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Characterization of Under-Building Contamination at Rocky Flats Implementing Environmental Measurement-While-Drilling Process with Horizontal Directional Drilling

Cecelia V. Williams, Grant J. Lockwood, Michael M. Selph, Randy A. Normann, and Thomas Lindsay

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Characterization of Under-Building Contamination at Rocky Flats Implementing Environmental Measurement-While-Drilling Process with Horizontal Directional Drilling

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ABSTRACT

Characterization is required on thirty-one buildings at Rocky Flats Environmental Technology Site (RFETS or the Site) with known or suspected under building contamination. The Site has teamed with Sandia National Laboratory (SNL) to deploy Environmental Measure-While-Drilling (EMWD) in conjunction with horizontal directional drilling (HDD) to characterize under building contamination and to evaluate the performance and applicability for future characterization efforts. The Environmental Measurement-While-Drilling-Gamma Ray Spectrometer (EMWD-GRS) system represents an innovative blend of new and existing technology that provides the capability of producing real-time environmental and drill bit data during drilling operations.

The project investigated two locations, Building 886 and Building 123. Building 886 is currently undergoing D&D activities. Building 123 was demolished in 1998; however, the slab is present with under building process waste lines and utilities. This report presents the results of the EMWD Gamma Ray Spectrometer logging of boreholes at these two sites. No gamma emitting contamination was detected at either location.

Acknowledgements

This Environmental Measurement-While-Drilling-Gamma Ray Spectrometer (EMWD-GRS) system technology demonstration was funded by the Office of Science and Technology (OST) under U.S. Department of Energy (U.S. DOE) contract number DE-AC04-94AL85000.

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ACRONYMS

AC	alternating current
Am	americium
COC	contaminants of concern
Co	cobalt
CPM	counts per minute
Cm	curium
Cs	cesium
DC	direct current
D&D	Decommissioning and Deactivation
DOE	U.S. Department of Energy
Em	Environmental Management
EMWD	Environmental Measurement-While-Drilling
FM	frequency modulated
GRS	Gamma Ray Spectrometer
HEUN	Highly Enriched Uranyl Nitrate
HDD	Horizontal Directional Drilling
IDW	Investigative Derived Waste
IHSS	Individual Hazardous Substance Site
kHz	kilo-hertz
PAC	Potential Area of Concern
ppm	Parts Per Million
Pu	Plutonium
RCRA	Resource Conservation and Recovery Act
RFETS	Rocky Flats Environmental Technology Site
SNL	Sandia National Laboratory
UBC	Under Building Contamination
U	uranium
V	Volt

Introduction

Characterization is required on thirty-one buildings at Rocky Flats Environmental Technology Site (RFETS) with known or suspected under building contamination. (UBC). UBCs are a result of known spills, leaks, or building processes during years of production. Recent demonstrations performed at other Nuclear Weapons Facilities (e.g. Hanford and Savannah River Site) have proven successful in characterization of subsurface contamination using the Environmental Measurement-While-Drilling technology with horizontal directional drilling. Sandia National Laboratories teamed with these sites to conduct the successful demonstrations.

The RFETS has teamed with Sandia National Laboratory (SNL) to deploy Environmental Measure-While-Drilling (EMWD) in conjunction with horizontal directional drilling (HDD) to characterize under building contamination and to evaluate the performance and applicability for future characterization efforts. Data collected using EMWD/HDD will be compared to data collected by conventional geoprobe techniques. The project investigated two locations, Building 886 and Building 123. Building 886 is currently undergoing D&D activities.

Background

The U.S. Department of Energy (DOE) Environmental Management (EM-50) has funded the development of the EMWD-GRS. During development, the EMWD-GRS system was tested at the U.S DOE radiation test facility in Grants, New Mexico and at the directional boring test site owned by Charles Machine Works in Perry, Oklahoma. The EMWD-GRS has been demonstrated at the Savannah River Site (SRS) F-Area Retention Basin. The EMWD-GRS with a Position Location Tool (PLT) was demonstrated at Hanford. The characterization activities at Rocky Flats represent the first deployment of the EMWD-GRS funded in part by Environmental Restoration (EM-40).

Rocky Flats Environmental Technology Site

The Rocky Flats Environmental Technology Site (RFETS or the Site) is located approximately 16 miles northwest of Denver, Colorado, in northern Jefferson County. RFETS comprises approximately 6,550 acres of land in Sections 1 through 4 and 9 through 15 of Township 2 South, Range 70 West, 6^{th} Principal Meridian. Major buildings are located within the industrial area, which encompasses approximately 400 acres and are surrounded by a buffer zone of approximately 6,150 acres. RFETS is government-owned, U.S. Department of Energy (DOE), contractor-operated facility in the nuclear weapons production complex. The former mission at RFETS was to produce components for nuclear weapons from plutonium, uranium, and non-radioactive materials.

The current mission is to safely close the Site under an aggressive schedule. The emphasis of closure is focused on Deactivation and Decommissioning (D&D) activities for the remaining buildings that have the highest priority and critical path at this time. To accomplish closure in a timely fashion, characterization is required on thirty-one buildings across the Site with suspected or verified Under Building Contamination (UBCs). UBCs resulted from known spills, leaks, or building processes during the years of production. Characterization activities will be required to be conducted in parallel with D&D activities in-order to meet the aggressive closure schedule.

Environmental Measurement-While-Drilling (EMWD)

The Environmental Measurement-While-Drilling Gamma Ray Spectrometer with position location capability (EMWD-GRS) system represents an innovative blend of new and existing technology that produces the capability of providing real-time environmental and drill bit data during drilling operations. These real-time measurements provide technical data for field screening (i.e., "steering" the drill bit in or out of contaminated zones). There are also time, cost, and safety advantages to using the EMWD-GRS system's field screening approach: (1) data on the nature of contamination are available in minutes, as opposed to weeks or months for offsite confirmatory analysis; (2) substantial cost savings result by minimizing the number of samples required for off-site confirmatory analyses; and (3) worker safety is enhanced through the minimization of waste generated during drilling and by quickly alerting field personnel to potentially hazardous conditions; and (4) the amount of investigation derived waste (IDW) is reduced.

The EMWD-GRS system is compatible with a variety of directional drilling techniques that include (1) push systems that use minimal drilling fluids generating little or no secondary waste and (2) mud systems using rotary drilling or mud motors The down hole sensors are located behind the drill bit and are linked by a high-speed data transmission system to a computer at the surface. Windows™-based software, developed by Sandia National Laboratories, is used for data display and storage. During drilling operations, data on the nature and extent of contamination are collected. Instant access to the data provides information for on-site decisions regarding drilling and sampling strategies.

Down-hole components of the EMWD-GRS system being deployed consist of a gamma ray spectrometer, a multichannel analyzer, a 900V power supply, a signal conditioning and transmitter board, and a coil containing coaxial cable for transmitting data to the surface. To protect them from the drilling environment, down-hole components are contained within O-ring-sealed stainless steel tubes. The up-hole system consists of a personal computer, a battery pack/coil, a pickup coil, and a receiver. During drilling, the GRS system monitors (1) gamma radiation, (2) the +12V and -12V required at the down-hole signal conditioning and transmitter board, (3) the up-hole battery voltage as measured down-hole, and (4) two temperatures associated with the detector and instrumentation. The system design incorporates data quality assurance techniques to ensure data reliability.

The EMWD system can provide real-time data on an 8 differential/single analog multiplexer and on any number of digital channels. Sampling speed from the analog channels can reach 100 kHz. For the EMWD-GRS system, three digital channels are used. Readings are taken at a rate of 20 per second. The telemetry system is programmable firmware that can easily support many different data formats and additional data channels. The currently used format (Digital FM Bi-phase, 4800 baud) provides excellent noise rejection. A Sandia National Laboratories (SNL) designed receiver removes FM carrier noise, generates data clock, and buffers data to be used by an IBM or compatible personal computer. A 28V rechargeable battery pack can supply down-hole instrumentation power for more than 18 hours of drilling. The battery pack remains topside for easy maintenance.

RFETS Deployment of EMWD-GRS

The RFETS teamed with Sandia National Laboratory (SNL) to use EMWD in conjunction with horizontal directional drilling to characterize under building contamination and to evaluate the performance and applicability for future characterization efforts. Data collected using horizontal directional drilling with real time measurement-while-drilling will be compared to data collected by conventional geoprobe techniques.

The project investigated two locations, UBC 123 and Building 886. UBC 123 was demolished in 1998; however, the slab is present with under building process waste lines and utilities. Building 886 is currently undergoing D&D activities. A brief summary of the site history and contaminants of concern is given here.

Field activities met the following objectives:

- Characterize the under building contamination at Buildings 123 and 886
- Implement Sandia National Laboratories' real time measurement-while-drilling system (Environmental Measurement-While-Drilling) in conjunction with horizontal drilling to determine the effectiveness for characterizing under building contamination.

Project Description for UBC 123

UBC 123 (Figure 1) is located on Central Avenue between Third and Fourth Streets in the RFETS Industrial Area. In 1998 the building, which covered approximately 18,444 square feet, was D&D. Utilities were either disconnected and abandoned in place or removed in their entirety during the demolition of the superstructure. Remaining structural components are the building slab on grade, perimeter grade beam and spread footings.

History

Building 123 was constructed in 1953 and was used as the Site Radiological Health Physics Laboratory. The lab analyzed water, biological materials, soil, air, and filter samples for the presence of plutonium, americium, uranium, alpha radiation, beta radiation, gamma radiation, tritium, beryllium, and organics. Personnel radiation badges were counted and repaired and in the building as well. Radiological low-level liquid and chemical wastes were generated at this location and transferred to the Site treatment system, Building 374, via the process waste lines system.

UBC 123 consists of several potential areas of contamination (PACs) and two Individual Hazardous Substance Sites (IHSSs)

- IHSS 121 – Original Process Waste Lines: process waste lines P-1, P-2 and P-3 (see Appendix I: Plates showing locations of Bores at UBC 123 and Building 886, Plate 2).
- IHSS 148 which was established due to possible leaks from line P-2 and reported nitrate-bearing spills along the east side of UBC 123.

Contaminants of Concern

While in service, the Site Radiological Health Physics Laboratory used a wide variety of chemical including acids, bases, solvents, metals, radionuclides, and other. Wastes from operations were transferred for disposal via the process waste lines. Radionuclides of concern include: various isotopes of plutonium (Pu), americium (Am), uranium (U), and curium (Cm). This report only addresses efforts to identify gamma-emitting contamination.

Figure 1. Under Building Contamination 123: the 'U' shaped concrete slab is located in the center of the photograph.

Environmental Measurement-While-Drilling/Horizontal Directional Drilling (EMWD/HDD)

Four HDD boring line locations (HDD Lines 1 – 4) have been chosen for characterization of the soils immediately beneath and along the process waste lines, manholes, and sumps of UBC 123. Locations of the bores are shown in Appendix B, Plate #1.

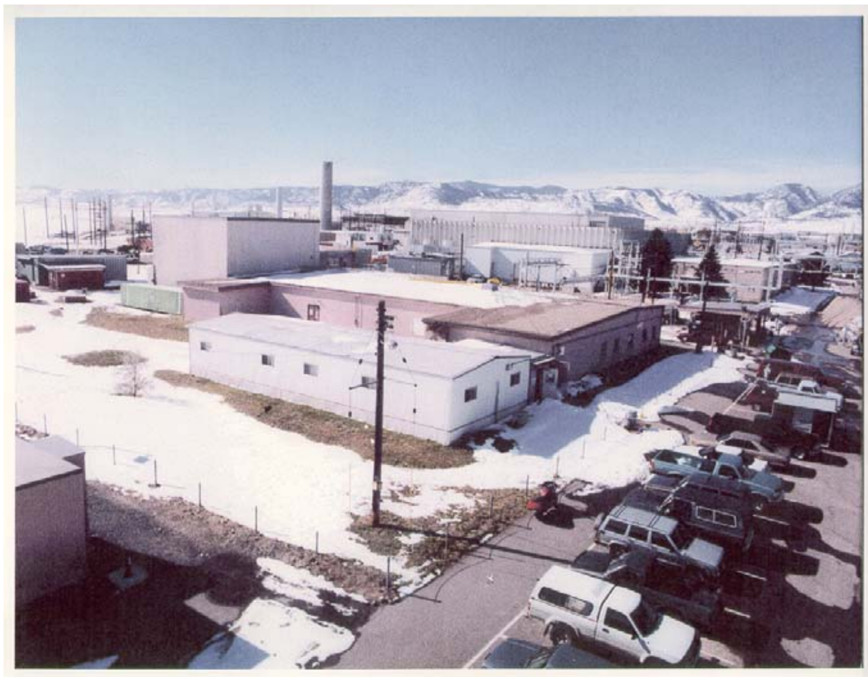
Project Description for Building 886

Building 886, located in the northeastern portion of the 800 Area (Figure 2), was put into service in 1965. The building is approximately 14,197 square feet. In approximately 1980, Trailer 886A was built immediately east of the building and was later connected by the existing breezeway. Trailer 886A currently houses offices and a small electronics/machine shop. Various underground utilities are adjacent the building on the west side that are process waste lines that feed two underground storage tanks

History

Building 886 housed the Critical Mass Laboratory where low-level criticality experiments were performed on liquids, powder, and solid forms of fissionable materials. The date of the last criticality experiment was in October 1987. No operations are currently performed in Building 886 except for D&D activities. Enriched uranium solutions, solid enriched uranium, and plutonium metal have been used in this building. Room 103 contained seven Highly enriched uranyl nitrate (HEUN) tanks and a tank storage pit. HEUN solutions were spilled numerous times in rooms 101 and 103 during operations. The HEUN solutions spills were decontaminated and followed by sealing the concrete floor with paint to fix any residual contamination. Fluctuations of high groundwater under the building have periodically permeated the floor slab and have stained the concrete floor in room 103 with yellow cake after groundwater subsidence. The process of decontamination and sealing the concrete surface was repeated a number of times. Individual Hazardous Substance Site 164.2 located around Building 886 perimeter, resulted from an incident on September 26, 1989 where a 500-gallon stainless steel tank was found leaking a colorless liquid from its drain valve onto a concrete surface.

Figure 2. Building 886: building 886 is located behind the trailer.



Contaminants of Concern

The primary contaminants of concern at Building 886 based on past operational history are metals and radionuclides. The specific radionuclides of concern include: Pu-239/240, U-233/234, U-235, U-238, and Am-241).

Environmental Measurement-While-Drilling/Horizontal Directional Drilling (EMWD/HDD)

The EMWD/HDD effort was conducted on the east side due to underground utilities on the west side of the building. Two horizontal directional boreholes, HDD line 5-6, were planned for this facility (See Appendix B, Plate #2). Room 101 is the criticality laboratory with perimeter walls that are constructed of reinforced concrete and 4 feet thick. These walls extend below grade approximately five feet deep and are heavily reinforced with #6 and #8 rebar at twelve inches on center each way. HDD Line 5 was not attempted because of the possible high levels of HEUN contamination.

Procedures

The calibration of the EMWD-GRS was conducted in a steel pipe. It was calibrated in the laboratory at Sandia National Laboratories using Cs-137, Co-60, and Na-22. It was also calibrated at the Field Calibration Facility for Environmental Measurement of radium, thorium, and potassium, DOE Grants Calibration Site, Grants, NM. The tool was calibrated using the thorium source and the potassium-40 source. The calibration curves age given in Appendix H: EMWD Gamma Ray Spectrometer Calibration.

RFETS selected Microtunneling as the directional drilling method. The Microtunneling technique uses a pneumatic hammer to develop the bore and install casing. This method was selected because it used no drilling fluid

EMWD, designed for use with rotating drilling methods, has never been tested in this environment. We had the following concerns using EMWD with the microtunneling:

- the pneumatic hammer would subject the EMWD tool to a shock environment for which it has not been tested;
- the magnetometer, for position location, could not be used;
- the Gamma spectrometer will be ~3 ft behind bit;
- cable handling would be a problem; and
- mounting the battery pack, that supplies power to the tool, would be an issue.

An alternative use of EMWD for Rocky Flats Deployment was devised. The following procedure was developed:

- A walkover position indicator is used to track drill bit position
- The casing would be emplaced to the first sampling point with the pneumatic hammer, without EMWD
- Pull out pneumatic hammer
- Push in EMWD, log hole as EMWD tool is withdrawn
- Push in sampler and take soil sample
- Re-insert pneumatic hammer to emplace casing to the next sampling point.

This procedure does not subject the EMWD tool to shock, but provides for real-time data on gamma contamination prior to taking soil sample. This was a completely new type of deployment of the EMWD tool. The method operation of the EMWD tool will not is given here, but can be found in Reference 4.

EMWD Tool Logging Set Up

The following procedure was used to collect gamma spectra in the RFETS bores:

1) EMWD tool set-up
   a) The EMWD tool is placed in a PVC housing.
   b) The tool is secured to the PVC housing so that tool does not turn and twist the cable off.

2) The EMWD tool is pushed into the open hole to the bit face, sampling point.

3) Data collection:
   a) Collect EMWD spectra at this point for 5 minutes.

b) Pull the EMWD tool out 1 foot, collect 1 spectrum. If no contamination is detected, continue this procedure until the tool reaches the next sampling point or exits the hole.
c) Repeat this procedure for each sampling point.

Results

UBC-123 Bore #1

UBC-123 HDD Line #1, located on the west side of UBC-123 and runs north-south (See Appendix B: Plates Showing Locations of Bores at UBC-123 and Building 886) was to be approximately 110 feet long and with seven soil samples to be taken. Background gamma spectra of the UBC-123 area were collected (Figure 3). The next spectra were taken at 20 ft (not a soil sampling point) into the bore (Figure 4). Comparison of Figures 3 and 4 indicate no readings above background at the 20 ft location. (Note: Only representative gamma spectra are included in the body of the report. The complete set of gamma spectra for all the soil sampling points are provided in Appendix D: EMWD Gamma Spectra for UBC 123 and Appendix D: EMWD Gamma Spectra for Building 886).

The next tool insertion was to be at 80 ft, the first soil sample point 1-01. Eighty feet was not achieved. A concrete footer was hit at ~40ft and could not be penetrated and the driller was having trouble getting depth reading from his locator tool. UBC-123HDD Line #1 was abandoned in place at the 40 ft point because the foundation wall of the building extension could not be penetrated.

Before pulling away from the first bore site, bore #1 was logged. The tool was pulled-back one foot at a time and a spectrum was taken. This was the technique use to fully log the remaining bores. A few representative samples of these spectra are given in Appendix D: EMWD Gamma Spectra for UBC 123 HHD #1. These spectra are essentially the same as the background spectra.

Figure 3. UBC-123 Gamma Spectrum background, Rocky Flats.

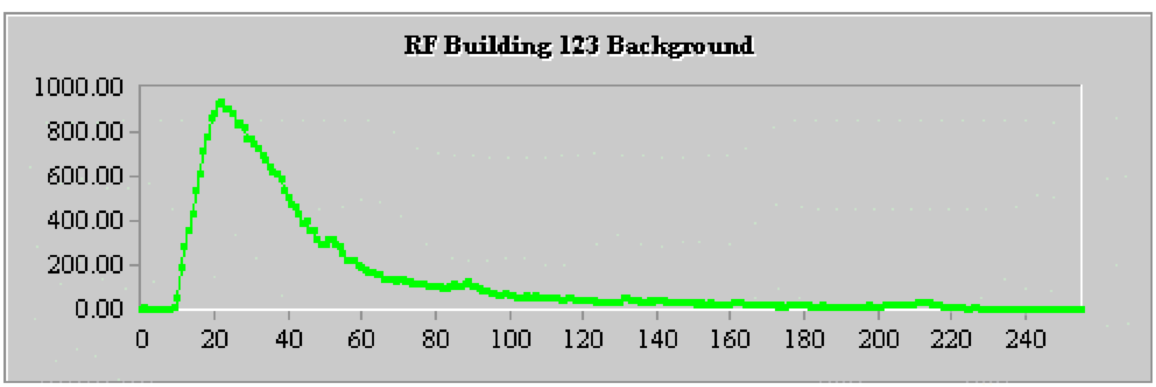
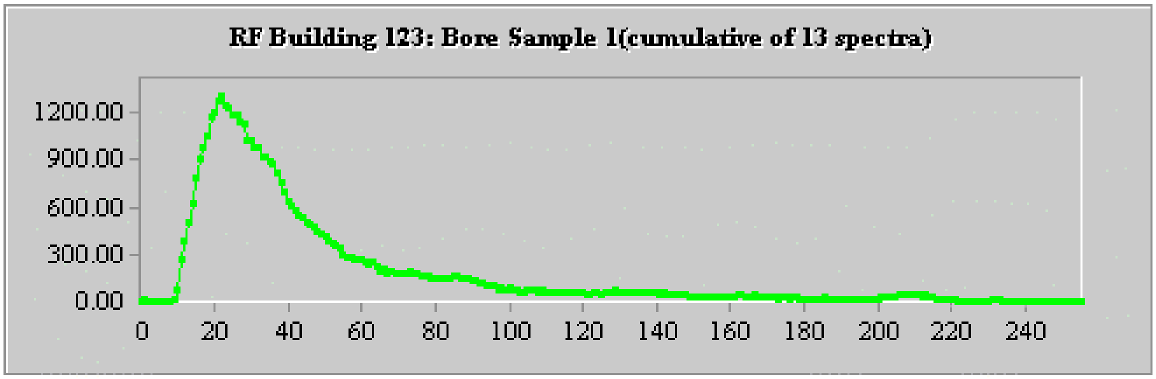


Figure 4. Cumulative Gamma Spectrum (13 spectra) from Bore 1 Sample 1, 20 ft into bore.



