

**RF/ER-94-0021.UN**

**High Gradient Magnetic Separation  
Soil Treatability  
Study**

for Treatment of  
Rocky Flats Environmental Technology Site  
Operable Unit No. 2  
Surficial Soil

U. S. DEPARTMENT OF ENERGY  
The Rocky Flats Environmental Technology Site  
Golden, Colorado

ENVIRONMENTAL RESTORATION PROGRAM DIVISION

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# **NOTICE:**

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## **1.0 INTRODUCTION**

This treatability study was conducted jointly by the Nuclear Materials Technology and Engineering Sciences and Applications Divisions of the Los Alamos National Laboratory (LANL) for the Environmental Restoration Group at the Rocky Flats Environmental Technology Site (RFETS). The purpose of this report is to describe the technical approach, results and assessment of the High Gradient Magnetic Separation (HGMS) Soil Treatability Study. Elements of the process used were developed under a Cooperative Research and Development Agreement between LANL and Lockheed Environmental Systems and Technologies Company (LESAT).

### **1.1 SITE DESCRIPTION**

#### **1.1.1 Site Name and Description**

RFETS, a 6,550 acre industrial reservation, is located in northern Jefferson County, Colorado. RFETS lies on two major geological units: unconsolidated surficial units (Rocky Flats Alluvium, various terrace alluvia, valley fill alluvium, and colluvium) underlain by Cretaceous bedrock (Arapahoe Formation, Laramie Formation, and Fox Hills Sandstone). Groundwater moves under confined conditions in surficial and shallow bedrock units. Additionally, confined groundwater flow occurs in deeper bedrock sandstones. Surficial soils are predominantly moderately deep to deep, well-drained clay loams of moderate to low permeability (Final Phase II RCRA Facility Investigation Remedial Investigation, Work Plan [Alluvial], U.S. Department of Energy, Rocky Flats Office, Golden, Colorado, 29 February 1991).

#### **1.1.2 History of Operation**

From the mid-1950s to the present, RFETS has been a government-owned (U.S. Department of Energy [DOE]), contractor-operated facility that fabricated nuclear weapon components from plutonium (Pu), uranium (U), and other non-radioactive metals (principally beryllium (Be) and stainless steel). Plutonium was also recovered in the facility when it reprocessed components after they were removed from obsolete weapons.

### **1.2 WASTE STREAM DESCRIPTION**

#### **1.2.1 Production Wastes**

Radioactive and nonradioactive wastes were generated in the production processes. Plant waste handling practices involved onsite and offsite recycling of hazardous materials, onsite storage of hazardous and radioactive mixed wastes, and offsite disposal of solid radioactive materials at other DOE facilities. In the past, hazardous, radioactive, and radioactive mixed wastes were stored onsite. Primary assessments under environmental remediation programs have identified some of these storage and disposal locations as potential sources of environmental contamination.

## 1.2.2 Pollutants/Chemicals

The 903 Pad, located on the south eastern side of the plant, is a portion of Operable Unit No. 2 (OU2) and covers an area 113 meters wide by 120 meters long. In 1958, waste drums were stored at this location. Contaminated soil was first discovered in 1964 in an area where 210 liter drums of plutonium-laden lathe coolant oil were stored. The drums contained cutting oil and carbon tetrachloride contaminated with plutonium and uranium cuttings from nuclear weapons components machining operations.

By 1968, all of the drums had been removed, processed, and shipped offsite for disposal. The contaminated area was covered with a pad consisting of successive layers of fill dirt, gravel, and a final layer of asphalt. The level of contamination in the soil ranged between 2,000 to 300,000 disintegrations per minute (dpm)/100 square centimeters (cm<sup>2</sup>), with penetration depths of 3 to 20 cm. The plutonium metal was originally deposited as fine metallics. It oxidized into PuO<sub>2</sub> in the environment. The average size of the PuO<sub>2</sub> particles was 0.2 microns (Soil Decontamination Criteria Report, J. A. Hayden, et al; Rockwell International, November, 1990).

## 1.2.3 Treatability Study Background

This study was undertaken to evaluate the effectiveness of HGMS in removing actinides from RFETS-OU2 soils. A treatability study was conducted by Lockheed Environmental Systems and Technology (LESAT) (Plutonium in Soils Treatability Studies, RF-OU2, T K Wenstrand and T M Murarik, Lockheed Environmental Systems and Technologies Co., Sept. 30, 1993) to evaluate the effectiveness of the TRUclean<sup>®</sup> gravity separation process in removing activity from RFETS-OU2 soils. This report describes all aspects of the Physical Separation Treatability Test, including operating features of the TRUclean<sup>®</sup> process. Because of the potential of HGMS in treating small particle contamination, a residue from the TRUclean<sup>®</sup> process was selected for HGMS evaluation (Sample 6 in the above referenced report).

## 1.3 TREATMENT TECHNOLOGY DESCRIPTION

### 1.3.1 Treatment Process, Description, and Operating Features

HGMS is a form of magnetic separation in which large magnetic field gradients are used to separate micron sized paramagnetic particles. The HGMS separator consists of a high-field, superconducting solenoid magnet, where the bore of the magnet contains a fine structured matrix material. The matrix material (usually ferromagnetic) locally distorts the magnetic field and creates large field gradients in the vicinity of the matrix elements. These matrix elements become the trapping sites for both paramagnetic and ferromagnetic particles. When the field gradients are sufficiently high, weakly paramagnetic particles can be physically captured and separated from diamagnetic host materials. Because most actinide compounds are paramagnetic, magnetic separation of actinide containing mixtures is feasible.

The application of HGMS involves passing a slurry of the contaminated mixture through a magnetized volume. Ferromagnetic and paramagnetic particles are extracted from the slurry by the ferromagnetic matrix while the diamagnetic fraction passes through the magnetized volume. The magnetic fraction is flushed from the matrix later when the magnetic field is

reduced to zero or the matrix is removed from the magnetized volume. The actinide containing concentrate can then be processed for disposal.

The slurry was pumped through the magnetic matrix using a peristaltic pump at constant flow rate. Feed slurry homogeneity was maintained using a mixer at the pump inlet. Back-flushing of the magnetic matrix was done at zero magnetic field and with the flow direction reversed. Feed backflush and multipass effluent samples were analyzed for contaminant concentration. Samples are analyzed for plutonium concentration using alpha spectroscopy.

#### **1.4 Previous Treatability Studies at the Site**

In addition to the LESAT Report, another soils treatability study was reported in August, 1994 entitled, "Rocky Flats Plant Soil Treatment Bench-Scale Treatability Studies (Nuclear Remediation Technologies Division, General Atomics-San Diego, California, GA-C21818). This study reported on preliminary characterization, flotation/attrition scrubbing tests, and leaching tests.

## 2.0 CONCLUSIONS AND RECOMMENDATIONS

### 2.1 CONCLUSIONS

This physical separation, soil treatability study evaluated the effectiveness of using HGMS to treat TRUclean<sup>®</sup> process residues for removal of actinides. Several separator operating parameters including superficial velocity, applied magnetic field and matrix packing density were systematically investigated along with various pretreatment protocols. The pretreatment protocols included pH adjustment, surfactant variation and organic destruction using an oxidizing agent, H<sub>2</sub>O<sub>2</sub>.

The objective of any physical separation process is to concentrate the most contaminant into the smallest fraction of the feed. Therefore, results which show high separation efficiencies but also have high mass fractions in the contaminant stream are undesirable. This study showed that HGMS can achieve significant separation of actinides from the processed soil residues investigated. A concentration of 51% of the activity in only 2% of the feed was achieved in Run 701 based on analysis of the feed and effluent streams (see Table 4.1.3-1 for a listing of all results). For Run 701 the feed concentration was 120 pCi/g and the effluent or clean stream concentration was 60 pCi/g.

The LESAT soil residue appears to have up to 10 wt% strongly magnetic content with as much as 20 wt% additional paramagnetic compounds. With such a large magnetic content present in addition to the actinides, selective separation of the various ferromagnetic and paramagnetic species is required. This is in addition to insuring liberation of the contaminants before HGMS processing. Several approaches were tried in this study, including pH control, surfactant type and concentration, sonication and oxidation. Results indicated that particle deagglomeration through sonication together with relatively high concentrations of hexametaphosphate surfactant at pH's greater than 10 was the most effective pretreatment protocol. Selective magnetic separations were achieved by controlling magnetic field, superficial velocity and matrix geometry.

### 2.2 RECOMMENDATIONS

#### 2.2.1 Additional Studies

In view of the large number of parameters affecting the HGMS process and the complexity of the soil-contaminant mixture, results from this initial study should be viewed as preliminary. In cases where the contaminant is liberated within the mixture, HGMS has been shown to be an effective method for separating the contaminant. The HGMS process has been analytically modeled, experimentally verified and is fairly well understood. However, when applied to complex mixtures where other magnetic species, which are not contaminants, are present, the successful application of HGMS requires development of a pretreatment protocol that insures contaminant particle liberation. This pretreatment process is strongly dependent on the soil composition, the method of contamination, and any previous soil treatment and is not well understood. Several pretreatment methods were investigated in this study, however, sufficient time was not available to repeat those particular runs which demonstrated significant separation or to conduct additional tests based on conclusions reached at the end of this evaluation.

Additional studies that focus on the operating regime and pretreatment protocol discussed above are necessary. It is also appropriate to further investigate other methods for contaminant liberation suggested by these results. In conjunction with the LANL analytical

model of the HGMS process, these additional data would form the basis for scale-up to a prototype system.

HGMS is an effective physical separation process for removing small particle contamination (<100  $\mu\text{m}$ ). Most soil washing methods are only effective on particles greater than 50 to 100  $\mu\text{m}$ . Although these traditional treatments can be effective in removing large particle contamination, their application frequently transports a significant portion of the contaminant into the fines. Once there, the contaminant is more difficult to remove and frequently requires a costly chemical treatment to reach remediation targets. As shown by this study, HGMS can be effective in treating the fines by physical separation and offers the potential to treat the bulk of the contaminated soil using physical separation methods. HGMS has been demonstrated on an industrial scale in the processing of kaolin clay and is cost effective in treating large volumes of material to remove small amounts of contaminants.

