080	10.2	26.2
Y-10-RF-E29	Yellow	21:00	9/11/03 1:30 PM	7.4186	1:30 PM	2:20 PM	17.9387	10.5201	10.1	27.1
Y-10-RF-E30	Yellow	21:50	9/11/03 2:20 PM	7.5748	2:20 PM	3:10 PM	17.9595	10.3847	10.0	28.1
Y-10-RF-E31	Yellow	22:40	9/11/03 3:10 PM	7.4045	3:10 PM	4:00 PM	18.2487	10.8442	10.4	29.0
Y-10-RF-E32	Yellow	23:30	9/11/03 4:00 PM	7.4177	4:00 PM	4:50 PM	18.6789	11.2612	10.8	30.0
Y-10-RF-E33	Yellow	0:20	9/11/03 4:50 PM	7.3598	4:50 PM	5:40 PM	17.8138	10.4540	10.0	30.9
Y-10-RF-E34	Yellow	1:10	9/11/03 5:40 PM	7.4346	5:40 PM	6:30 PM	17.6758	10.2412	9.8	31.8
Y-10-RF-E35	Yellow	2:00	9/11/03 6:30 PM	7.5238	6:30 PM	7:20 PM	17.3742	9.8504	9.4	32.6

Table B.10 (Contd)

Sample	Source Column	Elapsed Time at Start, hh:mm	Projected Date/Time	Vial + Cap Mass (g)	Sampling Start Time	Sampling End Time	Sample+Vial + Cap Mass (g)	Sample Mass (g)	Volume, mL	#CV processed
Y-10-RF-E36	Yellow	2:50	9/11/03 7:20 PM	7.5224	7:20 PM	8:10 PM	17.5411	10.0187	9.6	33.5
Y-10-RF-E37	Yellow	3:40	9/11/03 8:10 PM	7.5318	8:10 PM	9:00 PM	17.9184	10.3866	10.0	34.4
Y-10-RF-E38	Yellow	4:30	9/11/03 9:00 PM	7.6243	9:00 PM	9:50 PM	17.9472	10.3229	9.9	35.3
Y-10-RF-E39	Yellow	5:20	9/11/03 9:50 PM	7.4517	9:50 PM	10:40 PM	18.1343	10.6826	10.2	36.3
Y-10-RF-E40	Yellow	6:10	9/11/03 10:40 PM	7.4008	10:40 PM	11:30 PM	17.5461	10.1453	9.7	37.1
Y-10-RF-E41	Yellow	7:00	9/11/03 11:30 PM	7.4368	11:30 PM	12:20 AM	16.5908	9.1540	8.8	37.9
Y-10-RF-E42	Yellow	7:50	9/12/03 12:20 AM	7.3437	12:20 AM	1:10 AM	16.7619	9.4182	9.0	38.8
Y-10-RF-E43	Yellow	8:40	9/12/03 1:10 AM	7.4380	1:10 AM	2:00 AM	16.5752	9.1372	8.8	39.5
Y-10-RF-E44	Yellow	9:30	9/12/03 2:00 AM	7.5321	2:00 AM	2:50 AM	17.9350	10.4029	10.0	40.5
Y-10-RF-E45	Yellow	10:20	9/12/03 2:50 AM	7.4022	2:50 AM	3:40 AM	17.3880	9.9858	9.6	41.3
Y-10-RF-E46	Yellow	11:10	9/12/03 3:40 AM	7.4838	3:40 AM	4:30 AM	17.6332	10.1494	9.7	42.2
Y-10-RF-E47	Yellow	12:00	9/12/03 4:30 AM	7.3816	4:30 AM	5:20 AM	17.6592	10.2776	9.9	43.1
Y-10-RF-E48	Yellow	12:50	9/12/03 5:20 AM	7.4649	5:20 AM	6:10 AM	17.0614	9.5965	9.2	43.9
Y-10-RF-E49	Yellow	13:40	9/12/03 6:10 AM	7.4634	6:10 AM	7:00 AM	17.1771	9.7137	9.3	44.8
Y-10-RF-E50	Yellow	14:30	9/12/03 7:00 AM	7.3410	7:00 AM	7:50 AM	17.1580	9.8170	9.4	45.6
Y-10-RF-E51	Yellow	15:20	9/12/03 7:50 AM	7.4473	7:50 AM	8:40 AM	17.1261	9.6788	9.3	46.5
Y-10-RF-E52	Yellow	16:10	9/12/03 8:40 AM	7.4789	8:40 AM	9:30 AM	17.2817	9.8028	9.4	47.3
Y-10-RF-E53	Yellow	17:00	9/12/03 9:30 AM	7.4373	9:30 AM	10:20 AM	17.6046	10.1673	9.7	48.2
Y-10-RF-E54	Yellow	17:50	9/12/03 10:20 AM	6.9674	10:20 AM	11:10 AM	17.1073	10.1399	9.7	49.1
Y-10-RF-E55	Yellow	18:40	9/12/03 11:10 AM	7.3504	11:10 AM	12:00 PM	17.5381	10.1877	9.8	50.0
Y-10-RF-E56	Yellow	19:30	9/12/03 12:00 PM	7.5266	12:00 PM	12:50 PM	17.4380	9.9114	9.5	50.9
Y-10-RF-E57	Yellow	20:20	9/12/03 12:50 PM	7.4391	12:50 PM	1:40 PM	17.3814	9.9423	9.5	51.7
Y-10-RF-E58	Yellow	21:10	9/12/03 1:40 PM	6.8996	1:40 PM	2:30 PM	16.8334	9.9338	9.5	52.6
Y-10-RF-E59	Yellow	22:00	9/12/03 2:30 PM	7.5291	2:30 PM	3:20 PM	17.1321	9.6030	9.2	53.4
Y-10-RF-E60	Yellow	22:50	9/12/03 3:20 PM	6.9007	3:20 PM	4:10 PM	17.1673	10.2666	9.8	54.3
Y-10-RF-E61	Yellow	23:40	9/12/03 4:10 PM	7.3949	4:10 PM	5:00 PM	19.2039	11.8090	11.3	55.4
Y-10-RF-E62	Yellow	0:30	9/12/03 5:00 PM	7.4195	5:00 PM	5:50 PM	19.1105	11.6910	11.2	56.4
Y-10-RF-E63	Yellow	1:20	9/12/03 5:50 PM	7.4242	5:50 PM	6:40 PM	18.3462	10.9220	10.5	57.3

Table B.10 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, ml	count time, sec	gross counts	net counts	back ground	Tot cts-bck	control counts	C/Co
Y-10-RF-E01	9/18/03	3:02 PM	Y10RFE01	10.0	302.74	58695	54,027	0	54,027	1,465,371	3.69E-02
Y-10-RF-E02	9/18/03	3:10 PM	Y10RFE02	10.0	313.58	386205	360,343	0	360,343	1,465,371	2.46E-01
Y-10-RF-E03	9/19/03	11:06 AM	Y10RFE03	10.0	301.72	25478	257,588,882	0	257,588,882	2,734,884	9.42E+01
Y-10-RF-E04	9/19/03	11:12 AM	Y10RFE04	10.0	304.92	124306	1,124,160,556	0	1,124,160,556	2,734,884	4.11E+02
Y-10-RF-E05	9/19/03	11:18 AM	Y10RFE05	10.0	301.9	30934	280,483,260	0	280,483,260	2,734,884	1.03E+02
Y-10-RF-E06	9/19/03	11:39 AM	Y10RFE06	10.0	301.1	5661	52,263,232	0	52,263,232	2,734,884	1.91E+01
Y-10-RF-E07	9/19/03	11:49 AM	Y10RFE07	10.0	306.88	182607	17,163,991	0	17,163,991	2,734,884	6.28E+00
Y-10-RF-E08	9/22/03	8:40 AM	Y10RFE08	10.0	302.84	58534	4,984,578	0	4,984,578	2,734,884	1.82E+00
Y-10-RF-E09	9/22/03	8:47 AM	Y10RFE09	10.0	301.48	16935	1,420,815	0	1,420,815	2,734,884	5.20E-01
Y-10-RF-E10	9/15/03	1:46 PM	Y10RFE10	10.0	320.86	578256	531,345	0	531,345	2,734,884	1.94E-01
Y-10-RF-E11	9/15/03	1:53 PM	Y10RFE11	10.0	309.2	247078	228,378	0	228,378	2,734,884	8.35E-02
Y-10-RF-E12	9/15/03	2:02 PM	Y10RFE12	10.0	305.2	128417	118,358	0	118,358	2,734,884	4.33E-02
Y-10-RF-E13	9/15/03	2:07 PM	Y10RFE13	10.0	303.42	75154	68,819	0	68,819	2,734,884	2.52E-02
Y-10-RF-E14	9/15/03	2:14 PM	Y10RFE14	10.0	302.58	49756	46,064	0	46,064	2,734,884	1.68E-02
Y-10-RF-E15	9/15/03	2:21 PM	Y10RFE15	10.0	302.18	37740	34,340	0	34,340	2,734,884	1.26E-02
Y-10-RF-E16	9/15/03	2:27 PM	Y10RFE16	10.0	301.94	30322	27,064	0	27,064	2,734,884	9.90E-03
Y-10-RF-E17	9/15/03	2:53 PM	Y10RFE17	10.0	301.78	25630	22,840	0	22,840	2,734,884	8.35E-03
Y-10-RF-E18	9/15/03	3:16 PM	Y10RFE18	10.0	301.78	23567	20,921	0	20,921	2,734,884	7.65E-03
Y-10-RF-E19	9/15/03	3:30 PM	Y10RFE19	10.0	301.68	20092	17,778	0	17,778	2,734,884	6.50E-03
Y-10-RF-E20	9/15/03	3:41 PM	Y10RFE20	10.0	301.6	18380	16,170	0	16,170	2,734,884	5.91E-03
Y-10-RF-E21	9/15/03	3:48 PM	Y10RFE21	10.0	301.58	17135	15,435	0	15,435	2,734,884	5.64E-03
Y-10-RF-E22	9/15/03	4:09 PM	Y10RFE22	10.0	301.5	16615	15,062	0	15,062	2,734,884	5.51E-03
Y-10-RF-E23	9/15/03	4:24 PM	Y10RFE23	10.0	301.48	15537	13,826	0	13,826	2,734,884	5.06E-03
Y-10-RF-E24	9/15/03	4:33 PM	Y10RFE24	10.0	301.46	14704	13,110	0	13,110	2,734,884	4.79E-03
Y-10-RF-E25	9/15/03	4:43 PM	Y10RFE25	10.0	301.42	14010	12,668	0	12,668	2,734,884	4.63E-03
Y-10-RF-E26	9/16/03	7:52 AM	Y10RFE26	10.0	301.34	12925	11,368	0	11,368	2,734,884	4.16E-03
Y-10-RF-E27	9/16/03	8:52 AM	Y10RFE27	10.0	301.34	12621	11,060	0	11,060	2,734,884	4.04E-03
Y-10-RF-E28	9/16/03	10:21 AM	Y10RFE28	10.0	301.34	11820	10,335	0	10,335	2,734,884	3.78E-03
Y-10-RF-E29	9/16/03	10:42 AM	Y10RFE29	10.0	301.34	11773	10,143	0	10,143	2,734,884	3.71E-03
Y-10-RF-E30	9/16/03	10:53 AM	Y10RFE30	10.0	301.32	11634	10,401	0	10,401	2,734,884	3.80E-03
Y-10-RF-E31	9/26/03	12:09 PM	Y10RFE31	10.0	904.02	34196	30,107	0	30,107	8,298,693	3.63E-03
Y-10-RF-E32	9/26/03	11:52 AM	Y10RFE32	10.0	903.98	32719	28,268	0	28,268	8,298,693	3.41E-03
Y-10-RF-E33	9/26/03	11:36 AM	Y10RFE33	10.0	903.86	31152	26,412	0	26,412	8,298,693	3.18E-03
Y-10-RF-E34	9/26/03	11:13 AM	Y10RFE34	10.0	903.98	32656	28,747	0	28,747	8,298,693	3.46E-03
Y-10-RF-E35	9/26/03	10:55 AM	Y10RFE35	10.0	903.9	29832	25,272	0	25,272	8,298,693	3.05E-03
Y-10-RF-E36	9/26/03	10:28 AM	Y10RFE36	10.0	903.96	29665	26,407	0	26,407	8,298,693	3.18E-03
Y-10-RF-E37	9/23/03	8:14 AM	Y10RFE37	10.0	301.3	9127	7,860	0	7,860	2,734,884	2.87E-03
Y-10-RF-E38	9/26/03	10:00 AM	Y10RFE38	10.0	903.8	24989	21,152	0	21,152	8,298,693	2.55E-03
Y-10-RF-E39	9/26/03	9:43 AM	Y10RFE39	10.0	903.74	23826	20,388	0	20,388	8,298,693	2.46E-03
Y-10-RF-E40	9/26/03	9:26 AM	Y10RFE40	10.0	903.66	21601	18,235	0	18,235	8,298,693	2.20E-03