UBC-123 Bore #2

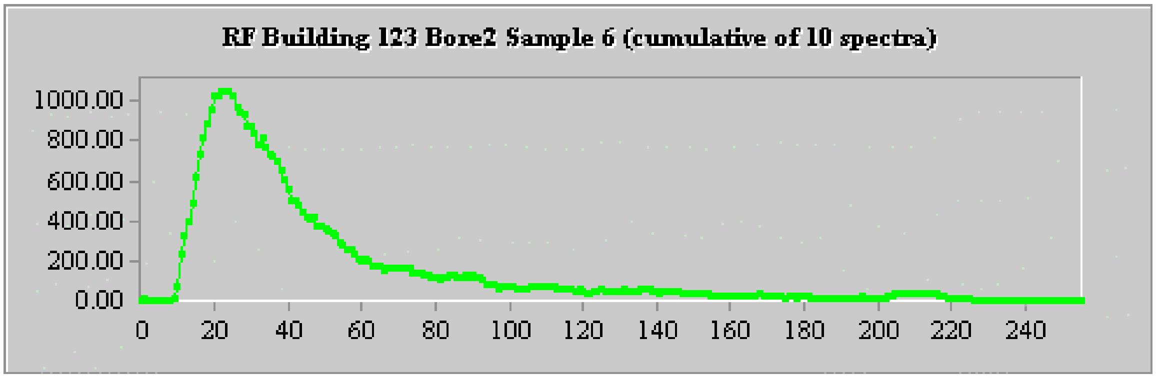
UBC-123 HDD Line #2 was to be approximately 190 feet long and thirteen soil samples were to be extracted (See Appendix B: Plates Showing Locations of Bores at UBC-123 and Building 886). HDD Line #2 is on the east side of the site and runs north south. This bore was completed to 126 feet at HDD #2 soil sample point 10. This bore was abandoned at this point because the casing was bent and further advancement could not be achieved.

Table 1 correlates the gamma spectra sampling locations with the soil sample locations and feet advanced. Sample point HDD Line #2-02 coincides with sampling point HDD Line #4-06. No gamma spectra were taken at UBC-123 HDD Line #2-02. Gamma spectral data for this point was taken onUBCu-123 HDD Line #4-06. Gamma spectra were collected at the soil sampling points and at 1-ft intervals between the soil sampling points. No gamma emitting contamination was detected anywhere along this bore. A representative gamma spectrum from UBC-123 HDD Line #2 indicating this fact is shown in Figure 5. Figure 5 is accumulative gamma spectrum of 10 gamma spectra collected at soil sampling point UBC-123 HHD Line #2-06 The gamma spectra for each soil sampling point of UBC-123 HDD Line #2 are given in Appendix D: EMWD Gamma Spectra for UBC-123. The gamma spectra gathered at the 1-ft intervals are not included in this report since no gamma contamination was detected.

Table 1: EMWD-GRS results from UBC-123 HDD Line #2.

Soil Sampling Number	Location (feet advanced)	EMWD-GRS Number	Results of GRS Reading
HDD #2-01	10	1	No contamination detected
HDD #2-03	27	2	No contamination detected
HDD #2-04	42.3	3	No contamination detected
HDD #2-05	54.4	4	No contamination detected
HDD #2-06	74	5	No contamination detected
HDD #2-07	92.3	6	No contamination detected
HDD #2-08	100	7	No contamination detected
HDD #2-08	102	8	No contamination detected
HDD#2-10	126	9	No contamination detected

Figure 5. Representative gamma spectrum for UBC-123 Bore #2: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 6.



UBC-123 Bore #3

UBC-123 HDD Line #3 was to be approximately 150 feet long and eleven soil samples were to be extracted. HDD Line #3 is on the south side of the site and runs east-west (See Appendix B: Plates Showing Locations of Bores at UBC-123 and building 886). This bore was completed to 63 feet at HDD #3 soil sample point 5. This bore was abandoned at this point because the casing was bent and further advancement could not be achieved.

Table 2 correlates the gamma spectra sampling locations with the soil sample locations and feet advanced. Gamma spectra were collected at the sampling points and at 1-ft intervals between the sampling points. No gamma emitting contamination was detected anywhere along this bore. A representative gamma spectrum from UBC-123 HDD Line #3 indicating this fact is shown in Figure 6. Figure 6 is accumulative gamma spectrum of 10 gamma spectra collected at soil sampling point UBC-123 HHD Line #3-03. The gamma spectra for each soil sampling point of UBC-123 HDD Line #3 are given in Appendix D: EMWD Gamma Spectra for UBC 123.

Table 2: EMWD-GRS results from UBC-123 HDD Line #3.

Soil Sampling Number	Location (feet advanced)	EMWD-GRS Number	Results of GRS Reading
HDD #3-02	18	2	No contamination detected
HDD #3-03	33	3	No contamination detected
HDD #3-04	48	4	No contamination detected
HDD #3-05	63	5	No contamination detected

UBC-123 Bore #4

UBC-123 HDD Line #4 was to be approximately 85 feet long and six soil samples were to be extracted. HDD Line #4 is on the north side of the site and runs east-west (See Appendix B: Plates Showing Locations of Bores at UBC-123 and Building 886). This bore was completed in its entirety.

Figure 6. Representative gamma spectrum for UBC-123 Bore #3: Cumulative Gamma Spectrum (10 spectra) from Bore 3 Sample 3.

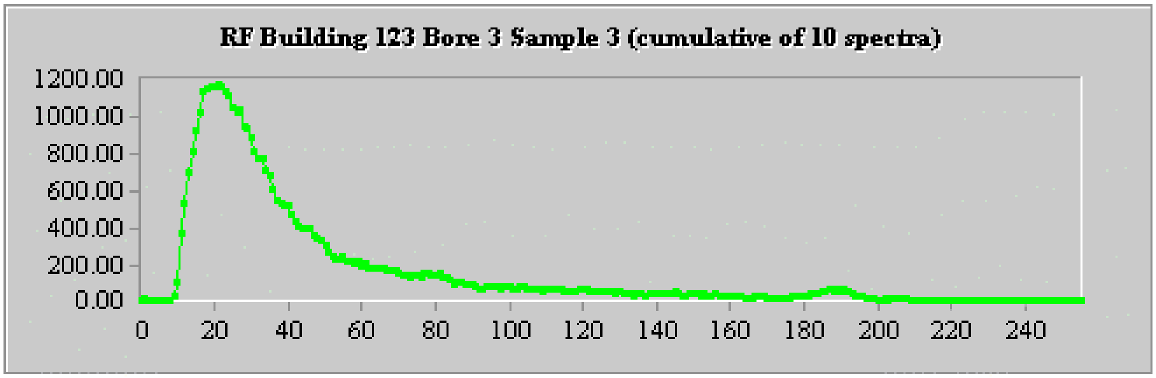
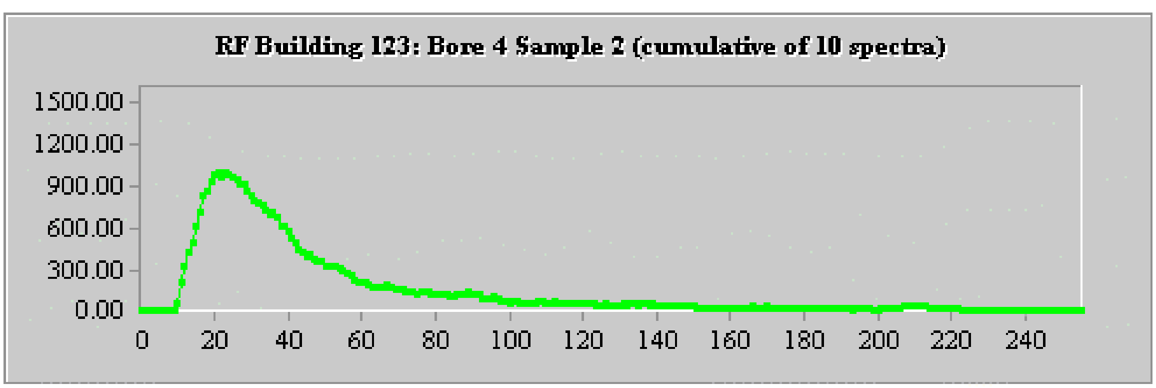


Table 3 correlates the gamma spectra sampling locations with the soil sample locations and feet advanced. Gamma spectra were collected at the soil sampling points and at 1-ft intervals between the soil sampling points. No gamma emitting contamination was detected anywhere along this bore. A representative gamma spectrum from UBC-123 HDD Line #4 indicating this fact is shown in Figure 7. Figure 7 is accumulative gamma spectrum of 10 gamma spectra collected at soil sampling point UBC-123 HHD Line #3-03. The gamma spectra for each soil sampling point of UBC-123 HDD Line #3 are given in Appendix D: EMWD Gamma Spectra for UBC 123.

Table 3: EMWD-GRS results from UBC-123 HDD Line #4.

Soil Sampling Number	Location (feet advanced)	EMWD-GRS Number	Results of GRS Reading
HDD #4-01	112	6	No contamination detected
HDD #4-02	102	5	No contamination detected
HDD #4-03	87	4	No contamination detected
HDD #4-04	72	3	No contamination detected
HDD #4-05	53	2	No contamination detected
HDD #4-06	42	1	No contamination detected

Figure 7. Representative gamma spectrum for UBC-123 Bore #4: Cumulative Gamma Spectrum (10 spectra) from Bore 4 Sample 2.



Building 886 Bore #6

Building 886 HDD Line # 6 was to be approximately 40 feet long and extract four soil samples as shown on Plate. This line went under the north end room 101 and runs east-west. (See Appendix B: Plates Showing Locations of Bores at UBC-123 and Building 886). This bore was completed to 18 feet at HDD #6 soil sample point 2. This bore was abandoned at this point because further advancement could not be achieved.

Background gamma spectra of the Building 886 area were collected (Figure 8). Table 4 correlates the gamma spectra sampling locations with the soil sample locations and feet advanced. Gamma spectra were collected at the sampling points and at 1-ft intervals between the sampling points. No gamma emitting contamination was detected anywhere along this bore. A representative gamma spectrum from Building 886 HDD Line #6 indicating this fact is shown in Figure 9. Figure 9 is accumulative gamma spectrum of 10 gamma spectra collected at soil sampling point Building 886 HHD Line #6-03. The gamma spectra for each soil sampling point of Building 886 HDD Line #6 are given in Appendix F: EMWD Gamma Spectra for Building 886.

Table 4: EMWD-GRS results from Building 886 HDD Line #6.

Soil Sampling Number	Location (feet advanced)	EMWD-GRS Number	Results of GRS Reading
HDD #6-02	18	1	No contamination detected
HDD #6-01	10	2	No contamination detected
HDD #6-bore opening	0	2	No contamination detected

Figure 8. Building 886 Gamma Spectrum background, Rocky Flats.

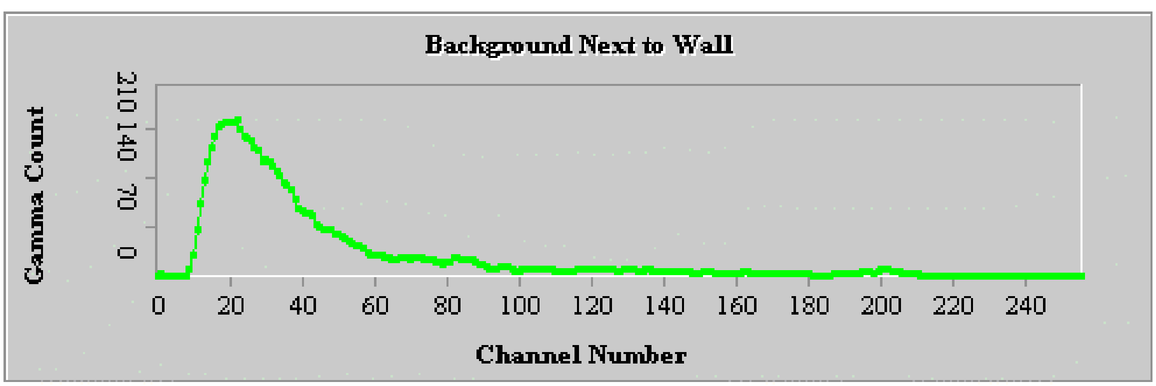
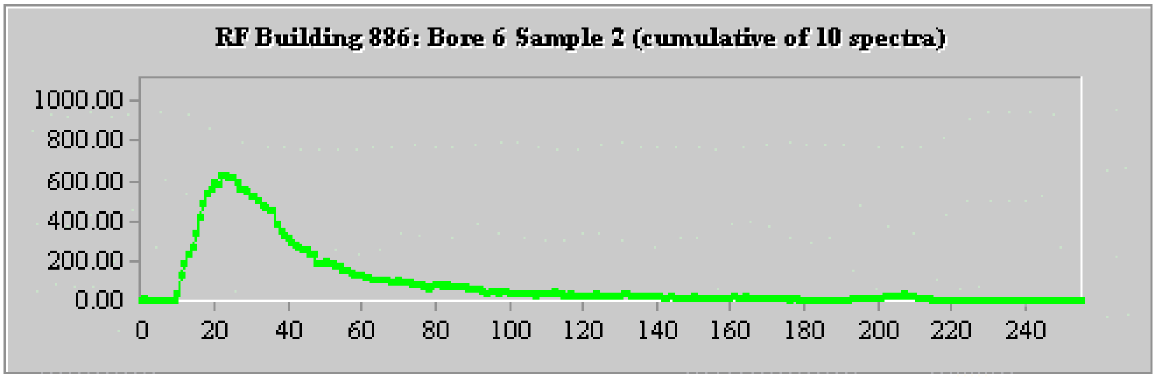


Figure 9. Representative gamma spectrum for Building 886 Bore #6: Cumulative Gamma Spectrum (10 spectra) from Bore 6 Sample 2.



SUMMARY

Five bores were drilled at two sites at the Rocky Flats Environmental Technology Site, four under UBC-123 and one under Building 886. The bores were developed using a microtunneling technique that uses a pneumatic hammer with no drilling fluid to advance the bore and install casing. Since the EMWD-GRS tool was not designed for this type of drilling, there were several concerns not the least of which the EMWD-GRS tool has never been tested in this type of shock environment. Additionally, since steel casing was installed, the EMWD-GRS position location capability could not be used. The EMWD-GRS tool was used to log the boreholes for gamma emitting contaminants prior to taking each soil sample.

Only one of the five bore attempted was completed in its entirety. The EMWD-GRS tool was used to log the bores for gamma emitting contaminants. No gamma emitting contaminants were detected.

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6. R. A. Normann, G. J. Lockwood, C. V. Williams, and M. M. Selph (1998*) "Integration and Evaluation of a Position Sensor with Continuous Read-out for use with the Environmental Measurement-While-Drilling Gamma Ray Spectrometer System,* SAND98-0476C, North American No Dig '98, Albuquerque, NM, April 1998.

7. C. V. Williams, G. J. Lockwood, and R. A. Normann, D. A. Myers. M. G. Gardner, T. Williamson, and J Huffman, *Environmental Measurement-While-Drilling System and Horizontal Directional Drilling Technology Demonstration, Hanford Site,* SAND99-1479, Sandia National Laboratories, Albuquerque, New Mexico.

8. R. Leino, D. C. George, B. N. Key, L. Knight, and W. D. Steele, (1994) *Field Calibration Facilities of Environmental Measurement of Radium, Thorium, and Potassium*, Doe/ID/12584-179; GJ/TMC-01 (Third Edition). RUST Geotech, Inc., Grand Junction, CO, 1994.

9. B. Shleien, (1992) *The Health Physics and Radiological Health Handbook* (Revised Edition). Scinta Inc., Silver Spring, MD, 1992.

10. Statement of Work for Characterization for Characterization of Under-building Contamination (UBC) at UBC 123 and Building 886 Implementing Horizontal Directional Drilling (HDD) Environmental Measurement-While-Drilling (EMWD) Process, Kaiser Hill L.L.C., February 2000

APPENDICES

A. Statement of Work for Sandia National Laboratories Implementing Environmental Measurement-While-Drilling at UBC 123 and Building 886.

B. Plates showing locations of Bores at UBC 123 and Building 886

C. EMWD Background Gamma Spectra: UBC 123

D. EMWD Gamma Spectra for UBC 123

E. EMWD Background Gamma Spectra: Building 886

F. EMWD Gamma Spectra for Building 886

G. EMWD Gamma Ray Spectrometer Calibration Methodology

H. EMWD Gamma Ray Spectrometer Calibration

I. Rocky Flats Field Notes

APPENDIX A - Statement of Work for SNL

Statement of Work for Sandia National Laboratories Implementing Environmental Measurement-While-Drilling at UBC 123 and Building 886

Statement of Work

1.0 Introduction

Sandia National Laboratories is working jointly with personnel at Rocky Flats to deploy the Environmental Measurement-While-Drilling (EMWD) system. The EMWD system is normally used while drilling. A number of factors resulted in the EMWD tool not being used while drilling for this deployment. In stead, the Rocky Flats drilling contractor will drill the hole without the EMWD tool. When the hole is completed or before a soil sample is taken, the Sandia EMWD tool will be manually placed into the hole using plastic tubing. With the tool in the hole, Sandia and Sandia contracted personnel will measure the wellbore gamma radiation levels.

The gamma radiation measurement is a full 256-channel spectrum. This data will be recorded in a Sandia supplied PC and Sandia software. If any notable radiation levels are detected, Sandia personnel will report and document their reading to Rocky Flats personnel. The Rocky Flats personnel will take appropriate action.

2.0 Scope of Work

2.1 Prior to deployment, Sandia will calibrate the EMWD for sub-surface gamma measurement. This calibration will be performed at the DOE calibration facility in Grants, NM.

2.2 Field Deployment of the EMWD

Sandia will supply one EMWD system and two appropriately trained personnel to the Rocky Flats Environmental Technology site. The Sandia and Sandia contracted personnel will support and/or assist in the deployment of the EMWD system to survey possible radioactive waste. Typical Sandia personnel duties may include:

- Assist in or perform placing the EMWD tool into the hole
- Record the measured results
- Report results to appropriate personnel

2.3 Training

The Sandia personnel are required to have a combination of 40-hour HAZWOPER with current HAZWOPER 8-hour refresher, DOE certificate of radiological training RW II, and complete site specific training ON site at Rocky Flats prior to start of work.

3.0 Task Control

Cecelia Williams, Department 6803, is the designated Task Leader and will be consulted for approval if technical decisions concerning the scope of the work are needed. Randy Normann will provide the day-to-day interface.

4.0 Deliverables

4.1 Sandia will provide radiation spectrums from calibration testing at Grants NM.
4.2 Sandia will provide timely radiation measurements prior to drilling contractor soil sampling.
4.3 Sandia will provide a record of gamma reading taken within 6 months following completion of the Rocky Flats deployment.

5.0 Expected level of funding from Rocky Flats to support this activity is $55K.

5.1 Calibration at Grants NM
5.2 Field support personnel for up to consecutive 6 weeks
5.3 Final report providing the entire gamma record for the deployment

APPENDIX B - Locations of Bores

Plates showing locations of Bores at UBC 123 and Building 886

APPENDIX C - EMWD Background Gamma Spectra (UBC 123)

EMWD Background Gamma Spectra Calibration: UBC 123

Figure C1a: Lab Calibration-Gamma Spectrum of K-40.

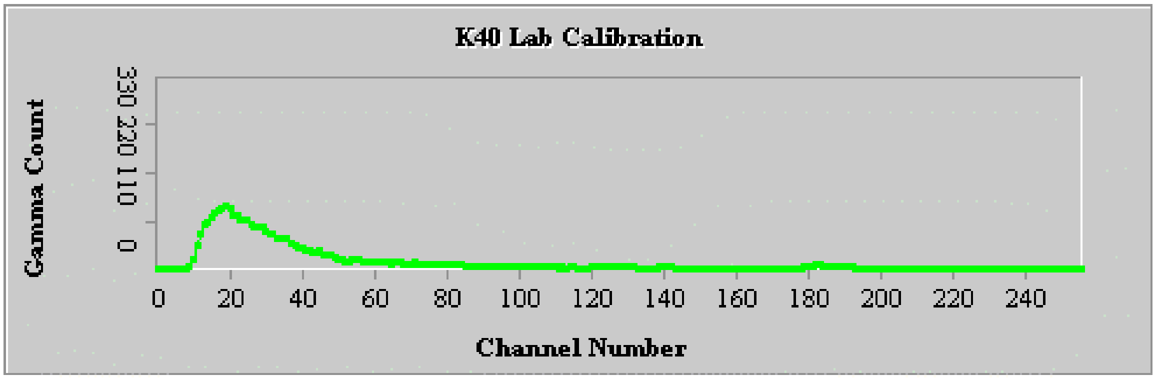


Figure C1b: Lab Calibration-Cumulative Gamma Spectrum (14 spectra) of K-40.