### **3.0 TREATABILITY STUDY APPROACH**

#### **3.1 TEST OBJECTIVES AND RATIONALE**

Magnetic separation has been shown to be effective at removing small particle size contaminants (<50  $\mu\text{m}$ ) from similar small sized particle slurries. Because of this, magnetic separation is thought to be a compatible technology with soil washing which is appropriate for treating larger particles (>50  $\mu\text{m}$ ). Frequently, treatment of the larger particles using conventional technologies results in migration of the contaminant to a smaller size fraction of the waste stream. Consequently the fines are usually enriched by the contaminant. Magnetic separation is a potential remediation technology that is capable of treating this fine fraction.

The objective of the treatability study was to evaluate the effectiveness of HGMS in removing actinide contamination from the LESAT treatment residues. Table 3.1-1 summarizes the experiment series by run.

The objectives by test series were as follows:

Series 1 to determine the effect of concentration of sodium hexametaphosphate, the influence of superficial velocity and applied magnetic field on separation performance.

Series 2 to determine the effect of pretreatment, specifically pH and  $\text{H}_2\text{O}_2$  addition, on separation performance and also introduce a scalping pass with a paramagnetic matrix at 2.0 T.

Series 3 to determine the effect of combining a paramagnetic scalping pass with a low field ferromagnetic pass.

**Table 3.1-1 HGMS Experiment Parameters**

Series	Run #	Magnetic Field <sup>5</sup> (T)	Uo <sup>1</sup> (cm/s)	Surfactant	pH	Solids Fraction	Matrix ID
1	701	0.5/6.5	0.5	0.2 % Hexamet <sup>2</sup>	10	0.10	VI
1	702	0.5/6.5	0.5	none	8	0.10	VI
1	703	0.5/6.5	0.5	0.05 % Hexamet	8	0.10	VI
1	704	0.5/6.5	0.25	0.05 % Hexamet	8	0.10	VI
1	705	0.5/6.5	1.0	0.05 % Hexamet	8	0.10	VI
2	706	2.0p <sup>3</sup> /2.0	0.5	0.2 % Hexamet	8	0.10	VII/VI
2	707	2.0p/2.0	0.5	0.2 % Hexamet	10	0.10	VII/VI
2	708	2p/2.0/6.5	0.5	0.2 % Hexamet	12	0.10	VII/VI
2	709 <sup>4</sup>	2.0p/2.0	0.5	0.2 % Hexamet	10	0.10	VII/VI
3	710	2p/0.5/6.5	0.5	0.2 % Hexamet	10	0.10	VII/VIII
3	711	2p/0.5/6.5	0.5	0.2 % Hexamet	10	0.05	VII/VIII
3	712 <sup>4</sup>	2p/0.5/6.5	0.5	0.2 % Hexamet	10	0.10	VII/VIII
3	713	2p/0.5/6.5	0.5	Alternative Surfactant	10	0.10	VII/VIII

<sup>1</sup>Superficial velocity<sup>2</sup>Sodium Hexametaphosphate<sup>3</sup>Paramagnetic matrix<sup>4</sup>Pretreat with H<sub>2</sub>O<sub>2</sub><sup>5</sup>Field for each pass, in tesla (T)

### 3.2 Experimental Design and Procedure

A treated waste stream residue was identified as an appropriate feed material for the magnetic separation treatability study. The thickener underflow from the LESAT processing circuit (<150 μm) was eventually selected. Activity levels of this material ranged from 100 to 144 pCi/g.

LESAT residues were wet sieved <53μm, slurried to a specified solids content (typically 10 wt%), treated with surfactant, pH adjusted with sodium hydroxide and bulk sonicated to insure particle deagglomeration. Each sample was then further treated depending upon test protocol to improve particle liberation.

Experiments were run at the LANL plutonium facility (TA-55) in PF-4, Rm 128. In Rm 128 the HGMS unit is mounted atop a vent hood wherein the environment is controlled to ensure that no materials are released to the laboratory.

The test protocol required rinsing of the ferromagnetic matrix with a solution of identical pH and surfactant concentration as the test slurry. The pretreatment was followed by pass

1 of the test slurry. Upon completion of pass 1, the matrix was rinsed at field and then backflushed at zero field. The magnetics were recovered prior to pass 2. The effluent from pass 1 was then used as the feed for pass 2. The process was repeated for additional passes as necessary. Samples of approximately 100 to 125 ml were taken from the feed and all effluents as generated. All backflushes and matrix rinses were collected for analysis.

### **3.3 Equipment and Materials**

#### **3.3.1 Magnetic Separator**

The magnetic separator consists of a solenoidal, superconducting magnet with a room temperature bore located outside the cryogenic space. The superconducting magnet is maintained at 4.2 K and can generate a magnetic field strength as high as 8 T within the warm bore. A stainless steel tube, capped at one end, extends out the top of the hood and fits into the warm bore of the magnet. The magnet is external to the hood but the high magnetic field region can be accessed from within the hood via the blind tube.

#### **3.3.2 Test Canister**

The test canister holds either a ferromagnetic or paramagnetic matrix and provides flow deceleration zones for the slurry and backflush. Flex hoses are attached to each end of the canister permitting the canister to be removed from the magnet bore without exposing the slurry.

#### **3.3.3 Peristaltic Pump**

Fluids were pumped through the test canister with a peristaltic pump. Because the pump operates by pinching the flex tube with rotating rollers, cross contamination between the various flow streams is minimized. The pump is easily calibrated and the flow direction can be reversed.

### **3.4 Sampling and Analysis**

The treated slurry is pumped through the magnetic separator. The emerging effluent is the decontaminated stream, whereas, the material retained by the separator is the magnetic fraction. After processing the sample, the magnetically trapped material was rinsed from the separator in a backflush operation outside the magnetic field. Feed slurry homogeneity was maintained using a mixer at the pump inlet. Feed and multipass effluent samples were analyzed for contaminant concentration. Samples were taken in test series 1 (701-705) by mixing the effluent and pouring a sample from the collection bottle. Samples were taken in test series 2 and 3 (706-709 and 710-713) by mixing the effluent in a squirt bottle and then discharging the sample from the bottom feed discharge tube. This procedure was an attempt to homogenize the effluent before sampling. All samples were collected in tared glass bottles then subsequently dried and weighed to provide data for a mass balance. Dried samples were analyzed for plutonium concentration using alpha spectroscopy by either Controls for Environmental Pollution (CEP), Santa Fe, NM (701-709) or Lockheed Analytical Services (LAS), Las Vegas, NV (710-713).

CEP and LAS both followed similar procedures for alpha spectroscopy. Received samples were quantitatively transferred to digestion beakers by acid rinsing of the sample bottles. A plutonium-242 tracer was added to the beaker that contained the sample. The entire sample was then digested with nitric acid and hydrofluoric acid. LAS used microwave digestion. A boric acid or perchloric acid solution was added to the soil residue to convert the plutonium to a +4 valence state. LAS concentrated the plutonium by adding a ferric standard solution then ammonium hydroxide to the digested solid sample to precipitate ferric hydroxide with the plutonium. LAS then collected and dissolved this solid with nitric acid. The sample was then passed through an anion exchange column, washed, and the plutonium eluted. LAS proceeded with a  $\text{Nd}^{3+}$  microprecipitation of the plutonium and collection on a 0.2 mm membrane filter, CEP proceeded with electroplating of the plutonium on stainless steel discs. The filters or discs were then counted by alpha spectroscopy.

### 3.5 Data Management

This treatability study was conducted to evaluate the feasibility of using HGMS to address RFETS soil remediation. It was conducted in accordance with applicable LANL procedures and practices governing the conduct of operations of the magnetic separation equipment. Procedures have been established that govern the conduct of HGMS experiments including safe operating procedures, data handling and documentation.

Experiment flowsheets were prepared and reviewed prior to all HGMS tests. Using these flowsheets, a test specification sheet was generated assigning experiment identification numbers and defining equipment settings for the proposed test. Sample identification labels were generated for all sample containers and sample locations were identified on the experiment flowsheet. Samples were collected in labeled, tared sample bottles, for oven drying and weighing. All samples were maintained in their original, labeled sample containers. All test data were recorded in laboratory notebooks.

## 4.0 RESULTS AND DISCUSSION

### 4.1 DATA ANALYSIS AND INTERPRETATION

#### 4.1.1 Analysis of Waste Stream Characteristics

As discussed in 3.1 activity levels of the treated material ranged from 100 to 144 pCi/g. Particle sizes were less than 53  $\mu\text{m}$ . More detailed information on the generation of this residue can be obtained from the LESAT Report cited in 1.2.3.

#### 4.1.2 Treatability Study Objectives

The magnetic separation process has a number of variables which influence the results. These are listed in Table 4.1.2-1 where they are categorized according to material characteristics or separator characteristics. In general, the material characteristics are determined by the application, i.e., the type of soil, the contaminant and its distribution, the particle sizes and the physical properties. Some material characteristics are controllable, such as, surfactant type and concentration, and solids concentration. However, the separator parameters are where most of the process control exists. These parameters are controlled by the matrix design, the magnetic field characteristics and the slurry fluid mechanics. It is necessary to select a set of operating parameters that are compatible with the contaminated medium and that maximize the magnetic separation process.

