SAND99-0461C

Aug 18-23, 1996
POSTER
SEATTLE, WA

ENVIRONMENTAL MEASUREMENT WHILE DRILLING SYSTEM FOR REAL-TIME FIELD SCREENING OF CONTAMINANTS

Cecelia V. Williams
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0719
(505) 844-5722

Grant J. Lockwood
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-1159
(505) 548-7007

Randy A. Normann
Sandia National Laboratories
P.O. Box 5800
Albuquerque, NM 87185-0986
(505) 845-9675

ABSTRACT

Sampling during environmental drilling is essential to fully characterize the spatial distribution and migration of subsurface contaminants. However, analysis of the samples is expensive and time-consuming: off-site laboratory analysis can take weeks or months. Real-time information on environmental conditions, drill bit location and temperature during drilling is valuable in many environmental restoration operations. This type of information can be used to provide field screening data and improved efficiency of site characterization activities.

The Environmental Measurement-While-Drilling (EMWD) System represents an innovative blending of new and existing technology in order to obtain real-time data during drilling. The system consists of two subsystems. The down-hole subsystem (at the drill bit) consists of sensors, a power supply, a signal conditioning and transmitter board, and a radio-frequency (RF) coaxial cable. The up-hole subsystem consists of a battery pack/coil, pickup coil, receiver, and personal computer. The system is compatible with fluid miser drill pipe, a directional drilling technique that uses minimal drilling fluids and generates little to no secondary waste.

In EMWD, downhole sensors are located behind the drill bit and linked by a high-speed data transmission system to a computer at the surface. Sandia-developed Windows™-based software is used for data display and storage. As drilling is conducted, data is collected on the nature and extent of contamination, enabling on-the-spot decisions regarding drilling and sampling strategies. Initially, the downhole sensor consisted of a simple gamma radiation detector, a Geiger-Mueller tube (GMT). The design includes data assurance techniques to increase safety by reducing the probability of giving a safe indication when an unsafe condition exists.

The EMWD system has been improved by the integration of a Gamma Ray Spectrometer (GRS) in place of the GMT. The GRS consists of a sodium iodide-thallium activated crystal coupled to a photomultiplier tube (PMT). The output of the PMT goes to a multichannel analyzer (MCA). The MCA data is transmitted to the surface via a signal conditioning and transmitter board similar to that used with the GMT.

The EMWD system is described and the results of the GRS field tests and field demonstration are presented.

I. INTRODUCTION

Sampling during environmental drilling is essential to fully characterize the spatial distribution and migration of subsurface contaminants. However, the analysis of these samples is not only expensive, but can take weeks or months when sent to an off-site laboratory. In contrast, Environmental Measurement-While-Drilling (EMWD) screening capability could save money and valuable time by quickly distinguishing between contaminated and uncontaminated areas. Real-time measurements provided by a EMWD system would enable on-the-spot decisions to be made regarding sampling strategies, enhance worker safety, and provide the added flexibility of being able to "steer" the drill bit in or out hazardous zones.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

During measurement-while-drilling, down-hole sensors are located behind the drill bit and linked by a rapid data transmission system to a computer at the surface. As drilling proceeds, data are collected on the nature and extent of the subsurface contamination in real-time. The first sensor to be integrated into the EMWD system was a Geiger-Mueller tube (GMT) gamma radiation detector. The EMWD-GMT system was field tested and the results reported [1]. The system defects discussed in this report were corrected and a second field test using the EMWD-GMT system was conducted. During this test two holes were drilled. The first was about 6 ft. deep, 120 ft. long, daylight to daylight. The second was slant bored to a vertical depth of 24 ft. through a hard shale layer. The system performed as designed and high quality data were obtained through-out the field test.

However using a GMT as the sensor, the system can only detect the presence of Gamma radiation above a predetermined lower energy limit and measure the source dose rate. To obtain identification of specific radionuclides a Gamma Ray Spectrometer (GRS) is required. The EMWD has been adaptated by the integration of a Gamma Ray Spectrometer (GRS) in place of the GMT. The integration of a GRS into the EMWD system is the topic of this paper.

