Field Test of the Rapid Transuranic Monitoring Laboratory

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ABSTRACT

A field test of the Rapid Transuranic Monitoring Laboratory (RTML) developed at the Idaho National Engineering Laboratory (INEL) was conducted as part of a demonstration sponsored by the Buried Waste Integrated Demonstration (BWID). The RTML is a mobile, field-deployable laboratory developed for use at buried radioactive waste remediation sites to allow onsite preparation and analysis of soil, smear, and air filter samples for alpha and gamma-emitting contaminants. Analytical instruments installed in the RTML include an extended range, germanium photon analysis spectrometer with an automatic sample changer, two large-area ionization chamber alpha spectrometers, and four alpha continuous air monitors. The performance of the RTML was tested at the Test Reactor Area and Cold Test Pit near the Radioactive Waste Management Complex at the INEL. Objectives, experimental procedures, and an evaluation of the performance of the RTML are presented.

SUMMARY

This report presents the results of a field test of the Rapid Transuranic Monitoring Laboratory (RTML) conducted at the Idaho National Engineering Laboratory (INEL) during the summer of 1993. The RTML is a mobile laboratory developed at the INEL for use in characterizing low-level radiological source terms at buried radioactive waste remediation sites. Analytical instruments installed in the RTML include a thin-window, germanium photon spectrometer equipped with an automatic sample changer, two large-area ionization chamber alpha spectrometers, and four alpha continuous air monitors (CAMs). The RTML was tested for the Buried Waste Integrated Demonstration (BWID) at the Test Reactor Area (TRA) and Cold Test Pit (CTP), which is adjacent to the INEL's Radioactive Waste Management Complex (RWMC). The CTP at the INEL was constructed to provide a nonradioactive and nonhazardous test bed for retrieval and other remedial action demonstrations. The pit measures approximately 150 ft long $\times$ 40 ft wide and is located in an old soil borrow area about 200 yards south of the RWMC boundary. This report presents an evaluation of the performance of the RTML during the field test.

Direct alpha spectrometry with a large-area ionization chamber and photon spectrometry with a high-resolution, n-type, extended range germanium spectrometer were shown to be rapid, sensitive methods for the measurement of transuranic isotopes on smears and in soil and dust samples. The two analysis techniques do not require elaborate sample preparation or time-consuming chemical separations; soil samples for the photon spectrometer are dried and sieved before analysis, and soil samples for the ionization chambers are dried, sieved, and ground in 30% ethanol before analysis. Smears and filters are analyzed directly without any sample preparation.

The RTML consists of two separate trailers that are powered from portable 30 and 50 kW diesel generators. One trailer, 2.4 m wide $\times$ 7.3 m long (8 $\times$ 24 ft), houses the sample preparation laboratory that is equipped with a Class A fume hood, a drying oven, sieving equipment, two analytical balances, and sample containers. Samples are received and prepared for analysis in this trailer. The second trailer, 2.4 m wide $\times$ 14.6 m long (8 $\times$ 48 ft), houses the germanium photon spectrometer, two ionization chamber alpha spectrometers, and a computer that controls operation and analyzes the spectral data acquired by the spectrometers. The computer is a VAX 4000 model 100 equipped with terminals and printers to display and generate the analysis results reports. The RTML is also equipped with four alpha CAMs that are operated remotely from the RTML analysis trailer. The alpha CAMs can be operated at distances up to 200 m from the trailer.

During June 1993 the RTML trailers were moved to a location adjacent to the CTP. Four alpha CAMs were installed inside the tent enclosing the CTP. Power for the trailers and alpha CAMs was supplied from three portable diesel or gasoline-fueled generators. Soil, smear, and air filter samples were collected from the pit, prepared for analysis in the sample preparation trailer, and analyzed using the RTML photon and alpha spectrometers. Air inside the tent enclosing the pit was monitored using the four RTML alpha CAMs. Before the field demonstration, 20 soil standards containing known activities of ^{239}Pu , ^{241}Am , ^{60}Co , and/or ^{137}Cs were prepared for the photon spectrometer and ionization chamber alpha spectrometers. The sample preparation procedures and containers used to make the standards were identical to those used to prepare soil samples collected from the CTP for analysis. During the field test, these prepared blind soil standards were randomly distributed among prepared CTP soil samples before delivery to the RTML analysis trailer.

The demonstration showed that powering the RTML with portable generators did not introduce noticeable electrical or microphonic noise. Spectral resolution, instrument background count rates, and lower limit of detection (LLD) concentrations for the analytical instruments remained the same as when the RTML was powered from plant power. Under field conditions, LLD concentrations for ^{239}Pu , ^{241}Am , ^{60}Co , and ^{137}Cs by x-ray/gamma-ray spectrometry, using a 15-minute count time, were confirmed to be 40, 1, 5, and 5 pCi/g, respectively. LLD concentrations for ^{239}Pu and ^{241}Am by large-area, ionization chamber alpha spectrometry were both 40 pCi/g for a 10-minute count.

Soil samples collected from the CTP were prepared for analysis by laboratory technicians who had no previous experience with the present sample preparation procedures. They were given demonstrations by the principal investigators and time to prepare a few samples to become familiar with the process. After this minimal training, they then prepared the actual samples used in the demonstration. The same individuals also became proficient in operating the photon and ionization chamber spectrometers after only 1 day of training.

Including quality control and blind soil standards, over 300 samples were analyzed by photon spectrometry, and 136 samples were analyzed by ionization chamber alpha spectrometry during the field test. Seventy-nine samples were analyzed during a 24-hour period with the photon spectrometer. In a 5-hour time period of continuous work, 33 prepared samples were analyzed with the two ionization chamber alpha spectrometers for an average rate of about 6 samples per hour. If we assume that this rate can be maintained for 7 hours during an 8-hour shift, the total number of samples that can be analyzed with the ionization chambers during an 8-hour shift is 42. Based on these sample throughput rates, which together equate to 121 samples being prepared and analyzed in 1 day, the cost to analyze one sample is about \$18.

All spectral analyses of the photon data were performed automatically with no input from the operator beyond basic sample parameters. No positive results were obtained for either the 143 CTP soil samples analyzed by photon spectrometry, or for the 96 CTP soil samples analyzed by ionization chamber alpha spectrometry. Each of the 96 analyses of the 20 blind soil standards performed by photon spectrometry identified and quantified one or more of the four radionuclides present in the standards. The concentration of ^{239}Pu was quantified by all photon spectrometry analyses but two, and the concentration of ^{241}Am was quantified in all cases by both x-ray and gamma-ray spectrometry. On the average, in the case of analyses performed with the photon analysis spectrometer, the concentration of ^{239}Pu was underestimated by 14% when no ^{241}Am was present and was underestimated by 18% when the standard contained ^{241}Am . Efforts to identify the sources of potential systematic errors are being actively pursued to remove this bias and reduce the total uncertainty (e.g., for ^{239}Pu activities of 500 Pci/g in soils, a total uncertainty of $\pm 5\%$ appears achievable). The XRAY program at times had difficulty accurately determining the ^{239}Pu component of the combined $^{239}\text{Pu}/^{241}\text{Am}$ x-ray peaks when the concentration of ^{241}Am was 50% or more of the concentration of ^{239}Pu .

Concentrations of ^{239}Pu measured by ionization chamber alpha spectrometry showed excellent agreement with the known values within the statistics of the measurements for 10-minute counts on 100-mg samples. Of the 40 measurements made on the blind soil standards, 33 measurements (83%) agreed with the known values within two standard deviations of the difference, and the remaining seven measurements were within three standard deviations. No analytical value was more than three

standard deviations away from the known. Samples not containing added alpha activity gave spectra that were equally clear and unequivocal.

The collimators installed on the alpha CAMs provided a significant benefit by improving spectral resolution and lowering the background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ region of interest (ROI). Full width half-maximum (FWHM) of the 6.00 MeV $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak for samplings performed in a laboratory at TRA ranged from 163 to 179 keV. FWHM of the 7.69 MeV ^{214}Po alpha peak ranged from 116 to 141 keV. The average background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI for samplings of ambient air performed in a laboratory setting were frequently below 0.2 cpm. Based on LLD concentrations previously reported for the Argonne National Laboratory-West alpha CAM, the LLD concentrations for the four RTML alpha CAMs are all less than 1 derived air concentration (DAC) (0.002 pCi/L) in 1 hour when airborne dust concentrations are below 0.01 $\mu\text{g/L}$.

Alpha CAM spectral resolution was poor, and background count rates were elevated during two air samplings performed at the CTP. This can be attributed to high concentrations of dust in the air within the tent that enclosed the CTP. The dust loading in the air within the tent was likely tens of micrograms per liter, or several thousand times higher than it was in the laboratory. If very high concentrations of airborne dust will be the rule rather than the exception during future buried waste remediation operations, serious consideration should be given to equipping the alpha CAMs with moving filters to ensure that good spectral resolution is maintained during air monitoring.

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ACRONYMS

ADC	Analog-to-digital converter
AIM	Acquisition interface module
ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory-West
BWID	Buried Waste Integrated Demonstration
CAM	Continuous air monitor
CCU	Contamination Control Unit
CTP	Cold Test Pit
DAC	Derived air concentration
DOE	U.S. Department of Energy
ERP	Environmental Restoration Program
FWHM	Full width half-maximum
FWTM	Full width tenth-maximum
FY	Fiscal year
INEL	Idaho National Engineering Laboratory
LLD	Lower limit of detection
MCA	Multichannel analyzer
PI	Principal investigator
PIPS	Passivated implanted planar silicon
ROI	Region of interest
RTML	Rapid Transuranic Monitoring Laboratory
RWMC	Radioactive Waste Management Complex
TRA	Test Reactor Area
TRU	Transuranic or transuranium

Field Test of the Rapid Transuranic Monitoring Laboratory

1. INTRODUCTION

This report presents the results of measurement systems field test installed in the Rapid Transuranic Monitoring Laboratory (RTML), a mobile laboratory developed at the Idaho National Engineering Laboratory (INEL) for use in characterizing low-level radiological source terms at buried radioactive waste remediation sites. RTML analytical instruments tested in the field include an extended range, germanium photon analysis spectrometer equipped with an automatic sample changer, two large-area, ionization chamber alpha spectrometers, and four alpha continuous air monitors (CAMs). Development of the RTML was sponsored by the Buried Waste Integrated Demonstration (BWID). BWID develops and demonstrates new technologies for remediating of buried waste at facilities throughout the U.S. Department of Energy (DOE) complex.

The technology of the first system involves the simultaneous measurement of L-shell x-rays and gamma-rays using a high-resolution, thin-window, coaxial germanium spectrometer. Plutonium isotopes that decay by alpha emission decay directly to isotopes of uranium. The photon spectrometer determines the presence of plutonium isotopes by counting the L-shell x-rays emitted from the uranium daughters following alpha decay of plutonium. It also simultaneously determines the presence of ^{241}Am and fission and activation product isotopes such as ^{60}Co and ^{137}Cs by counting the gamma-rays emitted during their decay. Soil samples are dried and then sieved to remove any particles larger than 300 μm . Eleven grams of sieved soil are loaded into an 8-mm high $\times$ 70-mm diameter, plastic sample container and counted with the sample container positioned near the face of the germanium detector end cap. Smears and air filters are taped to the center of the base of the same plastic sample container used to analyze soil samples and are counted directly using the same counting geometry.

The technology of the second system involves direct alpha spectrometry in a 34-cm diameter ionization chamber. The ionization chamber determines the presence of transuranic (TRU) isotopes by measuring the pulse height spectrum of alpha particles emitted from the sample. The concentration of a given TRU isotope is deduced from the count rate in the corresponding alpha peak in the collected alpha spectrum. Soil samples are dried, sieved, and finely ground. One hundred milligrams of the ground soil are suspended in an aqueous solution containing 30% ethanol that is sprayed uniformly onto a preheated 25.4-cm diameter stainless steel pan. The pan is reheated to evaporate any residual moisture, and following cooling to room temperature, is positioned in a recess in the bottom of the ionization chamber for counting. Air dusts are collected with a high-volume air sampler on 20 $\times$ 25-cm (8 $\times$ 10-in.) membrane filters with 1.0- μm pores. In the case of air filters, no sample preparation is required before counting in the ionization chamber. A milled cutout in the sample plate is used to position the air filter reproducibly inside the ionization chamber for counting.

The technology of the third system involves the direct measurement of alpha activity in air by pulse-height analysis of the alpha activity removed from air that is sampled. The measurement of airborne alpha-emitting radionuclides attached to particulate aerosols is performed by pulling a

continuous sample of ambient air through a two-stage inertial impactor and then through a filter having a pore size small enough to trap aerosolized particles. The impactor removes a large fraction of the naturally occurring radon daughter isotopes from the airstream before it passes through the sample filter. The alpha-emitting radionuclides are attached to the aerosol particles that are trapped by the filter. Alpha activity on the filter is measured by a solid-state silicon detector positioned about 7 mm from the influent face of the filter. The silicon detector is equipped with a 4-mm thick grid-type collimator to enhance spectral resolution.

During June 1993, the RTML was tested at the Test Reactor Area (TRA) and Cold Test Pit (CTP), which is located outside the boundary of the Radioactive Waste Management Complex (RWMC) at the INEL. The test was conducted in accordance with a test plan¹ that defined the test objectives and requirements for data quality. The four alpha CAMs were installed inside the tent enclosing the CTP. Power for the RTML sample preparation and analysis trailers and alpha CAMs was supplied from three portable diesel or gasoline-fueled generators. Soil, smear, and air filter samples were collected from the pit, prepared for analysis in the sample preparation trailer, and analyzed using the RTML photon and alpha spectrometers. Air inside the tent enclosing the pit was monitored using the four RTML alpha CAMs. Before the demonstration, 20 soil standards containing known activities of ²³⁹Pu, ²⁴¹Am, ⁶⁰Co, and/or ¹³⁷Cs were prepared for both the photon analysis spectrometer and ionization chamber alpha spectrometers. The sample preparation procedures and containers used to make the soil standards were identical to those used during the demonstration to prepare samples of soil collected from the CTP. During the field test, these soil standards were randomly distributed among prepared CTP soil samples before their delivery to the RTML analysis trailer.

Background information regarding the development of the RTML is presented in Section 2. The basic configuration of the RTML and analytical instruments installed in the RTML are described in Section 3. Objectives of the field test and experimental procedures used during the test are described in Sections 4 and 5. Experimental results for the three RTML measurement systems and estimates of operating costs and waste generation are discussed in Section 6. Conclusions and recommendations for future work are presented in Sections 7 and 8.

2. BACKGROUND

From fiscal year (FY) 1990 through FY-92 a number of promising measurement methods and systems were evaluated for possible use in monitoring low-level TRU concentrations in ambient air and in soil, smear, and dust samples collected during remediation of buried radioactive waste.^{2,3,4} The sensitivities of five different alpha CAMs for detection of airborne ^{239}Pu were determined experimentally.^{5,6,7,8,9} The following six methods^{7,10,11,12,13} of making quantitative measurements of TRU contamination on smears and in soil and dust samples were also evaluated experimentally: (a) alpha liquid scintillation spectrometry, (b) rapid radiochemical separation followed by high-resolution alpha spectrometry, (c) gamma-ray spectrometry, (d) x-ray/gamma-ray spectrometry, (e) direct alpha spectrometry using a large-area ionization chamber, and (f) gross alpha counting using a scintillation detector.

These evaluations demonstrated that the alpha CAM developed at Argonne National Laboratory (ANL) during the 1970s, which employs a virtual impactor and is currently in use at Argonne National Laboratory-West (ANL-W), had a sensitivity for airborne ^{239}Pu that was 10 to 20 times better than the sensitivities of the four commercial alpha CAMs that were also tested. Six of the ANL-type alpha CAM inertial impactor assemblies were fabricated during FY-92 according to engineering drawings obtained from ANL, and four of the impactor assemblies were used to construct four alpha CAMs during FY-92. Direct alpha spectrometry with a large-area ionization chamber and photon spectrometry with a high-resolution, thin-window germanium spectrometer were shown to be rapid, sensitive methods for the measurement of TRU isotopes on smears and in soil and dust samples. The two analysis techniques do not require elaborate and time-consuming chemical separations; soil samples for the photon spectrometer are dried and sieved before analysis, while soil samples for the ionization chambers are dried, sieved, and ground in an aqueous solution containing 30% ethanol before analysis. Smears and filters are analyzed directly without any sample pretreatment.

During spring 1993, a tractor trailer that had been previously used for a DOE environmental survey program was remodeled to serve as the RTML analysis laboratory. Two large-area, ionization chamber alpha spectrometers, a thin-window germanium photon spectrometer with an automatic sample changer, a VAX 4000 model 100 computer, four computer terminals with monitors, and a laser printer were installed in the trailer during March and April 1993. The four alpha CAMs fabricated during FY-92 were integrated into the RTML at the same time. Software that was written during FY-92 to operate the three measurement systems and display, analyze, and archive measured alpha and photon spectral data was installed on the VAX 4000 during March 1993. A sample preparation trailer equipped with a Class A fume hood was procured in June 1993. During June 1993, the RTML was tested at TRA, while power to the two trailers was supplied from portable generators. Soil samples that had been collected from the CTP before the start of the test were analyzed during the initial test conducted at TRA. The RTML sample preparation and analysis trailers and four alpha CAMs were then moved to a location adjacent to the CTP at the RWMC and field tested during June 1993 in conjunction with BWID's remote retrieval demonstration. As was previously mentioned, the tests were conducted in accordance with a test plan that defined test objectives and requirements for data quality. Draft operating procedures¹⁴ for the RTML, which were written before the field test, were updated following the completion of the test and published in October 1993.

3. DESCRIPTION OF RTML

3.1 Configuration

The RTML is equipped with apparatus and equipment to prepare soil, smear, and air filter samples for analysis and analyze these types of samples for low-level concentrations of alpha and gamma-emitting radionuclides. It is also equipped with four alpha CAMs that continuously monitor air for alpha-emitting TRU isotopes at locations up to 200 m from the RTML. Soil samples are not pretreated chemically before analysis but are simply dried and sieved before they are analyzed using spectrometric methods. Smear and air filter samples require no pretreatment.

The RTML consists of two separate mobile trailers and three portable electric generators. One trailer, 2.4 m wide $\times$ 7.3 m long (8 $\times$ 24 ft), houses the sample preparation laboratory that is equipped with a Class A fume hood, fume hood, high efficiency particulate air (HEPA) filter; gravity-flow drying oven; sieving equipment; analytical balances; compressed air cylinders; hotplates; and a supply of sample planchets and containers. Samples are received and prepared for analysis in this trailer. Power to the sample preparation trailer is supplied from a 50 kW or larger generator. The second trailer, 2.4 m wide $\times$ 14.6 m long (8 $\times$ 48 ft), houses the analytical instruments and computer used to acquire, analyze, and archive photon and alpha spectra from soil, smear, and air filter samples. The latter trailer also houses the computer terminal used to remotely control the operation of the four field-deployable alpha CAMs. Power to the analysis trailer is supplied from a generator rated at 30 kW or more, and power to the alpha CAMs is supplied from a 5 kW or larger generator.

A photograph of the two RTML trailers taken when the trailers were deployed at the CTP at the RWMC is shown in Figure 1. The analysis trailer is to the left in the background, and the sample preparation trailer is to the right in the foreground. The assembly that holds the fume hood HEPA filter and auxiliary and exhaust air fans is shown installed on the roof of the sample preparation trailer. This assembly is removed and stored inside the trailer before moving the trailer. The power cord for the sample preparation trailer and the two power cords for the analysis trailer are shown plugged into their respective receptacles on the two trailers. Figure 1 also shows three propane tanks mounted on the front of the sample preparation trailer that are used to heat the trailer.

To facilitate analyzing samples as quickly as possible after their collection, the RTML analysis trailer is equipped with an n-type, extended range, germanium photon spectrometer installed in an automatic sample changer; two large-area ionization chamber alpha spectrometers; a VAX 4000 model 100 computer; four computer terminals with monitors; and a laser printer. One of the four computer terminals in the analysis trailer controls operation of the four field-deployable alpha CAMs used to monitor airborne TRU concentrations. A block diagram of the alpha CAM system and instrumentation installed in the RTML analysis trailer is shown in Figure 2. All three measurement systems are controlled from the VAX 4000 computer by thin-wire Ethernet coaxial cables that link the VAX to the acquisition interface module (AIM) installed in each system. Photon and alpha spectral data are transmitted to the VAX over the same Ethernet cables. The photon spectrometer sample changer is controlled by the VAX computer through a personal computer.

Figure 1. RTML sample preparation and analysis trailers.

Figure 2. Block diagram of RTML electronics.

As shown in Figure 2, the alpha CAM system consists of four sampling cabinets and two electronics cabinets. Each electronics cabinet is equipped with one AIM and services two of the alpha CAM sampling cabinets.

3.2 Analytical Instruments

3.2.1 Photon Analysis Spectrometer

Plutonium isotopes that decay by alpha emission (i.e., ^{236}Pu , ^{238}Pu , ^{239}Pu , ^{240}Pu , and ^{242}Pu) decay directly to isotopes of uranium. The photon analysis spectrometer^{7,10,12} determines the presence of plutonium in soils, smears, and filters by counting the L-shell x-rays emitted from the uranium daughters following alpha decay of plutonium radioisotopes. It also simultaneously determines the presence of gamma-ray-emitting radionuclides such as ^{60}Co , ^{137}Cs , and ^{241}Am . The technique involves accumulating both x-rays and gamma-rays in one spectrum and analyzing the two energy regions of the spectrum simultaneously using two different spectrum analysis methods.

A photograph of the photon analysis spectrometer and sample changer is shown in Figure 3. (The spectrometer is shown outside the sample changer in Figure 3. During normal operation, the spectrometer is installed inside the steel shield, which is an integral part of the sample changer). The spectrometer consists of a 60-mm diameter, n-type, extended range germanium detector capable of efficiently measuring x-rays and gamma-rays. The gain is chosen to cover energies from about 10 to about 1,380 keV with an 8,192-channel analyzer. Under these conditions, the germanium spectrometer can simultaneously measure the presence of plutonium, ^{241}Am , and radioisotopes that emit gamma-rays having energies below 1,380 keV (e.g., ^{60}Co and ^{137}Cs). The detector is equipped with a 30-L liquid nitrogen dewar, dual energy pulser,¹⁵ and automatic sample changer capable of processing 100 samples without the need for operator intervention. The pulser injects pulses into the test input of the resistive feedback preamplifier. These pulses are processed through the preamplifier, linear amplifier, and analog-to-digital converter (ADC) in the same way that photon pulses are processed except that before storage, the pulser pulses are digitally incremented by a fixed number of channels after being converted to digital format so that pulser pulses are separated from photon pulses in the multichannel analyzer (MCA) spectrum. The pulser data are stored in each spectrum and subsequently are used during spectrum analysis to determine the energy calibration of the spectrum, the coefficients of the peak-width function, and dead time during spectrum accumulation.