Table B.10 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, ml	count time, sec	gross counts	net counts	back ground	Tot cts-bck	control counts	C/Co
Y-10-RF-E41	9/26/03	9:07 AM	Y10RFE41	10.0	903.64	19345	15,581	0	15,581	8,298,693	1.88E-03
Y-10-RF-E42	9/25/03	4:54 AM	Y10RFE42	10.0	903.64	20120	17,116	0	17,116	8,298,693	2.06E-03
Y-10-RF-E43	9/23/03	8:49 AM	Y10RFE43	10.0	301.24	7349	5,790	0	5,790	2,734,884	2.12E-03
Y-10-RF-E44	9/25/03	4:38 PM	Y10RFE44	10.0	903.62	20210	16,844	0	16,844	8,298,693	2.03E-03
Y-10-RF-E45	9/25/03	4:22 PM	Y10RFE45	10.0	903.56	18623	14,606	0	14,606	8,298,693	1.76E-03
Y-10-RF-E46	9/25/03	4:06 PM	Y10RFE46	10.0	903.52	17468	14,388	0	14,388	8,298,693	1.73E-03
Y-10-RF-E47	9/25/03	3:49 PM	Y10RFE47	10.0	903.54	16694	13,436	0	13,436	8,298,693	1.62E-03
Y-10-RF-E48	9/23/03	8:56 AM	Y10RFE48	10.0	903.48	15325	11,992	0	11,992	8,298,693	1.45E-03
Y-10-RF-E49	9/25/03	3:04 PM	Y10RFE49	10.0	903.44	15162	11,977	0	11,977	8,298,693	1.44E-03
Y-10-RF-E50	9/25/03	2:48 PM	Y10RFE50	10.0	903.44	15392	12,713	0	12,713	8,298,693	1.53E-03
Y-10-RF-E51	9/25/03	2:31 PM	Y10RFE51	10.0	903.44	15017	11,325	0	11,325	8,298,693	1.36E-03
Y-10-RF-E52	9/25/03	2:15 PM	Y10RFE52	10.0	903.42	15076	11,601	0	11,601	8,298,693	1.40E-03
Y-10-RF-E53	9/25/03	1:58 PM	Y10RFE53	10.0	903.32	15431	12,429	0	12,429	8,298,693	1.50E-03
Y-10-RF-E54	9/23/03	9:15 AM	Y10RFE54	10.0	903.52	15159	10,743	0	10,743	8,298,693	1.29E-03
Y-10-RF-E55	9/25/03	1:42 PM	Y10RFE55	10.0	903.44	14608	11,350	0	11,350	8,298,693	1.37E-03
Y-10-RF-E56	9/25/03	1:26 PM	Y10RFE56	10.0	903.38	13798	11,120	0	11,120	8,298,693	1.34E-03
Y-10-RF-E57	9/25/03	1:10 PM	Y10RFE57	10.0	903.38	13829	10,679	0	10,679	8,298,693	1.29E-03
Y-10-RF-E58	9/25/03	12:52 PM	Y10RFE58	10.0	903.42	13916	10,368	0	10,368	8,298,693	1.25E-03
Y-10-RF-E59	9/25/03	12:36 PM	Y10RFE59	10.0	903.38	12733	9,841	0	9,841	8,298,693	1.19E-03
Y-10-RF-E60	9/23/03	9:41 AM	Y10RFE60	10.0	903.54	14273	11,160	0	11,160	8,298,693	1.34E-03
Y-10-RF-E61	9/25/03	12:18 PM	Y10RFE61	10.0	903.46	15215	11,704	0	11,704	8,298,693	1.41E-03
Y-10-RF-E62	9/25/03	12:00 PM	Y10RFE62	10.0	903.42	14559	11,482	0	11,482	8,298,693	1.38E-03
Y-10-RF-E63	9/23/03	10:00 AM	Y10RFE63	10.0	903.44	13615	10,466	0	10,466	8,298,693	1.26E-03

Elution

Feed = 0.5 M HNO_3 at 25°C
Resin = Spherical RF, Resin #3
Bed Volume = 11 mL
Density 0.5 M HNO_3 = 1.014 g/mL

Flow Rate = approx 15.4 mL/hr or 1.4 CV/hr
Start Date and Time = 9/10/03 4:30 PM
End Date and Time = 9/12/03 6:20 PM

Table B.11. Elution of RF Blue Column—25°C, 0.5 M HNO_3 at Flow of 1.4 BV/h

Sample	Source	Elapsed Time at Start, hh:mm	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial Tare, g	Sample and Vial, g	Sample Mass (g)	Volume, mL	#CV processed
B-10-RF-E01	Blue	0:00	9/10/03 4:30 PM	4:30 PM	5:00 PM	7.5263	15.5444	8.0181	7.91	0.7
B-10-RF-E02	Blue	0:30	9/10/03 5:00 PM	5:00 PM	5:30 PM	7.4479	15.2127	7.7648	7.66	1.4
B-10-RF-E03	Blue	1:00	9/10/03 5:30 PM	5:30 PM	6:00 PM	7.4948	15.1647	7.6699	7.56	2.1
B-10-RF-E04	Blue	1:30	9/10/03 6:00 PM	6:00 PM	6:30 PM	7.4207	15.1547	7.7340	7.63	2.8
B-10-RF-E05	Blue	2:00	9/10/03 6:30 PM	6:30 PM	7:00 PM	7.5357	15.2636	7.7279	7.62	3.5
B-10-RF-E06	Blue	2:30	9/10/03 7:00 PM	7:00 PM	7:30 PM	7.3971	15.1297	7.7326	7.63	4.2
B-10-RF-E07	Blue	3:00	9/10/03 7:30 PM	7:30 PM	8:00 PM	7.3624	15.0297	7.6673	7.56	4.9
B-10-RF-E08	Blue	3:30	9/10/03 8:00 PM	8:00 PM	8:50 PM	7.5028	20.1628	12.6600	12.49	6.0
B-10-RF-E09	Blue	4:20	9/10/03 8:50 PM	8:50 PM	9:40 PM	7.4479	20.3492	12.9013	12.72	7.2
B-10-RF-E10	Blue	5:10	9/10/03 9:40 PM	9:40 PM	10:30 PM	7.5281	20.4067	12.8786	12.70	8.3
B-10-RF-E11	Blue	6:00	9/10/03 10:30 PM	10:30 PM	11:20 PM	7.4038	20.0615	12.6577	12.48	9.5
B-10-RF-E12	Blue	6:50	9/10/03 11:20 PM	11:20 PM	12:10 AM	7.4861	20.0821	12.5960	12.42	10.6
B-10-RF-E13	Blue	7:40	9/11/03 12:10 AM	12:10 AM	1:00 AM	7.4168	20.0805	12.6637	12.49	11.7
B-10-RF-E14	Blue	8:30	9/11/03 1:00 AM	1:00 AM	1:50 AM	7.5141	20.1630	12.6489	12.47	12.8
B-10-RF-E15	Blue	9:20	9/11/03 1:50 AM	1:50 AM	2:40 AM	7.4119	20.0945	12.6826	12.51	14.0
B-10-RF-E16	Blue	10:10	9/11/03 2:40 AM	2:40 AM	3:30 AM	7.4239	20.2099	12.7860	12.61	15.1
B-10-RF-E17	Blue	11:00	9/11/03 3:30 AM	3:30 AM	4:20 AM	7.3802	20.2249	12.8447	12.67	16.3
B-10-RF-E18	Blue	11:50	9/11/03 4:20 AM	4:20 AM	5:10 AM	7.5149	20.1103	12.5954	12.42	17.4
B-10-RF-E19	Blue	12:40	9/11/03 5:10 AM	5:10 AM	6:00 AM	7.4842	20.5501	13.0659	12.89	18.6
B-10-RF-E20	Blue	13:30	9/11/03 6:00 AM	6:00 AM	6:50 AM	7.3878	20.2640	12.8762	12.70	19.7
B-10-RF-E21	Blue	14:20	9/11/03 6:50 AM	6:50 AM	7:40 AM	7.3764	20.1643	12.7879	12.61	20.9
B-10-RF-E22	Blue	15:10	9/11/03 7:40 AM	7:40 AM	8:30 AM	7.6237	20.4091	12.7854	12.61	22.0
B-10-RF-E23	Blue	16:00	9/11/03 8:30 AM	8:30 AM	9:20 AM	7.5142	20.3524	12.8382	12.66	23.2
B-10-RF-E24	Blue	16:50	9/11/03 9:20 AM	9:20 AM	10:10 AM	7.5241	20.1274	12.6033	12.43	24.3
B-10-RF-E25	Blue	17:40	9/11/03 10:10 AM	10:10 AM	11:00 AM	7.3799	20.2118	12.8319	12.65	25.5
B-10-RF-E26	Blue	18:30	9/11/03 11:00 AM	11:00 AM	11:50 AM	7.4360	20.3037	12.8677	12.69	26.6
B-10-RF-E27	Blue	19:20	9/11/03 11:50 AM	11:50 AM	12:40 PM	7.4071	20.2819	12.8748	12.70	27.8
B-10-RF-E28	Blue	20:10	9/11/03 12:40 PM	12:40 PM	1:30 PM	7.4346	20.0355	12.6009	12.43	28.9
B-10-RF-E29	Blue	21:00	9/11/03 1:30 PM	1:30 PM	2:20 PM	7.3789	19.9960	12.6171	12.44	30.0
B-10-RF-E30	Blue	21:50	9/11/03 2:20 PM	2:20 PM	3:10 PM	7.3867	19.7749	12.3882	12.22	31.1
B-10-RF-E31	Blue	22:40	9/11/03 3:10 PM	3:10 PM	4:00 PM	7.3291	20.2502	12.9211	12.74	32.3
B-10-RF-E32	Blue	23:30	9/11/03 4:00 PM	4:00 PM	4:50 PM	7.4208	20.0615	12.6407	12.47	33.4
B-10-RF-E33	Blue	0:20	9/11/03 4:50 PM	4:50 PM	5:40 PM	7.4478	19.7393	12.2915	12.12	34.5
B-10-RF-E34	Blue	1:10	9/11/03 5:40 PM	5:40 PM	6:30 PM	7.4295	19.9281	12.4986	12.33	35.7
B-10-RF-E35	Blue	2:00	9/11/03 6:30 PM	6:30 PM	7:20 PM	7.3959	19.9502	12.5543	12.38	36.8

