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Environmental Measurement-While-Drilling System for Real-Time Field Screening of Contaminants

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Abstract

A prototype Measurement-While-Drilling (MWD) system has been developed and successfully field tested. 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 MWD system is described and the results of the field test presented.

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I. Introduction

Sampling during environmental drilling is essential to fully characterize the spatial distribution and migration of near surface 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, measurement-while-drilling (MWD) screening capability could save money and valuable time by quickly distinguishing between contaminated and uncontaminated areas. Real-time measurements provided by a MWD 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.

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 down-hole sensor is a Geiger-Mueller tube (GMT) gamma radiation detector. In addition to the GMT signal, the MWD system monitors these required down-hole voltages and two temperatures associated with the detector assembly.

The Gamma Ray Detection System (GRDS) and electronics package are discussed in Section II. The results of the field test are presented in Section III. Finally, our conclusions and discussion of future work are presented in Section IV.

II. Equipment and Procedures

The MWD 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, complete with a Geiger-Mueller tube (GMT) sensor and coaxial cable coil, is located inside the drill rod next to the drill bit. The cable provides both DC power and AC signal paths between the surface and the down-hole electronics package. Figure 1 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 2 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.

MWD Gamma Ray Detection System

To evaluate the performance of the GRDS at a radioactively cold site, a measurable signal 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 GMT. With this arrangement, a system signal of approximately 15 counts per second is generated. The count rate is verified to validate system operation at each step of the system assembly and during system operation.

In addition to the GMT 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 two temperatures associated with the detector assembly. The temperature of the board is measured at its midpoint and is labeled "Internal Temperature." The temperature of the aluminum can containing the power supply is measured and is labeled "External Temperature." The external temperature measurement did not record temperature 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, 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. However, 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 @ 30 V.

The MWD 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 ft) and the down-hole electronics power requirement, the present system can operate with coil lengths up to 700 feet. 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 ft. 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.

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.

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.

Data Transmission Surety

In areas where human safety is a major consideration, reliability and high data surety are requirements. The basic format used in the MWD 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.

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" at each pipe section pin, a 0.25" (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 to 500 psi but can go to as high as 1500 psi. A cord grip fitting is used to seal against the 0.07" (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 air (~ 3000 psi water) without leaking. The coaxial cable is pulled through each section of drill pipe using a 16 foot long, ¼" 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 Gamma Ray Detection System (GRDS) was tested at a directional boring test site owned by Charles Machine Works (CMW) in Perry, OK. Measurements were made with the GRDS in a drill housing located behind the drill bit of a 4/40A Jet Trac® during the drilling process. The 4/40A Jet Trac® is manufactured and sold by CMW.

The test plan called for drilling a daylight-to-daylight hole 150 feet in length. However, due to problems with the rod used to pull the cable through the drill pipe and head, the test was terminated after 60 feet. These problems will be discussed later in this section.

The data from the GRDS was collected, processed, and displayed by a computer in real-time. The computer was housed and powered by an instrument van supplied by CMW. Data print-out consisted of plots of gamma counts per second versus time in seconds. For these plots, the average gamma counts for three seconds are used rather than the raw data. A second print-out displays the support data consisting of the three voltages and two temperatures versus time in seconds. For these plots the raw data was used.

Figures 3 and 4 show the gamma count rate data and support data, respectively. The gamma count rate (Figure 3) is plotted as a three second moving average, with readings taken 18.75 times/second. Note that the count rate varies between ~ 12 and 19 counts/second. These variations in count rate are normal for radioactive emissions. A long-term average results in readings of approximately 15 counts/second. The support data shown in Figure 4 indicate the voltages are nominal and the external temperature of 27°C and internal temperature of 25°C are consistent with the laboratory environment.

Figures 5 and 6 show similar results to those displayed in Figures 3 and 4 with the instrument housing mounted to the beacon housing and drill bit prior to start of drilling. In this case the package had been in sunlight for some time. The measured external and internal temperatures were 35°C and 32°C, respectively. The gamma count rate is the same as seen in Figure 3. Typically the gamma count rate has a dropout reading at the beginning and/or end of a data set due to the method of averaging used.