*Table 4.1.2-1 HGMS Experiment Parameters*

Material Characteristics	Separator Parameters
Particle Size: 0.5 - 50 $\mu\text{m}$	Matrix Element Size: 5 - 100 $\mu\text{m}$
Impurity Concentration: 0.4 - 2000 ppm	Matrix Element Spacing: 80 - 1200 $\mu\text{m}$
Solids Concentration: 5 - 30 wt %	Magnetic Field Strength: 0.5 - 7.5 T
Magnetic Susceptibility* ( $\times 10^6$ ): 129 - 1478	Matrix Material: 430 Stainless Steel
Surfactant Concentration.: 0.00 - 0.2 wt %	Residence Time: 1.0 - 8.0 s
Slurry pH: 4 - 12	Superficial Velocity: 0.25 - 4.0 cm/s

\* SI units

Three sets of tests were performed on the RFETS soil residue to define the HGMS performance envelope. These tests, defined in 3.1, were used to generate an HGMS performance map for RFETS residue as shown in Fig. 4.1.2-1. This figure summarizes the results for all HGMS tests performed in this study and includes both mass fraction and separation efficiency. The mass fraction, defined as the ratio of the mass captured by the separator (as measured by the backflush) to the mass of the feed, is linear with applied magnetic field and the correlation is shown in Fig. 4.1.2-1. The separation efficiency, sometimes called the recovery, is the ratio of the activity in the magnetics (captured by the separator) to the activity in the feed. Separation efficiencies for all tests are shown in Fig. 4.1.2-1 along with their upper bound, obtained by interpolation. Results that combine a high separation efficiency with a low mass fraction indicate effective separation. The separation efficiency data have a large degree of scatter because of variations in sample

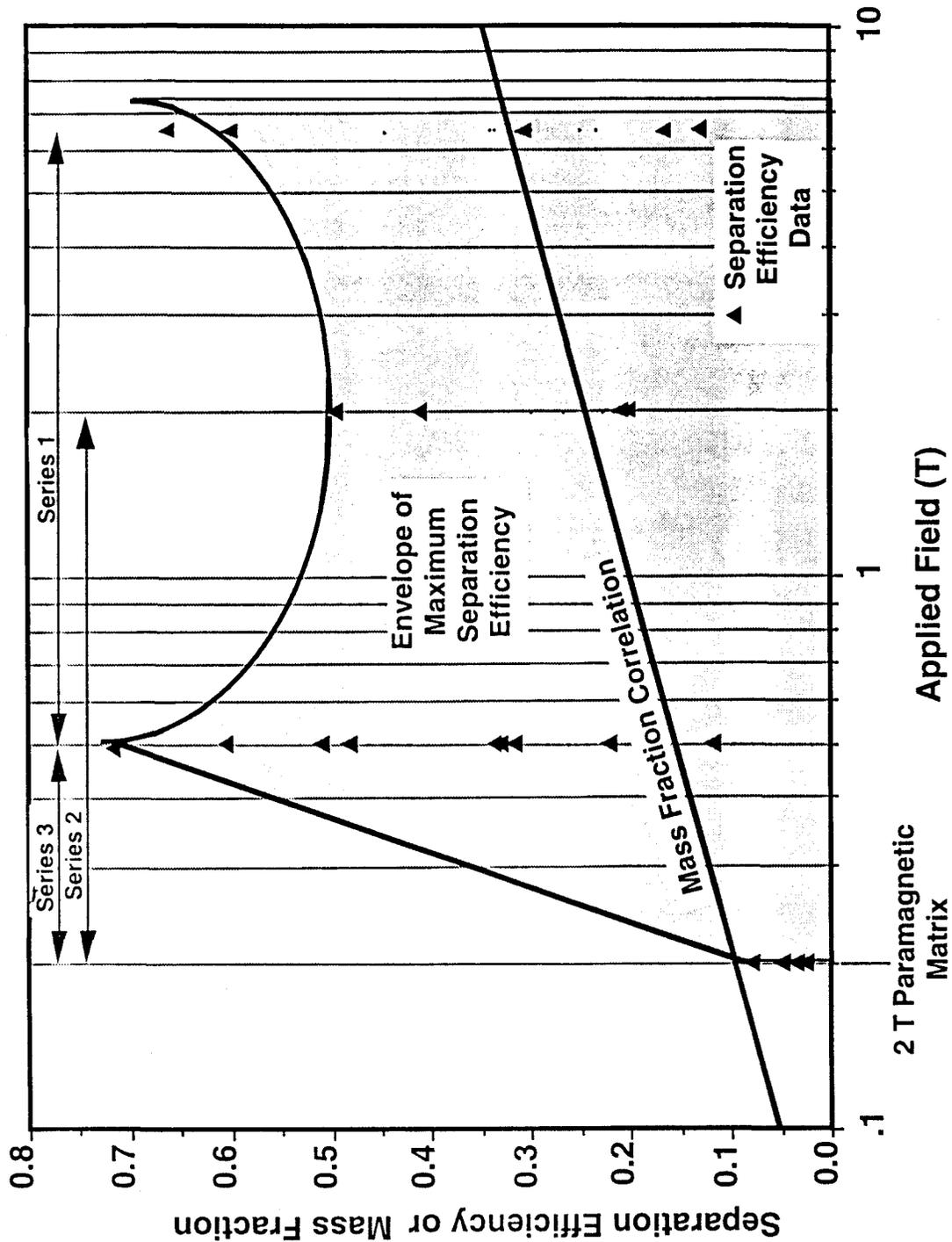


Fig. 4.1.2-1. HGMS Performance Map for RFETS Soil Residue (LESAT) Showing Mass Fraction Retained and Separation Efficiency.

#### 4.1.3 Treatability Study Results

pretreatment and separator operating parameters. The best results were obtained at an applied magnetic field near 0.5 T using a ferromagnetic matrix.

Test series 1 addressed the full field strength range of the magnetic separator while using a ferromagnetic matrix. These results showed the largest separation efficiencies. The mass fraction retained by the matrix increases nearly linearly with increasing applied magnetic field reaching 0.3 at the 6.5 T pass. In test series 2, a scalping pass at 2.0 T was introduced in an attempt to reduce the magnetic fraction of the soil. The scalping pass used a paramagnetic matrix which reduced the magnetic forces enabling the capture of only ferromagnetic (strongly magnetic) components from the soil. Because magnetite and certain other iron compounds are ferromagnetic, the scalping pass attempted to remove the iron compounds. In this series the second pass used a ferromagnetic matrix at a field of 2.0 T. This series also investigated the effect of pH. Test series 3 also started with the scalping pass but pass 2 was executed at 0.5 T with the ferromagnetic matrix in an attempt to reduce the mass fraction retained by the matrix. This was followed by a third pass at 6.5 T.

Appendix A contains the flow diagrams and detailed data sheets for each run. There is a separate flow diagram for each test series showing the parameters for each run in the series and the location and identification of each sample taken. The mass and activity for each sample analyzed (in bold) and certain derived values (plain text) are also included and grouped by series. Because material was removed for sampling at several points in the flow stream, it is convenient to use the mass weighted specific activity, which is the product of the mass fraction and the specific activity and is included in the tables in Appendix B, to determine separation efficiency. The separation efficiency was calculated three ways using the mass weighted specific activity from either the feed and backflush, the backflush and effluent or the feed and effluent. Equations for calculating the separation efficiency are found in Appendix C. If the mass and activity balance error were both zero, all three methods would give the same result. However, because of difficulties with either incomplete flushing of the matrix or inhomogeneous sampling of the effluent, one of these methods is usually more appropriate than the others.

In test series 1, the system activity balance indicated that backflushing of the matrix to remove the magnetic fraction was incomplete. The incomplete backflush was later verified by surrogate tests using the same test protocol. Therefore, separation efficiencies calculated using feed and effluent concentrations are probably more accurate than if the backflush concentrations were used. Several procedural changes were implemented in test series 2 and 3 in an attempt to improve the activity balances for these later tests. Backflushing was improved by incorporating air sparging into the liquid flush. By introducing bubbles into the flow stream, the scavenging of trapped material was improved and most of the material was liberated. In addition, effluents were sampled using bottom taps installed on the sample bottles. This modification in conjunction with the swirling motion employed to maintain particle suspension, appears to have resulted in a nonhomogeneous sampling of the effluent by preferentially collecting the heavier components containing higher activity from the mixture. Therefore, in test series 2 and 3 the feeds and backflushes had greater accuracy than the effluent samples and efficiencies for these runs were calculated using the feed and backflush concentrations. In general, activity balances were improved in the latter experiments with errors being less than  $\pm 20\%$ . Table 4.1.3-1 is a results summary of the HGMS experiments. Included are the mass

fractions and separation efficiencies for each pass of each run. Multiple data entries represent successive passes through the separator.

#### 4.1.3.1 Test Series 1

The following observations were made from test series 1:

- a. There was a high magnetic fraction in the feed. At B=6.5 T, the mass fraction retained by the matrix was approximately 0.2 for all runs.
- b. The high pH (>10) in Run 701 appeared to aid dispersion and reduced matrix loading. The mass fraction for pass 1 was only 0.021.
- c. Run 701 indicated surfactant concentrations approaching 0.2 wt% were necessary to insure high dispersion.
- d. Low superficial velocities (<0.5 cm/s) that normally improve separation efficiency resulted in unacceptably high mass retention in the matrix. Run 704 had the highest overall mass fraction at 0.332.
- e. Run 705 at superficial velocity of 1.0 cm/s showed an unexpectedly high separation effectiveness, comparable with Run 704.
- f. Activity balance was adversely affected by incomplete backflushing of the matrix.

#### 4.1.3.2 Test Series 2

The analysis for series 2 included the addition of a "forward flush" which was a rinse of the matrix at field to remove solids before the backflush. Although assayed separately, it was assumed to be part of the effluent stream when calculating effectiveness. Several modifications to the test procedure were incorporated into series 2 as follows:

- a. Modified sampling of the feed to assure sample uniformity.
- b. Backflushed matrix with air sparge to improve material recovery.
- c. Installed bottom taps on sample bottles to improve homogeneity in sampling.
- d. Adjusted backflush solution to pH12.

Results of test series 2 are as follows:

- a. The scalping passes were successful in removing magnetic soil components that did not include significant activity.
- b. Pass 2 with the ferromagnetic matrix at 2.0 T resulted in mass retention >0.22 along with activity removal in all runs.
- c. Organic destruction by peroxide pretreatment (Run 709) appeared to enhance liberation of the paramagnetic actinides. Compared with Run 707, more activity

was removed in the scalping pass after H<sub>2</sub>O<sub>2</sub> pretreatment. However, the effect was not significant.

#### 4.1.3.3 Test Series 3

Recognizing that the separation results from series 1 at B=0.5 T were better than series 2 results at 2.0 T, series 3 included a scalping pass at 2.0 T followed by a ferromagnetic pass at 0.5 T. Reduced solids fraction was also investigated to evaluate the effect of solids particle interference. A large population of solids in the slurry contributes to particle knock-off, a process where magnetic particles are striped from the matrix by random motion of the nonmagnetic solids. This action lowers separation efficiency. In addition, the H<sub>2</sub>O<sub>2</sub> pretreatment was repeated along with a run to evaluate a second surfactant, sodium silicate. The procedural modifications used in series 2 were continued for series 3 (the effluent sampling problem was not discovered until after test series 3 was completed).

