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Final Report of the Environmental Measurement-While-Drilling Gamma Ray Spectrometer System Technology Demonstration at the Savannah River Site F-Area Retention Basin

Grant J. Lockwood, Randy A. Normann, Cecelia V. Williams

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Final Report of the Environmental Measurement-While-Drilling- Gamma Ray Spectrometer System Technology Demonstration at the Savannah River Site F-Area Retention Basin

Grant J. Lockwood
Materials Radiation Science

Randy A. Normann
Geothermal Research

Cecelia V. Williams
Underground Storage Technology

Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0706

Abstract

The Environmental Measurement-While-Drilling-Gamma Ray Spectrometer (EMWD-GRS) system represents an innovative blend of new and existing technology that provides real-time environmental and drill bit data during drilling operations. The EMWD-GRS technology was demonstrated at Savannah River Site F-Area Retention Basin.

The EMWD-GRS technology demonstration consisted of continuously monitoring for gamma-radiation-producing contamination while drilling two horizontal boreholes below the backfilled retention basin. These boreholes passed near previously sampled vertical borehole locations where concentrations of contaminant levels of cesium had been measured. Contaminant levels continuously recorded by the EMWD-GRS system during drilling are compared to contaminant levels previously determined through quantitative laboratory analysis of soil samples.

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Introduction

The Environmental Measurement-While-Drilling-Gamma Ray Spectrometer (EMWD-GRS) system^{1,2,3} represents an innovative blend of new and existing technology providing real-time environmental and drill bit data acquisition during drilling operations. These real-time measurements provide technical data for field operations (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 analysis; (2) substantial cost savings result by minimizing the number of samples required for offsite analyses; (3) worker safety is enhanced by quickly alerting field personnel to potentially hazardous conditions; and (4) the amount of investigation derived waste (IDW) is reduced.

During development, the EMWD-GRS system was tested at the U.S. Department of Energy (DOE) radiation test facility in Grants, NM, and at the directional boring test site owned by Charles Machine Works, Inc. in Perry, OK. Demonstration at the Savannah River Site (SRS) F-Area Retention Basin (FRB) provided EMWD-GRS system performance data under field conditions at a previously characterized “hot” site. Demonstration participants included DOE-Savannah River, DOE-Albuquerque, Westinghouse Savannah River Company (WSRC), and Sandia National Laboratories (SNL).

The site” selected for the demonstration was the previously characterized SRS FRB (Figure 1). The basin is approximately 61 m long, 36.5 m wide and 2 m deep and has a total volume capacity of approximately 4,685 m³. This basin was constructed as an unlined, temporary container for potentially contaminated cooling water from the chemical separation process and storm sewer drainage from the F-Area Tank Farm. When contamination was detected in cooling water, the water was diverted to the retention basin or F-Area seepage basins. Additional contamination of this basin came from various spills or overflows at the basin. The basin was in active use from 1955 until 1972, when it was replaced by a lined retention basin. In 1978, the FRB was excavated, backfilled with soil and covered with grass. Backfill in the basin extends to a depth of approximately 3 m. The site was evaluated through soil sampling in early 1979. The sample locations are shown in Figure 2. The major radionuclides present included strontium (Sr-89/90) and cesium (Cs-137).

Radionuclide contaminant distributions for Cs-137 at sample locations FRB-05, 06, 07,08 and 19 are shown in Figure 3. As illustrated, the greatest concentrations of Cs-137 occur between the depths of 2.74 m (9 ft) and 5.79 m (19 ft).

Phase I of the demonstration at the FRB determined the background conditions for the site as seen by the EMWD-GRS. Background conditions were determined by drilling one angled borehole (1416° from horizontal to the ground surface) -17 m in length to a depth of -5 m, at an adjacent radiologically “clean” test site. The data on the background conditions were used in Phase II of the demonstration.

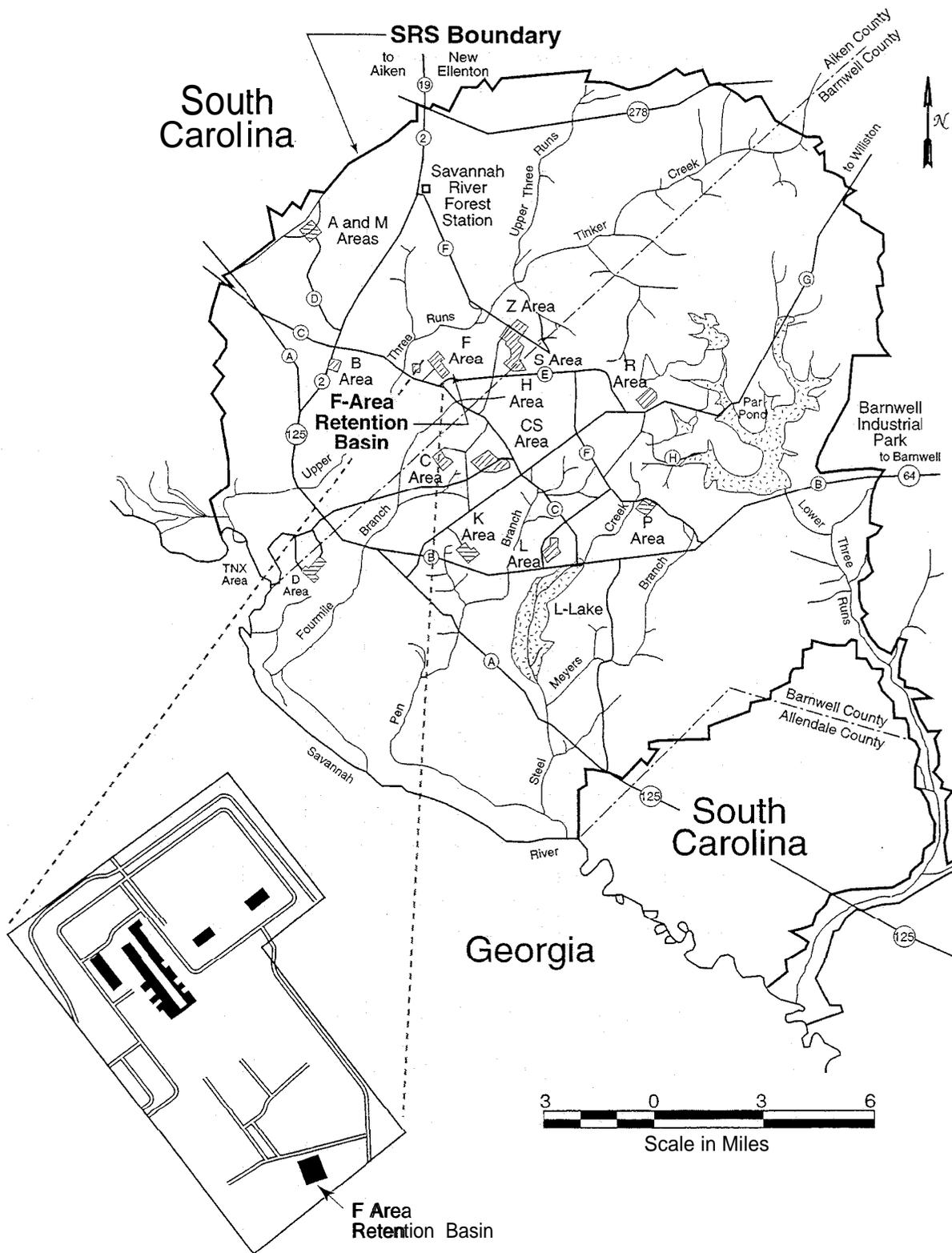


Figure 1. Location of the F-Area Retention Basin in relation to major SRS facilities⁴.

