NOTICE

All drawings located at the end of the document.

RF/RMRS-98-281.UN

ACTINIDE CONTENT AND AGGREGATE SIZE ANALYSES FOR SURFACE SOIL IN THE WALNUT CREEK AND WOMAN CREEK WATERSHEDS AT THE ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

Revision 1

September 1998

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

The purpose of this report is to provide data for Pu-239,240 and Am-241 activity in surface soil sampled in fiscal year 1998 (FY98) from the Walnut Creek and Woman Creek watersheds at the Rocky Flats Environmental Technology Site (Site). These data were acquired as part of the *Plan for Source Evaluation and Preliminary Actions for Walnut Creek Water-Quality Results* as required under the terms and conditions of the *Rocky Flats Cleanup Agreement* (RFCA). Collection of the data contained herein also satisfies data needs for the Site Actinide Migration Studies (AMS) and the McKay Bypass Ditch Extension Project. The sample analysis costs for Pu-239,240 and Am-241 activity and total organic carbon (TOC) were funded by the Colorado Department of Public Health and Environment (CDPHE). Determination of the particle size distribution of the soil and sediment samples was done at the Colorado School of Mines (CSM) under the direction of the AMS.

The data were collected to answer the following questions.

- What is the total Pu-239,240 and Am-241 activity in the top 5 centimeters (cm) of Site soils and in Walnut Creek bed sediments?
- What is the total organic carbon content of the Site soils and Walnut Creek bed sediments?
- What is the distribution of particle sizes in Site soils and Walnut Creek bed sediments?
- What is the actinide (Pu-239,240 and Am) distribution among soil and Walnut Creek sediment particle sizes?

The data are being used to investigate potential actinide source areas that might contribute actinides to streams via stormwater runoff and to calibrate the AMS Watershed Erosion Prediction Project (WEPP) model to estimate soil erosion and associated actinide transport.

All field sampling and laboratory analyses were performed in accordance with the RMRS *Quality Assurance Program Description* (QAPD) (RMRS 1997).

1.1 Background

Recent water quality monitoring results at a RFCA Point of Compliance (POC) located at GS03 (Walnut Creek at Indiana Street, Figure 1) show values above the Surface-Water Action Level and Standards Framework reporting value of 0.15 pCi/L for Pu and Am. The analytical results for the composite surface-water samples collected for the period 5/12/97 - 7/1/97 range from 0.184 pCi/L to 0.465 pCi/L for Pu and 0.056 pCi/L to 0.256 pCi/L for Am. The analytical results have been confirmed and there were no off-normal conditions noted at any D&D or

environmental cleanup activities during this time period. Analytical data collected from the outfall of Pond A-4 (GS11), a discharge location directly upstream of GS03, showed Pu and Am results of <0.01 pCi/l.

The objective of this investigation was to identify possible sources of actinide contamination that may contribute to elevated analytical measurements at RFCA POC monitoring station GS03 and at other gaging stations in the Walnut Creek and Woman Creek drainages. The contaminants of concern for this investigation are Pu and Am . The soil samples were analyzed primarily for these constituents. Selected samples were analyzed for Total Organic Carbon content. Data requirements to support this project were developed using criteria established in *Guidance for the Data Quality Objective Process*, EPA QA/G-4 (EPA 1994).

2.0 SAMPLING LOCATION SELECTION

2.1 Walnut Creek / GS03 Watershed

The surface soil sampling locations are identified by the points shown on Figure 2. The sampling locations in the GS03 drainage were selected by statistical methods described by Gilbert (1987). Gilbert describes a simple statistical method for locating sources of contaminants using grid systems. A triangular grid system is preferred and has been shown to likely provide more information than a square grid (Parkhurst, 1984). This system requires definition of data quality objectives, which are as follows.

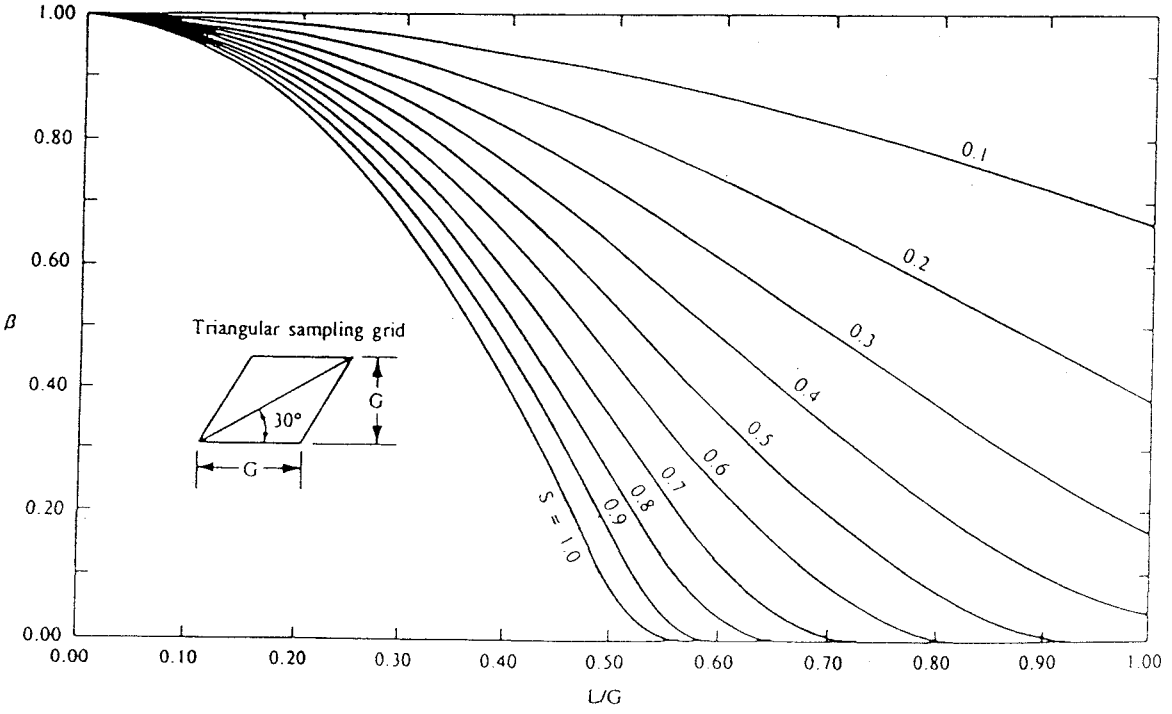
1. The shape of an elliptical target must be selected. For this investigation, a circular target was selected. A circular target has a ratio of its elliptical axes equal to 1 (S=1).
2. The length of the semi-major axis of the smallest target source important to detect (L) must be selected. For this investigation, L is equal to 400 feet. This means that a source area of 400 feet in diameter could be found. For reference, this is an area slightly smaller than the 903 Pad.
3. The acceptable probability of not finding the source (β) must be selected. For this study, β is equal to 0.10 (i.e. 10 percent). In other words, it is acceptable to have a 10 percent chance of not finding the source if one exists.
4. The parameters from items 1-3 above are entered into a nomagraph (Figure 3) for desired grid shape. The nomagraph gives the ratio L/G, which is the semi-major axis of the smallest target source important to detect divided by the grid spacing (G). For this study, the

nomagraph in Figure 3 yields the value of 0.49 as the ratio of L/G. Solving for G, the grid spacing is 816 feet. Therefore, a grid spacing of 800 feet was selected. Figure 3 is reproduced from Gilbert (1987) to show how this is done.

In summary, the surface soil sampling in the Walnut Creek (GS03) watershed was designed to locate a 400 foot diameter circular target source with 90 percent confidence of finding the source if one exists. Again, for reference, this source size would fit inside the area of the 903 Pad.

Nine soil sampling locations and three sediment sampling locations were selected in the Walnut Creek watershed for collection of split samples (field duplicates) for analysis of TOC content and aggregate size distribution. The selected soil sampling locations represent hillslope transects to potentially correlate TOC and aggregate size distribution of actinides with hillslope erosion processes. The Walnut Creek transect sampling locations are: SSSE00498, SSSE00598, SSSE00698, SSSE00798, SSSE01198, SSSE01398, SSSE01498, SSSE02198, and SSSE05198 (Figure 2). The sediment sampling locations selected are approximately equally spaced along the reach of channel from South Walnut Creek below Pond B-5 (station 16797) to the middle of the reach (station 16297), to the mouth of Love Gulch (station 15697). Each of the size fractions obtained from the aggregate size fraction analysis were analyzed for Pu-239,240 and Am-241 content to obtain the particle-size distribution of the actinides.

FIGURE 3. NOMAGRAPH RELATING L/G TO RISK OF NOT FINDING SOURCE FOR DIFFERENT TARGET SHAPES WHEN SAMPLING IS ON A TRIANGULAR GRID PATTERN (SOURCE: GILBERT, 1987



2.2 Woman Creek Watershed

AMS personnel determined that selected logical drainage sub-basins in the Woman Creek watershed lacked sufficient soil activity data to support the AMS WEPP modeling effort. Therefore, 14 sampling locations were sampled to provide a reasonable spatial distribution to complement existing soil activity data in the Woman Creek watershed. Six of these locations are located in the 903 Pad and Lip area (SSSE05298, SSSE05398, SSSE05498, SSSE05598, SSSE05698, and SSSE05798 (Figure 2). Field replicate samples were collected for TOC and particle-size fractionation and subsequent radiochemical analysis of the size fractions at these locations.

The sampling locations in the 903 Pad and Lip area were selected by aligning two down-slope transects that run from the top of the drainage hillslope down to the South Interceptor Ditch service road. One transect is located in an area with known high soil activity, and the other transect is located about 1500 feet east of the first transect in an area with lower levels of activity. Data for the transects will be used to investigate actinide mobility down the hillslopes by erosion processes.

Figure 4 shows how the watersheds have been preliminarily divided into logical drainage sub-basins (in red) with hillslope configurations suitable for erosion modeling using the WEPP model. The soil activity data shown on Figure 4 will be used to calibrate the WEPP model for the AMS. The model will be used to simulate and predict soil erosion in the Site watersheds. The spatial and particle-size distribution of Pu-239,240 and Am-241 in the surface soils will be used in conjunction with the WEPP model results to simulate and predict actinide transport due to surface erosion processes.

3.0 SAMPLING AND ANALYSES

Soil samples were collected at 68 locations shown in Figure 2. Each surface soil sample location was sampled by the Rocky Flats Plant (RFP) Method (4-E42-OPS-GT.08). and analyzed for Pu-239,240 and Am-241 by alpha spectrometry. A backup aliquot was collected and held for each location in the event that additional analyses might be required. One duplicate sample was be collected for every 20 soil samples collected. The soil sampling requirements are described in Table 1. Applicable procedures for the soil sampling are listed in Table 2.

Samples collected at 18 selected locations (Figure 2) were fractionated by sieving and by column settling analysis to determine the relative percentages of sand, silt, and clay-sized (<.2 mm, <.01 mm, and <.002 mm respectively) particles in the samples. These size fractions are consistent

with the WEPP model erosion output. The size fractionated material was analyzed for Pu-239,240 and Am-241 to obtain data on the particle size distribution of the radionuclides in the soil. Fifteen of these sampling locations are soil sampling locations, and three are sediment sampling locations 16797, 16297, and 15697 (Figure 2).

3.1 Analytical Laboratory Requirements

The following requirements apply to the radiochemical analysis of the soil materials.

1. Minimum Detectable Activity (MDA) was 0.3 pCi/gram.
2. Computation of the analytical uncertainty (counting error terms), MDA values, and other quality assurance and quality control computations and specifications conformed to the Site Analytical Services Division Statement of Work for Analytical Measurements, Module RC01-B.2: Isotopic Determinations by Alpha Spectrometry, and Module GR01-B.1: General Laboratory Requirements.

Table 1. Soil Sampling Requirements

Analytical Method	Number of Field Samples	Number of QC Samples	Total Number Samples	Containers, Preservatives, Holding Times
Alpha spectroscopy for Pu -239,240, Am -241	68	1 duplicate (1 per 20 samples) = 3 samples	71	500 ml wide mouth glass jar, NA, 6 months - soils; plus additional 250 ml wide mouth glass jar, NA, 6-month backup samples in 500 ml wide mouth glass jar, NA
Total Organic Carbon	18	3	21	500 ml wide mouth glass jar, NA
Grain Size Analysis for sand, silt, clay fractionation by mechanical sieving or air elutriation.	18	3	21	500 ml wide mouth glass jar, NA
Alpha spectroscopy for Pu -239,240, Am -241 and on Grain Size Fractions	18	3	21	Containers provided by lab performing particle size separation.

3.2 Field Logistics

Sampling sites were located in the field using 5-foot contour interval topographic maps (accurate within a few feet) and a compass. Wooden stakes were used to mark the approximate centroid of the soil sampling locations. RMRS AMS personnel installed the stakes labeled with location identifiers in waterproof marker at the desired sampling sites. RMRS and CSM AMS personnel

also made field observations of the hydrologic and pedologic conditions of the soils at each sampling location. Field observations included: vegetative cover, canopy height, Munsel color code for soil color, soil type and texture, and any observed erosion.

Advanced Sciences, Incorporated (ASI) personnel supplied a map showing the locations with their associated location codes to ensure that samples are properly labeled. The geographic coordinates of the soil sampling locations (as marked by the stakes) were determined by Global Positioning System (GPS) by RMRS personnel.

Soil samples were collected in accordance with Procedure GT.08: Soil Sampling. Sediment samples were collected in accordance with Procedure SW.06: Sediment Sampling. Samples were handled in accordance with FO.10: Receiving, Labeling, and Handling Environmental Material Containers, and FO.13: Containerization, Preserving, Handling and Shipping of Soil and Water Samples (Table 2). Disposable sampling tools were used wherever possible to eliminate decontamination waste streams.

Table 2. Applicable Field and Administrative Standard Operating Procedures

Procedure Number	Procedure Title
2-G18-ER-ADM-17.01	Records Capture and Transmittal
2-S47-ER-ADM-05.14	Use of Field Logbooks and Forms
5-21000-OPS / 4-E42-OPS-GT.08	Soil Sampling
5-21000-OPS-FO.3	General Equipment Decontamination
5-21000-OPS-FO.6	Handling of Personal Protective Equipment
5-21000-OPS-FO.7	Handling of Decontaminated Water and Waste Water
5-21000-OPS-FO.10	Receiving, Labeling, and Handling Environmental Material Containers
5-21000-OPS-FO.11	Field Communications
5-21000-OPS-FO.13	Containerization, Preserving, Handling and Shipping of Soil and Water Samples
5-21000-OPS-FO.16	Field Radiological Measurements
5-21000-OPS-FO.20	Sampling of Environmental Containers.
5-23000-WRP-WO-1101	Solid Radioactive Waste Packaging Outside the PA

4.0 DATA MANAGEMENT

A field logbook was used during this investigation by AMS and ASI sampling personnel and technical staff. Data for this project were collected, entered, and stored in a controlled and retrievable environment in accordance with RM-06.02, *Records Identification, Generation, and Transmittal.*

4.1 Quality Assurance

Analytical data collected in support of this investigation were evaluated using the guidance established by the Rocky Flats Administrative Procedure 2-G32-ER-ADM-08.02, *Evaluation of ERM Data for Usability in Final Reports*. This procedure establishes the guidelines for evaluating analytical data with respect to precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters. All of the soil sample analysis data will be validated. However, validation was not completed for preliminary publication of the analytical results herein.

For precision, the duplicate error ratio (DER) was used for the radiological analysis. The maximum DER is 1.42, where DER is calculated from:

$$DER = \frac{|S - D|}{2 \pm \sqrt{\sigma_S^2 + \sigma_D^2}}$$

where:

σ_S = total propagated uncertainty of the sample
σD = total propagated uncertainty of the duplicate
S = sample activity
D = duplicate activity

Duplicate results with DER less than 1.42 are deemed to be in statistical agreement. No DER exceeded 0.92. Therefore, the analytical reproducibility was determined to be acceptable. Accuracy was measured by comparing the required analytical method and detection limit with the actual method used and its detection limit for each medium and analyte and by ensuring that radiochemical tracer recoveries were between 20 percent and 100 percent. Data not meeting these criteria were rejected, and the laboratory analyzed the samples again until the criteria were met. Comparability of the data was ensured with respect to sampling and analysis protocols, media type, and temporal and spatial requirements set forth in the sampling and analysis plan (RMRS, 1998). Completeness is being evaluated by comparing the proposed number of samples to the number of samples that are valid and acceptable. With respect to the number of samples planned for collection and analysis (68 total), the data are complete.

Quality control data for the radiochemistry, organic carbon analyses and aggregate size determinations are in the appendix. Discussion of the quality assurance of the aggregate size determinations is included in the CSM report in the appendix.

5.0 DISCUSSION OF RESULTS

5.1 Spatial Distribution of Pu-239,240

Data mapped in Figure 4 show no presence of a manageable source of radionuclide contamination to overland flow and surface-water transport. A general trend toward higher Pu-239,240 activities with proximity to the 903 Pad area is observed. The data do not lend support to determination of specific remediation strategies to prevent radionuclide contamination of surface water. The total Pu-239,240 and Am-241 activity data for the FY98 surface soil samples are shown in Table 3. Total organic carbon (TOC) concentrations in FY98 surface soil samples are shown in Table 4.

5.2 Soil Aggregate Size Distribution of Actinides

The Appendix to this report contains a report on the aggregate size analysis and actinide distribution among the aggregate sizes by Dr. James Ranville, Ph.D. and Dr. Bruce Honeyman, Ph.D. of CSM. The report contains the methodology used to separate bulk soil samples into aggregate size fractions and the results of the analysis, which include the aggregate size distributions of the soils and the actinide content of each size fraction.

CSM separated the aggregates into 2, 10, and 200 micron size fractions to be consistent with the Watershed Erosion Prediction Project (WEPP) model that is being used by the Actinide Migration Studies (AMS) to predict soil erosion, sediment transport, and associated actinide mobility on the suspended sediment. The 2, 10, and 200 micron fractions represent the clay, silt, and sand size fractions in the WEPP model.

Most of the aggregate size distributions of Pu-239,240 and Am-241 on the soil particles follow an expected pattern with smaller particles having larger Pu-239,240 and Am-241 activity per gram than larger particles. This pattern is expected because smaller particles have more surface area per unit mass for adsorption than do larger ones. However, the counting errors associated with the analytical results (shown as error bars in the appendices) indicate that there is no difference between the Pu-239,240 and Am-241 activities for the 2 μm and 10 μm particles for most of the samples. In several samples, there is no difference in Pu-239,240 and Am-241 activities between all of the size fractions investigated. The particle size distributions of the Pu-239,240 and Am-241 in the soil and sediment samples are illustrated the Appendix.

5.3 Future Studies

CSM received a grant from the USEPA to investigate how Site soils are aggregated and what happens to the distribution of the Pu-239,240 and Am-241 activity when disaggregation occurs. CSM will disperse the aggregates by various physical and chemical means to determine the composition of the materials that aggregate the small soil particles into larger particles. This information will provide an understanding of how actinides may be transported in different hydrologic and geochemical regimes. The work is scheduled for completion in January 1999.

Table 3. Total Pu-239,240 and Am-241 Activities for FY98 Site Soil Samples.

Walnut Creek Sampling Locations	QC	Am-241 Result (pCi/g)	Am-241 Error (pCi/g)	Pu-239,240 Result (pCi/g)	Pu-239,240 Error (pCi/g)
SSSE00198		0.532	0.087	1.990	0.423
SSSE00298		0.675	0.096	1.360	0.145
SSSE00398		0.312	0.074	1.400	0.303
SSSE00498		0.254	0.050	1.100	0.153
SSSE00598		0.072	0.036	0.465	0.212
SSSE00698		0.099	0.041	0.144	0.087
SSSE00798		0.038	0.047	0.205	0.138
SSSE00898		-0.006	0.084	0.048	0.084
SSSE00998		0.050	0.042	0.143	0.112
SSSE01098		0.037	0.032	0.084	0.082
SSSE01198		0.045	0.030	0.247	0.160
SSSE01298		0.141	0.046	0.753	0.257
SSSE01398		0.034	0.049	0.240	0.092
SSSE01498	DUP	0.011	0.046	0.207	0.074
SSSE01498		0.064	0.031	0.241	0.136
SSSE01598		0.042	0.047	0.129	0.053
SSSE01698		0.037	0.046	0.068	0.108
SSSE01798		0.272	0.074	0.530	0.170
SSSE01898		0.037	0.026	0.103	0.077
SSSE01998		0.034	0.031	0.151	0.112
SSSE02098		-0.014	0.036	0.008	0.099
SSSE02198		0.038	0.031	0.070	0.083
SSSE02298		0.025	0.032	-0.011	0.015
SSSE02398		0.043	0.051	0.060	0.120
SSSE02498		0.037	0.041	0.008	0.045
SSSE02598		0.054	0.033	-0.002	0.017
SSSE02698		0.027	0.038	0.061	0.049
SSSE02798		0.030	0.038	0.057	0.056
SSSE02898		0.009	0.036	0.115	0.110
SSSE02998		0.058	0.050	0.029	0.047
SSSE03098		-0.011	0.034	0.063	0.059
SSSE03198		0.016	0.026	0.005	0.026
SSSE03298		0.010	0.033	0.086	0.055
SSSE03398		0.035	0.035	0.010	0.093
SSSE03498		0.010	0.039	0.017	0.061
SSSE03598		0.038	0.040	0.090	0.110
SSSE03698	DUP	0.004	0.052	0.012	0.023
SSSE03698		-0.010	0.049	0.042	0.041
SSSE03798		0.032	0.038	0.105	0.059
SSSE03898		0.013	0.030	0.027	0.053
SSSE03998		0.000	0.040	0.066	0.049
SSSE04098		0.020	0.029	0.108	0.062
SSSE04198		0.017	0.038	0.006	0.061
SSSE04298		0.032	0.040	0.015	0.055
SSSE04398		0.004	0.038	0.043	0.045
SSSE04498		0.041	0.032	0.048	0.050
SSSE04598		-0.018	0.038	0.055	0.053
SSSE04698		0.029	0.041	0.091	0.060
SSSE04798		0.031	0.035	0.055	0.070
SSSE04898		0.007	0.024	0.106	0.109
SSSE04998		0.042	0.038	0.460	0.162
SSSE05098		0.082	0.039	0.512	0.136
SSSE05198		0.252	0.064	1.320	0.200

	Am-241	Am-241 Error	Pu-239,240	Pu-239,240 Error
AVERAGE:	0.071	0.043	0.231	0.105
MINIMUM:	-0.018	0.024	-0.011	0.015
MAXIMUM:	0.675	0.096	1.990	0.423

Notes: 1) Data are preliminary and subject to revision. 2) DUP = Field duplicate sample.

Table 3. Total Pu-239,240 and Am-241 Activities for FY98 Site Soil Samples – continued.

Woman Creek Sampling Locations	QC	Am-241 Result (pCi/g)	Am-241 Error (pCi/g)	Pu-239,240 Result (pCi/g)	Pu-239,240 Error (pCi/g)
SSSE05298		6.350	0.352	34.200	1.050
SSSE05398		20.100	0.494	397	7.80
SSSE05498		0.855	0.122	4.770	0.399
SSSE05598		1.670	0.135	8.800	0.465
SSSE05698		0.845	0.104	3.250	0.329
SSSE05798		0.666	0.093	3.380	0.291
SSSE05798	DUP	0.658	0.089	3.440	0.271
SSSE05898		1.270	0.122	4.940	0.341
SSSE05998		0.735	0.090	3.310	0.294
SSSE06098		0.168	0.050	1.020	0.177
SSSE06198		0.175	0.063	0.348	0.100
SSSE06298		0.043	0.039	0.035	0.036
SSSE06398		0.008	0.027	0.028	0.035
SSSE06498		0.023	0.026	0.068	0.099
SSSE06598		0.030	0.028	0.132	0.111

	Am-241	Am-241 Error	Pu-239,240	Pu-239,240 Error
AVERAGE:	2.240	0.122	30.981	0.787
MINIMUM:	0.008	0.026	0.028	0.035
MAXIMUM:	20.100	0.494	397.000	7.800

Notes: 1) Data are preliminary and subject to revision. 2) DUP = Field duplicate sample.

Table 4. Total Organic Carbon Results for Site Soil Samples.

[QC = Quality Control Type, where DUP = Duplicate Sample]

SITE	QC	TOC (mg/kg)
SSSE00498		62,300
SSSE00598		31,500
SSSE00698		35,900
SSSE00798		31,500
SSSE01188		27,400
SSSE01398		35,200
SSSE01498		21,400
SSSE01498	DUP	19,200
SSSE02198		35,800
SSSE05198		42,600
SSSE05198		26,100
SSSE05298		33,200
SSSE05398		24,500
SSSE05498		26,700
SSSE05598		15,300
SSSE05698		28,300
SSSE05798		20,200

6.0 REFERENCES

EPA, 1992, US EPA Test Methods for Evaluating Solid Waste, Solid Waste-846, third edition, Method 8260A, Rev. 1., November.

EPA, 1994, Guidance for the Data Quality Objectives Process, EPA QA/G-4, September, 1994.

EMD Operating Procedures Manual, 1997, Volume I: Field Operations, 5-21000-OPS-FO, Rev 92, March 1992.

EMD Operating Procedures Manual, 1997, Volume III: Geotechnical, 5-21000-OPS-GT, Rev 92, March 1992.

EMD Operating Procedures Manual, 1997, Volume IV: Surface Water, 5-21000-OPS-SW, Rev 92, March 1992.

Gilbert, R.O., 1987, Statistical Methods for Environmental Pollution Monitoring, Van Nostrand Reinhold, New York, Chapter 10.

Kaiser-Hill Company, Analytical Services Division, May 9, 1997, Statement of Work for Analytical Measurements, Module RC01-B.2: Isotopic Determinations by Alpha Spectrometry, Rocky Flats Environmental Technology Site, Golden, CO.

Kaiser-Hill Company, Analytical Services Division, June 2, 1997, Statement of Work for Analytical Measurements, Module GR01-B.1: General Laboratory Requirements, Rocky Flats Environmental Technology Site, Golden, CO.