The photon spectrum consists of a low-energy region (<30 keV) composed primarily of x-rays and a higher-energy region (30 to 1,380 keV) composed of gamma-rays. The x-ray portion of each spectrum is analyzed by a linear least-squares spectral fitting technique originally developed for the analysis of spectra from NaI(Tl) detectors. The x-ray spectrum analysis code, LXRAY,¹⁶ was designed and written for use with the photon spectrometer. The gamma-ray portion of each spectrum is analyzed using VAXGAP,^{17,18} which is the gamma-ray spectrum analysis code that has been in routine use at the INEL for a number of years. The integration of LXRAY as a subroutine of VAXGAP has been completed, but the analysis results from these two programs are not combined yet.

The calibration needed to determine the L-shell x-ray emission rates of actinides is performed measuring the x-ray spectra of actinide standards. In each case, the standards are analyzed using

Figure 3. Photon analysis spectrometer and sample changer.

count times sufficiently long to obtain good statistical precision for each x-ray peak. For plutonium, it is performed by counting a plutonium standard free of ^{241}Am and other radioisotopes. The isotopic composition of this plutonium standard should be high-purity ^{239}Pu or, preferably, should closely represent the plutonium isotopic ratios anticipated in the unknown samples to be analyzed. For the purpose of this demonstration, high-purity ^{239}Pu was used and ^{239}Pu equivalent activity is reported in all cases. In addition to obtaining a high quality spectrum of plutonium, spectra are also obtained of a ^{241}Am standard and a blank. These spectra are standardized to 10^5 disintegrations and are the measured "response" spectra used in the linear least-squares fit of the L-shell x-ray region. Functionally, the linear least-squares fit provides a normalization factor by which to scale each standard component to yield the sample activity for the associated radionuclide.

The calibration for measuring the gamma-ray emission rates of fission and activation product radionuclides is performed by measuring the full-energy peak efficiency of the detector with two different standards, one containing only ^{241}Am and a second containing ^{54}Mn , ^{57}Co , ^{60}Co , ^{65}Zn , ^{88}Y , ^{109}Cd , ^{113}Sn , ^{139}Ce , ^{137}Cs , and ^{203}Hg . The gamma-rays emitted from ^{60}Co and ^{88}Y are in cascade coincidence. A coincidence summing correction for ^{60}Co was deduced from the counting efficiency data and was applied to ^{60}Co concentrations measured in the blind soil standards analyzed during the field test. Coincidence summing corrections for other radioisotopes having coincident gamma-rays will be calculated and applied as required next fiscal year.

3.2.2 Large-Area Ionization Chamber Alpha Spectrometers

Two gridded ionization chambers similar to those built by others^{19,20,21,22} were procured from Ordela, Inc., Oak Ridge, Tennessee. The two ionization chambers, models 8200A and 8210A, were constructed of nickel-plated mild steel about 10 mm thick to permit pressurization of the chambers to 100 kPa above atmospheric pressure. A photograph of the large-area ionization, chamber alpha spectrometers is shown in Figure 4.

The original 8210A was shorter internally than the 8200A, and the electrodes were closer together in anticipation of pressurizing the system. No operating conditions could be found for the 8210A that produced a spectral resolution as good as that obtained with the 8200A. Consequently, the 8210A was modified to have the same interelectrode distances as the 8200A and was made even taller to reduce the capacitance between the anode and top plate. This modification, used in the present work, was 34 cm in inside diameter and 25.8 cm in height with a volume of 23.4 L. The internal distances from the grid were 12.8 cm to the sample cathode at the bottom of the chamber, 3.2 cm to the collecting anode above the grid, and 13.0 cm to the top plate. The bias voltage on the anode was 2.75 kV with a voltage divider applying 45.5% of this voltage to the grid. A highly-filtered preamplifier, specially selected for its low noise and high resolution, was mounted on top of the chamber. The power supplies, amplifiers, ADCs, AIM, and printer for alpha spectrometry were all obtained commercially and were used with a VAX computer through a remote terminal. A marked improvement in spectral resolution was obtained by keeping the bias supply and amplifier in a separate NIM bin from the ADC and AIM. The 8200A chamber used was virtually identical internally to the final 8210A except that the distance from the anode to the top plate was a little shorter, which produced slightly higher capacitance and different operating characteristics.

A pressure-relief valve opening at about 120 kPa and a combination vacuum-pressure gauge that reads from -100 to +200 kPa were placed in the top wall of each chamber. The sample holders were

Figure 4. Large-area ionization chamber alpha spectrometers.

held in a reproducible geometry inside the chambers by fixed guides and had milled cutouts to hold both 25.4-cm circular pans and 20 × 25-cm rectangular filters. The sample pans were spun from 0.86-mm thick stainless steel sheets, and each pan had an inside diameter of 25.4 cm, a height of 3 mm, and an area of 507 cm². The 20 × 25-cm filters were held flat by a steel hold-down plate of the same outside dimensions with an opening 18 × 23 cm to match the effective filtration area of the high-volume sampler. The samples were placed into the chambers through a sealable access port.

The counting gas was P-10 (90% Ar and 10% CH₄) and was used without further purification from a commercial cylinder through a two-stage regulator. After leaving the regulator, the P-10 gas passed consecutively through a small gas shut-off valve to control the flow, through a 0.45-μm filter disk to remove any particulate material present, and then into the ionization chamber through one side of a three-way valve.

The vacuum/vent line for evacuating or venting the pressurized ionization chamber consisted of a piece of 9.5-mm (3/8-in.) copper tubing from the other side of the three-way valve from the ionization chamber consecutively through an in-line HEPA filter to remove possible radioactive contaminants, an absolute pressure gauge (Wallace and Tiernan, Belleville, New Jersey, model 61D-1D-0050) and then into the common side of a 9.5-mm (3/8-in.) three-way valve. One side of the valve was vented to the atmosphere. The other side was connected to a high-capacity vacuum pump (Leybold Vacuum Products, Albuquerque, New Mexico, type D-4-A) through a piece of 12.7-mm (1/2-in.) inside diameter, heavy-wall pressure tubing. The vacuum line was kept as short as possible to minimize pumping time. All components of the system were duplicated, including pumps, gauges, valves, filters, and tanks, to permit the two ionization chambers to be operated independently at all times, which maximized sample throughput.

3.2.3 Alpha Continuous Air Monitors

The presence of naturally occurring alpha-emitting isotopes in the environment complicates the measurement of airborne TRU isotopes. These background isotopes, which are present throughout the earth's crust, are products of three natural radioactive decay chains—the ²³⁸U, ²³²Th, and ²³⁵U series. All three of these radioactive decay chains yield isotopes of radon, which is a noble gas that may escape from the ground to the surrounding air. Radon decays to isotopes of polonium, lead, and bismuth and become attached to aerosols that are trapped by the alpha CAM sample collection filter. Alpha particles emitted by ²¹⁸Po, ²¹²Bi, ²¹⁴Po, and ²¹²Po have energies of 6.00, 6.06, 7.69, and 8.78 MeV, respectively. When degraded in energy as a result of interactions with the filter medium and overlaying dust, these alpha particles contribute a continuum of counts to the spectrum in the energy region of the ²³⁹Pu and ²⁴¹Am alpha peaks, which have energies of 5.15 and 5.48 MeV, respectively.

Mechanistic approaches have been developed for alpha CAMs to mitigate the effect of natural background alpha radiation. One such approach to reducing natural alpha background relies on separating the radon and thoron daughters, which are the main contributors to background alpha activity, from the TRU-bearing aerosols in the sample airstream by using an impactor. Wilkening²³ showed that radon and thoron daughters are primarily associated with dust particles having diameters smaller than 0.035 μm. Elder, et al.²⁴ reported that fabricating plants produced relatively large plutonium particles, with 90% of activity median aerodynamic diameters (AMADs) in the range 1 to 5 μm and over 50% of the total activity associated with particles in this same size range. They also

reported that a plutonium recovery plant produced very small plutonium aerosols, with the size range under 1 μm containing over 70% of the total activity. Whicker, et al.²⁵ reported that AMADs of plutonium aerosols in room air in laboratories at a Los Alamos National Laboratory plutonium facility ranged from 2.5 to 9.0 μm .

The RTML alpha CAMs, which were designed after the ANL alpha CAM,^{26,a} are each equipped with a two-stage virtual impactor to remove radon progeny and concentrate airborne TRU-bearing particulates. Air, which is sampled at the relatively high rate of 280 L/min (10 ft³/min), is drawn through a circular array of inlet jets and is directed towards a complementary array of receiving tubes. A major portion of the air leaving the jets (200 L/min) is drawn off laterally before the airstream enters the receiving tubes. Small particles entering the inlet jets follow the lateral flow of air and do not enter the receiving tubes. Large particles not able to follow the lateral airflow enter the receiving tubes. This arrangement is repeated in a second stage in the impactor, with the lateral flow in this stage being about 60 L/min. In principle, the major (260 L/min) airflow exhausted from the impactor contains the vast majority of the radon and thoron daughters that were present in the sample airstream and the minor (20 L/min) airflow exiting the second set of receiving tubes contains most of the TRU-bearing particulates that entered the impactor. Yule²⁶ measured the filter particle collection efficiency of the ANL impactor and showed that it was above 80% for particles with aerodynamic diameters between 2 and 8 μm . The cut-point (i.e., point at which the particle collection efficiency is 50%) of the impactor corresponds to an aerodynamic diameter of about 1.5 μm , which is equal to a geometric diameter of 0.4 μm for a PuO₂ particle.

This minor airflow exiting the second stage of the impactor is directed to a sample collection filter spaced about 7 mm from a 900-mm² passivated, implanted planar silicon (PIPS) detector. The sample collection filters used during the field test were 47-mm diameter Millipore Fluoropore filters with either 1.0 or 3.0 μm pores. To restrict the area over which aerosols were deposited on the sample collection filter to an area slightly smaller than the area of the detector face, metal filter hold-down rings were fabricated and positioned over the influent face of the filter during sampling. The diameter of the opening in each ring was 33 mm, about 0.9 mm less than the diameter of the detector face. Each ring was 0.28 mm thick and had an outside diameter of 48 mm.

CAMs 1 and 2 were each equipped with a Canberra Nuclear Products Group model CAM 900AM silicon detector, and CAMs 3 and 4 were each equipped with a Canberra, model PD900-27-100AM silicon detector. The former model is a special version of the latter model. The CAM 900AM PIPS detector has a 0.5- μm thick aluminum coating on the front surface to make the detector light-tight and also has a 1.0 μm -thick varnish coating to make the detector more resistant to abrasion. Because the model PD 9000-27-100AM detector lacks these coatings, it inherently has better alpha resolution than the model CAM detector.

Alpha particle collimators were fabricated from mild steel and installed on all four detectors. The collimators were each 4 mm thick and 35 mm in diameter and had 5.1-mm square openings on the side that were arranged in a grid pattern. Each collimator was held in position and electrically isolated from the detector by means of a lucite collar that was bonded to the perimeter of the lower face of the detector body using adhesive. The collimators were installed to enhance spectral

a. J. M. Larson and D. L. Hall, "ZPPR Plutonium Monitor," ZPR-I Memo No. 389, February 1976.

resolution. They improve resolution by preventing alpha particles emitted from the sample collection filter at oblique angles from reaching the detector. The collimators restricted the maximum alpha particle path length to about twice the perpendicular distance between the sample collection filter and the face of the detector.

Each RTML alpha CAM consists of an ANL-type two-stage inertial impactor, two air sampling pumps, two mass flow sensors, 900-mm² silicon detector, detector bias supply, preamplifier, linear amplifier, ADC, multiplexer, and AIM. The inertial impactor, silicon detector, preamplifier, air sampling pumps, and mass flow sensors are housed in one cabinet and the detector bias supply, linear amplifier, ADC, multiplexer, and AIM are housed in a separate electronics cabinet. The electronics for two CAMs are housed in one electronics cabinet. A photograph of the alpha CAM sampling and electronics cabinets is shown in Figure 5. For each CAM, the major and minor air flows through the inertial impactor are continuously monitored using two mass flow sensors (Sierra Instruments, Inc., Accu-Mass Flow Meter model 730-12V and McMillan Co., Flo-Sensor model 100-11). The voltage output of each mass flow sensor is input into a multiplexer that is stored with the spectral data in the AIM memory. Both flow rates are displayed and routinely updated in the corresponding spectrum display window on the alpha CAM X-terminal monitor located inside the RTML analysis trailer. Because the preamplifiers are temperature sensitive and outside temperatures vary diurnally, the upper half of each CAM sampling cabinet is insulated and equipped with a heater/air conditioner to keep the temperature inside the cabinet constant. Each electronics cabinet is insulated and equipped with an air conditioner to compensate for the heat generated by the electronics modules.

Figure 5. Alpha CAM sampling and electronics cabinets.

4. TEST OBJECTIVES

The field test of the RTML was conducted in accordance with a test plan¹ that defined test objectives and requirements for data quality. During the test, ambient air, soil, and deposited dust from the CTP were sampled and analyzed for alpha and gamma-emitting radionuclides using the RTML. The primary objective of the RTML field test was to demonstrate and evaluate the capability of the RTML to analyze soil, smear, and air filter samples for low-level concentrations of TRU isotopes (e.g., ²³⁹Pu, ²⁴¹Am) and long-lived gamma-emitting fission and activation products (e.g., ⁶⁰Co, ¹³⁷Cs). Before the demonstration, soil standards were prepared at TRA that contained both quantifiable amounts of activity and amounts near the detection limits claimed for the photon and ionization chamber alpha spectrometers. The standard soils were deposited on steel pans and placed in plastic sample containers identical to those used during the field test. During the field test, these previously prepared soil standards were randomly distributed among prepared CTP soil samples before they were delivered to the RTML analysis trailer.

Specific objectives of the test included

1. Evaluating the performance and reliability of analytical instrumentation installed in the RTML under field conditions when power is supplied from a portable generator.
2. Validating the lower limit of detection (LLD) concentrations for ²³⁹Pu, ²⁴¹Am, ⁶⁰Co, and ¹³⁷Cs and determining the precision and accuracy achieved with minimal counting times. (The count times selected for the photon and ionization chamber alpha spectrometers were 15 and 10 minutes, respectively).
3. Determining the practical sample throughput rates for the photon and ionization chamber alpha spectrometers.
4. Determining the cost of operating the RTML.

The RTML was only one of seven technologies that were demonstrated at the CTP during the summer of 1993. The overall BWID test objectives for the field tests conducted during 1993 are described in detail in *Buried Waste Integrated Demonstration Test Objectives*.²⁷

5. EXPERIMENTAL PROCEDURES

5.1 Logistics and Setup

The RTML sample preparation trailer is equipped with a lockable 2 5/16-in. towing coupler. The sample preparation trailer was towed to the CTP using a 3/4-ton pickup truck. The trailer was parked at a location near the CTP, timbers were placed under the four stabilizer jacks, and the jacks were lowered until the trailer was level. During transport, the HEPA filter assembly for the Class A fume hood is normally stored inside the sample preparation trailer and secured to the floor of the trailer. However, in this case, the HEPA filter assembly was moved to the CTP on a flatbed truck. After the sample preparation trailer was leveled and chocks were placed at the front and rear of the tires, a forklift was used to raise the HEPA filter assembly to the roof of the trailer, and the assembly was secured to the roof following procedures described in Reference 14.

Because an air conditioning unit is mounted on the front of the RTML analysis trailer, the tractor required to move the trailer must have an extended bed to provide sufficient room between the air conditioner and cab of the tractor. The RTML analysis trailer was hauled to the CTP using such a tractor. Delicate equipment such as the VAX computer, computer terminals, monitors, and germanium photon spectrometer were removed from the trailer and transported to the CTP in a van to minimize the possibility of damaging them during transit. The two large-area ionization chambers were placed on foam pads on the floor of the trailer, and the components of the photon spectrometer shield were spread out over the floor of the trailer before transportation. Because of their size and number, the six alpha CAM cabinets were transported separately in a truck with an enclosed bed. The six CAM cabinets were banded to pallets to provide stability during transportation and to allow handling with a fork lift. To avoid damaging the silicon detectors mounted inside the CAM impactors, the impactors were removed from the alpha CAM sampling cabinets before transportation. The analysis trailer stairs were too large to store inside the analysis trailer so they were transported on a flatbed truck.

The general arrangement of the RTML sample preparation and analysis trailers, portable generators, and alpha CAMs during the field test at the CTP is shown in Figure 6. As shown in Figure 6, the sample preparation and analysis trailers and associated portable generators were parked about 100 m from the northwest corner of the tent that enclosed the north end of the CTP. The generators were positioned to minimize personnel exposure to noise and diesel exhaust fumes. Alpha CAM sampling cabinets 1, 2, 3, and 4 were positioned, respectively, in the southwest, southeast, northeast, and northwest corners of the tent, usually about 2 m from the perimeter wall of the tent. The two CAM electronics cabinets were located near CAM sampling cabinets 2 and 3. The generator used to supply power to the six CAM cabinets was parked on the east side of the tent near the east-west centerline of the tent so that power cords could be strung avoiding vehicle traffic paths.

The Contamination Control Unit (CCU), which was the system used to spray water mists and dust fixants during remote retrieval operations, was located in a trench beneath the south wall of the CTP tent. The trench was about 1-m deep, just deep enough so that the roof of the CCU cleared a horizontal cross member of the tent located about 3-m abovegrade. During the field test of the RTML, a remotely operated front-end loader excavated simulated waste from a 3-m wide trench

Figure 6. General arrangement of the RTML at the CTP.

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within the tent enclosure. As shown in Figure 6, the trench that was excavated was aligned in the east-west direction near the centerline of the tent. During remote retrieval operations, empty waste boxes were delivered to the waste trench boundary and were subsequently filled with soil overburden and simulated waste. The waste boxes were delivered to the trench and removed from the tent either through a flap in the tent at the west end of the trench or through an opening intermittently made in the south wall of the tent. The wind blew steadily from the southwest between 15 and 20 mph on the 2 days the alpha CAMs were operated at the CTP. The wind blew through the openings in the tent wall and, as will be shown in Section 6.3, created high airborne dust concentrations within the tent.

During the field test, power for the RTML sample preparation and analysis trailers was provided with single-phase, 240 V, 60 Hz diesel generators rated at 30 and 50 kW. The 50 kW generator was mounted in a small trailer that was towed to the site behind a pickup truck. The 30 kW generator was not mobile but had an integrally connected fuel tank beneath the motor that also served as a skid. The 30 kW generator was delivered to the site on a flatbed truck. The four alpha CAM sampling cabinets and two electronics cabinets were powered from a mobile 120 V, 60 Hz, single-phase 6.5 kW gasoline generator that was towed to the site. Before operation, each of the three generator chassis was grounded to a 2.7-m long ground rod driven into the earth. The two power cords for the analysis trailer were plugged into receptacles mounted on the left front of the analysis trailer and into receptacles mounted on a breaker-box stand that served as an interface between the trailer and 30 kW electric generator. The power cord extending from the interface stand was connected to the power terminals of the 30 kW generator by a licensed electrician. The power cord for the sample preparation trailer was plugged into the receptacle on the front of the trailer, and the other end of the power cord was connected to the power terminals of the 50 kW generator by a licensed electrician. In the case of the 6.5 kW generator used with the alpha CAMs, the generator was equipped with six standard 120 V receptacles. The six power cords for the four alpha CAM sampling cabinets and two associated electronics cabinets were plugged into the 120 V receptacles.

Communication between the VAX computer in the analysis trailer and the alpha CAMs was accomplished via a thin-wire Ethernet coaxial cable that connected the AIM in each electronics cabinet to the alpha CAM computer terminal in the analysis trailer. The Ethernet cable was about 170 m long. Each sampling cabinet was equipped with bias supply and signal cables that were 17 m long so that each sampling cabinet could be positioned up to 17 m from its corresponding electronics cabinet.

5.2 Sample Collection and Treatment

Several hundred soil samples were collected from the CTP during June 1993. In addition, during the time the RTML was located at the CTP, 20 smear samples were collected from external surfaces of equipment and waste boxes located within the tent enclosing the CTP. On May 26, 1993, energy calibration standards specially prepared for the alpha CAMs were measured and ambient air was monitored for about 2-1/2 hours while all four alpha CAMs were located outside the TRA laboratory buildings and powered from a 6.5 kW generator. On June 27, 1993, the energy calibration standards were remeasured and ambient air was monitored for about 5-1/2 hours while all four alpha CAMs were located inside the CTP tent. A second air sampling was performed at the CTP on June 29, 1993, for about 3 hours. During the field test, 143 of the soil samples collected from the CTP were analyzed with the photon analysis spectrometer, and 96 were analyzed with the two large-area

ionization chamber alpha spectrometers. All 20 of the smear samples and 15 alpha CAM sample collection filters were analyzed with the photon spectrometer. The procedures used to collect soil and smear samples and prepare them for analysis by photon and alpha spectrometry are described in Sections 5.2.1 and 5.2.2.

5.2.1 Soil

Emphasizing collection from the finest material, soil from each sample area was selected to be as free as possible from root mat, stones, twigs or other debris, and overly muddy material. Using a small garden trowel, at least five separate scoops were taken from each area to obtain a representative sample and placed in a 1-qt, heavy-duty, polyethylene freezer bags with a friction closure and labeling area. Each bag was filled about half full without interfering with airtight closure of the bag or unduly contaminating the outside. The bag was then labeled with a serial number and the time and date the sample was collected. The same information and any other information needed to identify the position where the sample was taken was recorded in a sample logbook for permanent reference.

Soil samples collected from the CTP were delivered to the sample preparation trailer in cardboard boxes, usually 20 to 30 samples per box. When a soil sample was selected for preparation, it was first poured into a disposable aluminum pan, approximately 6-1/2 in.² × 1-1/4 in. deep, that was labeled with the sample identification number and sample collection date. Any root mat, twigs, stones, or other obvious debris were removed and discarded into a 4-gal polyethylene waste bucket. The pan was placed in a drying oven, baked between 30 minutes and 1 hour at 175°C until the sample was dry, and then removed and allowed to cool to room temperature. Any large clods were broken up with a porcelain pestle, taking care not to rupture the pan. The entire sample was poured into a 50-mesh (300-μm) stainless-steel standard testing sieve, 8 in. o.d. × 2 in. deep, and shaken with an automatic shaking machine until at least 50 g of soil passed through the sieve. About 50 g of the sieved soil was then transferred into a 2-oz polypropylene wide-mouth bottle. The bottle was shaken vigorously for a few seconds to further homogenize the contents, marked with the same identification number and collection date that were on the original polyethylene bag, and placed in numerical order in a 20-bottle carrier tray.

The material remaining in both the sieve and collection pan was discarded to the 4-gal waste bucket. The top of the sieve was rapped against the rim of the waste bucket to dislodge particles caught in the screen, and the screen itself was wiped gently on its underside with paper tissue to dislodge any particles still stuck in the mesh openings. The inside of the pan and sieve were also wiped gently with paper tissue to reduce cross contamination between samples. The sieves were reused without further cleaning.