Results of test series 3 are as follows:

- a. The scalping pass again extracted approximately 10% of the soil without removing appreciable activity.
- b. Mass fractions from the second pass (B=0.5 T) were higher than observed in series 1. Therefore, the scalping pass employed in this series may not be desirable.
- c. Reduced solids fraction increased both separation efficiency and mass retention at high magnetic field (6.5 T) with no net benefit.
- d. The H<sub>2</sub>O<sub>2</sub> pretreatment was ineffective in improving separation.
- e. The use of sodium silicate as a surfactant significantly increased separation efficiency (from 0.22 to 0.48) with only a slight increase in mass retention (from 0.18 to 0.26).

#### 4.2 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

QA/QC were maintained through data documentation as described in Section 3.5, Data Management.

Alpha spectroscopy analyses were performed on all samples by either CEP, Santa Fe, NM or LAS, Las Vegas, NV according to the following SOPs:

CEP: "The Radiochemistry of Plutonium", Environmental Measurements Lab, HASL-300

LAS: "Actinide Preparation, Nuclide Separation and Analysis", LAL-91-SOP-0108

*Table 4.1.3-1 HGMS Results Summary*

Series	Run #	Magnetic Field (T) per Pass	Surfactant	pH	Mass Fraction per Pass**	Separation Efficiency per Pass**

1	701	0.5/6.5	0.2 % Hexamet	10	.021/.234	.511/.466
1	702	0.5/6.5	none	8	.067/.203	.307/.371
1	703	0.5/6.5	0.05 % Hexamet	8	.071/.184	.314/.435
1	704	0.5/6.5	0.05 % Hexamet	8	.130/.202	.693/.112
1	705	0.5/6.5	0.05 % Hexamet	8	.056/.151	.595/.165
2	706	2.0p/2.0	0.2 % Hexamet	8	.081/.299	.023/.494
2	707	2.0p/2.0	0.2 % Hexamet	10	.091/.228	.031/.209
2	708	2p/0.5/6.5	0.2 % Hexamet	12	.050/.217	.035/.200
2	709*	2p/0.5/6.5	0.2 % Hexamet	10	.056/.267	.028/.409
3	710	2p/0.5/6.5	0.2 % Hexamet	10	.110/.176	.081/.220
3	711	2p/0.5/6.5	0.2 % Hexamet	10	.123/.284	.052/.317
3	712*	2p/0.5/6.5	0.2 % Hexamet	10	.083/.181	.037/.118
3	713	2p/0.5/6.5	0.5% Na <sub>2</sub> SiO <sub>3</sub>	10	.111/.264	.078/.481

\* Pretreat with H<sub>2</sub>O<sub>2</sub>

\*\* Passes 1 and 2 only

Although the sample preparation procedures used by each vendor differed slightly, total sample dissolution was achieved in every case. Therefore, alpha spectroscopy measurements from both vendors are directly comparable.

All experiments were conducted at the LANL Plutonium Facility under the following SOPs:  
 LANL-MSP-285, conventional magnetic separator  
 LANL-MSP-286, superconducting magnetic separator

Data quality objectives were not established for this study. Duplicate samples were evaluated in previous investigations using the test procedures herein described.

## Appendix A: Acronym List

A	Ampere
Be	beryllium
CEP	Controls for Environmental Pollution
cm	centimeters
cm <sup>2</sup>	square centimeters
cm/s	centimeters per second
DOE	Department of Energy
dpm	disintegrations per minute
g	gram
HGMS	High Gradient Magnetic Separation
H <sub>2</sub> O <sub>2</sub>	hydrogen peroxide
K	Kelvin
LAS	Lockheed Analytical Services
LANL	Los Alamos National Laboratory
LESAT	Lockheed Environmental Systems and Technologies Co.
ml/s	milliliters per second
Na <sub>2</sub> SiO <sub>3</sub>	sodium silicate
Nd	neodymium
OU	Operable Unit
pCi	pico Curies
pCi/g	pico Curies per gram
PF	Plutonium Facility
Pu	plutonium
PuO <sub>2</sub>	plutonium oxide
QA	Quality Assurance
QC	Quality Control

RCRA	Resource Conservation and Recovery Act
RF	Rocky Flats
RFETS	Rocky Flats Environmental Technology Site
T	tesla
TA	Technical Area
U	uranium
μm	micrometers

## MAGNETIC SEPARATION TEST

Date- 2/10 & 17/94

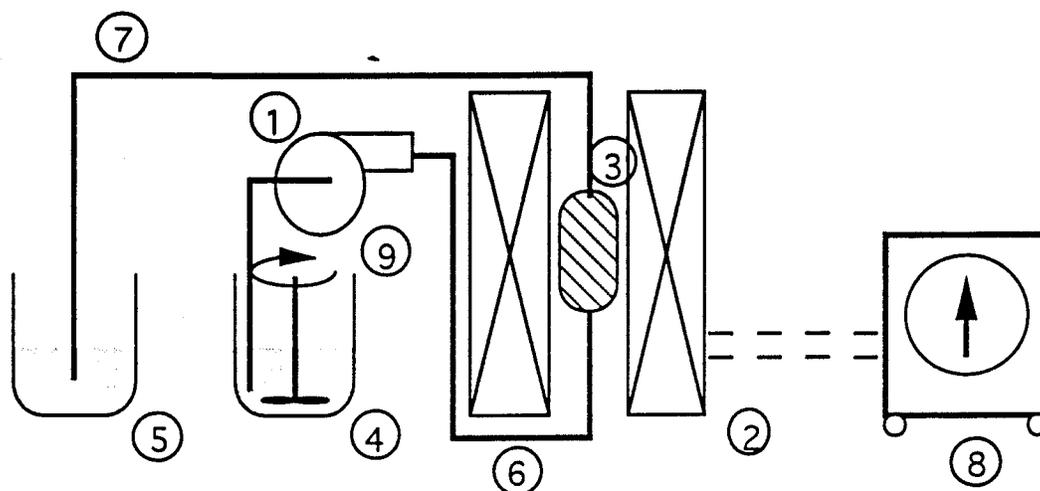
Location-TA55/PF4/RM128

### Separator-

Type	Magnet	Manufacturer	Descriptor
HGMS	3" Superconductor	Cryomagnetics	Internal

Objective-Test Series 1

### Experimental Schematic-



- (1) Monostat D Series Varistatic pump calibrated for tubing with 4 layers of tape in tube tray and foam to center tubing in tray
- (2) Cryomagnetics 3" warm bore S/C magnetic separator
- (3) Matrix
- (4) Supply beaker
- (5) Exit and sample beaker
- (6) Nalgene tubing 1/8" ID
- (7) Nalgene tubing 1/8" ID
- (8) Magnet power supply
- (9) Stirrer