Parkhust, D.F., 1984, Optimal Sampling Geometry for Hazardous Waste Sites, Environmental Science and Technology, 18:521-523.

Ranville, J.F., and Honeyman, B.D., 1998, Size Distribution of Actinides in Soil and Sediments at the Rocky Flats Environmental Technology Site, deliverable report to Kaiser-Hill Company, Colorado School of Mines, Golden, CO.

RMRS, 1997, RMRS Quality Assurance Program Description, RMRS-QAPD-001, Rev. 1, January.

RMRS, 1998, Sampling and Analysis Plan: Investigation of Surface Soil Actinide Content in the Walnut Creek and Woman Creek Watersheds at the Rocky Flats Environmental Technology Site., Revision 1, February 2, 1998.

Appendix

Laboratory Quality Control Data for Rocky Flats Environmental Technology Site Soil Samples Collected in February 1998.

Laboratory Sample Identifier	Analysis Date	Sample Type	Duplicate Sample Number	Am-241 (pCi/g)	Error Am-241 (pCi/g)	Pu-239,240 (pCi/g)	Error Pu-239,240 (pCi/g)	Am Tracer Yield (%)	Pu Tracer Yield (%)
QC491779	4/21/98	Blank		0.0134	0.025	0.00422	0.0226	88	91
QC491792	4/21/98	Blank		0.00286	0.025	0	0	92	79
QC491799	4/21/98	Blank		-5.9	0.0231	0.00452	0.018	93	85
QC491802	4/21/98	Blank		0.0348	0.0271	-0.0127	0.0101	81	81
QC491787	4/21/98	Duplicate	SSSE03998	0.0204	0.0336	0.023	0.0434	47	37
QC491793	4/21/98	Duplicate	SSSE02298	0.0162	0.0287	0.0744	0.0486	74	68
QC491800	4/21/98	Duplicate	SSSE05498	1.04	0.137	4.48	0.457	73	48
QC491803	4/21/98	Duplicate	SSSE05798	0.793	0.0913	3.56	0.296	100	92
QC491788	4/21/98	LCS		2.22	0.139	2.29	0.243	97	91
QC491781	4/21/98	LCS		5.23	0.388	2.38	0.245	106	103
QC491794	4/21/98	LCS		1.98	0.15	2.31	0.225	98	91
QC491801	4/21/98	LCS		2.07	0.157	2.33	0.258	99	95
QC491804	4/21/98	LCS		2.07	0.145	2.33	0.0503	104	87
QC505187	5/19/98	Blank		-0.000786	0.00297	0.00348	0.00681	100	94
QC505188	5/19/98	Duplicate	SSSE00298	0.35	0.064	1.69	0.165	92	80
QC505190	5/19/98	LCS		5.03	0.25	2.29	0.179	89	95
QC522335	8/6/98	Blank		0.0822	0.114	0.0628	0.0875	83	88
QC522338	8/6/98	Blank		0.0509	0.0478	-0.0186	0.0148	80	88
QC522341	8/6/98	Blank		0.0487	0.0485	0.00655	0.0261	106	90
QC522329	8/6/98	Blank		0.182	0.148	0.0237	0.0468	75	92
QC522337	8/6/98	LCS		8.36	0.839	8.18	0.778	85	91
QC522340	8/6/98	LCS		2.1	0.22	1.77	0.288	101	99
QC522343	8/6/98	LCS		2.57	0.337	1.98	0.3	91	91
QC522331	8/6/98	LCS		6.36	0.669			81	
EQUIPMENT RINSEATE DATA									
SSSE01498	2/20/98	EQ - RINSE		-0.0003	0.016	-0.003	0.018		
SSSE05798	2/20/98	EQ - RINSE		0.029	0.03	-0.009	0.011		
SSSE03698	2/20/98	EQ - RINSE		0.021	0.027	-0.006	0.006		
SSSE05798	2/26/98	TOC RINSEATE		1 mg / L					

Notes: 1) LCS = Laboratory Control Sample; 2) Duplicate = Lab Duplicate Analysis; 3) EQ - RINSE = Equipment Rinse

Size Distribution of Actinides in Soil and Sediments at the Rocky Flats Environmental Technology Site

J. F. Ranville, Department of Chemistry and Geochemistry, CSM, Golden, CO 80401
B. D. Honeyman, Division of Environmental Science and Engineering, CSM, Golden, CO 80401

Introduction

Because of the very low solubility and strong association of actinides with soil particles, actinide mobility may be largely controlled by soil erosion. Physical transport of soil particles is influenced by particle size and the size distribution of actinides is an important input parameter in the watershed erosion model, currently under development. We therefore size fractionated a series of soils in order to obtain the actinide distribution in four size ranges < 2000, <200, <10, and < 2 micrometer. The following report details the procedures used and the preliminary data for the size distributions of sample mass and actinide concentration. Interpretation of the data will be presented in a future report.

Methods

Sampling:

Eighteen soil and sediment samples (15 soils and 3 sediments) were collected from the east side of the plant by RFETS personnel and transferred to CSM for size fractionation. Soil sampling, by RFETS personnel, involved collecting 10 subsamples per site. A 10 x10 x 10 cm steel sampler was driven into the soil and soil contained in the sampler removed and transferred to a stainless steel bowl. The ten subsamples were mixed and for all but three sites a single sample was taken. At three of the sites, duplicate samples were taken from the integrated sample.

Samples were dried at 105°C overnight, lightly ground with a mortar and pestle to break up > 2 mm aggregates, and sieved through an 8 inch diameter, 2 mm stainless steel sieve in order to remove the gravel size. The mass of gravel was determined. The remainder of the size fractionation steps was performed on the < 2 millimeter fraction.

Size Fractionation:

Fraction 1 (< 200 micrometer): Subsamples of about 4 - 10 grams (Table 1) were weighed and about 200 ml of deionized water was added. The suspensions were allowed to stand for 1 -3 days. This allowed the dry aggregates to break apart. The suspensions were then passed through a 212 micrometer stainless steel sieve. This size was used because no sieve is available that is exactly 200 micrometer. This difference in size was considered to be insignificant and the fraction is reported as < 200 micrometers. Soil particles that were retained on the sieve were washed using a spray bottle containing deionized water to dislodge any < 212 micron particles that were retained on the sieve. This was done until no more particles were observed to be passing through the sieve. The suspension that passed through the sieve was allowed to stand for 24 hours to allow settling of the particles. After settling, the overlying water was decanted off and the remaining suspension was transferred to weighed glass bottles. The remaining water was evaporated off and the mass of soil determined by re-weighing the bottle.

Fraction 2 (< 10 micrometer): Subsamples of about 30-50 grams (Table 1) were taken, about 500 ml of deionized water was added and the sample was allowed to stand overnight. The suspension was then passed through a 75 micrometer sieve to remove large particles that might interfere with the settling. The particles remaining on the sieve were washed with about 500 ml of

water to ensure complete passage of the smaller particles. The suspensions were transferred to 1 liter glass graduated cylinders and water was added to obtain a total volume of 1 liter. The cylinder was shaken and the suspension was allowed to sediment for 1 hour. Using a peristaltic pump, all the supernatant in the upper 30 cm was removed. Based on Stokes law for settling of spherical particles, and assuming a density of 2.5 gm/cm^3, the settling resulted in a supernatant suspension that contained no particles greater than 10 micrometer. The soil that had settled contained all the particles > 10 micrometers and some of the particles < 10 micrometers. Therefore additional water was added to bring the volume back to 1 liter, the cylinder was reshaken, and the settling and decanting steps were repeated. This was done once more for a total of three repetitions. The suspensions from each step were combined and the water evaporated using a hot plate. When only a small volume remained, the suspension was transferred to weighed glass bottles and the evaporation was completed. The mass of the soil (< 10 micrometers) was determined by repeating the weighing of the glass bottles.

Fraction 3 (< 2 micrometers): Subsamples of about 40-160 grams (Table 1) were taken, about 500 ml of deionized water was added and the sample was allowed to stand overnight. A settling time of 24 hours was used and all other procedures were as for the 10 micrometer fractionation.

Particle Size Analysis:

The particle size distribution in each size fraction was determined using an optical particle counter. The particle counter was used to determine the number of particles of various sizes over the range of 0.5 to 400 micrometer. The operating principle is based on light attenuation by single particles as they pass between a laser and a photodiode detector. Each particle causes an attenuation in the light reaching the detector and the magnitude of this attenuation is proportional to the cross-sectional area of the particle. By calibrating the instrument with NIST-traceable monodisperse polystyrene spheres, the relationship between cross-sectional area and detector response can be determined. Assuming that the particles in a sample are spherical, the diameter of each particle can be computed. The accuracy of the method depends on only one particle being counted at a time and therefore very dilute samples are required. We have found that approximately 10,000 particles ml^{-1} is an ideal concentration for the particular instrument used (Particle Sizing Systems Accusizer SIS 780). Samples for particle counting were prepared by pipetting small quantities of the suspensions (50-500 microliters) into 500 ml of filtered deionized water. The samples were stirred during measurement using a magnetic stir bar. Deionized water blanks were found to contain less than 200 particles ml^{-1}. Because of the small size of the detector orifice, particles larger than 400 micrometers must be removed prior to analysis. Therefore only the samples for which the > 200 micrometer particles had been removed were analyzed with this method.

The direct output of the instrument is a number-based size distribution. This distribution was converted to a volume-based distribution by computing the volume of a single particle in each size class and multiplying by the number of particles in that size class. This distribution is normalized to the total volume of particles in the sample in order to obtain a volume % distribution. This distribution is directly related to the mass distribution, assuming a constant particle density across the size range.

Radiochemical Analysis:

Samples were returned to RFETS personnel for radiochemical analysis.

Results

Size Distribution: Soil Mass

The gravel fraction was ignored for the calculation of the mass distribution and also was not analyzed for actinides. The percentage distribution of mass among the various size fractions for the soil and sediment particles is given in Table 2 and Figure 1. In most cases the majority of the soil mass resided in the 2,000-200 micrometer fraction, closely followed by the 200 - 10 micrometer fraction. Four of the soils and all three sediments had the greatest mass in the 200 - 10 micrometer fraction. Although it is a small percentage of the mass (0.6 - 4 %), the < 2 micrometer fraction may be very significant for actinide migration.

The reproducibility of the soil fractionation was investigated by performing the method in duplicate on three samples. Results are shown in Table 3. The uncertainty in the mass distribution is generally less than 20 % except for the very small percentages obtained for the < 2 micrometer fractions of samples 1498 and 5198 that have roughly 40 % uncertainty.

Size Distribution: Particle sizer results

The results for the < 200 micron fractions of all samples are given in Appendix 1. The particle size analysis was also used to verify the accuracy of the size separation procedure (Figures 2-4 in Appendix 1). The effect of multiple processing of the < 10 micrometer sedimentation separation is shown by the number-based size distribution shown in Figure 2. A substantial amount of particles are found in the 2nd decanting step and a smaller but significant amount is found in the 3rd step as well. This demonstrates that multiple sedimentations are necessary to get an accurate measure of the mass of material in each non-settling fraction. The accuracy of the computed size fractions are shown in Figures 3 and 4 for the < 10 and < 2 micrometer fractions respectively. In general the fractionations are quite good, that is very little volume is seen above 10-15 micrometers in the < 10 micrometer fraction and a clear peak at 2 micrometers is seen in the < 2 micrometer fraction. A second peak in the < 2 micrometer fraction at about 8- 10 micrometer might be due to a small amount of low density material being present in the sample. This material would not settle as rapidly as the mineral fraction and will therefore remain suspended longer than the 24 hour period used.

Size Distribution of Actinides

The concentration of actinides (plutonium-239,240 (Pu) and americium-241 (Am)) in each size fraction is given in Table 4. In general the trend is an increase in activity with decreasing particle size. However the increase is not as great as would be predicted by a simple surface area model.

The reproducibility of the actinide size distributions is shown in Tables and Figures 5 and 6 for Pu and Am respectively. Reproducibility is quite good (< 10 %) for the samples with higher activity, except for the < 2 micrometer fraction of sample 5798 which have 27 % and 16 % uncertainties for the Pu and Am concentrations respectively. The poorer reproducibility for this sample is likely due to the small amount of mass obtained from the fractionation.

Future work will involve interpretation of the mechanisms influencing actinide distribution in soil size fractions. The importance of the size distributions of actinides in RFETS soils, for influencing actinide migration, is also under investigation.

Table 1. Mass of soil used in each fractionation step and the mass obtained in each less than fraction for RFETS soils and sediments.

	Mass fractionated and in each size class					
	<200		< 10		< 2	
Sample ID	Bulk mass	Fraction mass	Bulk mass	Fraction mass	Bulk mass	Fraction mass
Soils						
0498	4.54	1.558	43.97	0.701	56.071	0.400
0598	5.16	2.671	48.38	0.506	162.995	2.998
0698	6.17	2.737	48.858	1.394	164.021	1.566
0798	5.20	2.205	49.21	1.112	76.306	0.832
1198	5.03	3.465	50.523	4.345	89.005	2.551
1398	5.95	2.619	39.74	1.461	42.553	0.465
1498	5.03	2.743	44.532	1.902	56.098	0.704
1498 duplicate	4.86	3.181	42.584	2.056	150.126	3.024
2198	5.14	1.932	39.914	0.770	57.200	0.870
5198	6.39	3.789	48,858	0.927	151.958	2.140
5198 duplicate	6.45	3.417	42.658	0.714	69.244	0.381
5298	6.89	3.070	42.218	1.277	73.217	1.433
5398	6.08	3.010	38.137	0.956	55.734	1.029
5498	9.54	4.063	43.697	1.591	74.670	1.661
5598	6.85	2.987	33.826	0.684	72.842	0.834
5698	5.04	1.982	30.917	1.330	69.089	1.209
5798	5.93	2.904	45.497	1.269	75.281	1.353
5798 duplicate	7.14	3.182	42.340	1.165	68.719	1.168
Sediments						
15697	6.59	4.710	36.735	3.968	76.976	2.964
16297	5.11	3.045	3.993	0.958	64.930	0.716
16797	8.46	4.843	3.275	1.880	70.485	1.965

Table 2. Percent distribution of mass in each size fraction of RFETS soils and sediments

	% by weight in each size fraction					
Sample ID	> 200 um	< 200 um	< 10 um	< 2 um	200-10 um	10-2 um
0498	65.7%	34.3%	1.6%	0.7%	32.7%	0.9%
0598	48.2%	51.8%	1.0%	1.8%	50.8%	
0698	55.6%	44.4%	2.9%	1.0%	41.5%	1.9%
0798	57.6%	42.4%	2.3%	1.1%	40.1%	1.2%
1198	31.1%	68.9%	8.6%	2.9%	60.3%	5.7%
1398	56.0%	44.0%	3.7%	1.1%	40.3%	2.6%
1498	45.5%	54.5%	4.3%	1.3%	50.2%	3.0%
1498 duplicate	34.5%	65.5%	4.8%	2.0%	60.7%	2.8%
2198	62.4%	37.6%	1.9%	1.5%	35.7%	0.4%
5198	40.7%	59.3%	1.9%	1.4%	57.4%	0.5%
5198 duplicate	47.0%	53.0%	1.7%	0.6%	51.3%	1.1%
5298	55.4%	44.6%	3.0%	2.0%	41.6%	1.0%
5398	50.5%	49.5%	2.5%	1.8%	47.0%	0.7%
5498	57.4%	42.6%	3.6%	2.2%	39.0%	1.4%
5598	56.4%	43.6%	2.0%	1.1%	41.6%	0.9%
5698	60.7%	39.3%	4.3%	1.7%	35.0%	2.6%
5798	51.0%	49.0%	2.8%	1.8%	46.2%	1.0%
5798 duplicate	55.4%	44.6%	2.8%	1.7%	41.8%	1.1%
15697	28.5%	71.5%	10.8%	3.9%	60.7%	6.9%
16297	40.4%	59.6%	2.7%	1.1%	56.9%	1.6%
16797	42.8%	57.2%	5.0%	2.8%	52.2%	2.2%

Table 3 Average percent and range of mass in replicate soil size fractionations, illustrating the reproducibility of the size fractionation methods

	Mass %							
	> 200		< 200		< 10		< 2	
Sample	Ave	Range	Ave	Range	Ave	Range	Ave	Range
1498	40.0	±5.5	60.0	±5.5	4.6	±0.3	1.6	±0.4
5198	43.8	±3.2	56.2	±3.3	1.8	±0.1	1.0	±0.4
5798	53.2	±2.2	46.8	±2.2	2.8	±0.0	1.8	±0.1

Table 4. Actinide concentration (pCi / g) in each size fraction (micrometers) of RFETS soils and sediments. (Data provided by Rocky Mountain Remediation Services, LLC. and Colorado Department of Public Health and the Environment).

	Actinide Concentration (pCi/g)							
	< 2000		< 200		< 10		< 2	
Sample	Am	Pu	Am	Pu	Am	Pu	Am	Pu
0498	0.254	1.1	0.262	1.06	0.398	1.39	0.416	0.904
0598	0.0715	0.465	0.122	0.597	0.235	0.598	0.295	1.02
0698	0.0988	0.144	0.11	0.613	0.224	0.961	0.209	0.984
0798	0.038	0.205	0.123	0.294	0.145	0.734	0.146	0.467
1198	0.0448	0.247	0.0484	0.0336	0.0694	0.12	0.0643	0.199
1398	0.0342	0.24	0.0813	0.172	0.18	0.311	0.159	0.607
1498a	0.0641	0.241	0.074	0.135	0.066	0.195	0.0855	0.182
1498b	0.0106	0.207	0.117	0.108	0.113	0.0933	0.0996	0.0842
2198	0.0379	0.0698	0.0614	0.0659	0.0771	0.0752	0.0541	0.164
5198a	0.252	1.32	0.518	2.69	0.742	3.96	0.86	6.56
5198b	-	1.32	0.575	2.97	0.734	5.36	0.892	5.87
5298	6.35	34.2	5.83	33	9.6	56.3	10.7	59.1
5398	20.1	397	32.8	321	61.9	365	38.7	180
5498	0.855	4.77	0.773	4.48	1.38	8.28	1.19	6.4
5598	1.67	8.8	1.9	11.5	4.09	19.7	3.57	19.3
5698	0.845	3.25	1	4.07	1.17	6.83	0.872	3.94
5798a	0.658	3.44	0.816	4.13	1.32	6.37	1.02	8.16
5798b	0.666	3.38	1.01	4.83	1.39	7.89	1.4	4.66

Table 5 Pu-239,240 results for the three replicate samples

	Pu (pCi/g)							
	<2000		< 200		< 10		< 2	
Sample	Ave	Range	Ave	Range	Ave	Range	Ave	Range
1498	0.224	±0.017	0.119	±0.011	0.144	±0.051	0.133	±0.049
5198	1.320	-	2.830	±0.140	4.660	±0.700	6.215	±0.345
5798	3.410	±0.030	4.480	±0.350	7.130	±0.760	6.410	±1.750

Table 6 Am-241 results for the three replicate samples.

	Am (pCi/g)							
	< 2000		< 200		< 10		< 2	
Sample	Ave	Range	Ave	Range	Ave	Range	Ave	Range
1498	0.037	±0.027	0.095	±0.021	0.090	±0.024	0.093	±0.007
5198	0.252	-	0.546	±0.028	0.738	±0.004	0.876	±0.016
5798	0.662	±0.004	0.913	±0.097	1.355	±0.035	1.210	±0.190

Figure 1. Percentage of Mass Contributed by Each Size Fraction

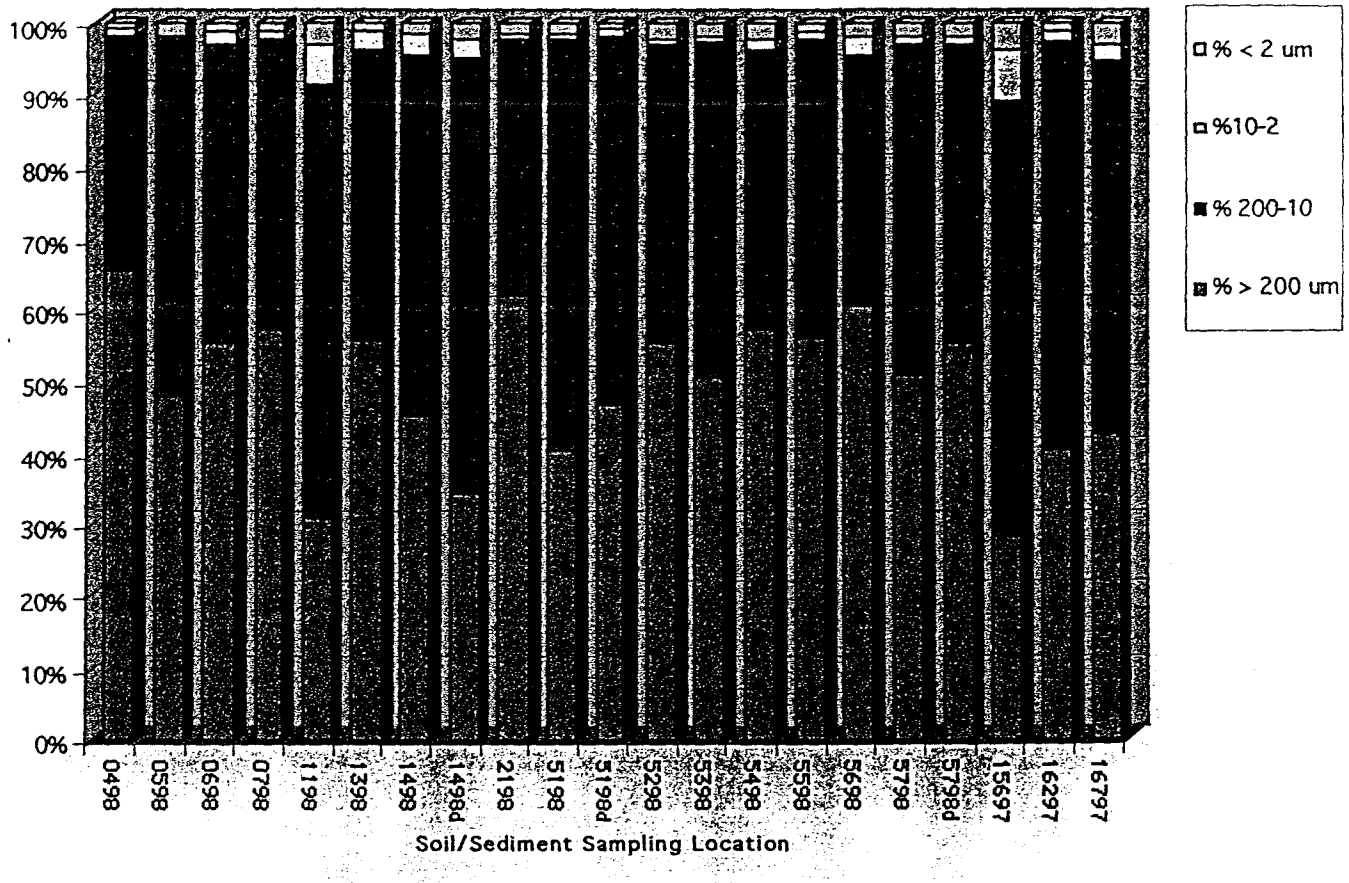


Figure 5. Reproducability of Pu-239,240 data (pCi/g)

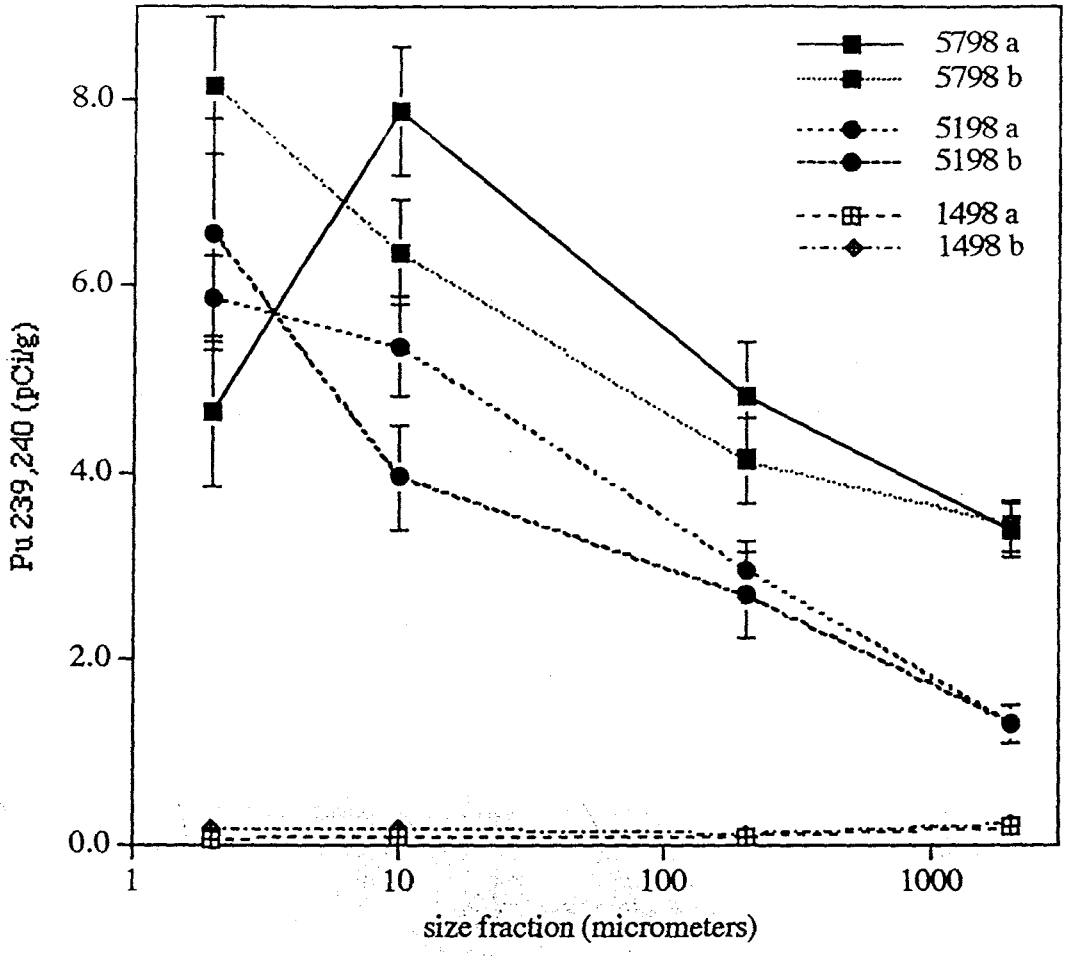
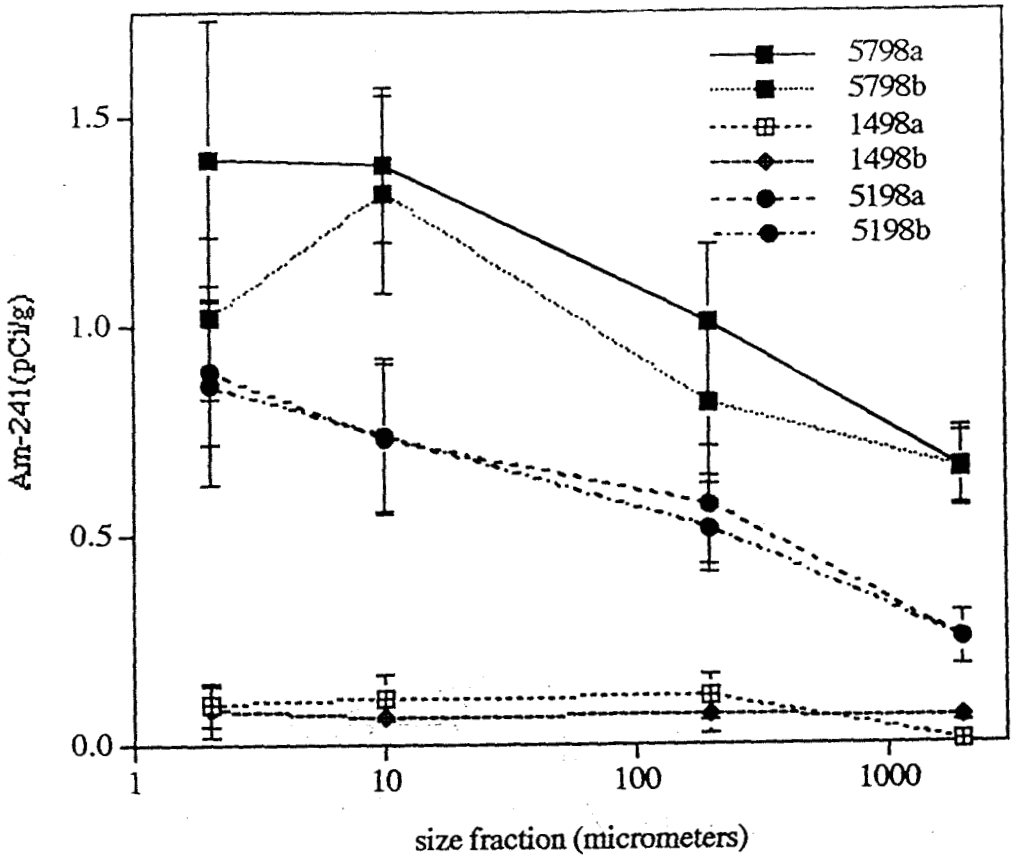


Figure 6. Reproducability of Am-241 data (pCi/g)



APPENDIX 1: Particle Sizer results.