II. EMWD GAMMA RAY SPECTROMETER

The EMWD-GRS system is comprised of four parts: a computer, magnetic pick-up coil and receiver, battery pack and magnetic coil, and the down-hole electronics package. The electronics package, with a Gamma Ray Spectrometer/Multichannel Analyzer and coaxial cable coil, is located inside the drill rod next to the drill bit Figure 1 shows the EMWD-GRS package layout. The cable provides both DC power and AC signal paths between the surface (Figure 2) and the down-hole electronics package (Figure 3). Figure 4 shows the instrumentation mounting locations on a typical drill rig.

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

To evaluate the performance of the EMWD-GRS at a radioactively cold site, a measurable spectrum is established using a naturally occurring radioactive material/consumer product. For this purpose, several Thor-Tung electrodes (2% thorium by weight), manufactured by Airco, are attached around the GRS. The spectrum is verified to validate system operation at each step of the system assembly and during system operation.

In addition to the GRS signal, the system monitors the +12 V and -12 V required at the down-hole signal conditioning and transmitter board, the up-hole battery voltage as measured down-hole, and a temperature associated with the detector assembly. A temperature measurement was not made at the drill bit during the test, although the system is fully capable of providing this information. In the future, this type of measurement will be an important parameter since temperature influences the drilling process. By measuring and displaying drill bit temperature in real-time, the operator will be able to mitigate the effect of heating and high temperatures encountered during drilling.

The electronics package, located near the drill bit (Figure 6), is easily adaptable to different sensors or data formats. Adaptability is gained through the use of an Actel 1020B programmable logic array. This small surface mount IC contains some 2000 logic gates. The Actel 1020B controls the data stream format, logic clock, and circuit interfaces. The Actel 1020B is programmed to provide the serial bit stream as bi-phase and NRZ digital. These two formats cover a wide range of communications systems including fiber optic, hardwire, and RF.

The field-tested system has a bit rate of 2400 bps, however, the bit rate can be easily increased. A practical limit to this FM system is ~ 30K bps. If the signal coupling at the surface continues to be strong and noise-immune, the Actel bi-phase output could drive the coaxial system directly. The bi-phase data rate could exceed 100K bps. Data rates that high are approaching imaged data requirements.

Another important attribute of adaptability is to provide different supply voltages for different sensors. Only battery power (30 V) is supplied on the coaxial cable. Once received, this voltage is converted to four different voltages, +12 V, -12 V, +5 V, and -5 V. A DC-to-DC converter generates these different voltages. The DC-to-DC converter increases battery life by reducing current drain from the batteries and allowing the battery voltage to range from 18-32 V without affecting sensor electronics. A second DC-to-DC converter generates the 900 V GMT bias voltage. The current requirements for the down-hole electronics is only 32 ma at 30 V.

The EMWD system uses the coaxial cable for both DC power and signal. This method of transmission limits cable length. Given the resistance of the small diameter (RG-178) coaxial cable (26 Ω/100 feet (30.48 m)) and the down-hole electronics power requirement, the present system can operate with coil lengths up to 700 feet (213.35 m). At these distances, operating time is reduced. To improve distance and/or to provide additional features requiring increased down-hole power requirements, the system can be converted to use the drill rod for DC power return. The resistance of such a system would be approximately 3 Ω/100 feet (30.48 m). The operating current capacity could then be increased to 150 ma to meet increased down-hole power requirements. Signal quality would not be harmed because the signal would continue to be transmitted in differential mode isolated from the drill rod.

A. Method of Data Transmission

Data transmission is digital FM in a bi-phase format. Digital FM is presently state-of-the-art for electrical data transmission, providing very high signal-to-noise ratios. Bi-phase is a technical term used in the telemetry industry that simply means each digital datum is a transition, not a level. In most digital systems, a "one" logic bit is sent as a 5 V level and a "zero" logic bit is a 0 V level. In our system, a "one" logic bit is transmitted by a transition from 5 V to 0 V and the "zero" logic bit is transmitted by a transition from 0 V to 5 V. This creates a serial bit stream that is proactive.