Table B.11 (Contd)

Sample	Source	Elapsed Time at Start, hh:mm	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial Tare, g	Sample and Vial, g	Sample Mass (g)	Volume, mL	#CV processed
B-10-RF-E36	Blue	2:50	9/11/03 7:20 PM	7:20 PM	8:10 PM	7.3929	19.6705	12.2776	12.11	37.9
B-10-RF-E37	Blue	3:40	9/11/03 8:10 PM	8:10 PM	9:00 PM	7.4692	20.0014	12.5322	12.36	39.0
B-10-RF-E38	Blue	4:30	9/11/03 9:00 PM	9:00 PM	9:50 PM	7.6079	20.1805	12.5726	12.40	40.1
B-10-RF-E39	Blue	5:20	9/11/03 9:50 PM	9:50 PM	10:40 PM	7.4826	21.0094	13.5268	13.34	41.3
B-10-RF-E40	Blue	6:10	9/11/03 10:40 PM	10:40 PM	11:30 PM	7.3722	19.7750	12.4028	12.23	42.5
B-10-RF-E41	Blue	7:00	9/11/03 11:30 PM	11:30 PM	12:20 AM	7.4196	19.8547	12.4351	12.26	43.6
B-10-RF-E42	Blue	7:50	9/12/03 12:20 AM	12:20 AM	1:10 AM	7.5055	20.6044	13.0989	12.92	44.7
B-10-RF-E43	Blue	8:40	9/12/03 1:10 AM	1:10 AM	2:00 AM	7.4203	18.5456	11.1253	10.97	45.7
B-10-RF-E44	Blue	9:30	9/12/03 2:00 AM	2:00 AM	2:50 AM	7.3890	19.8807	12.4917	12.32	46.9
B-10-RF-E45	Blue	10:20	9/12/03 2:50 AM	2:50 AM	3:40 AM	7.3968	19.9822	12.5854	12.41	48.0
B-10-RF-E46	Blue	11:10	9/12/03 3:40 AM	3:40 AM	4:30 AM	7.4017	19.9713	12.5696	12.40	49.1
B-10-RF-E47	Blue	12:10	9/12/03 4:20 PM	4:20 PM	5:20 PM	7.4925	17.7449	10.2524	10.11	50.0
B-10-RF-E48	Blue	13:10	9/12/03 5:20 PM	5:20 PM	6:20 PM	7.3569	17.7173	10.3604	10.22	51.0

Table B.11 (Contd)

Sample	Count date	Count start time	file name	volume counted	count time, sec	gross counts	net counts	back ground	Tot cts-bck	control counts	C/Co
B-10-RF-E01	9/17/03	8:13 AM	B10RFE01	5	302.98	64262	59,630	0	59,630	1,392,633	4.28E-02
B-10-RF-E02	9/17/03	8:21 AM	B10RFE02	5	307.78	210542	197,555	0	197,555	1,392,633	1.42E-01
B-10-RF-E03	9/17/03	8:29 AM	B10RFE03	5	312.36	346006	323,544	0	323,544	1,392,633	2.32E-01
B-10-RF-E04	9/18/03	1:31 PM	B10RFE04	5	312.62	349643	32,501,568	0	32,501,568	2,584,224	1.26E+01
B-10-RF-E05	9/18/03	2:06 PM	B10RFE05	5	301.88	31035	281,875,559	0	281,875,559	2,584,224	1.09E+02
B-10-RF-E06	9/18/03	2:22 PM	B10RFE06	5	302.26	43767	404,058,827	0	404,058,827	2,584,224	1.56E+02
B-10-RF-E07	9/18/03	2:29 PM	B10RFE07	5	301.24	12017	111,479,929	0	111,479,929	2,584,224	4.31E+01
B-10-RF-E08	9/17/03	9:25 AM	B10RFE08	10	310.64	292074	272,071	0	272,071	2,584,224	1.05E-01
B-10-RF-E09	9/17/03	9:38 AM	B10RFE09	10	301.72	23279	21,286	0	21,286	2,584,224	8.24E-03
B-10-RF-E10	9/11/03	3:30 PM	B10RFE10	10	301.24	11105	9,876	0	9,876	2,584,224	3.82E-03
B-10-RF-E11	9/11/03	9:05 PM	B10RFE11	10	301.14	7916	6,431	0	6,431	2,584,224	2.49E-03
B-10-RF-E12	9/11/03	9:10 PM	B10RFE12	10	602.18	13575	11,365	0	11,365	5,288,571	2.15E-03
B-10-RF-E13	9/11/03	9:30 AM	B10RFE13	10	602.04	8652	6,371	0	6,371	5,288,571	1.20E-03
B-10-RF-E14	9/11/03	10:50 PM	B10RFE14	10	1806.06	22270	15,685	0	15,685	15,527,376	1.01E-03
B-10-RF-E15	9/11/03	11:25 PM	B10RFE15	10	1805.84	15892	10,319	0	10,319	15,527,376	6.65E-04
B-10-RF-E16	9/11/03	11:55 PM	B10RFE16	10	1805.76	13391	9,339	0	9,339	15,527,376	6.01E-04
B-10-RF-E17	9/12/03	1:20 AM	B10RFE17	10	1805.7	11794	7,306	0	7,306	15,527,376	4.71E-04
B-10-RF-E18	9/12/03	2:10 AM	B10RFE18	10	1805.66	10023	4,487	0	4,487	15,527,376	2.89E-04
B-10-RF-E19	9/12/03	5:05 AM	B10RFE19	10	3611.14	16460	6,946	0	6,946	30,880,440	2.25E-04
B-10-RF-E20	9/12/03	7:05 AM	B10RFE20	10	3611.1	15646	5,841	0	5,841	30,880,440	1.89E-04

Table B.11 (Contd)

Sample	Count date	Count start time	file name	volume counted	count time, sec	gross counts	net counts	back ground	Tot cts-bck	control counts	C/Co
B-10-RF-E21	9/12/03	8:25 AM	B10RFE21	10	3611.16	14708	4,652	0	4,652	30,880,440	1.51E-04
B-10-RF-E22	9/12/03	9:40 AM	B10RFE22	10	3611.1	14160	4,828	0	4,828	30,880,440	1.56E-04
B-10-RF-E23	9/12/03	10:55 AM	B10RFE23	10	3611.12	13819	3,726	0	3,726	30,880,440	1.21E-04
B-10-RF-E24	9/12/03	12:00 PM	B10RFE24	10	3611.1	13433	3,339	0	3,339	30,880,440	1.08E-04
B-10-RF-E25	9/12/03	1:00 PM	B10RFE25	10	7222.34	26679	6,170	0	6,170	60,223,095	**1.61E-04**
B-10-RF-E26	9/12/03	4:00 PM	B10RFE26	10	7222.5	25767	4,571	0	4,571	60,223,095	7.59E-05
B-10-RF-E27	9/12/03	6:16 PM	B10RFE27	10	7222.52	24614	4,430	0	4,430	60,223,095	**1.21E-04**
B-10-RF-E28	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E29	--	--	--	--	--	--	--	--	--	--	**1.13E-04**
B-10-RF-E30	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E31	--	--	--	--	--	--	--	--	--	--	**1.04E-04**
B-10-RF-E32	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E33	--	--	--	--	--	--	--	--	--	--	**1.04E-04**
B-10-RF-E34	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E35	--	--	--	--	--	--	--	--	--	--	**1.10E-04**
B-10-RF-E36	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E37	--	--	--	--	--	--	--	--	--	--	**7.08E-05**
B-10-RF-E38	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E39	--	--	--	--	--	--	--	--	--	--	**6.22E-05**
B-10-RF-E40	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E41	--	--	--	--	--	--	--	--	--	--	**6.09E-05**
B-10-RF-E42	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E43	--	--	--	--	--	--	--	--	--	--	**5.17E-05**
B-10-RF-E44	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E45	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E46	--	--	--	--	--	--	--	--	--	--	--
B-10-RF-E47	9/22/03	10:31 AM	B10RFE47	10	3611.6	18311	8,001	0	8,001	30,880,440	2.59E-04
B-10-RF-E48	9/22/03	11:42 AM	B10RFE48	10	7225.3	31091	7,544	0	7,544	60,223,095	1.25E-04

- indicates no data

Bold numbers were calculated from GEA analysis

Elution

Feed = 0.5 M HNO_3 at 45°C
Resin = GG RF, Lot 6
Bed Volume = 11 mL
Density 0.5 M HNO_3 = 1.014 g/mL

Flow Rate = approx 15.4 mL/hr or 1.4 CV/hr
Start Date and Time = 9/10/03 4:30 PM
End Date and Time = 9/12/03 6:40 PM