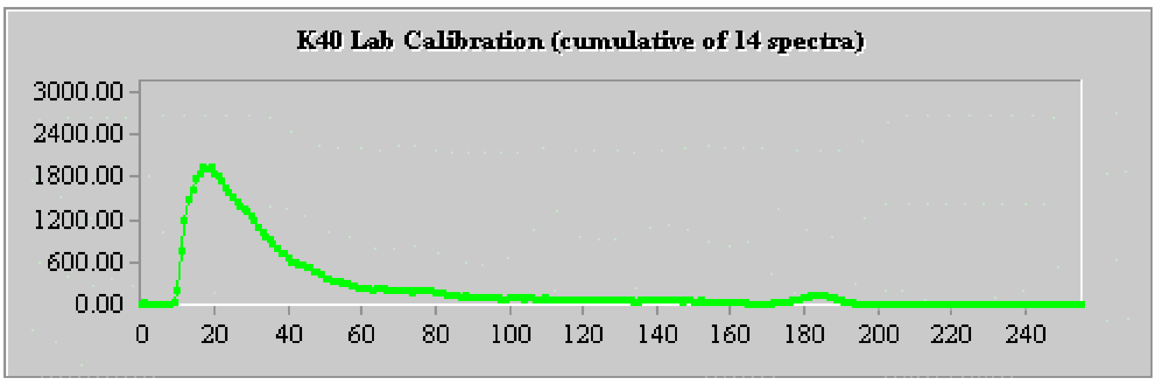


Figure C2a: Field Calibration-Gamma Spectrum of K-40 at UBC 123

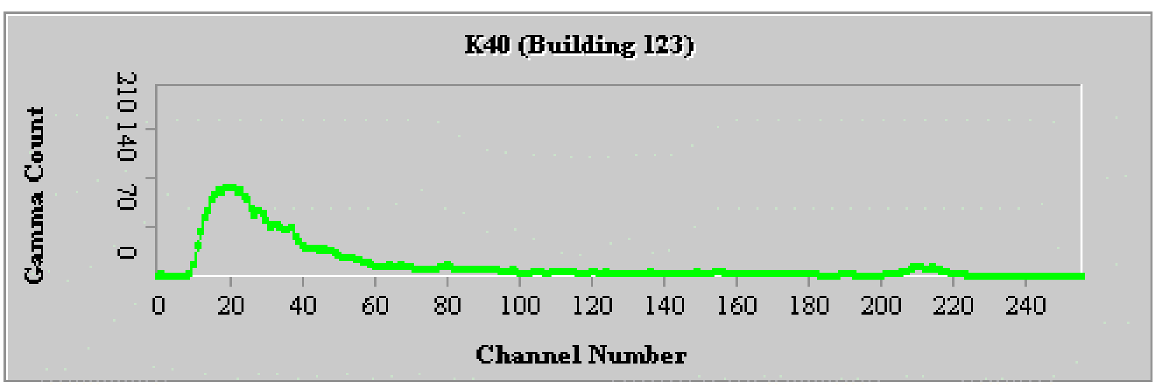


Figure C2b: Field Calibration-Cumulative Gamma Spectrum (8 spectra) of K-40 at UBC 123

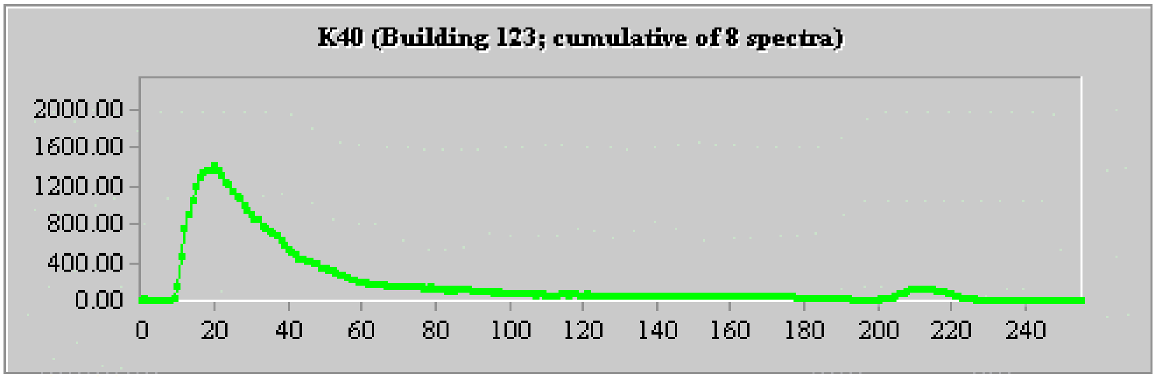


Figure C3a: Field Background Calibration-Gamma Spectrum of K-40 at UBC 123

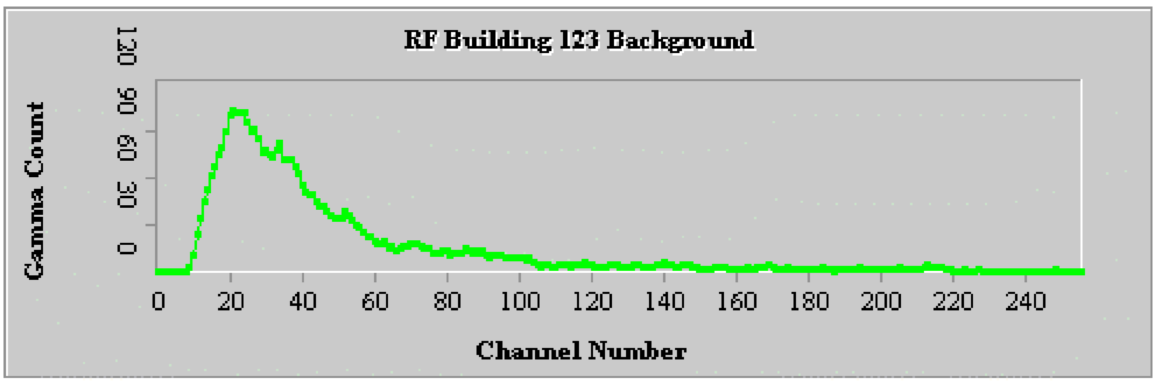
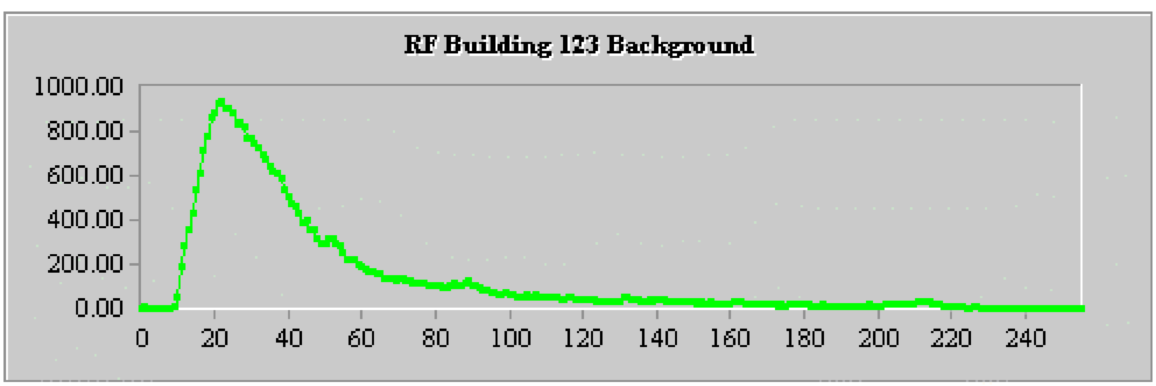


Figure C2b: Field Background Calibration-Cumulative Gamma Spectrum (8 spectra) of K-40 at UBC 123



EMWD Gamma Spectra for UBC 123

UBC 123-Bore Number 1

Figure D 1-1a: Gamma Spectrum from Bore 1 Sample 1.

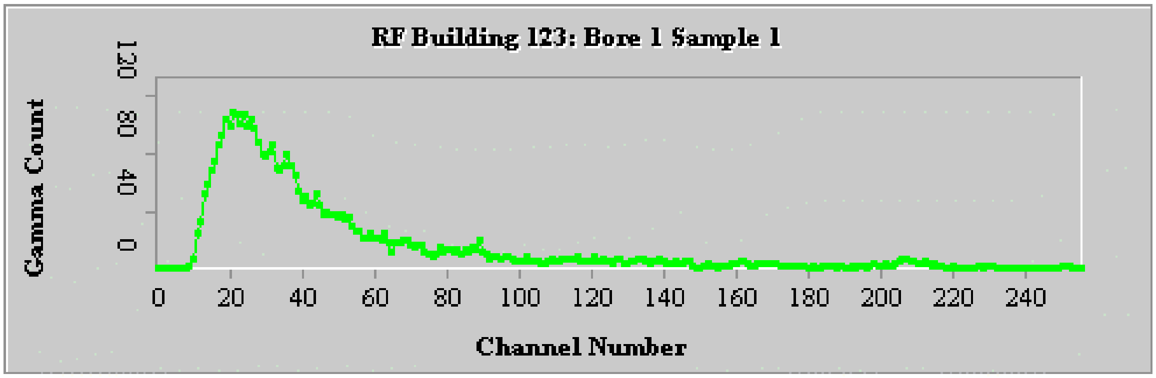


Figure D 1-1b: Cumulative Gamma Spectrum (13 spectra) from Bore 1 Sample 1.

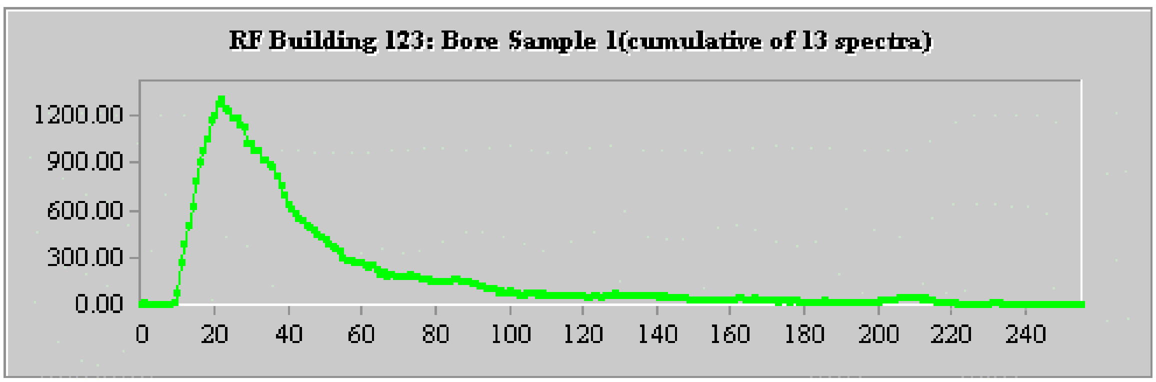


Figure D 1-2a: Gamma Spectrum from Bore 1 Sample 2.

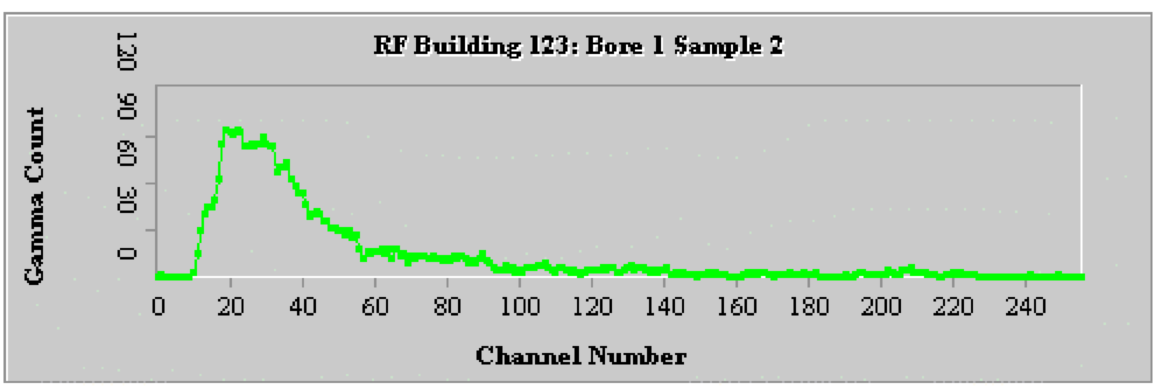


Figure D 1-2b: Cumulative Gamma Spectrum (15 spectra) from Bore 1 Sample 2.

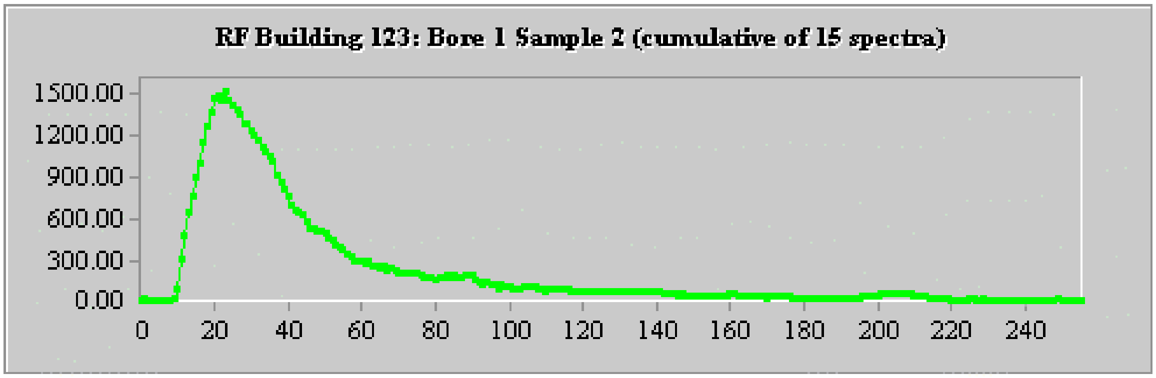


Figure D 1-3a: Gamma Spectrum from Bore 1 Sample 3.

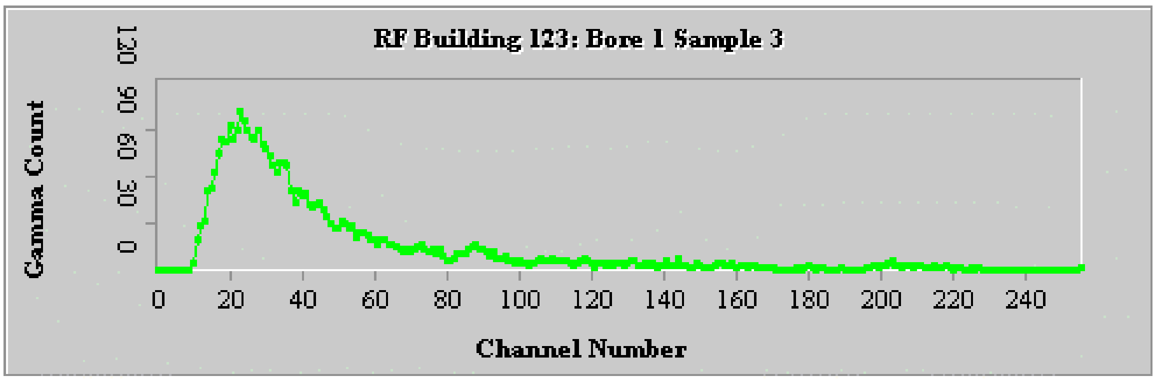
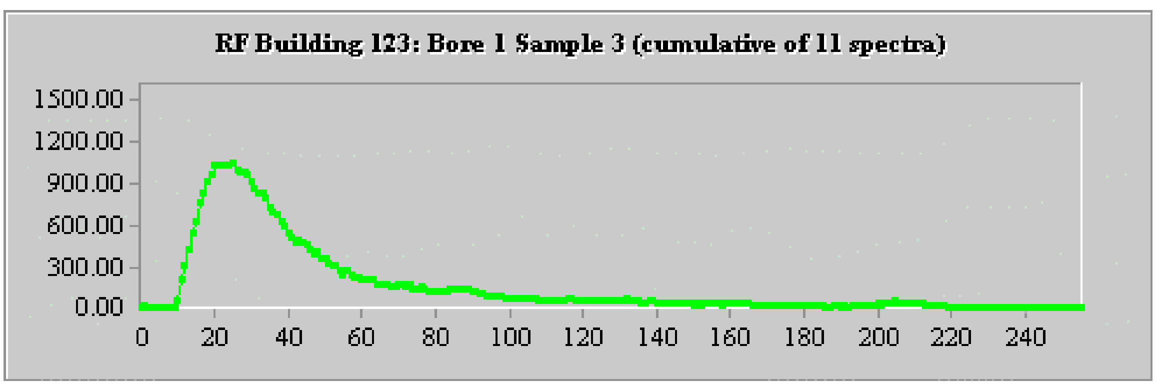


Figure D 1-3b: Cumulative Gamma Spectrum (11 spectra) from Bore 1 Sample 3.



UBC 123-Bore Number 2

Figure D 2-1a: Gamma Spectrum from Bore 2 Sample 1.

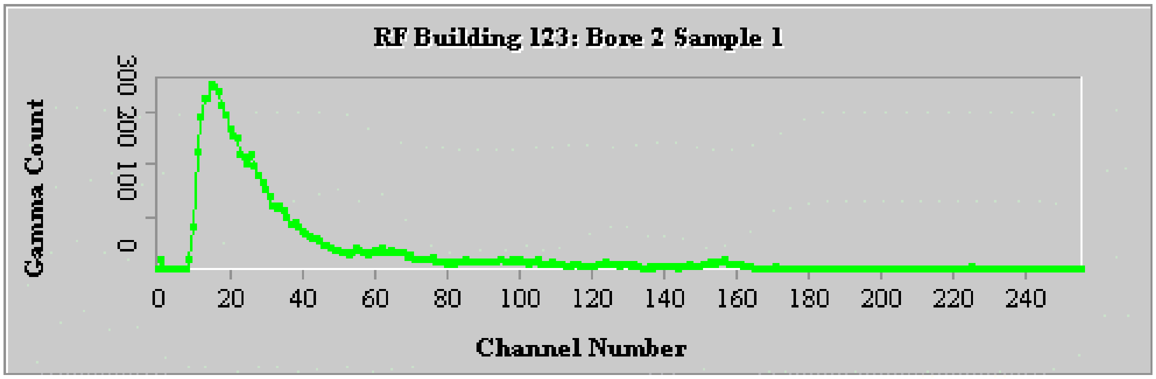


Figure D 2-1b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 1.

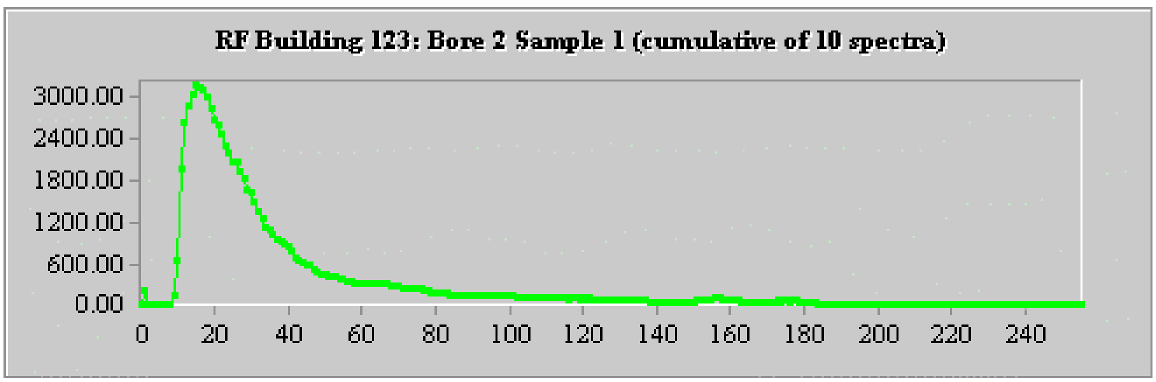


Figure D 2-2a: Gamma Spectrum from Bore 2 Sample 2.

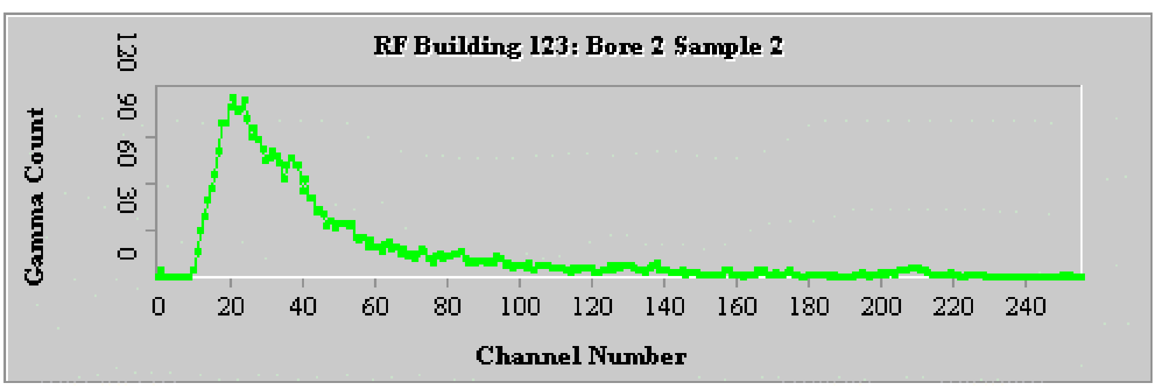


Figure D 2-2b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 2.

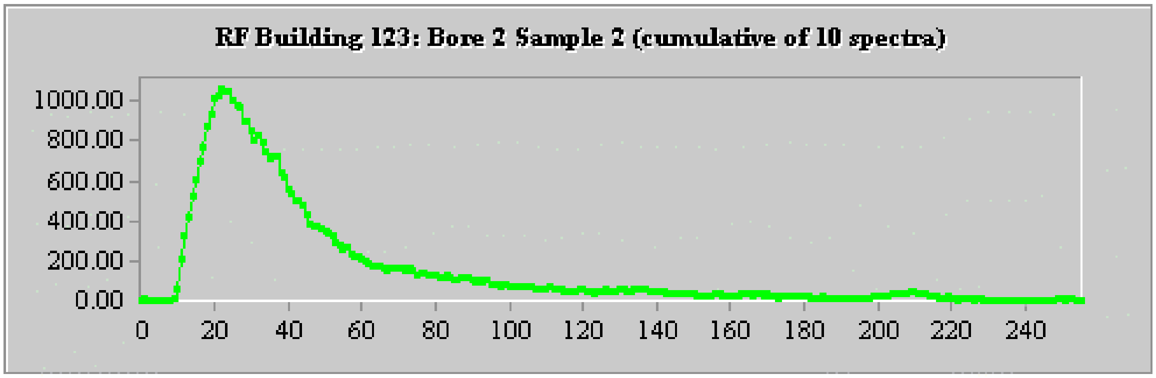


Figure D 2-3a: Gamma Spectrum from Bore 2 Sample 3.