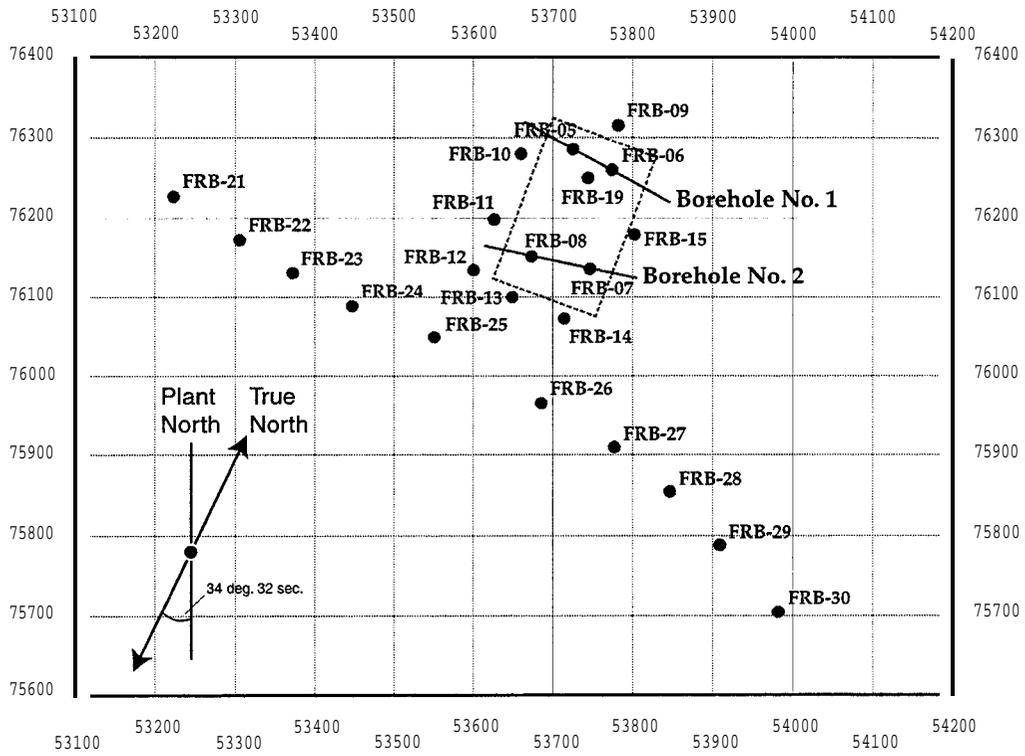


Figure 2. Locations of sample holes and boreholes at the SRS FRB⁴.

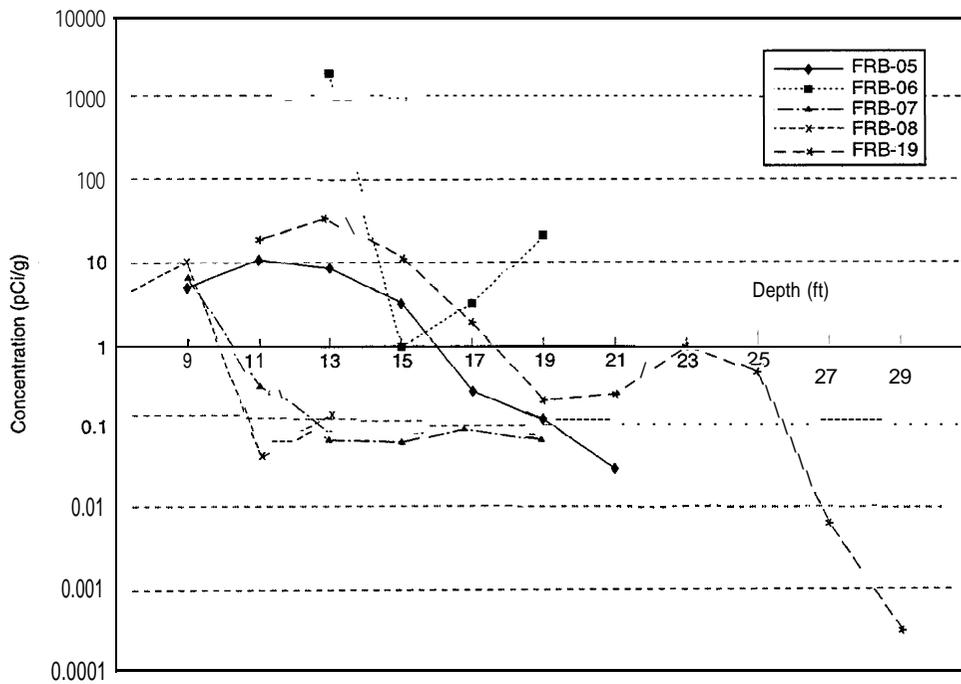


Figure 3. Concentration (pCi/g) of Cs-137 relative to depth at sampling locations FRB-05, 06, 07, 08 and 19 within the SRS FRB5.⁴

Phase II of the EMWD-GRS system demonstration consisted of monitoring environmental conditions in real-time while drilling two horizontal boreholes. These boreholes passed near sample locations FRB-05, 06,07 and 08 (Figure 2) where values of contaminant levels had been measured. Contaminant levels continuously recorded by the EMWD-GRS system during drilling are compared to contaminant levels previously determined through quantitative laboratory analysis of soil samples collected at these locations.

Apparatus

Drilling Platform

The drilling platform for this demonstration was a JT2511 JetTrac[®] boring system (manufactured and sold by Charles Machine Works, Inc.) using minimal drilling fluid and Fluid Miser[™] pipe. The boring system was supplied by Geneva Corporation-DitchWitch[™] of Georgia. This system uses a high-frequency electromagnetic beacon with a walkover monitor (Subsite[®]) to measure drill bit location and depth.

The FRB is subject to Comprehensive Environmental Response, Compensation and Liability Act requirements. The drilling contractor provided for decontamination of equipment and personnel to meet 29 CFR 1910.120-Hazardous Waste Operations and Emergency Response. The drilling operations minimized waste by using Fluid Miser[™] pipe during drilling operations. The drill bit entry pit, -0.34 m', was lined with plastic to contain the minimal amount of drilling generated waste for appropriate disposal.

No radioactive IDW was generated during the technology demonstration. Other waste generated during the demonstration was managed in accordance with SRS procedures and applicable regulations.

EMWD-GRS

The EMWD-GRS system is compatible with this drilling platform. The downhole sensor is located behind the drill bit (Figure 4) and is linked by a high-speed data transmission system, using a coaxial cable, to a personal computer (PC) at the surface. Windows[™]-based software, developed by SNL, is used for data display and storage. During drilling operations, data on the nature and extent of contamination are collected. Timely access to the data provides information for on-site decisions regarding drilling and sampling strategies.

Figure 5 shows the drilling steps. As the drill string is lengthened by adding drill rod, the coaxial cable is unspooled. The unspooled cable is attached to the battery pack and coil. The latter are mounted on the rotating spindle, which extends behind the hydraulic head. The coil couples the FM signal between the rotating drill pipe and the stationary coil and receiver, which are mounted on the drilling platform. The receiver converts the FM signal into a serial bit stream. A computer equipped with a telemetry serial card receives the data and displays downhole measurements in real time.

Downhole Components

Downhole components of the gamma-ray detection sensor system that was demonstrated consisted of a gamma-ray spectrometer, a multichannel analyzer (MCA), an 11 OOV power supply, a signal conditioning and transmitter board, and a coil containing coaxial cable for transmitting data to the surface. The downhole components were contained within O-ring sealed stainless steel tubes to protect them from the drilling environment.