Table B.12. Elution of RF Green Column—45°C, 0.5 M HNO_3 at a Flow of 1.4 BV/h

Sample	Source	Elapsed Time at Start, hh:mm	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial Tare, g	Sample and Vial, g	Sample Mass (g)	Volume, mL	#CV processed
G-10-RF-E01	Green	0:00	9/10/03 4:30 PM	4:30 PM	5:00 PM	7.4313	15.4435	8.0122	7.9016	0.72
G-10-RF-E02	Green	0:30	9/10/03 5:00 PM	5:00 PM	5:30 PM	7.3505	14.5774	7.2269	7.1271	1.37
G-10-RF-E03	Green	1:00	9/10/03 5:30 PM	5:30 PM	6:00 PM	7.4452	14.7274	7.2822	7.1817	2.02
G-10-RF-E04	Green	1:30	9/10/03 6:00 PM	6:00 PM	6:30 PM	7.3787	14.7260	7.3473	7.2459	2.68
G-10-RF-E05	Green	2:00	9/10/03 6:30 PM	6:30 PM	7:00 PM	7.6199	15.1844	7.5645	7.4601	3.36
G-10-RF-E06	Green	2:30	9/10/03 7:00 PM	7:00 PM	7:30 PM	7.5430	15.2644	7.7214	7.6148	4.05
G-10-RF-E07	Green	3:00	9/10/03 7:30 PM	7:30 PM	8:00 PM	7.4408	15.1274	7.6866	7.5805	4.74
G-10-RF-E08	Green	3:30	9/10/03 8:00 PM	8:00 PM	8:50 PM	7.4054	20.1052	12.6998	12.5245	5.88
G-10-RF-E09	Green	4:20	9/10/03 8:50 PM	8:50 PM	9:40 PM	7.6268	20.4046	12.7778	12.6014	7.02
G-10-RF-E10	Green	5:10	9/10/03 9:40 PM	9:40 PM	10:30 PM	7.4471	20.1514	12.7043	12.5289	8.16
G-10-RF-E11	Green	6:00	9/10/03 10:30 PM	10:30 PM	11:20 PM	7.5129	20.0090	12.4961	12.3236	9.28
G-10-RF-E12	Green	6:50	9/10/03 11:20 PM	11:20 PM	12:10 AM	7.4189	20.0112	12.5923	12.4184	10.41
G-10-RF-E13	Green	7:40	9/11/03 12:10 AM	12:10 AM	1:00 AM	7.4257	20.1303	12.7046	12.5292	11.55
G-10-RF-E14	Green	8:30	9/11/03 1:00 AM	1:00 AM	1:50 AM	7.3783	20.0302	12.6519	12.4772	12.68
G-10-RF-E15	Green	9:20	9/11/03 1:50 AM	1:50 AM	2:40 AM	7.4332	19.9849	12.5517	12.3784	13.81
G-10-RF-E16	Green	10:10	9/11/03 2:40 AM	2:40 AM	3:30 AM	7.4937	20.0476	12.5539	12.3806	14.93
G-10-RF-E17	Green	11:00	9/11/03 3:30 AM	3:30 AM	4:20 AM	7.4307	20.0297	12.5990	12.4250	16.06
G-10-RF-E18	Green	11:50	9/11/03 4:20 AM	4:20 AM	5:10 AM	7.6109	19.9390	12.3281	12.1579	17.17
G-10-RF-E19	Green	12:40	9/11/03 5:10 AM	5:10 AM	6:00 AM	7.4602	20.2739	12.8137	12.6368	18.32
G-10-RF-E20	Green	13:30	9/11/03 6:00 AM	6:00 AM	6:50 AM	7.4033	20.1207	12.7174	12.5418	19.46
G-10-RF-E21	Green	14:20	9/11/03 6:50 AM	6:50 AM	7:40 AM	7.5119	20.0305	12.5186	12.3458	20.58
G-10-RF-E22	Green	15:10	9/11/03 7:40 AM	7:40 AM	8:30 AM	7.4307	19.9606	12.5299	12.3569	21.70
G-10-RF-E23	Green	16:00	9/11/03 8:30 AM	8:30 AM	9:20 AM	7.3654	20.0992	12.7338	12.5580	22.85
G-10-RF-E24	Green	16:50	9/11/03 9:20 AM	9:20 AM	10:10 AM	7.5135	19.8896	12.3761	12.2052	23.95
G-10-RF-E25	Green	17:40	9/11/03 10:10 AM	10:10 AM	11:00 AM	7.3906	20.0093	12.6187	12.4445	25.09
G-10-RF-E26	Green	18:30	9/11/03 11:00 AM	11:00 AM	11:50 AM	7.4950	20.0406	12.5456	12.3724	26.21
G-10-RF-E27	Green	19:20	9/11/03 11:50 AM	11:50 AM	12:40 PM	7.6413	20.0806	12.4393	12.2676	27.33
G-10-RF-E28	Green	20:10	9/11/03 12:40 PM	12:40 PM	1:30 PM	7.4259	19.7589	12.3330	12.1627	28.43
G-10-RF-E29	Green	21:00	9/11/03 1:30 PM	1:30 PM	2:20 PM	7.4322	19.9344	12.5022	12.3296	29.55
G-10-RF-E30	Green	21:50	9/11/03 2:20 PM	2:20 PM	3:10 PM	7.3993	19.6979	12.2986	12.1288	30.66
G-10-RF-E31	Green	22:40	9/11/03 3:10 PM	3:10 PM	4:00 PM	7.4796	20.3691	12.8895	12.7115	31.81
G-10-RF-E32	Green	23:30	9/11/03 4:00 PM	4:00 PM	4:50 PM	7.4469	20.1395	12.6926	12.5174	32.95
G-10-RF-E33	Green	0:20	9/11/03 4:50 PM	4:50 PM	5:40 PM	7.5341	19.9462	12.4121	12.2407	34.06
G-10-RF-E34	Green	1:10	9/11/03 5:40 PM	5:40 PM	6:30 PM	7.4436	20.1789	12.7353	12.5595	35.20
G-10-RF-E35	Green	2:00	9/11/03 6:30 PM	6:30 PM	7:20 PM	7.4279	20.0653	12.6374	12.4629	36.34

Table B.12 (Contd)

Sample	Source	Elapsed Time at Start, hh:mm	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial Tare, g	Sample and Vial, g	Sample Mass (g)	Volume, mL	#CV processed
G-10-RF-E36	Green	2:50	9/11/03 7:20 PM	7:20 PM	8:10 PM	7.5209	20.0723	12.5514	12.3781	37.46
G-10-RF-E37	Green	3:40	9/11/03 8:10 PM	8:10 PM	9:00 PM	7.4719	20.1074	12.6355	12.4610	38.59
G-10-RF-E38	Green	4:30	9/11/03 9:00 PM	9:00 PM	9:50 PM	7.4784	20.0727	12.5943	12.4204	39.72
G-10-RF-E39	Green	5:20	9/11/03 9:50 PM	9:50 PM	10:40 PM	7.3630	20.1798	12.8168	12.6398	40.87
G-10-RF-E40	Green	6:10	9/11/03 10:40 PM	10:40 PM	11:30 PM	7.5091	19.9968	12.4877	12.3153	41.99
G-10-RF-E41	Green	7:00	9/11/03 11:30 PM	11:30 PM	12:20 AM	7.4261	19.9891	12.5630	12.3895	43.12
G-10-RF-E42	Green	7:50	9/12/03 12:20 AM	12:20 AM	1:10 AM	7.5072	20.7624	13.2552	13.0722	44.31
G-10-RF-E43	Green	8:40	9/12/03 1:10 AM	1:10 AM	2:00 AM	7.5305	18.6625	11.1320	10.9783	45.30
G-10-RF-E44	Green	9:30	9/12/03 2:00 AM	2:00 AM	2:50 AM	7.4367	20.0554	12.6187	12.4445	46.44
G-10-RF-E45	Green	10:20	9/12/03 2:50 AM	2:50 AM	3:40 AM	7.5073	20.2653	12.7580	12.5819	47.58
G-10-RF-E46	Green	11:10	9/12/03 3:40 AM	3:40 AM	4:30 AM	7.4021	19.8656	12.4635	12.2914	48.70
G-10-RF-E47	Green	12:00	9/12/03 4:30 AM	4:30 AM	5:20 AM	7.4326	20.1477	12.7151	12.5395	49.84
G-10-RF-E48	Green	12:50	9/12/03 5:20 AM	5:20 AM	6:10 AM	7.4325	19.8354	12.4029	12.2317	50.95
G-10-RF-E49	Green	13:40	9/12/03 6:10 AM	6:10 AM	7:00 AM	7.4122	19.7674	12.3552	12.1846	52.06
G-10-RF-E50	Green	14:30	9/12/03 7:00 AM	7:00 AM	7:50 AM	7.4194	19.7824	12.3630	12.1923	53.17
G-10-RF-E51	Green	15:20	9/12/03 7:50 AM	7:50 AM	8:40 AM	6.9655	19.3249	12.3594	12.1888	54.27
G-10-RF-E52	Green	16:10	9/12/03 8:40 AM	8:40 AM	9:30 AM	7.3664	19.8049	12.4385	12.2668	55.39
G-10-RF-E53	Green	17:00	9/12/03 9:30 AM	9:30 AM	10:20 AM	7.4257	19.9645	12.5388	12.3657	56.51
G-10-RF-E54	Green	17:50	9/12/03 10:20 AM	10:20 AM	11:10 AM	7.3432	19.8947	12.5515	12.3782	57.64
G-10-RF-E55	Green	18:40	9/12/03 11:10 AM	11:10 AM	12:00 PM	7.4855	19.9224	12.4369	12.2652	58.75
G-10-RF-E56	Green	19:30	9/12/03 12:00 PM	12:00 PM	12:50 PM	7.3574	19.8850	12.5276	12.3546	59.88
G-10-RF-E57	Green	20:20	9/12/03 12:50 PM	12:50 PM	1:40 PM	7.3590	20.0815	12.7225	12.5468	61.02
G-10-RF-E58	Green	21:10	9/12/03 1:40 PM	1:40 PM	2:30 PM	7.3278	19.7573	12.4295	12.2579	62.13
G-10-RF-E59	Green	22:00	9/12/03 2:30 PM	2:30 PM	3:20 PM	7.4594	19.3232	11.8638	11.7000	63.19
G-10-RF-E60	Green	22:50	9/12/03 3:20 PM	3:20 PM	4:10 PM	7.3505	20.0076	12.6571	12.4823	64.33
G-10-RF-E61	Green	23:40	9/12/03 4:10 PM	4:10 PM	5:00 PM	7.3812	20.1642	12.7830	12.6065	65.48
G-10-RF-E62	Green	0:30	9/12/03 5:00 PM	5:00 PM	5:50 PM	7.4663	19.8736	12.4073	12.2360	66.59
G-10-RF-E63	Green	1:20	9/12/03 5:50 PM	5:50 PM	6:40 PM	7.3819	19.7233	12.3414	12.1710	67.69

