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Advanced Mud Logging Based Spectral Gamma Ray Evaluation

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Abstract

Real-time information on subsurface characteristics is crucial in oil and gas drilling activities to reduce risks and improve operational efficiency. One widely used method is logging, including the Spectral Gamma Ray (SGR) technique, which functions to identify formation types and natural radioactive content. The integration of SGR in Mud Logging allows for more accurate formation monitoring during drilling. The development of Advanced Mud Logging (AML) further strengthens this capability through Cutting analysis, thus producing more comprehensive Petrophysical Information Logs (PILs) as a basis for well evaluation. This study analyzes the application of SGR technology in the AML system in drilling Well C in Field W, with a focus on improving the accuracy and efficiency of subsurface formation characterization. Research data were obtained from gamma radiation measurements on Cutting and further analysis using X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD). Primary data comes from field measurements and laboratory analysis, while secondary data is obtained from related literature. The results show that SGR is able to provide real-time formation mapping with higher accuracy than conventional methods, while reducing ambiguity in lithology and stratigraphy interpretation. Comparison with Measurement While Drilling (MWD) data demonstrated a high degree of agreement, supporting the validity of this technology. Overall, this research contributes to the development of more efficient, responsive, and accurate drilling monitoring systems.

Keywords: *Spectral Gamma Ray, Advanced Mud Logging, Formation Characterization*

INTRODUCTION

The integration of Spectral Gamma Ray (SGR) in Mud Logging provides real-time information on formation conditions during drilling, improving accuracy, efficiency, and operational safety. SGR utilizes natural radiation from U, Th, and K to specifically identify isotopes and provides higher lithological resolution than conventional gamma rays. Through Advanced Mud Logging (AML) and Cutting analysis, more comprehensive Petrophysical Information Logs (PILs) are generated for well evaluation.

This research develops an application of gamma spectroscopy that can be used directly in the field to monitor mineralogy, porosity, and other petrophysical properties. The use of SGR in cutting reduces ambiguity in formation evaluation and improves the accuracy of depth and formation character correlations, thus supporting faster and more accurate operational decision-making.

Research on Spectral Gamma Ray (SGR) is increasingly developing due to its ability to separate radioactive contributions from the elements potassium (K), uranium (U), and thorium (Th), so that lithological interpretation can be carried out more precisely than conventional gamma rays. Several researchers, such as Dyman et al. (2017), have demonstrated that SGR can provide more accurate lithological mapping in complex formation environments.

The study highlighted that the K/U and K/Th ratios can be used to differentiate organic shale, clay-rich shale, and clay-contaminated carbonate formations. This finding strengthens the function of SGR as a rapid geochemical indicator in stratigraphic interpretation. Furthermore, a study by Reeves & Carroll (2020) confirmed that SGR can reduce lithological ambiguity in the clay-sand transition zone, which often hinders total gamma-ray analysis. The integration of SGR with cutting data demonstrated a high correlation with core analysis results, thereby increasing the reliability of interpretation.

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METHODOLOGY

This research focuses on the application of Spectral Gamma Ray (SGR) technology in the Advanced Mud Logging (AML) system in well drilling. The main research object is the use of SGR to analyze gamma radiation emitted by natural radioactive elements such as Potassium (K), Uranium (U), and Thorium (Th) in geological formations, as well as its impact on improving the accuracy and efficiency of subsurface layer mapping.

This research will be carried out in several main stages, which include Literature Study, namely studying references related to the use of Spectral Gamma Ray in well drilling and Advanced Mud Logging (AML) applications in the oil and gas drilling industry and Field Data Collection, namely taking Cutting samples from well X in Field Y which are then analyzed using X-ray fluorescence (XRF) and X-Ray Diffraction (XRD). The data collected includes rock cutting samples (Cutting) and the results of gamma radiation measurements using X-ray fluorescence (XRF) and X-Ray Diffraction (XRD) instruments.

Data analysis was conducted by comparing the Spectral Gamma Ray (SGR) results obtained through the Advanced Mud Logging (AML) system with data from other methods such as Gamma Ray Wireline Logging, X-Ray Fluorescence (XRF), and Measurement While Drilling (MWD) to assess the level of accuracy and efficiency of formation monitoring. All data obtained were then validated and verified through direct comparison with the results of these alternative measurements to ensure consistency of values, minimize interpretation deviations, and test the level of accuracy of the AML system in characterizing subsurface formations.