**MAGNETIC SEPARATION TEST**

**RFP Soil LESAT Residue**

Date: 2/10/94 & 2/17/94

**Carrier Fluid**

**Surrogate**

Description
DI H2O

Description	Particle Size
LESAT Thickner Underflow	<53u

**Matrix**

Matrix #VI
------------

**Comments**

Test	Surf	pH
701	.2% HEX	10
702	0	8
703	.05% HEX	8
704	.05% HEX	8
705	.05% HEX	8

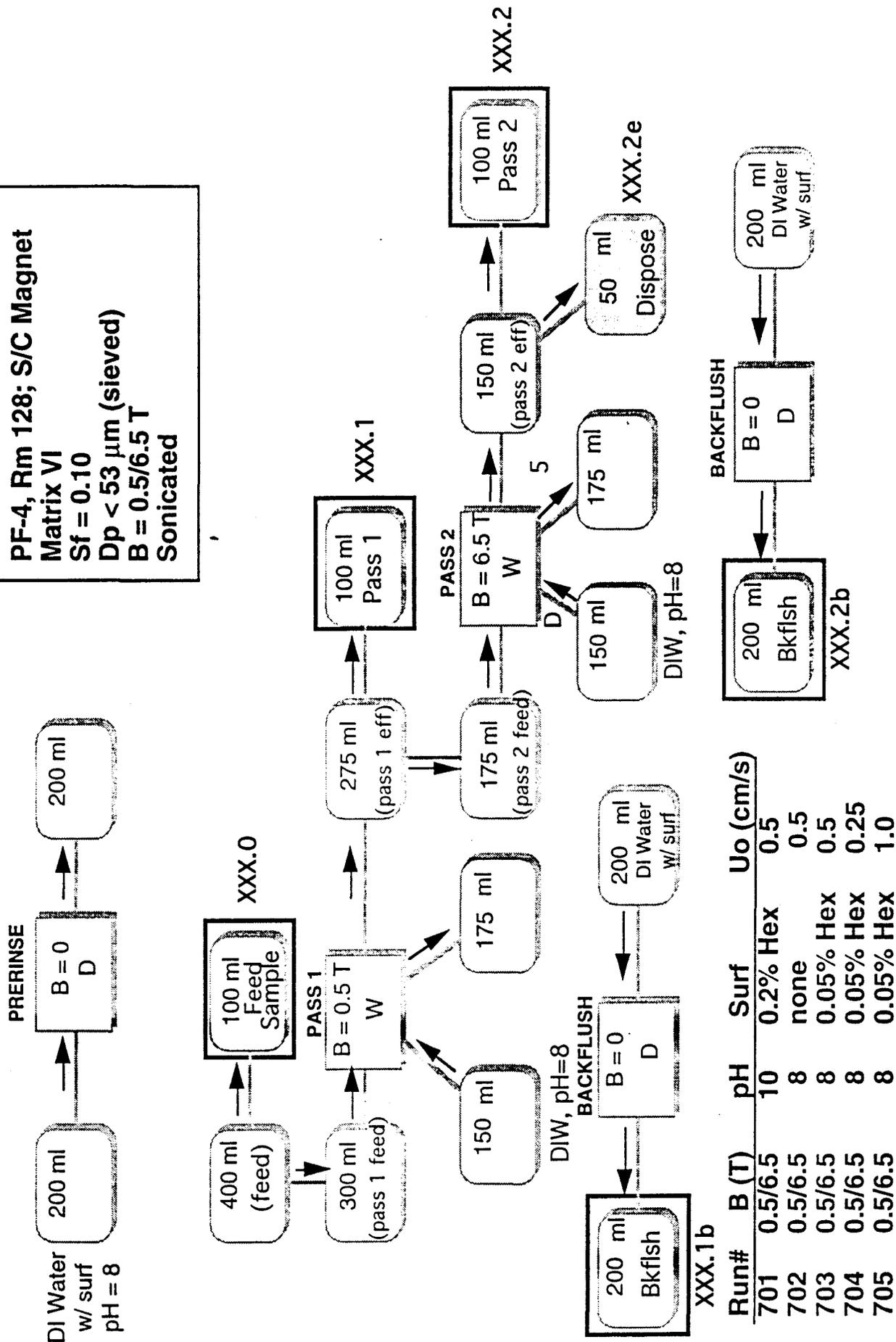
**DATA**

Test #	Pass #	Displayed Flow Rate (ml/s)	Corrected Flow Rate (ml/s)	Magnet Current (A)	Field Strength (Tesla)	Solids Conc. (%)	Temp. (C)	Flow Direction
701.0	0	-	-	0	0	10%	20	-
701.1	1	70	1.35	56	0.5	10%	20	D
701.2	2	70	1.35	56	6.5	10%	20	D
701.2b	2	400	7.5	0	0	10%	20	U
702.0	0	-	-	0	0	10%	20	-
702.1	1	70	1.35	56	0.5	10%	20	D
702.1b	1	400	7.5	0	0	10%	20	U
702.2	2	70	1.35	56	6.5	10%	20	D
702.2b	2	400	7.5	0	0	10%	20	U
703.0	0	-	-	0	0	10%	20	-
703.1	1	70	1.35	56	0.5	10%	20	D
703.1b	1	400	7.5	0	0	10%	20	U
703.2	2	70	1.35	56	6.5	10%	20	D
703.2b	2	400	7.5	0	0	10%	20	U
704.0	0	-	-	0	0	10%	20	-
704.1	1	35	0.675	56	0.5	10%	20	D
704.1b	1	400	7.5	0	0	10%	20	U
704.2	2	35	0.675	56	6.5	10%	20	D
704.2b	2	400	7.5	0	0	10%	20	U
705.0	0	-	-	0	0	10%	20	-
705.1	1	140	2.7	56	0.5	10%	20	D
705.1b	1	400	7.5	0	0	10%	20	U
705.2	2	140	2.7	56	6.5	10%	20	D
705.2b	2	400	7.5	0	0	10%	20	U

# 2/10&17/94 RFP Sample (LESAT Residue - Thickener underflow)

Determine effect of flowrate and surfactant

PF-4, Rm 128; S/C Magnet  
 Matrix VI  
 Sf = 0.10  
 Dp < 53 μm (sieved)  
 B = 0.5/6.5 T  
 Sonicated



Run#	B (T)	pH	Surf	Uo (cm/s)
701	0.5/6.5	10	0.2% Hex	0.5
702	0.5/6.5	8	none	0.5
703	0.5/6.5	8	0.05% Hex	0.5
704	0.5/6.5	8	0.05% Hex	0.25
705	0.5/6.5	8	0.05% Hex	1.0

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using		
								feed & bk	bk & effl	feed & effl
Run #701										
feed	37.7			120.00	4524.00					
XXX.0	9.6			120.00	1152.00					
Pass 1 feed	28.1		1.000	120.00	3372.00		120.000			
XXX.1	9.1			60	546.00					
XXX.1b	0.6		0.021	248	148.80		5.295	0.044	0.083	0.511
Pass 1 eff	27.5		0.979	60	1650.00		58.719			
Pass 2 feed	18.4		1.000	60	1104.00		60.000			
XXX.2	7.2			41.8	300.96					
XXX.2b	4.3		0.234	112.20	482.46		26.221	0.224	0.450	0.466
Pass 2 eff	14.1		0.766	41.80	589.38		32.032			
XXX.2e	7			41.8	292.60					
Total	37.8	0.27	0.255		2922.82	-35.39		0.258	0.496	0.739
Run #702										
feed	40		-	99.50	3980.00					
XXX.0	5.6			99.50	557.20					
Pass 1 feed	34.4		1.000	99.50	3422.80		99.500			
XXX.1	5.02			73.9	370.98					
XXX.1b	2.3		0.067	189	434.70		12.637	0.127	0.155	0.307
Pass 1 eff	32.1		0.933	73.9	2372.19		68.959			
Pass 2 feed	27.08		1.000	73.9	2001.21		73.900			
XXX.2	1.7			58.3	99.11					
XXX.2b	5.5		0.203	114.70	630.85		23.296	0.250	0.334	0.371
Pass 2 eff	21.58		0.797	58.30	1258.11		46.459			
XXX.2e	8			58.30	466.40					
Total	28.12	-29.70	0.270		2559.24	-35.70		0.345	0.437	0.564
Run #703										
feed	40			100	4000.00					
XXX.0	6.1			100	610.00					
Pass 1 feed	33.9		1.000	100	3390.00		100.000			
XXX.1	5.4			73.8	398.52					
XXX.1b	2.4		0.071	175	420.00		12.389	0.124	0.153	0.314
Pass 1 eff	31.5		0.929	73.8	2324.70		68.575			
Pass 2 feed	26.1		1.000	73.8	1926.18		73.800			
XXX.2	2.4			51.1	122.64					
XXX.2b	4.8		0.184	144.30	692.64		26.538	0.281	0.389	0.435
Pass 2 eff	21.3		0.816	51.10	1088.43		41.702			
XXX.2e	6.5			51.10	332.15					
Total	27.6	-31.00	0.255		2575.95	-35.60		0.370	0.482	0.613

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using		
								feed & bk	bk & effl	feed & effl
Run #704										
feed	40			140	5600.00					
XXX.0	5.3			140	742.00					
Pass 1 feed	34.7		1.000	140	4858.00		140.000			
XXX.1	5			49.4	247.00					
XXX.1b	4.5		0.130	124.7	561.15		16.171	0.116	0.273	0.693
Pass 1 eff	30.2		0.870	49.4	1491.88		42.994			
Pass 2 feed	25.2		1.000	49.4	1244.88		49.400			
XXX.2	1.7			55	93.50					
XXX.2b	5.1		0.202	129.90	662.49		26.289	0.185	0.375	0.112
Pass 2 eff	20.1		0.798	55.00	1105.50		43.869			
XXX.2e	6.9			55.00	379.50					
Total	28.5	-28.75	0.332		2685.64	-52.04		0.279	0.546	0.727
Run #705										
feed	40			144	5760.00					
XXX.0	6			144	864.00					
Pass 1 feed	34		1.000	144	4896.00		144.000			
XXX.1	6.9			61.8	426.42					
XXX.1b	1.9		0.056	233.2	443.08		13.032	0.090	0.183	0.595
Pass 1 eff	32.1		0.944	61.8	1983.78		58.346			
Pass 2 feed	25.2		1.000	61.8	1557.36		61.800			
XXX.2	3.2			60.79	194.53					
XXX.2b	3.8		0.151	168.90	641.82		25.469	0.184	0.330	0.165
Pass 2 eff	21.4		0.849	60.79	1300.91		51.623			
XXX.2e	6.9			60.79	419.45					
Total	28.7	-28.25	0.207		2989.30	-48.10		0.257	0.453	0.662

Mass Fraction (mf) = Mass/Mass Feed

Activity (a) = Mass \* Specific Activity

Mass Weighted Specific Activity (A) = Mass Fraction \* Specific Activity

Separation Efficiency (E) = Amags/Afeed

$$E_{1,2} = E_1 + E_2 - E_1 * E_2$$

# MAGNETIC SEPARATION TEST

Date- 7/14/94

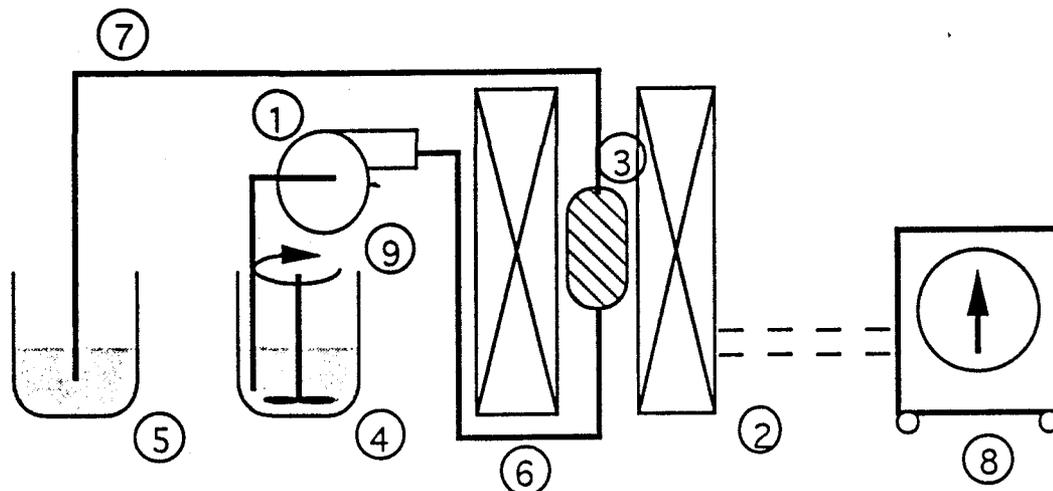
Location-TA55/PF4/RM128

## Separator-

Type	Magnet	Manufacturer	Descriptor
HGMS	3" Superconductor	Cryomagnetics	Internal

Objective-Test Series 2

## Experimental Schematic-



- (1) Monostat D Series Varistatic pump calibrated for tubing with 4 layers of tape in tube tray and foam to center tubing in tray
- (2) Cryomagnetics 3" warm bore S/C magnetic separator
- (3) Matrix
- (4) Supply beaker
- (5) Exit and sample beaker
- (6) Nalgene tubing 1/8" ID
- (7) Nalgene tubing 1/8" ID
- (8) Magnet power supply
- (9) Stirrer