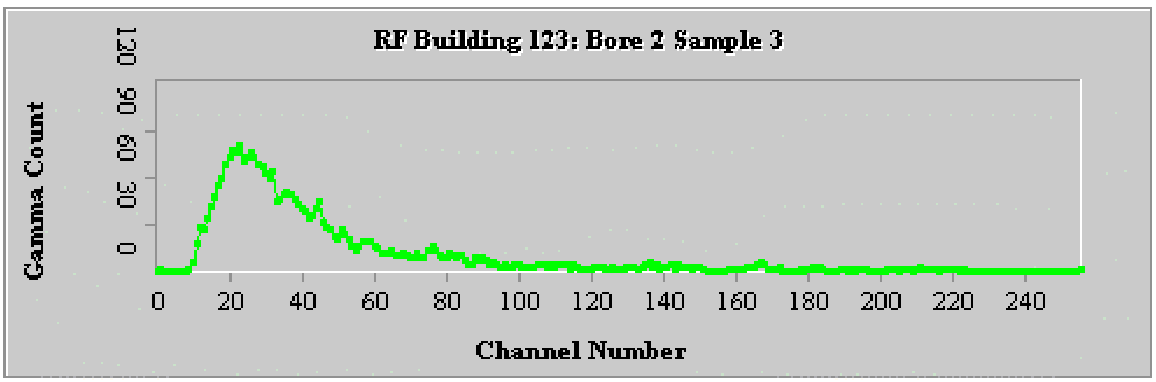


Figure D 2-3b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 3.

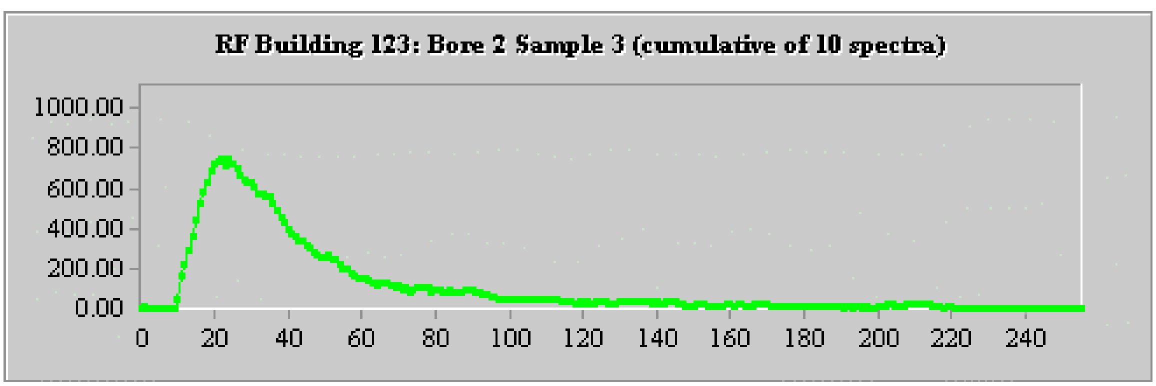


Figure D 2-4a: Gamma Spectrum from Bore 2 Sample 4.

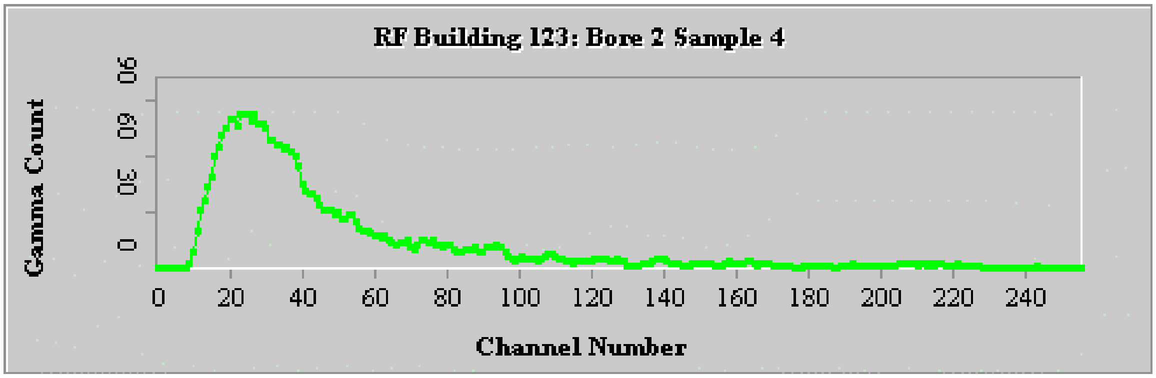


Figure D 2-4b: Cumulative Gamma Spectrum (9 spectra) from Bore 2 Sample 4.

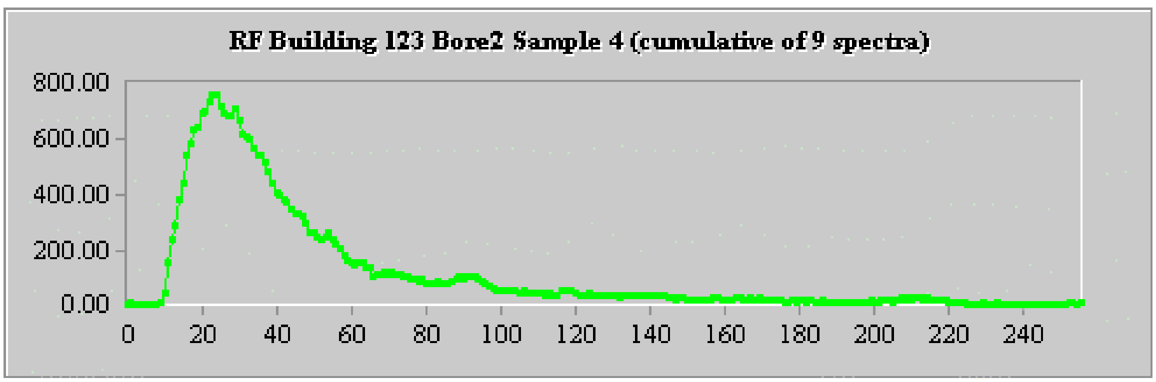


Figure D 2-5a: Gamma Spectrum from Bore 2 Sample 5.

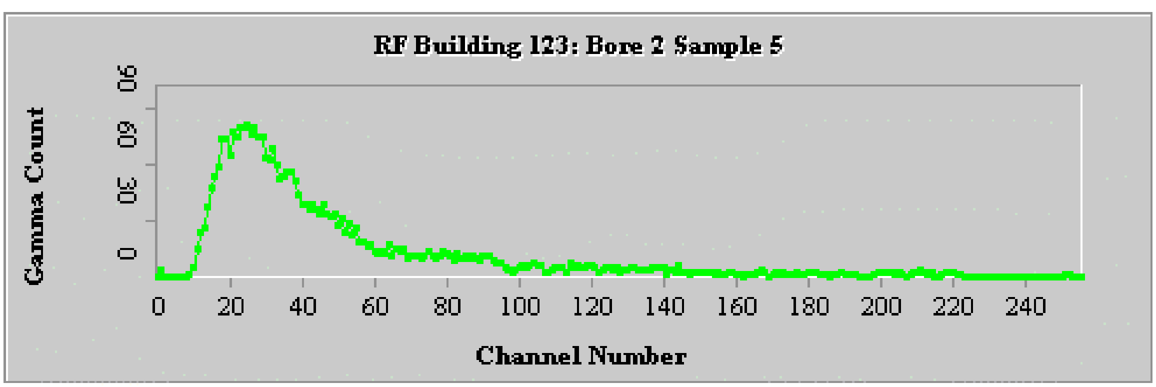


Figure D 2-5b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 5

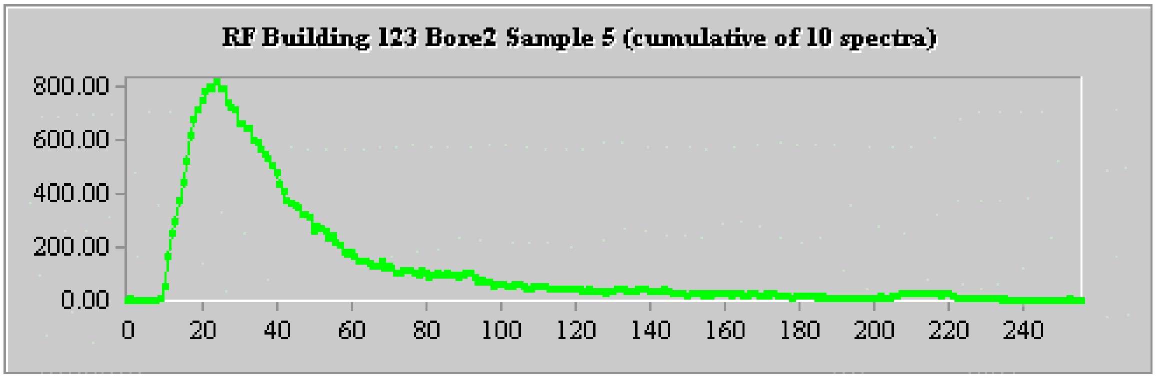


Figure D 2-6a: Gamma Spectrum from Bore 2 Sample 6.

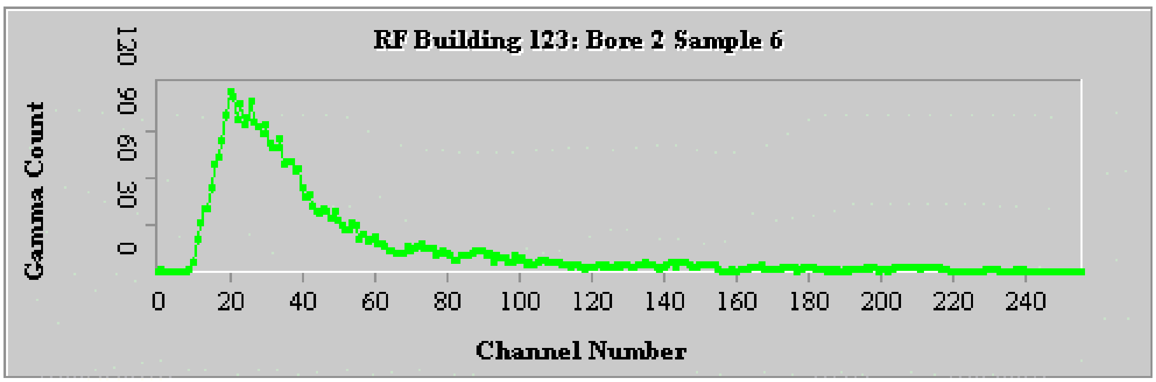


Figure D 2-6b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 6 .

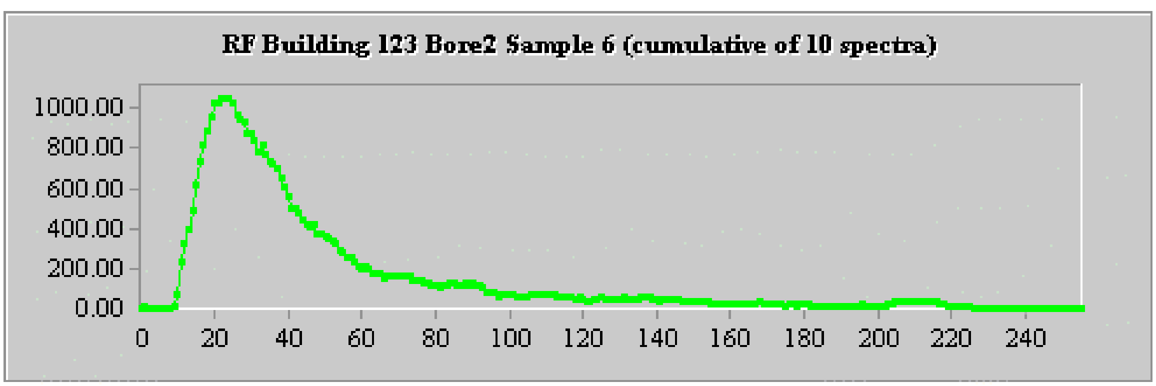


Figure D 2-7a: Gamma Spectrum from Bore 2 Sample 7.

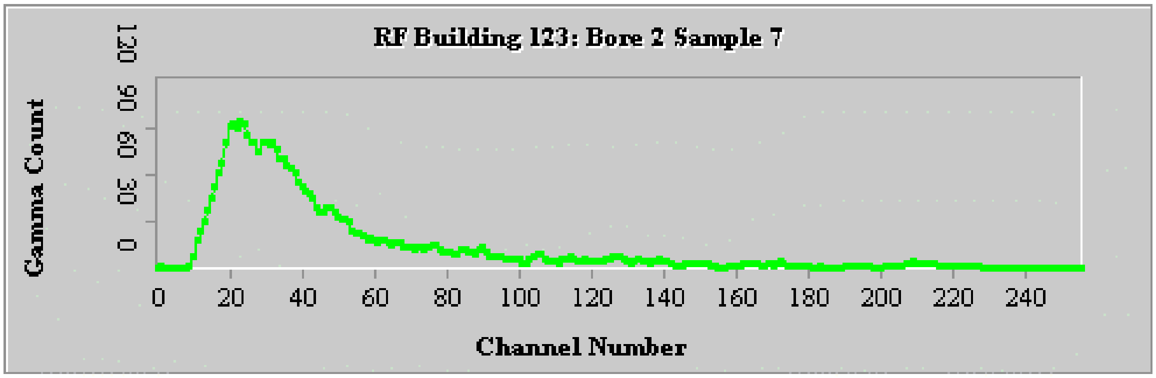


Figure D 2-7b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 7.

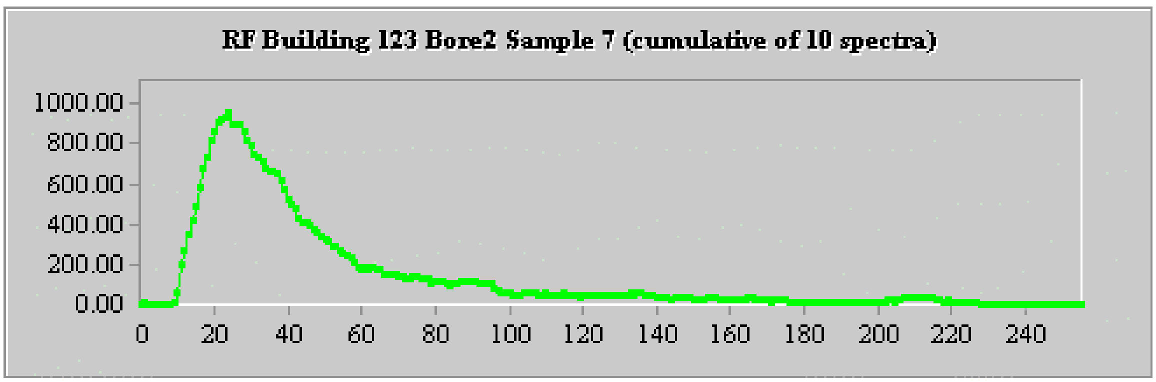


Figure D 2-8a: Gamma Spectrum from Bore 2 Sample 8.

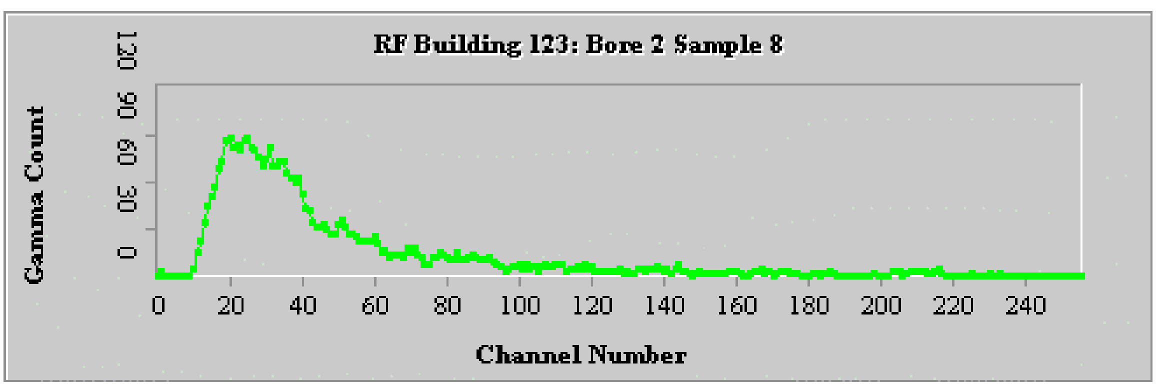


Figure D 2-8b: Cumulative Gamma Spectrum (10 spectra) from Bore 2 Sample 8.

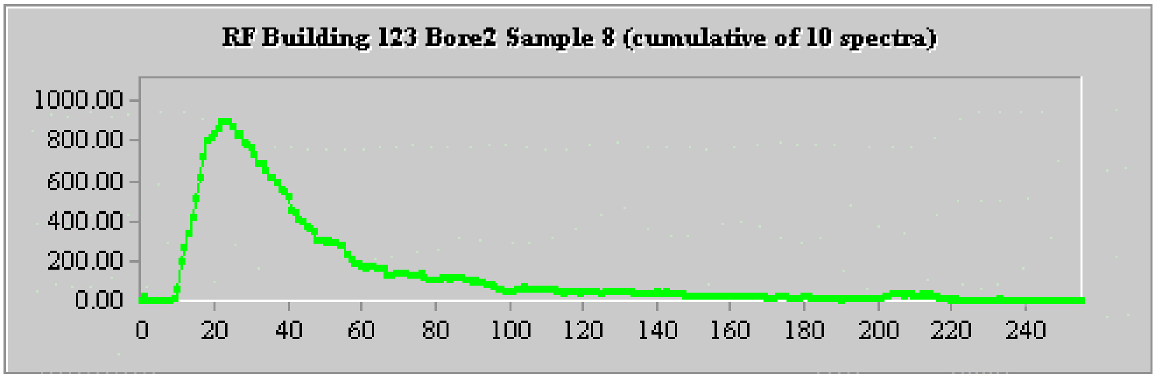


Figure D 2-9a: Gamma Spectrum from Bore 2 Sample 9.

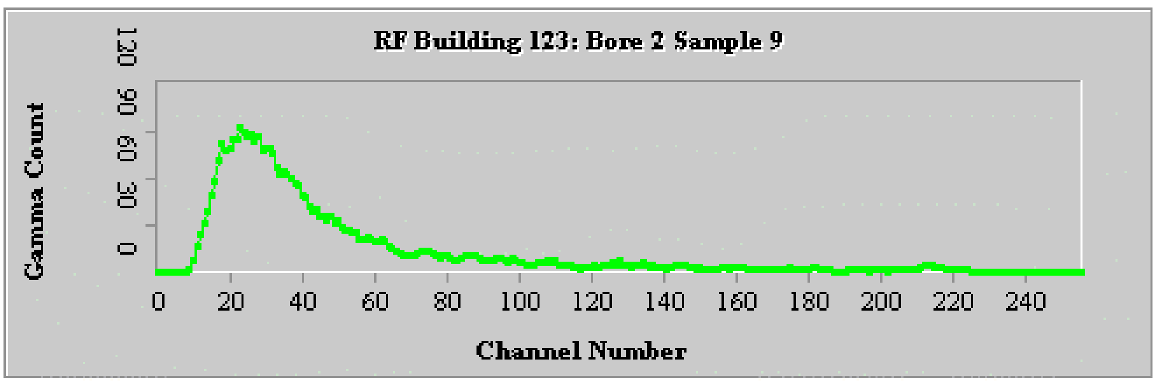
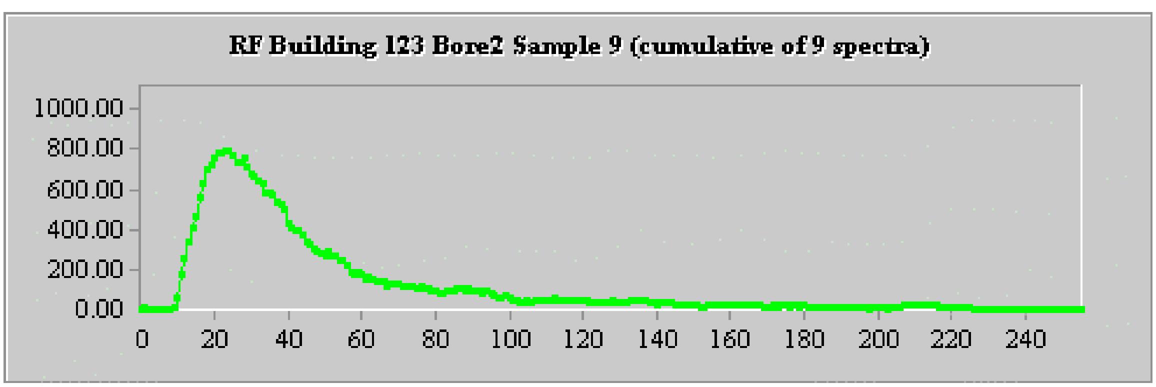


Figure D 2-9b: Cumulative Gamma Spectrum (9 spectra) from Bore 2 Sample 9.



UBC 123-Bore Number 3

Figure D 3-2a: Gamma Spectrum from Bore 3 Sample 2.

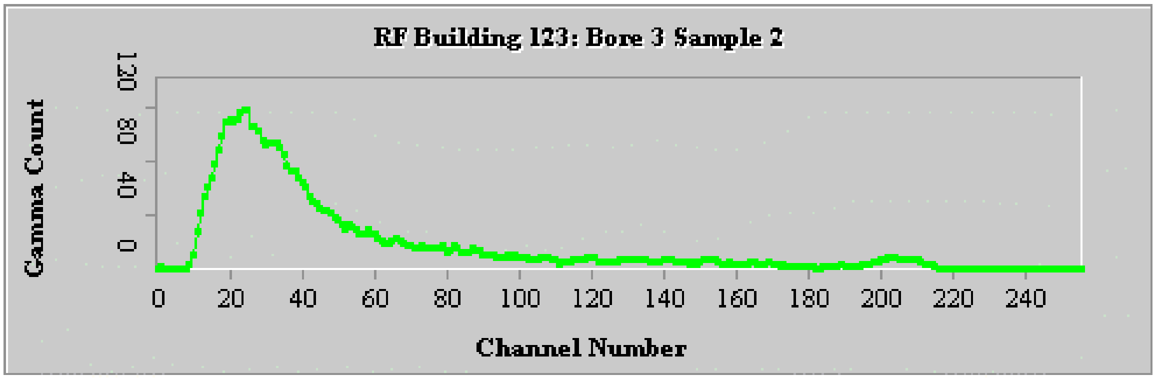


Figure D 3-2b: Cumulative Gamma Spectrum (6 spectra) from Bore 3 Sample 2.