The research flow diagram is shown in Figure 1 below:

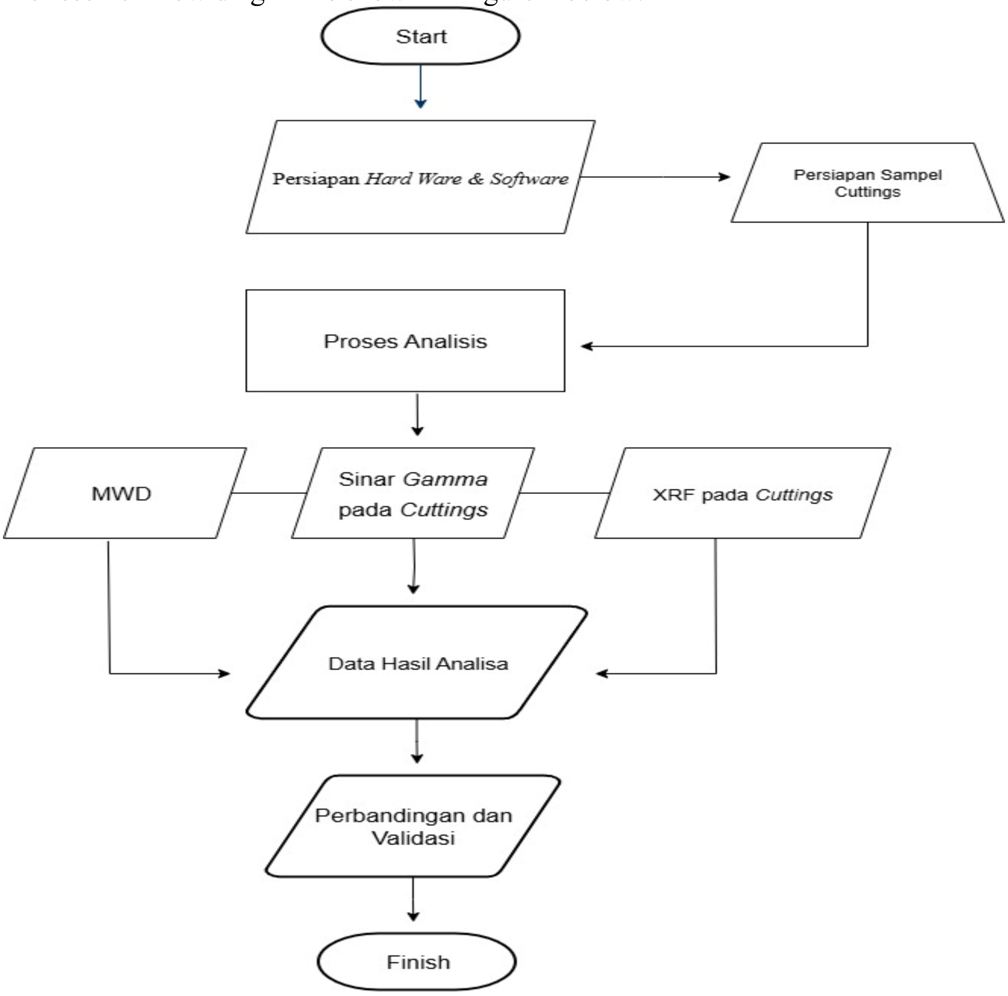

Figure 1. Research Flowchart

RESULTS AND DISCUSSION

Spectral Gamma Ray Measurements on Cuttings in Advanced Mud Logging

A gamma radiation detection system consists of three main components: a lead shield, a scintillation detector, and a photomultiplier tube (PMT). The lead shield blocks external radiation to ensure measurements are made solely from the sample. The scintillation detector converts gamma radiation into a flash of light, and the PMT converts this flash into an electrical signal and amplifies it for accurate analysis, even at low radiation levels. These three components work together to achieve precise radiation detection. The entire system is controlled by integrated software that manages instrument operation, automatically performs data acquisition, and provides data interpretation features to analyze measurement results according to research or application needs.

Hardware Preparation

The gamma scintillation detector uses a 76 × 76 mm NaI(Tl) crystal that produces a flash of light when exposed to radiation, which is then converted into an electrical signal by a PMT connected via optical coupling and sealed in a light-tight chamber to maintain stability. The system is compact, integrated with a preamplifier, high voltage, and digital processing directly connected to the MCA via USB, making it practical for field use. To minimize background radiation, the detector is protected by a 25–75 mm thick modular lead castle weighing ±270 kg, which can be quickly assembled. Cutting samples are housed in an airtight polypropylene container with a capacity of 0.25 dm^3 and can be reused without risk of contamination. With a compact, sensitive, protected, and efficient design, this system is able to provide fast, accurate, and cost-effective gamma ray measurements for geological analysis in the field.

Software Preparation

The Multichannel Analyzer (MCA) software controls the radiation detection hardware by performing data acquisition, parameter settings such as amplifier gain, shaping time, high voltage, and energy calibration, while displaying the 0–3 MeV spectrum in real-time and saving it in ASCII format for further analysis.