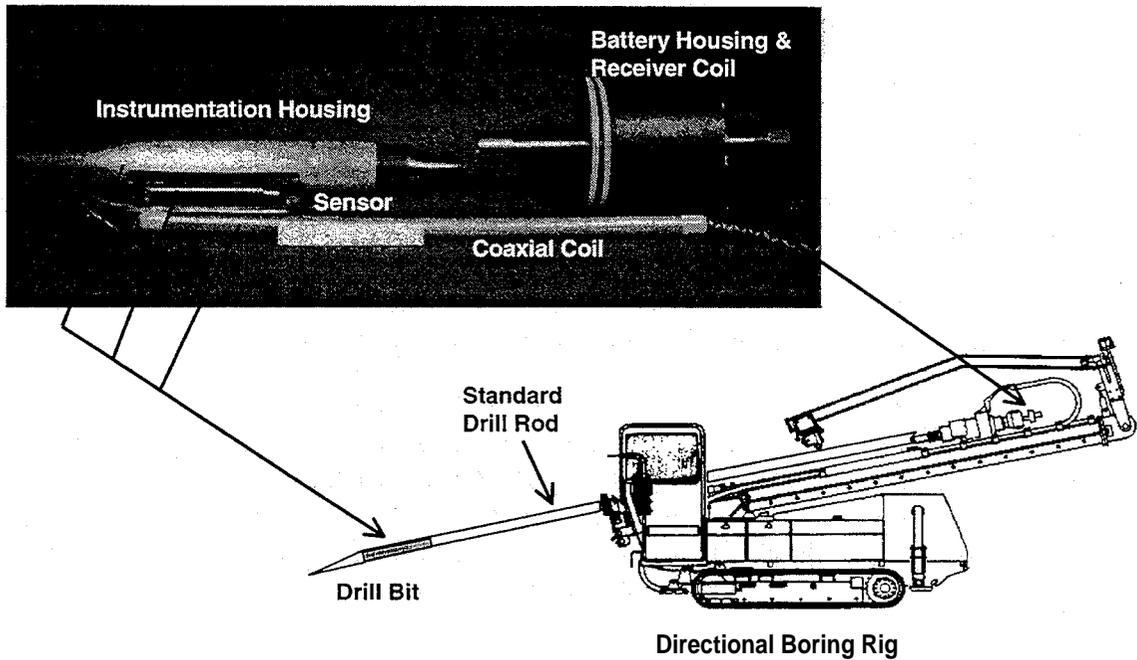


Figure 4. EMWD-GRS system component placement on a typical directional boring rig.

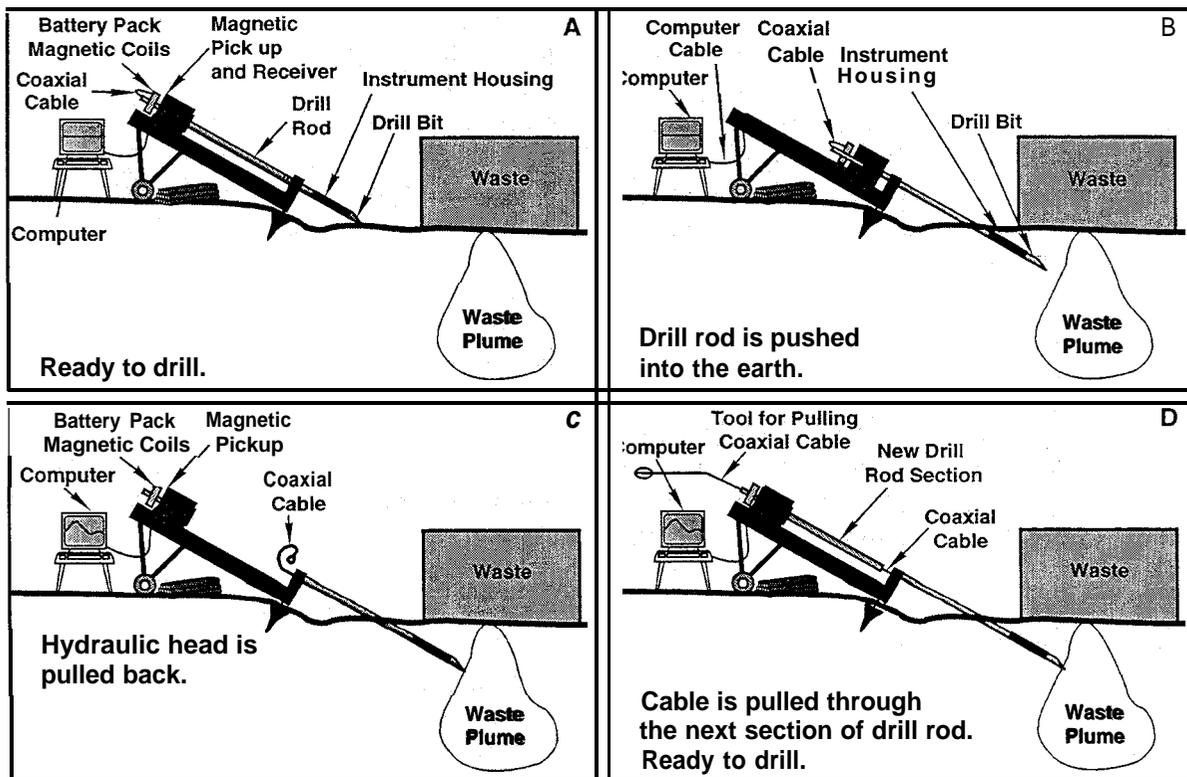


Figure 5. The EMWD process using a coaxial spool.

Uphole Components

The uphole system consisted of a battery pack/coil, pickup coil, receiver, and a PC. During drilling, the system monitors (1) gamma radiation with the gamma-ray spectrometer, (2) the +12V and -12V required at the downhole signal conditioning and transmitter board, (3) the uphole battery voltage as measured downhole and (4) two temperatures associated with the detector and instrumentation.

Reliability

Since personnel safety is a primary consideration, reliability and high data surety are priority system requirements. To meet this requirement, the system design incorporates data quality assurance techniques to ensure data reliability. The basic format used in the EMWD-GRS system is also used in the weapons complex. The high data rate enables transmitting spectral information three times, providing detection and correction for any bit error.

Cable Deployment System

The cable is contained in a spool located with the downhole components of the system. The cable from the downhole instrument package is pulled through each section of drill pipe and through the drill head to the battery pack/coil mounted on a spindle at the rear of the drill head. Because the cable connection must pass through the drill pipe, which is restricted to about 7.9 mm at each pipe section pin, a 6.35 mm outside diameter (OD) Lemo coaxial connector is used. The cable is sealed as it passes through the spindle at the battery pack/coil. The spindle leads to the drill fluid handling system. Drill fluid pressure is normally in the range of 1.44 kPa to 2.39 kPa, but can go as high as 7.18 kPa. A cord grip fitting is used to seal against the 1.8 mm OD coaxial cable. The sealing grommet in the cord grip fitting is slit so that it can be removed from the cable, allowing the connector to pass through the body of the cord grip fitting. This arrangement has been tested to 2.871 kPa air, which is approximately 14.35 kl/a water, without leakage. The coaxial cable is pulled through each section of drill pipe using a 4.88 m long, 6.35 mm diameter rod fashioned from two pieces of stainless steel rod threaded together. A tip consisting of a Lemo connector without a cable acts as a flexible guide as the rod is inserted through the drill head and pipe from the spindle to the end of the cable from the instrument housing. This guide tip is replaced with the cable Lemo connector. Thus, the cable is unspooled and is pulled through the drill pipe and head as the rod is withdrawn. The time required to add a new section of pipe, deploy the cable, and prepare to acquire data is an important parameter for evaluating the system's total performance. This time has been measured to be -3.5 min.

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Procedures

The drilling locations for the two horizontal boreholes are shown in Figure 2. The boreholes were drilled horizontally below the clean backfill in the retention basin. The drill rig was positioned outside of the backfilled retention basin at a location determined by drilling protocol. Horizontal Borehole #1 was drilled near previously sampled vertical holes FRB-05 and FRB-06. Horizontal Borehole #2 was drilled near previously sampled vertical holes FRB-07 and FRB-08.

EMWD-GRS Data Collection

The data collection procedures used with the EMWD-GRS system are the following:

1. Check for full operation of tool and computer interface prior to attachment of downhole tool to drill string or mounting uphole components on drill rig.
2. Mount system and verify system functionality.
 - a. Check downhole battery voltage >22V.
 - b. Take temperature measurement.
 - c. Collect normal background spectra at drill site.
 - d. Verify system lock reading.
3. Run decom software using default setup.
4. With system mounted behind the drill bit, test rotate the drilling rig while monitoring wired connections and computer.
5. After visual verification that the system is working, start the normal drilling process.
6. Start data storage by providing a file name and continuously record data while drilling as follows:
 - a. Each spectrum is a fixed accumulation of data for 19.2 sec.
 - b. After each drill rod segments, stop recording, close data file and name.
 - c. Restart recording under a new data file name; start drilling the next rod segment.
 - d. Repeat steps (b) and (c) until drilling is completed.
7. At sampling location, stop drilling and record spectra.
8. Close the PC file and store file to secondary backup system.
9. Commence pullback of drill rod.