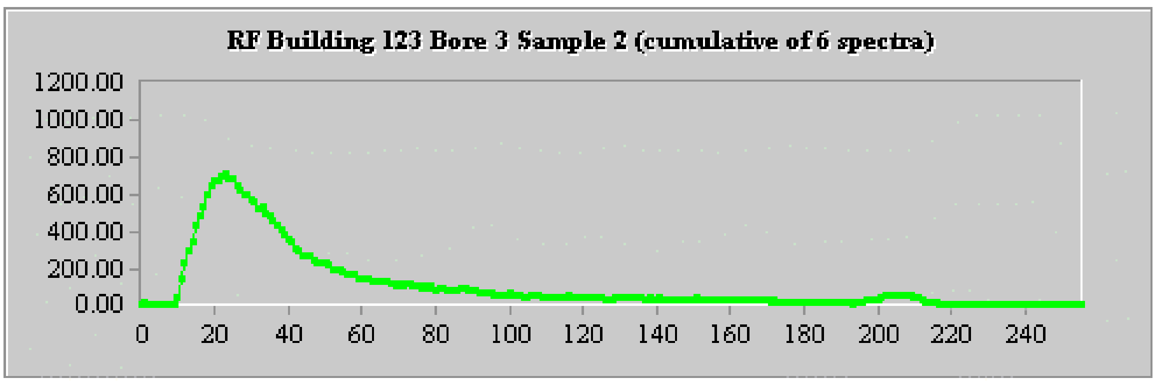


Figure D 3-3a: Gamma Spectrum from Bore 3 Sample 3.

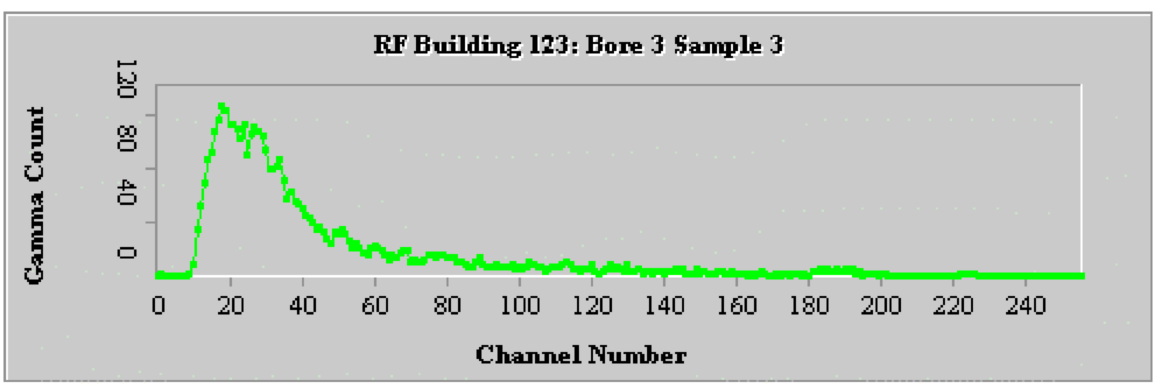


Figure D 3-3b: Cumulative Gamma Spectrum (10 spectra) from Bore 3 Sample 3.

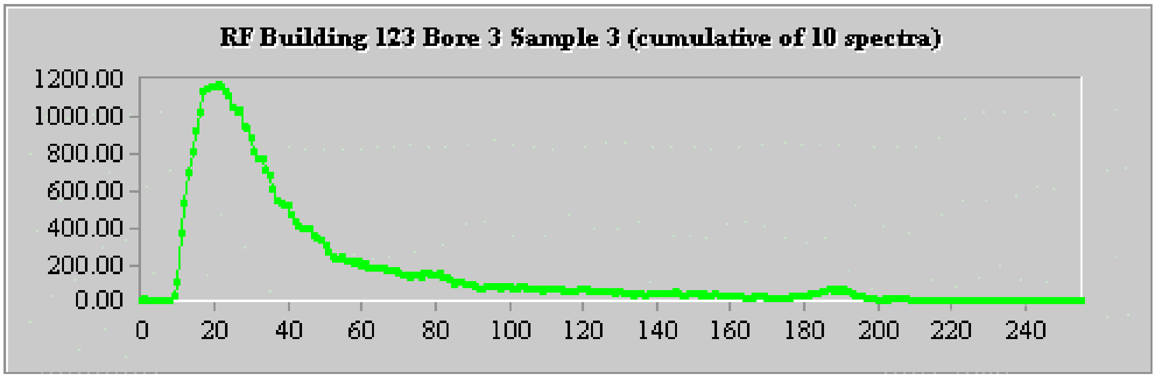


Figure D 3-4a: Gamma Spectrum from Bore 3 Sample 4.

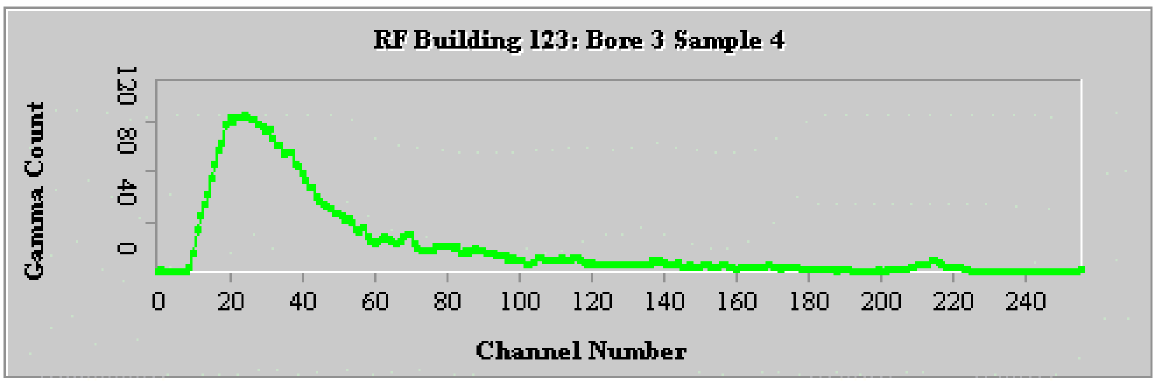


Figure D 3-4b: Cumulative Gamma Spectrum (8 spectra) from Bore 3 Sample 4.

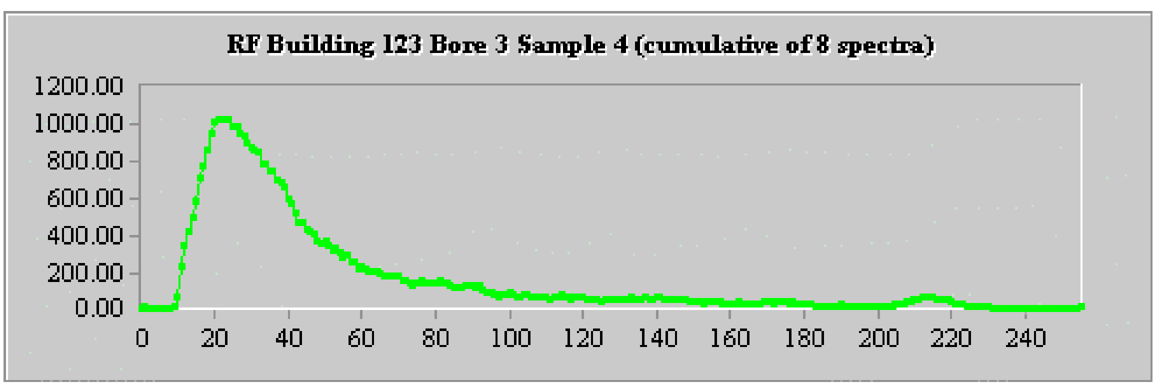


Figure D 3-5a: Gamma Spectrum from Bore 3 Sample 5.

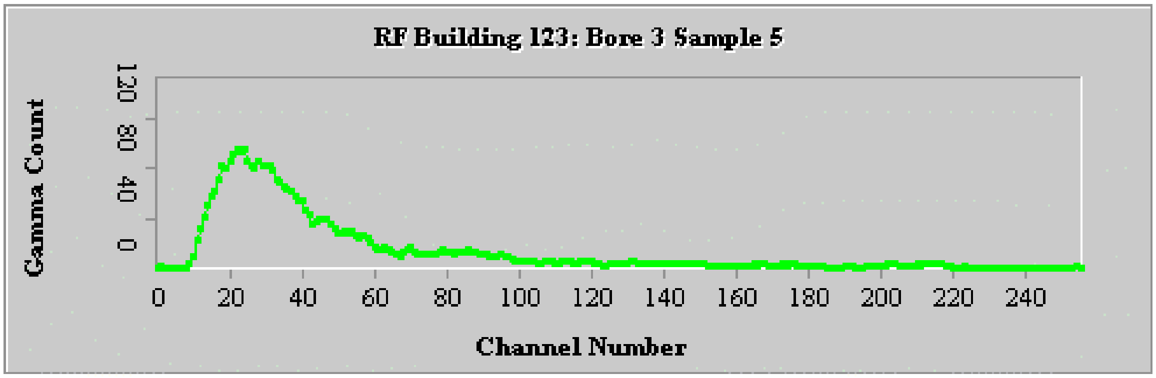
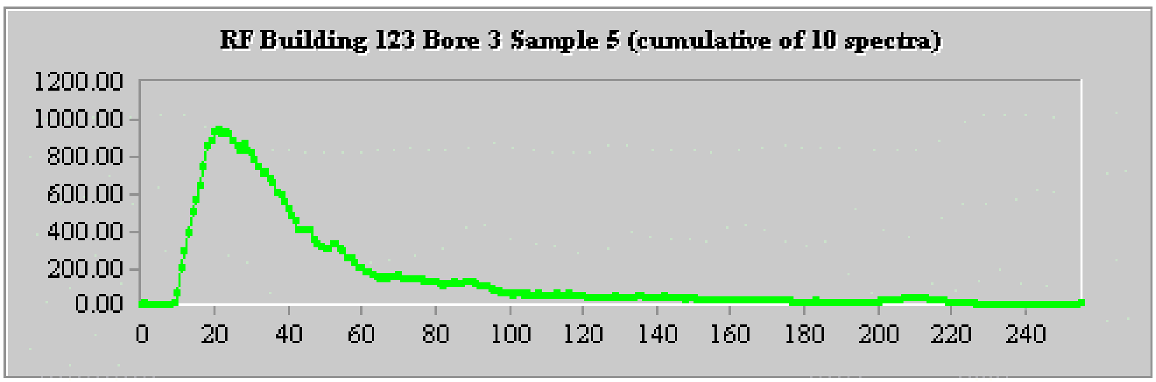


Figure D 3-5b: Cumulative Gamma Spectrum (10 spectra) from Bore 3 Sample 5.



UBC 123-Bore Number 4

Figure D 4-1a: Gamma Spectrum from Bore 4 Sample 1.

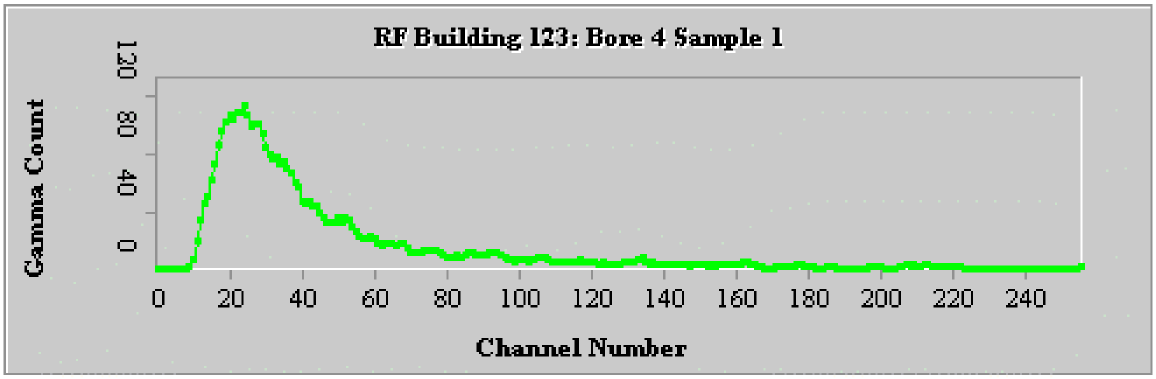


Figure D 4-1b: Cumulative Gamma Spectrum (15 spectra) from Bore 4 Sample 1.

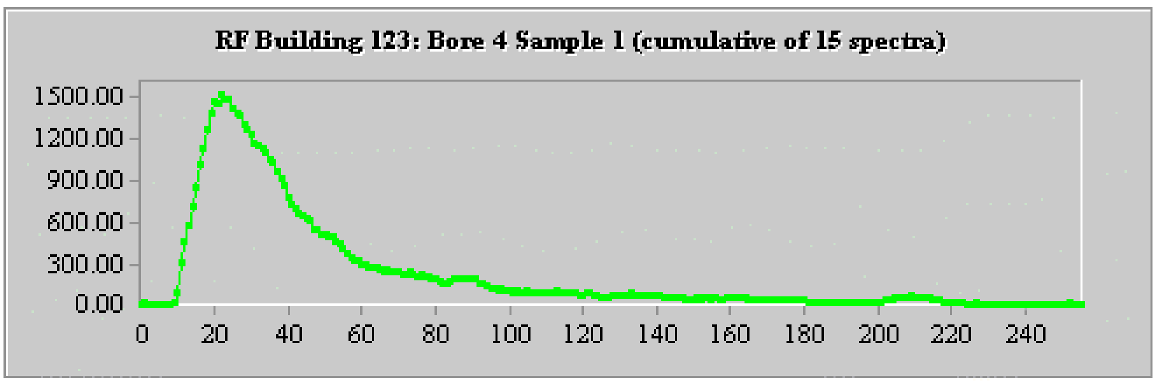


Figure D 4-2a: Gamma Spectrum from Bore 4 Sample 2.

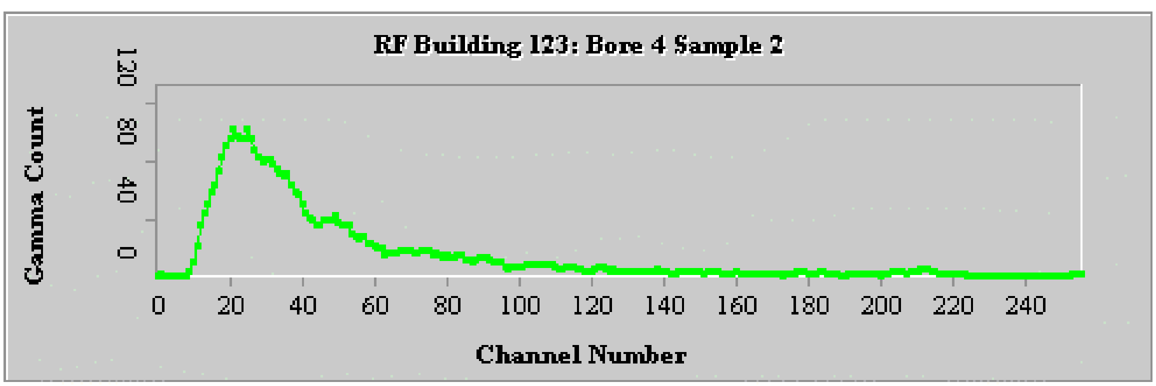


Figure D 4-2b: Cumulative Gamma Spectrum (10 spectra) from Bore 4 Sample 2.

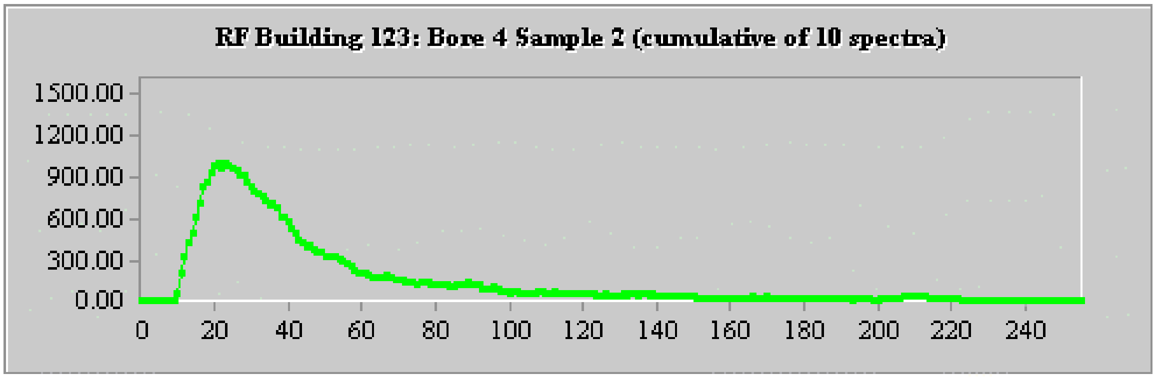


Figure D 4-3a: Gamma Spectrum from Bore 4 Sample 3.

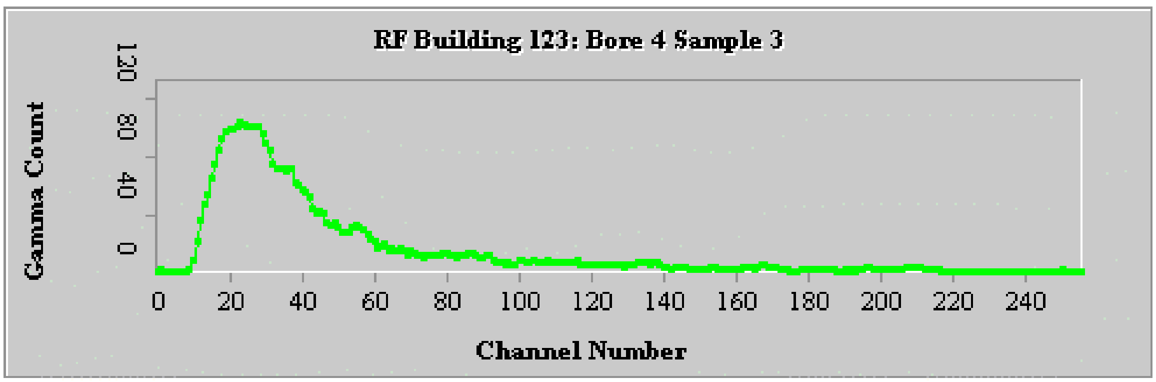


Figure D 4-4a: Gamma Spectrum from Bore 4 Sample 4.

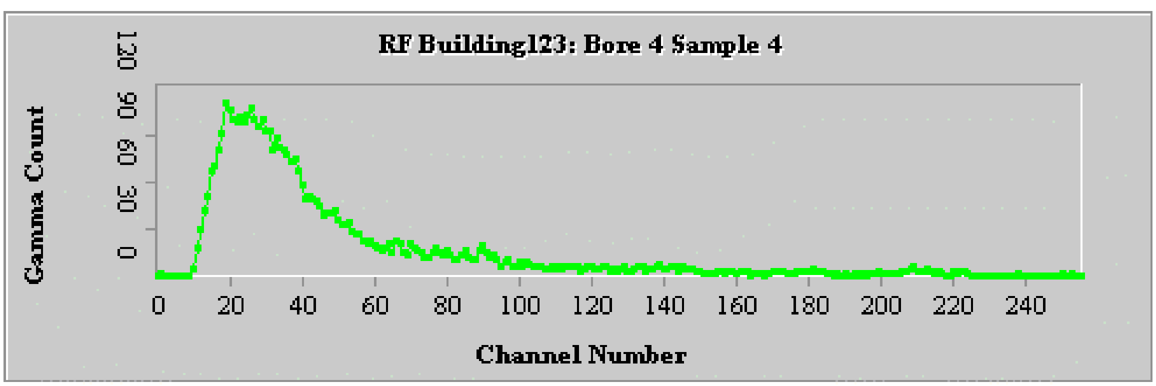


Figure D 4-4b: Cumulative Gamma Spectrum (10 spectra) from Bore 4 Sample 4.

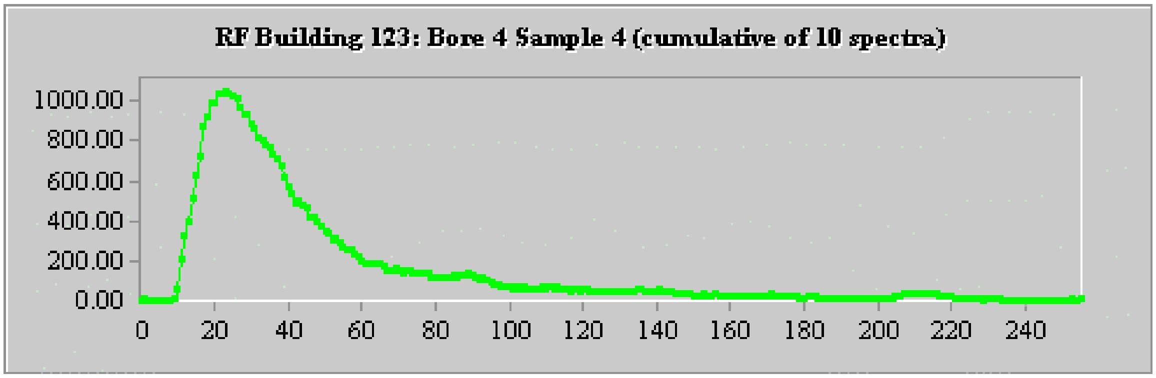


Figure D 4-5a: Gamma Spectrum from Bore 4 Sample 5.