Figures 7 and 8 show the data obtained when pipe sections two through five were used in drilling. The computer was allowed to run during the entire time it took to drill this forty feet. The three spaces between the four data records represent the time required to install a new pipe section, pull the cable through, and start drilling and data recording. From the record, this "down time" averaged just under six minutes. Considering this was the first time this function was performed, we feel this is a good result. Also seen in Figures 7 and 8 are several dropout readings. In all we had 70 dropouts in 22,000 readings. The low number of dropouts and the random nature of dropouts rule out interference from the beacon. Since the dropouts appear on all records, they are associated with data transmission and not the GMT.

One possible cause of the data dropouts was a poor connection at the battery pack. The connector can become contaminated when being pulled through the pipe sections. As the drill rod was rotated, the coaxial cable exerted a torsional force on the connector. A simple fix to this problem may be to support the coaxial cable by connecting it to the battery pack and using a cable puller that provides additional protection to the connector

The temperature records shown in Figure 8 indicate a cooling of the system with water cooling and depth of penetration from the sun-heated temperature at the start. Table 1 shows the count rate before, during, and after drilling. The count rates indicate the system was fully functional during drilling.

Table 1: GRDS count rates

Configuration	Count Rate
Before Drilling	14.55 counts/sec
During Drilling	14.56 counts/sec
After Drilling	14.61 counts/sec

The failure of the cable deployment system that necessitated termination after 60 feet of drilling was caused by a change in drill pipe. The rod was sized and material chosen to pull the cable through a hollow drill pipe. The new drill pipe in use by most of the industry is called Fluid Miser. Its main difference from the older version is a ¼" (ID) hose that runs the full length of the pipe. Only the hose carries drilling fluid and the volume is minimized, thus the name Fluid Miser. Since this pipe is now the standard, we chose to use it during the drilling test. The presence of the hose required a large increase in the force necessary to insert the rod and pull the cable through. The additional force resulted in failures at the thread joint where the two rod sections were joined and the attachment of the mating Lemo connector to the tip. However, failure did not occur until well into the test, thus allowing for adequate evaluation of the entire system.

IV. Conclusions and Future Work

Although the test hole was not completed, we feel the test of the GRDS was a success. A new pull rod has been designed and a section of Fluid Miser has been obtained. The new pull rod will be tested using Fluid Miser pipe to ensure long term functionality. The many data dropouts appear to be a problem at the connector interface with the battery pack/coil. A support system is planned that should correct this problem. Since this problem is not fatal to the test, it will be checked during the next test.

Additional real-time sensors are being investigated for integration into this system to improve its versatility as an environmental measurement-while-drilling tool. These include a gamma-ray spectrometer, a volatile organic compound detector, and a drill bit location system.

Future Work

The unique capability of real-time, high-speed data transmission up-hole during drilling gives this measurement-while-drilling system high commercial potential. Its low cost and generic design, offering maximum flexibility to integrate additional sensors, make it an attractive platform for a variety of down-hole sensors. A market analysis is underway to determine its potential of use in the environmental, oil, and utility industry. We are in the process of soliciting potential partners for adapting the system to accept other sensor types and multiple sensor systems. Additionally, we hope to modify the system to interface with other drilling systems.