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

5598
File Name = 81298R07.CB Time Date = 17:21:50 8/12/1998
Sensor Model: 1e400-0.5 SUM S/N: 9710908 Cal. File: CSMS.SNS
Date of Calibration: 5-14-98

Elapsed Time of Data Collection = 123 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.50 um) = 445544
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 60.0 ml No. of Channels = 128
NUM-WT Mean = 2.26 um Mode = 0.64 um Median = 0.88
VOL-WT Mean = 38.91 um Mode = 31.04 um Median = 32.76 (0.000 % Threshold)

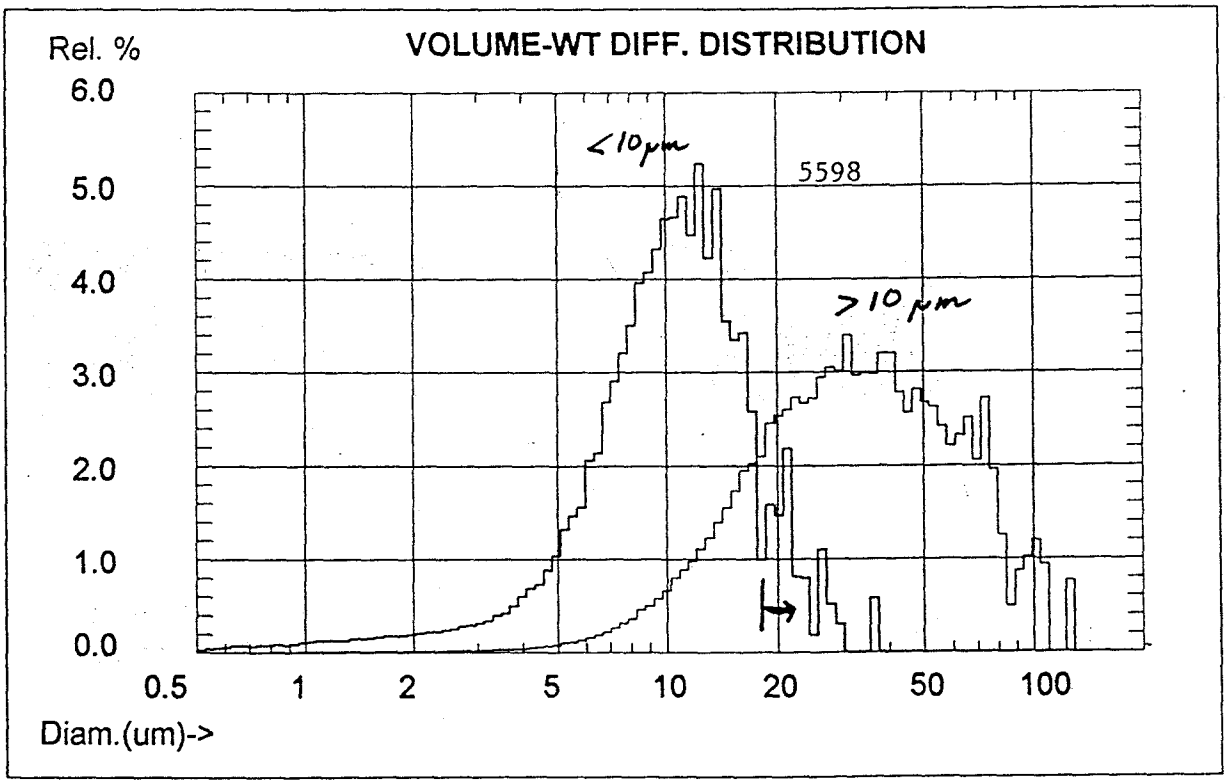


Figure 3. Results for the 10 micrometer size fractionation of sample 5598.

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

File Name = RF004A.CB Time Date = 21:21:44 6/17/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 123 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1055318
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 60.0 ml No. of Channels = 128
NUM-WT Mean = 0.80 um Mode = 0.60 um Median = 0.67
VOL-WT Mean = 5.91 um Mode = 36.50 um Median = 2.59 (0.000 % Threshold)

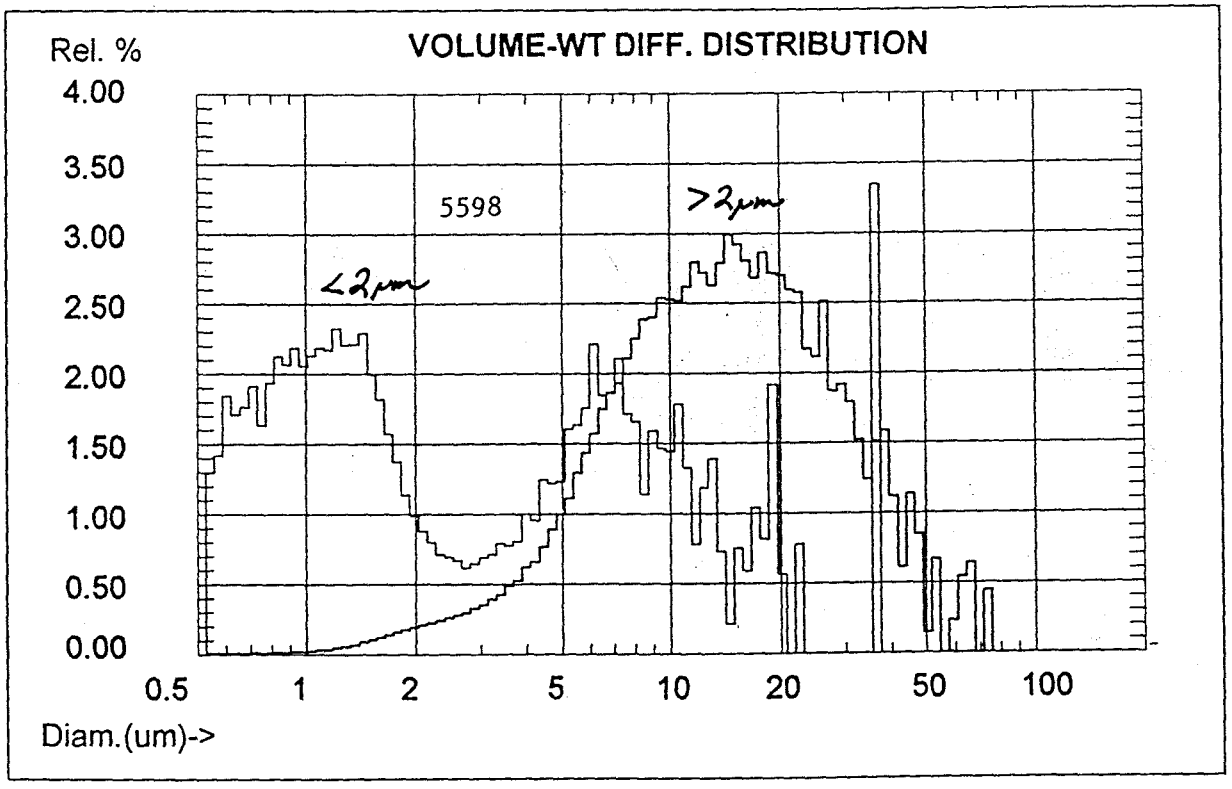


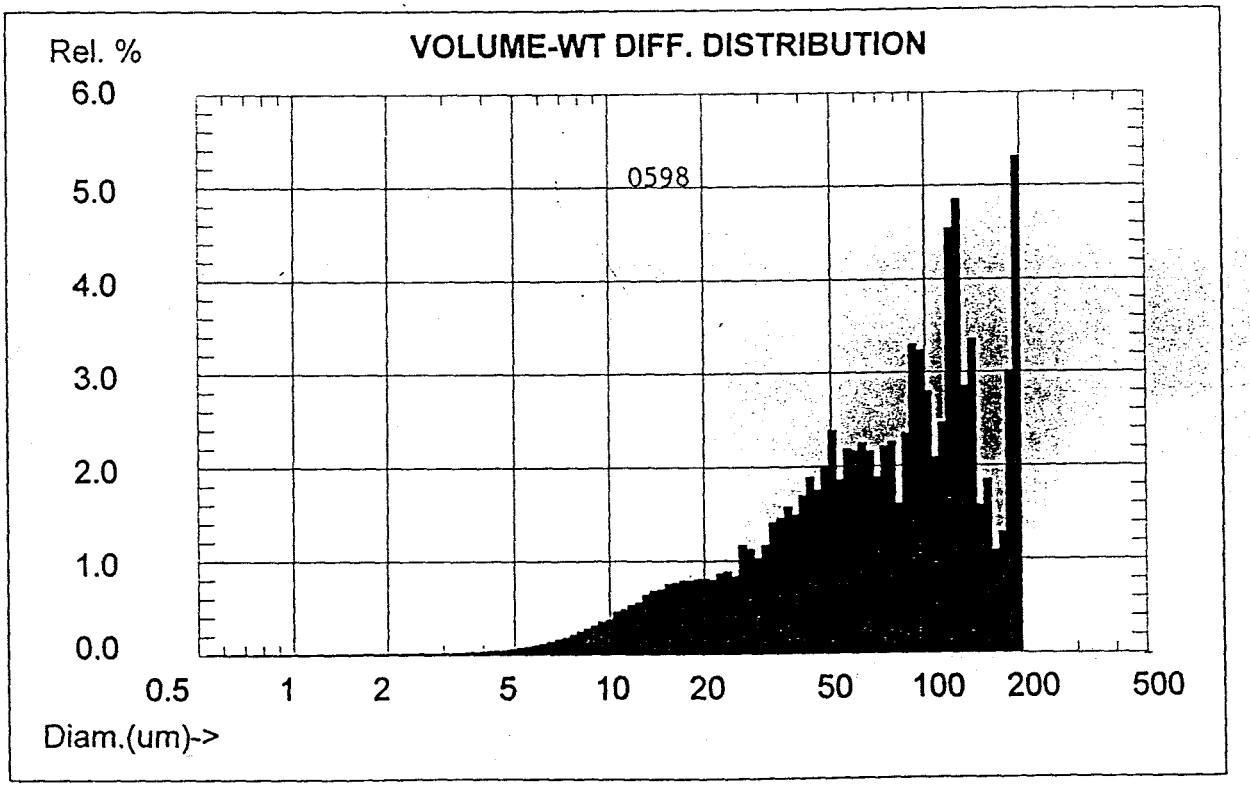
Figure 4. Results for the 2 micrometer size fractionation of sample 5598.

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

00598 < 200
File Name = 0598200A.CB Time Date = 16:23:31 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1011379
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.38 um Mode = 0.54 um Median = 0.75
VOL-WT Mean = 83.79 um Mode = 194.45 um Median = 73.61 (0.000 % Threshold)

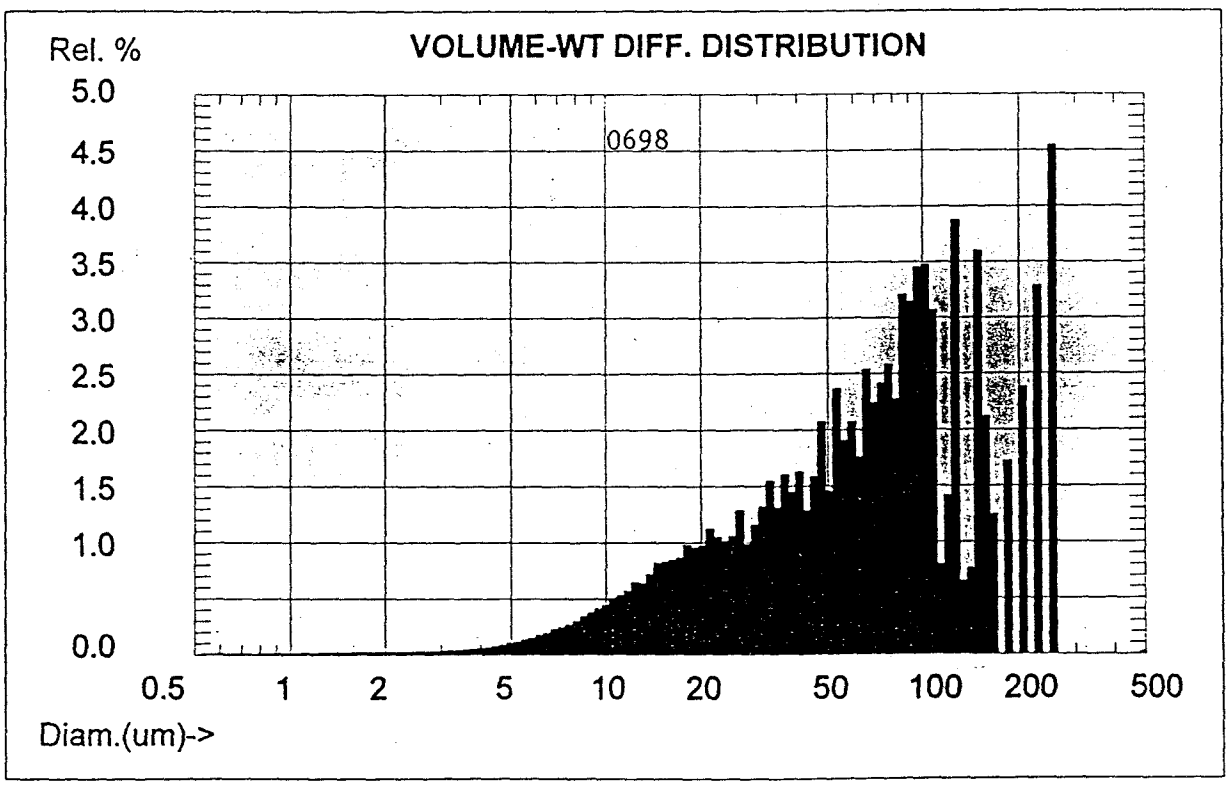


Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

0698 < 200
File Name = 0698200A.CB Time Date = 16:37:29 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1314956
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.32 um Mode = 0.54 um Median = 0.75
VOL-WT Mean = 86.49 um Mode = 254.68 um Median = 69.74 (0.000 % Threshold)

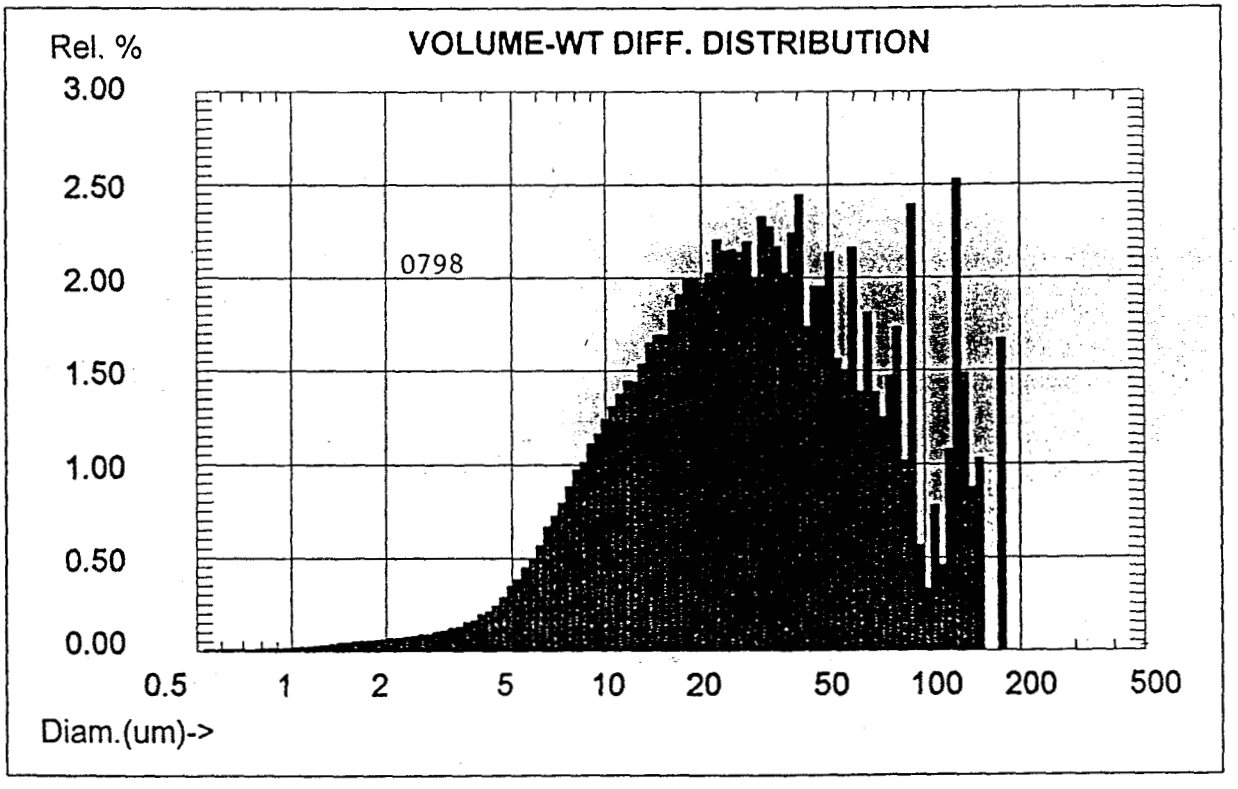


Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

~~00598 > 10um 1st and 3rd sedimentation separations~~
File Name = 0798250A.CB Time Date = 12:58:17 5/23/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1871206
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.72 um Mode = 0.60 um Median = 0.93
VOL-WT Mean = 43.32 um Mode = 126.27 um Median = 29.41 (0.000 % Threshold)

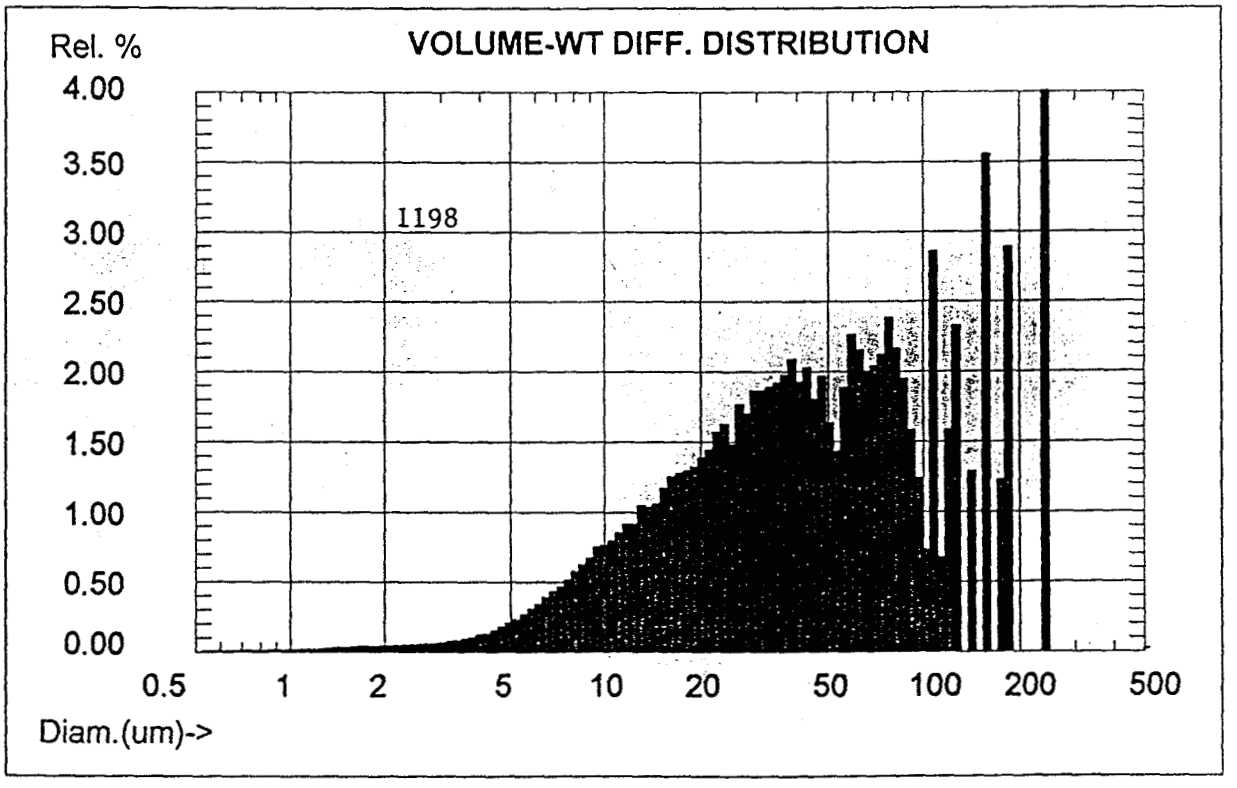


Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

~~00598 > 10um 1st and 3rd sedimentation separations~~
File Name = 1198200A.CB Time Date = 15:33: 8 5/23/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1845356
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.63 um Mode = 0.60 um Median = 0.93
VOL-WT Mean = 69.95 um Mode = 241.30 um Median = 47.80 (0.000 % Threshold)



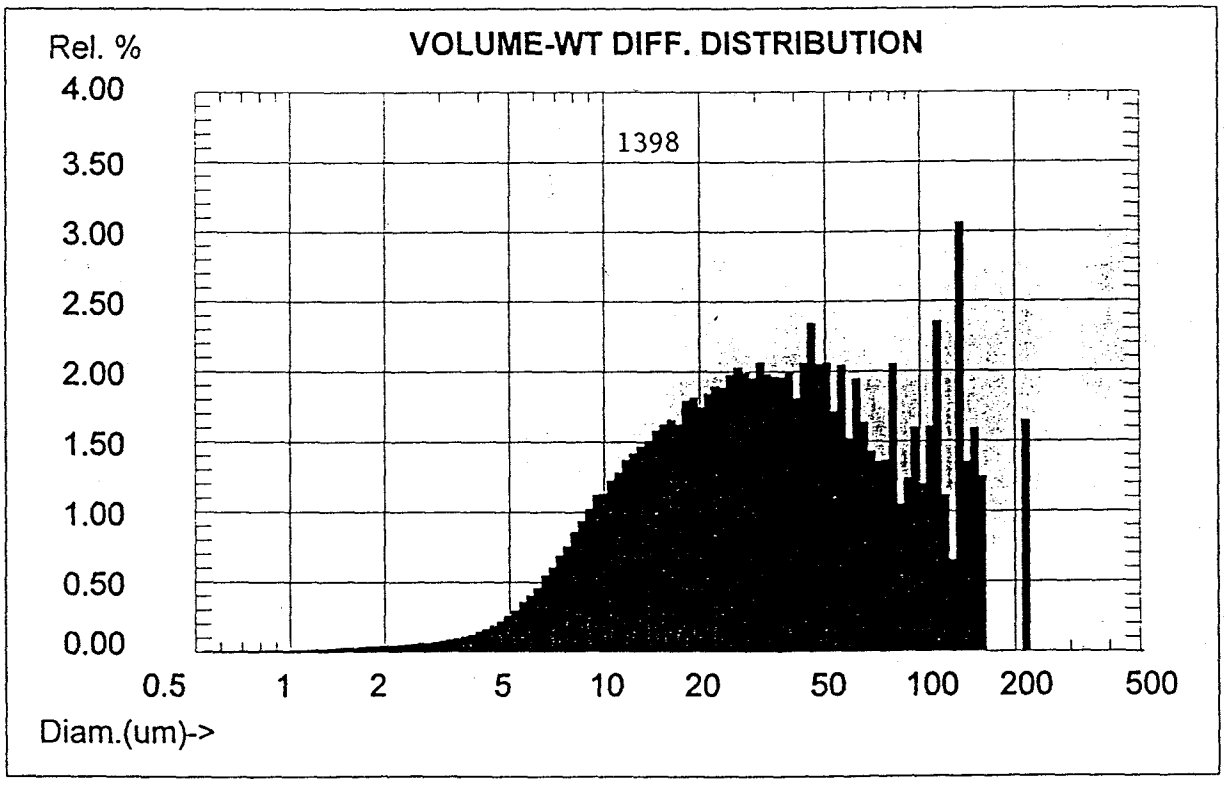
1198200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