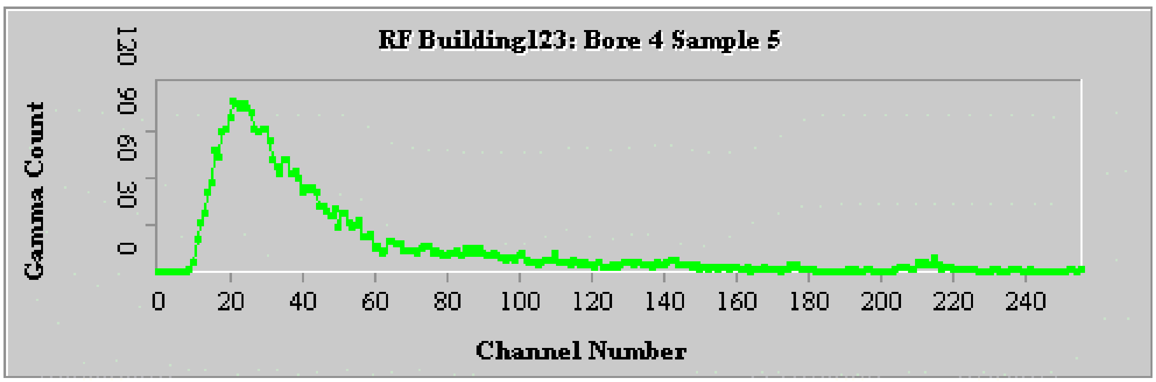


Figure D 4-5b: Cumulative Gamma Spectrum (10 spectra) from Bore 4 Sample 5.

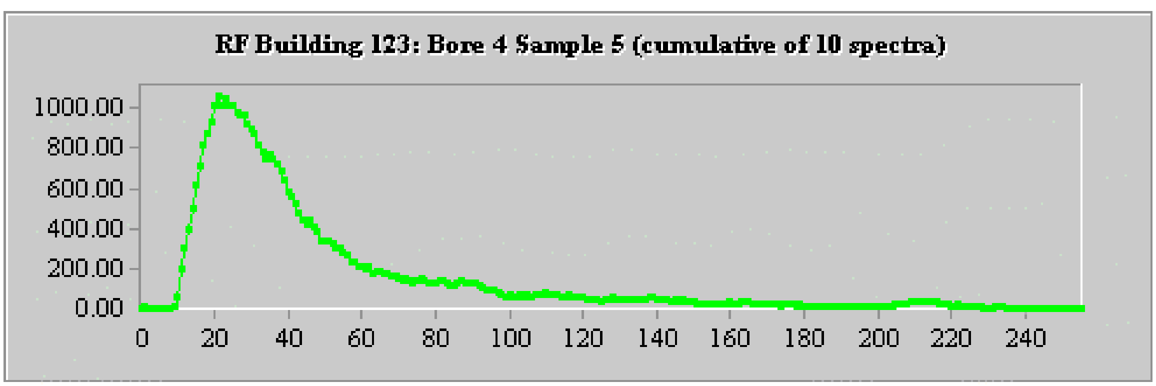


Figure D 4-6a: Gamma Spectrum from Bore 4 Sample 6.

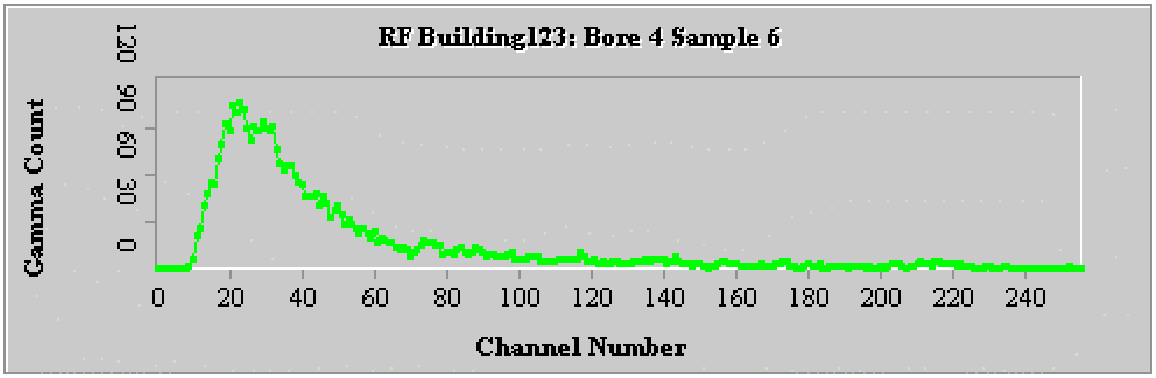
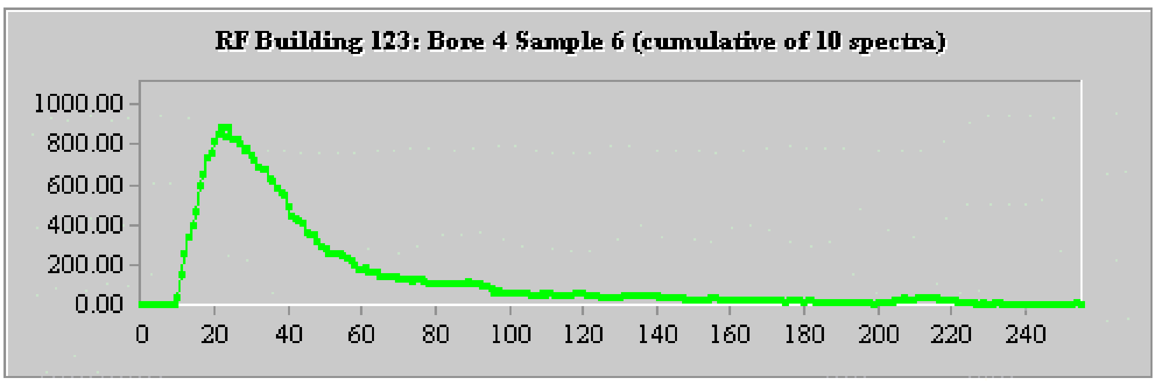


Figure D 4-6b: Cumulative Gamma Spectrum (10 spectra) from Bore 4 Sample 6.



APPENDIX E - EMWD Background Gamma Spectra (Bldg 886)

EMWD Background Gamma Spectra: Building 886

Figure E 1a: Lab Calibration-Gamma Spectrum of K-40

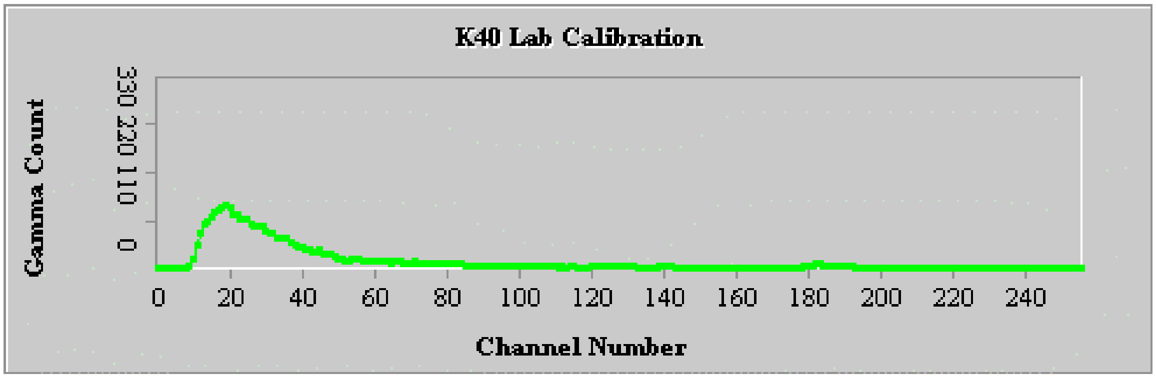


Figure E 1b: Lab Calibration-Cumulative Gamma Spectrum (14 spectra) of K-40.

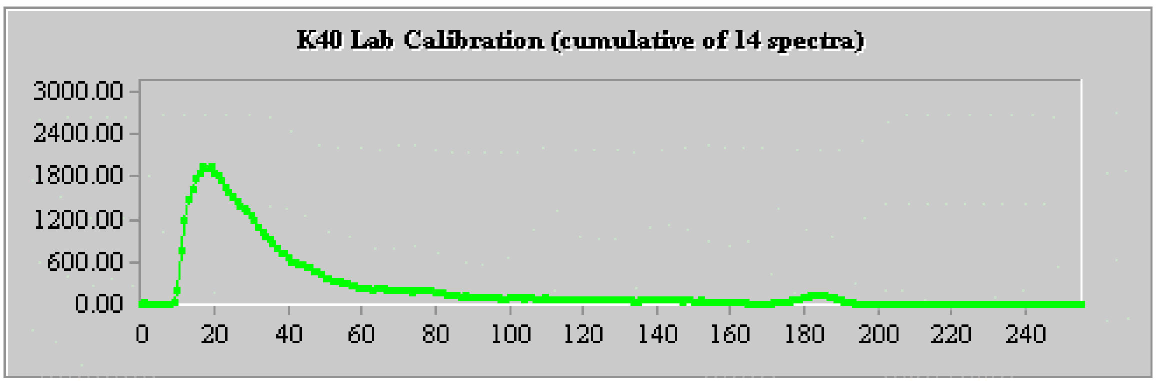


Figure E 2a: Field Calibration-Gamma Spectrum of K-40 at Building 886

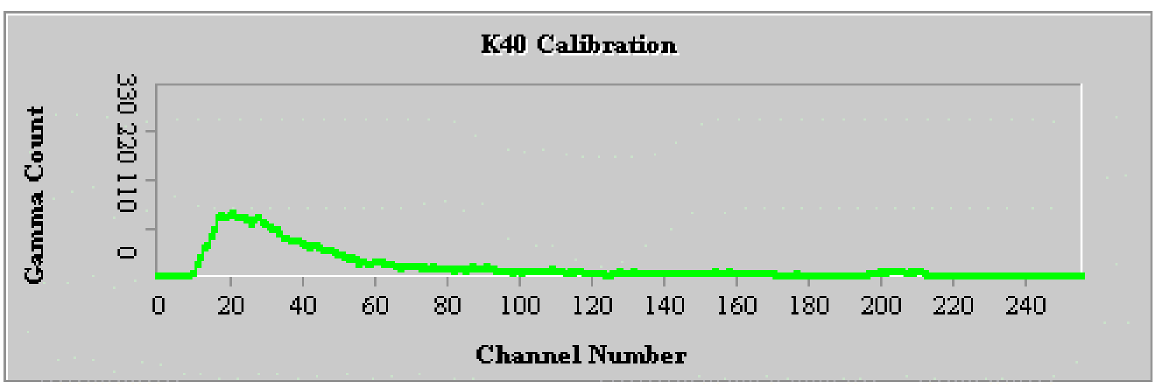


Figure E 2b: Field Calibration-Cumulative Gamma Spectrum (20 spectra) of K-40 at Building 886

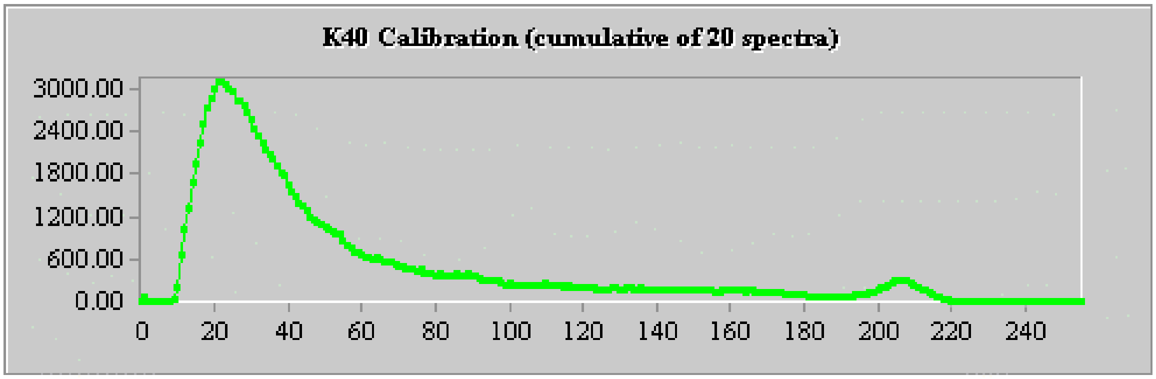


Figure E 3a: Field Calibration-Gamma Spectrum of K-40 at Building 886 next to wall

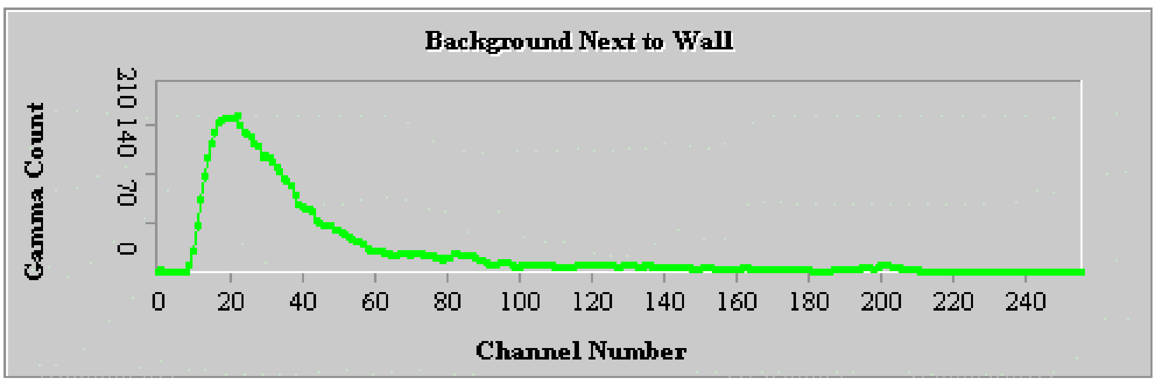
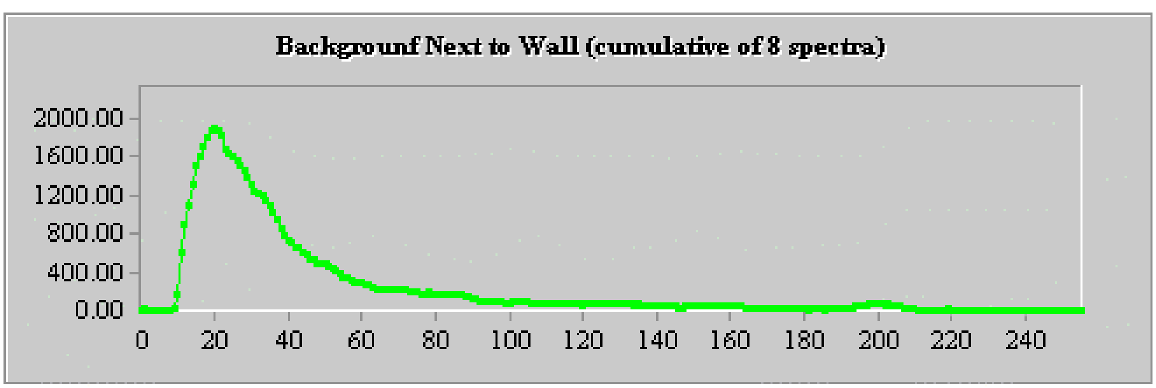


Figure E 2b: Field Calibration-Cumulative Gamma Spectrum (8 spectra) of K-40 at Building 886 next to wall.



EMWD Gamma Spectra for Building 886

Building 886-Bore Number 5: This bore was not carried out.

Building 886-Bore Number 6

Figure F 6-1a: Gamma Spectrum from Bore 6 Sample 1

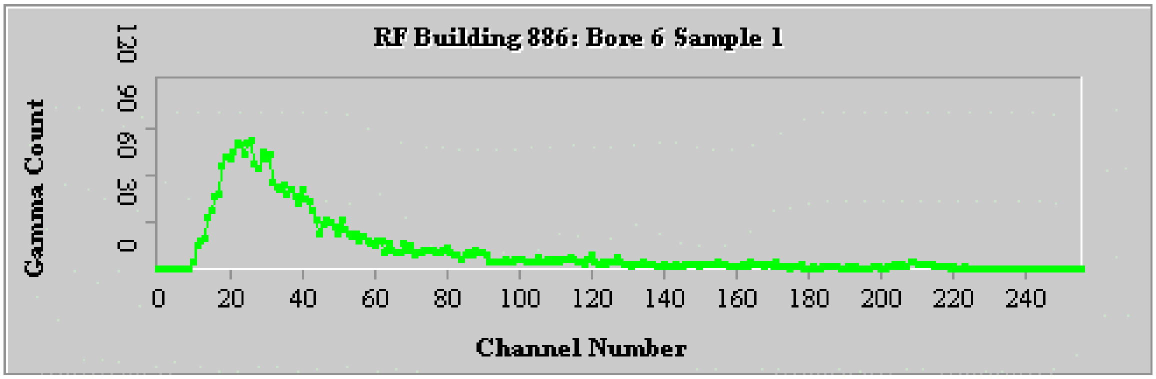


Figure F 6-1b: Cumulative Gamma Spectrum (10 spectra) from Bore 6 Sample 1.

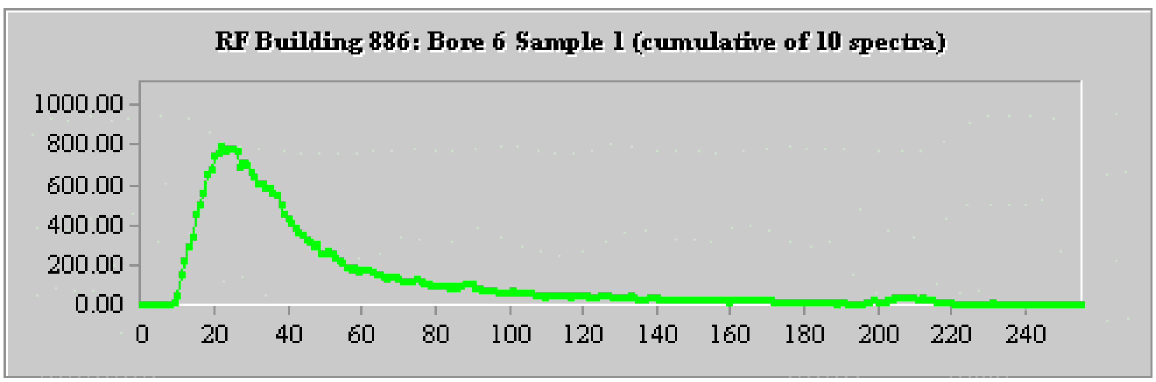


Figure F 6-2a: Gamma Spectrum from Bore 6 Sample 2.

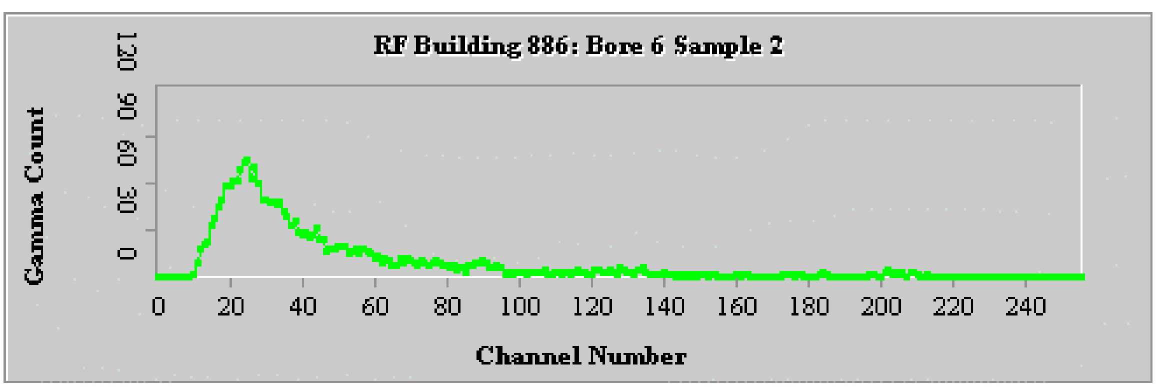


Figure F 6-2b: Cumulative Gamma Spectrum (10 spectra) from Bore 6 Sample 2.

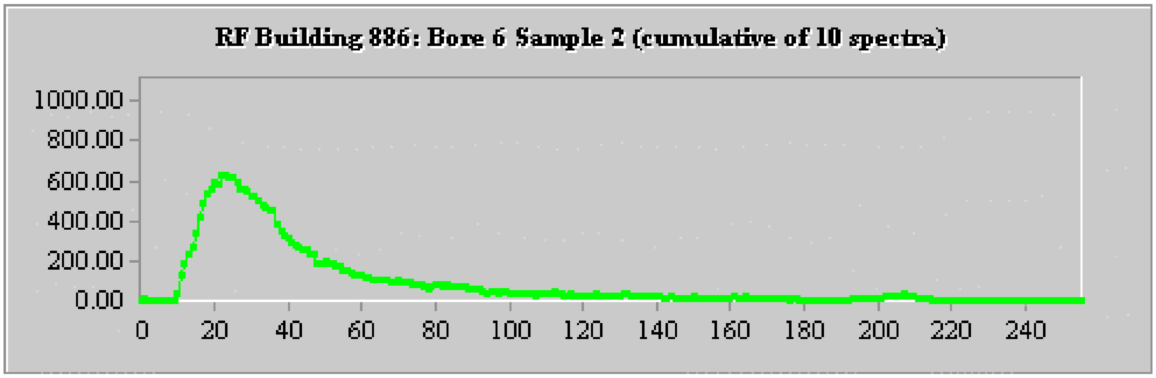


Figure F 6-3a: Gamma Spectrum from Bore 6 Sample 3.