# MAGNETIC SEPARATION TEST

# RFP Soil LESAT Residue

Date: 7/15/94

## Carrier Fluid

Description
DI H2O

## Surrogate

Description	Particle Size
LESAT Thickner Underflow	<53u

## Matrix

pass 1 Matrix VII
pass 2 Matrix VI

## Comments

Test	pH
706	8
707	10
708	12
709	10

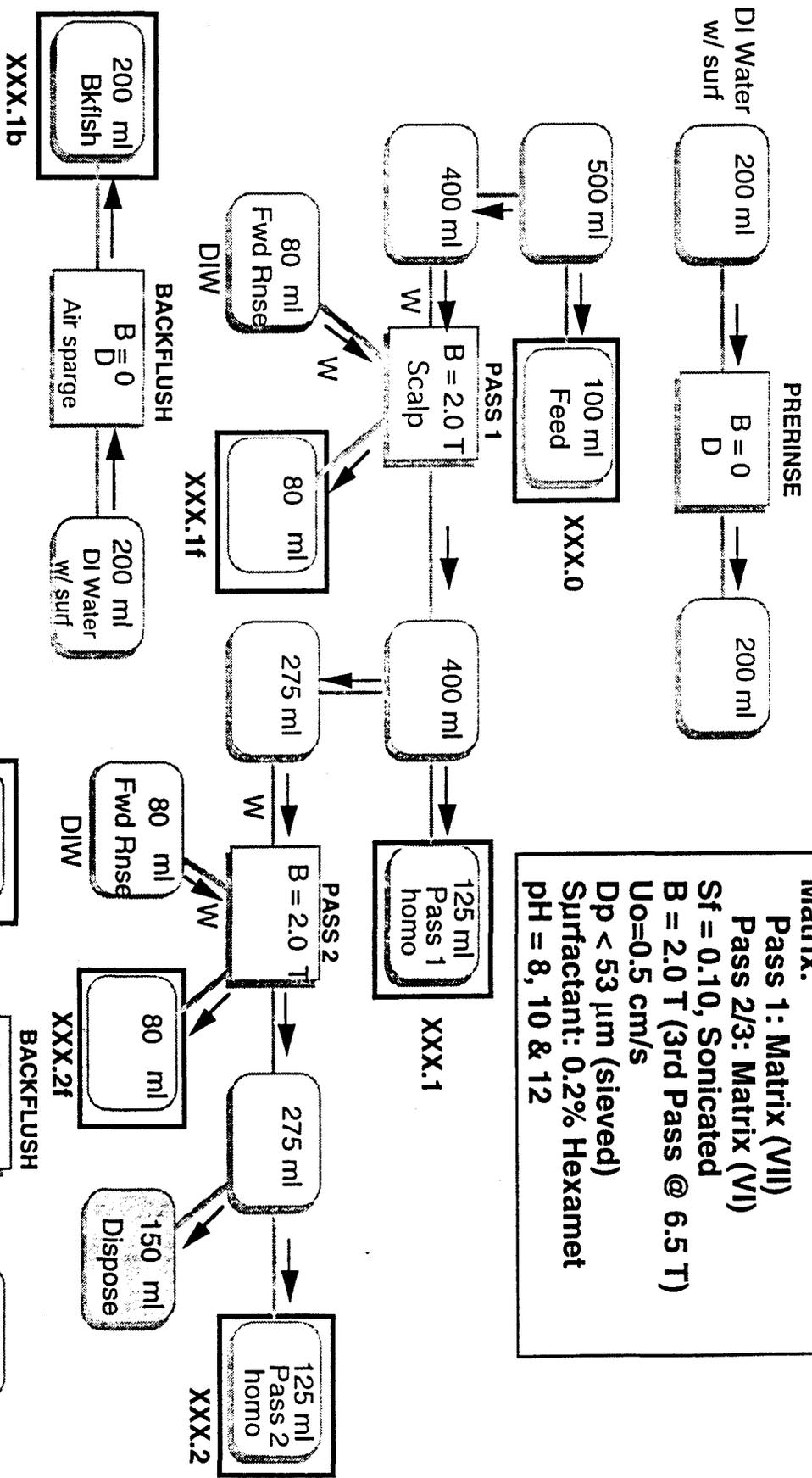
## DATA

Test #	Pass #	Displayed Flow Rate (ml/s)	Corrected Flow Rate (ml/s)	Magnet Current (A)	Field Strength (Tesla)	Solids Conc. (%)	Temp. (C)	Flow Direction
706.0	0	-	-	0	0	10%	20	-
706.0	0	-	-	0	0	10%	20	-
706.1	1	70	1.35	16.9	2	10%	20	D
706.1b	1	400	7.5	0	0	10%	20	U
706.2	2	70	1.35	16.9	2	10%	20	D
706.2b	2	400	7.5	0	0	10%	20	U
707.0	0	-	-	0	0	10%	20	-
707.1	1	70	1.35	16.9	2	10%	20	D
707.1b	1	400	7.5	0	0	10%	20	U
707.2	2	70	1.35	16.9	2	10%	20	D
707.2b	2	400	7.5	0	0	10%	20	U
708.0	0	-	-	0	0	10%	20	-
708.1	1	70	1.35	16.9	2	10%	20	D
708.1b	1	400	7.5	0	0	10%	20	U
708.2	2	70	1.35	16.9	2	10%	20	D
708.2b	2	400	7.5	0	0	10%	20	U
708.3	3	70	1.35	16.9	2	10%	20	D
708.3b	3	400	7.5	0	0	10%	20	U
709.0	0	-	-	0	0	10%	20	-
709.1	1	70	1.35	16.9	2	10%	20	D
709.1b	1	400	7.5	0	0	10%	20	U
709.2	2	70	1.35	16.9	2	10%	20	D
709.2b	2	400	7.5	0	0	10%	20	U

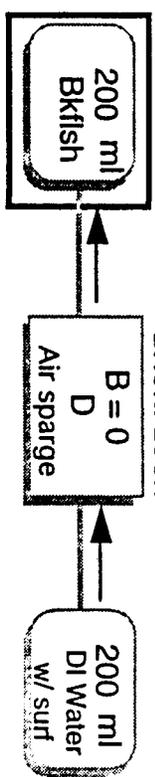
# 7/15/94 RFP Sample (LESAT Residue - Thickener underflow)

## Determine effect of pH and H2O2 pretreatment

PF-4, Rm 128; S/C Magnet  
 Matrix:  
 Pass 1: Matrix (VII)  
 Pass 2/3: Matrix (VI)  
 Sf = 0.10, Sonicated  
 B = 2.0 T (3rd Pass @ 6.5 T)  
 Uo=0.5 cm/s  
 Dp < 53 μm (sieved)  
 Surfactant: 0.2% Hexamet  
 pH = 8, 10 & 12



Run#	B (T)	pH	Surf	Uo (cm/s)
706**	2.0p/2.0	8	0.2% Hex	0.5
707	2.0p/2.0	10	0.2% Hex	0.5
708****	2.0p/2.0	12	0.2% Hex	0.5
709*	2.0p/2.0	10	0.2% Hex	0.5



\*\*\*2 feed samples  
 \*\*With H2O2 pretreatment for organics; 3 Passes  
 \*\*\*\*3 Passes

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using		
								feed & bk	bk & effl	feed & effl
<b>Run #706</b>										
<b>feed</b>	50			68.3	3415.00					
<b>XXX.0</b>	18.46			68.3	1260.82					
Pass 1 feed	31.54		1.000	68.3	2154.18		68.300			
<b>XXX.1</b>	7.24			80.4	582.10					
<b>XXX.1f</b>	1.51		0.048	19.4	29.29		0.929			
<b>XXX.1b</b>	2.54		0.081	19.4	49.28		1.562	0.023	0.022	-0.040
Pass 1 eff	27.49		0.872	80.4	2210.20		70.076			
Pass 2 feed	20.25		1.000	80.4	1628.10		80.400			
<b>XXX.2</b>	5.31			118	626.58					
<b>XXX.2f</b>	0.66		0.033	32.4	21.38		1.056			
<b>XXX.2b</b>	6.05		0.299	120.00	726.00		35.852	0.494	0.310	0.006
Pass 2 eff	13.54		0.669	118.00	1597.72		78.900			
<b>XXX.2e</b>	12			118.00	1416.00					
<b>Total</b>	<b>53.77</b>	<b>7.54</b>	<b>0.379</b>		<b>4711.45</b>	<b>37.96</b>		<b>0.506</b>	<b>0.324</b>	<b>-0.034</b>
<b>Run #707</b>										
<b>feed</b>	38.75			94	3642.50					
<b>XXX.0</b>	8.16			94	767.04					
Pass 1 feed	30.59		1.000	94	2875.46		94.000			
<b>XXX.1</b>	5.56			99.1	551.00					
<b>XXX.1f</b>	1.56		0.051	17	26.52		0.867			
<b>XXX.1b</b>	2.78		0.091	31.6	87.85		2.872	0.031	0.032	0.086
Pass 1 eff	26.25		0.858	99.1	2601.38		85.040			
Pass 2 feed	20.69		1.000	99.1	2050.38		99.100			
<b>XXX.2</b>	5.22			73.5	383.67					
<b>XXX.2f</b>	1.17		0.057	65.7	76.87		3.715			
<b>XXX.2b</b>	4.71		0.228	92.20	434.26		20.989	0.209	0.271	0.432
Pass 2 eff	14.81		0.716	73.50	1088.54		52.612			
<b>XXX.2e</b>	9.1			73.50	668.85					
<b>Total</b>	<b>38.26</b>	<b>-1.26</b>	<b>0.319</b>		<b>2996.06</b>	<b>-17.75</b>		<b>0.234</b>	<b>0.295</b>	<b>0.481</b>

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using		
								feed & bk	bk & effl	feed & effl
Run #708										
feed	38.75			81	3138.75					
XXX.0	8.16			81	660.96					
Pass 1 feed	30.59		1.000	81	2477.79		81.000			
XXX.1	6.83			32.8	224.02					
XXX.1f	0.76		0.025	35.2	26.75		0.875			
XXX.1b	1.53		0.050	57.1	87.36		2.856	0.035	0.084	0.615
Pass 1 eff	28.3		0.925	32.8	928.24		30.345			
Pass 2 feed	21.47		1.000	32.8	704.22		32.800			
XXX.2	4.96			94.2	467.23					
XXX.2f	0.62		0.029	93.2	57.78		2.691			
XXX.2b	4.65		0.217	76.10	353.87		16.482	0.200	0.183	-1.249
Pass 2 eff	16.2		0.755	94.20	1526.04		71.078			
Pass 3 feed	11.24		1.000	94.2	1058.81		94.200			
XXX.3	3.8			73.70	280.06					
XXX.3f	0.9		0.080	33.5	30.15		2.682			
XXX.3b	3.16		0.281	86.30	272.71		24.262	0.289	0.328	0.472
Pass 3 eff	7.18		0.639	73.70	529.17		47.079			
XXX.3e	3.49			73.70	257.21					
Total	38.86	0.28	0.548		2718.11	-13.40		0.451	0.497	0.542
Run #709										
feed	50			96.1	4805.00					
XXX.0	12.5			96.1	1201.25					
Pass 1 feed	37.5		1.000	96.1	3603.75		96.100			
XXX.1	9.49			85.9	815.19					
XXX.1f	2.3		0.061	20.1	46.23		1.233			
XXX.1b	2.11		0.056	48.4	102.12		2.723	0.028	0.034	0.198
Pass 1 eff	33.09		0.882	85.9	2842.43		75.798			
Pass 2 feed	23.6		1.000	85.9	2027.24		85.900			
XXX.2	8.03			87.4	701.82					
XXX.2f	1.19		0.050	50	59.50		2.521			
XXX.2b	6.29		0.267	152.00	956.08		40.512	0.409	0.394	0.276
Pass 2 eff	16.12		0.683	87.40	1408.89		59.699			
Pass 3 feed	8.09		1.000	87.4	707.07		87.400			
XXX.3	5.29			70.20	371.36					
XXX.3f	1.29		0.159	2016	2600.64		321.464			
XXX.3b	3.64		0.450	18.00	65.52		8.099	0.102	0.023	-2.992
Pass 3 eff	3.16		0.391	70.20	221.83		27.421			
XXX.3e	2.91			70.20	204.28					
Total	55.04	10.08	0.773		7124.00	48.26		0.485	0.428	-1.318