1398 < 200
File Name = 1398200A.CB Time Date = 10:51: 7 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 2094481
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 2.10 um Mode = 0.60 um Median = 1.09
VOL-WT Mean = 50.58 um Mode = 133.28 um Median = 34.58 (0.000 % Threshold)



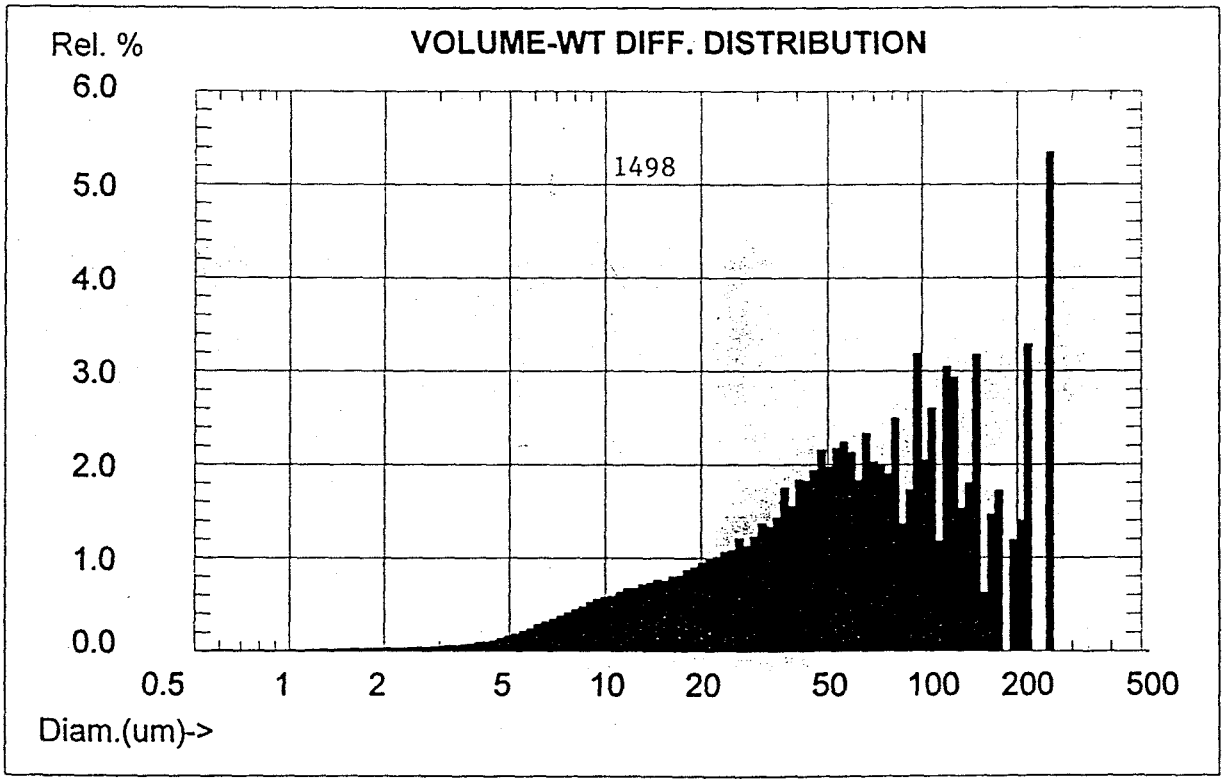
1398200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

1498 < 200 #2
File Name = 1498200A.CB Time Date = 9:50:51 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 2087199
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.59 um Mode = 0.54 um Median = 0.88
VOL-WT Mean = 84.65 um Mode = 254.68 um Median = 66.08 (0.000 % Threshold)



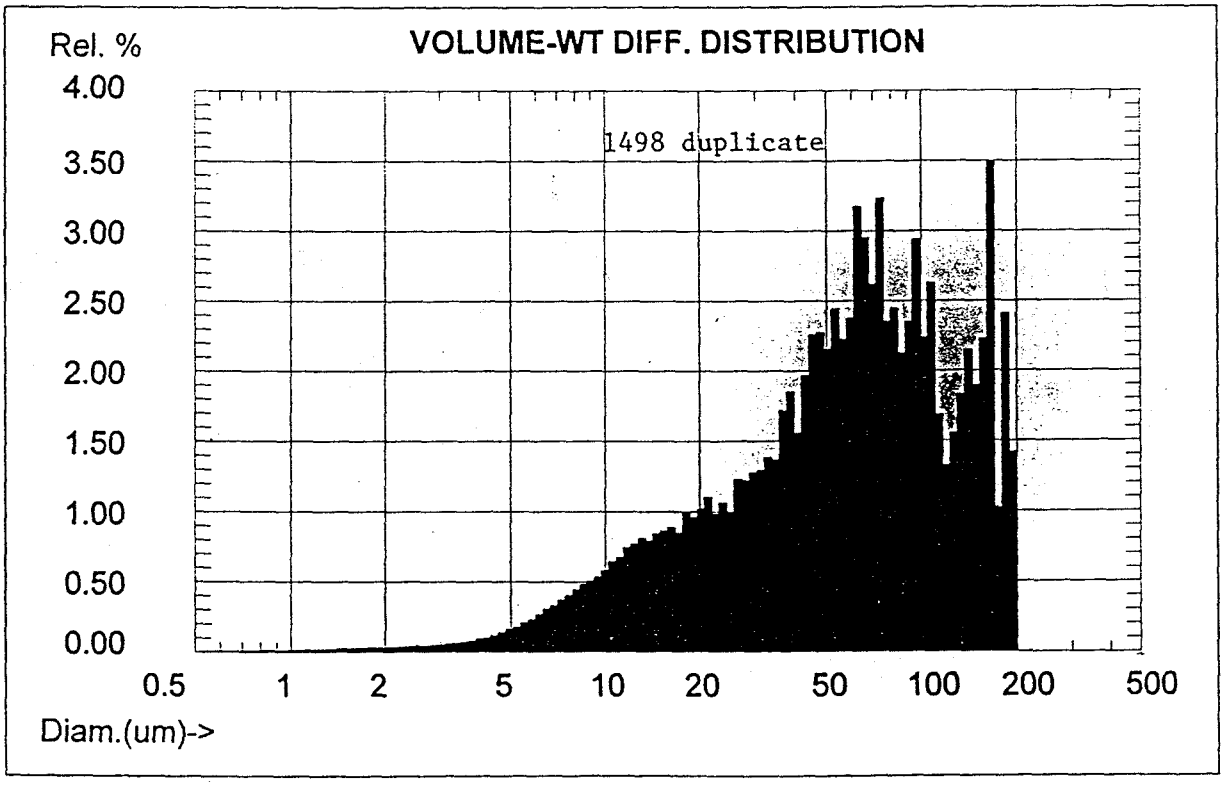
1498200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

1498 < 200 #1
File Name = 1498200B.CB Time Date = 16:30:50 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1980432
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.50 um Mode = 0.54 um Median = 0.83
VOL-WT Mean = 71.21 um Mode = 165.39 um Median = 62.61 (0.000 % Threshold)

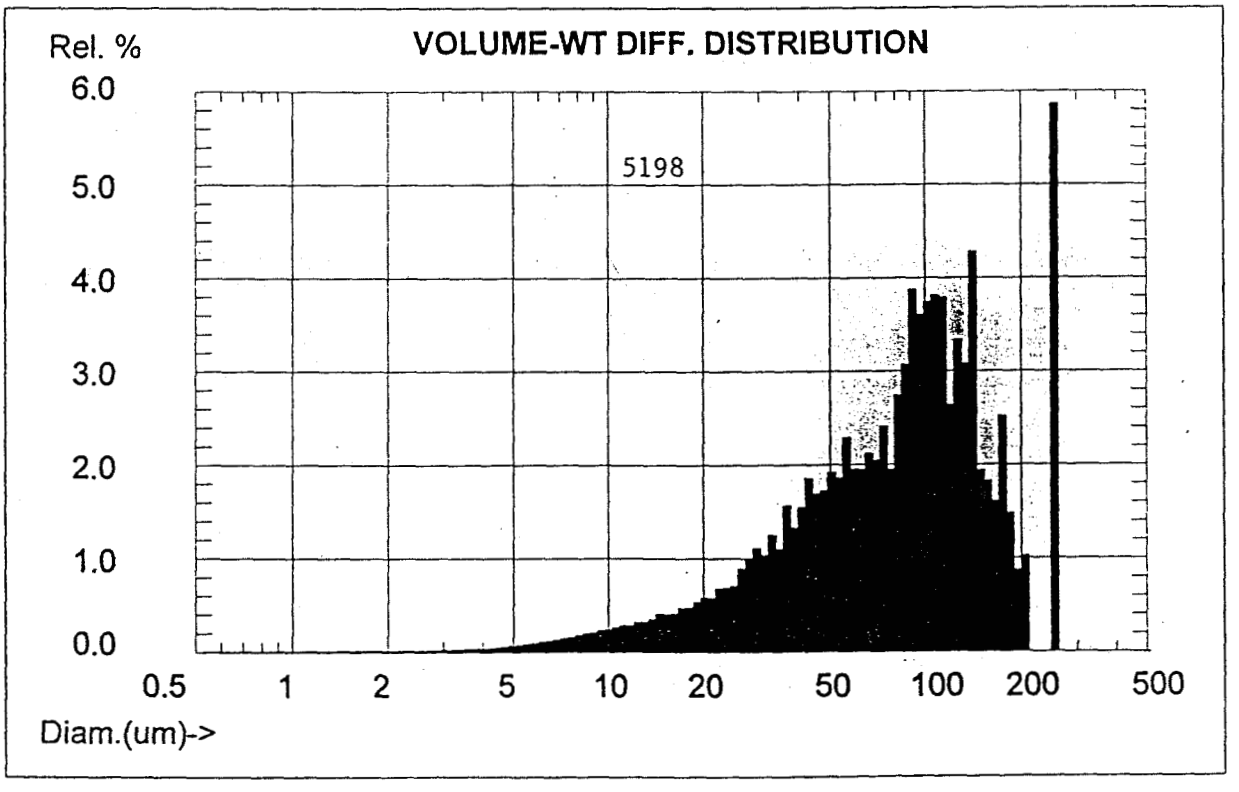


Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

05198 < 200 #2
File Name = 5198200A.CB Time Date = 9:44:19 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1504668
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.51 um Mode = 0.60 um Median = 0.83
VOL-WT Mean = 95.15 um Mode = 254.68 um Median = 86.55 (0.000 % Threshold)



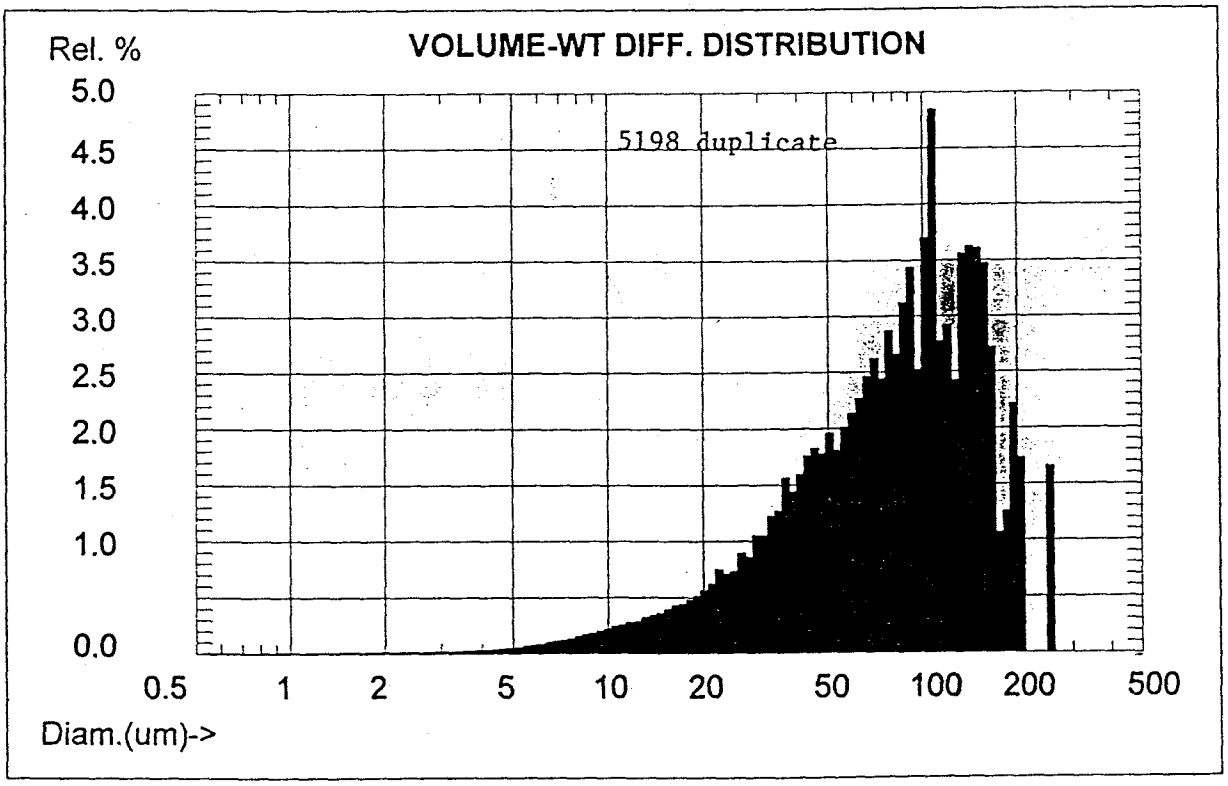
5198200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

05198 < 200 #1
File Name = 5198200B.CB Time Date = 9:58:33 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1426803
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.57 um Mode = 0.54 um Median = 0.83
VOL-WT Mean = 91.41 um Mode = 107.40 um Median = 86.55 (0.000 % Threshold)



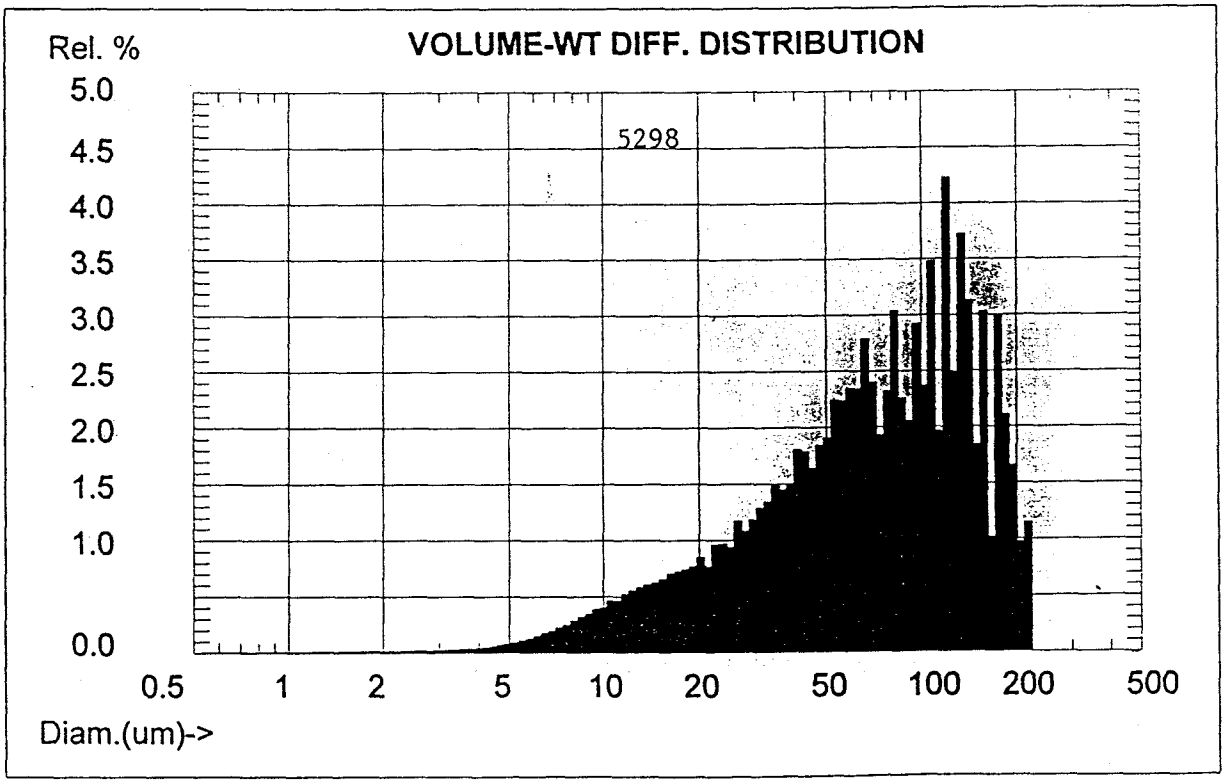
5198200B.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

5298 < 200
File Name = 5298200A.CB Time Date = 16:44: 7 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1559782
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.70 um Mode = 0.54 um Median = 0.83
VOL-WT Mean = 82.87 um Mode = 119.64 um Median = 73.61 (0.000 % Threshold)



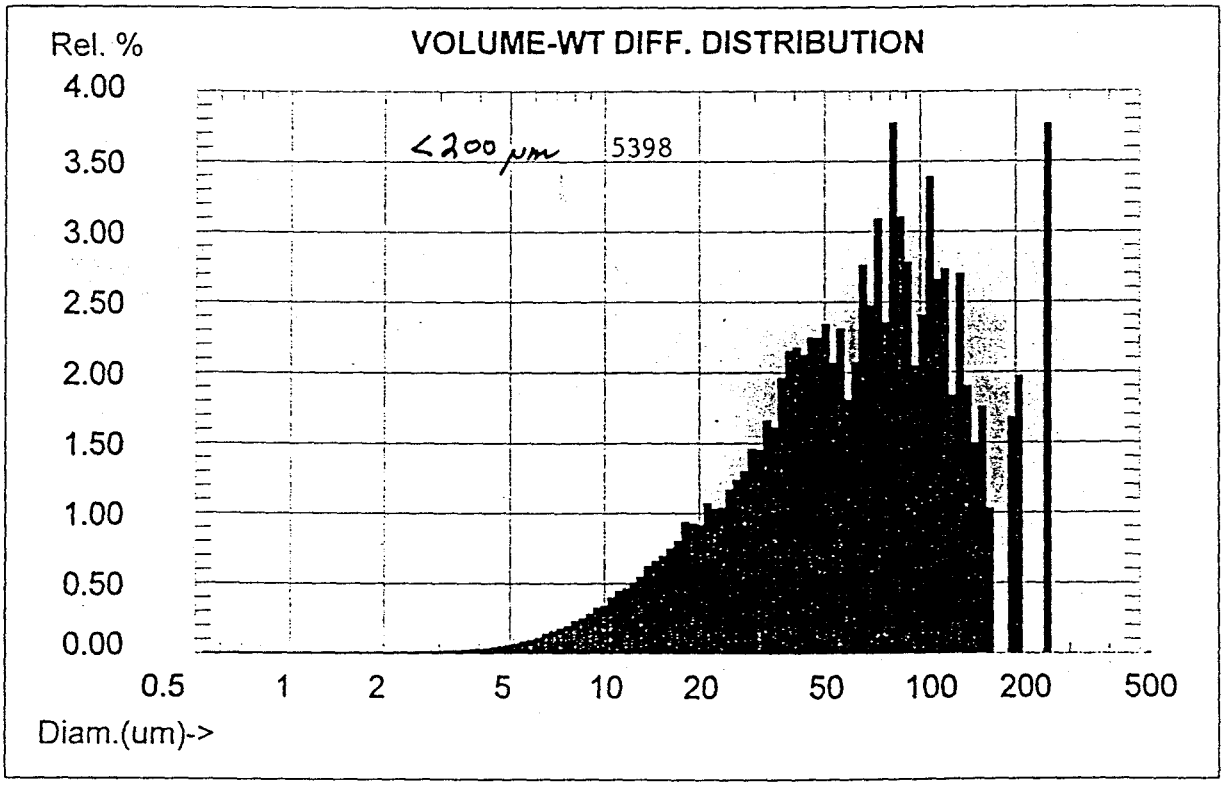
5298200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

5398 < 200
File Name = 5398200A.CB Time Date = 16:50:54 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1052478
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.37 um Mode = 0.54 um Median = 0.71
VOL-WT Mean = 79.11 um Mode = 82.00 um Median = 66.08 (0.000 % Threshold)



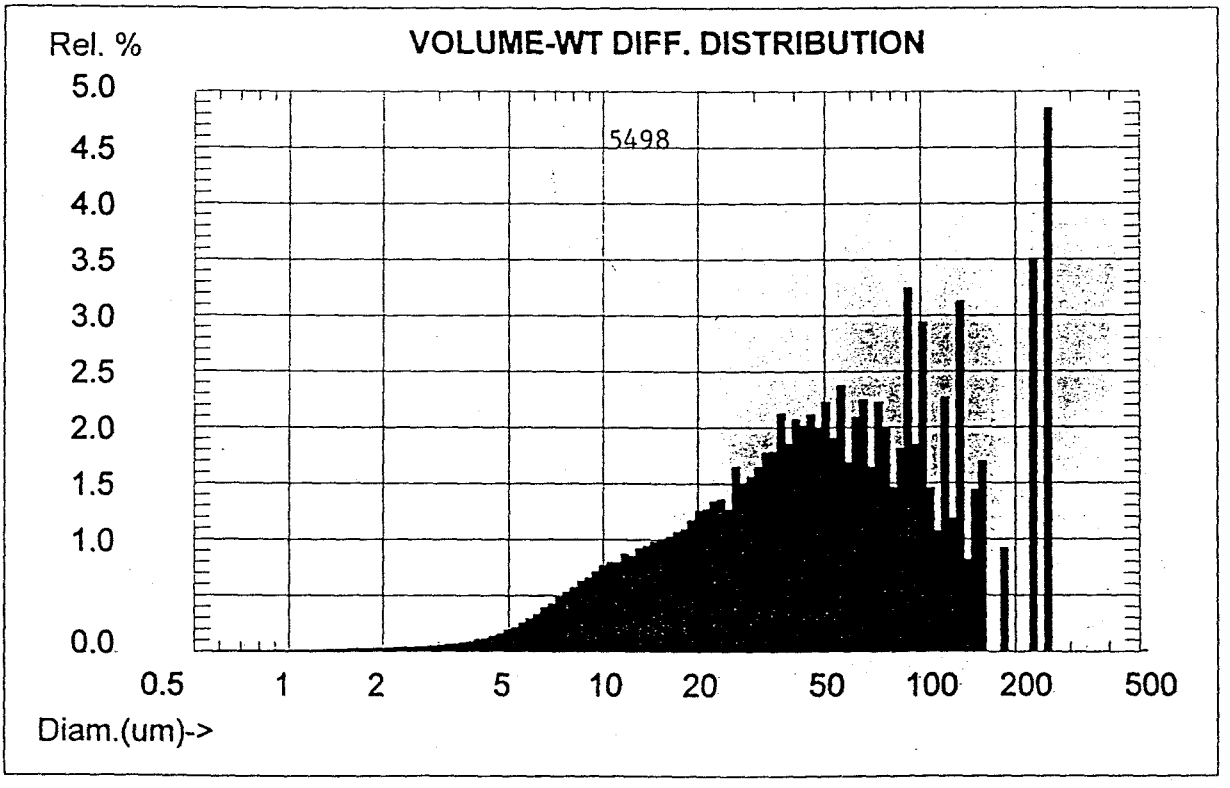
5398200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

05498 < 200
File Name = 5498200A.CB Time Date = 10:38: 2 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1994193
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.86 um Mode = 0.54 um Median = 0.98
VOL-WT Mean = 73.05 um Mode = 254.68 um Median = 50.45 (0.000 % Threshold)