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Data

Using the procedures outlined above, spectra were obtained while drilling boreholes 1 and 2. Background data (Figure 6) were also obtained using these procedures. Due to the statistical uncertainty of low background count rates, the average background count plus three standard deviations was used to correct the raw data from boreholes 1 and 2. As an example of the raw data obtained while drilling, Figure 7 shows seven successive spectra obtained while drilling through the region of highest Cs-137 concentration in Borehole 1. The Cs-137 peak is located at channel 98. Plotted here are the counts per channel obtained for each 19.2 sec spectral accumulation.

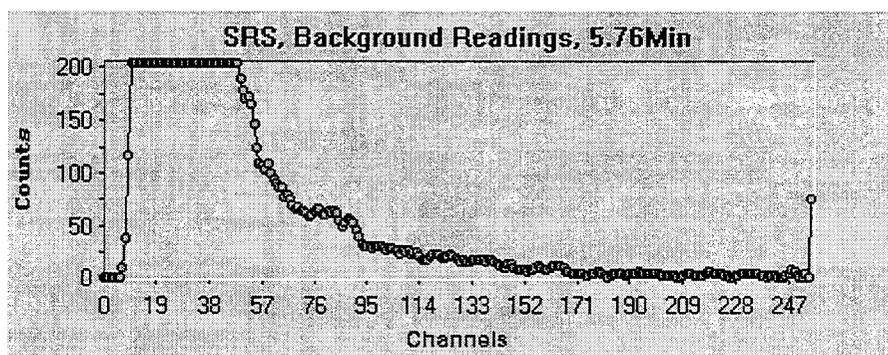


Figure 6. Background readings for last drill rod in the “clean” test site borehole. A total of 1541 counts were obtained during a 5.76 min interval. The count information was integrated from window 78-118.

Calibration

The Technology Demonstration Plan⁶ (TDP) called for the contaminant levels continuously recorded by the EMWD-GRS system during drilling to be compared with contaminant levels previously determined through quantitative laboratory analysis of soil samples collected at locations FRB-05, 06, 07 and 08. These previous determinations are given in units of pCi/g averaged for a 61 cm long core sample. The gamma-ray producing contaminant of interest was Cs-137. It is desirable to calibrate the EMWD-GRS using a distributed Cs-137 source in the range of 10 to 1000 pCi/g. However, there is no known calibration facility that can provide a distributed source of Cs-137. The DOE has developed facilities for calibrating gamma-ray-measuring instruments used in uranium exploration. These facilities provide distributed sources of radium (Ra), thorium (Th) and potassium (K). A secondary calibration facility is located in Grants, NM.

The method chosen to calibrate the EMWD-GRS for Cs-137 consisted of three parts. First a laboratory measurement of energy vs. the MCA channel number was made. Then a K-40 calibration was performed at the DOE calibration facility in Grants, NM. Finally the ratio of the GRS detector efficiencies for 0.662 MeV Cs-137 γ -ray and the 1.46 MeV K-40 γ -ray was determined.

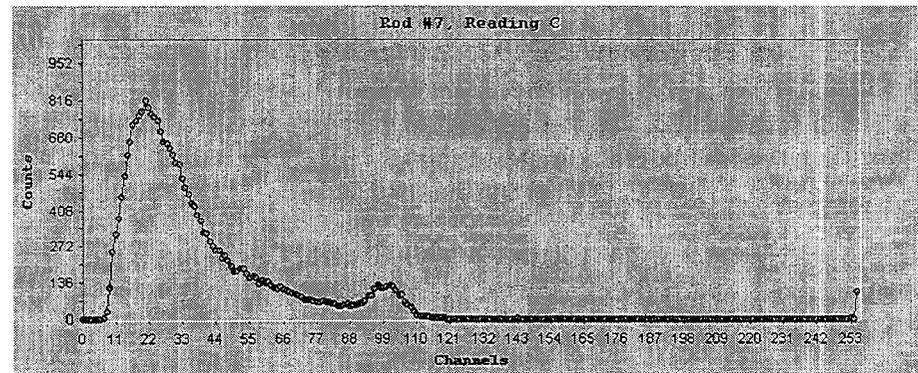
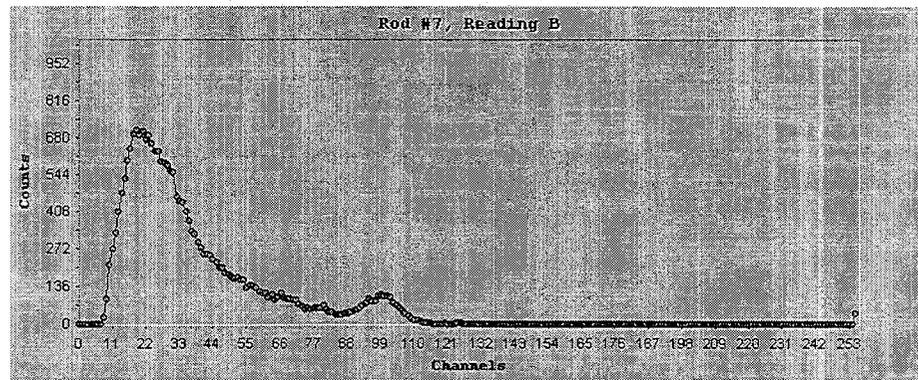
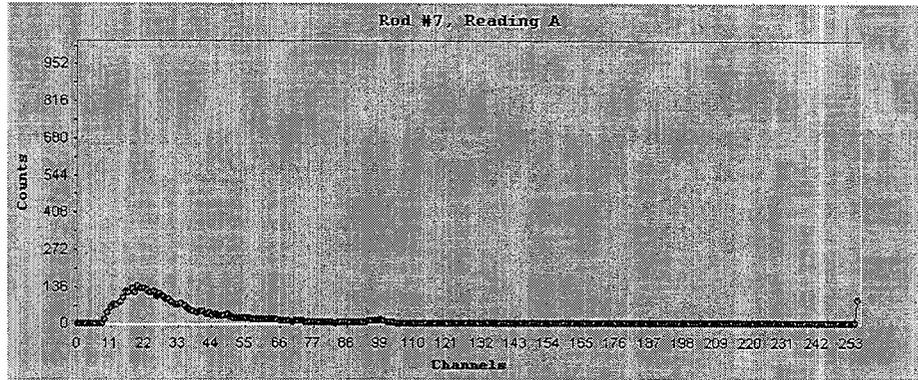


Figure 7. EMWD-GRS spectral gamma raw data obtained while drilling through a "hot" region.