The spectrum data is then processed using G-rays software which has activity calibration, data interpretation, and result recording modules. With its built-in correction algorithm, G-rays is able to correct energy shifts, reduce background radiation, detect automatic peaks, calculate baselines, and determine Limits of Detection (LOD), so that the concentration of radioactive elements such as K, U, Th and Gamma Ray (GR) values in API units can be calculated accurately as a basis for geological analysis and mineral exploration.

Cuttings samples were taken directly from the shale shaker, cleaned of mud, and approximately 500 grams of 0.63 μm–3 mm material was placed in a 0.25-liter container with no voids ready for analysis. Prior to measurement, background radiation was recorded for 15 minutes using an empty container, performed once per day to ensure consistency of results.

Each sample was then measured for 15 minutes, with data automatically recorded by the MCA software, background-corrected, smoothed, and processed using basic algorithms to improve spectral quality. The system also automatically corrects for energy shifts up to ±100 keV, with manual calibration only required when shifts exceed this limit, which has never occurred to date. This procedure allows for efficient, stable, and accurate analysis of up to four samples per hour during drilling operations.

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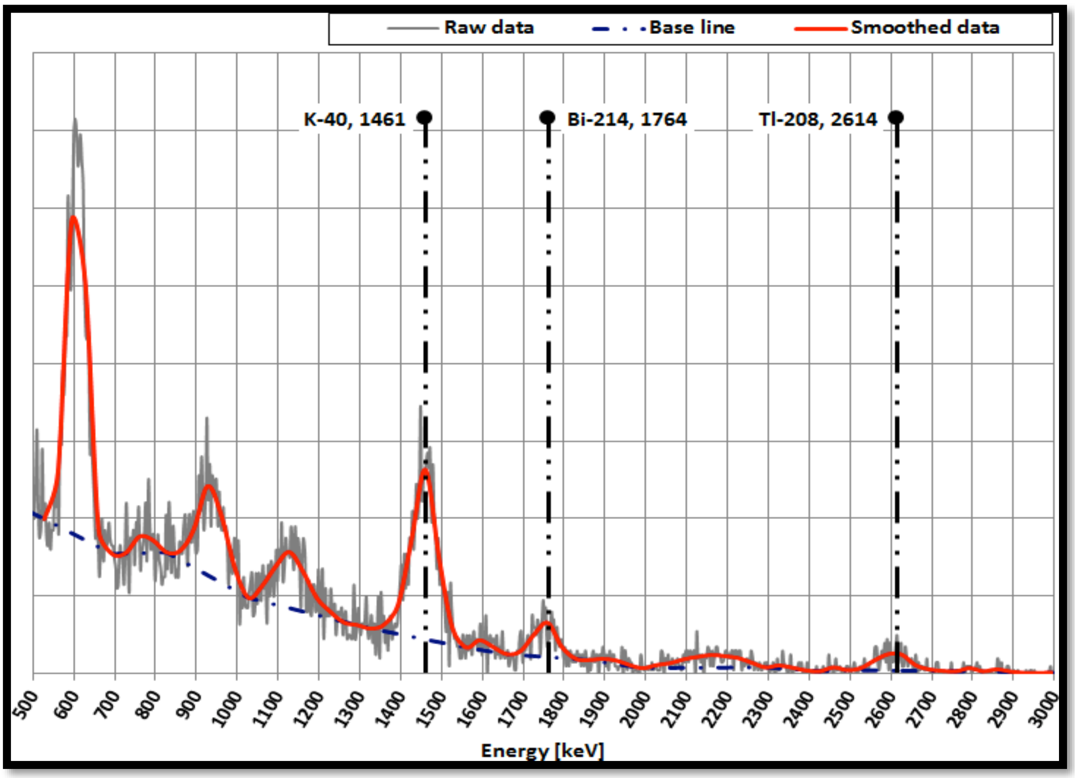

Figure 2. Gamma ray spectrum of sample 166 GR (Source: PT. Schlumberger)

The gamma spectrum displays energy on the horizontal axis and counts on the vertical axis, with peaks indicating the presence of specific radioactive isotopes. The noisy raw data is baseline processed to isolate relevant signals, then smoothed to clearly identify energy peaks—such as K-40 at 1461 keV, Bi-214 at 1764 keV, and Tl-208 at 2614 keV. K, U, and Th concentrations are calculated from the integration of the spectrum area over specific energy windows, so proper window selection is critical.

While background radiation can affect readings at low detection limits, the system maintains stable Limit of Detection values of 0.1% (K), 1 ppm (U), and 2 ppm (Th), ensuring accurate and reliable analysis results. Figure 3 integrates the XRD mineralogical data with GR (API) and U, Th, and K concentrations at various depths, providing a comprehensive picture of the formation's lithology and radioactivity variations.