Table B.12 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, g	count time, sec	gross counts	Total Net counts	back ground	Tot cts-bck	control counts/ g	C/Co
G-10-RF-E01	9/18/03	11:48 AM	G10RFE01	5.0	305.12	130641	121,235	0	121,235	1,392,633	8.71E-02
G-10-RF-E02	9/18/03	11:56 AM	G10RFE02	5.0	310.02	276857	258,264	0	258,264	1,392,633	1.85E-01
G-10-RF-E03	9/18/03	12:02 PM	G10RFE03	5.0	314.82	418294	387,912	0	387,912	1,392,633	2.79E-01
G-10-RF-E04	9/18/03	12:08 PM	G10RFE04	5.0	316.12	455295	421,839	0	421,839	1,392,633	3.03E-01
G-10-RF-E05	9/18/03	12:16 PM	G10RFE05	5.0	317.04	481088	446,653	0	446,653	1,392,633	3.21E-01
G-10-RF-E06	9/22/03	2:04 PM	G10RFE06	5.0	303.48	75122	697,928,391	0	697,928,391	1,392,633	5.01E+02
G-10-RF-E07	9/22/03	1:58 PM	G10RFE07	5.0	303.78	83441	639,603,463	0	639,603,463	1,392,633	4.59E+02
G-10-RF-E08	9/22/03	2:11 PM	G10RFE08	10.0	301.64	18600	165,739,300	0	165,739,300	2,584,224	6.41E+01
G-10-RF-E09	9/22/03	9:01 AM	G10RFE09	10.0	301.62	21619	2,014,105	0	2,014,105	2,584,224	7.79E-01
G-10-RF-E10	9/22/03	9:10 AM	G10RFE10	10.0	304.2	99117	1,014,840	0	1,014,840	2,584,224	3.93E-01
G-10-RF-E11	9/16/03	1:54 PM	G10RFE11	10.0	316.2	451823	421,403	0	421,403	2,584,224	1.63E-01
G-10-RF-E12	9/16/03	2:00 PM	G10RFE12	10.0	308	214210	200,174	0	200,174	2,584,224	7.75E-02
G-10-RF-E13	9/16/03	2:07 PM	G10RFE13	10.0	304.28	101219	93,910	0	93,910	2,584,224	3.63E-02
G-10-RF-E14	9/16/03	2:15 PM	G10RFE14	10.0	302.52	48067	44,809	0	44,809	2,584,224	1.73E-02
G-10-RF-E15	9/16/03	2:25 PM	G10RFE15	10.0	301.9	28778	26,349	0	26,349	2,584,224	1.02E-02
G-10-RF-E16	9/16/03	2:46 PM	G10RFE16	10.0	301.74	22683	20,402	0	20,402	2,584,224	7.89E-03
G-10-RF-E17	9/16/03	2:54 PM	G10RFE17	10.0	301.56	18889	17,113	0	17,113	2,584,224	6.62E-03
G-10-RF-E18	9/16/03	3:00 PM	G10RFE18	10.0	301.52	16888	15,112	0	15,112	2,584,224	5.85E-03
G-10-RF-E19	9/16/03	3:06 PM	G10RFE19	10.0	301.44	14895	13,265	0	13,265	2,584,224	5.13E-03
G-10-RF-E20	9/16/03	3:12 PM	G10RFE20	10.0	301.38	13057	11,676	0	11,676	2,584,224	4.52E-03
G-10-RF-E21	9/16/03	3:18 PM	G10RFE21	10.0	301.34	11894	10,555	0	10,555	2,584,224	4.08E-03
G-10-RF-E22	9/16/03	3:24 PM	G10RFE22	10.0	301.3	10769	9,030	0	9,030	2,584,224	3.49E-03
G-10-RF-E23	9/16/03	3:54 PM	G10RFE23	10.0	301.28	9927	8,690	0	8,690	2,584,224	3.36E-03
G-10-RF-E24	9/16/03	4:01 PM	G10RFE24	10.0	301.24	8853	7,799	0	7,799	2,584,224	3.02E-03
G-10-RF-E25	9/16/03	4:10 PM	G10RFE25	10.0	301.22	8321	7,413	0	7,413	2,584,224	2.87E-03
G-10-RF-E26	9/16/03	4:17 PM	G10RFE26	10.0	301.2	7817	6,912	0	6,912	2,584,224	2.67E-03
G-10-RF-E27	9/16/03	4:24 PM	G10RFE27	10.0	301.18	7099	6,197	0	6,197	2,584,224	2.40E-03
G-10-RF-E28	9/16/03	4:30 PM	G10RFE28	10.0	301.16	6832	5,775	0	5,775	2,584,224	2.23E-03
G-10-RF-E29	9/16/03	4:36 PM	G10RFE29	10.0	301.16	6438	5,242	0	5,242	2,584,224	2.03E-03
G-10-RF-E30	9/16/03	4:42 PM	G10RFE30	10.0	301.16	6039	4,913	0	4,913	2,584,224	1.90E-03
G-10-RF-E31	9/17/03	12:21 PM	G10RFE31	10.0	1806.26	33267	27,152	0	27,152	15,527,376	1.75E-03
G-10-RF-E32	9/17/03	12:56 PM	G10RFE32	10.0	903.14	16265	13,476	0	13,476	7,709,337	1.75E-03
G-10-RF-E33	9/17/03	1:15 PM	G10RFE33	10.0	903.16	15735	12,297	0	12,297	7,709,337	1.60E-03
G-10-RF-E34	9/17/03	1:53 PM	G10RFE34	10.0	903.12	14860	12,036	0	12,036	7,709,337	1.56E-03
G-10-RF-E35	9/17/03	2:17 PM	G10RFE35	10.0	903.06	13278	10,345	0	10,345	7,709,337	1.34E-03
G-10-RF-E36	9/17/03	2:37 PM	G10RFE36	10.0	903.08	13573	10,240	0	10,240	7,709,337	1.33E-03
G-10-RF-E37	9/17/03	2:56 PM	G10RFE37	10.0	903.02	13010	10,440	0	10,440	7,709,337	1.35E-03
G-10-RF-E38	9/17/03	3:12 PM	G10RFE38	10.0	903.04	12432	9,825	0	9,825	7,709,337	1.27E-03
G-10-RF-E39	9/17/03	3:29 PM	G10RFE39	10.0	903.06	12489	9,882	0	9,882	7,709,337	1.28E-03
G-10-RF-E40	9/17/03	3:45 PM	G10RFE40	10.0	903	12169	9,851	0	9,851	7,709,337	1.28E-03

Table B.12 (Contd)

Sample	Count date	Count start time	file name	Volume Counted, g	count time, sec	gross counts	Total Net counts	back ground	Tot cts-bck	control counts/ g	C/Co
G-10-RF-E41	9/17/03	4:01 PM	G10RFE41	10.0	902.88	11881	8,949	0	8,949	7,709,337	1.16E-03
G-10-RF-E42	9/17/03	4:16 PM	G10RFE42	10.0	902.9	11184	8,505	0	8,505	7,709,337	1.10E-03
G-10-RF-E43	9/17/03	4:41 PM	G10RFE43	10.0	902.9	10724	7,972	0	7,972	7,709,337	1.03E-03
G-10-RF-E44	9/17/03	4:57 PM	G10RFE44	10.0	902.96	10253	7,863	0	7,863	7,709,337	1.02E-03
G-10-RF-E45	9/18/03	9:19 AM	G10RFE45	10.0	903.06	10310	7,194	0	7,194	7,709,337	9.33E-04
G-10-RF-E46	9/18/03	8:47 AM	G10RFE46	10.0	903.06	9904	6,824	0	6,824	7,709,337	8.85E-04
G-10-RF-E47	9/18/03	9:03 AM	G10RFE47	10.0	903.04	9578	6,354	0	6,354	7,709,337	8.24E-04
G-10-RF-E48	9/18/03	9:35 AM	G10RFE48	10.0	902.94	9412	5,972	0	5,972	7,709,337	7.75E-04
G-10-RF-E49	9/18/03	9:52 AM	G10RFE49	10.0	902.98	9195	6,697	0	6,697	7,709,337	8.69E-04
G-10-RF-E50	9/18/03	10:08 AM	G10RFE50	10.0	903	8910	5,794	0	5,794	7,709,337	7.52E-04
G-10-RF-E51	9/18/03	10:26 AM	G10RFE51	10.0	903	8605	5,890	0	5,890	7,709,337	7.64E-04
G-10-RF-E52	9/18/03	10:42 AM	G10RFE52	10.0	902.94	8454	6,137	0	6,137	7,709,337	7.96E-04
G-10-RF-E53	9/18/03	10:58 AM	G10RFE53	10.0	902.94	8146	5,684	0	5,684	7,709,337	7.37E-04
G-10-RF-E54	9/18/03	11:14 AM	G10RFE54	10.0	902.9	8078	5,254	0	5,254	7,709,337	6.82E-04
G-10-RF-E55	9/18/03	11:31 AM	G10RFE55	10.0	902.9	7833	5,261	0	5,261	7,709,337	6.82E-04
G-10-RF-E56	9/18/03	12:28 PM	G10RFE56	10.0	1805.86	15503	10,149	0	10,149	15,527,376	6.54E-04
G-10-RF-E57	9/18/03	1:00 PM	G10RFE57	10.0	1805.76	15593	10,346	0	10,346	15,527,376	6.66E-04
G-10-RF-E58	9/24/03	4:35 PM	G10RFE58	10.0	1806.5	15511	9,468	0	9,468	15,527,376	6.10E-04
G-10-RF-E59	9/24/03	4:04 PM	G10RFE59	10.0	1806.54	14862	9,326	0	9,326	15,527,376	6.01E-04
G-10-RF-E60	9/24/03	1:20 PM	G10RFE60	10.0	1806.44	14285	8,495	0	8,495	15,527,376	5.47E-04
G-10-RF-E61	9/24/03	3:31 PM	G10RFE61	10.0	1806.46	13709	7,232	0	7,232	15,527,376	4.66E-04
G-10-RF-E62	9/24/03	2:54 PM	G10RFE62	10.0	1806.44	13435	7,934	0	7,934	15,527,376	5.11E-04
G-10-RF-E63	9/24/03	1:51 PM	G10RFE63	10.0	1806.42	13328	7,177	0	7,177	15,527,376	4.62E-04

Second Water Rinse

Feed = DI water
Resin = SuperLig 644, batch #C-01-05-28-02-35-60
Bed Volume = 11 mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/12/03 6:45 PM
End Date and Time = 9/12/03 8:25 PM

Table B.13. Data Collection During Second Water Rinse of Pink Column—50-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial+ Cap Mass (g)	Sample Mass (g)
P-10-RF-WR2	Pink	1	1:40	9/12/2003 6:45 PM	6:45 PM	8:25 PM	14.5297	77.4881	62.9584

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ mL sample	counts/ mL control
P-10-RF-WR2	10/2/2003	9:25 AM	P5mLWR2	302.2	275	237	19	23	42745	0.0005	5	8549

Second Water Rinse

Feed = DI water
Resin = SuperLig 644, batch #C-01-05-28-02-35-60
Bed Volume = 11 mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/12/03 6:45 PM
End Date and Time = 9/12/03 8:30 PM

Table B.14. Data Collection During Second Water Rinse of Yellow Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial+ Cap Mass (g)	Sample Mass (g)
Y-10-RF-WR2	Yellow	1	1:45	9/12/2003 6:45 PM	6:45 PM	8:30 PM	14.4582	73.8744	59.4162

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ mL sample	counts/ mL control
Y-10-RF-WR2	10/2/2003	9:40 AM	Y5mLWR2	302.2	275	269	17	55	42745	0.0013	11	8549

Second Water Rinse

Feed = DI water
Resin = SuperLig 644, batch #C-01-05-28-02-35-60
Bed Volume = 11 mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/12/03 6:25 PM
End Date and Time = 9/12/03 8:00 PM

Table B.15. Data Collection During Second Water Rinse of Blue Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial+ Cap Mass (g)	Sample Mass (g)
B-10-RF-WR2	Blue	1	1:35	9/12/2003 6:25 PM	6:25 PM	8:00 PM	14.3939	75.0442	60.6503

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ mL sample	counts/ mL control
B-10-RF-WR2	10/2/2003	10:00 AM	B5mLWR2	302.2	269	264	16	50	42545	0.0012	10	8509

Second Water Rinse

Feed = DI water
Resin = SuperLig 644, batch #C-01-05-28-02-35-60
Bed Volume = 11 mL

Flow Rate = approx 33 mL/hr or 3 CV/hr
Start Date and Time = 9/12/03 6:45 PM
End Date and Time = 9/12/03 8:25 PM

Table B.16. Data Collection During Second Water Rinse of Green Column—10-ppm Feed

Sample	Source Column	# CV	Elapsed Time	Projected Date/Time	Sampling Start Time	Sampling End Time	Vial + Cap Mass (g)	Sample+Vial+ Cap Mass (g)	Sample Mass (g)
G-10-RF-WR2	Blue	1	1:40	9/12/2003 6:25 PM	6:45 PM	8:25 PM	14.4399	70.8120	56.3721

Sample	Count date	Count start time	file name	Count Time, sec	gross counts	Net counts	back ground	Sample cts - background	AN105 control	C/Co, Cs-137	count/ mL sample	counts/ mL control
G-10-RF-WR2	10/2/2003	10:15 AM	G5mLWR2	302.2	239	236	15	22	42545	0.0005	4	8509

Table B.17. Data Collection for Resin Mass—Before and After Column Run Pink Column—10-ppm Feed

Ground Gel RF Loaded with 10 ppm AN-105 Simulant -Pink Column

Resin: Ground Gel RF, pre-conditioned 8/03- Acid Form

Mass Initial Resin	5.09192	prior to column loading
F-factor	0.7240	
Initial Dry Wt resin	3.6867	
Mass Final Resin	3.1664	after column elution
F-factor	1.0417	
Final Dry wt resin	3.2985	
Mass Change	0.3882	
% Mass Change	11%	

F-Factor Data and Calculation- Initial Resin

Drying Temp, °C	Vial Tare Wt, g	Vial + Resin Wt, g	Wet Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Dry Wt #4, g	Dry Wt #5, g	Frinal Dry Resin Wt., g	F-Factor	average
50	16.9956	17.5039	0.5083	17.3927	17.3736	17.3696	17.3632	17.3640	0.3684	0.7248	0.7240
50	17.2032	17.7059	0.5027	17.5920	17.5772	17.5725	17.5647	17.5668	0.3636	0.7233	