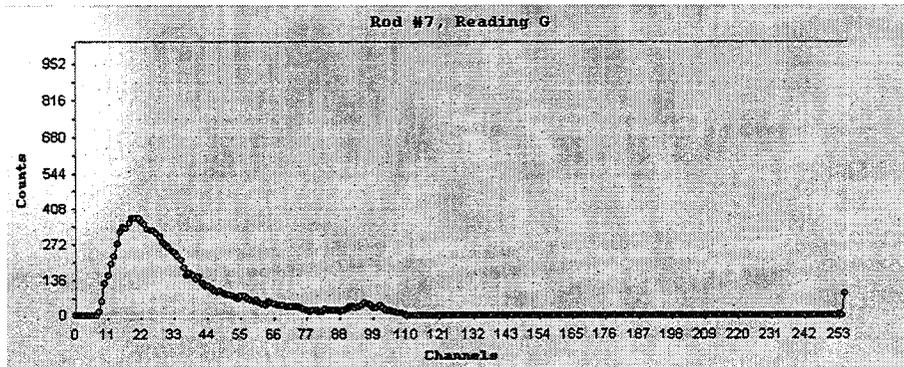
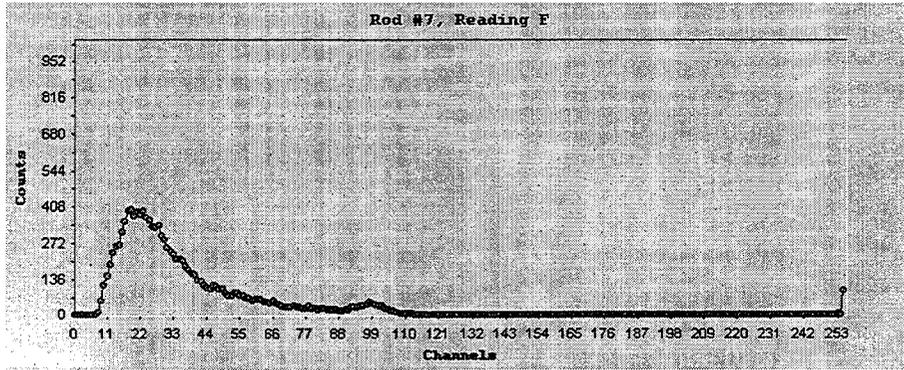
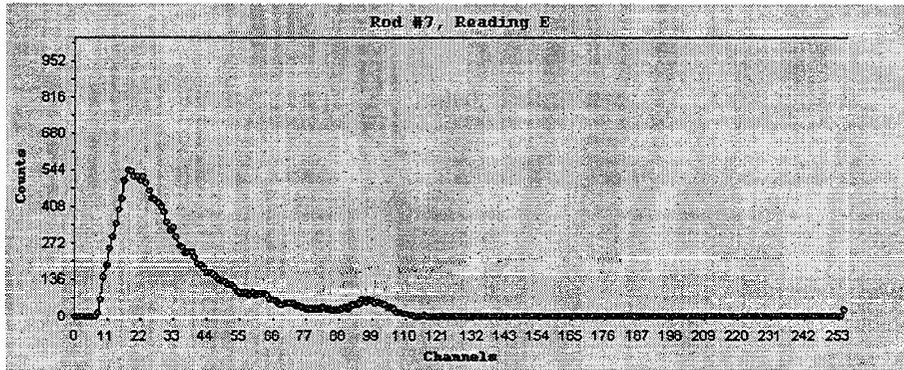
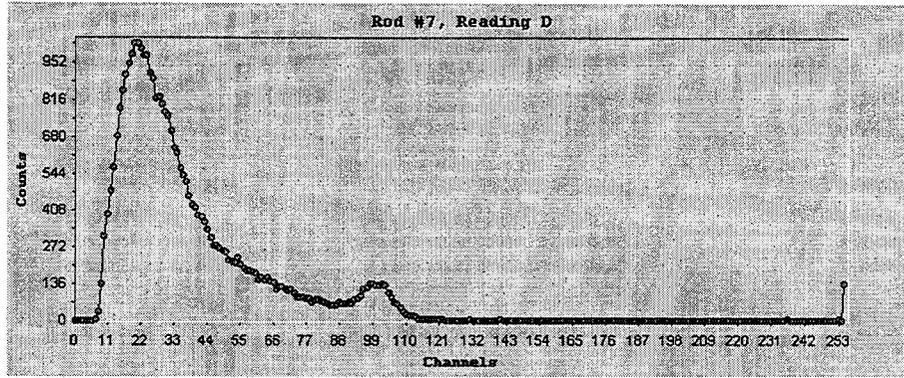


Figure 7. EMWD-GRS spectral gamma raw data obtained while drilling a “hot” region (continued).

The energy calibration of the MCA channel number was performed using known radioactive sources. The gamma-ray spectra measured during this procedure are shown in Figure 8. The peak energies and corresponding channel numbers for each radioactive element are shown in Table 1.

Table 1
Linear calibration

Element	Peak Energy MeV	Peak Channel Number
Cs-137	0.662	98
Mn-54	0.835	121
CO-60	1.173	177
	1.132	201
Na-22	0.511	78
	1.275	188

Field calibration of the EMWD-GRS was performed using the GBK well section of the GBT/GBK Model at Grants, NM. The GBK section is doped with the quantities of materials shown in Table 2.

Table 2
Assigned parameters for calibration of spectral g-ray logging system model

Model	Concentration (pCi/g)		
	Ra-226	Th-232	K-40
GBK	1.1 ± 0.1	0.1 ± 0.0	52.2 ± 1.8

The spectrum obtained by summing readings for 652.8 sec is shown in Figure 9. The K-40 peak is clearly seen at channel 206. Integrating the signal from channel 186 to channel 226, the total counts were 2039. The average counts per sec for K-40 is 3.12 c/s. Assuming the Th and Ra contributions to be zero, the calibration factor for K-40 is 16.71 (pCi/g) / (c/s).

Finally a correction for the difference in detector efficiencies for K-40 and CS-137 was determined. Using three gamma-ray energies the signals for constant geometry and data collection time were measured. Corrections to the data were made for current source activity, probability per decay⁸ and exponential signal decay background. With this we determined that the detector is five times more efficient for counting Cs-137 y-rays as it is for counting K-40 y-rays.

Based on field calibration for K-40 and the efficiency ratio the calibration factor used to obtain contamination levels for from the EMWD-GRS data is 3.34 (pCi/g) / (c/s).

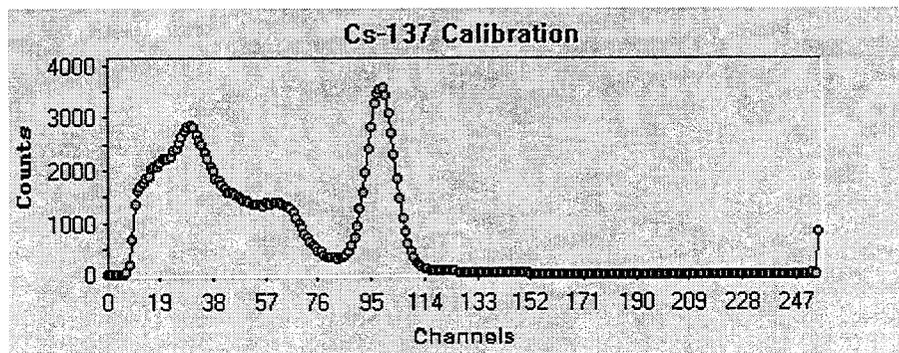
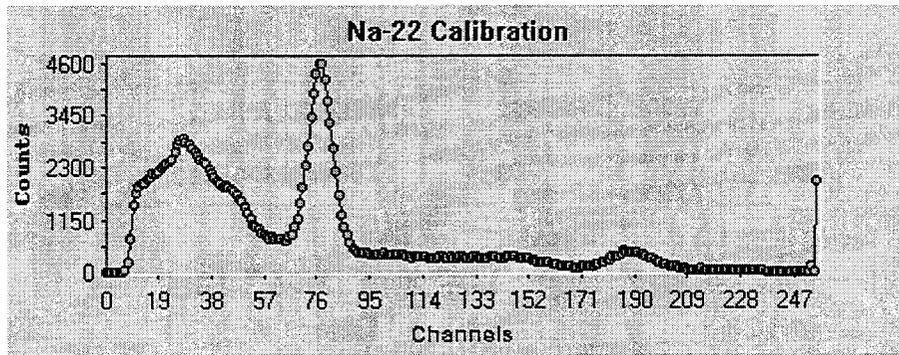
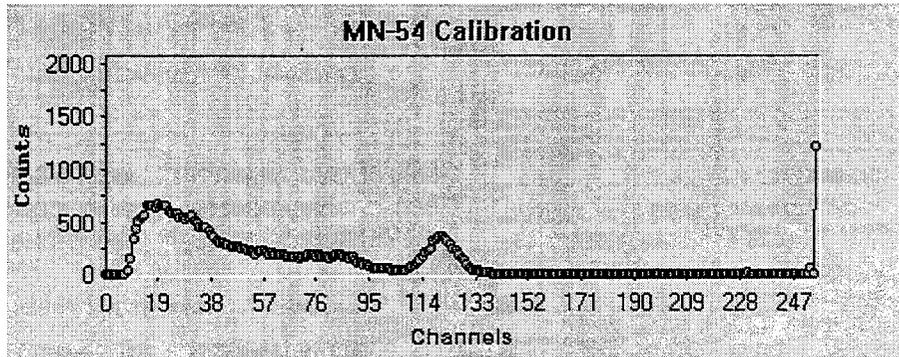
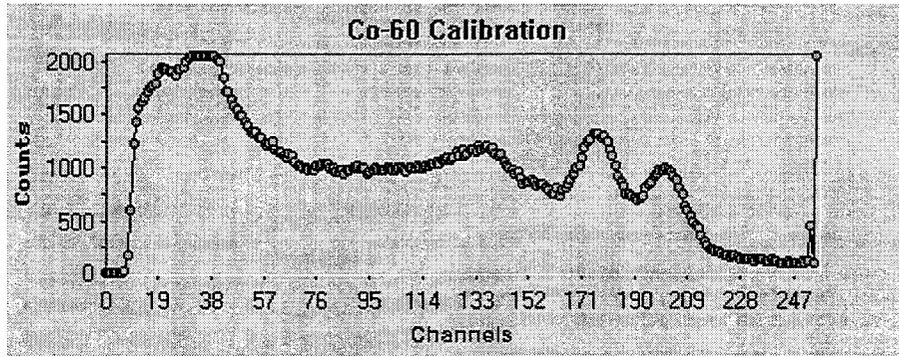


Figure 8. EMWD-GRS laboratory gamma spectra for channel calibration.