In the case of soil samples prepared for the large-area ionization chamber alpha spectrometers, a 100-mg sample of the sieved soil was dry ground in a diamonite mortar for at least 1 minute, using a rapid circular motion of the pestle in a counterclockwise direction while rotating the mortar slowly in the opposite direction. As the mortar and contents were rotated, the pestle was directed visually to grind all individual particles of soil as thoroughly as possible. Ten drops of an aqueous solution containing 30% ethanol were added a drop at a time to the ground deposit to convert the powder to a thick mud with no separate liquid phase. The grinding was then continued for another minute using the same technique previously described. Using a 1-mL suction-type pipet, 2 mL of 30%

ethanol was then added to the mortar, and grinding was continued until all mud on both the mortar and pestle was thoroughly suspended in the liquid phase. Using the same pipet, the suspension was transferred to the reservoir tube of an all-glass, air-operated sprayer. The pestle and walls of the mortar were rinsed with another 2 mL of 30% ethanol, and this solution was also transferred to the reservoir tube. The rinsing and transferring were repeated two more times to complete the process.

A 25.4-cm stainless steel pan was placed on an electric hotplate set at medium to high heat, leaving about 3 cm of the pan extending over the front edge of the hotplate. When the protruding edge became moderately warm to the touch, the pan was removed and leaned against the back of the fume hood that was previously covered with a large piece of blotting paper to collect any spray that might miss the pan. The sprayer nozzle assembly was placed in the sprayer reservoir tube just tightly enough to keep it from coming out. The vent opening in the sprayer was covered with the thumb, and the assembly was inverted and shaken gently to resuspend the ground soil as well as possible. The air hole in the sprayer was then covered with the thumb and about one-third of the suspension was sprayed onto the hot pan. The perimeter region of the pan was sprayed moving the sprayer around the outside edge of the pan at a distance of 6 to 8 in. from the pan with the stream directed inward, and then the middle area was covered moving the sprayer rapidly from side-to-side over the central region of the pan. The pan was placed back on the hotplate and reheated until the sprayed material was completely dry. The contents of the tube were again shaken vigorously to resuspend the solid material and about one-half of the remaining suspension was then sprayed onto the pan. The pan was again heated, and the remaining suspension was mixed thoroughly and sprayed onto the pan. Two milliliters of 30% ethanol was then added to the sprayer, the assembly was shaken vigorously to rinse the tube and sprayer, and the rinse was sprayed onto the pan again after reheating. The dried sample was then counted in one of the two ionization chambers. (When the entire suspension was sprayed in a single operation without intermediate drying and reheating, the liquid invariably condensed into large droplets and rivulets that degraded the alpha spectrum.)

The soil samples were prepared for direct alpha spectrometry by three individuals who had no previous experience with the present grinding and spraying procedures. They were given a single demonstration by the principal investigator (PI) and then given time to prepare a few samples without direct supervision to become familiar with the process. After this minimal training, they prepared the actual samples used in the demonstration. Although the samples were adequate for the intended purpose, a few individual weaknesses were noted that will be corrected easily before operational use.

In the case of soil samples prepared for the photon analysis spectrometer, 11.000 ± 0.001 g of the sieved soil were weighed into a circular plastic container having an inside depth of 3 mm and inside diameter of 64 mm. The soil was spread uniformly over the area of the container with a straightedge, and the container was sealed with a tight-fitting plastic lid.

5.2.2 Smears

Smears of surface dust taken for analysis by photon spectrometry were collected on 47-mm diameter cellulose acetate filters. In each case, the smear sample was collected over an area of about 100 cm^2 . Each smear was placed directly into a 3-mm deep plastic sample container normally used with the photon spectrometer and was attached to the container base by placing tape across opposite edges of the filter. The container was then sealed with a plastic lid, and a gummed label with the sample identification number and sample collection date was attached to the bottom of the container.

Although no smear samples were collected for analysis by ionization chamber alpha spectrometry, two different methods have been developed to collect samples of dust for analysis with the ionization chambers. In the first method, dust is drawn directly onto a 10-cm diameter membrane filter using a vacuum cleaner brush connected to a high-volume air sampler by means of an adapter. In the second method, dust is collected on a 20 × 25-cm membrane filter using an 18-cm wide paint roller to press the filter against the surface being smeared. Both types of samples are placed directly in the ionization chamber for counting.

5.3 Instrument Operation

Procedures used to operate the VAX 4000 computer, photon analysis spectrometer, two large-area ionization chamber alpha spectrometers, and the four alpha CAMs are described in detail in Reference 14. Procedures used to determine the energy calibrations and absolute counting efficiencies of the three measurement systems are also described in Reference 14.

5.4 Data Calculations

5.4.1 Photon Analysis Spectrometer

A linear least-squares spectral fitting technique was used to analyze the L x-ray spectral data. This technique consisted of measuring the spectral response of the detector for single (pure) radionuclides anticipated to be in the unknown sample. The number of radionuclide components is not limited by the mathematics but, as a practical matter, should not exceed about five. These response functions (spectra) can be normalized to correspond to a specific number of decays of the radionuclide or ²³⁹Pu "equivalent" in the case of plutonium. In the case of the plutonium component, minor concentrations of several plutonium isotopes other than ²³⁹Pu may actually be present in the unknown sample. When a spectrum of an unknown sample was acquired, these individual spectral components in the x-ray region were combined by linear least-squares fitting to determine the contribution of each component to the composite spectrum.

The method outlined by L. A. Currie²⁸ for the determination of LLDs that meet specific statistical criteria is in wide use. However, since several spectral components overlap in the L x-ray region and contribute to a sample composite spectrum, it is difficult to find regions that are free of interferences. Therefore, in this application, the detection limits for plutonium and americium in soil were most easily determined by relating them to the estimated standard deviation in the measured activity. An activity with a reported statistical uncertainty of $\geq 30\%$ (one estimated standard deviation) was regarded as being at the detection limit.

Spectra collected using the photon analysis spectrometer were analyzed automatically using the XGAP photon spectrum analysis code installed on the VAX 4000 computer. Each spectrum collected using the photon spectrometer included the x-rays and gamma-rays emitted between 10 keV and 1,380 keV. The x-ray and gamma-ray regions of the spectrum were analyzed automatically using, respectively, the LXRAY and VAXGAP subroutines of the XGAP program. Following completion of spectrum analysis, the analysis results for each spectrum were automatically printed on the laser printer. Analysis results for TRU isotopes and fission and activation products were reported as concentrations, with associated uncertainties, expressed as picocuries per gram (pCi/g) for soil

samples, picocuries per square centimeter (pCi/cm²) for smear samples, and picocuries per liter (pCi/L) for air filter samples. Following analysis, the photon spectrum and spectrum analysis results were automatically stored in computer memory.

5.4.2 Large-Area Ionization Chamber Alpha Spectrometers

In the case of soil samples, the concentration of a given alpha-emitting TRU isotope, C_s , expressed as pCi/g, was calculated as

$$C_s = \frac{C_G - B}{2.22 G F Y T M} \quad (1)$$

where

C_G = total counts in TRU ROI (counts)

B = background counts in TRU ROI (counts)

2.22 = number of disintegrations per minute per pCi

G = geometric counting efficiency (counts per disintegration)

F = fraction of total TRU alpha peak counts that are within the ROI defined for the peak

Y = yield

T = count time (minutes)

M = sample mass (g).

The number of background counts in the TRU ROI was estimated from blanks and the spectrum above the high-energy edge of the TRU alpha peak. The geometric counting efficiencies of the ionization chambers were determined by measuring standards prepared by evaporating carrier-free standard solutions of TRU radionuclides uniformly on 25.4-cm diameter stainless steel sample pans. The value for both chambers was 0.485, very close to the 2- π limit. The ROI can also be determined easily from any spectrum containing only the radionuclide of interest and prepared under the conditions used with actual samples. However, because of difficulties in determining the physical losses incurred in grinding and spray-mounting, the entire product GFY was simpler to determine by mounting and counting a standard soil under conditions identical to those used with actual samples. For the conditions used in the present work, the value of the product GFY was 0.235.

Alpha spectra collected using the large-area ionization chamber alpha spectrometers were analyzed semiautomatically using the ION alpha spectrum analysis code installed on the VAX 4000 computer. Spectrum analysis was semiautomatic in the respect that the operator first set the ROI for each TRU alpha peak using the spectrum display cursors, initiated analysis using the X-terminal

mouse, and entered an estimate of the number of background counts in the TRU alpha peak before an analysis was performed. Analysis results for each TRU alpha peak were displayed on the ionization chamber X-terminal monitor above the spectrum. The operator selected the analysis results displayed on the monitor that were to be saved and printed on the laser printer. In the case of the ionization chamber alpha spectrometers, spectra and analysis results were not automatically saved in computer memory. The operator had to save these data using the X-terminal mouse and/or keyboard commands.

5.4.3 Alpha Continuous Air Monitors

The alpha spectrum analysis algorithm developed for the alpha CAMs is currently designed to determine the airborne concentrations of ^{239}Pu and ^{241}Am . These two TRU isotopes emit alpha particles having average energies of 5.155 and 5.480 MeV, respectively. Each alpha CAM collects airborne activity on a fixed sample collection filter. The average airborne concentration of ^{239}Pu and ^{241}Am over any given interval during sampling was determined through sequential analysis of the cumulative alpha spectrum. The general equation for the number of net counts in a TRU alpha peak at the end of sampling interval, n , is

$$C_n = C_{n-1} + 2.22\epsilon \left\{ \sum_{i=1}^{n-1} Y(X_{\text{Pu}})_i F_i \Delta t_i \right\} \Delta t_n + 2.22\epsilon Y(X_{\text{Pu}})_n F_n \frac{\Delta t_n^2}{2} \quad (2)$$

where

- C_n = net counts in peak at the end of sampling interval, n
- C_{n-1} = net counts in peak at the beginning of sampling interval, n
- 2.22 = number of disintegrations per minute per pCi
- ϵ = absolute counting efficiency of detector (counts per disintegration)
- Y = activity collection efficiency of CAM
- $(X_{\text{Pu}})_i$ = airborne concentration of TRU isotope during sampling interval, i (pCi/L)
- F_i = average sampling flow rate during sampling interval, i (Lpm)
- Δt_i = length of sampling interval, i (minutes)
- Δt_n = length of sampling interval, n (minutes)
- $(X_{\text{Pu}})_n$ = airborne concentration of TRU isotope during sampling interval, n (pCi/L)
- F_n = average sampling flow rate during sampling interval, n (Lpm).

Equation 2 shows that at the end of sampling interval n , the net counts in a TRU alpha peak are equal to the sum of the net counts already accumulated in the peak at the start of the sampling interval, plus the net counts accumulated in the peak during the interval from the TRU activity already deposited on the sample collection filter before the start of sampling interval n , plus the net counts accumulated in the peak due to the TRU activity deposited on the filter during sampling interval n .

For cases where $\Delta t_i \neq \Delta t_n$ and $F_i \neq F_n$, the average airborne concentration of ^{239}Pu and ^{241}Am during the first sampling interval, $(X_{\text{Pu}})_1$, was calculated using

$$(X_{\text{Pu}})_1 = \frac{C_1}{2.22 \epsilon Y F_1 \frac{\Delta t_1^2}{2}} \quad (3)$$

The average airborne concentration of ^{239}Pu and ^{241}Am during the second sampling interval, $(X_{\text{Pu}})_2$, was calculated as

$$(X_{\text{Pu}})_2 = \frac{C_2 - C_1 - 2C_1(\Delta t_2/\Delta t_1)}{2.22 \epsilon Y F_2 \frac{\Delta t_2^2}{2}} \quad (4)$$

The average airborne concentration of ^{239}Pu and ^{241}Am during subsequent sampling intervals, $(X_{\text{Pu}})_n$, was calculated as

$$(X_{\text{Pu}})_n = \frac{(C_n - C_{n-1}) - (C_{n-1} - C_{n-2})(\Delta t_n/\Delta t_{n-1})}{2.22 \epsilon Y F_n \frac{\Delta t_n^2}{2}} - (X_{\text{Pu}})_{n-1} \frac{\Delta t_{n-1} F_{n-1}}{\Delta t_n F_n} \quad (5)$$

Equation 5 shows that the airborne TRU concentration calculated for sampling interval, n , is dependent on the airborne concentration calculated for the preceding sampling interval. Equations 3, 4, and 5 were used to calculate airborne concentrations of ^{239}Pu and ^{241}Am during a number of samplings of ambient air performed with the alpha CAMs before the field test. For all these samplings of ambient air, calculated airborne concentrations oscillated between positive and negative values. A fundamental problem was that net counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI, which encompassed alpha particle energies from 3.71 to 5.60 MeV, were often negative when normal ambient air was sampled. For the purpose of providing an analysis methodology that could be used during the field test of the RTML, an interim spectrum analysis method was developed. This method calculated the maximum $^{239}\text{Pu}/^{241}\text{Am}$ airborne concentration ignoring the first two terms on the right hand side of Equation 2. The maximum airborne $^{239}\text{Pu}/^{241}\text{Am}$ concentration during each sampling interval was calculated as

$$(X_{Pu})_n^{Max} = \frac{C_n}{2.22 \epsilon Y F_n \frac{\Delta_n^2}{2}} \quad (6)$$

The average airborne $^{239}\text{Pu}/^{241}\text{Am}$ concentration from the beginning of sampling was also calculated using the following equation.

$$(X_{Pu})^{Av} = \frac{C_n}{2.22 \epsilon Y \left\{ \sum_{i=1}^n F_i \Delta_i \right\} \frac{(RT)}{2}} \quad (7)$$

where

RT = elapsed real time at the end of sampling interval, n, measured from the start of sampling (minutes).

The function used to estimate background counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI is shown in Figure 7. The total counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI were determined by summing the counts in the alpha CAM spectrum from 3.71 to 5.60 MeV, an energy range that encompasses the energies of the alpha particles emitted by ^{239}Pu and ^{241}Am . The number of background counts in the same region was determined using a linear regression method. The counts in sixteen channels on the low-energy side of the $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak at 6.00 MeV were fit to the following exponential function.

$$S_i = Y \exp[(X_i - C) k_n] \quad (8)$$

where

S_i = background counts in channel i

Y = counts in channel C

X_i = channel i (from C-10 to C+5)

C = channel 14 channels below the centroid of the 6.00 MeV peak

k_n = coefficient whose value is determined by fitting the background count data to the channel data.

The number of background counts in each channel from 3.71 to 5.60 MeV, B_i , was then calculated as

Figure 7. Function used to estimate background counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI in alpha CAM spectra.

$$\begin{aligned} B_i &= S_i \text{ when } S_i > Z \\ B_i &= Z \text{ when } S_i \leq Z \end{aligned} \quad (9)$$

where

Z = the average number of counts in the 10 channels from 3.57 to 3.71 MeV.

The total number of background counts from 3.71 to 5.60 MeV was then calculated by summing the counts per channel estimated using Equation 9 over channels from 3.71 to 5.60 MeV. The net counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI were then estimated by subtracting the calculated background counts from the total counts between 3.71 and 5.60 MeV.

Alpha spectra collected using the alpha CAMs were analyzed automatically using the ACAM alpha spectrum analysis code installed on the VAX 4000 computer. During air sampling the cumulative alpha spectrum was transferred to the VAX computer and analyzed at regular intervals. (The analysis interval is shown as Δt_n or Δt_i in Equations 6 and 7.) The operator selected the length of the interval before the start of sampling. The intervals used during the field test were 15, 30, and 60 minutes. Following each analysis, the date, real time since the start of sampling, average sampling flow rate during the interval, total number of counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI, net number of counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI, average airborne $^{239}\text{Pu}/^{241}\text{Am}$ concentration since the start of sampling and its estimated uncertainty, expressed as Pci/L, and the maximum airborne $^{239}\text{Pu}/^{241}\text{Am}$ concentration during the interval and its estimated uncertainty, expressed as Pci/L, were automatically stored in computer memory. The operator obtained a hard copy of the analysis results at any time for any given sampling dates using the ACAM_REPORT subroutine. Analysis results were printed on the laser printer.

5.5 Blind Soil Standards

To determine the sensitivity and reliability with which both alpha and gamma-emitting radionuclides could be detected under field conditions, 20 soil standards containing known activities of ^{239}Pu , ^{241}Am , ^{60}Co , and/or ^{137}Cs were prepared for both the photon analysis spectrometer and large-area, ionization chamber alpha spectrometers before the start of the field test. The sample preparation procedures and containers used to make the soil standards were identical to those used to prepare CTP soil samples for the two measurement systems. The activities in the soil standards were not known to any of the RTML analysts until after all the analytical results had been obtained and recorded in both computer memory and on hard copy. Then the final radionuclide concentrations in the standards were calculated, and the results were made available to all participants. During the field test, these prepared soil standards were distributed randomly among prepared CTP soil samples before their delivery to the RTML analysis trailer. Identification numbers on the standards were changed by personnel in the sample preparation trailer each time they were introduced into the sample stream so that RTML analysts could not physically identify them as being standards.

The activity concentrations in the soil standards are given in Table 1. As shown in Table 1, all 20 blind soil standards were spiked with ^{239}Pu , but only six were also spiked with ^{241}Am . Four were spiked with ^{60}Co and ^{137}Cs , and three were spiked with either ^{60}Co or ^{137}Cs . Some of the soil

Table 1. Activity concentrations in the blind soil standards.

Ident. number	^{60}Co (pCi/g)	^{137}Cs (pCi/g)	^{239}Pu (pCi/g)	^{241}Am (pCi/g)
1	NA ^a	NA	100.6 $\pm$ 1.1	NA
2	NA	NA	78.6 $\pm$ 0.9	NA
3	NA	NA	224 $\pm$ 3	NA
4	NA	NA	281 $\pm$ 3	NA
5	NA	NA	175.8 $\pm$ 1.9	NA
6	NA	NA	98.9 $\pm$ 1.3	52.6 $\pm$ 1.3
7	44.4 $\pm$ 0.5	50.5 0.9	101.4 $\pm$ 1.1	NA
8	36.4 $\pm$ 0.4	47.0 0.9	239.2 $\pm$ 1.0	NA
9	57.3 $\pm$ 0.6	NA	108.1 $\pm$ 0.4	42.8 $\pm$ 0.2
10	NA	NA	492 $\pm$ 6	38.0 $\pm$ 0.2
11	NA	NA	503 $\pm$ 6	10 $\pm$ 2
12	35.4 $\pm$ 0.4	NA	471 $\pm$ 5	NA
13	NA	87.5 1.6	453 $\pm$ 5	NA
14	41.5 $\pm$ 0.4	41.5 0.8	187 $\pm$ 2	NA
15	47.6 $\pm$ 0.5	40.8 0.8	97.4 $\pm$ 1.1	NA
16	NA	132 2	142.8 $\pm$ 1.6	NA
17	NA	NA	491 $\pm$ 5	NA
18	NA	NA	162.9 $\pm$ 1.8	78.0 $\pm$ 0.4
19	60.2 $\pm$ 0.6	NA	96.9 $\pm$ 1.1	NA
20	NA	57.1 $\pm$ 1.1	199 $\pm$ 2	42.1 $\pm$ 0.2

a. None added.

standards were spiked at levels only about a factor of two higher than the LLD concentrations previously reported^{1,7} for the photon and ionization chamber alpha spectrometers to confirm that these LLDs are achievable in the field. Some of the soil standards were spiked at much higher levels to determine the precision and accuracy of quantitative analyses.

6. EXPERIMENTAL RESULTS

6.1 Photon Analysis Spectrometer

The photon analysis spectrometer was operated for 5 days during the 2-week period that the RTML was field tested. As was previously stated, operations at both TRA and the CTP were performed using diesel-fueled electric generators. The laboratory facilities at TRA were not used during the test because line power and running water were not available at the CTP and would not normally be available in the field.

The dual energy pulser that accurately measured the energy scale of the spectrometer was recalibrated periodically. The energy equivalent values of the pulser peaks were maintained to within ± 0.05 keV (0.29 channels) for the lower pulser peak and ± 0.78 keV (4.46 channels) for the upper pulser peak over approximately a 2-month period. The values of the pulser equivalents and energy and width parameters were also measured by these calibrations and are given in Table 2.

The samples collected from the CTP were all counted for a 15-minute live time and automatically analyzed without operator input immediately after the count by the XRAY and VAXGAP programs. Plots of the entire photon spectrum and x-ray region of the spectrum were printed for each of the "unknown" samples as a quality control measure to verify the presence or absence of radionuclides. Examples of plots of the full spectrum and L-shell x-ray region of the same spectrum measured for blind soil standard No. 6 are shown in Figures 8 and 9, respectively. The combined ^{239}Pu and ^{241}Am L-shell x-ray peaks, the ^{241}Am 59-keV gamma-ray peak, and the two pulser peaks are identified in Figure 8. The combined x-ray peaks and the 26 and 59-keV gamma-ray peaks of ^{241}Am are shown more clearly in Figure 9.

Table 2. Pulser calibration data for the photon analysis spectrometer.

Date	Time	Energy equivalency of pulser peaks		Energy coefficients		Width coefficients	
		Low peak (keV)	High peak (keV)	Zero (keV)	Gain (keV/ch)	Intercept	Slope
06/14/93	1543	12.32	1328.03	0.0785	0.17446	3.144	1.783E-3
06/28/93	0851	12.22	1329.75	0.1048	0.17461	3.132	1.811E-3
06/28/93	0918	12.21	1329.10	0.1102	0.17461	3.021	1.811E-3
06/30/93	1037	12.21	1328.70	0.0905	0.17452	2.916	1.845E-3
08/02/93	1554	12.29	1327.98	0.1066	0.17475	3.095	1.721E-3

Figure 8. Photon spectrum of blind soil standard No. 6.

Figure 9. L-shell x-ray spectrum of blind soil standard No. 6.

6.1.1 Quality Control Samples

To monitor the quality of the ^{239}Pu and ^{241}Am activity concentration measurements and confirm that the photon analysis spectrometer was operating within acceptable limits, known quality control samples were analyzed several times with the photon spectrometer. The quality control samples consisted of soil and smear samples containing known ^{239}Pu and/or ^{241}Am activities. Measurement results for ^{239}Pu and ^{241}Am for the quality control samples are presented in Appendix A, Tables A-1 and A-2, respectively, along with the known ^{239}Pu and ^{241}Am activities or activity concentrations. As noted in Table A-2, for those samples that contained ^{239}Pu , the ^{241}Am concentration in each sample was 2.7% of the ^{239}Pu concentration.

Of the 21 measurements made on five quality control standards, ten ^{239}Pu activities or activity concentrations (48%) agreed with the known values within two standard deviations of the difference; five (24%) agreed within four standard deviations; and for six measurements (29%), the deviations from the known values were greater than four standard deviations of the difference. Since uncertainties reported include only the statistical component, these large deviations imply that the statistical component has been underestimated or that significant components of the total uncertainty have not been identified. More relevant, for all quality control samples but one, measured ^{239}Pu concentrations agreed within 20% of the known concentrations. In the case of the quality control standard containing 103 pCi/g ^{239}Pu (only a factor of two above the plutonium LLD), the average fractional deviation of measured ^{239}Pu concentrations from the known value was -38%. Of the 20 ^{241}Am activities or activity concentrations measure by x-ray spectrometry, nine (45%) agreed with the known values within two standard deviations of the difference; five (25%) agreed within three standard deviations; three (15%) agreed within four standard deviations; and for three measurements, the deviations from the know values were greater than four standard deviations of the difference. Of the 19 ^{241}Am activities or activity concentrations measured by gamma-ray spectrometry, nine (47%) agreed with known values within two standard deviations of the difference; five (26%) agreed within three standard deviations; and five agreed within four standard deviations. Again, this is due to underestimating the statistical component and/or not identifying significant components to the total uncertainty. More relevant is that the measured ^{241}Am concentrations for both x-ray and gamma-ray analysis agreed within 8% of the known concentrations.