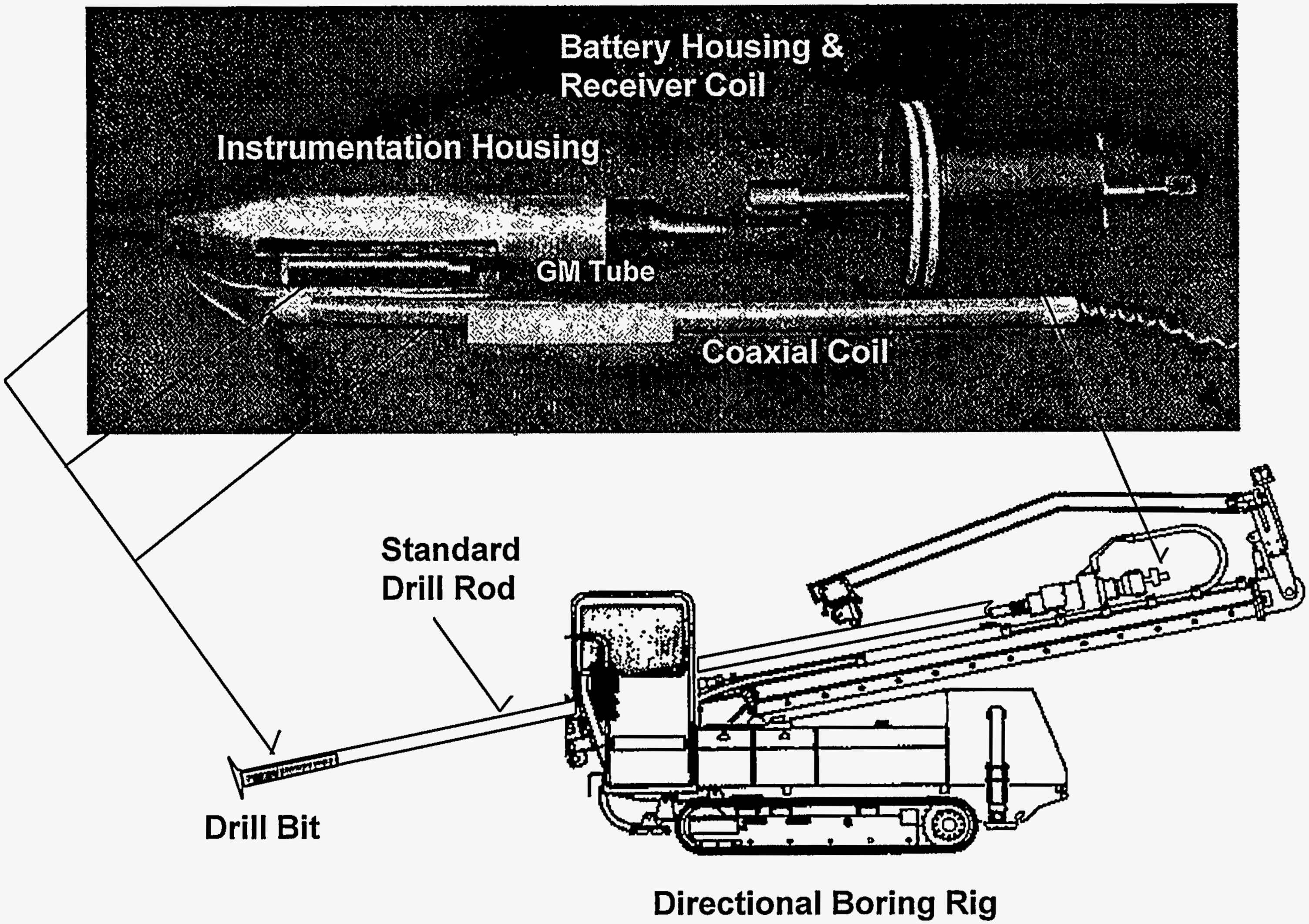

Figure 1. MWD Component Placement