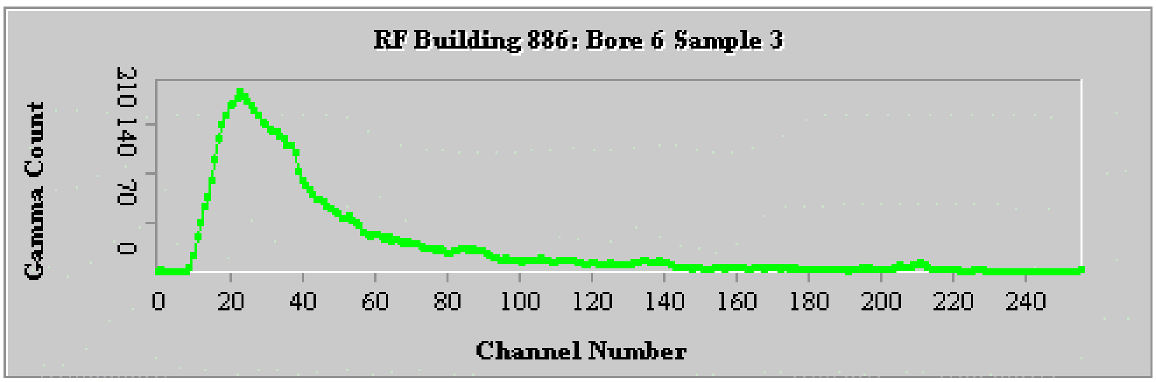
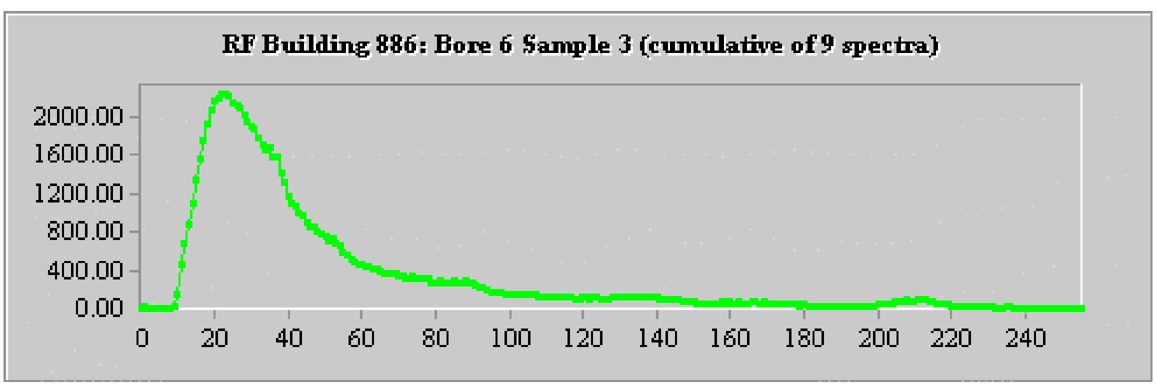


Figure F 6-3b: Cumulative Gamma Spectrum (10 spectra) from Bore 6 Sample 3.



APPENDIX G - EMWD Gamma Ray Spectrometer Methodology

EMWD Gamma Ray Spectrometer
Calibration Methodology

EMWD Spectral Gamma Calibration and Field Measurement

Introduction

There are two main elements for converting spectral gamma energy readings into an indication of soil contamination levels. First is the linear correlation of gamma energy Vs channel location. In general this correlation can be determined in the lab using known source material emitting gamma particles at differing energy levels. Second is the calibration of gamma flux density Vs contamination levels. This second process is not directly determined by laboratory standards. In fact this second step is under investigation at many DOE waste sites.

In this report a calibration process is looked at for the spectral gamma NaI detector used in the Environmental Measurement-While-Drilling system (EMWD). A quick look at linear channel calibration is given, using actual EMAD laboratory data. To better understand the unfolding process for calculating radionuclides, a short explanation for unfolding naturally occurring radionclides for uranium exploration is given. This process is also used to gage the performance of newly developed spectral systems for environmental work. Following the unfolding process for natural radiation will be a look at actual spectral logging data from a waste site and an unfolding method for cesium and cobalt.

The final goal of this work is to justify and document reasoning for taking a simpler approach concentrating on cesium detection.

Gamma Energy Vs Channel Location

This function very closely matches a straight line with a zero intercept, measured gamma energy = a * (Channel Number) + b. The NaI crystal sensor is exposed to differing radio nuclide, emitting gamma particles of differing energy levels. Exposure is continued until peaks appear in the spectrum at count levels assuring accurate peak channel measurement, normally >100 counts or X10 background. Below are the laboratory-measured values for the given sources.

Table 1: Linear Calibration Results

Source Element	Peak Energy (MeV)	Peak Channel Number	% Difference From Calc.
Cs 137	0.662	92	1.1
Co 60	1.173, 1.332	163, 186	0.7, 0
Mn 54	0.835	115	1.7
Na 22	0.511, 1.275	74,178	2.9, 0

The resulting linear regression for energy Vs channel number is: Y MeV = 7.18 $X10^{-3}$ MeV * (Channel Number) – $4.90XIO^{-3}$ MeV @ room temperature. Working backwards using the given channel number and the known energy gamma the percent deference was calculated. The correlation coefficient of Table I values is 0.9996. The linear response of a NaI detector is very good. However, a number of factors can cause the slope ‘a’ to change while drilling, primarily temperature, high voltage drift, and photon-multiplier tube aging. Controlling these parameters is critical to proper measurement.

Flux Density Vs Contamination Levels

Gamma counts rate is a relative measure of gamma flux, dependent on many factors as detector size, housings, etc. This flux is proportional to the amount of radioactive material in the soil. Thus, the measured flux is converted to pCi/g by calibration coefficients derived from calibration models. These models have known amounts of source material distributed in a large enough volume to appear infinitely large to traveling gamma rays, about a two to four foot radius about the sensor.

However, soil conditions infinitely vary for moister content and physical make up. Moister and soil types influence the measured gamma flux Limitations in calibration for flux density Vs contamination levels in soil result in an assumption that all soil conditions are consistent with the calibration models.

The most commonly used calibration models are maintained for Doe's Grand Junction Projects Office in Grand Junction Co. by contract with Rust Geodic Inc[a]. These models were built to calibrate instrumentation used for uranium exploration. As such these models contain three naturally occurring elements, K-40, Ra-226, and Th-232, (KUT). Because these models are well characterized and documented they are used to set baseline accuracy for all subterranean gamma instrumentation. Stromswold (1981) uses gamma count windows centered about energy peaks of the three naturals that unfold from highest energy to lowest. Table 2 shows his suggested windows.

Table 2 Spectral Energy Windows for Unfolding KUT

Element	Unique Gamma Ray (MeV)	Energy Window (MeV)
Potassium (K40)	1.46	1.320-1.575
Uranium (Ra-226)	1.76 & 2.20	1.650-2.390
Thorium (Th-232)	2.61	2.475-2.765

In working with subterranean gamma there is a problem of higher energy gamma rays being counted in lower channels, down scattering. By choosing the Thorium. Window about the 2.6 1 MeV gamma, Thorium can be solved for because potassium and uranium don't have any gamma rays higher than 2.39MeV. Once thorium is known then the solution for uranium can be found because potassium is below the 1.65MeV window used for uranium. This process is called unfolding. The Grand Junction B models are well suited for this unfolding process. The B model concentrations listed in Table 3 below.

Table 3. Grand Junction B-Model Concentrations

Model	Concentration Th (Pci/g)	Concentration Ra (Pci/g)	Concentration K (Pci/g)
BT Upper	58.78 ± 1.53	10.46 ± 0.51	10.13 ± 1.34
BU Upper	0.65 ± 0.06	194.59 ± 5.94	10.63 ± 1.00
BK Lower	0.10 ± 0.02	1.03 ± 1.67	54.00 ± 1.67

By placing the spectrometer into each of the three models, subtracting electrical noise, and counting gamma for each of the three windows in Table 2, a rate matrix R is produced. Matrix R is guaranteed to be nonsingular because of the window selection process assures an upper triangular form. Using the concentrations of Table 3 a set of coefficients relating window count rates to concentrations (pCi/g) can be solved for using Eq1. An important note on counting periods; The statistical nature of gamma counting requires long enough counting periods to gain a meaning full count rate. The standard deviation of the gamma count is equal to its square root, i.e. 100counts has a 10count sdv.

$$A \quad = \quad CR^{-1} \quad \text{Eq1}$$

A is a 3X3 Matrix of Calibration Coefficients
R is a 3X3 Matrix of Count Rate reading for each of the three windows
C is a 3X3 Matrix of Known model concentrations from Table 3

Once A is known then the system is tested against a forth model (BM) which is a mix of all three elements. A properly calibrated spectrometer then solves for concentration levels for KUT using equation Eq2.

$$C \quad = \quad AR \quad \text{Eq2}$$

Equation 2 is used to convert gamma flux rates to density measurements in pCi/g as the system is drilling or logging. There are a number of additional considerations to the process which should be addressed. First, the linear calibration relating gamma energy peaks to channel numbers in the spectrum is used for setting the KUT windows of Table 2. Anything that alters this calibration affects the calculated concentration levels. The measure of the gamma rate is dependent on concentration levels but also the MCA conversion rate. Low power MCAs normally employ slow conversion methods increasing dead time (DT). Where DT and R are both in units of seconds, Eq3 below is used compensate for a slow MCA.

$$R' = R^{*} \text{ 1sec} / (\text{1sec} - DT) \text{ Eq3.}$$

DT is a function of MCA total counts and conversion time
R' is a new MCA compensated rate matrix

In the general solution of converting gamma count rates to KUT soil concentrations, a basic assumption was made; Only naturally occurring gamma sources are found in the soil. The man-made radioactive waste creates a new set of gamma mitters in contaminated soils.
In the case of Cesium (Cs-137), its' gamma ray is at 0.66MeV. Using this unfolding process Cesium would be unfolded after potassium. Too follow this logic; every radioactive element distributed within the soil must be accounted for in the unfolding process. The dominant waste radionuclides generally found in the soils at Hanford and Savannah River are Cesium- 137, Europium- 154, Europium-1 52, and Cobalt-60. Ina Westinghouse Savannah River 1994 report on H-Area retention basin list maximum concentrations as shown in Table 4. Table 4 is by no means a complete list of man-made waste, radioactive or otherwise.

Table 4. Example of found Radionuclides at a Waste Site

Radionuclides	**Max. Concentration, pCi/g**
Cesium- 13 7	33000
Europium-152	47
Europium-1 54	33
Cobalt-60	1.8

Figure 1 is log data taken with a HPGe detector used at Hanford, (C.J. Koizumi, 1993). There are two important attributes demonstrated by this data. First, the total count is a good indicator of waste radionuclides in the soil. Second, cesium waste maybe independent of other radionuclides.

A complete gamma spectrum is shown in Figure 2. This spectrum was taken at 16.8m depth in the log run shown in Figure 1. Here the spectrum is scaled out to 2.8MeV. By scaling out so high the thorium peak at 2.61 MeV can be monitored for changing backgrounds. The measured concentrations for this spectrum at as follows: 3 pCi/g of Co-60, 29 pCi/g of Eu-154 and 8 pCi/g of K-40. The vast majority of spectral activity is below the K-40 peak at 1.46MeV.

Looking again at Figure 2, the down scattering of higher energy gamma into the 0.66MeV energy channel is a concern. Because of the low energy Cs-137 gamma virtually all background and other man-made radioactive waste interferes with the cesium measurement.

Unfolding Co and Cs From Background, An Example

Unfolding the three naturals along with cesium and cobalt (Randall and Stromswold, 1995) used windows 1.105 to 1.420MeV for cobalt and 0.590 to 0.715MeV for cesium. Lumping the background Th and U counts as a single constant term, the Cs and Co unfolding formulas are shown below.

$$C_{co} = aR_{co}. - bR_K - cR_{CS} - BKG_{C0} \quad \text{Eq4.}$$

$$C_{cs} = dR_{cs} - ER^2_{cs} - fR_{co} - BKG \quad \text{Eq5.}$$

Terms "a" – "f" are unique coefficients.

BKG is the constant background subtraction of each element.
In all cases BKGcs, > BKGco.

Both equations 4 and 5 use the K40 rates directly. This is done because the cobalt upper gamma is very near that of potassium. The NaI detector resolution will overlap gamma counts. In Eq5 has a cobalt count rate term for calculation of cesium. Often cesium and cobalt are found together and the down scattering of the higher energy cobalt is a significant. Eq5 incorporates a squared term for pile up correction at very high count rates.

Suggested Approaches For EMWD

The EMWD MCA is a 256 channel multi-channel analyzer. The NaI crystal is (at present) a four by one inch cylinder. Complete spectrums are transmitted to the surface every 30 seconds. Spectrums are not being taken while data is being transmitted. The actual sample period is ~20 seconds. Spectrums can be summed at the surface to longer sample periods.

The main focus of the EMWD system is to detect and measure cesium contamination levels while drilling. There are no cesium waste models for calibration of spectral gamma logging systems. Even if such a model existed there are too many types of mixed radionuclides at each DOE site for any NaI system to accurately unfold. Two methods are suggested for calibrating a system to unfold Cs-13 7 from natural background spectrums. In both cases, total gamma counts will be used to detect increased levels of man-made waste. The total count might also help detect when count rates are increased by manmade waste other than Cs-13 7 by the simple relationship in Eq6.

$$TC - aR_{cs} - bR_K - BKG_{TC} = 0 \quad \text{Eq6}$$

TC = total counts
BKG_{TC} taken from reading is a clean area
a & b coefficients derived from field testing.

Calibration Method I
This method would treat the spectrum readings in the same fashion as calibrating any spectral gamma logging system as addressed earlier in this report.

Set the linear range to 2.8OmeV, full scale. Choose windows for all three naturals plus Cs-137. Eq1 is now composed of 4X4 matrixes. B-models can be used where the model concentration of Cs-137 is assumed zero. To solve for matrix A, a fourth model of known concentration of Cs-137 must be used. This Cs-137 model may actually be a characterized well as logged in Figure 1 at a waste site. This approach is heavily dependent on the quality of the Cs-137 model. The matrix inversion simultaneous solution of linear equations produces a least squares fit to given data. The solution maybe sensitive to slight changes in concentration levels, non-robust. This problem is compounded by the lack of a properly configured mixed model to help test the solution.

Calibration Method 2
The energy range will be low, upper end limited at 1.6MeV. This is done to utilize system sensitivity about the range of interest, see Figure 2. Gamma rays above this threshold are counted as a total and stored in channel 255. By monitoring this channel normal thorium and uranium background levels can be monitored. These background levels will be characterized at the site by drilling a short bore outside of the contaminated area. Along with channel 255, the potassium and cesium windows will also be characterized for background down scattering. Using the B-model, the cesium window can be characterized for potassium down scattering.

$C_{cs} = aR_{cs} - bR_K - BKG_{cs}$ Eq7

Several cesium dominated wells of differing levels will be required to curve fit system response to cesium. If background reading remain constant and Cs-137 dominates all other types of man-made waste then the linear relationship should be well bounded.

Conclusion

The EMWD spectrometer is capable of linear calibration of gamma energy peaks at room temperature. The logging industry in cooperation with DOE has developed spectral gamma calibration methods and facilities. These method and facilities are not sufficient to fully calibrate spectral gamma systems for subterranean measurement of man-made mixed waste.

Actual logging data taken of radioactive waste by a HPGe system points to the complexity of the problem. For the EMWD system using a NaI detector there is no recognized solution for calibration or unfolding spectrums in man-made radioactive waste sites with unknown radionuclide.

Two methods were looked for calibration and unfolding. One method expands the accepted method used for spectral gamma logging tool calibration used in uranium exploration wells. The second method assumes a fixed background and attempts to equate a linear relationship between gamma count rates in cesium directly. Both methods or some combination of approaches needs to be tested before release for site characterization.

‘R- Leino, D.C. George, B.N. Key, L. Knight, and W.D. Steele, June 1994, Third Edition, Field Calibration Facilities for Environmental Measurement of Radium, Thorium, and Potassium, technical Measurements Center Grand Junction Projects Office.

APPENDIX H - EMWD Gamma Ray Spectrometer Calibration

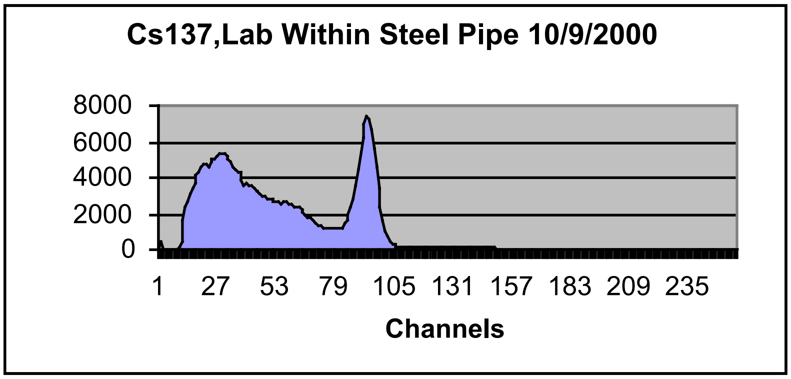
EMWD Gamma Ray Spectrometer Calibration

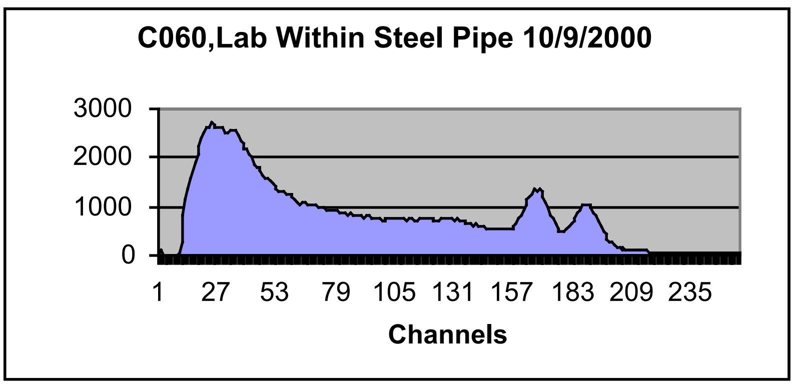
The EMWD Gamma Ray Spectrometer (GRS) was calibrated in the laboratory and in the DOE calibration models at the Grants Facility. These models were built to calibrate instrumentation used for uranium exploration. As such these models contain three naturally occurring elements, K-40, Ra-226, and Th-232, (KUT).

The calibration in the laboratory was conducted in a steel pipe to simulate the steel housing. The results for calibration with Cs-137, Co-60, and Na are shown in Figure H 1. The Cs-137 peak occurs between channels 80-100. The Co-60 spectra contains two peaks occurring in the range of channels 160-200. The Na spectra is bimodal with predominant peak occurring in ~channel 75 and a second broader peak occurring at about channel 180.

The EMWD-GRS also was calibrated using the calibration models at the DOE Grants Calibration Facility. The results for the Th and K-40 calibrations are shown in Figure H-2. The Th spectra occur as a shoulder in the area of channels 85 and 121. The K-40 spectra show a broad peak in the range of channels 200.

Figure H-1: Laboratory calibration of the EMWD-GRS using Cs-137, Co60, and Na.





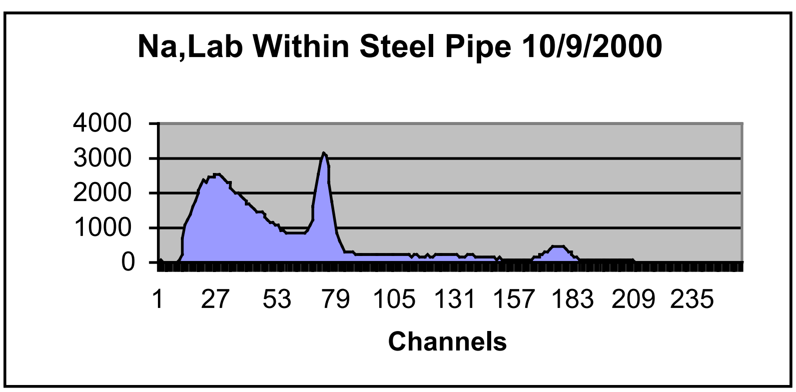
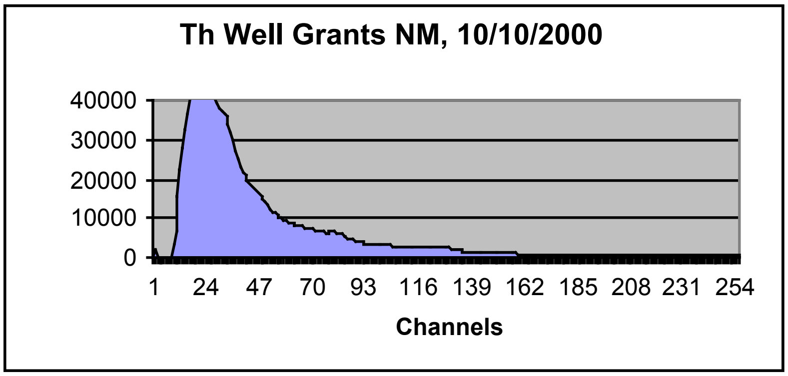
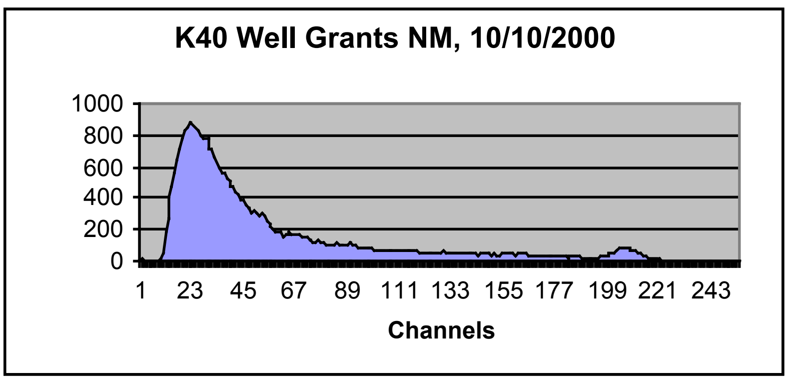


Figure H-2: EMWD-GRS calibration curves for Th and K-40 using the calibration models at the DOE Grants Calibration Facility





APPENDIX I - Rocky Flats Field Data

Rocky Flats UBC 123 and Building 886 Field Data

I-1: UBC 123 Bore #1

Rocky Flats EMWD Deployment

Date: 10/27/2000 Starting time: 8:32 am

Bore: First actual bore

File Name: SER1.PCM

Notes: Bore hit foundation at ~50ft. Bore stopped.