F-Factor Determination - Spent Resin

Vial ID	Vial Tare Wt, g	Vial + Resin Wt, g	Net Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Final Dry Mass	F-factor
Blue RF F-Factor	16.8763	17.3818	0.5055	17.3816	17.3779	17.3740	0.4977	0.9846
Yellow RF F-Factor	16.9352	17.4210	0.4858	17.4436	17.4366	17.4346	0.4994	1.0280
Pink RF F-Factor	16.9303	17.4287	0.4984	17.4568	17.4530	17.4495	0.5192	1.0417
Green RF F-Factor	16.8770	17.3830	0.5060	17.3545	17.3478	17.3419	0.4649	0.9188

Table B.18. Data Collection for Resin Mass—Before and After Column Run Yellow Column—10-ppm Feed

Ground Gel RF Loaded with 10 ppm AN-105 Simulant -Yellow Column
Resin: Ground Gel RF, pre-conditioned 8/03- Acid Form

Mass Initial Resin	5.09031	prior to column loading
F-factor	0.7240	
Initial Dry Mass	3.6855	
Mass Final Resin	3.2113	after column elution
F-factor	1.0280	
Final Dry Mass	3.3012	
Mass Change	0.3843	
% Mass Change	10%	

F-Factor Data and Calculation- Initial Resin

Drying Temp, °C	Vial Tare Wt, g	Vial + Resin Wt, g	Wet Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Dry Wt #4, g	Dry Wt #5, g	Frinal Dry Resin Wt., g	F-Factor	average
50	16.9956	17.5039	0.5083	17.3927	17.3736	17.3696	17.3632	17.3640	0.3684	0.7248	0.7240
50	17.2032	17.7059	0.5027	17.5920	17.5772	17.5725	17.5647	17.5668	0.3636	0.7233	

F-Factor Determination - Spent Resin

Vial ID	Vial Tare Wt, g	Vial + Resin Wt, g	Net Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Final Dry Mass	F-factor
Blue RF F-Factor	16.8763	17.3818	0.5055	17.3816	17.3779	17.3740	0.4977	0.9846
Yellow RF F-Factor	16.9352	17.4210	0.4858	17.4436	17.4366	17.4346	0.4994	1.0280
Pink RF F-Factor	16.9303	17.4287	0.4984	17.4568	17.4530	17.4495	0.5192	1.0417
Green RF F-Factor	16.8770	17.3830	0.5060	17.3545	17.3478	17.3419	0.4649	0.9188

Table B.19. Data Collection for Resin Mass—Before and After Column Run Blue Column—10-ppm Feed

Spherical RF Loaded with 10 ppm AN-105 Simulant -Blue Column
Resin: Spherical RF, pre-conditioned 8/03- Acid Form

Mass Initial Resin	5.5237	prior to column loading
F-factor	0.4896	
Initial Dry Mass	2.7044	
Mass Final Resin	2.7542	after column elution
F-factor	0.9846	
Final Dry Mass	2.7117	
Mass Change	-0.0073	
% Mass Change	0%	

F-Factor Data and Calculation- Initial Resin

Drying Temp, °C	Vial Tare Wt, g	Vial + Resin Wt, g	Wet Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Dry Wt #4, g	Dry Wt #5, g	Frinal Dry Resin Wt., g	F-Factor	average
50	16.9956	17.5039	0.5083	17.3927	17.3736	17.3696	17.3632	17.3640	0.3684	0.7248	0.7240
50	17.2032	17.7059	0.5027	17.5920	17.5772	17.5725	17.5647	17.5668	0.3636	0.7233	

F-Factor Determination - Spent Resin

Vial ID	Vial Tare Wt, g	Vial + Resin Wt, g	Net Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Final Dry Mass	F-factor
Blue RF F-Factor	16.8763	17.3818	0.5055	17.3816	17.3779	17.3740	0.4977	0.9846
Yellow RF F-Factor	16.9352	17.4210	0.4858	17.4436	17.4366	17.4346	0.4994	1.0280
Pink RF F-Factor	16.9303	17.4287	0.4984	17.4568	17.4530	17.4495	0.5192	1.0417
Green RF F-Factor	16.8770	17.3830	0.5060	17.3545	17.3478	17.3419	0.4649	0.9188

Table B.20. Data Collection for Resin Mass—Before and After Column Run Green Column—10-ppm Feed

Ground Gel RF Loaded with 10 ppm AN-105 Simulant -Green Column

Resin: Ground Gel RF, pre-conditioned 8/03- Acid Form

Mass Initial Resin	5.08706	prior to column loading
F-factor	0.7240	
Initial Dry Mass	3.6832	
Mass Final Resin	3.6208	after column elution
F-factor	0.9188	
Final Dry Mass	3.3267	
Mass Change	0.3565	
% Mass Change	10%	

F-Factor Data and Calculation- Initial Resin

Drying Temp, °C	Vial Tare Wt, g	Vial + Resin Wt, g	Wet Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Dry Wt #4, g	Dry Wt #5, g	Frinal Dry Resin Wt., g	F-Factor	average
50	16.9956	17.5039	0.5083	17.3927	17.3736	17.3696	17.3632	17.3640	0.3684	0.7248	0.7240
50	17.2032	17.7059	0.5027	17.5920	17.5772	17.5725	17.5647	17.5668	0.3636	0.7233	

F-Factor Determination - Spent Resin

Vial ID	Vial Tare Wt, g	Vial + Resin Wt, g	Net Resin Mass, g	Dry Wt #1, g	Dry Wt #2, g	Dry Wt #3, g	Final Dry Mass	F-factor
Blue RF F-Factor	16.8763	17.3818	0.5055	17.3816	17.3779	17.3740	0.4977	0.9846
Yellow RF F-Factor	16.9352	17.4210	0.4858	17.4436	17.4366	17.4346	0.4994	1.0280
Pink RF F-Factor	16.9303	17.4287	0.4984	17.4568	17.4530	17.4495	0.5192	1.0417
Green RF F-Factor	16.8770	17.3830	0.5060	17.3545	17.3478	17.3419	0.4649	0.9188

Appendix C

Batch-Contact Data

Appendix C: Batch-Contact Data

Table C.1. Batch-Contact Data for RF Ground-Gel Resin with AN-105 Simulant

ID Number	RFGG C1 A	RFGG C1 B	RFGG C1 C	RFGG C1 D	RFGG C1 E	RFGG C2 A	RFGG C2 B	RFGG C2 C	RFGG C2 D	RFGG C2 E
Material	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel
Batch ID	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6
Date Performed	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003
Measured Isotope	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RFGG C1 A	RFGG C1 B	RFGG C1 C	RFGG C1 D	RFGG C1 E	RFGG C2 A	RFGG C2 B	RFGG C2 C	RFGG C2 D	RFGG C2 E
Start time	7:40 AM	7:41 AM	7:42 AM	7:43 AM	7:44 AM	7:36 AM	7:37 AM	7:38 AM	7:39 AM	7:40 AM
Start date	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003
Stop time	1:16 PM	1:17 PM	1:18 PM	1:19 PM	1:20 PM	1:22 PM	1:23 PM	1:24 PM	1:25 PM	1:26 PM
Stop date	10/16/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003
Total time, hrs	53.6	53.6	53.6	53.6	53.6	53.8	53.8	53.8	53.8	53.8
Mass, g	61.4992	65.0182	63.0556	62.9643	64.2414	65.1965	62.6975	61.5411	62.4865	65.0984
Volume, mL	49.68	52.52	50.93	50.86	51.89	52.66	50.64	49.71	50.47	52.58
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634
Resin Mass, g	0.4927	0.4974	0.4958	0.4915	0.4999	0.5022	0.4954	0.4929	0.4953	0.4978
Phase Ratio, mL/g	101	106	103	103	104	105	102	101	102	106
Counting Data										
Control counts, 5 mL @ 1	50,276	50,276	50,276	50,276	50,276	53,076	53,076	53,076	53,076	53,076
Sample counts (-bkg)	1,629	1,732	1,786	1,700	1,516	1,694	1,569	1,510	1,570	1,764
Kd	**3944**	**3913**	**3676**	**3864**	**4437**	**4247**	**4420**	**4513**	**4402**	**4067**
Cs-137 mole/L	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09
Cs-133 mole/L	1.020E-06	1.020E-06	1.020E-06	1.020E-06	1.020E-06	5.150E-07	5.150E-07	5.150E-07	5.150E-07	5.150E-07
initial sol Cs, mole	5.09E-08	5.38E-08	5.22E-08	5.21E-08	5.32E-08	2.74E-08	2.63E-08	2.59E-08	2.62E-08	2.73E-08
final sol Cs, mole	1.65E-09	1.85E-09	1.85E-09	1.76E-09	1.60E-09	8.74E-10	7.79E-10	7.35E-10	7.76E-10	9.09E-10
loaded Cs,moles	4.93E-08	5.20E-08	5.04E-08	5.04E-08	5.16E-08	2.65E-08	2.56E-08	2.51E-08	2.55E-08	2.64E-08
mole Cs loaded/g resin	1.00E-07	1.05E-07	1.02E-07	1.02E-07	1.03E-07	5.28E-08	5.16E-08	5.10E-08	5.14E-08	5.31E-08
final sol Cs, mole/L	3.32E-08	3.53E-08	3.64E-08	3.47E-08	3.09E-08	1.66E-08	1.54E-08	1.48E-08	1.54E-08	1.73E-08
average of 5 mole/g resin	1.02E-07					5.20E-08				
average of 5 mole/l sol	3.41E-08					1.59E-08				
deviation of mole/g resin	1.70E-09					9.27E-10				

K_d values have been bolded. Mole Cs loaded/g resin , the mass is dry-weight basis, H-form. Divided the value by F-factor (0.7634) to convert to vacuum dried resin mass shown in Table 3.11.