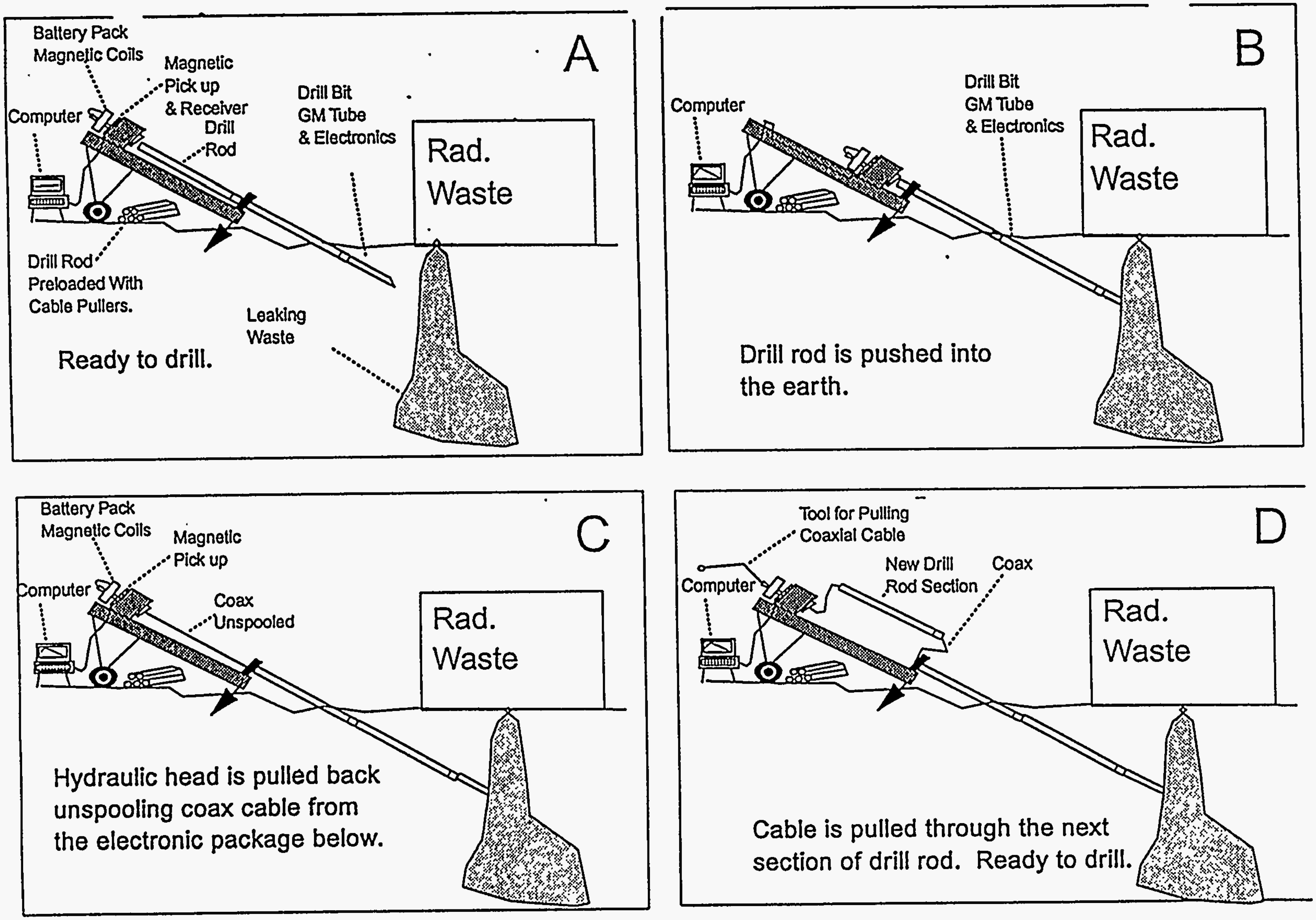

Figure 2. The MWD process using a coaxial spool.