Self-clocking data benefits bi-phase data transmission. In simple digital data transmission, a series of zero logic bits creates a static condition where no signal is received. If the data series is very long, then the receiver can confuse a period of 12 zeros with 11 zeros or 13 zeros. In the worse case, a transmission system can fail and the receiver believes the data stream is all zero logic levels. By clocking the data in a bi-phase form, the proper operation of the timing circuits is validated. A possible failure mode for any system making a rate measurement verses time can be caused by the crystal-based timer oscillating at a harmonic. For example, a 5 MHz timing clock can run at 10 MHz. Because time is relative, a system running at twice the expected clock speed means the gamma rate calculation is halved. This fault could prevent the operator from seeing a dangerous condition. To detect clock error, the bi-phase data is tied to the clock such that any error in the timing clock is measured in the data transition rate at the surface. This validates proper operation of the instrumentation clock at all times.

B. Bit Stream Format

For these tests, a simple bit stream comprised of all the basic elements was used. The bit stream had an eight-bit gamma counter, a data frame counter, and a sync-word (sixteen unique bits repeated for each frame of data). The computer receives the bit stream and qualifies the incoming data for data rate, proper number of bits, and the correct sync-word. If any of these elements are incorrect, the data sync indicator changes from green to red and the data display halts. The minimum word size is sixteen bits where the upper four bits are dedicated to word count (data position in the bit stream) and parody. Naturally, the number of data channels (i.e. gamma count) is unlimited for any practical purpose.

C. Data Transmission Surety

In areas where human safety is a major consideration, reliability and high data surety are requirements. basic format used in the EMWD system is also used in the weapons complex for very high data surety where destructive testing may cost hundreds of millions of dollars and getting "one shot" reliable data is imperative. In measuring gamma counts while drilling, the overall safety concern is that a system error could cause the gamma reading to be low yielding a safe reading when an unsafe condition actually exists. The probability of the data transmission system creating this fault undetected is < 0.002.

D. Cable Deployment System

The cable from the down-hole instrument package is pulled through each piece of drill pipe and the drill head to the battery pack/coil mounted on a spindle at the rear of the drill head. Because the cable connector must pass through the drill pipe, which is restricted to about 5/16" (7.9 mm) at each pipe section pin, a 0.25" (6.35 mm) 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 300 psi (1.435 kPa) to 500 psi (2.392 kPa), but can go to as high as 1500 psi (7.177 kPa). A cord grip fitting is used to seal against the 0.07" (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 600 psi (2.871 kPa) air, which is approximately 3000 psi (14.354 kPa) water, without leaking. The coaxial cable is pulled through each section of drill pipe using a 16 foot (4.88 m) long, " (6.35 mm) diameter rod fashioned from two pieces of aluminum rod threaded together. A tip consisting of steel wire bent backward to act as a flexible guide as the rod is inserted through the drill head and pipe from the spindle to the instrument housing. This guide tip is replaced with a tip containing the mating 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 total system performance.

III. DATA AND RESULTS

The preliminary tests of the EMWD Gamma Ray System (EMWD-GRS) field tests were conducted at Sandia National Laboratories and at the Grants, New Mexico radioactive calibration facility. The Sandia test included all parts of the measurement system short of a real drilling operation including a prototype gamma ray counter, FM transmitter, and FM receiver. Results showed that the detector, as designed, will work in the presence of and extended radioactive source. The energy calibration of the channel numbers was performed in the laboratory, using known radioactive elements. The results of these calibrations are shown in Figures 7. The energy peaks and corresponding channel numbers are shown in Table 1. The tests at the Grants facility involved calibration of the EMWD-GRS with extended radioactive sources including K-40, Ra-226, and Th-232.

Table 1. Calibration Results

Radioactive Element	Peak Energy (MeV)	PeakChannel Number
Cs-137	0.662	100
Co-60	1.173, 1.332	173, 197
Mn-54	0.835	122
Na-22	0.511, 1.275	78, 187

The EMWD-GRS was tested at a directional boring test site owned by Charles Machine Works (CMW) in Perry, OK. Measurements were made with the GRS in a drill housing located behind the drill bit of a JT2320 during the drilling process.