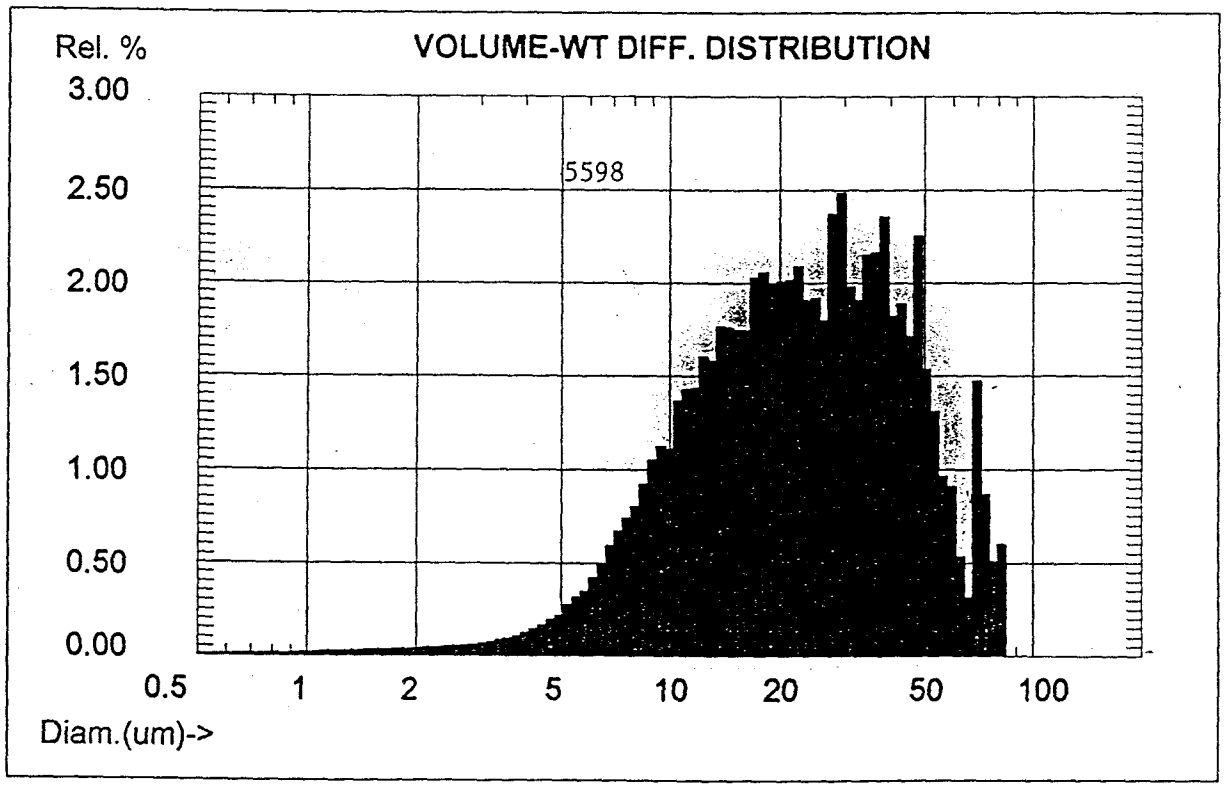
5498200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

5598
File Name = 81298R05.CB Time Date = 17: 8:50 8/12/1998
Sensor Model: le400-0.5 SUM S/N: 9710908 Cal. File: CSMS.SNS
Date of Calibration: 5-14-98

Elapsed Time of Data Collection = 123 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.50 um) = 490712
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 60.0 ml No. of Channels = 128
NUM-WT Mean = 1.58 um Mode = 0.64 um Median = 0.83
VOL-WT Mean = 90.87 um Mode = 283.71 um Median = 31.04 (0.000 % Threshold)



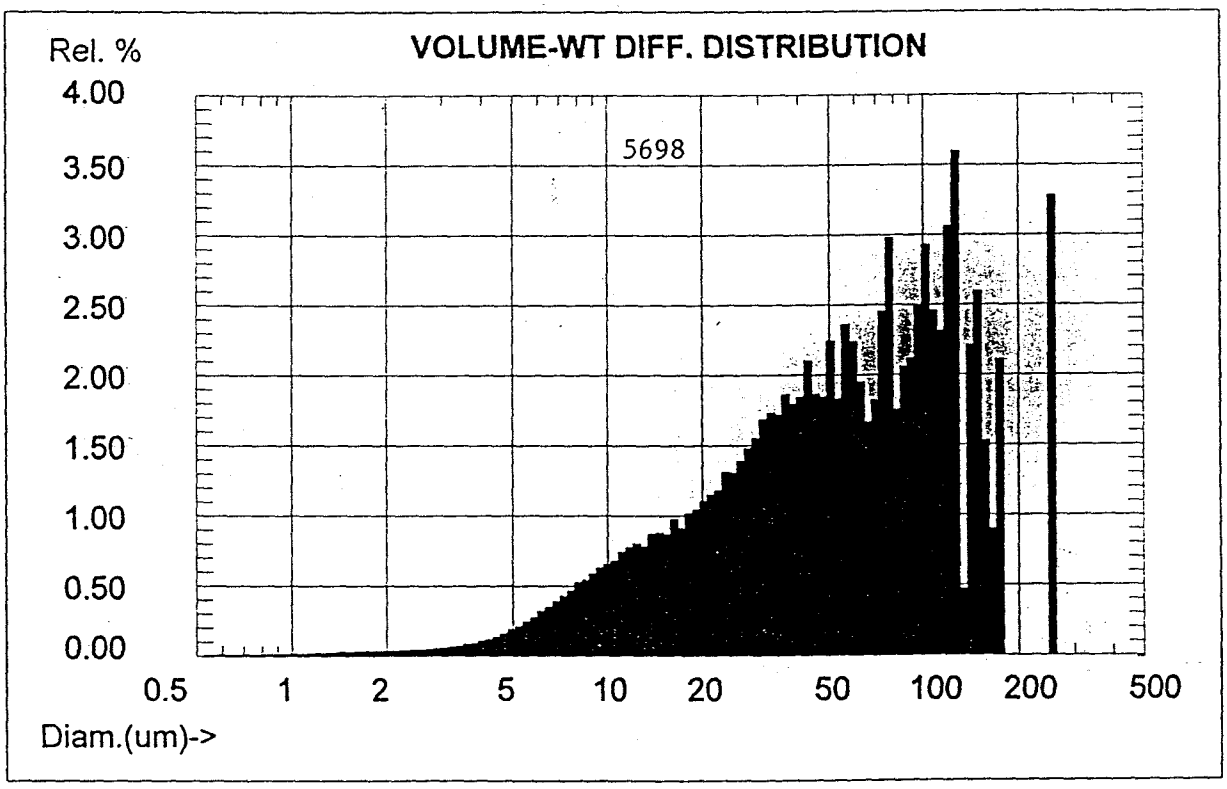
81298R05.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

05698 < 200
File Name = 5698200A.CB Time Date = 10:31:34 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 2139811
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.52 um Mode = 0.60 um Median = 0.88
VOL-WT Mean = 70.99 um Mode = 126.27 um Median = 56.20 (0.000 % Threshold)



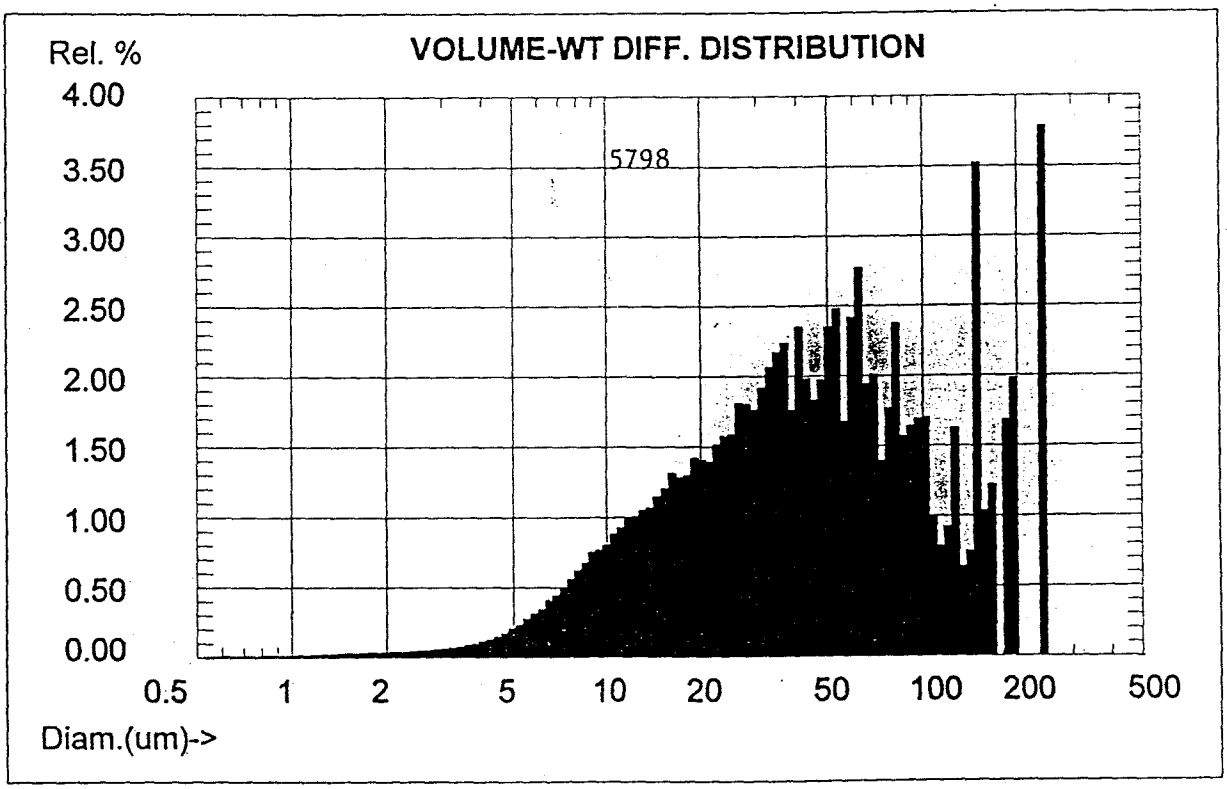
5698200A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

05798 < 200 #2
File Name = 5798200A.CB Time Date = 10:44:42 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1715192
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.53 um Mode = 0.54 um Median = 0.83
VOL-WT Mean = 64.69 um Mode = 241.30 um Median = 45.29 (0.000 % Threshold)

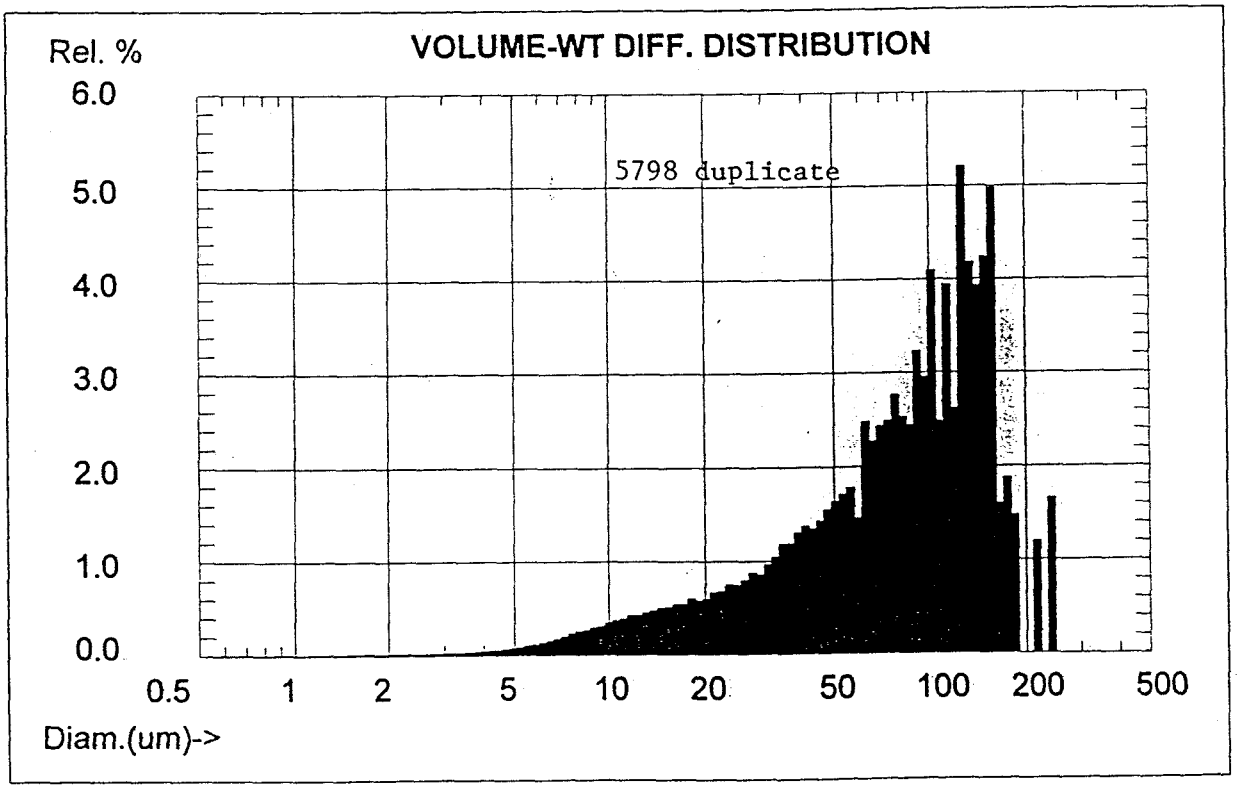


Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

05798 < 200 #1
File Name = 5798200B.CB Time Date = 16:15: 5 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1439629
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.62 um Mode = 0.54 um Median = 0.83
VOL-WT Mean = 90.72 um Mode = 126.27 um Median = 86.55 (0.000 % Threshold)



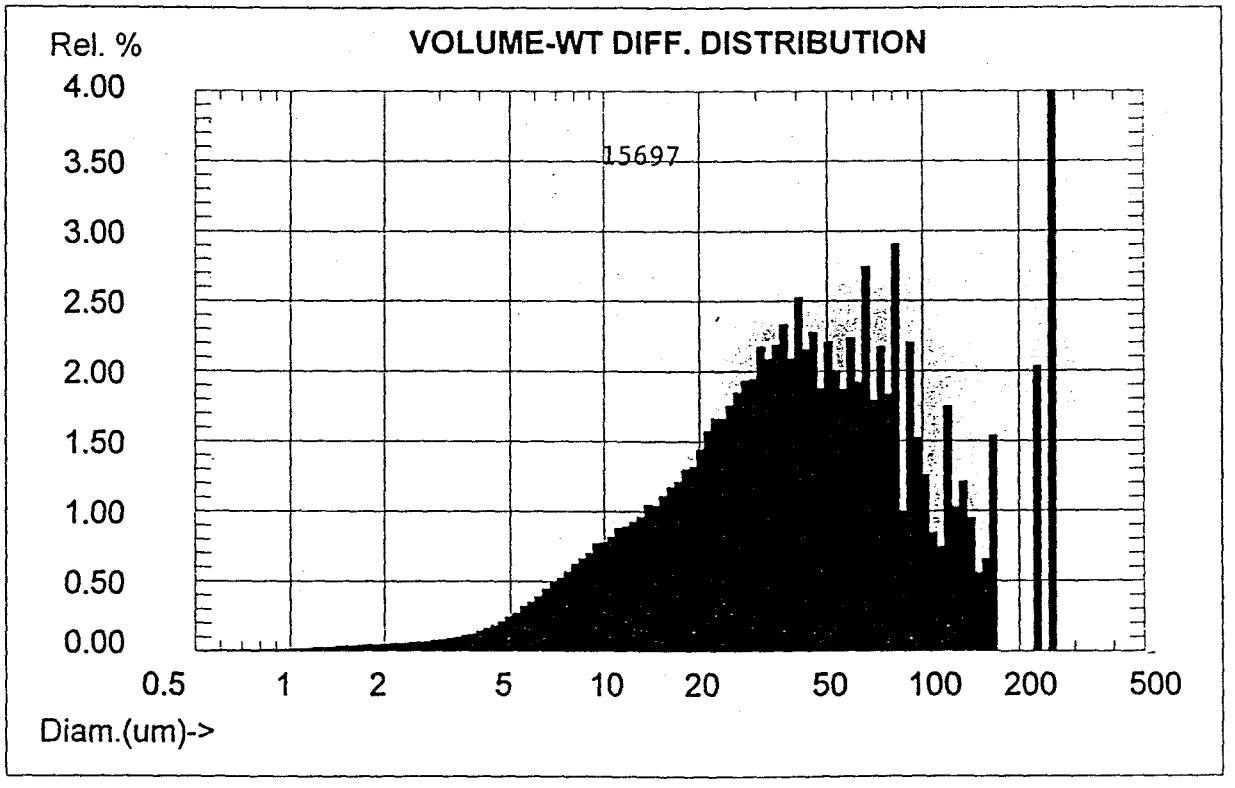
5798200B.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

15697 < 200
File Name = 1569720A.CB Time Date = 10:10:55 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 2516148
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.73 um Mode = 0.60 um Median = 0.98
VOL-WT Mean = 64.84 um Mode = 254.68 um Median = 42.91 (0.000 % Threshold)



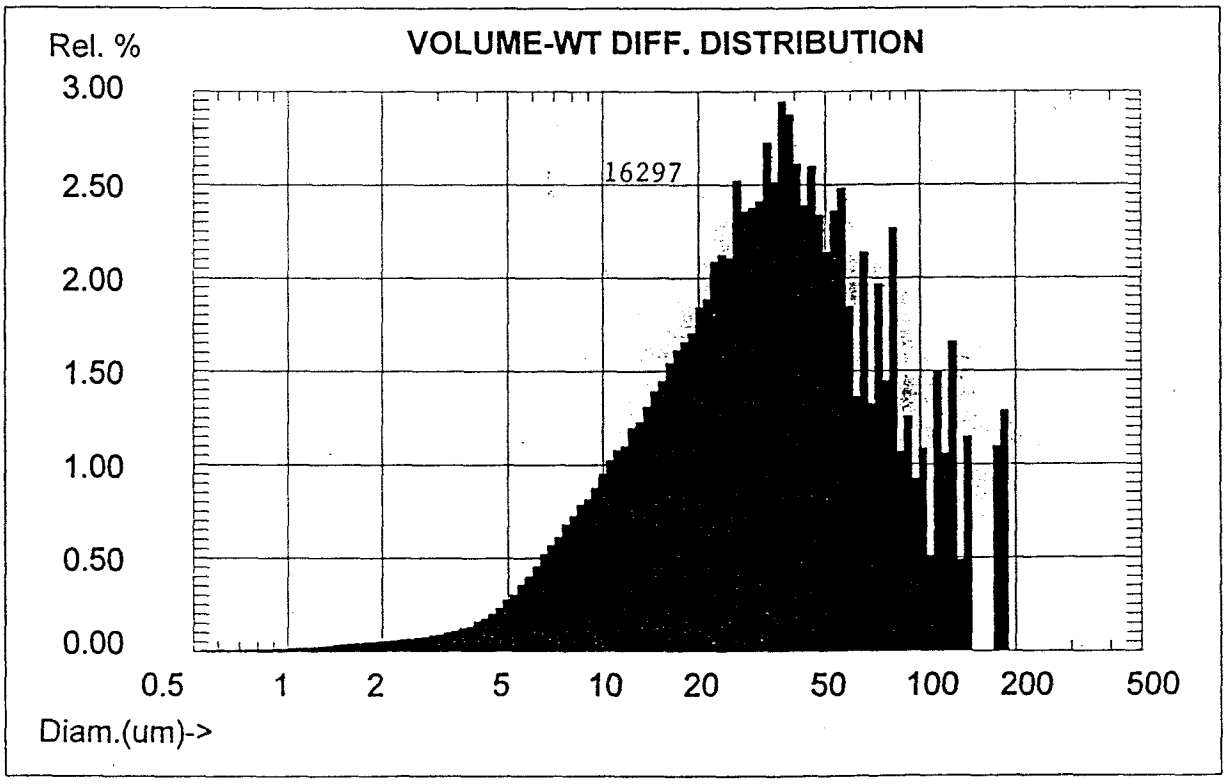
1569720A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

Model 770 AccuSizer

16297 <200um
File Name = 1629720A.CB Time Date = 9:37: 6 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 2322993
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.75 um Mode = 0.60 um Median = 0.98
VOL-WT Mean = 45.13 um Mode = 36.50 um Median = 34.58 (0.000 % Threshold)



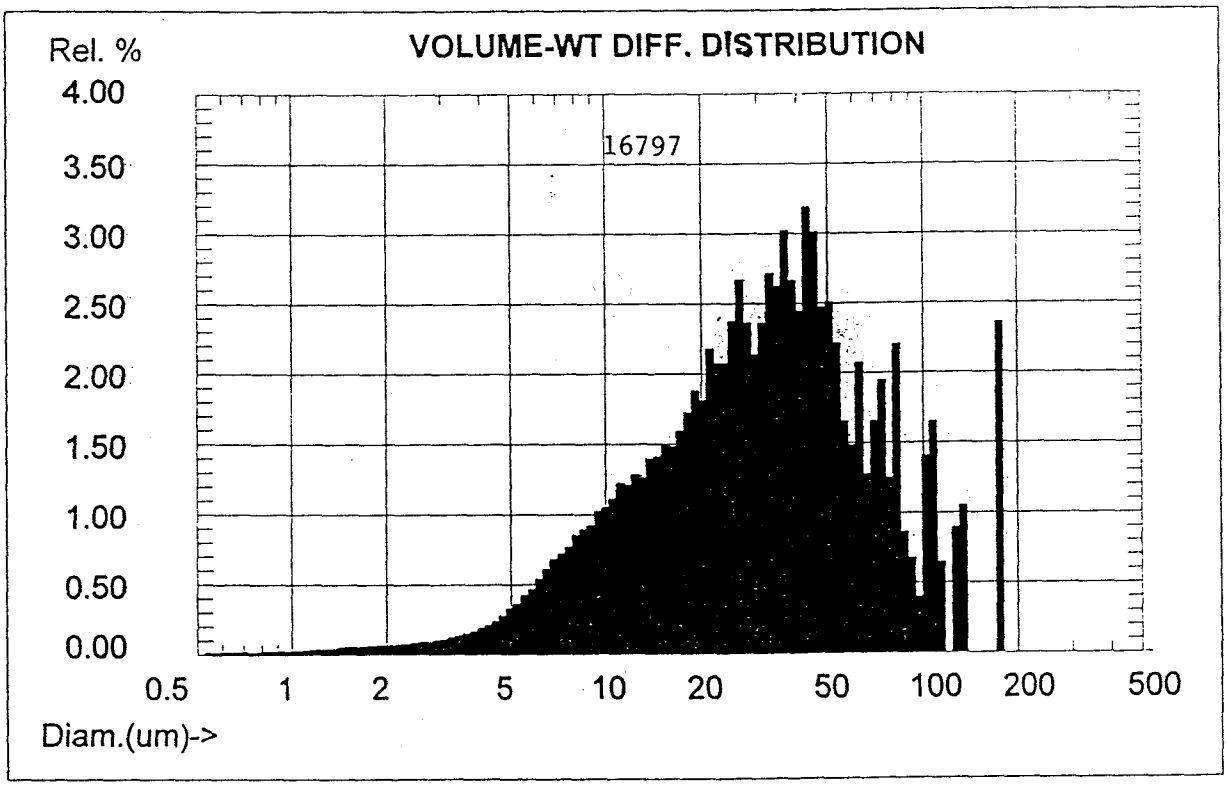
1629720A.CB

Particle Sizing Systems, Inc.
Santa Barbara, Calif., USA

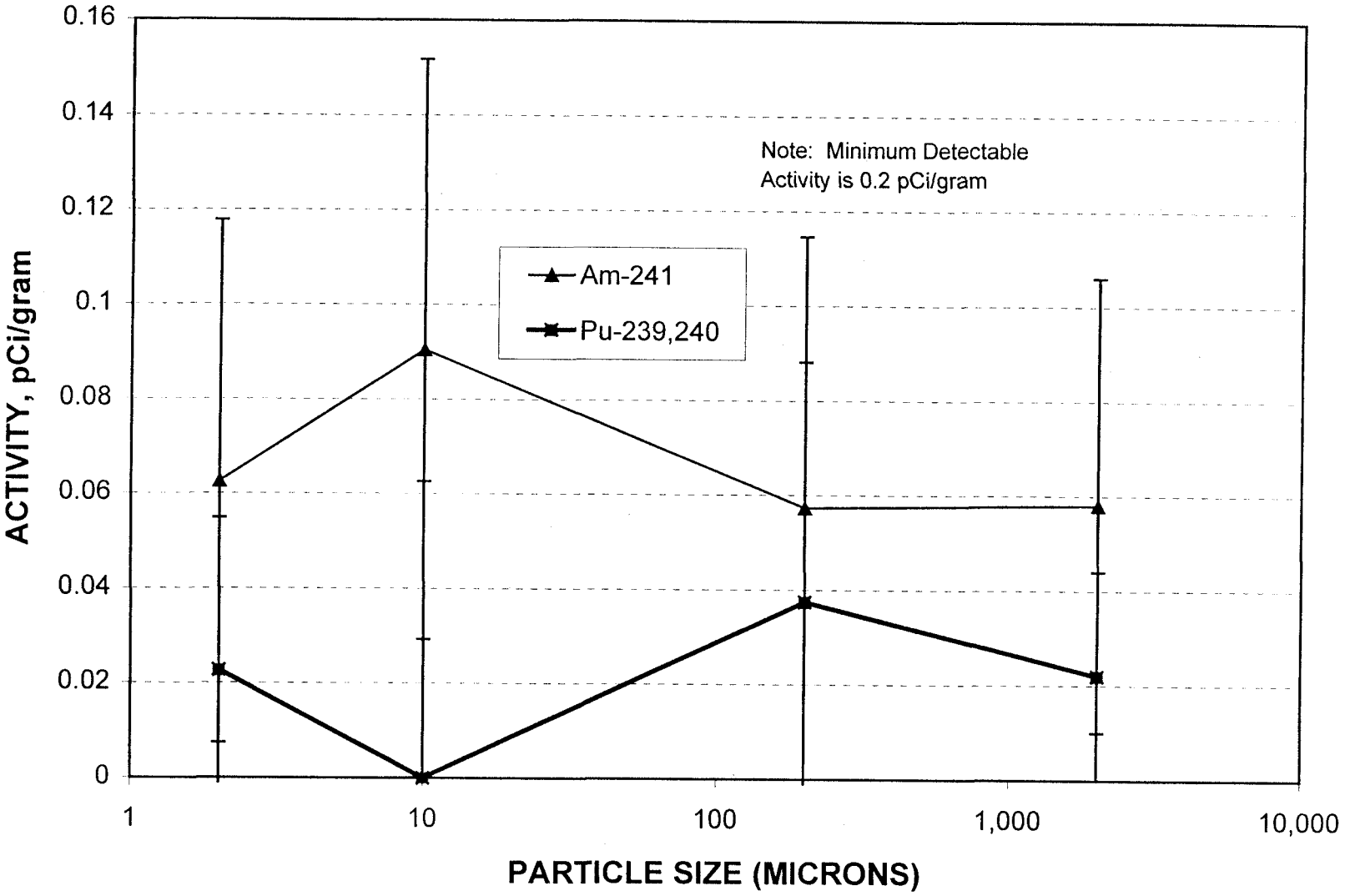
Model 770 AccuSizer

16797 < 200
File Name = 1679720B.CB Time Date = 10:24: 7 5/25/1998
Sensor Model: LE400-0.5 SUM S/N: 9710908 Cal. File: 9710908S.SNS
Date of Calibration: 10-29-97