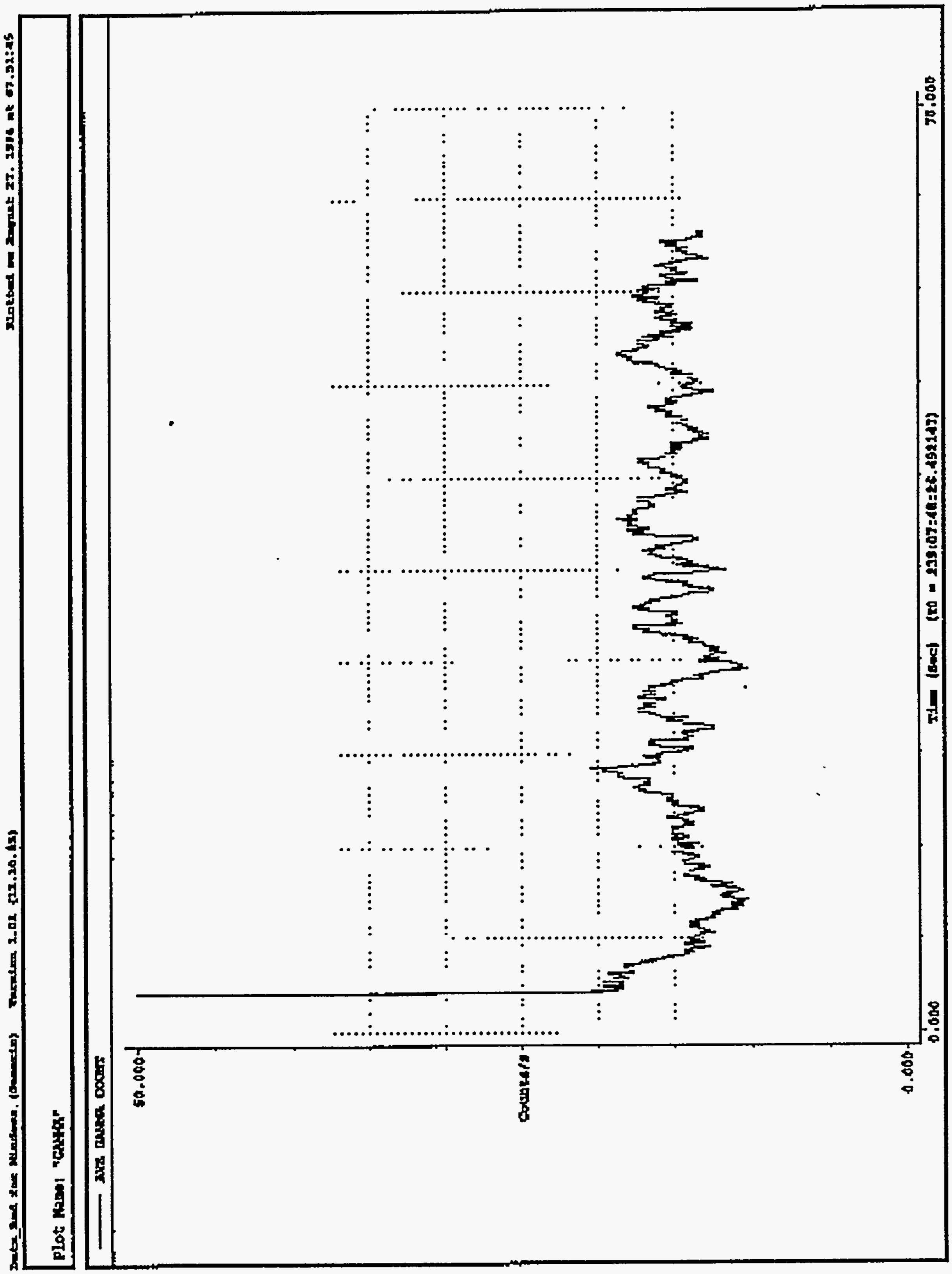

FIGURE 3: GRDS data recorded prior to shipment

FIGURE 4: Diagnostics data recorded prior to shipment