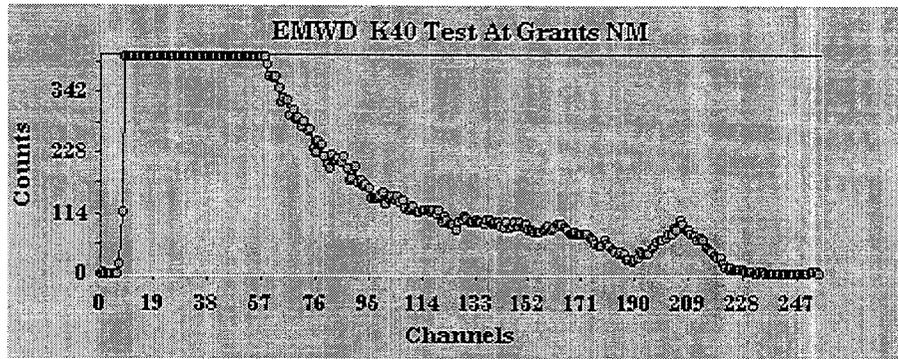


Figure 9. The spectrum obtained at Grants, NM, using the GBK well section (652.8 see).

Results

Comparison to WSRS Data

The TDP called for two boreholes to pass near sample locations FRB-05, 06,07,08 and 19. The five sample locations could not be intersected by two boreholes. We chose to bore the first hole on a line to pass close to FRB-05 and 06 and the second borehole on line with FRB-07 and 08. This meant that FRB-19 would be no closer than 6.1 m from the nearest borehole, and data comparison would have little meaning.

The TDP further states “contaminant levels continuously recorded by the EMWD-GRS system during drilling will be compared to contaminant levels previously determined through quantitative laboratory analysis of soil samples collected at locations FRB-05, 06,07, 08 and 19.” For this comparison, the raw data was converted to pCi/g using the calibration factor derived above. These results, as a function of drill rod number, are shown in Figures 10 and 11 for boreholes 1 and 2, respectively. Under normal conditions, 3-7 spectra were obtained for each 3.05 m length of drill rod. At the points of closest approach to FRB-05, 06, 07 and 08, the drilling operation was stopped so additional spectra could be gathered from these areas before drilling continued. At the discretion of the scientific team, drilling was halted at other points of interest, and spectra were accumulated. The concentration data for each drill rod is adjusted by subtracting measured background variance as determined during Phase I and shown evenly distributed along that drill rod. In addition, the borehole depths, as a function of drill rod number for each borehole, are shown in Figures 12 and 13.

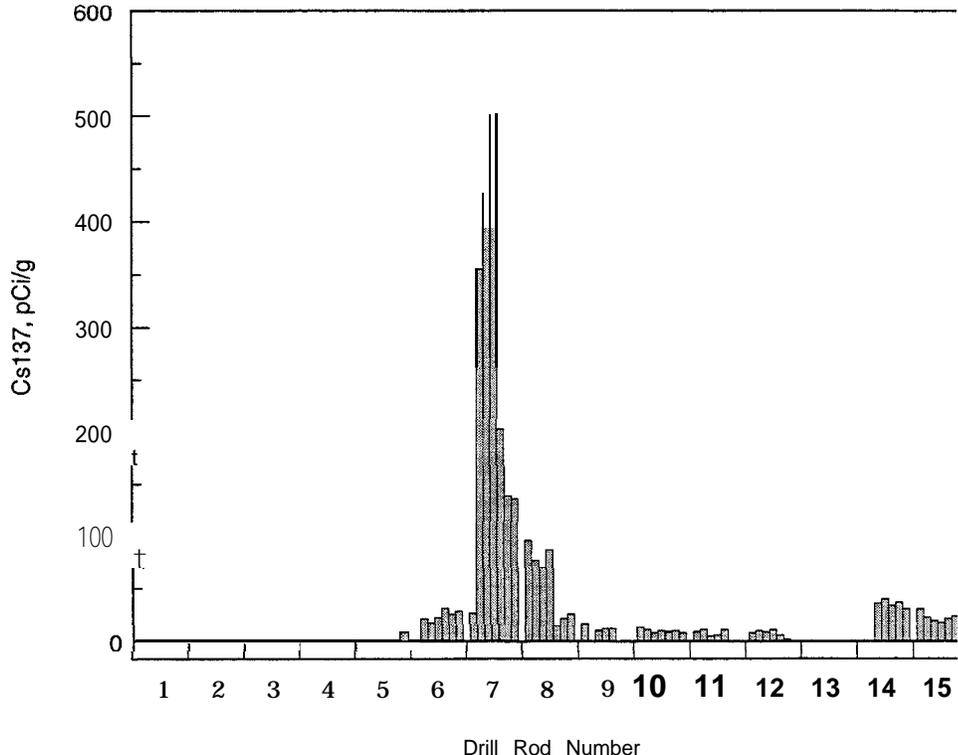


Figure 10. Cesium concentration—Borehole #1.

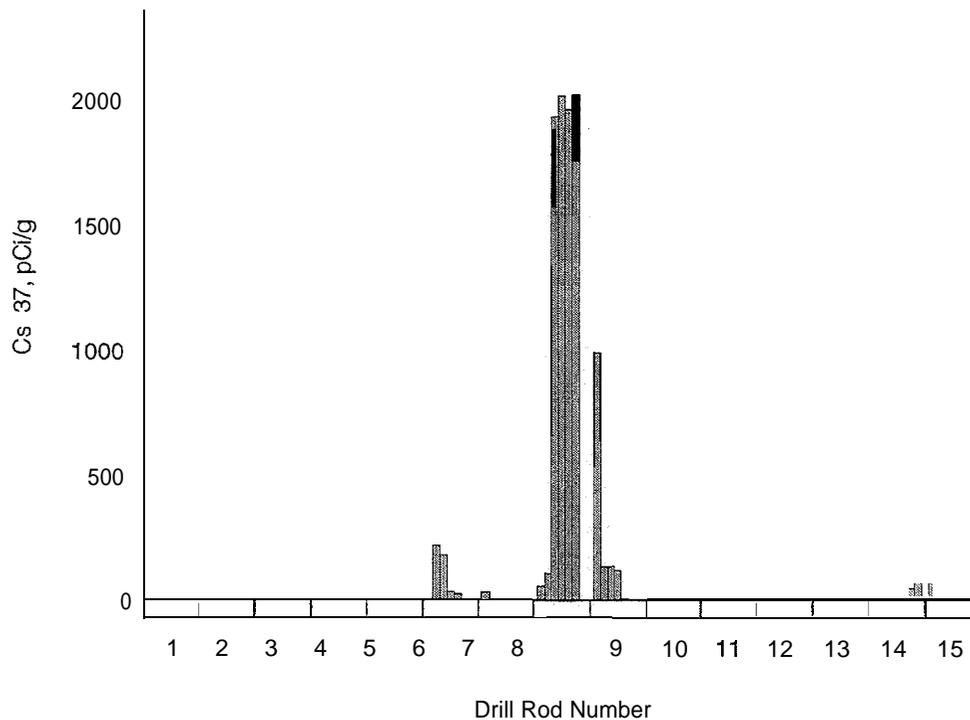


Figure 11. Cesium concentration—Borehole #2.