Spectrum #	Total Count Reading
1	2968 at Bit
2	3230
3	2940
4	2722
5	2898
6	3065
7	2929
8	2890
9	2833
10	2976
11	2090
12	2923
13	3183

First attempted log. Tool placed in hole. (2 spectrum taken at bit Bit1.pcm) see next page

Tool then pulled out ~1ft for each reading. Files SER 1, 2 & 3 are in series covering out the entire 50ft. The operator used a 1ft mark on the ground to measure 1ft. His eye was mostly off as we have only 39 spectrums.

Rocky Flats EMWD Deployment

Date: 10/27/2000 Starting time: 8:23

Bore: First actual bore. Really from the bit at 250ft

File Name: Bit 2

Notes: The bore was stopped short hitting the foundation. This is not a single point.

Spectrum #	Total Count Reading
1	2904
2	2949

Rocky Flats EMWD Deployment

Date: 10/27/2000 Starting time: 8:49 am

Bore: Second set coming out of the first actual bore

File Name: SER 2

Notes: Joint with SER 1 & 3. Created files in case the computer crashed

Spectrum #	Total Count Reading
1	2994
2	3098
3	3210
4	2984
5	2721
6	3115
7	3066
8	3002
9	2861
10	2996
11	2914
12	3021
13	3051
14	2993
15	2880

Rocky Flats EMWD Deployment

Date: 10/27/2002 Starting time: 8:57 a.

Bore: First Actual Bore

File Name: SER3

Notes: This goes with files SER1 & 2.

Spectrum #	Total Count Reading
1	2994
2	2980
3	2884
4	3025
5	3079
6	3108
7	3062
8	2977
9	2836
10	2853
11	4848 * At the foundation wall. Image SER3Wall.BMP

I-2: UBC 123 Bore #2

Rocky Flats EMWD Deployment

Date: 11-7-00 Starting time: ____________

Bore: #2 1st SAMPLE @ 10"

File Name: RFB2 S1 (5min @ SAMPLE PT)

Notes: AT 01 PLATE 2 BUILDING 123 HDD LINES

Spectrum #	*	Total Count Reading
1	0	
2	1	
3	2	
4	3	
5	4	

AT 10" ONLY

S1

	TOTAL COUNTS
1	5672
2	5747
3	5809
4	5769
5	5256
6	5147
7	5327
8	5342
9	5179
10	5211

NOTE: 1.46 MeV ~ 187 CH
Temp ~ 3°C

RFB2 K40 TOOL ON GND w/ salt on top

4908
4863
4820
4878
4869
4708
4940
4732
4894
4901

* DISTANCE BACK FROM SAMPLE PT. IN FT.
NOTE! DETECTOR IN CORED HOLE IN FOUNDATION

Rocky Flats EMWD Deployment

Date: 11-7-00 Starting time: 1:39

Bore: #2 2nd SAMPLE @ 27'

File Name: RFB2S2 (5min @ SAMPLE Pt.) RFB2S3 (@ 1' INTERVALS)

Notes: AT 03+ PLATE 2 BUILDING 123 HDD LINES

TIME 1:30

TEMP 12-14 °C

Spectrum #	*	S3 Total Count Reading
1	0	3104
2	1	3126
3	2	2877
4	3	2899
5	4	2917
6	5	3188
7	6	3257
8	7	3089
9	8	3019
10	9	3357
11	10	3338
12	11	3380
13	12	3353
14	13	3449
15	14	3813
16	15	3398
17	16	3276
18	17	3294
19	18	3409
20	19	3283
21	20	3278
22	21	3452
23	22	3339
24	23	3351
25	24	3198
26	25	2828

S2	TOTAL COUNTS
1	3183
2	3275
3	3218
4	3174
5	3203
6	3244
7	3156
8	3198
9	3273
10	3244

<3217>

* DISTANCE BACK FROM SAMPLE Pt. IN FEET

+ PLATE 2 IS IN ERROR BORE 4-06 COINSIDES WITH BORE 2-02 THUS BORE 2-02 WILL NOT BE A SAMPLE POINT. THE SECOND SAMPLE POINT IN BORE 2 WILL BE 03

Rocky Flats EMWD Deployment

Date: 11-7-00 Starting time: 359

Bore: #2 3rd SAMPLE @ 4/2.3'

File Name: RFB2S4 (5min @ SAMPLE PT) RFB2S5 (@ 1' INTERVALS)

Notes: AT 04 PLATE 2 BUILDING 123 HDD LINES

Spectrum #	*	S5 Total Count Reading	S4 TOTAL COUNTS		TIME
1	0	2234	1	2288	3:53
2	1	2681	2	2337	
3	2	2580	3	2266	
4	3	2636	4	2353	
5	4	2563	5	2349	
6	5	2829	6	2297	
7	6	2981	7	2285	
8	7	2908	8	2415	
9	8	2901	9	2266	
10	9	2727	10	2326	
11	10	2660			
12	11	2830			
13	12	2948			
14	13	3049			
15	14	3242			

↑ TEMP 10-12°C

(2318)

← TEMP 12-14°C

* DISTANCE BACK FROM SAMPLE POINT IN FEET.

Rocky Flats EMWD Deployment

Date: 11-8-00 Starting time: ____________

Bore: #2, 4th sample @ 54.4'

File Name: RFB2S6 (5min @ sample Pt.), RFB2S7 (@ 1' intervals)

Notes: AT 05 PLATE 2 BUILDING 123 HDD LINES

Spectrum #	*	S7 Total Count Reading
1	0	2717
2	1	2950
3	2	2934
4	3	2755
5	4	2713
6	5	2637
7	6	2695
8	7	2625
9	8	2679
10	9	2623
11	10	2769
12	11	2654
13	12	2430
14	13	2576
15	14	2581

S6 1:05

	S6 TOTAL COUNTS	
1	2619	
2	2684	
3	2625	
4	2712	
5	2686	5-7°C
6	2692	
7	2619	
8	2689	
9	2685	<2662>
10	2602	

+RFB2S8 RETAKE OF S6 DATE - TOOL ~ RmTem

1	2772	
2	2628	
3	2632	
4	2692	
5	2603	
6	2645	12-14°C
7	2697	
8	2662	
9	2693	
10	LOCKED UP	

LOCKED UP TWICE AT START

<2669>

* DISTANCE BACK FROM SAMPLE POINT IN FEET.

+NOTE: TEMP DURING S6 5-7°C — Will warm tool in trailer during sampling and Retake sample point data after sampling (RFB2S8)

Rocky Flats EMWD Deployment

Date: 11-9-00 Starting time: ______

Bore: #2, 5th SAMPLE @ 74'

File Name: RFB2S9 (5min @ SAMPLE Pt.) RFB2S10 (@ 1' INTERVALS)

Notes: AT 06 PLATE 2 BUILDING 123 HDD LINES

8:47 - 9:22

TEMP 11-12°C

Spectrum #	*	S10 Total Count Reading		S9 TOTAL COUNTS
1	0	2577	1	2540
2	1	3014	2	2576
3	2	2893	3	2664
4	3	2952	4	2542
5	4	2786	5	2549
6	5	2750	6	2565
7	6	2872	7	2586
8	7	2756	8	2594
9	8	2731	9	2625
10	9	2542	10	2556
11	10	2157		
12	11	2400		⟨2580⟩
13	12	2510		
14	13	2564		
15	14	2661		
16	15	2851		
17	16	2474		
18	17	2549		13-14°C
19	18	2515		
20	19	2738		

* DISTANCE BACK FROM SAMPLE POINT IN FEET.
20 SPECTRUM TO COVER THE DISTANCE BETWEEN SAMPLE POINTS 05 AND 06.

Rocky Flats EMWD Deployment

Date: 11-9-00 Starting time: ______

Bore: #2 6th SAMPLE @ 92.3'

File Name: RFB2S11 (5min @ SAMPLE PT.) RFB2S12 (@ 1' INTERVALS)

Notes: AT07 PLATE 2 BUILDING 123 HDD LINES

3:00

Spectrum #	*	S12 Total Count Reading	S13	S11	S11 TOTAL COUNTS
1	0	3229	3170	1	3301
2	1	3284	3140	2	3308
3	2	3452	3233	3	3193
4	3	3196	3255	4	3249
5	4	3020	3317	5	3195
6	5	↑ 2886	2865	6	3251
7	6		STUCK 2922	7	3200
8	7		Free 3204	8	3220
9	8		3269	9	3166
10	9		2784	10	3130
11	10		2805		<3221>
12	11		2912		14 – 16 °C
13	12		3173		
14	13		3025		
15	14		3068		
16	15		2849		
17	16		3059		
18	17		3016		
19	18		2882		

LOCKED UP TWICE
SHUT DOWN ONCE

3025 when stuck

* DISTANCE BACK FROM SAMPLE POINT IN FEET

↑ TOOL STUCK - WHEN IT WAS JARRED TO FREE IT THE CONNECTOR CAME OFF THE CABLE - [illegible] OUT & RETERMINATED

NEW DATA SET RFB2S13

Rocky Flats EMWD Deployment

Date: 11-10-00 Starting time: ____________

Bore: #2 7th SAMPLE @ 100'

File Name: RFB2S14 (5min @ SAMPLE Pt.) RFB2S15 (@ 1' INTERVALS)

Notes: AT 08 PLATE 2 BUILDING 123 HDD LINE

Spectrum #	*	S15 Total Count Reading		S14 TOTAL COUNTS
1	0	2844	1	2939
2	1	2788	2	3047
3	2	2969 Lost connection	3	3001
4	3	to tool	4	2977
			5	2989
			6	2982
			7	2999
			8	2928
			9	2874
			10	2935

* DISTANCE BACK FROM SAMPLE POINT IN FEET

Splice connection in poly Tubing broke, will pull and repair or replace.

Rocky Flats EMWD Deployment

Date: 11-13-00 Starting time: ____________

Bore: #2 8th Sample @ 102'

File Name: RFB2517 (5min @ sample point) RFB2518 (@1' intervals)

Notes: AT 8 repeat 08 PLATE 2 BUILDING 123 HDD LINE

Spectrum #	*	Total Count Reading (5-18)
1	0	2765
2	1	2957
3	2	2827
4	3	2707
5	4	2809
6	5	2949
7	6	3092
8	7	3134
9	8	2904
10	9	3089
11	10	3032

	TOTAL COUNTS 5-17
1	2788
2	2807
3	2801
4	2776
5	2798
6	2814
7	2774
8	2901
9	2858
10	2794

* DISTANCE BACK FROM SAMPLE POINT IN FEET

Pulled New cable thru poly and Terminated both ends Tested - OK!

Rocky Flats EMWD Deployment

Date: 11-14-00 Starting time: 12:55

Bore: #2 9th Sample @ 126'

File Name: RFB 2519 (5 min @ sample point) RFB 2520 (@ 1' intervals)

Notes: AT ~~08~~ 10 PLATE 2 BUILDING 123 HDD LINES

Spectrum #	*	S20 Total Count Reading			S19 TOTAL COUNTS	
1	0	2778	2849	1	2825	2821
2	1	3017	2844	2	2813	2876
3	2	3031	2819	3	2912	2828
4	3	2924	3033	4	2856	2804
5	4	2979	2894	5	2828	2783
6	5	2970	2819	6	2844	2835
7	6		2809	7	2814	2859
8	7		2610	8	2845	2850
9	8		2933	9	2762	2842
10	9		2564	10	2780	2818
11	10		2876			
12	11		2680			
13	12		2862			
14	13		2883			
15	14		2933			
16	15		2839			
17	16		2972			
18	17		2669			
19	18		2713			
20	19		2921			
21	20		2855			
22	21		3007			
23	22		2941			
24	23		2949			
25	24		3004			
26	25		3064			
27	26		2984			
28	27		3329			
29	28		2992			
30	29		2539			
31	30		2810			

I-3: UBC 123 Bore #3

Rocky Flats EMWD Deployment

Date: 11-28-00 Starting time: 2:20

Bore: #3 3rd Sample @ 33'

File Name: RFB353 (5min @ Sample point) RFB354 (@ 1' INTERVALS)

Notes: AT PLATE 2 BUILDING 123 HDD LINE 3

Spectrum #	*	S4 Total Count Reading
1	0	3790
2	1	3391
3	2	2939
4	3	2647
5	4	2104
6	5	3180
7	6	3145
8	7	3221
9	8	3305
10	9	3380
11	10	3250
12	11	11795 (3547)
13	12	7629 (3610)
14	13	3780
15	14	3875
16	15	4289 (4896)
17	16	3867 (4331)
		@18' 3614
		TOTAL of 28 spectrums

S3	
1	3172
2	3047
3	3065
4	3140
5	3115
6	3058
7	3205
8	3088
9	3130
10	3139

* DISTANCE BACK FROM SAMPLE POINT IN FEET

Rocky Flats EMWD Deployment

Date: 11-29-00 Starting time: 8:50

Bore: 3

File Name: RFB3UT

Notes: UTILITY LINE PVC @ 0'

Spectrum #	* Total Count Reading
	4341
	4400
	4283
	4362
	4318
	4399
	4473
	4385
	4368
	4357
	4250
	4279
	4263
	4269
	4237
	4401
	4271
	4332
	4309
	4247
	4399
	4258
	4297
	4241
	4197
	4312
	4208
	4262
	4308
	4222

* Survey of UTILITY Line

Rocky Flats EMWD Deployment

Date: 12-01-00 Starting time: 9:45

Bore: #3 4th Sample @ 48'

File Name: RFB355 (5min @ sample point) RFB356 (@1' INTERVALS)

Notes: AT PLATE 2 BUILDING 123 HDD LINE 3

Spectrum #	*	Total Count Reading 56
1	0	4082
2	1	4230
3	2	4435
4	3	4229
5	4	4021
6	5	4234
7	6	4381
8	7	4239
9	8	4235
10	9	4569
11	10	4239
12	11	4188
13	12	3825
14	13	3705
15	14	3576
16	15	3316
17	16	3310

55	
1	4270
2	4048
3	4206
4	4093
5	4076
6	4244
7	4155
8	4168
9	4203
10	4251

* Distance back from sample point in feet

Rocky Flats EMWD Deployment

Date: 12-01-00 Starting time: ______

Bore: #3 5th Sample point @ 63'

File Name: RFB357 (5min @ Sample Point) RFB358 (@1' INTERVALS)

Notes: AT PLATE 2 BUILDING 123 HDD LINE 3

Spectrum #	*	58 Total Count Reading		57
1	0	3059	1	3021
2	1	2998	2	2864
3	2	2874	3	2987
4	3	2953	4	3003
5	4	3044	5	3071
6	5	2836	6	2998
7	6	2862	7	3004
8	7	2768	8	2978
9	8	2864	9	2989
10	9	3013	10	2948
11	10	4785		
12	11	4468		
13	12	4002		
14	13	4092		
15	14	4088		
16	15	4085		
17	16	4400		
18	17	4654 →4664		

* DISTANCE BACK FROM SAMPLE POINT IN FEET.

I-4: UBC 123 Bore #4

Rocky Flats EMWD Deployment

Date: 10-31-00 Starting time: 2:28

Bore: RFB 4 (S1 5min) (S2 15@ 30sec ea)

File Name: RFB4S1 + RFB4S2

Notes: 1st SAMPLE POINT @ 42'
at 06 PLATE 2 BLDG 123

Spectrum #	Total Count Reading
1	3486
2	3446
3	3366
4	3100
5	2963
6	3173
7	3077
8	2762
9	2528
10	3015
11	3082
12	3200
13	3041
14	2914
15	3111

2:35

DURING 5min Run
THESE are some
of the total
counts
SORRY I DIDn't get
[illegible] all.

3306
3387
3397
3446
3458

3440

Rocky Flats EMWD Deployment

Date: 11-1-00 Starting time: 11:03

Bore: #4

File Name: RFB4 S3, RFB4S4

Notes: 2nd SAMPLE PT. @ 57', S3 IS 5min TEST & S4 @ 30 [illegible] FOOT at 05

Spectrum #	S4	Total Count Reading
1	0	3169
2	1	3386
3	2	3578
4	3	3508 *
5	4	3316
6	5	3174
7	6	3103
8	7	3426
9	8	3459
10	9	3079
11	10	3216
12	11	3080
13	[illegible]	3211
14	[illegible]	3395
15	[illegible]	3377

S3

TOTAL COUNTS	
1	3217
2	3039
3	3156
4	3197
5	3146
6	3094
7	3061
8	3200
9	3159
10	3111
	3138

Time 10:56

* 3431
3349
3344
3399

Rocky Flats EMWD Deployment

Date: 11-1-00 Starting time: 3:34

Bore: #4 3rd SAMPLE POINT @ 72'

File Name: RFB455 (5min @ sample Pt) RFB456(@ 1' intervals)

Notes: At 04 Plate 2 Building 123 HDD lines

56

Spectrum #	Total Count Reading
1	3141
2	3539
3	3721 *
4	3759
5	3627
6	3702
7	3707
8	3569
9	3489
10	3329
11	3302
12	3311
13	3154
14	3194
15	3090

3:26

55 TOTAL COUNTS

1	3206
2	3165
3	3225
4	3176
5	3073
6	3304
7	3171
8	3206
9	3173
10	3119
	3182
*	3763
	3760
	3794
	3764
	3851

Rocky Flats EMWD Deployment

Date: 11-2-00 Starting time: 10:30 - 10:50

Bore: 4 4th SAMPLE POINT @ 87'

File Name: RFB4S7 (5min @ SAM[illegible]) RFB4S8a (@ 1' [illegible])

Notes: AT 03 PLATE 2 BUILDING [illegible]

S8a

Spectrum #	*	Total Count Reading
1	0	RESTART 3267
2	1	3373
3	2	3589
4	3	3434
5	4	3564
6	5	3254
7	6	3684
[illegible]	7	3652
9	8	3263
10	9	3059
11	10	3173
[illegible]	[illegible]	3372
[illegible]	12	3163
[illegible]	13	3212
[illegible]	14	

TOTAL CTS. S7 10:21

1	3227
2	3203
3	3260
4	3277
5	3239
6	3172
7	3245
8	3355
9	3280
10	3350

3272

* DISTANCE BACK FROM SAMPLE POINT IN FT.

Rocky Flats EMWD Deployment

Date: 11-2-00 Starting time: ____________

Bore: 4 5th sample pt. @ 10 2'

File Name: RFB4S9 (5min @ sample pt) RFB4S10 (@ 1' intervals)

Notes: A102 PLATE 2 BUILDING 122 HDD LINES

S10

Spectrum #	*	Total Count Reading
1	0	3252 --- 3259
2	1	3195
3	2	3375
4	3	3128
5	4	3137
6	5	3141
7	6	3180
8	7	3309
9	8	3274
10	9	3074
11	10	3226
12	11	3260
13	12	3189
14	13	3329
15	14	3268

S9 4:47

TOTAL COUNTS

1	3181
2	3295
3	3240
4	3296
5	3232
6	3312
7	3373
8	3297
9	3240
10	3288
	3275

* DISTANCE BACK FROM SAMPLE [illegible]

Rocky Flats EMWD Deployment

Date: 11-3-00 Starting time: ______

Bore: 4 6th SAMPLE PT @ 112'

File Name: RFB4S11 (5min @ SAMPLE PT) RFB4S12 (@ 1' INTERVALS)

Notes: AT 01 PLATE 2 BUILDING [illegible] HOODLINES

Spectrum #	*	S12 Total Count Reading	S11 TOTAL COUNTS ~11:27
1	0	3030	3058
2	1	2850	3112
3	2	3133	3104
4	[illegible]	3301	3024
5	[illegible]	3046	3023
6	[illegible]	3239	3121
7	[illegible]	3237	2965
8	[illegible]	3067	3104
9	[illegible]	3044	3112
[illegible]	[illegible]	3131	3113
[illegible]	[illegible]	3146	
[illegible]			3074
[illegible]	[illegible]		
[illegible]	13		
[illegible]	14		

* DISTANCE BACK FROM SAMPLE PT. IN FEET

I-5: Building 886 Bore #6

Rocky Flats EMWD Deployment

Date: 7 Dec 2000 Starting time: 4:40 T = 13-14°C

Bore: # 6 886 Sample @ ~~20ft~~ 18ft cw

File Name: RF886s1 ; RF886s2

Notes: Push 10 ft, sampled, pushed ~~10ft~~ 8ft cw more & logged hole

T = 14-15°C

	Spectrum #	*	Total Count Reading S2		S1
18ft	1	0	2546 ; 2711	1	2466
	2	1	2414	2	2553
	3	2	2505	3	2500
15ft	4	3	2410	4	2522
	5	4	2425	5	2490
	6	5	2022	6	2522
	7	6	2235	7	2450
cw ~~10ft~~	8	7	2155	8	2501
10ft	9	8	1815	9	2497
cw	~~10~~	~~9~~		10	2474
cw	~~11~~	~~10~~			

* distance back from sample pt in feet

Other Files:

Air: RF886S0

K40: RF886SK

Floor: RF886SF

Wall: RF886SW

Rocky Flats EMWD Deployment

Date: 7 Dec 2000 Starting time: 5:08

Bore: # 6 886 Sample @ 10ft

File Name: RF886s3 ; RF886s4

T = 15-16°C

Notes: Battery Voltage = 24 for S3

24.4 ~~25.1~~

Spectrum #	*	S4 Total Count Reading		S3
1 (10ft)	0	1851	1	1895
2	1	2224	2	1874
3	2	2622	3	1903
4	3	2471	4	1880
5	4	2050	5	1884
6 (5ft)	5	2136	6	1893
7	6	2733	7	1938
8	7	2718	8	1930
9	8	3239	9	1904
10	9	6751	10	1921
11 (0ft)	10	7786		

* distance back from sample pt in feet

Note: Computer locks up each time try to Record

Rocky Flats EMWD Deployment

Date: 7 Dec 2000 Starting time: 5:23

Bore: #6 886 Sample @ 0 ft

File Name: RF886s 5

T = 17-18°

Notes:

Spectrum #	Total Count Reading

	S5
1	7706
2	7733
3	7799
4	7853
5	7689
6	7918
7	7748
8	7731
9	7944
10	7937

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