6.1.2 Blind Soil Standards

Over the 5 days the RTML was field tested, 143 of the soil samples gathered from the CTP were prepared and counted. Interspersed with these samples were 20 soil standards spiked with ^{60}Co , ^{137}Cs , ^{239}Pu , and/or ^{241}Am that were repeatedly introduced and counted a total of 96 times during the test. These 239 analyses provided the basis for validating the LLD concentrations previously reported^{1,7} for the photon analysis spectrometer and evaluating the capability of the photon analysis spectrometer to correctly identify and accurately measure radionuclide activities.

In addition to the 143 soil samples, 20 smear samples collected from external surfaces of equipment and waste boxes located within the tent that enclosed the CTP and 15 air filter samples used during samplings performed with the RTML alpha CAMs were counted. No blind spiked smear or air filter samples were prepared.

6.1.3 Analysis Protocol

The results of analyses performed with the photon analysis spectrometer were compiled and evaluated by an individual who worked independently of the personnel in the analysis trailer. This individual's responsibilities included overseeing the preparation of the samples, assigning sample ID numbers, and introducing blind soil standards among the prepared CTP soil samples. The following procedure was used to evaluate the results of analyses performed with the photon spectrometer:

1. Verify that the reduced chi square value of the linear least-squares spectral fit from the XRAY program is not above 1.7. If the reduced chi square is above 1.7, the x-ray results should be identified as questionable.
2. Compare the ^{241}Am concentrations calculated by the XRAY and XGAP programs. If no activity is reported for the 59-keV ^{241}Am gamma-ray, assume that any activity reported by the XRAY program is erroneous. Identify these results. Report the ^{241}Am activity concentration calculated from the 59-keV gamma-ray.
3. Any activity concentrations that are below the LLD concentrations given in Table 3 are to be considered zero and reported as such.
4. Activity concentrations with uncertainties greater than 30% are to be set equal to zero.

6.1.4 Results

No manmade activity was detected in any of the 143 soil, 20 smear, or 15 alpha CAM air filter samples analyzed with the photon spectrometer. Each of the 96 analyses of the 20 blind soil standards performed during the field test identified and quantified one or more of the four radionuclides present in the standards. Concentrations of ^{239}Pu and ^{241}Am in the blind soil standards measured by x-ray spectrometry are presented in Appendix A, Tables A-3 and A-4, respectively. Concentrations of ^{241}Am , ^{60}Co , and ^{137}Cs in these standards measured by gamma-ray spectrometry are presented in Appendix A, Tables A-5, A-6, and A-7, respectively. As shown in the tables, the concentration of ^{239}Pu was quantified by all analyses but two, and the concentration of ^{241}Am was quantified in all cases by both x-ray and gamma-ray spectrometry. Two analyses failed to quantify

Table 3. Photon spectrometer LLD concentrations.^a

Radionuclide	Photon measured	LLD (pCi/g)
^{239}Pu (equivalent)	L x-ray	40
^{241}Am	L x-ray	4
	60 keV gamma-ray	1
^{137}Cs	661 keV gamma-ray	5
^{60}Co	1,173 keV gamma-ray	5

a. LLD based on the terminology defined by L. Currie for the case where LLD occurs when uncertainty is equal to $\pm 30.5\%$ at the one-sigma level.

^{60}Co , and one failed to quantify ^{137}Cs . The gamma-rays of the two radionuclides were obviously present in the spectral plots, but because of limitations in the automated analysis program, they were not identified by the program. The mean measured activity concentration of each of the four radionuclides in each standard and its standard deviation are also presented in Tables A-3 through A-7. As shown in Tables A-3 and A-4, the standard deviations of the mean concentrations of ^{239}Pu and ^{241}Am measured by x-ray spectrometry were often a factor of 2 to 3 times larger than the statistical uncertainties that were assigned to individual measurement results. This shows that the uncertainties calculated by the XRAY program for individual measurements were far too low and implies that either the values assigned to existing uncertainty components were underestimated or that significant uncertainty components exist beyond those that have been considered to date.

Two blind soil standards were each misidentified one time. The first misidentification was the result of a labeling error. On one occasion, standard No. 6 was mislabeled with the same sample number as standard No. 14. The mislabeling became evident following an examination of the spectrum for the standard, which is shown in Figures 8 and 9. The spectrum did not show the presence of ^{60}Co or ^{137}Cs but did show the presence of ^{241}Am . The measured ^{241}Am concentrations from the L x-rays and gamma-rays were 56.8 ± 2.1 and 63.9 ± 1.7 pCi/g, respectively. Therefore, from Table 1, the blind standard initially thought to be No. 14 was actually No. 6.

The second misidentification was the result of spectral interference. For one analysis of blind soil standard No. 18, a ^{239}Pu activity concentration of 64 ± 24 pCi/g was measured. As was previously stated, activities with uncertainties greater than 30% were set equal to zero. This sample also contained ^{241}Am at a concentration of 78.0 ± 0.4 pCi/g. For this particular analysis, the concentration of ^{241}Am was measured to be 83.2 ± 2.0 and 85.5 ± 2.4 pCi/g by its L x-rays and 59-keV gamma-ray, respectively. Further examination of analysis results for blind standards No. 18 and No. 6, which contained ^{241}Am at a concentration of 52.6 ± 1.3 pCi/g, indicated that an activity ratio of $^{239}\text{Pu}/^{241}\text{Am}$ greater than two may be necessary for the XRAY program to properly fit the ^{239}Pu produced L x-ray components of the combined L x-ray peaks. Apparently the ^{241}Am produced L x-rays begin to swamp the signature L x-rays from ^{239}Pu when the $^{239}\text{Pu}/^{241}\text{Am}$ activity ratio is <2 .

The absolute values of the deviations of the measured concentrations of ^{239}Pu from the known values for each blind soil standard are plotted in Figures 10 and 11, where the deviations are expressed in units of standard deviations of the difference between the measured and known values. Figure 10 shows the ^{239}Pu results for the 14 blind soil standards that did not contain ^{241}Am , while Figure 11 shows the ^{239}Pu results for the six standards that were also spiked with ^{241}Am . Of the 65 measurements made on the 14 blind soil standards that did not contain ^{241}Am , 32 ^{239}Pu activity concentrations (49%) agreed with the known values within two standard deviations of the difference; 14 (22%) agreed within three standard deviations; nine (14%) agreed within four standard deviations; and for 10 measurements (15%), the deviations from the known values were greater than four standard deviations of the difference. Of the 29 measurements made on the six blind soil standards that also contained ^{241}Am , 11 ^{239}Pu activity concentrations (38%) agreed with the known values within two standard deviations of the difference; six (21%) agreed within three standard deviations, four (14%) agreed within four standard deviations; and for eight measurements (28%), the deviations from the known values were greater than four standard deviations of the difference. For samples without ^{241}Am , fractional deviations of measured ^{239}Pu concentrations from known concentrations ranged from about -63% to +24%, and for samples containing ^{241}Am , they ranged from about -57% to +23%. As one might expect, among those standards that were also spiked with ^{241}Am , the

measured ^{239}Pu concentrations for the two samples containing the highest concentrations of ^{239}Pu exhibited the smallest dispersion.

The absolute values of the deviations of the measured concentrations of ^{241}Am from the known values for the six blind soil standards that were spiked with ^{241}Am are plotted in Figures 12 and 13, where, again, the deviations are expressed in units of standard deviations of the difference between the measured and known values. Figure 12 is a plot of the deviations of the ^{241}Am concentrations measured by x-ray spectrometry, and Figure 13 is a plot of the deviations of the ^{241}Am concentrations measured by gamma-ray spectrometry. Of the 30 x-ray spectrometry measurements made on the six blind soil standards, 18 ^{241}Am activity concentrations (60%) agreed with the known values within two standard deviations of the difference; five (17%) agreed within three standard deviations; two (7%) agreed within four standard deviations; and for five measurements (17%), the deviations from the known values were greater than four standard deviations of the difference. Of the 30 ^{241}Am activity concentrations measured by gamma-ray spectrometry, 15 (50%) agreed with the known values within two standard deviations of the difference; nine (30%) agreed within three standard deviations; three (10%) agreed within four standard deviations; and for three measurements, the deviations from the known values were greater than four standard deviations of the difference. For both measurement methods, measured ^{241}Am concentrations usually agreed within 20% of known concentrations, but the gamma-ray results showed less scatter than the x-ray results.

Similar results for ^{60}Co and ^{137}Cs are plotted in Figures 14 and 15, respectively. Of the 29 ^{60}Co activity concentrations measured with the photon spectrometer, one (3%) agreed with the known value within two standard deviations of the difference; four (14%) agreed within three standard deviations; four agreed within four standard deviations; and for 20 measurements (69%), the deviations from the known values were greater than four standard deviations of the difference. Of the 29 ^{137}Cs activity concentrations measured with the photon spectrometer, 22 (76%) agreed with the known values within one standard deviation of the difference, and seven agreed within two standard deviations.

The mean fractional deviations of the activity concentrations measured with the photon spectrometer from the known concentrations of the four radionuclides present in the blind soil standards are presented in Table 4 expressed in percent. The standard deviation of each fractional deviation is also given in Table 4. Both the gamma-ray and x-ray spectrometry results for ^{241}Am are given in Table 4. On the average, the concentration of ^{239}Pu was underestimated $14 \pm 19\%$ when no ^{241}Am was present and was underestimated $18 \pm 16\%$ when the standard contained ^{241}Am . The source of this apparent systematic error has not yet been identified but may be due to spectral shifts following the acquisition of the ^{239}Pu and ^{241}Am component calibration spectra, differences in plutonium isotopic abundances between the component calibration standard and the blind soil standards, or it may be due to an error in the x-ray spectrum analysis algorithm. The concentration of ^{241}Am measured by gamma-ray spectrometry was overestimated an average of $8 \pm 8\%$. The measured concentrations of ^{60}Co were biased low an average of $23 \pm 8\%$, while those of ^{137}Cs showed no significant bias. The apparent biases in the gamma-ray results for ^{241}Am and ^{60}Co indicate that the absolute counting efficiencies measured at the low and high gamma-ray energies might be in error.

Figure 12. Deviations of ^{241}Am concentrations measured by x-ray spectrometry from known ^{241}Am concentrations in blind soil standards.

Figure 13. Deviations of ^{241}Am concentrations measured by gamma-ray spectrometry from known ^{241}Am concentrations in blind soil standards.

Figure 14. Deviations of ^{60}Co concentrations measured by gamma-ray spectrometry from known ^{60}Co concentrations in blind soil standards.

Figure 15. Deviations of ^{137}Cs concentrations measured by gamma-ray spectrometry from known ^{137}Cs concentrations in blind soil standards.

Table 4. Mean fractional deviations of the activity concentrations measured with the photon spectrometer from known concentrations in blind soil standards.

Ident. Number	Known concentration		Mean fractional deviation $\pm$ std deviation (%) ^a				
	²³⁹ Pu (pCi/g)	²⁴¹ Am (pCi/g)	²³⁹ Pu	²⁴¹ Am		⁶⁰ Co	¹³⁷ Cs
				gamma-ray	x-ray		
1	100.6 $\pm$ 1.1	NA ^b	- 20 $\pm$ 30				
2	78.6 $\pm$ 0.9	NA	- 20 $\pm$ 30				
3	224 $\pm$ 3	NA	- 16 $\pm$ 16				
4	281 $\pm$ 3	NA	- 4 $\pm$ 10				
5	175.8 $\pm$ 1.9	NA	- 18 $\pm$ 8				
6	98.9 $\pm$ 1.3	52.6 $\pm$ 1.3	- 15 $\pm$ 14	16 $\pm$ 5	3 $\pm$ 4		
7	101.4 $\pm$ 1.1	NA	- 10 $\pm$ 30			- 22 $\pm$ 5	- 1 $\pm$ 4
8	239.2 $\pm$ 1.0	NA	- 30 $\pm$ 30			- 23 $\pm$ 14	0 $\pm$ 3
9	108.1 $\pm$ 0.4	42.8 $\pm$ 0.2	- 28 $\pm$ 19	7 $\pm$ 3	1 $\pm$ 7	- 20 $\pm$ 5	
10	492 $\pm$ 6	38.0 $\pm$ 0.2	- 20 $\pm$ 6	6 $\pm$ 2	- 9 $\pm$ 11		
11	503 $\pm$ 6	10 $\pm$ 2	- 14 $\pm$ 3	2 $\pm$ 12	- 20 $\pm$ 30		
12	471 $\pm$ 5	NA	- 15 $\pm$ 8			- 24 $\pm$ 12	
13	453 $\pm$ 5	NA	- 22 $\pm$ 19				- 1 $\pm$ 4
14	187 $\pm$ 2	NA	- 20 $\pm$ 20			- 20 $\pm$ 2	- 4 $\pm$ 3
15	97.4 $\pm$ 1.1	NA	- 14 $\pm$ 17			- 29 $\pm$ 11	- 1 $\pm$ 4
16	142.8 $\pm$ 1.6	NA	0 $\pm$ 20				0 $\pm$ 3
17	491 $\pm$ 5	NA	0 $\pm$ 6				
18	162.9 $\pm$ 1.8	78.0 $\pm$ 0.4	- 10 $\pm$ 30	9 $\pm$ 1	- 7 $\pm$ 9		
19	96.9 $\pm$ 1.1	NA	- 10 $\pm$ 20			- 20 $\pm$ 4	
20	199 $\pm$ 2	42.1 $\pm$ 0.2	- 20 $\pm$ 30	5 $\pm$ 5	8 $\pm$ 19		- 1 $\pm$ 5

a. For each analysis, the fractional deviation in percent was calculated as the measured concentration minus the known concentration divided by the known concentration times 100.

b. None added.

6.2 Large-Area Ionization Chamber Alpha Spectrometers

The 20 soil standards prepared on 25.4-cm diameter steel pans before the start of the field test were analyzed along with 43 blank CTP soil samples during 2 days of testing on generator power, while the RTML was still parked adjacent to but separated from the permanent laboratory buildings at TRA. The RTML was then relocated to the CTP site, and a formal demonstration was carried out. The same 20 soil standards were again mixed randomly with 53 freshly-prepared CTP soil blanks and analyzed. In a 5-hour time period of continuous work, 33 prepared samples were analyzed by the PI using two ionization chambers for an average rate of about six samples per hour. Because a single vacuum pump was used to evacuate both chambers consecutively, the average throughput can undoubtedly be increased by addition of a second pump to permit both chambers to be used independently of each other. The results obtained for ^{239}Pu by alpha spectrometry for both the preliminary and the formal demonstrations are shown in Table 5 along with the known values of the standard soils. The uncertainties reported are the statistical uncertainties of all random components incurred anywhere in the entire measurement process propagated to the final result. The identification numbers assigned to the known standards during each test are also shown to

Table 5. Concentrations of ^{239}Pu in blind soil standards measured by direct large-area ionization chamber alpha spectrometry.

Known value		Measured value			
		TRA		CTP	
No.	pCi/g	No.	pCi/g	No.	pCi/g
1	1.006 $\pm$ 0.011E2	42	1.28 $\pm$ 0.18E2	3	9.6 $\pm$ 1.5 E1
2	7.86 $\pm$ 0.09 E1	6	9.2 $\pm$ 1.1 E1	6	1.04 $\pm$ 0.16E2
3	2.24 $\pm$ 0.03 E2	52	2.4 $\pm$ 0.2 E2	9	2.4 $\pm$ 0.3 E2
4	2.81 $\pm$ 0.03 E2	56	3.1 $\pm$ 0.3 E2	12	3.0 $\pm$ 0.3 E2
5	1.758 $\pm$ 0.019E2	15	1.7 $\pm$ 0.2 E2	15	1.5 $\pm$ 0.2 E2
6	9.89 $\pm$ 0.13 E1	2	9.9 $\pm$ 1.6 E1	18	9.0 $\pm$ 1.5 E1
7	1.014 $\pm$ 0.011E2	23	1.09 $\pm$ 0.15E2	21	1.05 $\pm$ 0.16E2
8	2.392 $\pm$ 0.010E2	60	2.7 $\pm$ 0.3 E2	24	2.5 $\pm$ 0.3 E2
9	1.081 $\pm$ 0.004E2	57	9.4 $\pm$ 1.4 E1	59	1.04 $\pm$ 0.16E2
10	4.92 $\pm$ 0.06 E2	44	4.2 $\pm$ 0.3 E2	58	4.1 $\pm$ 0.4 E2
11	5.03 $\pm$ 0.06 E2	45	4.2 $\pm$ 0.3 E2	57	4.3 $\pm$ 0.4 E2
12	4.71 $\pm$ 0.05 E2	9	4.0 $\pm$ 0.4 E2	56	4.8 $\pm$ 0.4 E2
13	4.53 $\pm$ 0.05 E2	61	4.0 $\pm$ 0.4 E2	51	3.8 $\pm$ 0.3 E2
14	1.87 $\pm$ 0.02 E2	11	1.51 $\pm$ 0.13E2	48	1.8 $\pm$ 0.2 E2
15	9.74 $\pm$ 0.11 E1	13	7.7 $\pm$ 0.7 E1	40	9.8 $\pm$ 1.5 E1
16	1.428 $\pm$ 0.016E2	59	1.6 $\pm$ 0.2 E2	39	1.11 $\pm$ 0.16E2
17	4.91 $\pm$ 0.05 E2	55	5.4 $\pm$ 0.4 E2	33	4.8 $\pm$ 0.4 E2
18	1.629 $\pm$ 0.018E2	37	2.2 $\pm$ 0.3 E2	36	1.8 $\pm$ 0.2 E2
19	9.69 $\pm$ 0.11 E1	26	1.44 $\pm$ 0.19E2	30	1.28 $\pm$ 0.18E2
20	1.99 $\pm$ 0.02 E2	28	1.8 $\pm$ 0.2 E2	27	1.8 $\pm$ 0.2 E2

demonstrate the random manner in which they were mixed with the CTP blanks into the analytical lineup.

Every sample containing added ^{239}Pu and ^{241}Am gave peaks in the proper energy ROI that were detected clearly, and the quantitative values obtained showed excellent agreement with the known values within the statistics of the measurements for 10-minute counts on 100 mg of sample. Of the 40 measurements made on the blind soil standards, 33 measurements (83%) agreed with the known values within two standard deviations of the difference, and the remaining seven measurements were within three standard deviations. No analytical value was more than three standard deviations away from the known. Samples not containing added alpha activity gave spectra that were equally clear and unequivocal with the total number of counts in the ^{239}Pu ROI averaging about three counts with a maximum of eight for the 10-minute spectra.

6.3 Alpha Continuous Air Monitors

6.3.1 Energy Calibration

An energy calibration standard containing $1.91 \pm 0.03 \text{ nCi } ^{237}\text{Np}$, $1.84 \pm 0.03 \text{ nCi } ^{239}\text{Pu}$, $2.23 \pm 0.04 \text{ nCi } ^{241}\text{Am}$, and $2.27 \pm 0.03 \text{ nCi } ^{244}\text{Cm}$ was specially prepared for each of the four alpha CAMs. In each case, the activities were dissolved in nitric acid, and the acid was deposited with a micropipet on a thin, 47-mm diameter, stainless steel disk. A thin ring was tack-welded to the perimeter of the disk to duplicate the geometry of the sample collection filter and hold-down ring used during routine air sampling. The solution was smeared as uniformly as practical over the disk using the tip of the pipet. The zero and gain of each alpha CAM spectrometer was measured by installing the corresponding standard in the CAM filter holder assembly and counting it, usually for 60 minutes, to obtain 10,000 or more counts in each of the four alpha peaks. The average energies of the alpha particles emitted by the four TRU isotopes are 4.781, 5.155, 5.480, and 5.796 MeV.

Zero and gain values measured before and during the field test are presented in Appendix B, Table B-1. The results show that the gains of all four alpha CAMs varied by no more than 0.2 keV/channel over a 43-day period. Operating the CAMs outside on generator power did not produce any gain shifts. The results in Table B-1 indicate that modest zero shifts did occur when the CAMs were moved to the CTP. Following their installation at the CTP, CAM 4 exhibited the largest zero shift, which was + 75 keV or about + 5 channels.

The positions of the centroids of ^{237}Np , ^{239}Pu , ^{241}Am , and ^{244}Cm in energy calibration spectra measured before and during the field test are given in Appendix B, Table B-2. The results given in Tables B-1 and B-2 show that the energy calibrations of the four CAMs remained very stable over a 43-day period and were not significantly affected when the CAMs were operated outside and powered from a portable electric generator.

6.3.2 Counting Efficiency

The absolute counting efficiencies of the alpha CAMs were determined by measuring filter standards containing $1.84 \pm 0.03 \text{ pCi of } ^{239}\text{Pu}$. In each case, the ^{239}Pu was coprecipitated with $280 \mu\text{g}$ of NdF_3 over a 40.3-mm diameter area on a 47-mm diameter Metrical polypropylene filter with 0.1- μm pores. The average mass load on each filter standard was, therefore, about $22 \mu\text{g/cm}^2$.

Since the filter hold-down rings positioned over the sample collection filters during routine samplings had only 33-mm diameter openings, the ^{239}Pu activity on each standard within the ring opening had to be measured. Each filter standard was counted in a Ludlum gross alpha counter for 20 minutes and was then recounted centered beneath its corresponding filter hold-down ring. In all four cases, the count rate with the ring in place was $75.3 \pm 0.8\%$ of the count rate measured without the ring. Therefore, the effective ^{239}Pu activity on each of the four filter standards was 1.39 ± 0.03 pCi.

The absolute counting efficiencies measured for CAMs 1, 2, 3, and 4 were, respectively, 0.059 ± 0.001 , 0.058 ± 0.001 , 0.061 ± 0.001 , and 0.059 ± 0.001 counts per disintegration (c/d). These counting efficiencies are about a factor of 5 lower than the counting efficiency of the ANL-W alpha CAM that was evaluated experimentally during FY-90. The original ANL-W alpha CAM was not equipped with a collimator, and its detector was positioned only 3 mm from the sample collection filter. The obvious reason for the lower counting efficiencies of the RTML alpha CAMs compared to the original ANL-W alpha CAM is the 4-mm thick collimator that was installed over the face of each silicon detector. The RTML alpha CAM counting efficiencies are, however, about a factor of 2 higher than the counting efficiency of the Merlin Gerin Edgar alpha CAM evaluated in FY-91. The latter CAM is equipped with a vane-type collimator and uses a detector-filter separation of 11 mm.

6.3.3 Resolution

While the collimators reduced counting efficiency, they provided a significant benefit by improving spectral resolution and lowering the background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI. This is evident in Figure 16, which is a plot of a spectrum of ambient air measured at TRA with alpha CAM 4 after a sampling time of 69 hours. During this May 21-24, 1993, sampling, all four CAMs were located inside a laboratory at TRA and were powered from plant power. As shown in Figure 16, the resolution of the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po background alpha peaks is excellent. Similar plots of the spectra measured with CAMs 1, 2, and 3 during this same sampling are presented in Appendix B, Figures B-1, B-2, and B-3, respectively. The spectrum of ambient air measured at the CTP June 27, 1993, with alpha CAM 4 after a sampling time of 5-1/2 hours is shown in Figure 17. The spectrum shown in Figure 17 is representative of the spectra measured with the other three CAMs on the same date and shows that spectral resolution was severely degraded during this sampling at the CTP. The poor resolution was the result of high concentrations of airborne dust within the CTP tent.