If we are to make a valid comparison of the EMWD-GRS data with that obtained by laboratory analysis of soil samples, a comparison of the physical conditions for the two methods is required. The soil samples were obtained using a split-spoon soil sampler. This device was used to collect 7.6 cm diameter by 61 cm long soil samples at 61 cm intervals. The results published for Cs-137 were for an average of the entire sample and thus has a location uncertainty of + 30.5 cm. With the soil sampling system, only contamination captured within the 7.6 cm diameter sample contributed to the results.

The spectrometer associated with the EMWD-GRS system collected data from an approximately spherical volume surrounding the sodium iodide (NaI) crystal. The part of the sphere along the drill string did not contribute to the signal. The radius of the “sphere” from which data was obtained is a function of the soil and the energy of the y-ray being studied. A calculation was done to determine the relative flux in the borehole as a function of source region radius through a 0.64 cm thick wall iron pipe, in sand, as a function of y-ray energy. The results for 0.5 MeV and 1.0 MeV γ -ray photons are shown in Figure 14. Here it can be seen that the flux for both energies achieves a constant value by a 76 cm radius. Thus for the EMWD-GRS system, we chose 76 cm to depict the data collection radius for Cs-137 when comparing the two different data sets. Figures 15 and 16 show a vertical cross section through the soil sample collection hole and the EMWD-GRS borehole at the distance of closest approach. In these figures, we assume the soil samples were obtained from vertical holes and that the drill path followed a straight line between the two survey points closest to the sample hole. The depths shown are those published for the sampler and those obtained using a Subsite[®] locating system supplied by the driller.

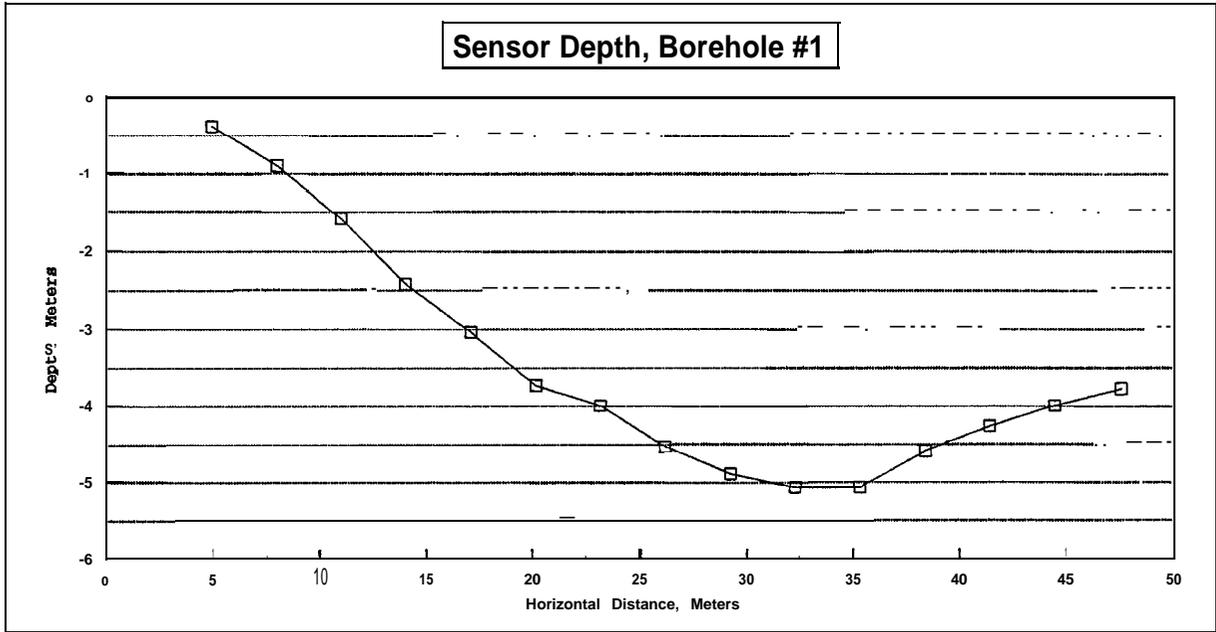


Figure 12. Sensor depth—Borehole #1 (The square symbols represent the location of the end of the drill rod. The line connecting the squares are there only to guide the eye.)

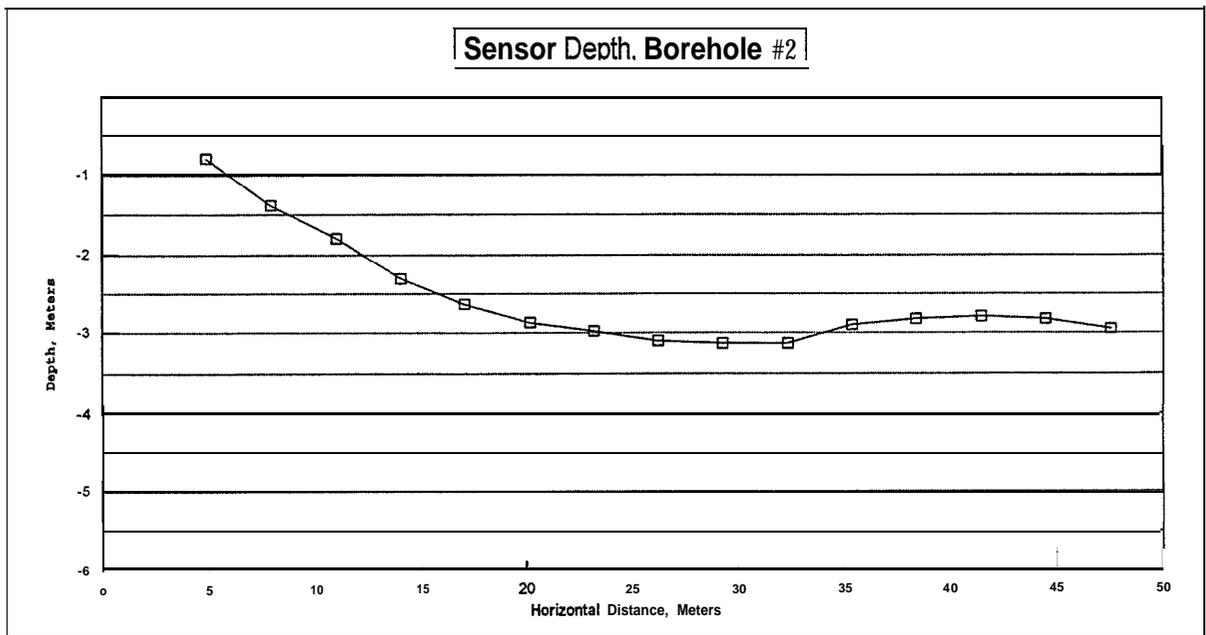


Figure 13. Sensor depth—Borehole #2 (The square symbols represent the location of the end of the drill rod. The line connecting the squares are there only to guide the eye.)