Initial testing of the GRDS protype called for two daylight to daylight 150 ft. (45m) bores. During the first bore the gamma detector bias voltage was shorted, stopping data collection. This problem has been corrected and the system was tested successfully additional at the CMW facility. This bore was approximately 120 ft (36m) to a depth of 17 ft (5 m). The spectral data taken while drilling was in progress is shown in Figure 8. The EMWD-GRS system take approximately 30 seconds to take a full spectrum. Figure 9 shows the actual data display. Both show counts versus channel numbers.

IV. CONCLUSIONS AND FUTURE WORK

The integration of a spectral gamma measurement into the EMWD system has been successfully demonstrated. Both the EMWD-GMT and the EMWD-GRS are operational. The EMWD-GRS system is capable of taking two spectra a minute while drilling.

The EMWD-GRS will be demonstrated at the Savannah River Site (SRS) F-Area Retention Basin in Aiken, South Carolina. The basin was in active use from 1955 until 1972. This basin was constructed as an unlined, temporary container for potentially contaminated cooling water associated with the chemical separations process and storm sewer drainage from the F-Area Tank Farm. Contamination of this basin came from contaminated cooling water as well as various spills or overflows at the basin (WSRC, 1995/ESH-EMS-950563). In 1978 the F-Area

Retention Basin was excavated, backfilled with soil, and covered with grass The site was evaluated through soil sampling in early 1979. The major radionuclides present included Strontium (Sr)-89/90 and Cesium (Cs)-137. Sampling results indicated maximum Cs-137 concentrations of 1,410 pCi/g in the berm and 430 pCi/g in the basin floor. Maximum Sr-89/90 concentrations in the basin berm were 1,000 pCi/g (WSRC, 1994/WSRC-RP-94-498, Rev 1).

The demonstration of the EMWD system demonstration at the F-Area Retention Basin will consist of monitoring environmental conditions in real-time while drilling two boreholes daylight-to-daylight. These holes will pass through four sample locations (FRB-05, 06, 07, and 08) and adjacent to sample location FRB-19, where values of contaminant levels are known. Contaminant levels continuously recorded by the EMWD Gamma Ray Detection 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. The results of this demonstration will be presented at the meeting.

ACKNOWLEDGMENTS

This work is funded by the United States Department of Energy, Office of Science and Technology Development through the Plume Focus Area, Heavy Metals and Radionuclides Product Line under Contract DE-AC04-94AL85000.

REFERENCES

1. Lockwood, R.A. Normann, L.B. Bishop, R.J. Floran, C.V. Williams, Conference papers of the North American Society for Trenchless Technology, NO-DIG'95 (Tronto, Canada, 1995) p. 2A-2:1

2. J. Lockwood, R. A. Normann, L. B. Bishop, M. M. Selph, and C. V. Williams. *Environmental Measurement-While-Drilling System for Real-time Field Screening of Contaminants*, American Defense Preparedness Association 22nd Environmental Symposium & Exhibition, Orlando, March 1996.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

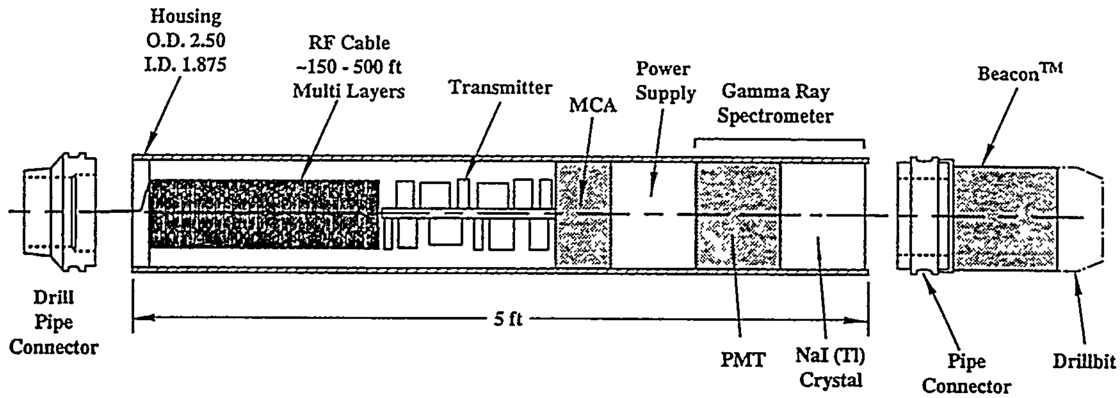

Figure 1. EMWD-GRS downhole package layout.