The spectra shown in Figures 16, B-1, B-2, and B-3 each contain a spurious alpha peak at 6.51 MeV, about 500 keV above the $^{218}\text{Po}/^{212}\text{Bi}$ peak, and another at 8.08 MeV, about 350 keV above the ^{214}Po peak. Tests were conducted that showed that these peaks were probably not caused by electrical noise. One possible explanation for these two peaks is that a small fraction of the aerosols passing through the impactor became attached to surfaces of the collimator rather than to the sample collection filter. Because the collimator was closer to the detector than the sample collection filter, alpha particles emitted from surfaces of the collimator traversed less air and consequently lost less energy before striking the detector than alpha particles emitted from the sample collection filter. The two spurious peaks are likely $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po . Their presence does not affect spectral analysis.

Figure 16. Spectrum collected at TRA May 21-24, 1993, with alpha CAM 4 showing the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks after sampling time of 69 hours.

Figure 17. Spectrum collected at the CTP June 27, 1993, with alpha CAM 4 showing the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks after a sampling time of 5-1/2 hours.

The full widths of the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks at one-half and one-tenth their maximum heights, which are normally referred to as full width half-maximum (FWHM) and full width tenth-maximum (FWTM), for samplings performed during May and June 1993 are summarized in Table 6. For each sampling, Table 6 also provides the average background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI, which ranged from 3.71 to 5.60 MeV for all four CAMs. For the spectrum shown in Figure 18, this ROI ranged from channel 197 through channel 325. (For the sake of completeness, the FWHM values of the four alpha peaks in the energy calibration spectra measured during this same period are given in Appendix B, Table B-3). The results given in Table 6 show that the average FWHM of the 6.00 MeV $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak for samplings performed inside a laboratory at TRA were 179, 176, 163, and 163 keV for CAMs 1, 2, 3, and 4, respectively. Similar results for the 7.69 MeV ^{214}Po alpha peak were 141, 140, 116, and 123 keV, respectively. Average FWTM values of the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks for the same samplings ranged from 386 keV (CAM 4) to 464 keV (CAM 2) and from 289 (CAM 3) to 348 keV (CAM 1), respectively.

These resolution values are excellent. From an examination of the resolution results for the original ANL CAM that are presented in Reference 9, it is obvious that the RTML alpha CAM has better alpha peak resolution than the original ANL alpha CAM. During samplings performed with the ANL alpha CAM in FY-90, in a laboratory setting similar to the one used during the current work, the average FWHMs of the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks were 325 and 353 keV, respectively, and the average FWTMs of the same peaks were 746 and 903 keV, respectively.

The excellent resolution of the RTML alpha CAM provides an important benefit—a low background count in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI. As shown in Table 6, the average background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI for samplings of ambient air performed in a laboratory setting were 0.23, 0.22, 0.14, and 0.15 counts per minute (cpm) for CAMs 1, 2, 3, and 4, respectively. For several samplings performed with CAM 3, the average background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI was less than 0.1 cpm. Background count rates measured for the ANL alpha CAM in FY-90 ranged between 7 and 8 cpm in an ROI that encompassed only the ^{239}Pu alpha peak (3.00 to 5.29 MeV). Because the background count rates for the ANL alpha CAM would have been significantly higher if the ROI previously used had extended to 5.60 MeV, under conditions of modest airborne dust concentration the collimator reduced the background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI by at least a factor of between 30 and 60. Because Currie's method the LLD concentration is proportional to the square root of the number of background counts and is inversely proportional to the counting efficiency, the reduction in background count rate more than compensates for the loss of counting efficiency, and the net result is that the LLD concentrations for the RTML alpha CAMs under conditions of modest airborne dust loading are at least 10 to 35% better than that of the ANL alpha CAM. Based on LLD concentrations previously reported⁹ for the ANL alpha CAM, the LLD concentrations for the four RTML alpha CAMs are all less than 1 derived air concentration (DAC) (0.002 pCi/L) in 1 hour when airborne dust concentrations are below 0.01 $\mu\text{g}/\text{L}$.

As shown in Table 6, the average count rates in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI during the two samplings performed at the CTP on June 27 and 29, 1993, were as much as 60 times higher than average count rates measured when the CAMs were operated in a laboratory setting. The poor resolution and high background count rates on these two sampling dates can be attributed to extremely high concentrations of dust in the air within the tent that enclosed the CTP. At the end of the 5 1/2-hour sampling performed June 27, the mass of dust collected on the four alpha CAM sample collection filters ranged between 95 and 121 mg. At the end of the 3-hour sampling performed June 29, the

Table 6. FWHM and FWTM of $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks and average background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI for selected samplings of ambient air performed using the alpha CAMs.

Sampling date(s)	Time (min)	Filter pore size (μm)	²¹⁸ Po/ ²¹² Bi		²¹⁴ Po		Background count rate (cpm)
			FWHM (keV)	FWTM (keV)	FWHM (keV)	FWTM (keV)	
CAM 1							
05/14-17/93	3,941	3.0	180	490	141	348	0.327
05/17-19/93	2,462	1.0	187	446	139	341	0.194
05/19-21/93	931	1.0	183	399	137	327	0.171
05/19-21/93	2,373	1.0	180	459	141	338	0.232
05/21-24/93	4,144	1.0	192	440	148	353	0.199
05/26/93	155	1.0	ND ^a	ND	144	337	0.129
06/15-17/93	2,584	1.0	170	468	140	360	0.219
06/17-18/93	1,622	1.0	164	462	144	372	0.242
06/27/93	240	1.0	256	ND	252	1,308	7.063
06/27/93	333	1.0	263	ND	254	ND	7.095
06/29/93	181	3.0	153	ND	122	1,280	2.966
Average ^b :			179	452	141	348	0.226
Standard deviation:			10	28	4	15	0.051
CAM 2							
05/14-17/93	3,914	3.0	231	593	166	412	0.518
05/17-19/93	2,462	1.0	185	478	135	351	0.335
05/19-21/93	931	1.0	155	461	136	338	0.287
05/19-21/93	2,373	1.0	176	476	135	333	0.330
05/21-24/93	4,144	1.0	186	451	148	348	0.122
05/26/93	155	1.0	ND	ND	123	319	0.091
06/15-17/93	2,584	1.0	163	460	145	348	0.130
06/17-18/93	1,622	1.0	191	460	141	339	0.129
06/27/93	240	1.0	257	ND	274	ND	5.874
06/27/93	333	1.0	178	ND	276	ND	6.003
06/29/93	181	3.0	88	ND	144	1055	1.436
Average:			176	464	140	343	0.222
Standard deviation:			14	11	6	7	0.106

a. Peak resolution was not determined because the peak did not contain a sufficient number of counts.

b. Results for 05/26, 06/27, and 06/29/93 were not included in the calculated average and standard deviation.

Table 6. (continued).

Sampling date(s)	Time (min)	Filter pore size (μm)	²¹⁸ Po/ ²¹² Bi		²¹⁴ Po		Background count rate (cpm)
			FWHM (keV)	FWTM (keV)	FWHM (keV)	FWTM (keV)	
CAM 3							
05/14-17/93	3,940	3.0	158	399	116	293	0.243
05/17-19/93	2,462	1.0	166	409	115	294	0.144
05/19-21/93	931	1.0	159	355	112	273	0.092
05/19-21/93	2,372	1.0	185	393	119	283	0.176
05/21-24/93	4,144	1.0	164	390	118	288	0.118
05/26/93	155	1.0	ND	ND	125	364	0.091
06/15-17/93	2,584	1.0	155	399	113	288	0.089
06/17-18/93	1,622	1.0	152	388	122	306	0.093
06/27/93	240	1.0	244	ND	207	1504	8.186
06/27/93	333	1.0	251	ND	210	1511	7.871
06/29/93	181	3.0	252	ND	174	855	2.810
Average:			163	390	116	289	0.136
Standard deviation:			11	17	4	10	0.057
CAM 4							
05/14-17/93	3,903	3.0	147	392	115	288	0.198
05/17-19/93	2,462	1.0	155	372	120	288	0.142
05/19-21/93	931	1.0	162	356	107	273	0.119
05/19-21/93	2,372	1.0	153	380	121	278	0.204
05/21-24/93	4,144	1.0	151	380	113	285	0.109
06/15-17/93	2,584	1.0	183	394	164	352	0.128
06/17-18/93	1,622	1.0	188	427	122	342	0.160
06/27/93	240	1.0	246	ND	231	1439	4.505
06/27/93	333	1.0	260	ND	225	1574	4.203
06/29/93	181	3.0	175	ND	147	583	1.745
Average:			163	386	123	301	0.151
Standard deviation:			16	22	19	32	0.038

mass of collected dust ranged from 31 to 59 mg. Using an average flow rate of 19.5 L/min, this means during the sampling performed June 27, the air passing through the alpha CAM sample collection filters contained about 3 µg/L of dust. Because the CAM impactors probably removed greater than 90% of the dust entrained in the air that entered the impactors, the dust loading in the air within the tent was likely tens of micrograms per liter or several thousand times higher than it was in the laboratory.

The maximum and average background concentrations of airborne $^{239}\text{Pu}/^{241}\text{Am}$, expressed as pCi/L that were calculated using Equations 6 and 7 are presented in Table 7 for the sampling of ambient air performed May 21-24, 1993. Similar results for alpha CAMs 1, 2, and 3 for the same sampling are presented in Appendix B, Tables B-4, B-5, and B-6, respectively. In each of these tables, the sampling date and time of day at the end of each sampling (analysis) interval are shown in columns 1 and 2, respectively. The average flow rate during each sampling interval is given in column 3, expressed as liters per minute. The elapsed real time since the start of sampling is listed in column 4. The total and net counts in the 3.71 to 5.60 MeV ROI that encompasses both the ^{239}Pu and ^{241}Am alpha peaks are listed in columns 5 and 6, respectively. The average airborne $^{239}\text{Pu}/^{241}\text{Am}$ concentration since the start of sampling, calculated at the end of each sampling interval, and its uncertainty are given in columns 7 and 8, respectively. The maximum airborne $^{239}\text{Pu}/^{241}\text{Am}$ concentration during each sampling interval and its uncertainty are listed in columns 9 and 10, respectively. At the present time, the percent fractional uncertainties in the average and maximum $^{239}\text{Pu}/^{241}\text{Am}$ concentration are calculated as the square root of the reciprocal of the net counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI. The equation used to calculate uncertainties will be modified during FY-94 to take into account the uncertainties in the measured background counts, the background counts estimated using Equation 9, counting efficiency, and average flow rate during the sampling interval.

As shown in Table 7, for the May 21-24 sampling of ambient air performed with CAM 4, the total number of counts accumulated in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI after 75-1/2 hours was 526, which equates to an average background count rate of 0.12 cpm over the entire sampling. For CAM 4, the net counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI, estimated using the method described in Section 5.4.3, were consistently positive and were usually between 20 and 30% of the total counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI for the corresponding sampling interval. As shown in Tables B-4, B-5, and B-6, the average background count rates measured for CAMs 1, 2, and 3 after 75-1/2 hours were 0.21, 0.12, and 0.12 cpm, respectively. In the case of CAM 1, net counts were negative during the first 2 days of sampling and then remained positive during the remainder of the sampling. Net counts measured with CAM 2 were usually negative while those measured with CAM 3 were mainly positive. For CAMs 1, 2, and 3 the number of net counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI calculated for any given sampling interval was typically less than 20% of the total counts in the ROI. Theoretically, the net counts should have always been identically zero since no TRU activity was present in the air that was sampled. The results show that the method developed for estimating the background counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI worked reasonably well but could be refined.

Maximum background concentrations of airborne $^{239}\text{Pu}/^{241}\text{Am}$ were calculated using Equation 6 and are presented in column 9 of Tables 7, B-4, B-5, and B-6. In the case of CAM 4, during any given one-hour interval during the May 21-24 sampling they ranged from 9×10^{-6} pCi/L between 5 and 6 hours after the start of sampling to about 2×10^{-3} pCi/L (1 DAC) near the end of sampling. Average concentrations since the start of sampling, which were calculated using Equation 7, are given

Table 7. Results for air sampling performed at TRA May 21-24, 1993, with alpha CAM 4.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
52193	1216	272.2	60.2	0.	1.	1.550E-05	100.0	1.550E-05	100.0
	1316	271.9	120.2	3.	3.	1.165E-05	57.8	4.672E-05	57.8
	1416	272.1	180.3	5.	5.	8.637E-06	44.8	7.781E-05	44.8
	1516	271.6	240.3	8.	8.	7.779E-06	35.4	1.247E-04	35.4
	1616	271.2	300.4	10.	-6.	-3.615E-06	41.6	-9.058E-05	41.6
	1716	271.1	360.4	15.	1.	2.548E-07	100.0	9.200E-06	100.0
	1816	270.8	420.5	19.	5.	1.481E-06	46.4	7.281E-05	46.4
	1916	270.7	480.5	21.	7.	1.647E-06	38.5	1.058E-04	38.5
	2016	271.0	540.6	23.	9.	1.704E-06	33.7	1.383E-04	33.7
	2116	270.4	600.6	26.	9.	1.328E-06	34.4	1.333E-04	34.4
	2216	270.4	660.7	28.	9.	1.221E-06	32.6	1.481E-04	32.6
	2316	270.6	720.7	32.	14.	1.509E-06	26.9	2.179E-04	26.9
052293	16	271.5	780.8	37.	5.	4.382E-07	46.0	7.399E-05	46.0
	116	271.8	840.8	42.	10.	8.316E-07	31.0	1.627E-04	31.0
	216	272.2	900.9	48.	5.	3.485E-07	44.7	7.813E-05	44.7
	316	272.5	961.0	55.	12.	7.442E-07	28.7	1.898E-04	28.7
	416	272.1	1021.0	61.	13.	7.003E-07	27.9	2.019E-04	27.9
	516	272.6	1081.1	69.	21.	9.967E-07	22.1	3.217E-04	22.1
	616	272.8	1141.1	72.	18.	7.857E-07	23.6	2.823E-04	23.6
	716	273.2	1201.2	78.	27.	1.043E-06	19.5	4.149E-04	19.5
	816	273.3	1261.2	85.	21.	7.557E-07	21.8	3.314E-04	21.8
	916	273.4	1321.3	91.	34.	1.083E-06	17.4	5.210E-04	17.4
	1016	273.6	1381.3	104.	44.	1.299E-06	15.3	6.833E-04	15.3
	1117	273.1	1441.4	106.	44.	1.199E-06	15.2	6.877E-04	15.2
	1217	273.1	1501.4	113.	48.	1.195E-06	14.6	7.434E-04	14.6
	1317	273.4	1561.5	121.	30.	6.824E-07	18.5	4.591E-04	18.5
	1417	272.7	1621.5	133.	40.	8.628E-07	15.9	6.276E-04	15.9
	1517	273.3	1681.6	142.	44.	8.633E-07	15.4	6.740E-04	15.4
	1617	272.7	1741.6	149.	43.	8.046E-07	15.4	6.754E-04	15.4
	1717	272.4	1801.7	156.	48.	8.213E-07	14.7	7.386E-04	14.7
	1817	272.0	1861.7	162.	50.	8.077E-07	14.4	7.767E-04	14.4
	1917	271.6	1921.8	168.	37.	5.671E-07	16.6	5.816E-04	16.6
	2017	271.3	1981.8	174.	41.	5.902E-07	15.8	6.447E-04	15.8
	2117	271.4	2041.9	181.	43.	5.802E-07	15.4	6.725E-04	15.4
	2217	272.2	2102.0	187.	31.	3.898E-07	18.2	4.771E-04	18.2
	2317	272.3	2162.0	193.	33.	3.932E-07	17.6	5.093E-04	17.6
052393	17	272.5	2222.1	204.	40.	4.541E-07	16.0	6.208E-04	16.0
	117	272.9	2282.1	207.	31.	3.310E-07	18.2	4.767E-04	18.2
	217	273.1	2342.2	219.	44.	4.452E-07	15.4	6.748E-04	15.4
	317	273.0	2402.2	224.	30.	2.945E-07	18.3	4.699E-04	18.3
	417	273.8	2462.3	228.	34.	3.118E-07	17.4	5.212E-04	17.4
	517	273.3	2522.3	238.	45.	3.970E-07	15.1	6.972E-04	15.1
	617	273.2	2582.4	242.	45.	3.777E-07	15.1	6.960E-04	15.1
	717	273.3	2642.4	257.	62.	4.963E-07	13.0	9.573E-04	13.0
	817	273.5	2702.5	259.	65.	4.981E-07	12.7	1.004E-03	12.7
	917	273.3	2762.5	263.	37.	2.690E-07	16.7	5.672E-04	16.7
	1017	273.1	2822.6	271.	44.	3.097E-07	15.3	6.824E-04	15.3
	1117	272.8	2882.6	279.	50.	3.400E-07	14.3	7.818E-04	14.3
	1217	272.7	2942.7	289.	58.	3.762E-07	13.4	9.022E-04	13.4
	1317	272.5	3002.8	293.	59.	3.673E-07	13.2	9.179E-04	13.2

Table 7. (continued).

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	$^{239}\text{Pu}/^{241}\text{Am}$ ROI (3.71 to 5.60 MeV)		$^{239}\text{Pu}/^{241}\text{Am}$ Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
052493	1417	272.5	3062.8	298.	63.	3.752E-07	12.9	9.750E-04	12.9
	1517	272.0	3122.9	303.	70.	4.009E-07	12.2	1.086E-03	12.2
	1617	272.3	3182.9	313.	79.	4.374E-07	11.5	1.229E-03	11.5
	1717	272.7	3243.0	320.	83.	4.443E-07	11.2	1.294E-03	11.2
	1817	272.0	3303.0	328.	88.	4.498E-07	11.0	1.362E-03	11.0
	1917	271.9	3363.1	334.	76.	3.786E-07	11.7	1.189E-03	11.7
	2017	272.2	3423.1	343.	85.	4.087E-07	11.1	1.329E-03	11.1
	2118	272.8	3483.2	350.	86.	3.956E-07	11.1	1.329E-03	11.1
	2218	273.2	3543.2	360.	99.	4.405E-07	10.4	1.529E-03	10.4
	2318	273.4	3603.3	364.	87.	3.749E-07	11.0	1.345E-03	11.0
	18	273.5	3663.3	378.	97.	4.048E-07	10.5	1.500E-03	10.5
	118	273.7	3723.4	389.	110.	4.443E-07	9.9	1.700E-03	9.9
	218	273.7	3783.4	396.	115.	4.489E-07	9.7	1.773E-03	9.7
	318	273.8	3843.5	399.	114.	4.321E-07	9.7	1.761E-03	9.7
	418	273.9	3903.6	408.	120.	4.400E-07	9.5	1.849E-03	9.5
	518	273.8	3963.6	417.	111.	3.963E-07	9.8	1.718E-03	9.8
	618	273.8	4023.7	428.	123.	4.251E-07	9.4	1.898E-03	9.4
	718	273.6	4083.7	439.	128.	4.297E-07	9.2	1.980E-03	9.2
	818	273.8	4143.8	450.	133.	4.332E-07	9.0	2.053E-03	9.0
	941	273.7	4227.0	460.	127.	3.995E-07	9.2	1.025E-03	9.2
	1041	273.6	4287.1	473.	118.	3.589E-07	9.5	1.825E-03	9.5
	1141	273.7	4347.1	487.	115.	3.419E-07	9.6	1.784E-03	9.6
	1241	273.8	4407.2	498.	120.	3.470E-07	9.4	1.860E-03	9.4
	1341	274.1	4467.3	511.	124.	3.493E-07	9.3	1.923E-03	9.3
	1441	274.3	4527.3	526.	125.	3.426E-07	9.3	1.935E-03	9.3

in column 7 of the tables. They declined from about 2×10^{-5} pCi/L after the first hour of sampling to about 3×10^{-7} pCi/L after 75-1/2 hours.

Analysis results for the 5 1/2-hour sampling of ambient air performed June 27, 1993, at the CTP are given in Table 8. Similar results for alpha CAMs 1, 2, and 3 for the June 27 sampling are presented in Appendix B, Tables B-7, B-8, and B-9, respectively. As shown in Table 8, in the case of CAM 4, the total number of counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI after 5-1/2 hours was 1,389, which equates to an average background count rate of 4.2 cpm over the sampling. The net counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI are spurious results and indicate a deficiency in a subroutine of the alpha CAM spectrum analysis algorithm. Before Equation 8 is applied to estimate background counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI, the centroid of the $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak at 6.00 MeV must first be found. The subroutine used during the field test searched for the centroid from channel 250 through channel 430. The results given in Table 8 show that the code passed over the $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak and identified a channel with an energy well above 6.00 MeV as being the centroid of the $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak. To avoid this problem in the future, the code must be corrected to limit the upper end of the search range to an energy only slightly above 6.00 MeV. However, this modification will not solve the fundamental difficulty of estimating background counts in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI when the air being sampled contains high concentrations of dust. If high concentrations of airborne dust will be the rule rather than the exception during future buried waste remediation operations, serious consideration should be given to equipping the alpha CAMs with moving filters to ensure that good spectral resolution is maintained during air monitoring.

6.4 Operating Costs

The direct labor cost per sample during routine operation of the RTML was estimated using the following assumptions: (a) the sample preparation and analysis laboratories will be staffed for 8 hours each day with four senior technicians whose burdened cost is \$65/hour, and (b) the sample throughput rates for the photon and ionization chamber spectrometers will be 79/day and 42/8-hour shift, respectively, which are the maximum throughputs for the two measurement systems based upon the results of the field test. Therefore, a total of 121 samples can be analyzed during a 24-hour period at a labor cost of \$2,080 for a single 8-hour shift. For this case of maximum throughput, the labor cost per sample analyzed is then about \$17.

The costs of consumables such as laboratory tissues, ethanol, drying pans, discarded sample containers, and fuel for the electric generators have not been estimated in detail. The total cost of items consumed during a 24-hour period is probably less than \$100. If we estimate \$1/sample analyzed, then the total cost to analyze a sample, again assuming a throughput of 121 samples/day, is about \$18.