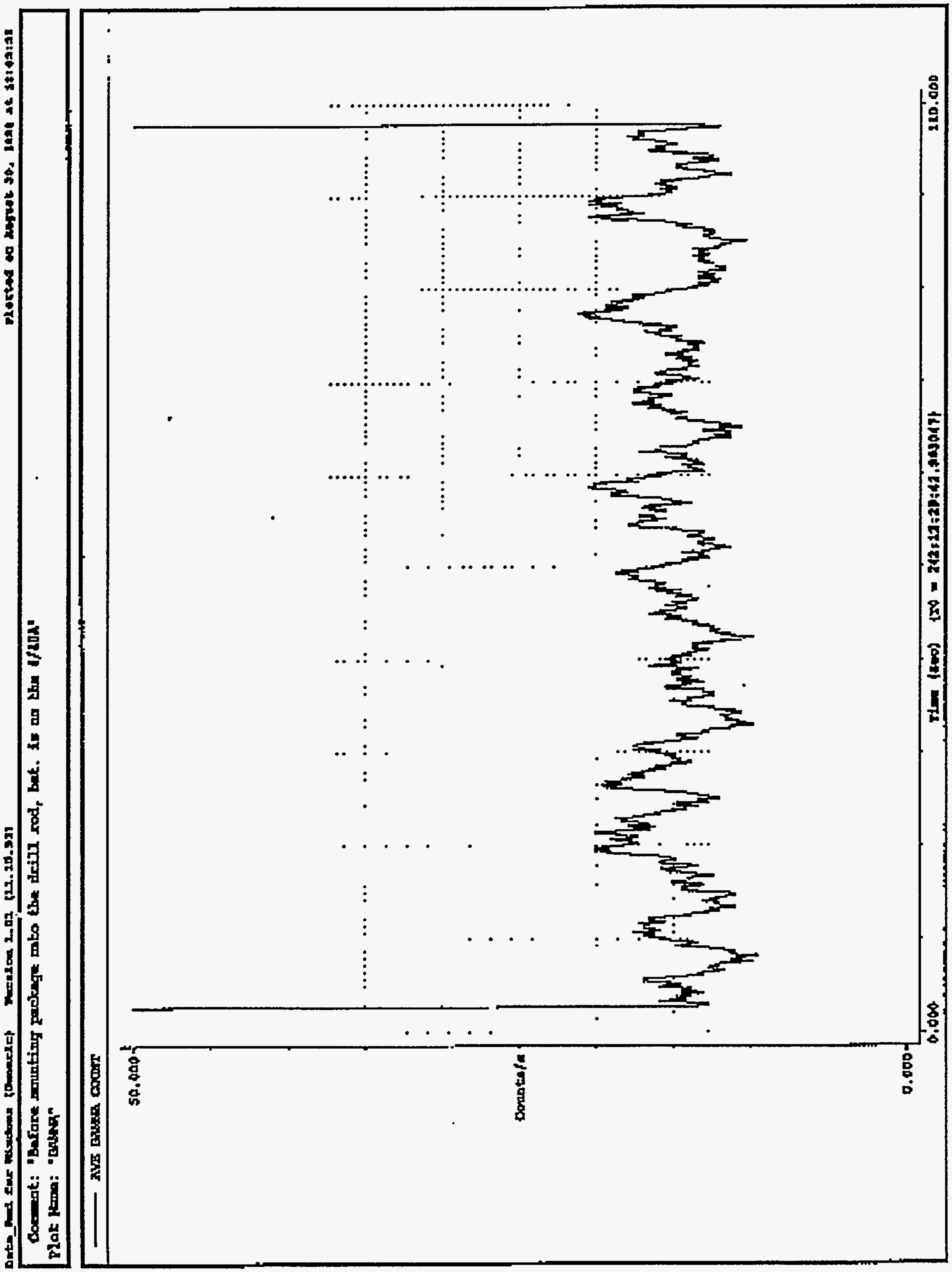

Figure 5: GRDS data recorded prior to start of drilling

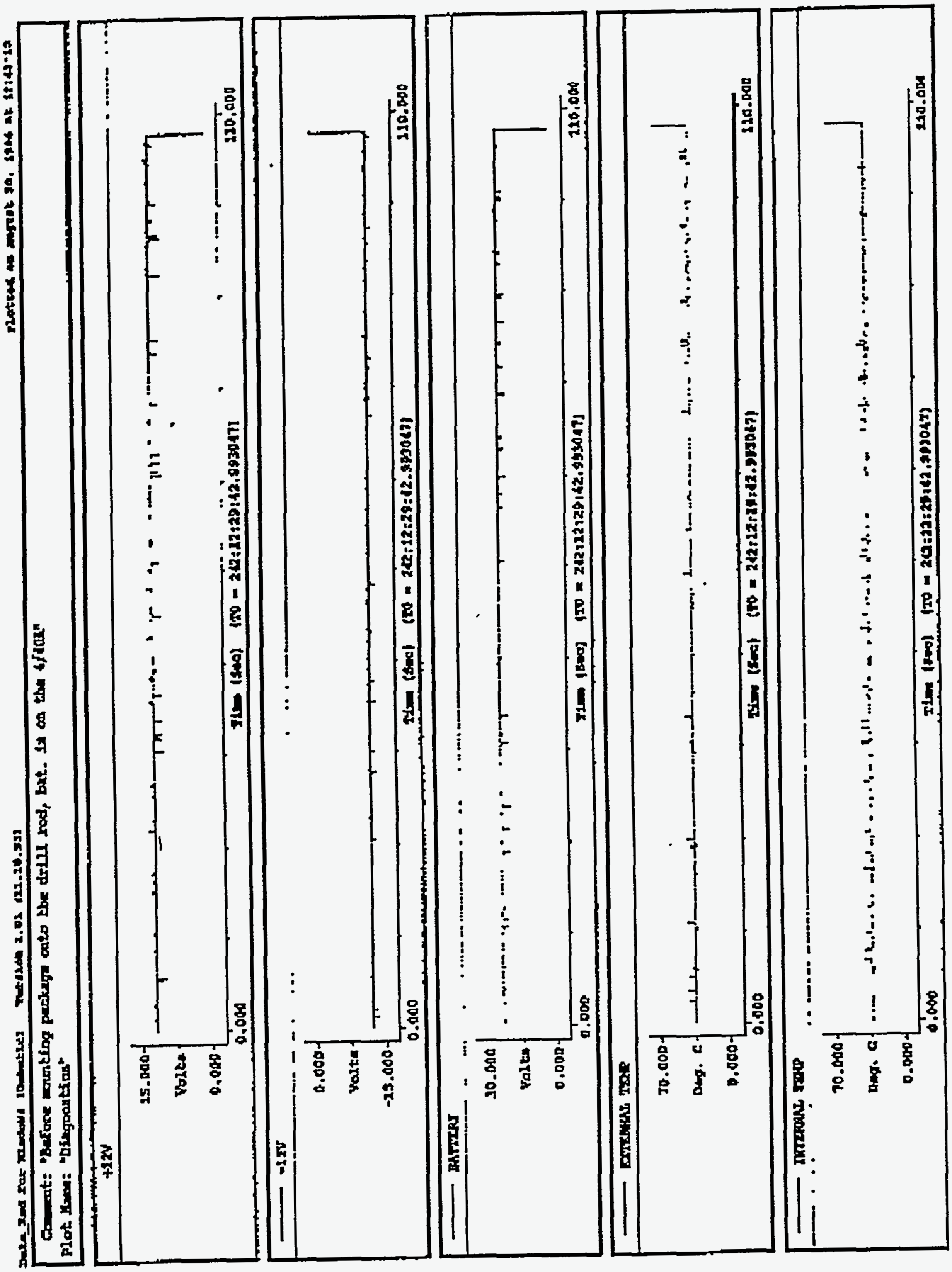