Table C.1 (Contd)

ID Number	RFGG C3 A	RFGG C3 B	RFGG C3 C	RFGG C3 D	RFGG C3 E	RFGG C4 A	RFGG C4 B	RFGG C4 C	RFGG C4 D	RFGG C4 E
Material	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel
Batch ID	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6
Date Performed	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003
Measured Isotope	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RFGG C3 A	RFGG C3 B	RFGG C3 C	RFGG C3 D	RFGG C3 E	RFGG C4 A	RFGG C4 B	RFGG C4 C	RFGG C4 D	RFGG C4 E
Start time	7:31 AM	7:32 AM	7:33 AM	7:34 AM	7:35 AM	7:11 AM	7:12 AM	7:13 AM	7:14 AM	7:15 AM
Start date	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003
Stop time	1:29 PM	1:30 PM	1:31 PM	1:32 PM	1:33 PM	1:35 PM	1:36 PM	1:37 PM	1:38 PM	1:39 PM
Stop date	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003
Total time, hrs	54.0	54.0	54.0	54.0	54.0	54.4	54.4	54.4	54.4	54.4
Mass, g	65.561	63.6615	62.0947	65.885	63.5391	62.4547	61.3803	63.4476	62.155	62.8108
Volume, mL	52.96	51.42	50.16	53.22	51.32	50.45	49.58	51.25	50.21	50.74
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634	0.7634
Resin Mass, g	0.5075	0.49	0.4929	0.4939	0.4919	0.5017	0.4938	0.5022	0.4992	0.5016
Phase Ratio, mL/g	104	105	102	108	104	101	100	102	101	101
Counting Data										
Control counts, 5 mL @ 1	50,108	50,108	50,108	50,108	50,108	50,124	50,124	50,124	50,124	50,124
Sample counts (-bkg)	1,616	1,523	1,533	1,738	1,519	1,567	1,643	1,732	1,594	1,570
Kd	**4225**	**4361**	**4225**	**3938**	**4365**	**4156**	**3890**	**3807**	**4064**	**4172**
Cs-137 mole/L	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09
Cs-133 mole/L	1.030E-08	1.030E-08	1.030E-08	1.030E-08	1.030E-08	1.040E-09	1.040E-09	1.040E-09	1.040E-09	1.040E-09
initial sol Cs, mole	8.13E-10	7.89E-10	7.70E-10	8.17E-10	7.88E-10	3.07E-10	3.02E-10	3.12E-10	3.06E-10	3.09E-10
final sol Cs, mole	2.62E-11	2.40E-11	2.35E-11	2.83E-11	2.39E-11	9.60E-12	9.89E-12	1.08E-11	9.72E-12	9.67E-12
loaded Cs,moles	7.86E-10	7.65E-10	7.46E-10	7.88E-10	7.64E-10	2.97E-10	2.92E-10	3.01E-10	2.96E-10	2.99E-10
mole Cs loaded/g resin	1.55E-09	1.56E-09	1.51E-09	1.60E-09	1.55E-09	5.93E-10	5.91E-10	6.00E-10	5.93E-10	5.96E-10
final sol Cs, mole/L	4.95E-10	4.66E-10	4.69E-10	5.32E-10	4.65E-10	1.90E-10	1.99E-10	2.10E-10	1.94E-10	1.91E-10
average of 5 mole/g resin	1.55E-09					5.94E-10				
average of 5 mole/l sol	4.86E-10					1.97E-10				
deviation of mole/g resin	2.95E-11					3.46E-12				

K_d values have been bolded. Mole Cs loaded/g resin , the mass is dry-weight basis, H-form. Divided the value by F-factor (0.7634) to convert to vacuum dried resin mass shown in Table 3.11.

Table C.2. Batch-Contact Data for RF Spherical Resin with AN-105 Simulant

ID Number	RFsph C1 A	RFsph C1 B	RFsph C1 C	RFsph C1 D	RFsph C1 E	RFsph C2 A	RFsph C2 B	RFsph C2 C	RFsph C2 D	RFsph C2 E
Material	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical
Batch ID	#3	#3	#3	#3	#3	#3	#3	#3	#3	#3
Date Performed	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003
Measured Isotope	**137Cs**	**137Cs**	**137Cs**	**137Cs**	**137Cs**	**137Cs**	**137Cs**	**137Cs**	**137Cs**	**137Cs**
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RFsph C1 A	RFsph C1 B	RFsph C1 C	RFsph C1 D	RFsph C1 E	RFsph C2 A	RFsph C2 B	RFsph C2 C	RFsph C2 D	RFsph C2 E
Start time	1:22 PM	1:23 PM	1:24 PM	1:25 PM	1:26 PM	1:09 PM	1:10 PM	1:11 PM	1:12 PM	1:13 PM
Start date	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003
Stop time	11:13 AM	11:14 AM	11:15 AM	11:16 AM	11:17 AM	11:19 AM	11:20 AM	11:21 AM	11:22 AM	11:23 AM
Stop date	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003
Total time, hrs	45.9	45.8	45.8	45.8	45.8	46.2	46.2	46.2	46.2	46.2
Mass, g	63.4507	64.0786	63.3862	65.0866	62.5657	65.8734	70.9357	66.3043	70.6179	64.9221
Volume, mL	51.25	51.76	51.20	52.57	50.54	53.21	57.30	53.56	57.04	52.44
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565
Resin Mass, g	0.5089	0.4903	0.4929	0.4983	0.491	0.4957	0.499	0.5044	0.4923	0.5028
Phase Ratio, mL/g	101	106	104	106	103	107	115	106	116	104
Counting Data										
Control counts, 5 ml @ 10	50,276	50,276	50,276	50,276	50,276	50,302	50,302	50,302	50,302	50,302
Sample counts (-bkg)	6,335	6,727	6,333	6,327	6,055	6,274	6,120	6,160	6,468	6,183
Kd	**1255**	**1228**	**1295**	**1317**	**1351**	**1354**	**1490**	**1367**	**1411**	**1337**
Cs-137 Mole/L	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09
Cs-133 mole/L	1.020E-06	1.020E-06	1.020E-06	1.020E-06	1.020E-06	5.150E-07	5.150E-07	5.150E-07	5.150E-07	5.150E-07
initial sol Cs, mole	5.25E-08	5.31E-08	5.25E-08	5.39E-08	5.18E-08	2.77E-08	2.98E-08	2.79E-08	2.97E-08	2.73E-08
final sol Cs, mole	6.62E-09	7.10E-09	6.61E-09	6.78E-09	6.24E-09	3.45E-09	3.63E-09	3.41E-09	3.81E-09	3.35E-09
loaded Cs,moles	4.59E-08	4.60E-08	4.59E-08	4.71E-08	4.56E-08	2.42E-08	2.62E-08	2.44E-08	2.59E-08	2.39E-08
mole Cs loaded/g resin	9.02E-08	9.37E-08	9.31E-08	9.45E-08	9.28E-08	4.89E-08	5.24E-08	4.85E-08	5.25E-08	4.76E-08
final sol Cs, mole/L	1.29E-07	1.37E-07	1.29E-07	1.29E-07	1.23E-07	6.49E-08	6.33E-08	6.37E-08	6.69E-08	6.39E-08
average of 5 mole/g resin	9.29E-08					5.00E-08				
average of 5 mole/l sol	1.30E-07					6.45E-08				
stdev mole/g resin	1.62477E-09					2.33793E-09				

K_d values have been bolded. Mole Cs loaded/g resin , the mass is dry-weight basis, H-form. Divided the value by F-factor (0.5565) to convert to vacuum dried resin mass shown in Table 3.12.

Table C.2 (Contd)

ID Number	RFsph C3 A	RFsph C3 B	RFsph C3 C	RFsph C3 D	RFsph C3 E	RFsph C4 A	RFsph C4 B	RFsph C4 C	RFsph C4 D	RFsph C4 E
Material	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical
Batch ID	#3	#3	#3	#3	#3	#3	#3	#3	#3	#3
Date Performed	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003	October 14, 2003
Measured Isotope	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs	137Cs
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RFsph C3 A	RFsph C3 B	RFsph C3 C	RFsph C3 D	RFsph C3 E	RFsph C4 A	RFsph C4 B	RFsph C4 C	RFsph C4 D	RFsph C4 E
Start time	1:15 PM	1:16 PM	1:17 PM	1:18 PM	1:19 PM	1:03 PM	1:04 PM	1:05 PM	1:06 PM	1:07 PM
Start date	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003	10/14/2003
Stop time	11:25 AM	11:26 AM	11:27 AM	11:32 AM	11:33 AM	11:35 AM	11:36 AM	11:37 AM	11:38 AM	11:39 AM
Stop date	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003	10/16/2003
Total time, hrs	46.2	46.2	46.2	46.2	46.2	46.5	46.5	46.5	46.5	46.5
Mass, g	65.12	63.2968	67.5382	65.07	64.6058	64.2718	68.9488	64.9598	64.9413	69.2801
Volume, mL	52.60	51.13	54.55	52.56	52.19	51.92	55.69	52.47	52.46	55.96
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565	0.5565
Resin Mass, g	0.5042	0.5012	0.4947	0.4996	0.4946	0.5079	0.4938	0.4935	0.5023	0.4966
Phase Ratio, mL/g	104	102	110	105	106	102	113	106	104	113
Counting Data										
Control counts, 5 ml @ 10	50,108	50,108	50,108	50,108	50,108	50,124	50,124	50,124	50,124	50,124
Sample counts (-bkg)	6,481	6,270	6,818	6,181	6,089	6,133	6,446	6,830	6,392	6,778
Kd	**1262**	**1282**	**1258**	**1344**	**1371**	**1318**	**1373**	**1211**	**1284**	**1295**
Cs-137 Mole/L	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09	5.046E-09
Cs-133 mole/L	1.030E-08	1.030E-08	1.030E-08	1.030E-08	1.030E-08	1.040E-09	1.040E-09	1.040E-09	1.040E-09	1.040E-09
initial sol Cs, mole	8.07E-10	7.85E-10	8.37E-10	8.07E-10	8.01E-10	3.16E-10	3.39E-10	3.19E-10	3.19E-10	3.41E-10
final sol Cs, mole	1.04E-10	9.82E-11	1.14E-10	9.95E-11	9.73E-11	3.87E-11	4.36E-11	4.35E-11	4.07E-11	4.61E-11
loaded Cs,moles	7.03E-10	6.86E-10	7.23E-10	7.07E-10	7.04E-10	2.77E-10	2.95E-10	2.76E-10	2.79E-10	2.95E-10
mole Cs loaded/g resin	1.39E-09	1.37E-09	1.46E-09	1.42E-09	1.42E-09	5.46E-10	5.98E-10	5.59E-10	5.54E-10	5.93E-10
final sol Cs, mole/L	1.98E-09	1.92E-09	2.09E-09	1.89E-09	1.86E-09	7.45E-10	7.83E-10	8.29E-10	7.76E-10	8.23E-10
average of 5 mole/g resin	1.41E-09					5.70E-10				
average of 5 mole/l sol	1.95E-09					7.91E-10				
stdev mole/g resin	3.44548E-11					2.37899E-11				

K_d values have been bolded. Mole Cs loaded/g resin , the mass is dry-weight basis, H-form. Divided the value by F-factor (0.5565) to convert to vacuum dried resin mass shown in Table 3.12.

Table C.3. Batch-Contact Data for RF Spent Resin with AN-105 Simulant

ID Number	RFGG B10 A	RFGG B10 B	RFGG B10 C	RFGG B10 D	RFGG B10 E	RFGG B10 F	RFGG B10 G	RFSPH B10 A	RFSPH B10 B	RFSPH B10 C
Material	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Spherical	RF Spherical	RF Spherical
Batch ID	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6
Date Performed	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003
Measured Isotope	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RFGG B10 A	RFGG B10 B	RFGG B10 C	RFGG B10 D	RFGG B10 E	RFGG B10 F	RFGG B10 G	RFSPH B10 A	RFSPH B10 B	RFSPH B10 C
Start date/time	9:59 AM	9:59 AM	10:00 AM	10:01 AM	10:02 AM	10:03 AM	10:04 AM	10:05 AM	10:06 AM	10:07 AM
Start date	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003
Stop date/time	12:38 PM	12:39 PM	12:40 PM	12:41 PM	12:42 PM	12:43 PM	12:43 PM	12:52 PM	12:53 PM	12:54 PM
Stop date	10/14/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003
Total time, hrs	50.6	50.7	50.7	50.7	50.7	50.7	50.6	50.8	50.8	50.8
Solution Mass, g	63.6	62.8	64.0	63.4	62.7	64.7	63.0	64.3	62.8	65.4
Volume, mL	51.4	50.8	51.7	51.2	50.7	52.2	50.9	52.0	50.7	52.9
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	0.8097	0.8097	0.8097	0.8097	0.8097	0.8097	0.8097	0.7375	0.7375	0.7375
Resin Mass, g	0.5198	0.5212	0.5042	0.5036	0.5149	0.5128	0.5104	0.5005	0.4957	0.5163
Phase Ratio, mL/g	99	97	103	102	98	102	100	104	102	102
Counting Data										
Control counts, 5 mL @ 10 min (-bkg)	196,713	196,713	196,713	196,713	196,713	196,713	196,713	196,713	196,713	196,713
Sample counts (-bkg)	7,735	7,283	8,239	8,037	7,619	7,783	7,822	33,166	34,060	33,149
Kd	**3695**	**3884**	**3479**	**3538**	**3700**	**3730**	**3617**	**827**	**782**	**842**
% Removed	96%	96%	96%	96%	96%	96%	96%	83%	83%	83%

Kd values have been bolded.