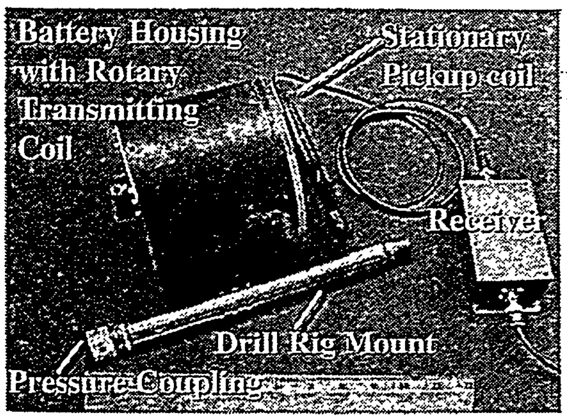

Figure 2. EMWD-GRS surface components.

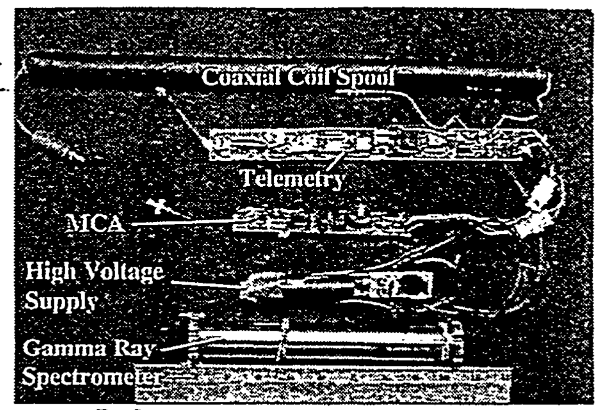

Figure 3. EMWD-GRS downhole components (unpotted).

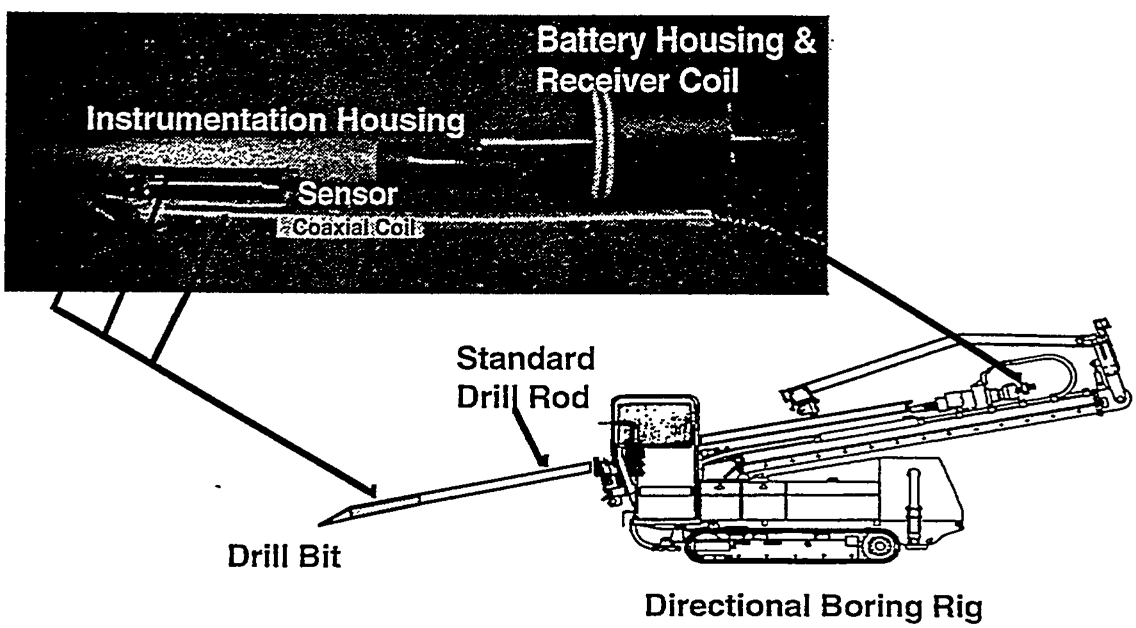

Figure 4. EMWD component placement.