FIGURE 6: Diagnostics data recorded just prior to drilling

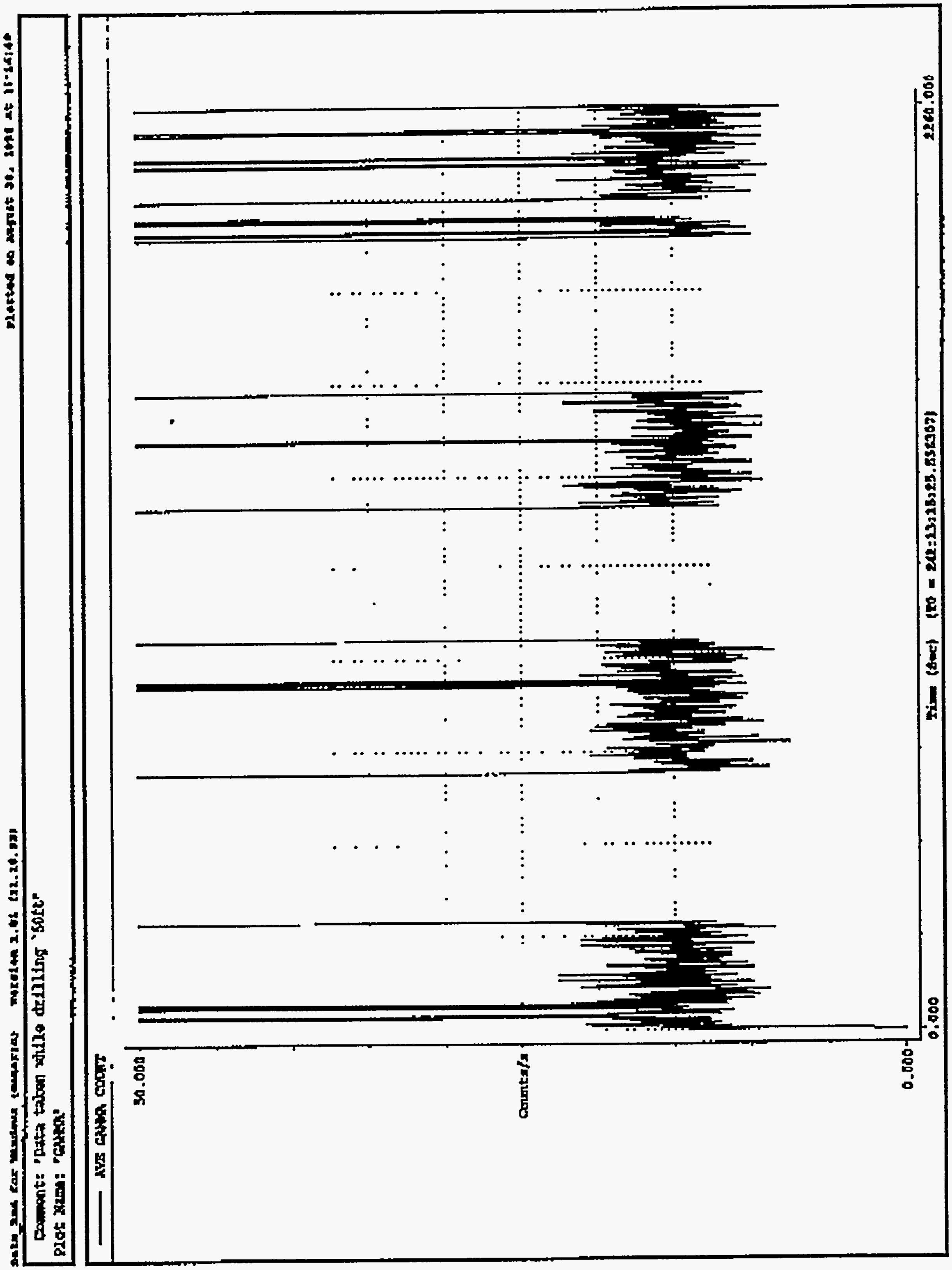