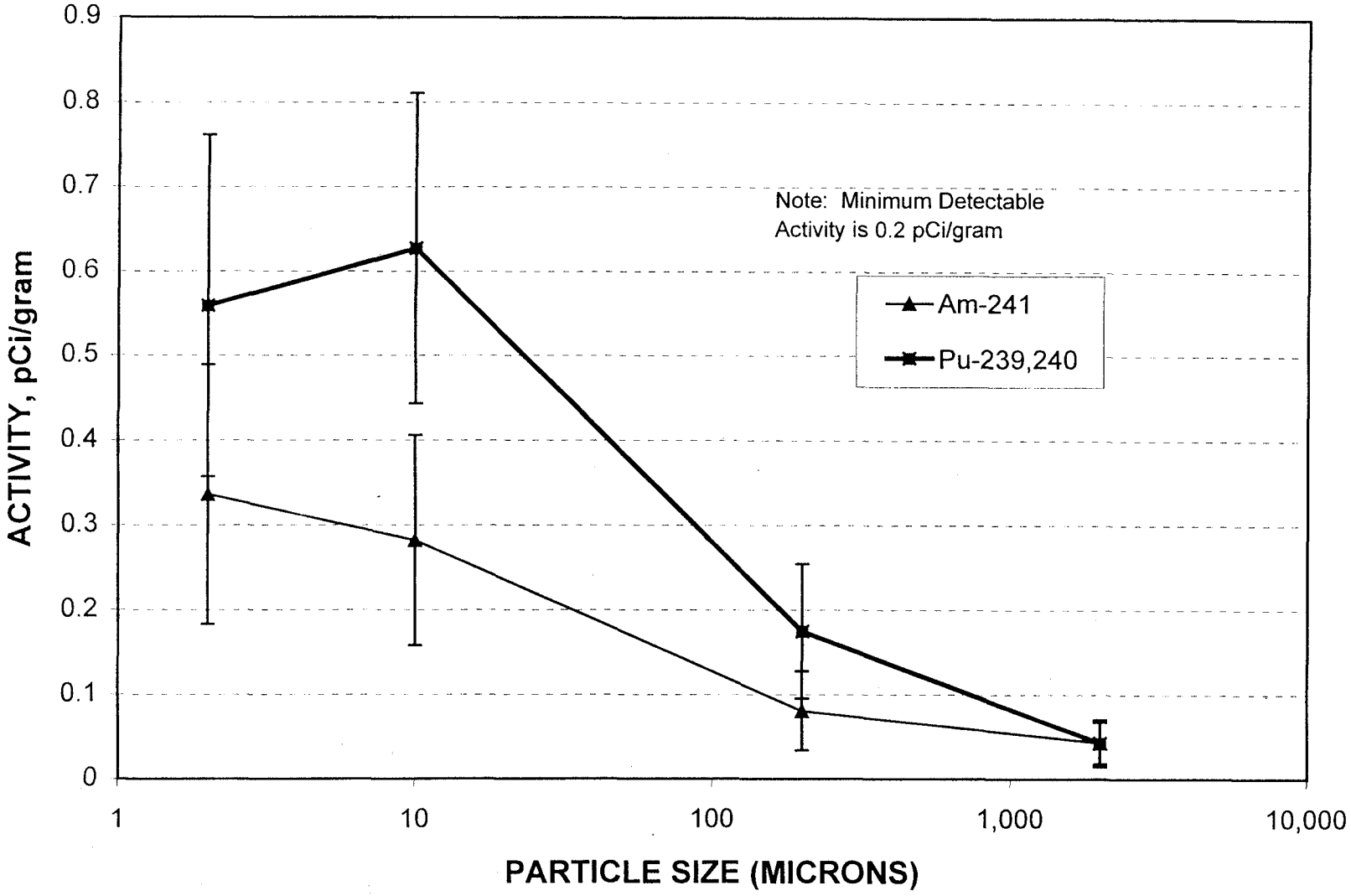
Elapsed Time of Data Collection = 205 Sec.
Background File = NONE
Total # Part. Sized (>=Thres. 0.53 um) = 1924097
Calculated Total No. of Particles in Sample = ---
Dilution Factor = 1.00
Fluid Volume Sampled = 100.0 ml No. of Channels = 128
NUM-WT Mean = 1.40 um Mode = 0.60 um Median = 0.83
VOL-WT Mean = 41.36 um Mode = 42.91 um Median = 32.76 (0.000 % Threshold)



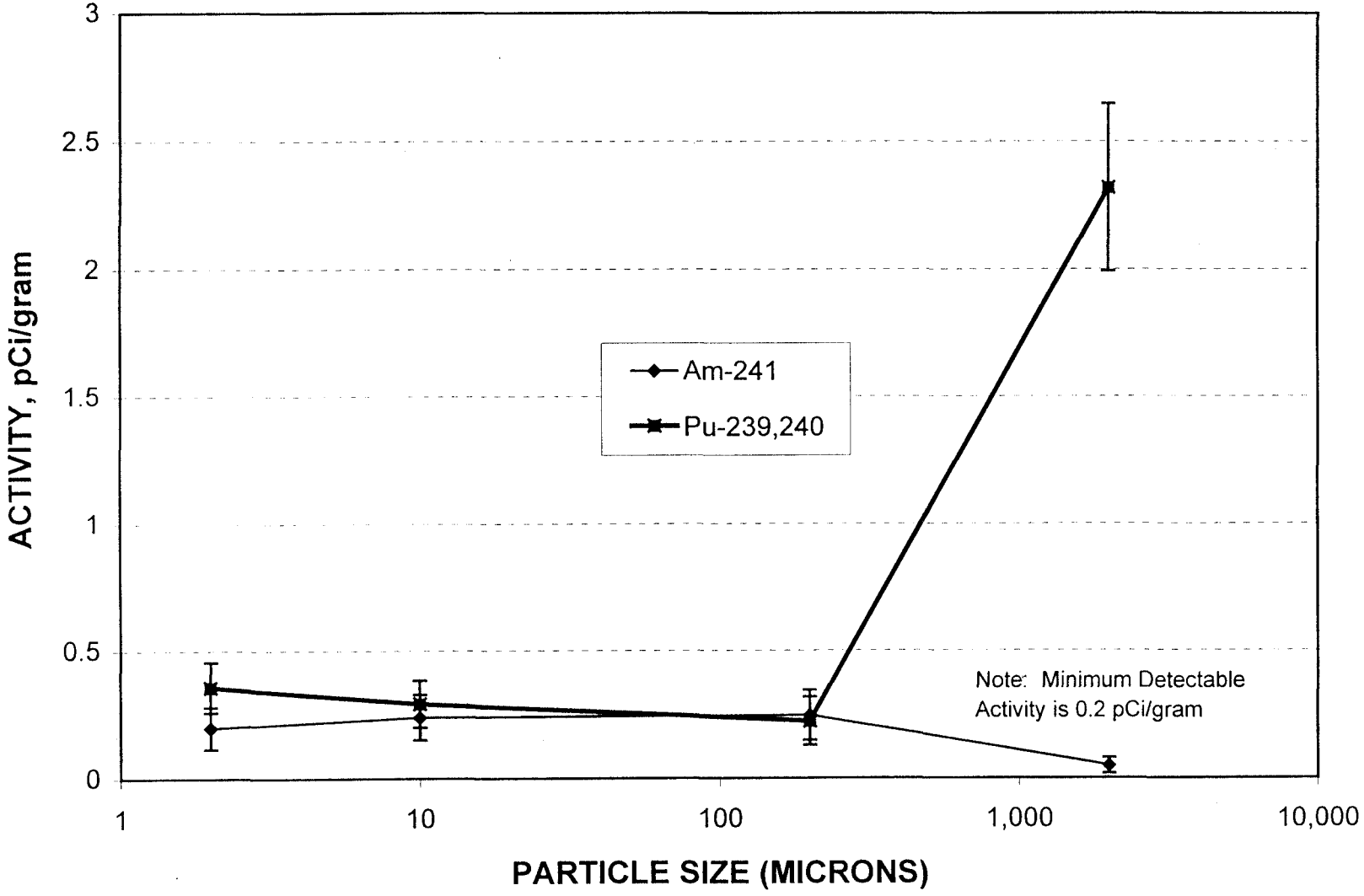
Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Sediment Station 15697



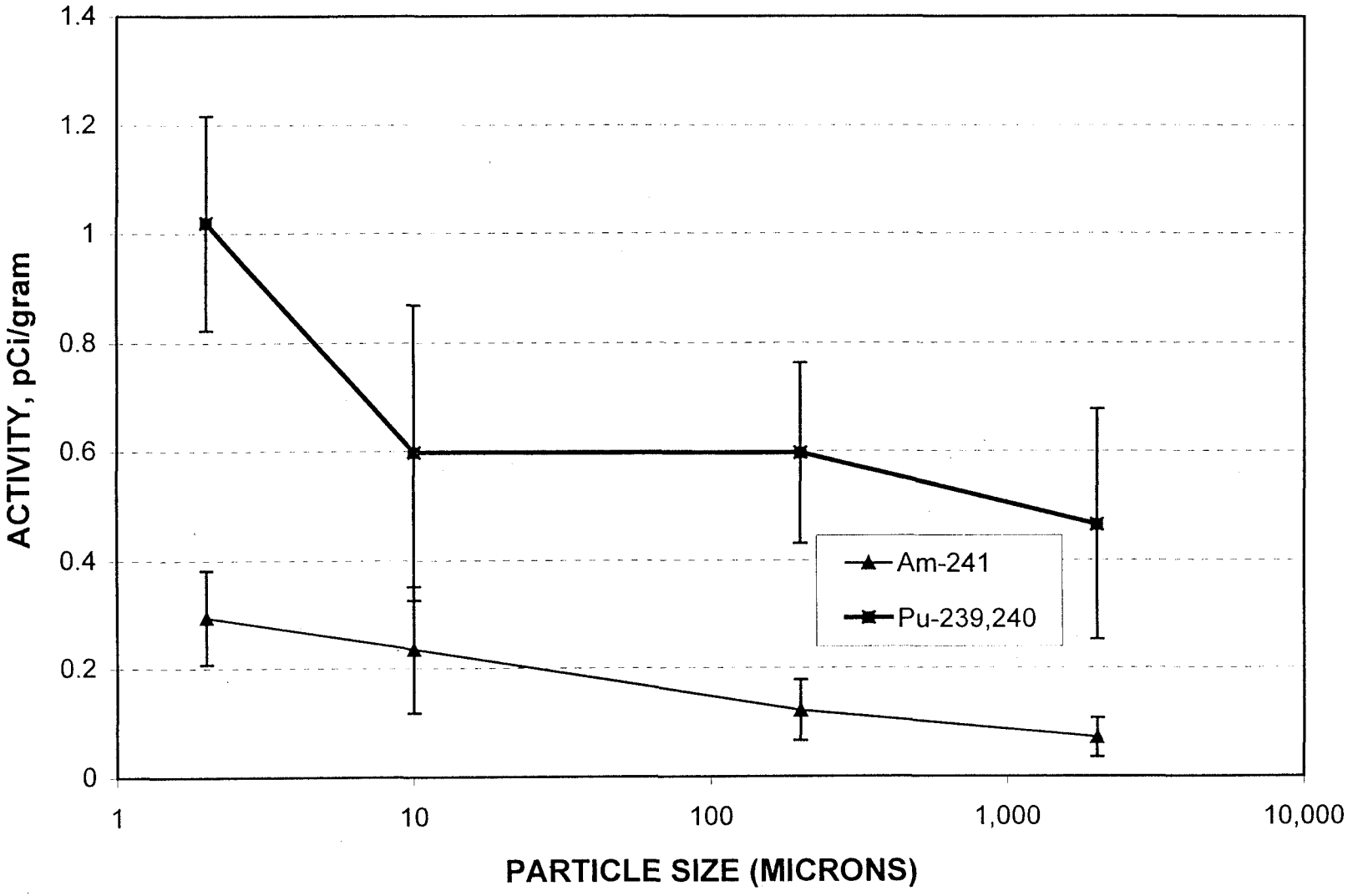
Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Sediment
Station 16297

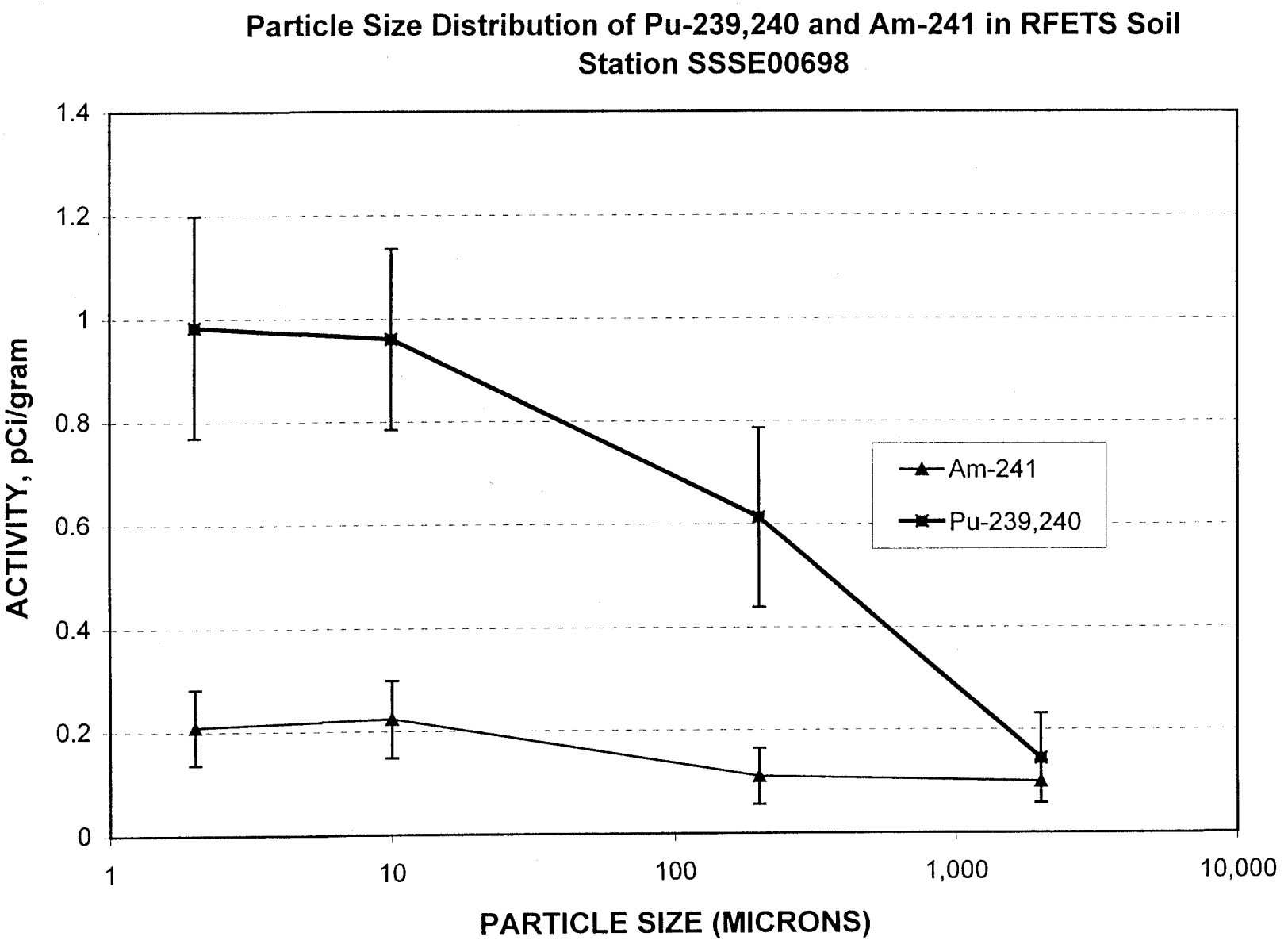


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Sediment
Station 16797

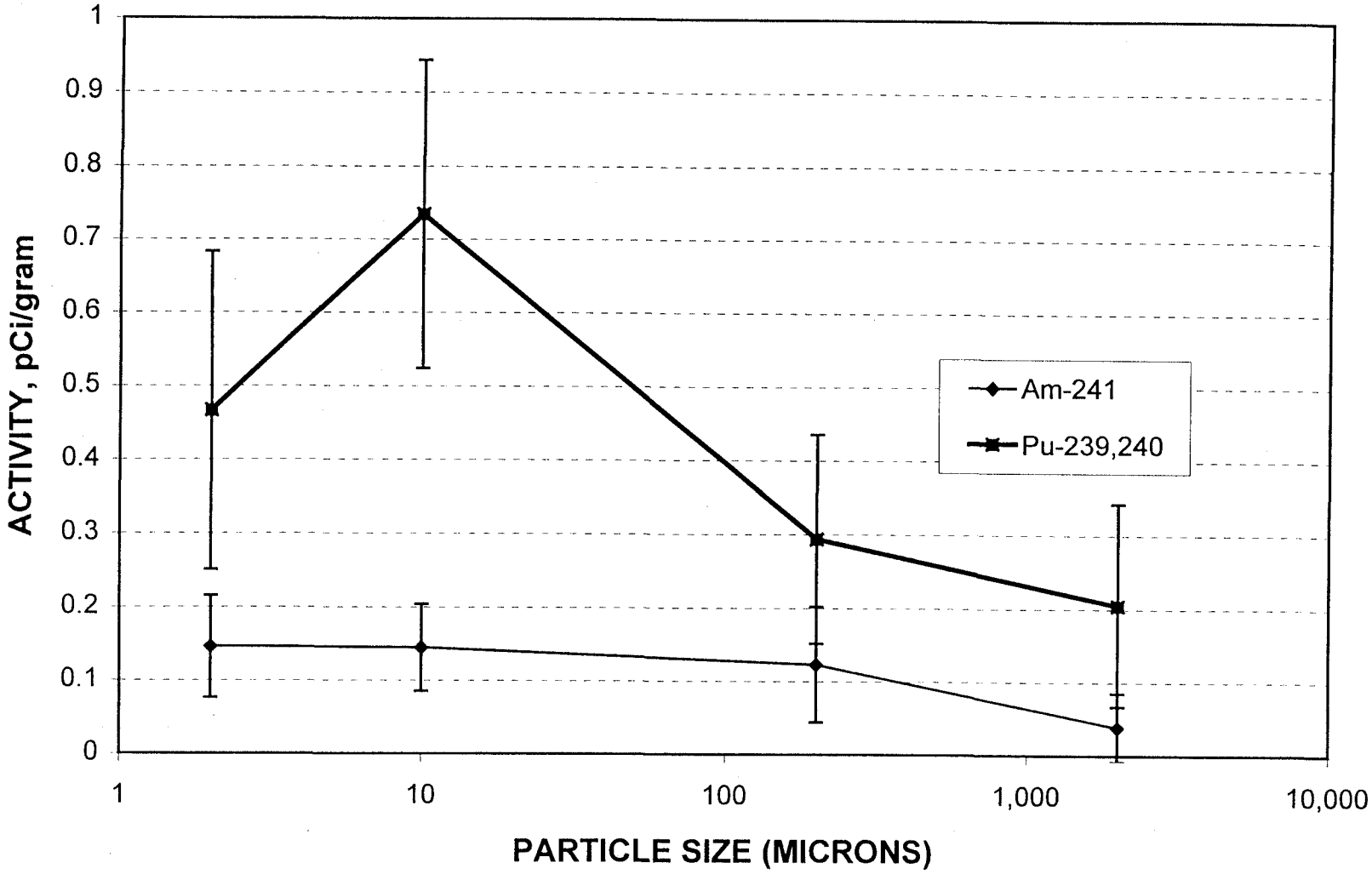


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE00598

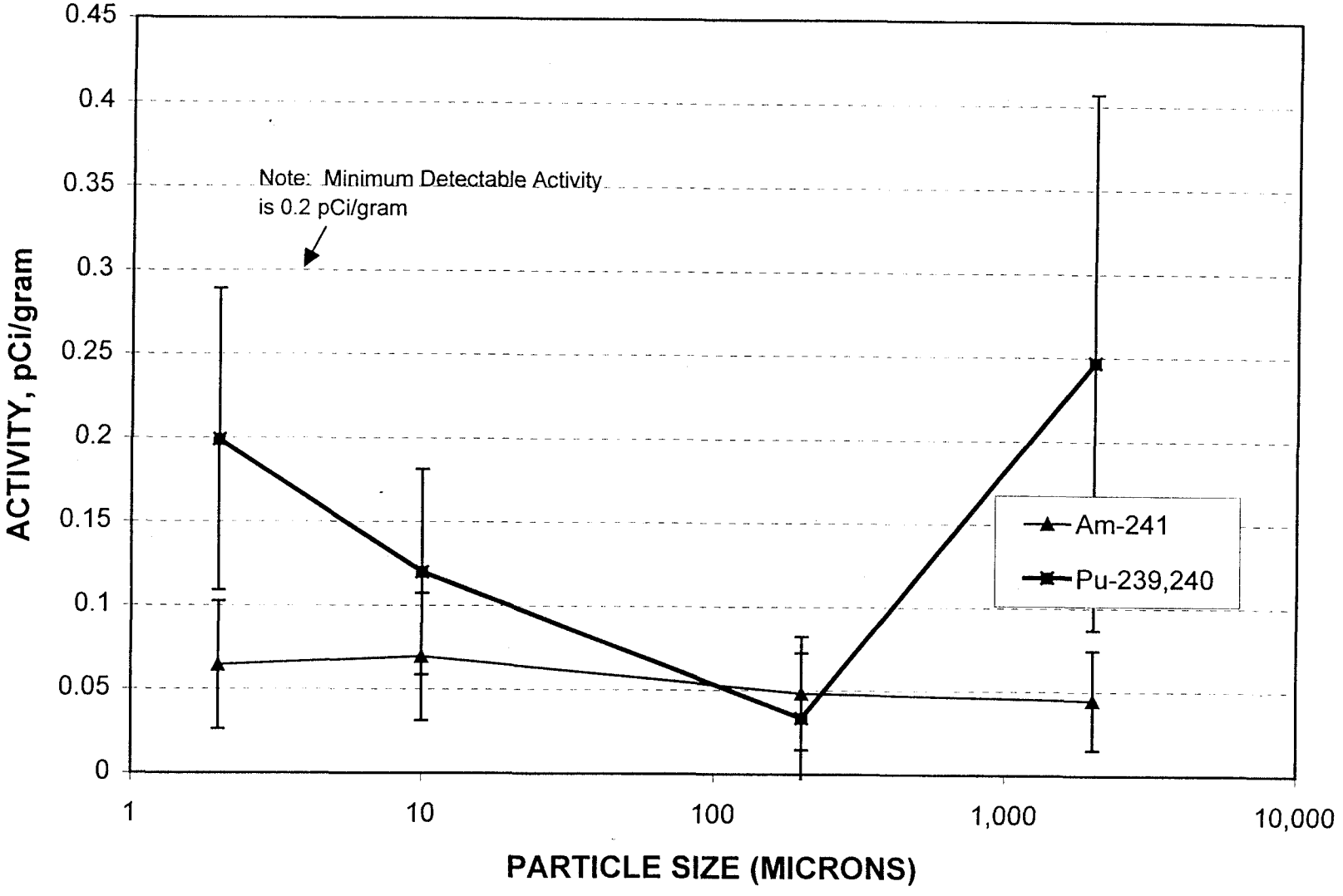


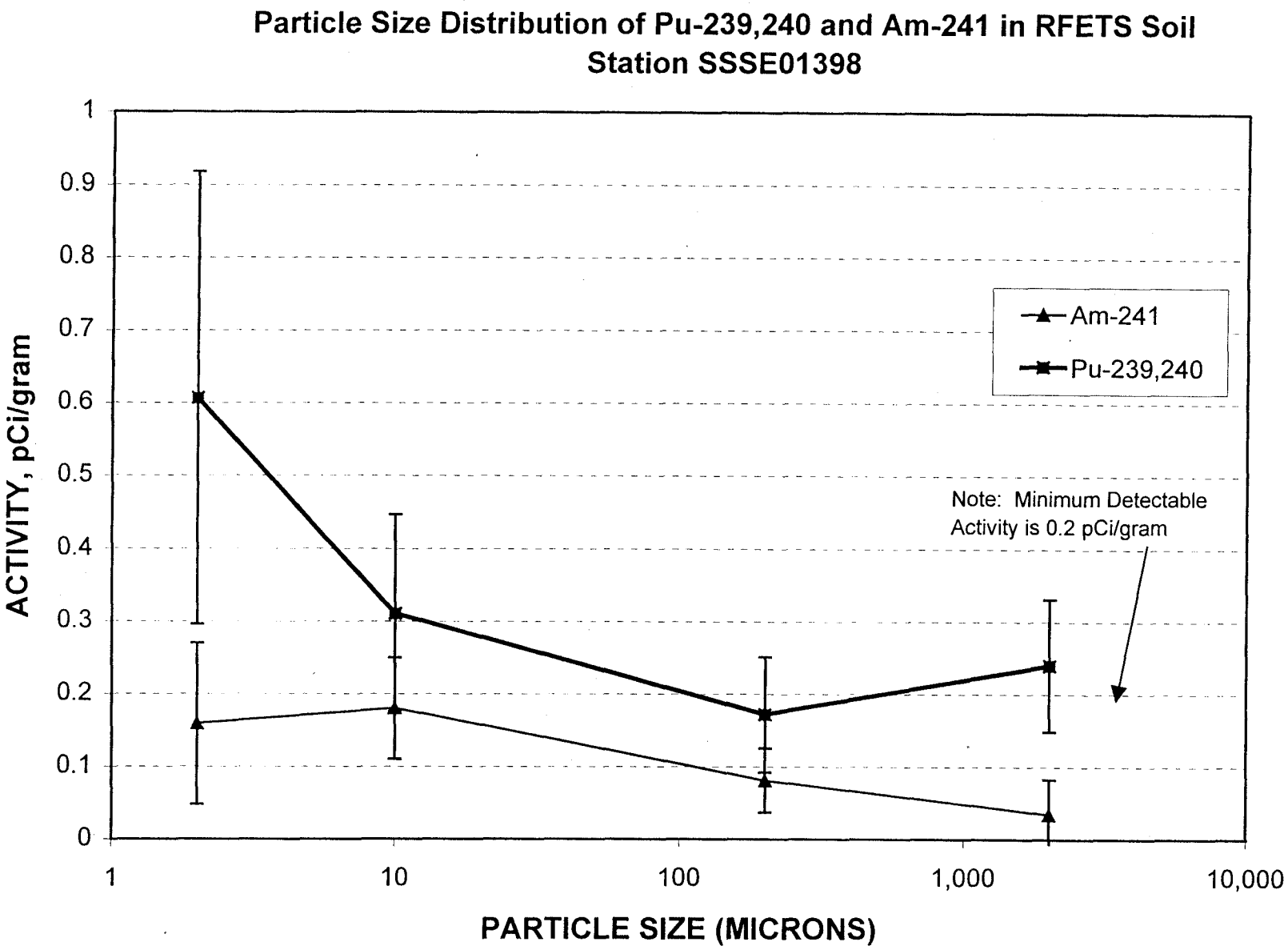

Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE00698
ACTIVITY, pCi/gram
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)
Am-241
Pu-239,240