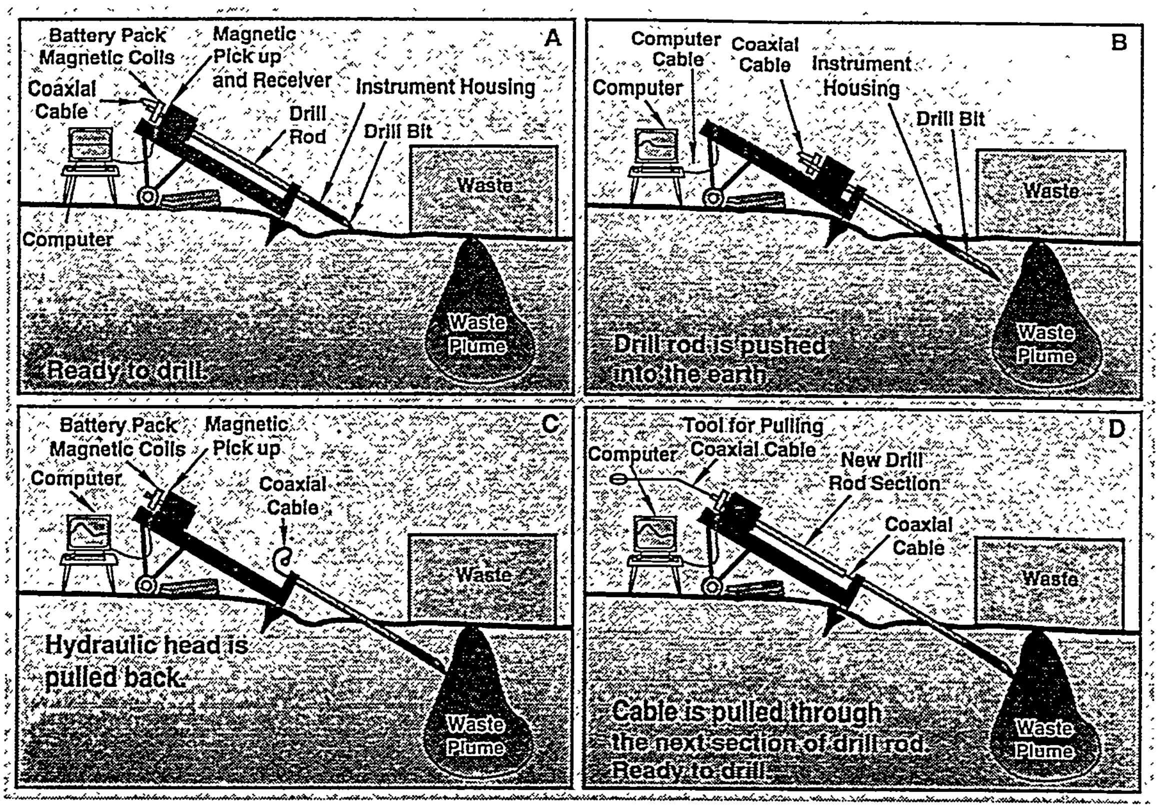

Figure 5. EMWD Process.