FIGURE 7: GRDS data recorded during drilling operation

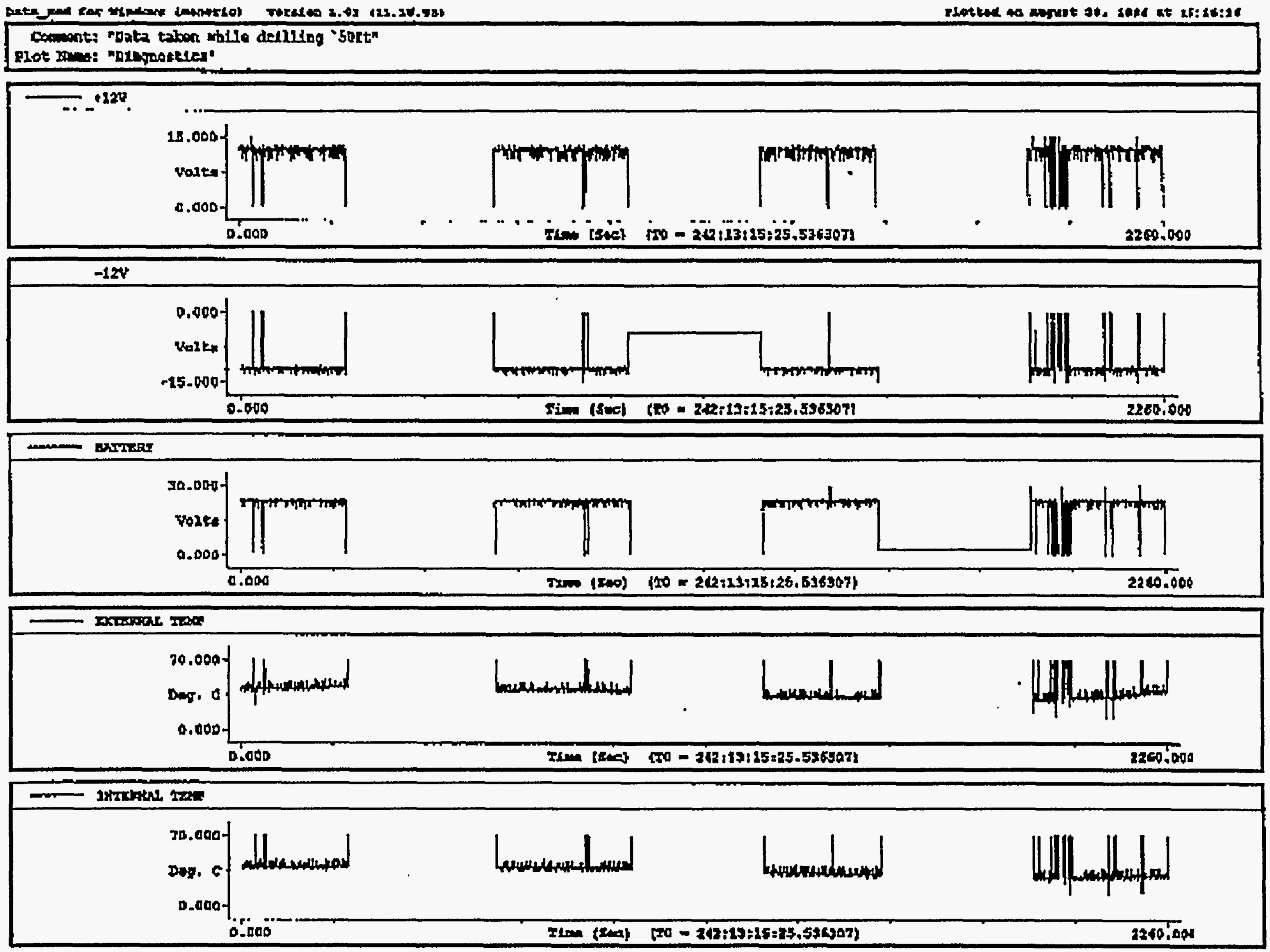

FIGURE 8: Diagnostics data recorded during drill operation