6.5 Waste Generation

The types of solid waste generated during RTML operation are (a) damaged or contaminated soil drying pans, (b) tissues used to clean the sieves, sample containers, etc., (c) weighing papers, (d) damaged or contaminated plastic sample containers and steel sample pans used with the photon and ionization chamber spectrometers, and (e) blotting paper used to cover surfaces inside the fume hood in the preparation trailer. The only liquid waste generated during routine operation is water

Table 8. Results for air sampling performed at the CTP June 27, 1993, with alpha CAM 4.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
62793	1007	269.5	30.1	12.	12.	7.513E-04	29.0	7.513E-04	29.0
	1037	269.8	60.1	41.	-13.	-2.025E-04	27.9	-8.108E-04	27.9
	1107	275.0	90.2	87.	48.	3.330E-04	14.6	2.961E-03	14.6
	1137	269.6	120.2	177.	164.	6.392E-04	8.2	1.028E-02	8.2
	1207	270.9	150.2	353.	-3904.	-9.747E-03	3.0	-2.439E-01	3.0
	1237	263.8	180.3	679.	-8005.	-1.394E-02	2.7	-5.137E-01	2.7
	1307	261.4	210.3	912.	397.	5.101E-04	5.6	2.567E-02	5.6
	1337	262.4	240.4	1083.	392.	3.870E-04	5.6	2.530E-02	5.6
	1407	261.2	270.4	1220.	-4756.	-3.718E-03	2.9	-3.075E-01	2.9
	1437	258.5	300.5	1309.	-3408.	-2.165E-03	3.0	-2.230E-01	3.0
	1507	257.6	330.5	1389.	-2925.	-1.540E-03	3.1	-1.922E-01	3.1

containing trace amounts of ethanol. The quantities of solid and liquid wastes generated during an 8-hour shift will probably be proportional to the number of samples analyzed. Based on the amount of waste generated during the field test, the average quantities of solid and liquid waste generated each day during routine operation of the RTML will likely be less than 100 g and 300 mL, respectively.

7. CONCLUSIONS

The field test of the RTML conducted at TRA and at the RWMC's CTP showed that the RTML is field deployable and the logistics of setting it up in the field are not unduly complicated. The RTML was moved from TRA to the CTP without incurring any damage to the trailers or the analytical instrumentation and made fully operational in less than 1 day. The demonstration showed that the RTML can be ready for field use by Environmental Restoration and Waste Management during FY-94.

During the field test the RTML sample preparation and analysis trailers and alpha CAMs were powered from portable electric generators. Powering the RTML with portable generators did not introduce noticeable electrical or microphonic noise. Spectral resolution, instrument background count rates, and LLD concentrations for the analytical instruments remained the same as they were when the RTML was powered from plant power. Under field conditions, LLD concentrations for ^{239}Pu , ^{241}Am , ^{60}Co , and ^{137}Cs by x-ray/gamma-ray spectrometry, using a 15-minute count time, were confirmed to be 40, 1, 5, and 5 pCi/g, respectively. LLD concentrations for ^{239}Pu and ^{241}Am by large-area ionization chamber alpha spectrometry were both 40 pCi/g for a 10-minute count.

Soil samples collected from the CTP were prepared for analysis by individuals who had no previous experience with the present sample preparation procedures. They were given demonstrations by the PIs and then were given time to prepare a few samples without guidance to become familiar with the process. After this minimal training, they then prepared the actual samples used in the demonstration. The same individuals also became proficient in operating the photon and ionization chamber spectrometers after only 1 day of training.

Including quality control and blind soil standards, over 300 samples were analyzed by photon spectrometry and 136 samples were analyzed by ionization chamber alpha spectrometry during the field test. The maximum number of samples analyzed during a 24-hour period with the photon spectrometer was 79. In a 5-hour time period of continuous work, 33 prepared samples were analyzed with the two ionization chamber alpha spectrometers for an average rate of about 6 samples/hour. If we assume that this rate can be maintained for 7 hours during an 8-hour shift, the total number of samples that can be analyzed with the ionization chambers during an 8-hour shift is 42. Based on these sample throughput rates, which together equate to 121 samples being prepared and analyzed in 1 day, the cost to analyze one sample is about \$18.

Each of the 96 analyses of the 20 blind soil standards performed by photon spectrometry identified and quantified one or more of the four radionuclides present in the standards. The concentration of ^{239}Pu was quantified by all analyses but two, and the concentration of ^{241}Am was quantified in all cases by both x-ray and gamma-ray spectrometry. On the average, the concentration of ^{239}Pu was underestimated by 14% when no ^{241}Am was present and was underestimated by 18% when the standard contained ^{241}Am . The source of this systematic error has not yet been identified. The results showed that the XRAY program had difficulty determining the ^{239}Pu component of the combined $^{239}\text{Pu}/^{241}\text{Am}$ x-ray peaks when the concentration of ^{241}Am was 50% or more of the concentration of ^{239}Pu . The concentrations of ^{241}Am measured by gamma-ray spectrometry were overestimated by an average of 8%. The measured concentrations of ^{60}Co were biased low an average of 23%. The systematic errors in the gamma-ray results for ^{241}Am and ^{60}Co indicate that the

absolute counting efficiencies used at the low and high energies are probably biased and should be remeasured, or the spectral data used to develop the efficiency curve should be reanalyzed.

Concentrations of ^{239}Pu measured by ionization chamber alpha spectrometry showed excellent agreement with the known values within the statistics of the measurements for 10-minute counts on 100-mg samples. Of the 40 measurements made on the blind soil standards, 33 measurements (83%) agreed with the known values within two standard deviations of the difference, and the remaining seven measurements were within three standard deviations. No analytical value was more than three standard deviations away from the known. Samples not containing added alpha activity gave spectra that were equally clear and unequivocal with no evidence of alpha peaks in the collected spectra. The total number of counts in the ^{239}Pu ROI for these blank samples averaged about 3 counts with a maximum of 8 for the 10-minute spectra.

No analyses results indicated the presence of manmade activity in either the 143 CTP soil samples analyzed by photon spectrometry or in the 96 CTP soil samples analyzed by ionization chamber alpha spectrometry. That is, no false positive results were obtained for any of the 239 blank soil samples that were analyzed.

While the collimators installed on the alpha CAMs reduced counting efficiency, they provided a significant benefit by improving spectral resolution and lowering the background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI. FWHM of the 6.00 MeV $^{218}\text{Po}/^{212}\text{Bi}$ alpha peak for samplings performed inside a laboratory at TRA ranged from 163 to 179 keV. FWHM of the 7.69 MeV ^{214}Po alpha peak ranged from 116 to 141 keV. These resolutions are much better than the alpha peak resolutions of the original ANL alpha CAM. The average background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI for samplings of ambient air performed in a laboratory setting were frequently below 0.2 cpm. Background count rates measured for the ANL alpha CAM in FY-90 ranged between 7 and 8 cpm. Under conditions of modest airborne dust concentration the collimator reduced the background count rate in the $^{239}\text{Pu}/^{241}\text{Am}$ ROI by at least a factor of between 30 and 60. The LLD concentrations for the four RTML alpha CAMs were shown to be all less than 1 DAC (0.002 pCi/L) in 1 hour when airborne dust concentrations were below 0.01 $\mu\text{g/L}$.

The poor resolution and high background count rates measured during two air samplings performed at the CTP can be attributed to extremely high concentrations of dust in the air within the tent that enclosed the CTP. The dust loading in the air within the tent was likely tens of micrograms per liter, or several thousand times higher than it was in the laboratory. If high concentrations of airborne dust will be the rule rather than the exception during future buried waste remediation operations, serious consideration should be given to equipping the alpha CAMs with moving filters to ensure that good spectral resolution is maintained during air monitoring.

8. RECOMMENDATIONS FOR FUTURE WORK

The following work is recommended for FY-94 to augment RTML analysis capabilities, document RTML instrumentation and analysis methodologies, and prepare the RTML for routine use by Environmental Restoration and Waste Management.

8.1 Beta Detector for ^{90}Sr

The RTML does not now have the capability to analyze samples for ^{90}Sr , which is a pure beta emitter. Traditional chemical methods used to determine ^{90}Sr in solid samples are quite laborious and time consuming. Analytical methods that might be used to screen samples for ^{90}Sr that do not require elaborate sample pretreatment and chemical separation should be investigated and selected methods should be evaluated experimentally. Analytical instruments that should be investigated include (a) large-area beta detector²⁹ developed recently at Pacific Northwest Laboratories (PNL), (b) large-area scintillation beta counter, (c) silicon detector electron spectrometer, and (d) bremsstrahlung spectrometer with either phoswich or germanium diode detector.

8.2 Alpha Spectral Analysis

Previous work has shown that, in the case of spectra collected using the alpha CAMs, the background under the ^{239}Pu and ^{241}Am alpha peaks is strongly affected by the concentration of dust in the air being sampled. Similarly, in the case of alpha spectra collected using the ionization chambers, the background and counting efficiency in the region of the TRU alpha peaks are affected by irregularities in the distribution of the sample over the sample pan or membrane filter. Alpha spectrum analysis techniques that have been developed and adopted by the RTML should be refined and tested experimentally to determine the adequacy of the background correction methods over a range of experimental conditions. The alpha CAMs should be tested in environments with relatively high airborne dust concentrations to determine the practical operating limits of the fixed-filter design. Methods of spraying soil suspensions on steel sample pans should be improved to decrease losses and increase spectral resolution. Additional experimental work should be done to determine which filters should be used to collect smear and air filter samples for analysis with the large-area ionization chamber alpha spectrometers. Because certain filters that provide excellent spectral resolution are also expensive, a number of candidate filters should be tested and the data subjected to a cost benefit analysis. Based on the results of these evaluations, existing RTML alpha spectrum analysis software will be modified to improve analysis reliability and sensitivity.

8.3 Photon Spectrum Analysis Code

The field test showed that the statistical calculations now performed by the LXRAY spectrum analysis code developed for the photon spectrometer are incomplete and underestimate the uncertainty in the reported plutonium and ^{241}Am concentrations (see Tables A-1 through A-4). The x-ray spectrum analysis software should be upgraded so that uncertainties are calculated including contributions from the finite size of the zero and gain shifts. The field test also revealed a systematic error in the ^{239}Pu activity concentrations measured with the photon spectrometer. The measured ^{239}Pu concentrations in blind soil standards were, on the average, biased low by about 16%. The source of this bias must be identified and corrected if optimal performance is to be achieved. The

upgrade of the LXRAY program should also incorporate changes that will permit the background scaling factor to search for the best background value. An off-line spectrum analysis capability should also be developed to permit the reanalysis of spectral data using different components and backgrounds. In addition, modifications to the XRAY program should be contemplated that will allow the XRAY program to use the VAXGAP gamma-ray results for ^{241}Am to calculate the ^{241}Am component of the combined $^{239}\text{Pu}/^{241}\text{Am}$ L-shell x-ray peaks.

8.4 Peer-Reviewed Journal Articles

Little has been published in refereed journals to document RTML instrumentation and analysis methodologies. Articles describing the analysis technologies developed for the RTML should be written and submitted to appropriate peer-reviewed journals.

8.5 Bar Code-Based Sample Analysis and Logging Data Base Code

During routine operation of the RTML, samples submitted for analysis must be uniquely identified, and analysts must be able to determine what analyses are to be performed on a given sample and, at any given time, need to be able to review the status of the analyses requested for a given sample. A bar code printer and several readers should be installed in the RTML and software written and implemented to provide RTML analysts with this capability. Implementing such a system will involve installing a video terminal, bar code printer, laser printer, and terminal server in the RTML sample preparation trailer and bar code readers on all terminals in both RTML trailers. The development of software for the sample logging and analysis data base for the RTML will be simplified by using as a starting point the sample tracking database and user interface currently used by the Radiation Measurements and Development Unit of EG&G Idaho, Inc.

8.6 Software Configuration and Management Plan

A software configuration and management plan should be written for the RTML that documents RTML software and describes formal procedures for making changes to RTML software.

8.7 Quality Assurance/Quality Control Program

A quality assurance/quality control (QA/QC) program for the RTML should be implemented and managed by the Data Management Section of the Radiation Measurements and Development Unit of EG&G Idaho. The implementation of a QA/QC program will involve writing QA/QC procedures for the RTML, participating in a sample cross check program, maintaining records needed to verify equipment calibration, and preparing an annual QA/QC report for the RTML.

8.8 Sample Containers for Photon Analysis Spectrometer

Only 500, 3-mm deep and 500, 5-mm deep sample containers were purchased during FY-93. Many of these containers were used to prepare calibration and test samples and many others were used during the field test of the RTML. An additional 5,000 containers should be purchased to provide an adequate number for future characterization and remediation analysis work.

8.9 Spare Equipment

The RTML is now equipped with two large-area ionization chamber alpha spectrometers. A third ionization chamber should be procured and dedicated to research and development so that experimentation is not interrupted when the RTML is deployed in the field in FY-94. In addition, certain critical components of the photon spectrometer and alpha CAMs (e.g., ADC and AIM) that cannot be procured within 30 days should be duplicated to avoid lengthy down times.

9. REFERENCES

1. C. V. McIsaac, et al., *Test Plan for Demonstration of Rapid Transuranic Monitoring Laboratory*, EGG-WTD-10758, June 1993.
2. P. G. Shaw, et al., *Test Plan for Contamination Control Related Experiments*, EGG-WM-9059, March 1990.
3. G. G. Loomis and C. V. McIsaac, "Rapid Monitoring for Transuranic Contamination During Buried Waste Retrieval," *Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education, Vol.I, Proceedings, Symposium on Waste Management at Tucson, Arizona, February 24-28, 1991*:723-728.
4. G. G. Loomis, *Technology Status Report Transuranic Contamination Control at INEL*, EGG-WTD-9899, September 1991.
5. C. V. McIsaac and C. R. Amaro, *Real-time Transuranic Monitoring with a Victoreen Model 758 Alpha Continuous Air Monitor*, EGG-WM-8774, September 1989.
6. C. V. McIsaac, et al., "Sensitivities of Alpha Continuous Air Monitors for Detection of Airborne ^{239}Pu ," *Waste Processing, Transportation, Storage and Disposal, Technical Programs and Public Education, Vol.II, Proceedings, Symposium on Waste Management at Tucson, Arizona, February 24-28, 1991*:695-705.
7. C. V. McIsaac, et al., *Rapid Monitoring for Transuranic Contaminants During Buried Waste Retrieval*, EGG-WTD-9412, March 1991.
8. M. R. Winberg, *Test Plan for FY-91 Alpha CAM Evaluation*, EGG-WTD-9571, March 1991.
9. C. V. McIsaac and C. R. Amaro, *Sensitivities of Five Alpha Continuous Air Monitors for Detection of Airborne ^{239}Pu* , EGG-WTD-10314, July 1992.
10. C. W. Sill and R. J. Gehrke, *Test Plan for Rapid Transuranic Monitoring of Soil and Air Dusts by Direct Large-Area Alpha Spectrometry and L-Shell X-Ray Spectrometry*, EGG-WTD-9735, May 1991.
11. C. W. Sill, *Rapid Monitoring of Soil, Smears, and Air Dusts by Direct Large-area Alpha Spectrometry*, EGG-WTD-10080, January 1992.
12. R. J. Gehrke, et al., "Rapid Assay of Plutonium in Soils by Passive L X-Ray Counting," *Trans of the Amer Nucl Soc*, 64:94, 1991.
13. C. W. Sill, "Rapid Monitoring of Soil, Water, and Air Dusts by Direct Large-area Alpha Spectrometry," *Health Physics*, September 1992.
14. C. V. McIsaac, et al., *Operating Procedures for Rapid Transuranic Monitoring Laboratory*, EGG-WTD-10898, October 1993.

15. J. K. Hartwell and S. G. Goodwin, "Pulser Injection with Subsequent Removal-Implementation and Applications," *IEEE Trans on Nucl Sci*, NS-36, No.1, 1989.
16. M. H. Putnam, *An Operator's Guide to LXRAY*, March 1993.
17. E. W. Killian and J. K. Hartwell, *VAXGAP: A Code for the Routine Analysis of Gamma-Ray Pulse Height Spectra on a VAX Computer*, EGG-2533, May 1988.
18. E. W. Killian and D. A. Femec, *An Operator's Guide to VAXGAP*, Rev. 2.0, ST-CS-031-90, November 1990.
19. R. V. Osborne and C. R. Hill, "High Resolution Alpha Particle Spectroscopy at Very Low Specific Activities," *Nucl Inst & Methods* 29:101-106, 1964.
20. H. Hotzl and R. Winkler, "Large Area Gridded Ionization Chamber and Electrostatic Precipitator. Application to Low-level Alpha Spectrometry of Environmental Air Samples," *Nucl Inst & Methods* 150:177-181, 1978.
21. H. Hotzl and R. Winkler, "Experiences with Large Area Frish Grid Chambers in Low-level Alpha Spectrometry," *Nucl Inst & Methods in Phys Res* 223:290-294, 1984.
22. L. Johansson, B. Roos, and C. Samuelsson, "Alpha-particle Spectrometry of Large-area Samples Using an Open-flow Pulse Ionization Chamber," *Appl Radiat Isot* 43:119-125, 1992.
23. M. H. Wilkening, *Rev. Sci. Instr.* 23:13, 1952.
24. J. C. Elder, M. Gonzales, and H. J. Ettinger, "Plutonium Aerosol Size Characteristics," *Health Physics*, Vol.27:45-53, 1974.
25. J. Whicker, "CAM Correlation to Fixed Air Sample Data at LANL," *5th Workshop of the Operating Contractors Air Monitoring User Group at Idaho Falls, Idaho, November 30-December 2, 1992*, April 1993.
26. T. J. Yule, "An On-Line Monitor for Alpha-Emitting Aerosols," *IEEE Tran on Nucl Sci*, Vol.NS-25, No.1:762-766, 1978.
27. J. L. Morrison and R. E. Heard, *Buried Waste Integrated Demonstration Test Objectives*, EGG-WTD-10878, May 1993.
28. L. A. Currie, "Limits for Qualitative Detection and Quantitative Determination," *Anal Chem* 40:586-593, 1968.
29. A. J. Schilk, et al., *Surface and Subsurface Characterization of Uranium Contamination at the Fernald Environmental Management Site*, PNL-8617, April 1993.

Appendix A

Supplemental Data for Photon Analysis Spectrometer

Appendix A

Supplemental Data for Photon Analysis Spectrometer

Table A-1. Concentrations of ^{239}Pu in quality control standards measured with photon analysis spectrometer.

QC sample number	Analysis date	Measured plutonium concentration (pCi/g)	Mean $\pm$ std deviation (pCi/g)	QC value (pCi/g)
4139301	06/16/93	9 ± 9		Blank
4139301	06/17/93	-5 ± 7		Blank
4139301	06/25/93	-5.2 ± 1.8		Blank
4139302	06/16/93	1023 ± 18		1003 ± 14
4139304	06/17/93	548 ± 18	510 ± 40	515 ± 7
4139304	06/25/93	513 ± 18		
4139304	06/28/93	541 ± 18		
4139304	06/30/93	455 ± 18		
4139305	06/16/93	290 ± 13	300 ± 50	300 ± 4
4139305	06/17/93	235 ± 13		
4139305	06/25/93	342 ± 13		
4139305	06/28/93	311 ± 13		
4139305	06/29/93	350 ± 13		
4139305	06/30/93	242 ± 13		
4139306	06/16/93	901 ± 18	980 ± 90	1026 ± 14
4139306	06/17/93	990 ± 20		
4139306	06/25/93	1130 ± 20		
4139306	06/28/93	930 ± 19		
4139306	06/30/93	951 ± 19		
4139307	06/16/93	64 ± 11	85 ± 16	103.0 ± 1.4
4139307	06/17/93	83 ± 11		
4139307	06/25/93	31 ± 15^a		
4139307	06/28/93	92 ± 10		
4139307	06/30/93	100 ± 10		

a. This measurement is outside acceptable limits and is not included in the calculated standard deviation.

Table A-2. Concentrations of ^{241}Am in quality control standards measured with photon analysis spectrometer.

QC sample number	Analysis date	L x-ray measured value (pCi/g)	Gamma-ray measured value (pCi/g)	Mean $\pm$ std deviation of gamma-ray value (pCi/g)	QC value ^a (pCi/g)
4139301	06/16/93	0			Blank
4139301	06/17/93	0.8 ± 1.0			Blank
4139301	06/25/93	-0.6 ± 1.8			Blank
4139302	06/16/93	-3 ± 5			Blank
4139304	06/17/93	10.3 ± 1.3	16.8 ± 1.4	16.5 ± 0.5	13.9 ± 0.2
4139304	06/25/93	18.0 ± 1.6	15.9 ± 0.9		
4139304	06/28/93	11.0 ± 1.4			
4139304	06/30/93	19.4 ± 1.7	17.0 ± 0.9 16.1 ± 0.9		
4139305	06/16/93	4.8 ± 1.4	8.6 ± 0.7	8.5 ± 1.0	8.1 ± 0.1
4139305	06/17/93	9.0 ± 1.1	9.6 ± 0.7		
4139305	06/25/93	7.9 ± 1.2	8.4 ± 0.7		
4139305	06/28/93	8.0 ± 1.2	8.0 ± 0.6		
4139305	06/29/93	5.6 ± 1.1	9.5 ± 0.7		
4139305	06/30/93	8.8 ± 1.2	7.0 ± 0.6		
4139306	06/16/93	22.1 ± 1.3	23.8 ± 1.1	24.2 ± 1.6	27.7 ± 0.4
4139306	06/17/93	21.6 ± 1.7	24.1 ± 1.1		
4139306	06/25/93	17.5 ± 1.8	27.0 ± 1.1		
4139306	06/28/93	27.2 ± 1.7	22.7 ± 1.6		
4139306	06/30/93	21.5 ± 1.6	23.5 ± 1.0		
4139307	06/16/93	4.7 ± 1.2	2.7 ± 0.5	3.3 ± 0.5	2.80 ± 0.04
4139307	06/17/93	4.5 ± 1.0	3.2 ± 0.4		
4139307	06/25/93	11.1 ± 1.2^b	c		
4139307	06/28/93	3 ± 2	3.9 ± 0.5		
4139307	06/30/93	3.4 ± 0.9	3.2 ± 0.5		

a. ^{241}Am QC value was measured to be 2.7% of the ^{239}Pu activity.

b. This measurement is outside acceptable limits (a significant portion of this intensity is misassigned). It belongs to the plutonium component.

c. The ^{241}Am 60 keV gamma-ray is observed in the plotted spectrum but was not reported in the results.

Table A-3. Concentrations of ^{239}Pu in blind soil standards determined by x-ray spectrometry.

Sample number	Sample collection date	Ident.	Measured plutonium value (pCi/g)	Mean $\pm$ std deviation (pCi/g)	Known plutonium value (pCi/g)
42	06/10/93	1	97 $\pm$ 10	80 $\pm$ 30	100.6 $\pm$ 1.1
49	06/11/93		89 $\pm$ 11		
1	06/21/93		91 $\pm$ 11		
3	06/27/93		42 $\pm$ 13		
6	06/10/93	2	47 $\pm$ 10	70 $\pm$ 20	78.6 $\pm$ 0.9
31	06/11/93		58 $\pm$ 9		
2	06/21/93		94 $\pm$ 10		
6	06/27/93		45 $\pm$ 10		
45	06/28/93		82 $\pm$ 11		
52	06/10/93	3	141 $\pm$ 11	190 $\pm$ 40	224 $\pm$ 3
7	06/11/93		209 $\pm$ 14		
3	06/21/93		183 $\pm$ 13		
9	06/27/93		221 $\pm$ 13		
82	06/10/93	4	312 $\pm$ 13	270 $\pm$ 30	281 $\pm$ 3
56	06/10/93		242 $\pm$ 13		
45	06/11/93		265 $\pm$ 13		
4	06/21/93		251 $\pm$ 12		
12	06/27/93		300 $\pm$ 14		
42	06/28/93		254 $\pm$ 13		
15	06/10/93	5	137 $\pm$ 11	144 $\pm$ 13	175.8 $\pm$ 1.9
72	06/10/93		157 $\pm$ 12		
52	06/11/93		122 $\pm$ 11		
5	06/21/93		151 $\pm$ 11		
15	06/27/93		144 $\pm$ 12		
9	06/29/93		155 $\pm$ 11		
2	06/10/93	6	82 $\pm$ 19	83 $\pm$ 14	98.9 $\pm$ 1.3
51	06/11/93		74 $\pm$ 15		
32	06/11/93		68 $\pm$ 18		
6	06/21/93		106 $\pm$ 16		
18	06/27/93		80 $\pm$ 20		
6	06/29/93		93 $\pm$ 16		
23	06/10/93	7	106 $\pm$ 12	90 $\pm$ 30	101.4 $\pm$ 1.1
55	06/11/93		80 $\pm$ 12		
7	06/21/93		126 $\pm$ 13		
21	06/27/93		64 $\pm$ 15		
51	06/28/93		56 $\pm$ 12		

Table A-3. (continued).