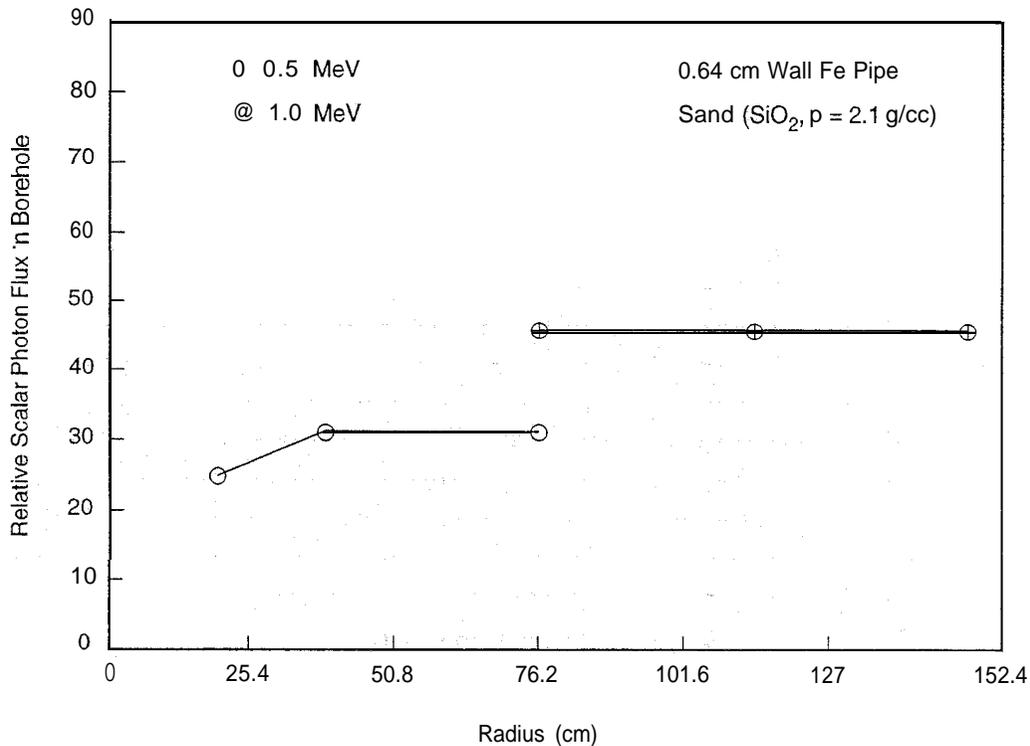


Figure 14. Calculated relative borehole flux.

In Figures 15a and 16b it can be seen that the Cs-137 levels are low, as measured by both systems, and that the results are consistent. Of greater interest is the comparison shown in Figures 15b and 16a. In Figure 15b, the sample shows little contamination (0.455 pCi/g) between 305 cm and 366 cm while the sample obtained between 366 cm and 427 cm resulted in a Cs-137 concentration of 2070 pCi/g. The concentration goes to 0.966 pCi/g in the sample from 427 cm and 488 cm. This is compared with the EMWD-GRS result of 500 pCi/g from a volume that barely intersects the sample hole. Since the EMWD-GRS did not have a directional window, we do not know how the Cs-137 was distributed around the sensor. However, there appears to be a thin < 61 cm thick plume containing a relatively high concentration of Cs-137, which appears to extend at FRB-06.

In Figure 16a the EMWD-GRS results show a Cs-137 concentration of 2000 pCi/g while the adjacent soil sample shows only 6.6 pCi/g. Clearly the sample from FRB-07 is outside a high concentration area as defined by the EMWD-GRS.

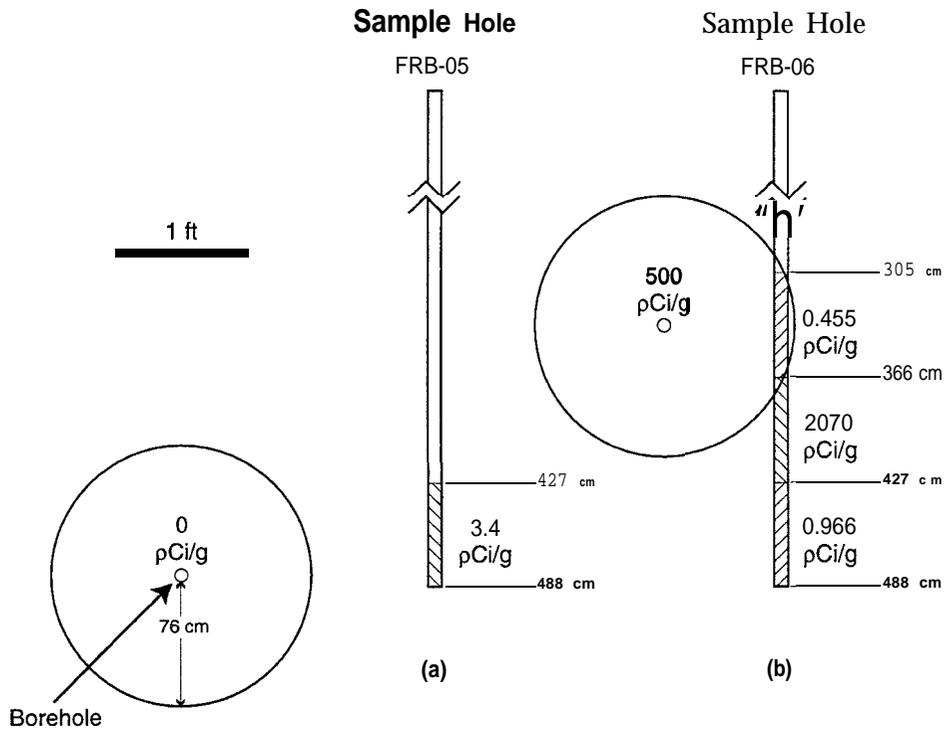


Figure 15. Vertical cross section through sample hole and the EMWD-GRS at the distance of closest approach—Borehole #1.

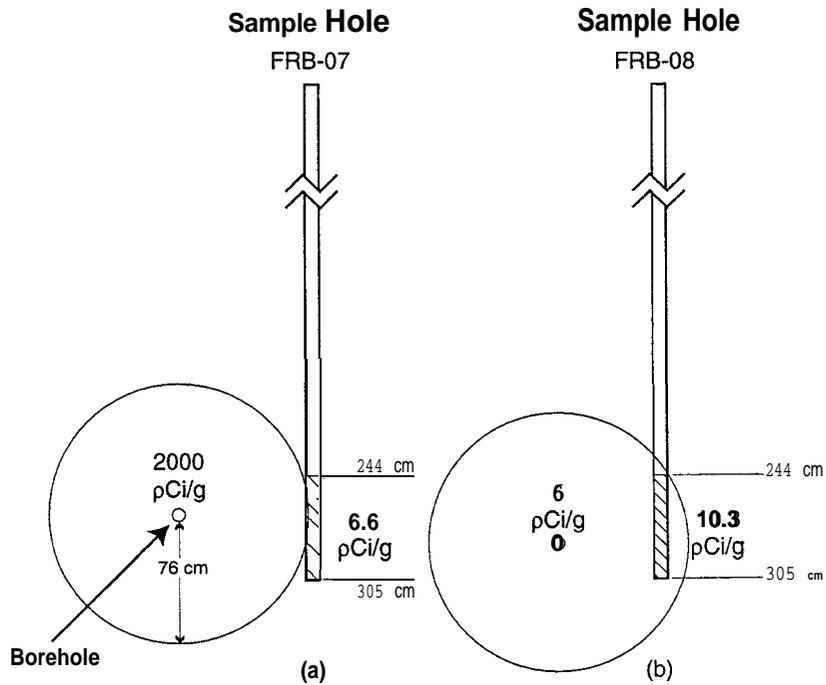


Figure 16. Vertical cross section through sample hole and the EMWD-GRS at the distance of closest approach—Borehole #2.

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Conclusions

Based on the results presented in the previous section, the demonstration of the EMWD-GRS was a complete success. Spectral data were obtained continuously while drilling. The results show general agreement between the soil sampling and EMWD-GRS techniques that Cs-137 is present. EMWD-GRS identified areas of Cs-137 concentrations not previously identified by the soil sampling process. In addition, the soil volume examined for Cs-137 by EMWD-GRS was much greater than that studied by sampling.

However, three areas were identified as needing improvement to make the system better satisfy our customers' needs. A distributed Cs-137 source is needed, within the complex, so that a direct calibration of spectrometers or other environmental radiation sensors can be made. This source could be similar to the Grand Junction standard U, Th and K distributed sources. Second, as mentioned, the direction of the Cs-137 source relative to the spectrometer would add valuable information. This requires a windowed detector, which could be added to the system. For this purpose, a simple windowed Geiger-Muller tube would suffice. Finally, the Subsite® locator was used only when a new section of pipe was added. Basically, the position and depth of the spectrometer was checked as each new rod was installed and as we approached each of the sampled locations. Thus the results were presented as a function of drill rod number. A continuous locator system that would allow us to know the location of each spectrum as it is obtained is needed. We are presently working on such a system.

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