Table C.3 (Contd)

ID Number	RFSPH B10 D	RFSPH B10 E	RFSPH B10 F	RFSPH B10 G	RF10 BLUE 1	RF10 BLUE 2	RF10 BLUE 3	RF10 BLUE 4	RF10 PINK 1	RF10 PINK 2
Material	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Spherical	RF Ground Gel	RF Ground Gel
Batch ID	lot 6	lot 6	lot 6	lot 6	#3	#3	#3	#3	lot 6	lot 6
Date Performed	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003
Measured Isotope	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RFSPH B10 D	RFSPH B10 E	RFSPH B10 F	RFSPH B10 G	RF10 BLUE 1	RF10 BLUE 2	RF10 BLUE 3	RF10 BLUE 4	RF10 PINK 1	RF10 PINK 2
Start date/time	10:08 AM	10:08 AM	10:09 AM	10:10 AM	9:42 AM	9:43 AM	9:44 AM	9:45 AM	9:46 AM	9:47 AM
Start date	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003
Stop date/time	12:55 PM	12:56 PM	12:57 PM	12:58 PM	12:59 PM	1:00 PM	1:01 PM	1:02 PM	1:03 PM	1:04 PM
Stop date	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003
Total time, hrs	50.8	50.8	50.8	50.8	51.3	51.3	51.3	51.3	51.3	51.3
Solution Mass, g	63.0	62.2	63.8	62.5	58.6	59.4	59.8	62.8	62.8	62.2
Volume, mL	50.9	50.3	51.6	50.5	47.4	48.0	48.3	50.8	50.7	50.3
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	0.7375	0.7375	0.7375	0.7375	0.9846	0.9846	0.9846	0.9846	1.0	1.0
Resin Mass, g	0.4949	0.4938	0.5186	0.5154	0.5139	0.5214	0.5047	0.5069	0.4944	0.5073
Phase Ratio, mL/g	103	102	99	98	92	92	96	100	103	99
Counting Data										
Control counts, 5 mL @ 10 min (-bkg)	196,602	196,602	196,602	196,602	196,602	196,602	196,602	196,602	196,602	196,602
Sample counts (-bkg)	33,066	31,289	32,569	29,613	18,603	20,555	20,495	21,026	5,895	6,034
Kd	**812**	**858**	**839**	**919**	**1096**	**994**	**1004**	**1025**	**3751**	**3629**
% Removed	83%	84%	83%	85%	91%	90%	90%	89%	97%	97%

Kd values have been bolded.

Table C.3 (Contd)

ID Number	RF10 PINK 3	RF10 PINK 4	RF10 GREEN 1	RF10 GREEN 2	RF10 GREEN 3	RF10 GREEN 4	RF10 YELLOW 1	RF10 YELLOW 2	RF10 YELLOW 3	RF10 YELLOW 4
Material	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel	RF Ground Gel
Batch ID	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6	lot 6
Date Performed	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003
Measured Isotope	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**	**^{137}Cs**
Solution	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant	AN-105 Simulant
Solution ID	RF10 PINK 3	RF10 PINK 4	RF10 GREEN 1	RF10 GREEN 2	RF10 GREEN 3	RF10 GREEN 4	RF10 YELLOW 1	RF10 YELLOW 2	RF10 YELLOW 3	RF10 YELLOW 4
Start date/time	9:48 AM	9:49 AM	9:50 AM	9:51 AM	9:52 AM	9:53 AM	9:54 AM	9:55 AM	9:56 AM	9:57 AM
Start date	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003	10/15/2003
Stop date/time	1:05 PM	1:06 PM	1:06 PM	1:07 PM	1:07 PM	1:08 PM	12:43 PM	12:44 PM	12:46 PM	12:48 PM
Stop date	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003	10/17/2003
Total time, hrs	51.3	51.3	51.3	51.3	51.3	51.2	50.8	50.8	50.8	50.8
Solution Mass, g	62.0	61.7	62.3	63.7	62.7	63.8	65.0	62.5	62.0	61.3
Volume, mL	50.1	49.9	50.3	51.4	50.7	51.5	52.5	50.5	50.1	49.5
Temp, ° C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C	24-25°C
F-Factor	1.0	1.0	0.9188	0.9188	0.9188	0.9188	1.0	1.0	1.0	1.0
Resin Mass, g	0.5055	0.5148	0.7811	0.4896	0.5129	0.4841	0.5107	0.4960	0.4885	0.5126
Phase Ratio, mL/g	99	97	64	105	99	106	103	102	103	97
Counting Data										
Control counts, 5 mL @ 10 min (-bkg)	196,602	196,602	196,602	196,602	196,602	196,602	196,602	196,602	196,602	196,602
Sample counts (-bkg)	5,768	6,130	6,445	6,700	6,833	6,556	8,118	7,764	8,530	7,834
Kd	**3791**	**3543**	**3851**	**3778**	**3648**	**3872**	**2824**	**2847**	**2560**	**2766**
% Removed	97%	97%	97%	97%	97%	97%	96%	96%	96%	96%

Kd values have been bolded.

Appendix D

Graph Data Not Presented in Tables

Appendix D: Graph Data Not Presented in Tables

Table D.1. Data for Figure 3.4—Residual Cesium on RF Resin for Columns Loaded with 10 µg/ml Cs in AN-105 Simulant

Blue Column		Pink Column		Yellow Column		Green Column	
BV	µg Cs/g dry spent resin	BV	µg Cs/g dry spent resin	BV	µg Cs/g dry spent resin	BV	µg Cs/g dry spent resin
0.7	9220	0.7	15707	0.6	14845	0.7	26560
1.4	9216	1.4	15705	1.3	14839	1.4	26556
2.1	9210	2.1	15702	2.0	12679	2.0	26549
2.8	8849	2.8	15698	2.7	3021	2.7	26542
3.5	5720	3.5	13684	3.4	690	3.4	26534
4.2	1234	4.2	8226	4.0	256	4.0	14065
4.9	6.23	4.9	4083	4.7	111	4.7	2690
6.0	1.28	6.1	325	5.8	41.6	5.9	65.5
7.2	0.89	7.2	48.7	6.9	21.9	7.0	33.4
8.3	0.70	8.4	25.6	8.0	14.5	8.2	17.3
9.5	0.59	9.5	17.7	9.1	11.4	9.3	10.7
11	0.49	11	13.8	10	9.85	10.4	7.61
12	0.43	12	11.6	11	8.89	11.5	6.12
13	0.38	13	10.3	12	8.26	12.7	5.41
14	0.35	14	9.44	13	7.80	13.8	5.00
15	0.32	15	8.86	14	7.44	14.9	4.68
16	0.30	16	8.41	16	7.14	16.1	4.41
17	0.29	17	8.06	17	6.88	17.2	4.18
19	0.28	19	7.77	18	6.64	18.3	3.97
20	0.27	20	7.52	19	6.44	19.5	3.78
21	0.26	21	7.29	20	6.26	20.6	3.62
22	0.25	22	7.09	21	6.07	21.7	3.48
23	0.25	23	6.89	22	5.90	22.8	3.34
24	0.24	24	6.70	22	5.75	24.0	3.22
25	0.24	25	6.53	23	5.60	25.1	3.10
27	0.23	27	6.37	24	5.46	26.2	2.99
28	0.23	28	6.22	25	5.33	27.3	2.90
29	0.22	29	6.07	26	5.21	28.4	2.81
30	0.21	30	5.94	27	5.10	29.6	2.73
31	0.21	31	5.80	28	4.98	30.7	2.65
32	0.20	32	5.66	29	4.86	31.8	2.58
33	0.20	33	5.54	30	4.75	32.9	2.51
35	0.19	35	5.42	31	4.65	34.1	2.44
36	0.19	36	5.30	32	4.54	35.2	2.38
37	0.18	37	5.19	33	4.45	36.3	2.32
38	0.18	38	5.08	34	4.36	37.5	2.27
39	0.18	39	4.98	34	4.27	38.6	2.22
40	0.17	40	4.89	35	4.19	39.7	2.16
41	0.17	41	4.80	36	4.11	40.9	2.11
42	0.17	43	4.72	37	4.04	42.0	2.06
44	0.17	44	4.63	38	3.99	43.1	2.01
45	0.16	45	4.49	39	3.93	44.3	1.96
46	0.16	46	4.36	40	3.88	45.3	1.93
47	0.16	47	4.27	40	3.81	46.4	1.89
48	0.16	48	4.19	41	3.76	47.6	1.85
49	0.15	49	4.10	42	3.71	48.7	1.81
50	0.15	50	4.04	43	3.66	49.8	1.78
		51	3.97	44	3.62	50.9	1.75
		52	3.90	45	3.58	52.1	1.71
		53	3.83	46	3.53	53.2	1.68
		54	3.77	46	3.49	54.3	1.65
		56	3.71	47	3.45	55.4	1.62
		57	3.65	48	3.40	56.5	1.59
		58	3.60	49	3.37	57.6	1.56
		59	3.55	50	3.32	58.8	1.54
		60	3.49	51	3.28	59.9	1.51
		61	3.44	52	3.25	61.0	1.48
		62	3.39	53	3.21	62.1	1.46
		63	3.34	53	3.17	63.2	1.44

Calculations for Data in Table D.1

Calculations for Table D.1

The amount of cesium remaining on the resin at any point in time is equal to the final residual cesium plus the amount of cesium eluted from the resin up to that sampling time. The first step in the calculation was to determine the amount of cesium eluted from the resin in each sample.

$$Cs_{Elut} = \sum_{i=0}^{i-N} (C/C_0) * Cs_{133} * \Delta V$$

where
Cs_{Elut} = amount of cesium eluted from the resin, µg
C = ^{137}Cs counts in each loading sample
C_0 = ^{137}Cs counts in the initial feed
C_{133} = initial feed ^{133}Cs concentration, µg/ml
ΔV = volume of feed processed between each sample (including sample volume), mL
N = number of samples collected during loading.

After determining the amount of cesium eluted from the resin for each sample, the amount of cesium present on the resin would be equal to the amount eluted from the resin plus the residual cesium measured on the resin. Thus, one must work backward using the last elution sample and the resin residual cesium level.

$$Cs_{Resin} = Cs_{End} + \sum_{i=0}^{i-N} (C/C_0) * Cs_{133} * \Delta V$$

where
Cs_{Resin} = amount of cesium remaining on the resin at each data point, µg
Cs_{End} = amount of residual cesium on the resin at the end of elution, µg
C = ^{137}Cs counts in each loading sample
C_0 = ^{137}Cs counts in the initial feed
C_{133} = initial feed ^{133}Cs concentration, µg/ml
ΔV = volume of feed processed between each sample (including sample volume), ml
N = number of samples collected during loading.

After determining the Cs_{Resin} value at each elution sample (µg Cs), those values were divided by the final dry weight mass of the spent resin to provide the reported value in (µg Cs/ g H-form vacuum-dried resin). This data is reported in Table D1.

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