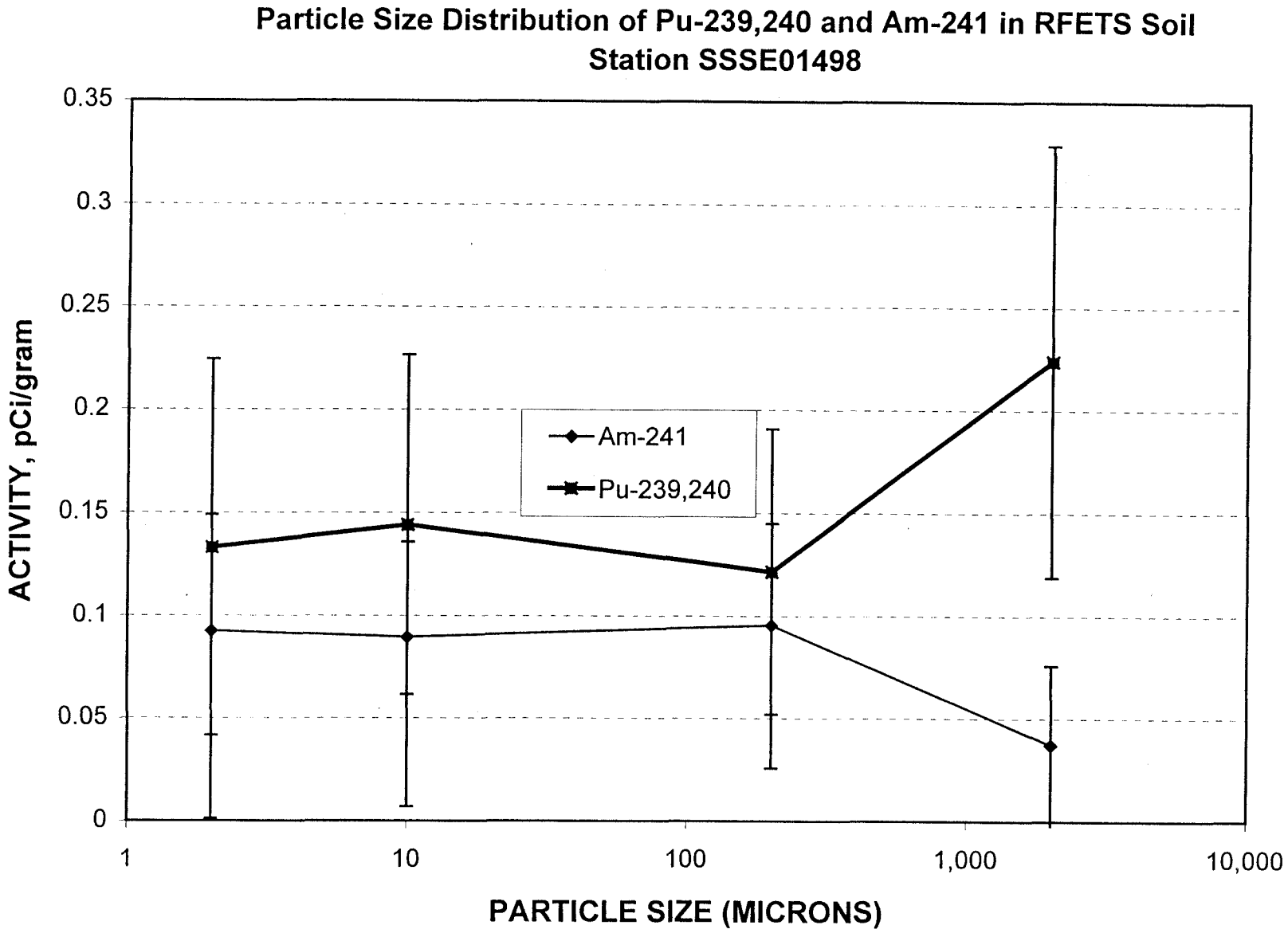
Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE00798

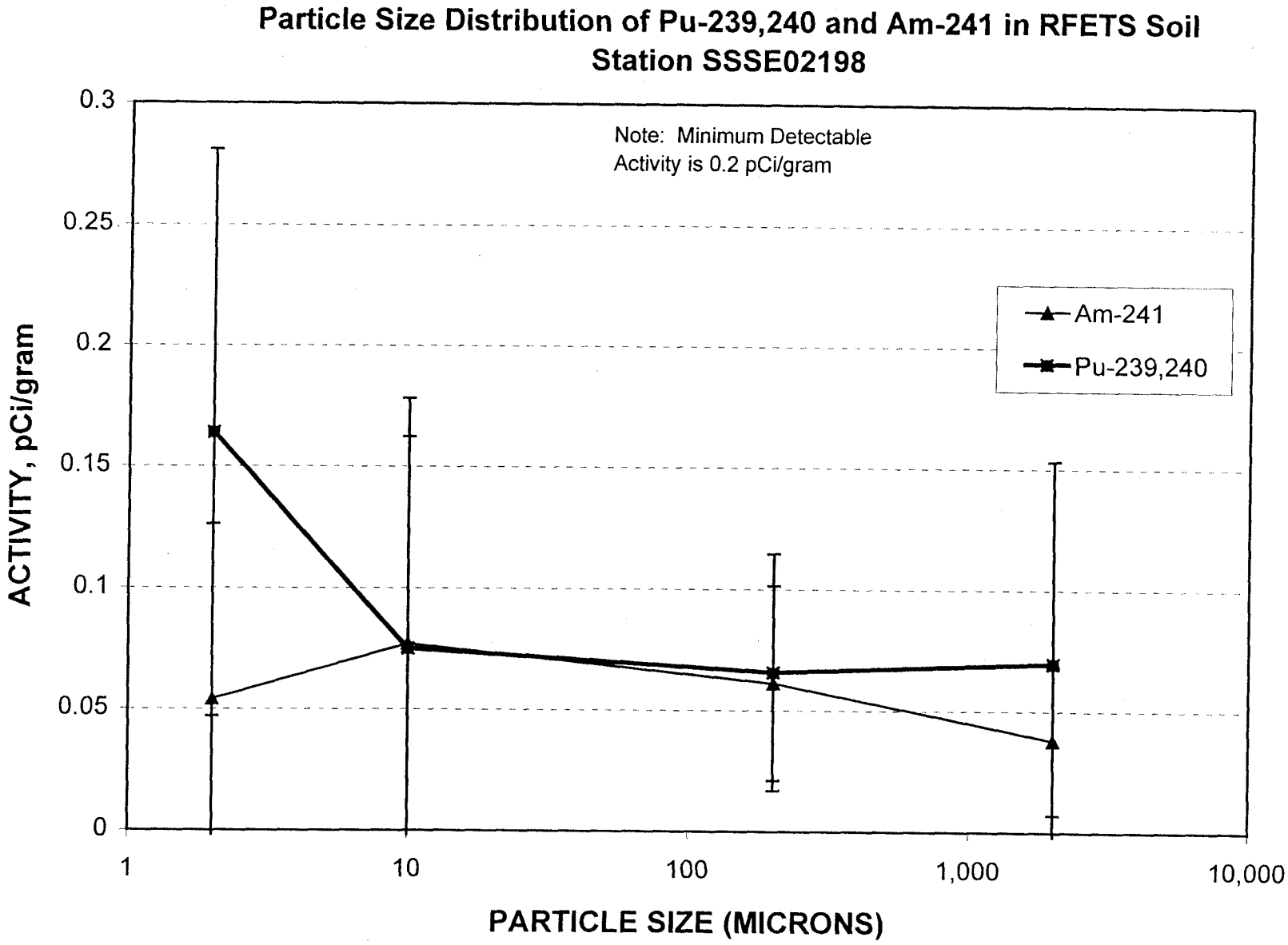


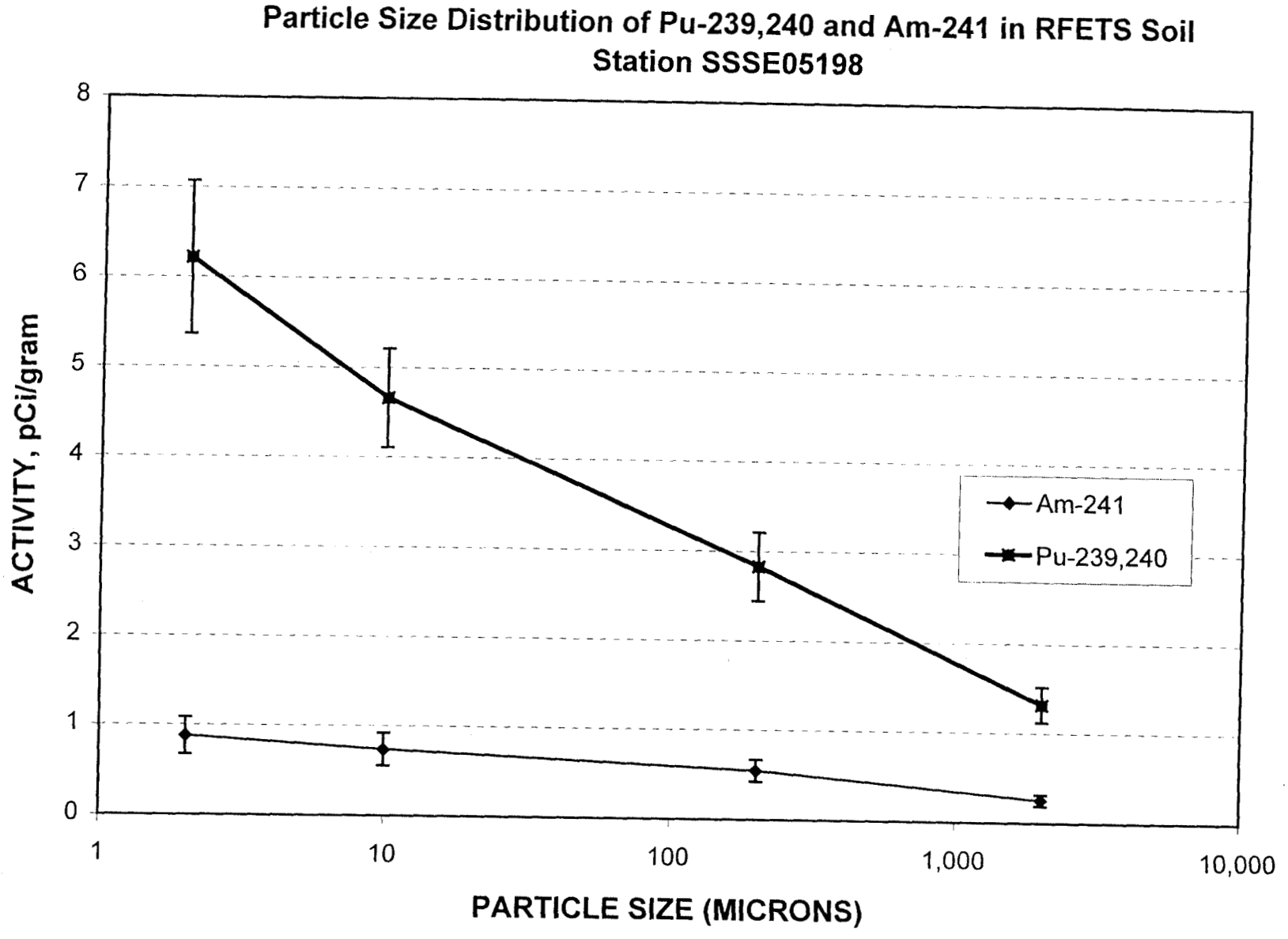
Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE01198

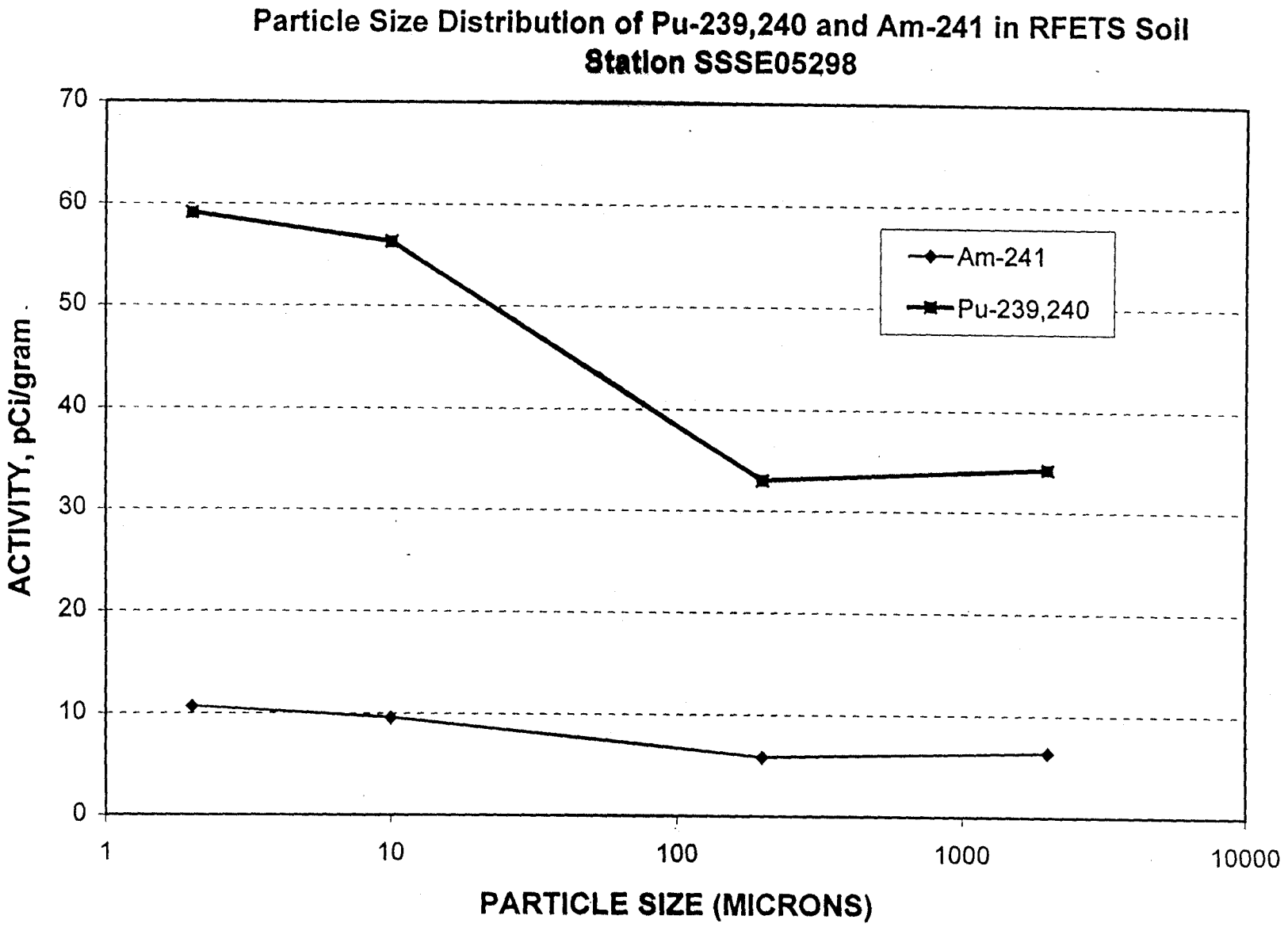


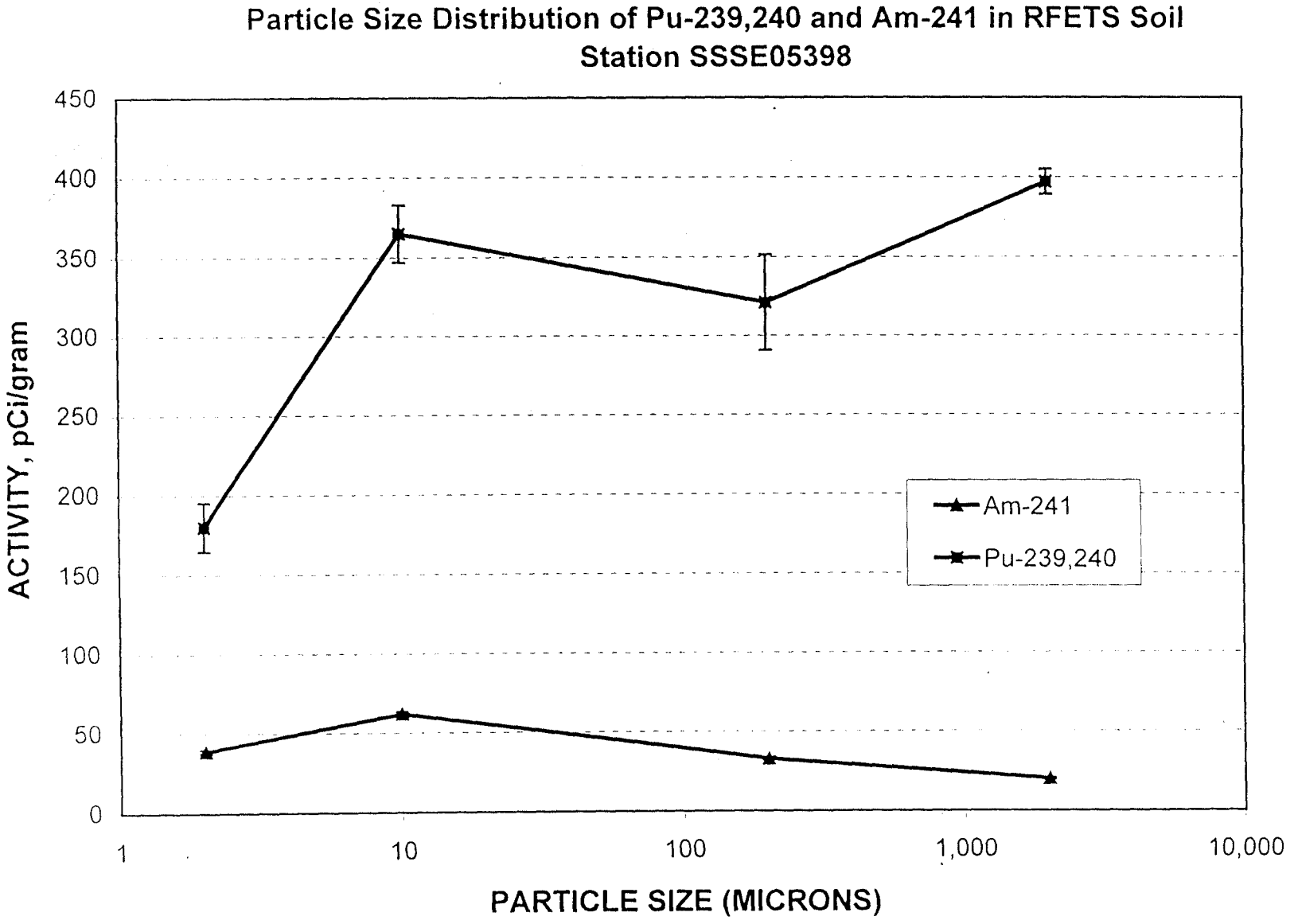

Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE01398
ACTIVITY, pCi/gram
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Am-241
Pu-239,240
Note: Minimum Detectable
Activity is 0.2 pCi/gram
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)

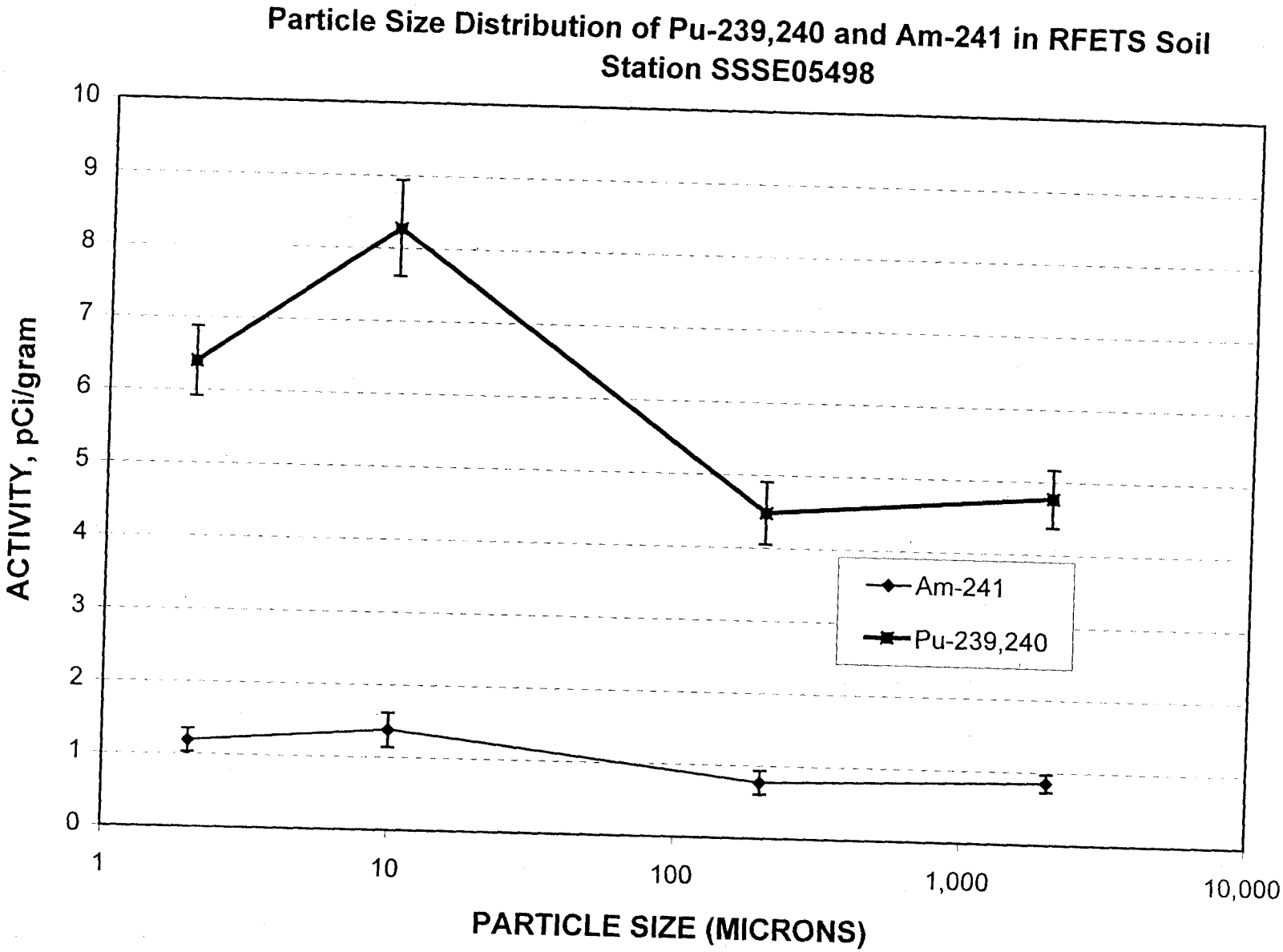

Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE01498
ACTIVITY, pCi/gram
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Am-241
Pu-239,240
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)