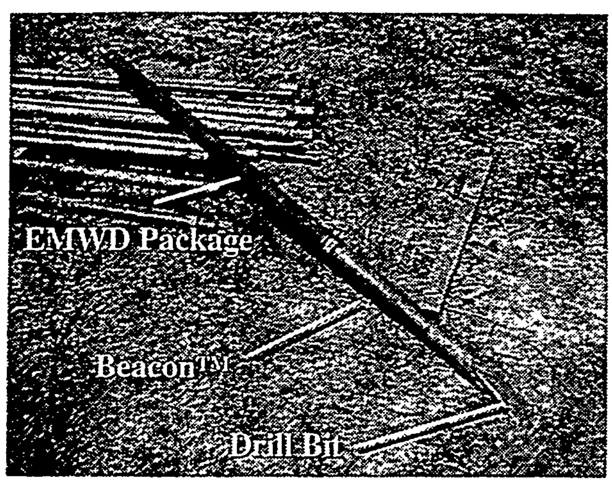

Figure 6. EMWD downhole package mounted behind Beacon™ and drill bit.

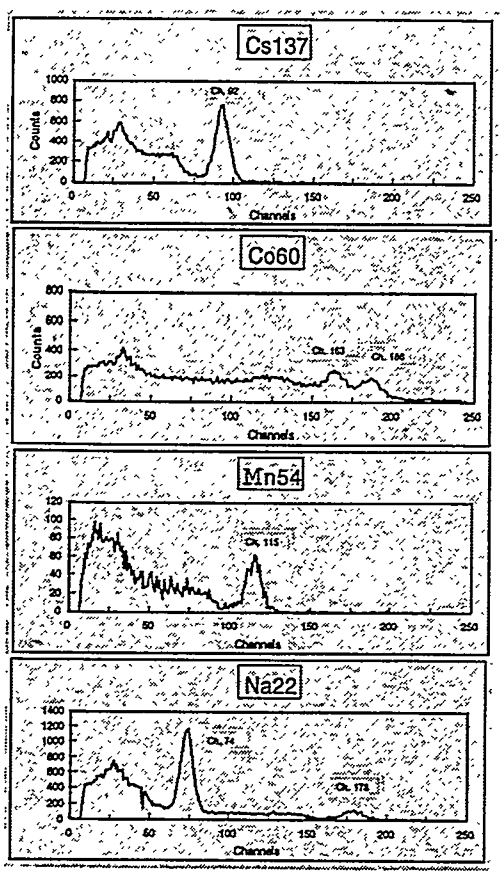

Figure 7. EMWD-GRS: spectrometer calibration.

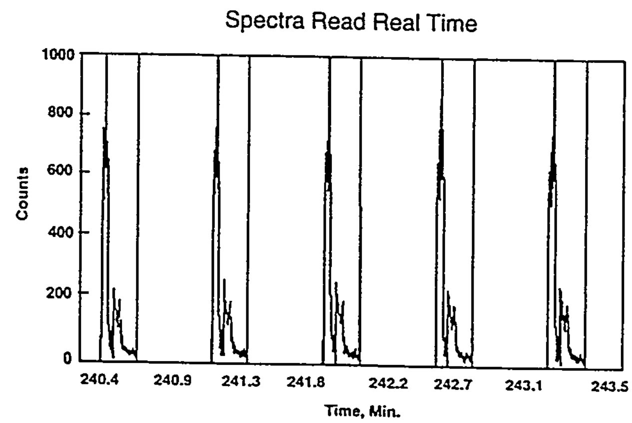

Figure 8. EMWD-GRS: field data, spectra read real time.

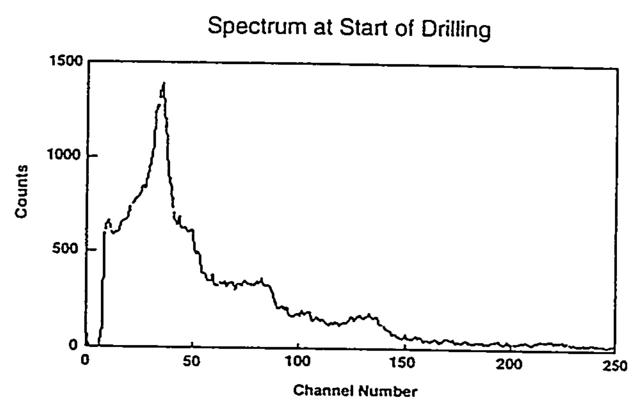

Figure 9. EMWD-GRS: actual data display, spectrum recorded at start of drilling.