Sample number	Sample collection date	Ident.	Measured plutonium value (pCi/g)	Mean $\pm$ std deviation (pCi/g)	Known plutonium value (pCi/g)
60	06/10/93	8	234 $\pm$ 15	170 $\pm$ 70	239.2 $\pm$ 1.0
95	06/10/93		219 $\pm$ 15		
8	06/21/93		208 $\pm$ 12		
24	06/27/93		89 $\pm$ 16		
3	06/29/93		109 $\pm$ 14		
57	06/10/93	9	83 $\pm$ 15	80 $\pm$ 20	108.1 $\pm$ 0.4
37	06/11/93		46 $\pm$ 19		
9	06/21/93		104 $\pm$ 15		
27	06/27/93		82 $\pm$ 13		
48	06/28/93		73 $\pm$ 19		
44	06/10/93	10	360 $\pm$ 16	390 $\pm$ 30	492 $\pm$ 6
40	06/11/93		380 $\pm$ 16		
10	06/21/93		445 $\pm$ 18		
30	06/27/93		389 $\pm$ 14		
54	06/28/93		387 $\pm$ 15		
45	06/10/93	11	443 $\pm$ 16	433 $\pm$ 16	503 $\pm$ 6
85	06/10/93		421 $\pm$ 15		
39	06/11/93		442 $\pm$ 15		
11	06/21/93		419 $\pm$ 16		
31	06/27/93		457 $\pm$ 15		
69	06/28/93	12	417 $\pm$ 15	400 $\pm$ 40	471 $\pm$ 5
9	06/10/93		414 $\pm$ 16		
74	06/10/93		388 $\pm$ 16		
12	06/21/93		356 $\pm$ 14		
32	06/27/93		441 $\pm$ 16		
68	06/10/93	13	449 $\pm$ 17	350 $\pm$ 90	453 $\pm$ 5
13	06/21/93		396 $\pm$ 16		
33	06/27/93		250 $\pm$ 20		
57	06/28/93		310 $\pm$ 20		
11	06/10/93	14	153 $\pm$ 14	160 $\pm$ 40	187 $\pm$ 2
73	06/10/93		196 $\pm$ 14		
14	06/21/93		172 $\pm$ 13		
34	06/27/93		100 $\pm$ 16		

Table A-3. (continued).

Sample number	Sample collection date	Ident.	Measured plutonium value (pCi/g)	Mean $\pm$ std deviation (pCi/g)	Known plutonium value (pCi/g)
13	06/10/93	15	102 $\pm$ 13	84 $\pm$ 17	97.4 $\pm$ 1.1
9	06/11/93		77 $\pm$ 11		
15	06/21/93		64 $\pm$ 10		
35	06/27/93		94 $\pm$ 12		
69	06/10/93	16	149 $\pm$ 15	140 $\pm$ 30	142.8 $\pm$ 1.6
54	06/11/93		130 $\pm$ 15		
16	06/21/93		172 $\pm$ 17		
36	06/27/93		a		
66	06/28/93		103 $\pm$ 18		
55	06/10/93	17	512 $\pm$ 16	490 $\pm$ 30	491 $\pm$ 5
14	06/11/93		476 $\pm$ 15		
17	06/21/93		459 $\pm$ 14		
37	06/27/93		526 $\pm$ 16		
37	06/10/93	18	120 $\pm$ 20	150 $\pm$ 40	162.9 $\pm$ 1.8
48	06/11/93		b		
18	06/21/93		201 $\pm$ 18		
38	06/27/93		127 $\pm$ 16		
26	06/10/93	19	91 $\pm$ 11	80 $\pm$ 20	96.9 $\pm$ 1.1
84	06/10/93		100 $\pm$ 10		
42	06/11/93		58 $\pm$ 12		
19	06/21/93		107 $\pm$ 11		
39	06/27/93		62 $\pm$ 12		
63	06/28/93		89 $\pm$ 12		
28	06/10/93	20	169 $\pm$ 17	170 $\pm$ 50	199 $\pm$ 2
15	06/11/93		127 $\pm$ 18		
20	06/21/93		128 $\pm$ 16		
40	06/27/93		237 $\pm$ 19		

a. Measured concentration was below the LLD.

b. Uncertainty was greater than 30%.

Table A-4. Concentrations of ^{241}Am in blind soil standards determined by x-ray spectrometry.

Sample number	Sample collection date	Ident.	Measured ^{241}Am value (pCi/g)	Std deviation (pCi/g)	Known ^{241}Am value (pCi/g)
2	06/10/93	6	53.8 ± 1.8	54 ± 2	52.6 ± 1.3
51	06/11/93		51.1 ± 1.8		
32	06/11/93		57 ± 2		
6	06/21/93		54.1 ± 1.7		
18	06/27/93		56 ± 2		
6	06/29/93		52 ± 2		
57	06/10/93	9	42.8 ± 1.4	43 ± 3	42.8 ± 0.2
37	06/11/93		45.3 ± 1.9		
9	06/21/93		46.4 ± 1.7		
27	06/27/93		41.7 ± 1.8		
48	06/28/93		39 ± 2		
44	06/10/93	10	33.7 ± 1.5	35 ± 4	38.0 ± 0.2
40	06/11/93		31.3 ± 1.5		
10	06/21/93		30.3 ± 1.6		
30	06/27/93		37.1 ± 1.6		
54	06/28/93		40.2 ± 1.6		
45	06/10/93	11	11.4 ± 1.3	8 ± 3	10 ± 2
85	06/10/93		8.0 ± 1.1		
39	06/11/93		11.4 ± 1.1		
11	06/21/93		4.8 ± 1.3		
31	06/27/93		8.1 ± 1.2		
69	06/28/93		6.4 ± 1.2		
37	06/10/93	18	71 ± 2	72 ± 7	78.0 ± 0.4
48	06/11/93		83 ± 2		
18	06/21/93		67 ± 2		
38	06/27/93		68 ± 2		
28	06/10/93	20	39.6 ± 1.9	46 ± 8	42.1 ± 0.2
15	06/11/93		50 ± 2		
20	06/21/93		54.8 ± 1.7		
40	06/27/93		38 ± 2		

Table A-5. Concentrations of ^{241}Am in blind soil standards determined by gamma-ray spectrometry.

Sample number	Sample collection date	Ident.	Measured ^{241}Am value (pCi/g)	Mean $\pm$ std deviation (pCi/g)	Known ^{241}Am value (pCi/g)
2	06/10/93	6	59 ± 2	61 ± 2	52.6 ± 1.3
51	06/11/93		62.5 ± 1.7		
32	06/11/93		63.9 ± 1.7		
6	06/21/93		58 ± 2		
18	06/27/93		63.2 ± 1.7		
6	06/29/93		60 ± 2		
57	06/10/93	9	44.9 ± 1.4	45.7 ± 1.5	42.8 ± 0.2
37	06/11/93		45.9 ± 1.4		
9	06/21/93		44.1 ± 1.5		
27	06/27/93		48 ± 2		
48	06/28/93		45.8 ± 1.5		
44	06/10/93	10	38.9 ± 1.5	40.2 ± 0.9	38.0 ± 0.2
40	06/11/93		40.3 ± 1.4		
10	06/21/93		40.9 ± 1.4		
30	06/27/93		39.8 ± 1.4		
54	06/28/93		41.0 ± 1.4		
45	06/10/93	11	9.0 ± 0.7	10.2 ± 1.2	10 ± 2
85	06/10/93		12.1 ± 0.8		
39	06/11/93		9.7 ± 0.7		
11	06/21/93		9.1 ± 0.7		
31	06/27/93		10.7 ± 0.7		
69	06/28/93		10.6 ± 0.8		
37	06/10/93	18	83.7 ± 1.9	85.0 ± 1.1	78.0 ± 0.4
48	06/11/93		86 ± 2		
18	06/21/93		85 ± 3		
38	06/27/93		86 ± 2		
28	06/10/93	20	45 ± 2	44 ± 2	42.1 ± 0.2
15	06/11/93		41.3 ± 1.8		
20	06/21/93		44.0 ± 1.9		
40	06/27/93		46.2 ± 1.4		

Table A-6. Concentrations of ^{60}Co in blind soil standards determined by gamma-ray spectrometry.

Sample number	Sample collection date	Ident.	Measured ^{60}Co value (pCi/g)	Mean $\pm$ std deviation (pCi/g)	Known ^{60}Co value (pCi/g)
23	06/10/93	7	34.5 ± 1.9	35 ± 2	44.4 ± 0.5
55	06/11/93		35 ± 2		
7	06/21/93		38 ± 2		
21	06/27/93		33 ± 2		
51	06/28/93		33 ± 2		
60	06/10/93	8	32.5 ± 1.9	28 ± 5	36.4 ± 0.4
95	06/11/93		29.4 ± 1.8		
8	06/21/93		28.4 ± 1.7		
24	06/27/93		27.3 ± 1.7		
3	06/29/93		20 ± 2		
57	06/10/93	9	45 ± 2	46 ± 3	57.3 ± 0.6
37	06/11/93		49 ± 2		
9	06/21/93		48 ± 3		
27	06/27/93		41 ± 2		
48	06/28/93		45 ± 2		
9	06/10/93	12	24.0 ± 1.7	29 ± 5	35.4 ± 0.4
74	06/10/93		a		
12	06/21/93		25.1 ± 1.9		
32	06/27/93		32 ± 3		
11	06/10/93	14	34 ± 2	33.0 ± 1.0	41.5 ± 0.4
73	06/10/93		b		
14	06/21/93		32 ± 2		
34	06/27/93		33 ± 2		
13	06/10/93	15	40 ± 3	34 ± 5	47.6 ± 0.5
9	06/11/93		33.9 ± 1.7		
15	06/21/93		35 ± 2		
35	06/27/93		27 ± 3		
26	06/10/93	19	49 ± 2	48 ± 2	60.2 ± 0.6
84	06/10/93		46 ± 2		
42	06/11/93		48 ± 2		
19	06/21/93		46 ± 2		
39	06/27/93		52 ± 3		
63	06/28/93		49 ± 2		

a. Uncertainty was greater than 30%.

b. No activity was detected by automated analysis program from a gain shift.

Table A-7. Concentrations of ^{137}Cs in blind soil standards determined by gamma-ray spectrometry.

Sample number	Sample collection date	Ident.	Measured ^{137}Cs value (pCi/g)	Mean $\pm$ std deviation (pCi/g)	Known ^{137}Cs value (pCi/g)
23	06/10/93	7	50 $\pm$ 3	49 $\pm$ 2	50.5 $\pm$ 0.9
55	06/11/93		46 $\pm$ 3		
7	06/21/93		51 $\pm$ 3		
21	06/27/93		47 $\pm$ 2		
51	06/28/93		51 $\pm$ 3		
60	06/10/93	8	48 $\pm$ 2	47.2 $\pm$ 1.3	47.0 $\pm$ 0.9
95	06/10/93		47 $\pm$ 2		
8	06/21/93		48 $\pm$ 2		
24	06/27/93		48 $\pm$ 2		
3	06/29/93		45 $\pm$ 2		
68	06/10/93	13	86 $\pm$ 4	77 $\pm$ 3	87.5 $\pm$ 1.6
13	06/21/93		83 $\pm$ 3		
33	06/27/93		91 $\pm$ 3		
57	06/28/93		86 $\pm$ 3		
11	06/10/93	14	39 $\pm$ 3	39.7 $\pm$ 1.2	41.5 $\pm$ 0.8
73	06/10/93		a		
14	06/21/93		41 $\pm$ 3		
34	06/27/93		39 $\pm$ 2		
13	06/10/93	15	41 $\pm$ 2	40.3 $\pm$ 1.7	40.8 $\pm$ 0.8
9	06/11/93		40 $\pm$ 2		
15	06/21/93		42 $\pm$ 2		
35	06/27/93		38 $\pm$ 3		
69	06/10/93	16	127 $\pm$ 4	132 $\pm$ 4	132 $\pm$ 2
54	06/11/93		134 $\pm$ 5		
16	06/21/93		137 $\pm$ 4		
36	06/27/93		130 $\pm$ 4		
66	06/28/93		133 $\pm$ 4		
28	06/10/93	20	58 $\pm$ 2	57 $\pm$ 3	57.1 $\pm$ 1.1
15	06/11/93		59 $\pm$ 3		
20	06/21/93		52 $\pm$ 3		
40	06/27/93		57 $\pm$ 3		

a. Measured concentration was below the LLD.

Appendix B

Supplemental Data for Alpha CAMs

Appendix B

Supplemental Data for Alpha CAMs

Table B-1. Energy calibration coefficients for the alpha CAMs.

Count date	Zero (MeV)	Gain (MeV/ch)	Count date	Zero (MeV)	Gain (MeV/ch)
CAM 1			CAM 2		
06/27/93	1.144	0.0139	06/27/93	1.093	0.0139
06/17/93	1.069	0.0140	06/17/93	1.082	0.0138
06/15/93	1.056	0.0140	06/15/93	1.089	0.0138
05/26/93	1.052	0.0140	05/26/93	1.062	0.0138
05/17/93	1.075	0.0140	05/17/93	1.071	0.0139
05/14/93	1.079	0.0139			
CAM 3			CAM 4		
06/27/93	0.816	0.0148	06/27/93	0.867	0.0146
06/17/93	0.802	0.0147	06/17/93	0.832	0.0145
06/15/93	0.791	0.0147	06/15/93	0.818	0.0146
05/26/93	0.764	0.0148	05/27/93	0.824	0.0146
05/17/93	0.765	0.0148	05/17/93	0.816	0.0147
05/14/93	0.769	0.0148			

Table B-2. Positions of centroids of ^{237}Np , ^{239}Pu , ^{241}Am , and ^{244}Cm alpha peaks in energy calibration spectra collected with the alpha CAMs.

Count date	Count time (sec)	^{237}Np centroid channel	^{239}Pu centroid channel	^{241}Am centroid channel	^{244}Cm centroid channel
CAM 1					
05/14/93	2,573	265.5	292.8	316.6	338.6
05/17/93	4,076	265.7	292.6	316.5	338.7
05/26/93	3,600	266.5	293.3	317.4	339.2
06/15/93	3,599	266.1	292.6	316.6	338.8
06/17/93	3,599	265.9	292.4	316.4	338.8
06/27/93	3,600	262.2	289.8	313.3	335.8
Average:		265.8	292.6	316.5	338.7
Standard deviation:		0.2	0.1	0.1	0.1
CAM 2					
05/17/93	4,064	267.9	294.7	319.0	341.5
05/26/93	3,600	268.8	295.9	320.0	342.4
06/15/93	3,600	267.7	295.2	319.2	341.6
06/17/93	3,600	268.1	295.2	319.5	341.9
06/27/93	3,600	266.3	293.0	317.4	339.7
Average:		267.9	295.0	319.2	341.7
Standard deviation:		0.2	0.2	0.2	0.2
CAM 3					
05/14/93	2,573	271.4	296.5	319.1	340.3
05/17/93	3,045	271.1	297.2	319.8	340.7
05/26/93	3,600	271.9	297.3	319.6	340.9
06/15/93	3,600	271.3	296.5	319.3	340.5
06/17/93	3,600	271.1	296.7	319.5	340.5
06/27/93	3,599	268.4	293.9	316.3	337.5
Average:		271.2	296.7	319.4	340.5
Standard deviation:		0.1	0.3	0.3	0.1
CAM 4					
05/17/93	4,064	270.5	295.9	318.7	340.0
05/27/93	4,727	271.4	297.0	319.9	341.3
06/15/93	3,600	272.0	297.4	320.4	341.9
06/17/93	3,599	271.6	297.2	320.2	341.7
06/27/93	3,600	268.5	293.9	317.0	338.4
Average:		271.4	296.9	319.8	341.2
Standard deviation:		0.5	0.6	0.7	0.7

Table B-3. FWHM of ^{237}Np , ^{239}Pu , ^{241}Am , and ^{244}Cm alpha peaks in energy calibration spectra collected with the alpha CAMs.

Count date	Count time (sec)	^{237}Np FWHM (keV)	^{239}Pu FWHM (keV)	^{241}Am FWHM (keV)	^{244}Cm FWHM (keV)
CAM 1					
05/14/93	2,573	270	208	213	194
05/17/93	4,076	307	248	246	226
05/26/93	3,600	313	259	241	229
06/15/93	3,599	288	258	230	212
06/17/93	3,599	318	257	261	222
06/27/93	3,600	337	265	261	226
Average:		296	243	237	214
Standard deviation:		18	20	18	12
CAM 2					
05/17/93	4,064	283	232	224	222
05/26/93	3,600	279	231	220	210
06/15/93	3,600	271	226	216	194
06/17/93	3,600	274	240	218	205
06/27/93	3,600	268	232	223	199
Average:		276	232	220	207
Standard deviation:		5	6	4	11
CAM 3					
05/14/93	2,573	247	233	206	197
05/17/93	3,045	253	218	215	185
05/26/93	3,600	279	227	229	220
06/15/93	3,600	236	230	188	188
06/17/93	3,600	257	221	211	193
06/27/93	3,599	274	230	212	205
Average:		248	226	205	191
Standard deviation:		8	6	10	4
CAM 4					
05/17/93	4,064	205	164	168	157
05/27/93	4,727	205	159	162	150
06/15/93	3,600	201	161	172	158
06/17/93	3,599	213	170	181	158
06/27/93	3,600	218	182	164	166
Average:		206	163	171	156
Standard deviation:		4	4	7	3

Figure B-1. Spectrum collected at TRA May 21-24, 1993, with alpha CAM 1 showing the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks after a sampling time of 69 hours.

Figure B-2. Spectrum collected at TRA May 21-24, 1993, with alpha CAM 2 showing the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks after a sampling time of 69 hours.

Figure B-3. Spectrum collected at TRA May 21-24, 1993, with alpha CAM 3 showing the $^{218}\text{Po}/^{212}\text{Bi}$ and ^{214}Po alpha peaks after a sampling time of 69 hours.

Table B-4. Results for air sampling performed at TRA May 21-24, 1993, with alpha CAM 1.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
52193	1215	285.3	60.1	4.	-34.	-5.100E-04	17.2	-5.100E-04	17.2
	1315	285.5	120.2	9.	-43.	-1.579E-04	15.5	-6.322E-04	15.5
	1415	285.3	180.2	18.	-48.	-7.855E-05	14.7	-7.076E-04	14.7
	1515	284.6	240.3	26.	-57.	-5.271E-05	13.5	-8.455E-04	13.5
	1615	284.5	300.3	37.	-76.	-4.509E-05	11.7	-1.129E-03	11.7
	1715	283.7	360.4	47.	-49.	-2.019E-05	14.5	-7.300E-04	14.5
	1816	283.5	420.4	58.	-71.	-2.161E-05	12.1	-1.064E-03	12.1
	1916	283.1	480.5	64.	-65.	-1.508E-05	12.7	-9.699E-04	12.7
	2016	283.5	540.5	73.	-51.	-9.424E-06	14.2	-7.658E-04	14.2
	2116	282.8	600.6	82.	-54.	-8.043E-06	13.8	-8.080E-04	13.8
	2216	283.6	660.7	93.	-76.	-9.368E-06	11.7	-1.136E-03	11.7
	2316	284.3	720.7	106.	-79.	-8.149E-06	11.5	-1.173E-03	11.5
052293	16	285.1	780.8	121.	-68.	-6.006E-06	12.4	-1.012E-03	12.4
	116	285.3	840.8	133.	-61.	-4.626E-06	13.1	-9.037E-04	13.1
	216	285.5	900.8	144.	-94.	-6.191E-06	10.6	-1.388E-03	10.6
	316	285.7	960.9	153.	-82.	-4.785E-06	11.3	-1.219E-03	11.3
	416	285.9	1021.0	164.	-84.	-4.325E-06	11.2	-1.244E-03	11.2
	516	285.8	1081.0	178.	-83.	-3.793E-06	11.3	-1.224E-03	11.3
	616	286.1	1141.1	189.	-75.	-3.107E-06	11.8	-1.116E-03	11.8
	716	286.2	1201.1	204.	-61.	-2.281E-06	13.0	-9.076E-04	13.0
	816	286.2	1261.2	225.	-51.	-1.726E-06	14.2	-7.579E-04	14.2
	916	286.6	1321.2	231.	-49.	-1.506E-06	14.5	-7.246E-04	14.5
	1016	286.3	1381.3	241.	-44.	-1.228E-06	15.3	-6.467E-04	15.3
	1116	286.3	1441.3	258.	-36.	-9.375E-07	16.8	-5.377E-04	16.8
	1216	286.1	1501.4	270.	-33.	-7.771E-07	17.7	-4.840E-04	17.7
	1316	286.2	1561.4	286.	-30.	-6.591E-07	18.4	-4.439E-04	18.4
	1416	286.2	1621.5	299.	-22.	-4.465E-07	21.5	-3.243E-04	21.5
	1516	286.3	1681.5	309.	-19.	-3.536E-07	23.3	-2.762E-04	23.3
052393	1616	286.1	1741.6	318.	-16.	-2.776E-07	25.3	-2.327E-04	25.3
	1716	285.6	1801.7	334.	-12.	-1.938E-07	29.3	-1.743E-04	29.3
	1816	285.3	1861.7	345.	-17.	-2.585E-07	24.6	-2.484E-04	24.6
	1916	284.9	1921.8	365.	-1.	-9.756E-09	100.0	-1.000E-05	100.0
	2016	284.9	1981.8	380.	11.	1.494E-07	30.3	1.629E-04	30.3
	2116	284.7	2041.9	397.	22.	2.812E-07	21.5	3.255E-04	21.5
	2216	285.4	2101.9	412.	29.	3.573E-07	18.6	4.375E-04	18.6
	2316	285.7	2162.0	426.	31.	3.524E-07	18.2	4.560E-04	18.2
	16	286.0	2222.0	444.	20.	2.141E-07	22.6	2.924E-04	22.6
	116	286.1	2282.1	454.	16.	1.670E-07	24.9	2.405E-04	24.9
	216	286.2	2342.1	475.	36.	3.527E-07	16.8	5.349E-04	16.8
	316	286.2	2402.2	496.	49.	4.533E-07	14.5	7.232E-04	14.5
	416	286.2	2462.2	507.	-12.	-1.090E-07	28.6	-1.826E-04	28.6
	517	286.3	2522.3	520.	-22.	-1.827E-07	21.6	-3.212E-04	21.6
	617	286.2	2582.3	536.	-18.	-1.468E-07	23.5	-2.706E-04	23.5
	717	286.3	2642.4	552.	-6.	-4.942E-08	39.5	-9.539E-05	39.5
	817	286.7	2702.4	559.	-25.	-1.865E-07	20.0	-3.761E-04	20.0
	917	286.4	2762.5	568.	-25.	-1.747E-07	20.2	-3.685E-04	20.2
	1017	286.3	2822.5	583.	-14.	-9.661E-08	26.5	-2.128E-04	26.5
	1117	286.4	2882.6	589.	-4.	-2.844E-08	47.6	-6.532E-05	47.6
	1217	286.1	2942.6	598.	0.	-1.441E-09	100.0	-3.451E-06	100.0
	1317	286.0	3002.7	612.	12.	7.140E-08	28.9	1.782E-04	28.9

Table B-4. (continued).