## Notes to table

Forward flushes (XXX.Xf) are combined with effluent when calculating efficiencies

Mass Fraction (mf) = Mass/Mass Feed

Activity (a) = Mass \* Specific Activity

Mass Weighted Specific Activity (A) = Mass Fraction \* Specific Activity

Separation Efficiency (E) =  $A_{mags}/A_{feed}$

$E_{1,2} = E_1 + E_2 - E_1 * E_2$

$E_{1,2,3} = E_1 + E_2 + E_3 - E_1 * E_2 - E_1 * E_3 - E_2 * E_3 + E_1 * E_2 * E_3$

# MAGNETIC SEPARATION TEST

Date- 9/15/94

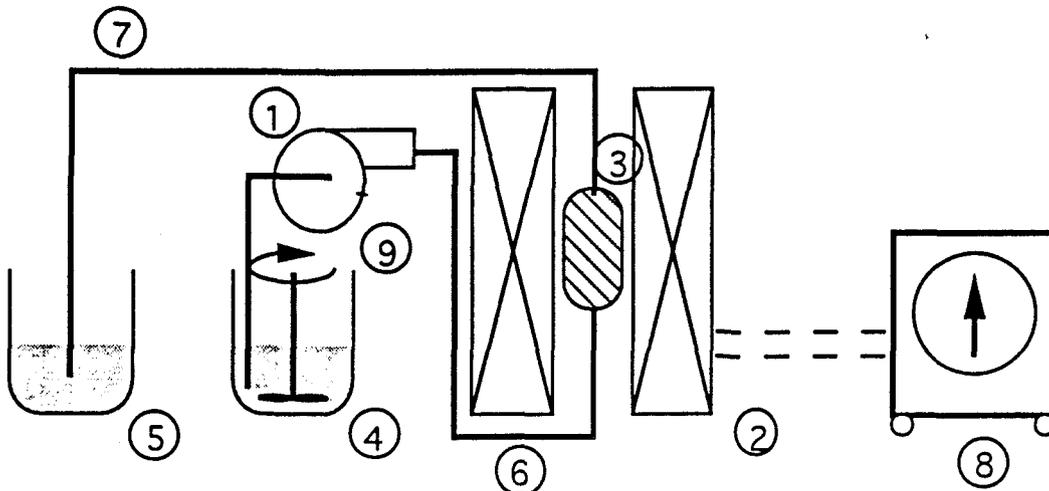
Location-TA55/PF4/RM128

## Separator-

Type	Magnet	Manufacturer	Descriptor
HGMS	3" Superconductor	Cryomagnetics	Internal

Objective-Test Series 3

## Experimental Schematic-



- (1) Monostat D Series Varistatic pump calibrated for tubing with 4 layers of tape in tube tray and foam to center tubing in tray
- (2) Cryomagnetics 3" warm bore S/C magnetic separator
- (3) Matrix
- (4) Supply beaker
- (5) Exit and sample beaker
- (6) Nalgene tubing 1/8" ID
- (7) Nalgene tubing 1/8" ID
- (8) Magnet power supply
- (9) Stirrer

**MAGNETIC SEPARATION TEST**

**RFP Soil LESAT Residue**

Date: 9/15/94

**Carrier Fluid**

Description
DI H2O

**Surrogate**

Description	Particle Size
LESAT Thickner Underflow	<53u

**Matrix**

pass 1 Matrix VII
pass 2 Matrix VIII

**Comments**

Test	pH	Sf	Surf
710	10	0.1	.2% hex
711	10	0.05	.2% hex
712	10	0.1	.2% hex
713	10	0.1	Sodium Silicate

**DATA**

Test #	Pass #	Displayed Flow Rate (ml/s)	Corrected Flow Rate (ml/s)	Magnet Current (A)	Field Strength (Tesla)	Solids Conc. (%)	Temp. (C)	Flow Direction
710.0	0	-	-	0	0	5%	20	-
710.1	1	70	1.35	16.9	2	5%	20	D
710.1f	1	70	1.35	16.9	2	5%	20	D
710.1b	1	400	7.5	0	0	5%	20	U
710.2	2	70	1.35	3.8	0.5	5%	20	D
710.2f	2	70	1.35	3.8	0.5	5%	20	D
710.2b	2	400	7.5	0	0	5%	20	U
710.3	3	70	1.35	56	6.5	5%	20	D
710.3f	3	70	1.35	56	6.5	5%	20	D
710.3b	3	400	7.5	0	0	5%	20	U
711.0	0	-	-	0	0	5%	20	-
711.1	1	70	1.35	16.9	2	5%	20	D
711.1f	1	70	1.35	16.9	2	5%	20	D
711.1b	1	400	7.5	0	0	5%	20	U
711.2	2	70	1.35	3.8	0.5	5%	20	D
711.2f	2	70	1.35	3.8	0.5	5%	20	D
711.2b	2	400	7.5	0	0	5%	20	U
711.3	3	70	1.35	56	6.5	5%	20	D
711.3f	3	70	1.35	56	6.5	5%	20	D
711.3b	3	400	7.5	0	0	5%	20	U
712.0	0	-	-	0	0	5%	20	-
712.1	1	70	1.35	16.9	2	5%	20	D
712.1f	1	70	1.35	16.9	2	5%	20	D
712.1b	1	400	7.5	0	0	5%	20	U
712.2	2	70	1.35	3.8	0.5	5%	20	D
712.2f	2	70	1.35	3.8	0.5	5%	20	D
712.2b	2	400	7.5	0	0	5%	20	U
712.3	3	70	1.35	56	6.5	5%	20	D
712.3f	3	70	1.35	56	6.5	5%	20	D
712.3b	3	400	7.5	0	0	5%	20	U

**MAGNETIC SEPARATION TEST**

**RFP Soil LESAT Residue**

Date: 9/15/94

Carrier Fluid

Surrogate

Description
DI H2O

Description	Particle Size
LESAT Thickner Underflow	<53u

Matrix

pass 1 Matrix VII
pass 2 Matrix VIII

Comments

Test	pH	Sf	Surf
710	10	0.1	.2% hex
711	10	0.05	.2% hex
712	10	0.1	.2% hex
713	10	0.1	Sodium Silicate

713.0	0	-	-	0	0	5%	20	-
713.1	1	70	1.35	16.9	2	5%	20	D
713.1f	1	70	1.35	16.9	2	5%	20	D
713.1b	1	400	7.5	0	0	5%	20	U
713.2	2	70	1.35	3.8	0.5	5%	20	D
713.2f	2	70	1.35	3.8	0.5	5%	20	D
713.2b	2	400	7.5	0	0	5%	20	U
713.3	3	70	1.35	56	6.5	5%	20	D
713.3f	3	70	1.35	56	6.5	5%	20	D
713.3b	3	400	7.5	0	0	5%	20	U

# 9/15/94 RFP Sample (LESAT Residue - Thickener underflow)

Determine effect of Surfactant and H2O2 pretreatment

PF-4, Rm 128; S/C Magnet

Matrix:

Pass 1: Matrix (VII)

Pass 2/3: Matrix (VIII)