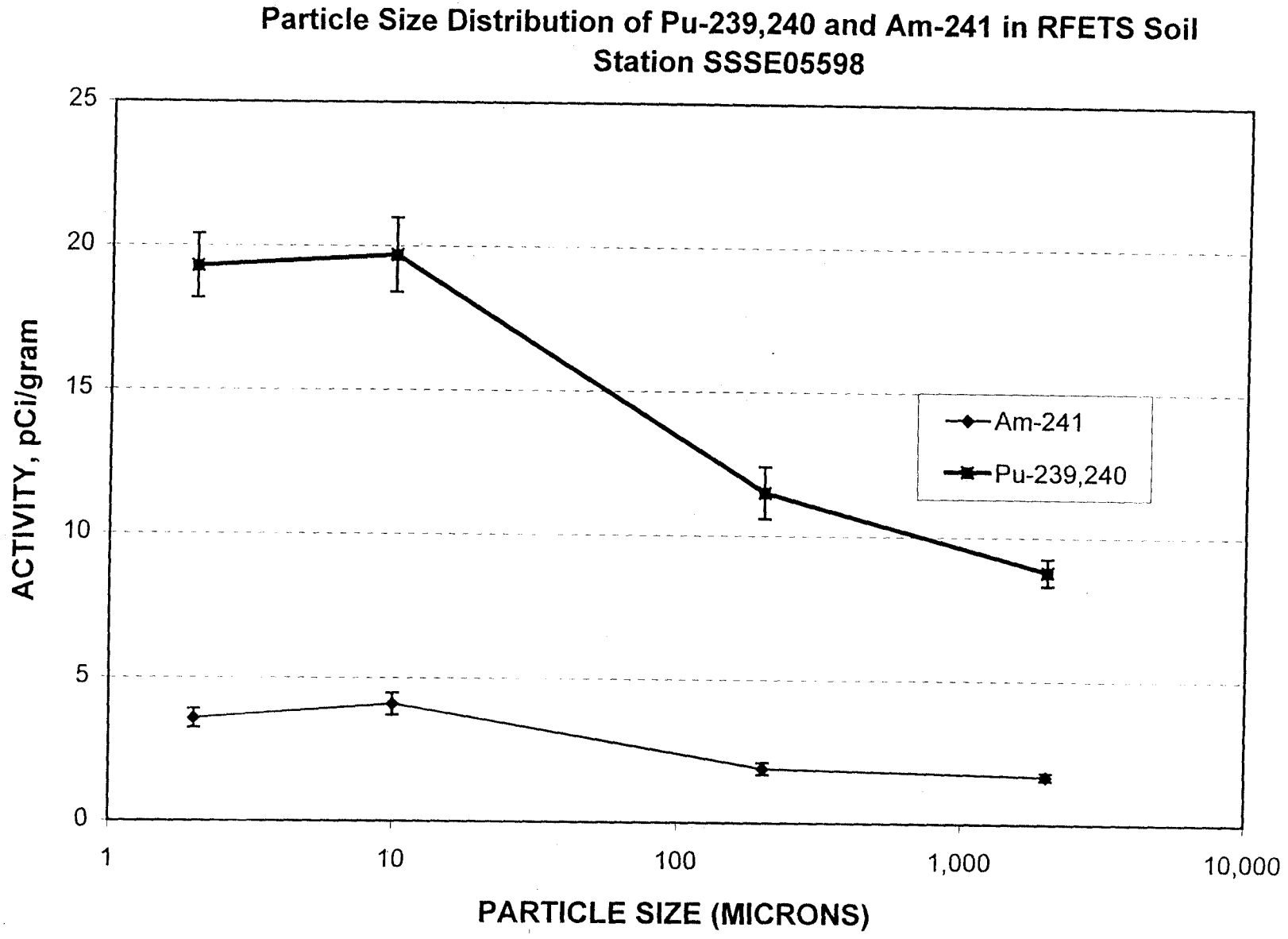

Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE02198
Note: Minimum Detectable
Activity is 0.2 pCi/gram
Am-241
Pu-239,240
ACTIVITY, pCi/gram
0.3
0.25
0.2
0.15
0.1
0.05
0
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)

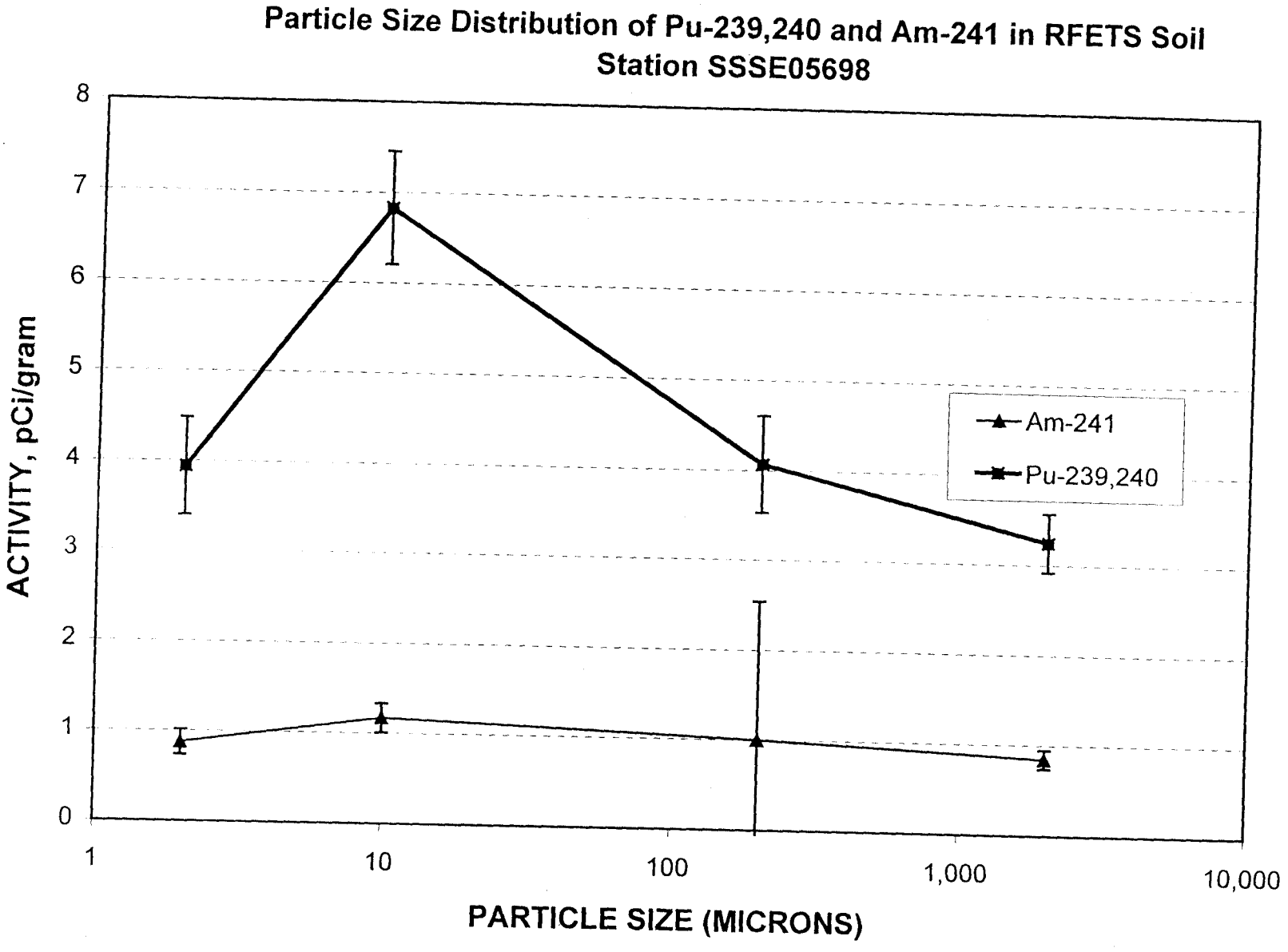

Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05198
ACTIVITY, pCi/gram
8
7
6
5
4
3
2
1
0
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)
Am-241
Pu-239,240


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05298
70
60
50
40
30
20
10
0
ACTIVITY, pCi/gram
Am-241
Pu-239,240
1
10
100
1000
10000
PARTICLE SIZE (MICRONS)


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05398
ACTIVITY, pCi/gram
450
400
350
300
250
200
150
100
50
0
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)
Am-241
Pu-239,240


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05498
ACTIVITY, pCi/gram
10
9
8
7
6
5
4
3
2
1
0
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)
Am-241
Pu-239,240


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05598
25
20
15
10
5
0
ACTIVITY, pCi/gram
Am-241
Pu-239,240
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)


Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05698
ACTIVITY, pCi/gram
0
1
2
3
4
5
6
7
8
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)
Am-241
Pu-239,240

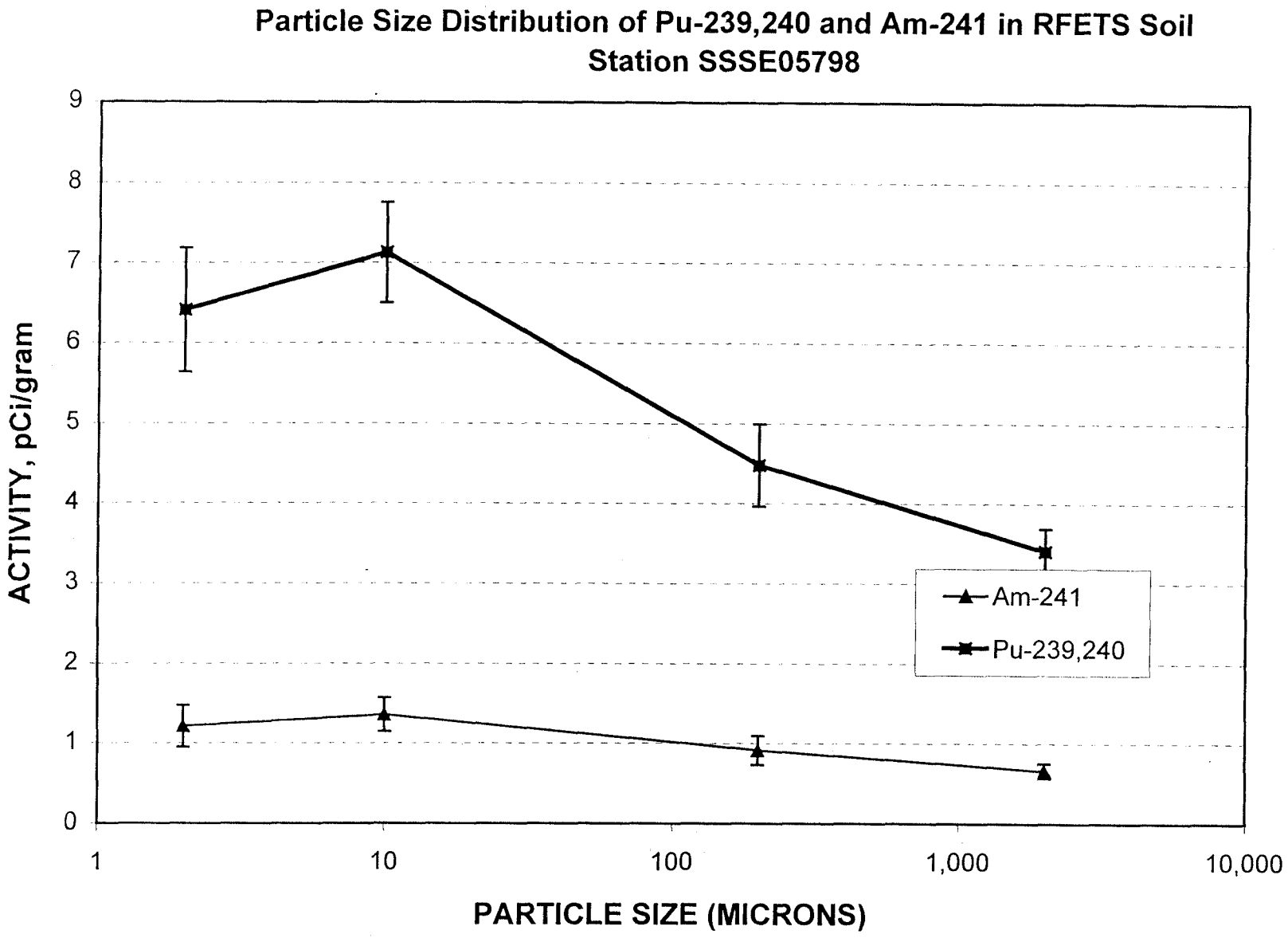
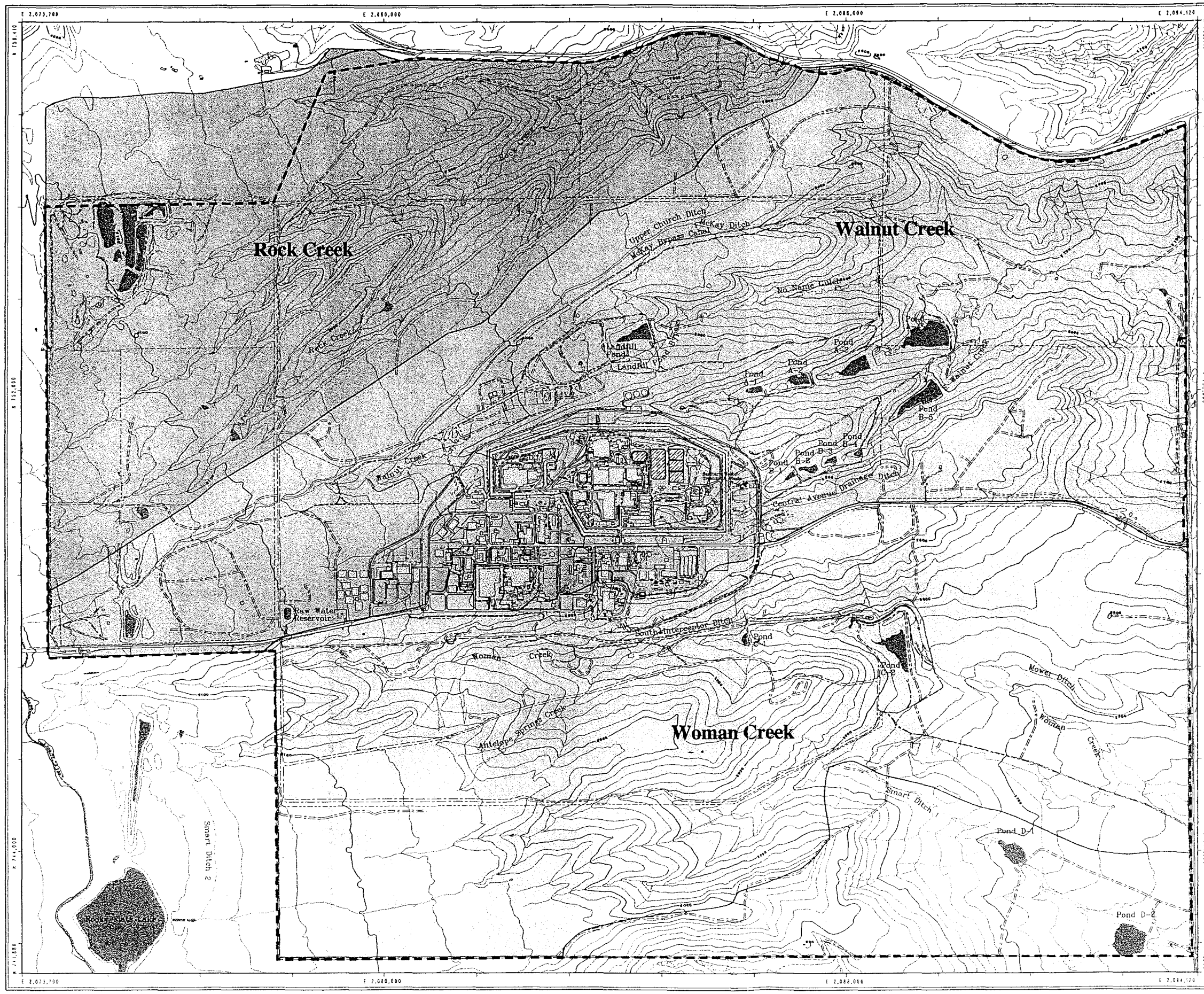

Particle Size Distribution of Pu-239,240 and Am-241 in RFETS Soil
Station SSSE05798
ACTIVITY, pCi/gram
0
1
2
3
4
5
6
7
8
9
1
10
100
1,000
10,000
PARTICLE SIZE (MICRONS)
Am-241
Pu-239,240

Figure 1

Major Drainage Basins at Rocky Flats



EXPLANATION

- Rock Creek
- Walnut Creek
- Woman Creek

Standard Map Features

- Buildings and other structures
- Solar evaporation ponds
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Contour (20-Foot)
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas.
Digitized from the orthophatographs. 1/95
Topology (contours) were derived from digital elevation model (DEM) data by Morrison Knudson (MK) using ESRI Arc TIN and LATTICE to process the DEM data to create 5-foot contours. The DEM data was capture by the Remote Sensing Lab, Las Vegas, NV, 1994 Aerial Flyover at ~ 10 meter resolution. The DEM post-processing performed by MK, Winter 1997.

Scale = 1 : 21330
1 inch represents approximately 1778 feet

500 0 1000 2000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by:

RMRS Rocky Mountain Remediation Services, L.L.C.
Geographic Information Systems Group
Rocky Flats Environmental Technology Site
P.O. Box 464
Golden, CO 80402-0464

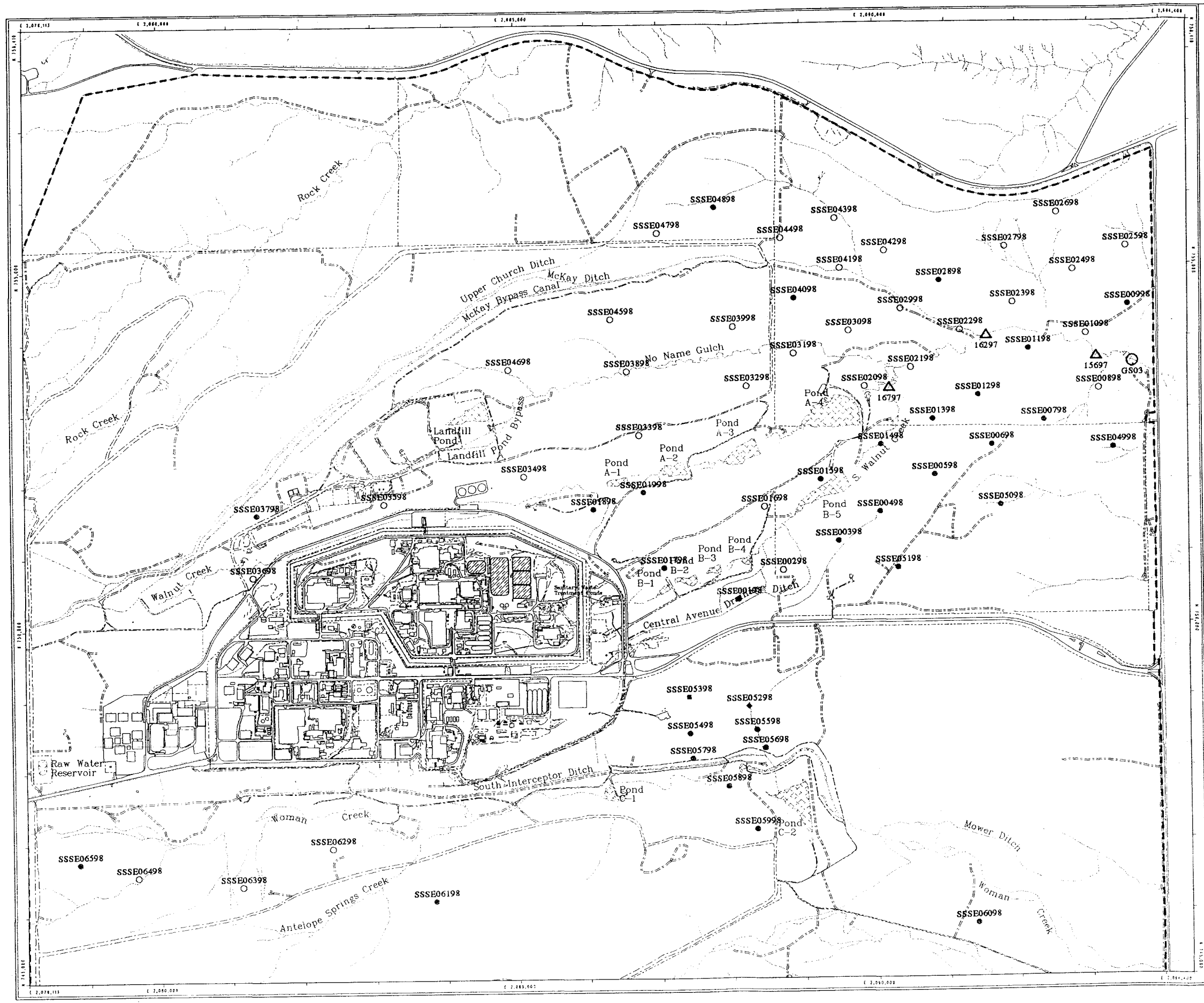
MAP ID: 98-0178

October 15, 1998

/gis2/projects/fy98/98-0178/rl-basins.aml

Figure 2

1998 Surface Soil Sampling Locations



LEGEND

- △ Soil sediment location
- ○ Gaging station

Pu-239,240 Activity in pCi/g

- ○ <= 0.1
- ● 0.1 - 10
- ◆ 10 - 100
- ■ 100 - 1000

Standard Map Features

- Buildings and other structures
- Solar evaporation ponds
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs. 1/96

Scale = 1 : 17200
1 inch represents approximately 1433 feet

600 0 1000 2000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

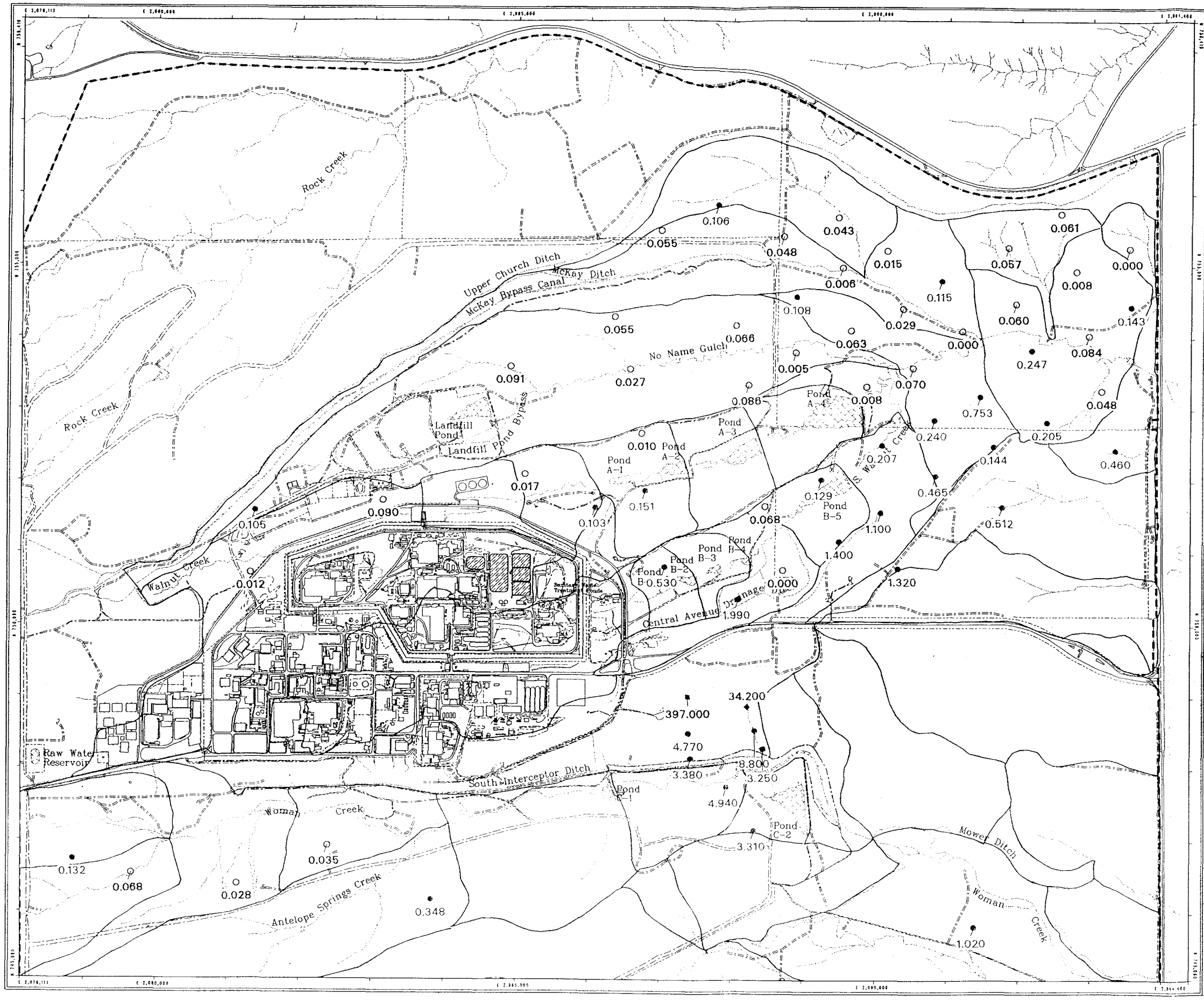
Prepared by:
RMRS Rocky Mountain Remediation Services, L.L.C.
Geographic Information Systems Group
Rocky Flats Environmental Technology Site
P.O. Box 464
Golden, CO 80402-0464

MAP ID: 98-0247 October 16, 1998

/gis2/projects/hy98/98-0247/ses-kirk/ses98-loc-map.aml

Figure 4

1998 Surface Soil Sampling Locations



Pu-239,240 Activity in pCi/g

- ○ < = 0.1
- ● 0.1 - 10
- ◆ 10 - 100
- ■ 100 - 1000

— Watershed Boundary

Standard Map Features

- Buildings and other structures
- Solar evaporation ponds
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fences and other barriers
- Rocky Flats boundary
- Paved roads
- Dirt roads

DATA SOURCE:
Buildings, fences, hydrography, roads and other structures from 1994 aerial fly-over data captured by EG&G RSL, Las Vegas. Digitized from the orthophotographs, 1/96

Scale = 1 : 17200
1 inch represents approximately 1433 feet

500 0 1000 2000ft

State Plane Coordinate Projection
Colorado Central Zone
Datum: NAD27

U.S. Department of Energy
Rocky Flats Environmental Technology Site

Prepared by:

RMRS Rocky Mountain Remediation Services, L.L.C.
Geographic Information Systems Group
Rocky Flats Environmental Technology Site
P.O. Box 464
Golden, CO 80402-0464

MAP ID: 98-0222 October 16, 1998

/gis2/projects/fy98/98-0222/fe98-map.aml