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
052493	1417	286.2	3062.8	622.	19.	1.096E-07	22.9	2.846E-04	22.9
	1517	285.9	3122.8	636.	35.	1.931E-07	17.0	5.214E-04	17.0
	1617	285.8	3182.9	649.	29.	1.510E-07	18.9	4.238E-04	18.9
	1717	285.6	3242.9	655.	20.	9.990E-08	22.7	2.913E-04	22.7
	1817	285.4	3303.0	666.	12.	6.085E-08	28.5	1.842E-04	28.5
	1917	285.6	3363.0	680.	26.	1.228E-07	19.8	3.852E-04	19.8
	2017	285.0	3423.1	692.	40.	1.826E-07	16.0	5.944E-04	16.0
	2117	285.1	3483.1	706.	39.	1.724E-07	16.2	5.808E-04	16.2
	2217	286.1	3543.2	718.	48.	2.027E-07	14.7	7.043E-04	14.7
	2317	286.1	3603.2	726.	52.	2.158E-07	14.0	7.756E-04	14.0
	17	286.6	3663.3	736.	46.	1.852E-07	14.9	6.861E-04	14.9
	117	286.5	3723.3	751.	36.	1.377E-07	16.9	5.276E-04	16.9
	217	286.6	3783.4	762.	16.	5.827E-08	25.4	2.305E-04	25.4
	317	286.5	3843.4	772.	20.	7.139E-08	22.7	2.915E-04	22.7
	417	287.1	3903.5	788.	34.	1.203E-07	17.3	5.057E-04	17.3
	517	286.9	3963.6	793.	21.	7.258E-08	21.8	3.146E-04	21.8
	617	287.4	4023.6	803.	3.	9.436E-09	59.2	4.211E-05	59.2
	717	288.0	4083.6	815.	5.	1.546E-08	45.6	7.091E-05	45.6
	817	288.1	4143.7	825.	11.	3.481E-08	30.0	1.644E-04	30.0
	941	287.4	4227.5	845.	16.	4.878E-08	24.9	1.235E-04	24.9
	1041	287.7	4287.5	859.	30.	8.832E-08	18.3	4.475E-04	18.3
	1141	287.1	4347.6	888.	43.	1.228E-07	15.4	6.403E-04	15.4
	1241	286.8	4407.6	900.	41.	1.131E-07	15.8	6.073E-04	15.8
	1341	286.6	4467.7	921.	52.	1.400E-07	14.0	7.727E-04	14.0
	1441	286.7	4527.8	935.	121.	3.147E-07	9.4	1.783E-03	9.4

Table B-5. Results for air sampling performed at TRA May 21-24, 1993, with alpha CAM 2.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
52193	1304	275.5	60.1	4.	-10.	-1.521E-04	32.2	-1.521E-04	32.2
	1404	276.1	120.2	7.	-82.	-3.208E-04	11.3	-1.283E-03	11.3
	1504	275.9	180.2	15.	-22.	-3.748E-05	21.7	-3.375E-04	21.7
	1604	275.8	240.3	22.	-7.	-7.140E-06	37.1	-1.143E-04	37.1
	1704	275.5	300.3	27.	5.	3.014E-06	45.7	7.546E-05	45.7
	1804	275.0	360.4	33.	8.	3.536E-06	35.2	1.276E-04	35.2
	1904	274.7	420.4	40.	21.	6.690E-06	22.0	3.289E-04	22.0
	2004	274.8	480.5	46.	20.	4.821E-06	22.7	3.092E-04	22.7
	2104	274.1	540.5	50.	23.	4.512E-06	20.9	3.672E-04	20.9
	2204	274.4	600.6	57.	10.	1.551E-06	31.9	1.556E-04	31.9
	2304	275.1	660.7	60.	-5.	-6.585E-07	44.5	-7.972E-05	44.5
052293	4	275.5	720.7	63.	-5.	-5.366E-07	45.2	-7.720E-05	45.2
	104	275.7	780.8	68.	-5.	-4.967E-07	43.4	-8.382E-05	43.4
	204	276.1	840.8	76.	1.	1.106E-07	85.2	2.161E-05	85.2
	305	276.2	900.9	79.	5.	3.167E-07	47.0	7.105E-05	47.0
	405	276.2	960.9	83.	8.	4.944E-07	35.3	1.262E-04	35.3
	505	276.1	1021.0	89.	2.	1.129E-07	69.4	3.256E-05	69.4
	605	276.7	1081.0	100.	6.	2.877E-07	41.1	9.280E-05	41.1
	705	276.5	1141.1	106.	-1.	-3.062E-08	100.0	-1.102E-05	100.0
	805	277.0	1201.1	113.	-6.	-2.273E-07	41.6	-9.051E-05	41.6
	905	277.3	1261.2	126.	5.	1.880E-07	43.6	8.245E-05	43.6
	1005	277.1	1321.2	138.	8.	2.712E-07	34.7	1.306E-04	34.7
	1105	277.2	1381.3	145.	19.	5.675E-07	23.0	2.988E-04	23.0
	1205	276.7	1441.3	154.	23.	6.180E-07	21.1	3.550E-04	21.1
	1305	276.6	1501.4	158.	19.	4.701E-07	23.2	2.931E-04	23.2
	1405	276.8	1561.4	165.	20.	4.531E-07	22.8	3.054E-04	22.8
	1505	276.8	1621.5	175.	3.	6.244E-08	58.8	4.536E-05	58.8
	1605	276.7	1681.6	178.	-20.	-4.001E-07	22.5	-3.130E-04	22.5
	1705	276.5	1741.6	189.	-25.	-4.596E-07	20.3	-3.860E-04	20.3
	1805	276.2	1801.7	195.	-38.	-6.576E-07	16.5	-5.916E-04	16.5
	1905	275.6	1861.7	202.	-32.	-5.199E-07	17.9	-5.005E-04	17.9
	2005	275.7	1921.8	213.	-41.	-6.216E-07	15.9	-6.374E-04	15.9
	2105	275.3	1981.8	219.	-24.	-3.509E-07	20.4	-3.829E-04	20.4
	2205	275.8	2041.9	227.	-40.	-5.374E-07	16.1	-6.217E-04	16.1
052393	2305	276.1	2101.9	234.	-29.	-3.705E-07	18.8	-4.537E-04	18.8
	5	275.9	2162.0	245.	-19.	-2.272E-07	23.2	-2.945E-04	23.2
	105	276.2	2222.0	257.	-44.	-5.048E-07	15.3	-6.907E-04	15.3
	205	276.7	2282.1	265.	-41.	-4.412E-07	15.9	-6.355E-04	15.9
	305	276.6	2342.1	273.	-51.	-5.266E-07	14.2	-7.995E-04	14.2
	405	276.9	2402.2	282.	-44.	-4.323E-07	15.3	-6.897E-04	15.3
	505	276.9	2462.2	288.	-53.	-4.986E-07	13.9	-8.357E-04	13.9
	605	277.0	2522.3	298.	-55.	-4.868E-07	13.7	-8.560E-04	13.7
	705	277.0	2582.3	299.	-58.	-4.924E-07	13.4	-9.076E-04	13.4
	805	277.5	2642.4	303.	-60.	-4.876E-07	13.1	-9.395E-04	13.1
	905	277.1	2702.4	310.	-56.	-4.340E-07	13.6	-8.761E-04	13.6
	1005	277.4	2762.5	317.	-62.	-4.569E-07	13.0	-9.628E-04	13.0
	1105	276.8	2822.5	324.	-54.	-3.862E-07	13.8	-8.514E-04	13.8
	1205	276.6	2882.6	332.	-47.	-3.199E-07	14.8	-7.358E-04	14.8
	1306	276.2	2942.6	338.	-42.	-2.774E-07	15.5	-6.662E-04	15.5
	1406	276.2	3002.7	347.	-26.	-1.621E-07	19.8	-4.053E-04	19.8

Table B-5. (continued).

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	$^{239}\text{Pu}/^{241}\text{Am}$ ROI (3.71 to 5.60 MeV)		$^{239}\text{Pu}/^{241}\text{Am}$ Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
052493	1506	276.2	3062.8	353.	-18.	-1.088E-07	23.7	-2.828E-04	23.7
	1606	276.3	3122.8	359.	-19.	-1.124E-07	22.8	-3.038E-04	22.8
	1706	276.0	3182.9	367.	-17.	-9.648E-08	24.2	-2.713E-04	24.2
	1806	275.7	3242.9	375.	-3.	-1.651E-08	57.1	-4.825E-05	57.1
	1906	275.8	3303.0	384.	-64.	-3.302E-07	12.8	-1.001E-03	12.8
	2006	275.8	3363.0	391.	-56.	-2.808E-07	13.6	-8.814E-04	13.6
	2106	275.6	3423.1	401.	7.	3.463E-08	37.4	1.128E-04	37.4
	2206	276.1	3483.1	409.	-16.	-7.425E-08	25.2	-2.499E-04	25.2
	2306	276.9	3543.2	415.	-16.	-7.162E-08	25.2	-2.487E-04	25.2
	6	276.8	3603.2	426.	-23.	-1.006E-07	20.9	-3.615E-04	20.9
	106	277.1	3663.3	437.	-19.	-7.807E-08	23.4	-2.896E-04	23.4
	206	277.5	3723.3	445.	-32.	-1.322E-07	17.7	-5.061E-04	17.7
	306	277.7	3783.4	451.	-29.	-1.159E-07	18.6	-4.576E-04	18.6
	406	277.7	3843.4	460.	-46.	-1.754E-07	15.0	-7.144E-04	15.0
	506	278.2	3903.5	466.	-52.	-1.927E-07	14.1	-8.085E-04	14.1
	606	278.1	3963.6	477.	-49.	-1.759E-07	14.5	-7.614E-04	14.5
	706	278.3	4023.6	484.	-61.	-2.134E-07	13.0	-9.512E-04	13.0
	806	278.4	4083.6	492.	-79.	-2.660E-07	11.6	-1.221E-03	11.6
	906	278.2	4143.7	504.	-78.	-2.557E-07	11.6	-1.210E-03	11.6
	1006	278.3	4203.7	514.	-72.	-2.308E-07	12.0	-1.124E-03	12.0
	1106	278.1	4263.8	520.	-70.	-2.188E-07	12.2	-1.095E-03	12.2
	1206	278.3	4323.9	525.	-64.	-1.931E-07	12.8	-9.940E-04	12.8
	1306	278.0	4384.0	534.	-59.	-1.729E-07	13.3	-9.161E-04	13.3
	1406	277.4	4444.0	544.	-57.	-1.627E-07	13.5	-8.885E-04	13.5
	1506	277.3	4504.1	556.	-64.	-1.787E-07	12.7	-1.002E-03	12.7

Table B-6. Results for air sampling performed at TRA May 21-24, 1993, with alpha CAM 3.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
52193	1216	285.3	60.2	3.	-126.	-1.803E-03	9.2	-1.803E-03	9.2
	1316	285.7	120.2	4.	-41.	-1.457E-04	15.9	-5.832E-04	15.9
	1416	284.6	180.3	8.	-36.	-5.782E-05	16.8	-5.221E-04	16.8
	1516	285.5	240.3	11.	-27.	-2.429E-05	19.4	-3.887E-04	19.4
	1616	284.1	300.4	13.	-25.	-1.415E-05	20.3	-3.550E-04	20.3
	1716	285.1	360.4	18.	-10.	-3.913E-06	32.0	-1.409E-04	32.0
	1816	283.9	420.5	25.	0.	-7.674E-08	100.0	-3.775E-06	100.0
	1916	284.9	480.5	27.	-5.	-1.087E-06	45.5	-6.957E-05	45.5
	2016	284.1	540.6	31.	-5.	-9.130E-07	44.2	-7.417E-05	44.2
	2116	284.1	600.6	36.	4.	6.275E-07	47.9	6.288E-05	47.9
	2216	284.9	660.7	41.	12.	1.388E-06	29.4	1.679E-04	29.4
	2316	284.3	720.7	48.	14.	1.377E-06	27.0	1.986E-04	27.0
052293	16	285.3	780.8	52.	1.	1.109E-07	87.6	1.871E-05	87.6
	116	284.6	840.8	53.	1.	4.935E-08	100.0	9.680E-06	100.0
	216	286.2	900.9	57.	-1.	-5.520E-08	100.0	-1.236E-05	100.0
	316	285.3	961.0	65.	11.	6.153E-07	30.3	1.573E-04	30.3
	416	286.4	1021.0	73.	18.	8.836E-07	23.9	2.541E-04	23.9
	516	286.5	1081.1	81.	24.	1.068E-06	20.5	3.445E-04	20.5
	616	286.2	1141.1	91.	26.	1.039E-06	19.7	3.734E-04	19.7
	716	287.7	1201.2	101.	16.	5.796E-07	25.0	2.299E-04	25.0
	816	286.5	1261.2	111.	23.	7.433E-07	21.1	3.265E-04	21.1
	916	287.1	1321.3	123.	22.	6.559E-07	21.4	3.156E-04	21.4
	1016	286.8	1381.3	133.	15.	3.985E-07	26.2	2.099E-04	26.2
	1116	286.0	1441.4	136.	15.	3.711E-07	26.0	2.133E-04	26.0
	1216	286.9	1501.4	141.	21.	4.752E-07	22.1	2.957E-04	22.1
	1316	286.5	1561.5	150.	25.	5.219E-07	20.3	3.517E-04	20.3
	1416	286.0	1621.5	156.	13.	2.547E-07	27.9	1.854E-04	27.9
	1516	286.9	1681.6	159.	-5.	-8.715E-08	45.9	-6.803E-05	45.9
052393	1616	285.5	1741.6	167.	-10.	-1.621E-07	32.5	-1.364E-04	32.5
	1716	286.5	1801.7	176.	-3.	-4.922E-08	56.9	-4.418E-05	56.9
	1816	285.8	1861.7	180.	-1.	-9.390E-09	100.0	-9.021E-06	100.0
	1916	285.2	1921.8	186.	7.	1.016E-07	37.2	1.042E-04	37.2
	2017	285.6	1981.8	189.	8.	1.090E-07	34.8	1.187E-04	34.8
	2117	284.7	2041.9	194.	-5.	-6.542E-08	43.6	-7.588E-05	43.6
	2217	285.9	2102.0	201.	1.	1.569E-08	86.4	1.919E-05	86.4
	2317	285.8	2162.0	206.	-11.	-1.206E-07	30.4	-1.563E-04	30.4
	17	285.8	2222.1	214.	-9.	-9.441E-08	33.4	-1.292E-04	33.4
	117	286.7	2282.1	220.	-3.	-2.922E-08	58.3	-4.205E-05	58.3
	217	286.5	2342.2	229.	2.	2.066E-08	67.6	3.135E-05	67.6
	317	287.0	2402.2	236.	8.	6.900E-08	36.1	1.099E-04	36.1
	417	287.3	2462.3	243.	9.	8.051E-08	32.6	1.346E-04	32.6
	517	286.8	2522.3	249.	-5.	-3.689E-08	47.0	-6.485E-05	47.0
	617	286.8	2582.4	258.	1.	7.549E-09	100.0	1.391E-05	100.0
	717	287.8	2642.4	269.	7.	5.359E-08	37.2	1.031E-04	37.2
	817	287.4	2702.5	282.	20.	1.391E-07	22.7	2.803E-04	22.7
	917	287.4	2762.5	288.	10.	7.013E-08	31.2	1.476E-04	31.2
	1017	288.1	2822.6	294.	13.	8.709E-08	27.4	1.910E-04	27.4
	1117	287.3	2882.6	302.	21.	1.275E-07	22.2	2.924E-04	22.2
	1217	286.2	2942.7	310.	27.	1.587E-07	19.5	3.809E-04	19.5
	1317	286.9	3002.8	313.	21.	1.215E-07	21.8	3.030E-04	21.8

Table B-6. (continued).

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
052493	1417	286.2	3062.8	324.	34.	1.845E-07	17.5	4.793E-04	17.5
	1517	285.8	3122.9	331.	19.	9.930E-08	23.2	2.687E-04	23.2
	1617	286.7	3182.9	337.	25.	1.283E-07	20.1	3.596E-04	20.1
	1717	285.6	3243.0	356.	28.	1.383E-07	19.0	4.039E-04	19.0
	1817	285.6	3303.0	365.	40.	1.886E-07	16.0	5.712E-04	16.0
	1917	286.4	3363.1	371.	39.	1.783E-07	16.2	5.584E-04	16.2
	2017	285.6	3423.1	384.	50.	2.194E-07	14.4	7.138E-04	14.4
	2117	286.6	3483.2	394.	54.	2.288E-07	13.9	7.681E-04	13.9
	2217	286.4	3543.2	402.	56.	2.320E-07	13.5	8.065E-04	13.5
	2317	286.5	3603.3	410.	56.	2.211E-07	13.6	7.947E-04	13.6
	17	287.8	3663.3	417.	65.	2.505E-07	12.6	9.267E-04	12.6
	117	287.2	3723.4	424.	52.	1.949E-07	14.0	7.464E-04	14.0
	217	287.4	3783.4	434.	68.	2.463E-07	12.4	9.727E-04	12.4
	317	288.4	3843.5	450.	76.	2.650E-07	11.7	1.077E-03	11.7
	417	288.0	3903.6	460.	74.	2.498E-07	11.9	1.049E-03	11.9
	517	288.0	3963.6	467.	68.	2.241E-07	12.4	9.700E-04	12.4
	618	289.0	4023.7	475.	77.	2.445E-07	11.7	1.087E-03	11.7
	718	288.8	4083.7	484.	77.	2.392E-07	11.6	1.097E-03	11.6
	818	288.5	4143.8	490.	80.	2.416E-07	11.4	1.142E-03	11.4
	941	289.8	4227.3	504.	78.	2.264E-07	11.6	5.729E-04	11.6
	1041	288.7	4287.3	518.	86.	2.410E-07	11.1	1.220E-03	11.1
	1141	288.8	4347.4	526.	92.	2.498E-07	10.7	1.298E-03	10.7
	1241	288.5	4407.5	537.	85.	2.244E-07	11.2	1.200E-03	11.2
	1341	287.5	4467.5	551.	86.	2.233E-07	11.0	1.231E-03	11.0
	1441	286.7	4527.6	560.	91.	2.297E-07	10.8	1.304E-03	10.8

Table B-7. Results for air sampling performed at the CTP June 27, 1993, with alpha CAM 1.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
62793	1006	280.4	30.1	15.	15.	9.016E-04	25.9	9.016E-04	25.9
	1036	281.9	60.2	51.	48.	7.150E-04	14.7	2.857E-03	14.7
	1106	286.8	90.2	121.	45.	2.985E-04	15.1	2.654E-03	15.1
	1136	282.0	120.2	260.	84.	3.137E-04	11.2	5.042E-03	11.2
	1206	285.8	150.3	491.	213.	5.080E-04	7.3	1.261E-02	7.3
	1236	285.5	180.3	907.	481.	7.957E-04	5.2	2.850E-02	5.2
	1306	288.0	210.4	1372.	740.	8.983E-04	4.4	4.346E-02	4.4
	1336	289.9	240.4	1698.	-62.	-5.711E-05	13.0	-3.597E-03	13.0
	1406	290.1	270.5	1964.	-31.	-2.260E-05	18.2	-1.801E-03	18.2
	1436	289.1	300.5	2192.	135.	7.968E-05	9.0	7.881E-03	9.0
	1506	288.9	330.5	2345.	110.	5.351E-05	9.9	6.424E-03	9.9

Table B-8. Results for air sampling performed at the CTP June 27, 1993, with alpha CAM 2.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
62793	1006	303.1	30.1	17.	-530.	-3.009E-02	5.0	-3.009E-02	5.0
	1036	296.1	60.2	47.	20.	2.904E-04	22.4	1.179E-03	22.4
	1106	297.0	90.2	124.	-21.	-1.321E-04	22.2	-1.198E-03	22.2
	1136	291.7	120.2	247.	-147.	-5.362E-04	8.6	-8.739E-03	8.6
	1206	293.6	150.3	447.	153.	3.569E-04	8.5	9.016E-03	8.5
	1236	292.6	180.3	815.	188.	3.051E-04	7.7	1.111E-02	7.7
	1306	294.1	210.3	1176.	301.	3.601E-04	6.3	1.774E-02	6.3
	1336	296.2	240.4	1412.	199.	1.816E-04	7.5	1.160E-02	7.5
	1406	296.0	270.5	1630.	144.	1.038E-04	8.7	8.388E-03	8.7
	1437	295.6	300.5	1833.	-32.	-1.865E-05	17.9	-1.865E-03	17.9
	1507	294.6	330.5	1984.	341.	1.651E-04	6.0	2.005E-02	6.0

Table B-9. Results for air sampling performed at the CTP June 27, 1993, with alpha CAM 3.

Date	Time	Average Flow Rate (LPM)	Sampling Time (MIN)	²³⁹ Pu/ ²⁴¹ Am ROI (3.71 to 5.60 MeV)		²³⁹ Pu/ ²⁴¹ Am Concentration			
				Total Counts	Net Counts	Average (pCi/L)	Uncert. (%)	Maximum (pCi/L)	Uncert. (%)
62793	1006	287.5	30.1	17.	-3.	-1.889E-04	54.8	-1.889E-04	54.8
	1037	282.0	60.2	65.	32.	4.619E-04	17.8	1.873E-03	17.8
	1107	282.7	90.2	150.	44.	2.779E-04	15.4	2.518E-03	15.4
	1137	272.8	120.3	347.	184.	6.678E-04	7.8	1.104E-02	7.8
	1207	276.1	150.3	700.	-1278.	-2.982E-03	3.7	-7.580E-02	3.7
	1237	274.3	180.4	1203.	-150.	-2.431E-04	8.5	-8.915E-03	8.5
	1307	276.5	210.4	1679.	-504.	-6.028E-04	5.1	-2.983E-02	5.1
	1337	277.5	240.4	1968.	-521.	-4.781E-04	5.0	-3.077E-02	5.0
	1407	277.3	270.5	2208.	-1420.	-1.029E-03	3.6	-8.357E-02	3.6
	1437	275.0	300.5	2407.	-805.	-4.730E-04	4.3	-4.790E-02	4.3
	1507	273.4	330.6	2602.	-666.	-3.239E-04	4.6	-3.982E-02	4.6

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