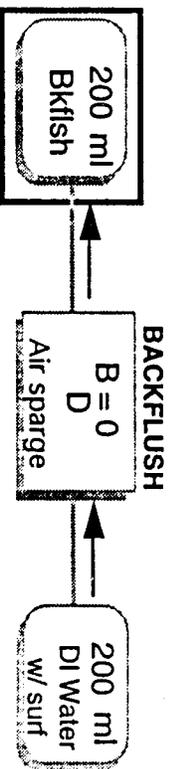
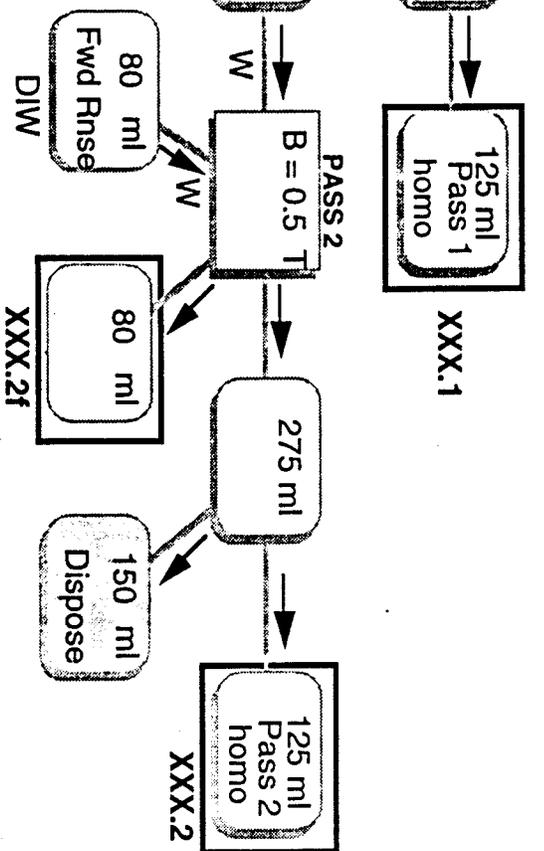
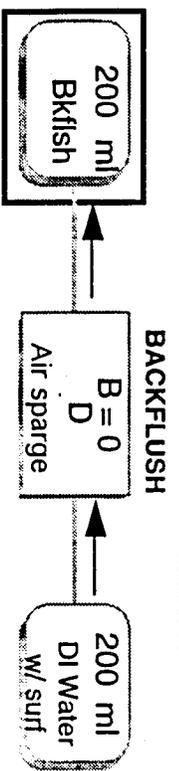
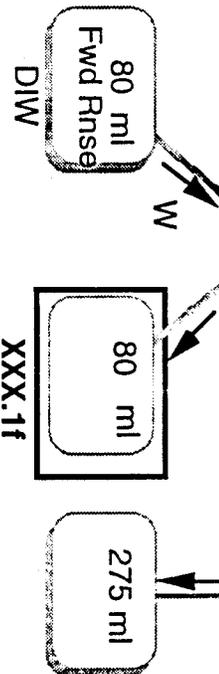
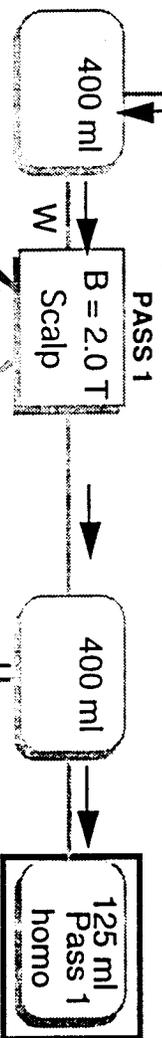
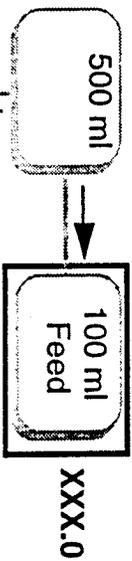
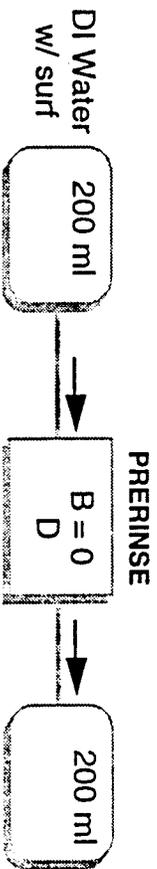
Uo=0.5 cm/s, Sonicated

B = 2.0/0.5/6.5 T; Uo=0.5 cm/s

Dp < 53 μm (sieved)

Surfactant: Sodium Silicate & 0.2% Hexamet

pH = 10



Run#	B (T)	pH	Surf	Sf
710**	2.0/0.5/6.5	10	0.2% Hex	0.1
711	2.0/0.5/6.5	10	0.2% Hex	0.05
712*	2.0/0.5/6.5	10	0.2% Hex	0.1
713	2.0/0.5/6.5	10	Sodium Silicate	0.1

All runs have 3rd Pass at 6.5 T  
 \*With H2O2 pretreatment for organics  
 \*\*Replaced hoses between passes

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using		
								feed & bk	bk & effl	feed & effl
Run #710										
feed	55.50			132.00	7326.00					
XXX.0	11.40			132.00	1504.80					
Pass 1 feed	44.10		1.000	132.00	5821.20		132.000			
XXX.1	10.96			77.40	848.30					
XXX.1f	4.60		0.104	89.60	412.16		9.346			
XXX.1b	4.86		0.110	96.50	468.99		10.635	0.081	0.132	0.469
Pass 1 eff	34.64		0.785	77.40	2681.14		60.797			
Pass 2 feed	23.68		1.000	77.40	1832.83		77.400			
XXX.2	8.00			134.30	1074.40					
XXX.2f	2.08		0.088	90.90	189.07		7.984			
XXX.2b	4.16		0.176	170.50	709.28		29.953	0.220	0.219	-0.381
Pass 2 eff	17.44		-0.736	134.30	2342.19		98.910			
Pass 3 feed	9.44		1.000	134.30	1267.79		134.300			
XXX.3	2.60			130.50	339.30					
XXX.3f	1.20		0.127	73.48	88.18		9.341			
XXX.3b	5.00		0.530	153.60	768.00		81.356	0.630	0.600	0.597
Pass 3 eff	3.24		0.343	130.50	422.82		44.790			
XXX.3e	0.00			130.50	0.00					
Total	54.86	-1.15	0.816		6402.48	-12.61		0.735	0.729	0.704
Run #711										
feed	27.75			99.98	2774.45					
XXX.0	6.66			99.98	665.87					
Pass 1 feed	21.09		1.000	99.98	2108.58		99.980			
XXX.1	4.75			164.50	781.38					
XXX.1f	3.30		0.156	96.60	318.78		15.115			
XXX.1b	2.60		0.123	42.25	109.85		5.209	0.052	0.038	-0.336
Pass 1 eff	15.19		0.720	164.50	2498.76		118.481			
Pass 2 feed	10.44		1.000	164.50	1717.38		164.500			
XXX.2	3.31			163.10	539.86					
XXX.2f	1.44		0.138	68.50	98.64		9.448			
XXX.2b	2.97		0.284	120.40	357.59		34.252	0.317	0.248	0.370
Pass 2 eff	6.03		0.578	163.10	983.49		94.204			
Pass 3 feed	2.72		1.000	163.10	443.63		163.100			
XXX.3	1.30			166.17	216.02					
XXX.3f	0.50		0.184	51.91	25.96		9.542			
XXX.3b	2.00		0.735	96.70	193.40		71.103	0.689	0.756	0.859
Pass 3 eff	0.22		0.081	166.17	36.56		13.440			
XXX.3e	0.00			166.17	0.00					
Total	28.83	3.89	1.143		3307.34	19.21		0.799	0.823	0.881

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using		
								feed & bk	bk & effl	feed & effl
Run #712										
feed	50.00			113.30	5665.00					
XXX.0	12.80			113.30	1450.24					
Pass 1 feed	37.20		1.000	113.30	4214.76		113.300			
XXX.1	10.00			73.20	732.00					
XXX.1f	4.20		0.113	71.70	301.14		8.095			
XXX.1b	3.10		0.083	50.27	155.84		4.189	0.037	0.059	0.409
Pass 1 eff	29.90		0.804	73.20	2188.68		58.835			
Pass 2 feed	19.90		1.000	73.20	1456.68		73.200			
XXX.2	6.90			133.20	919.08					
XXX.2f	2.80		0.141	86.70	242.76		12.199			
XXX.2b	3.60		0.181	77.95	280.62		14.102	0.118	0.121	-0.401
Pass 2 eff	13.50		-0.678	133.20	1798.20		90.362			
Pass 3 feed	6.60		1.000	133.20	879.12		133.200			
XXX.3	2.30			186.70	429.41					
XXX.3f	0.40		0.061	66.41	26.56		4.025			
XXX.3b	2.40		0.364	48.69	116.86		17.705	0.138	0.137	0.163
Pass 3 eff	3.80		0.576	186.70	709.46		107.494			
XXX.3e	0.00			186.70	0.00					
Total	48.50	-3.00	0.628		4654.51	-17.84		0.268	0.286	0.307
Run #713										
feed	55.50			76.80	4262.40					
XXX.0	13.06			76.80	1003.01					
Pass 1 feed	42.44		1.000	76.80	3259.39		76.800			
XXX.1	10.40			115.20	1198.08					
XXX.1f	5.00		0.118	48.60	243.00		5.726			
XXX.1b	4.70		0.111	53.79	252.81		5.957	0.078	0.059	-0.232
Pass 1 eff	32.74		0.771	115.20	3771.65		88.870			
Pass 2 feed	22.34		1.000	115.20	2573.57		115.200			
XXX.2	6.92			89.00	615.88					
XXX.2f	3.45		0.154	36.48	125.86		5.634			
XXX.2b	5.90		0.264	145.10	856.09		38.321	0.481	0.400	0.502
Pass 2 eff	12.99		0.581	89.00	1156.11		51.751			
Pass 3 feed	6.07		1.000	89.00	540.23		89.000			
XXX.3	1.40			62.15	87.01					
XXX.3f	1.40		0.231	33.37	46.72		7.697			
XXX.3b	6.80		1.120	128.55	874.14		144.010	2.563	1.109	1.159
Pass 3 eff	-2.13		-0.351	62.15	-132.38		-21.809			
XXX.3e	0.00			62.15	0.00					
Total	59.03	6.36	1.495		5302.60	24.40		1.748	1.061	1.097

## Notes to table

Forward flushes (XXX.Xf) are combined with effluent when calculating efficiencies

Mass Fraction (mf) = Mass/Mass Feed

Activity (a) = Mass \* Specific Activity

Mass Weighted Specific Activity (A) = Mass Fraction \* Specific Activity

Separation Efficiency (E) =  $A_{mags}/A_{feed}$

$$E_{1,2} = E_1 + E_2 - E_1 * E_2$$

$$E_{1,2,3} = E_1 + E_2 + E_3 - E_1 * E_2 - E_1 * E_3 - E_2 * E_3 + E_1 * E_2 * E_3$$

## Appendix C: Equations for Calculating Separation Efficiency

### Nomenclature

A = Mass Weighted Specific Activity (pCi/g)

E = Separation Efficiency

mf = Mass Fraction

subscripts

b = backflush

e = effluent

f = feed

1 = pass 1

2 = pass 2

3 = pass 3

### Efficiency relations

#### Pass 1

$$E(f,b)_1 = A_{b1}/A_{f1}$$

$$E(b,e)_1 = A_{b1}/(A_{b1}+A_{e1})$$

$$E(f,e)_1 = (A_{f1}-A_{e1})/A_{f1}$$

#### Pass 2

$$E(f,b)_2 = A_{b2}/(A_{f1}-A_{f2})*(1-mf_{b1})$$

$$E(b,e)_2 = A_{b2}/(A_{b2}+A_{e2})$$

$$E(f,e)_2 = (A_{f2}-A_{e2})/A_{f2}$$

#### Pass 3

$$E(f,b)_3 = A_{b3}/((A_{f1}-A_{f2})/(1-mf_{b1})-A_{b2})*(1-mf_{b2})$$

$$E(b,e)_3 = A_{b3}/(A_{b3}+A_{e3})$$

$$E(f,e)_3 = (A_{f3}-A_{e3})/A_{f3}$$