All data was acquired in real time using Geoservices Advanced Cutting Characterization and combined with other petrophysical logs. This integration enables more comprehensive formation interpretation, improves the accuracy of rock characterization, and supports fast and accurate decision-making during drilling operations.

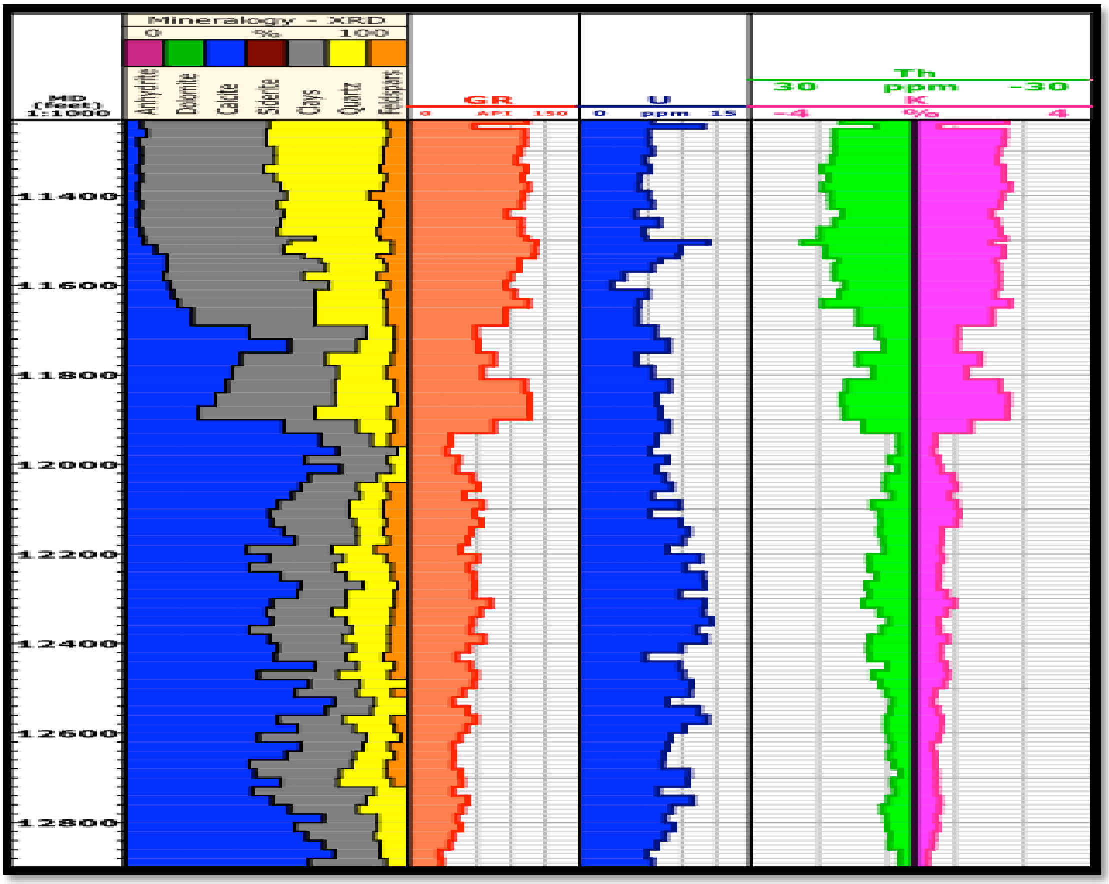

Figure 3. Gamma ray log section, plotted next to the XRD results (Source: PT. Schlumberger)

Kedalaman (feet)	Mineral Dominan	Calcite (%)	Clays (%)	Quartz (%)	eldspars (%	GR (API)	U (ppm)	Th (ppm)	K (%)
11300 - 11400	Dominan Clay dan Quartz	5	45	45	5	110	6.5	-5	0
11400 - 11500	Dominan Clay dan Quartz	5	45	45	5	110	6	-10	0
11500 - 11600	Dominan Clay dan Quartz	5	45	45	5	110	6	5	0
11600 - 11700	Dominan clay dengan campuran Calcite dan Quartz	20	40	35	5	100	3	0	0
11700 - 11800	Dominan Calcite	70	25	10	5	90	6	-20	-1
11800 - 11900	Dominan Calcite dan Clay	40	40	15	5	75	6	-5	0
11900 - 12000	Dominan Calcite dan Clay	65	25	5	5	115	8	-15	-3
12000 - 12100	Dominan Calcite	80	15	5	0	40	8	-25	-3
12100 - 12200	Dominan Calcite	75	15	5	5	35	7	-20	-3
12200 - 12300	Dominan Calcite dan Clay	65	20	10	5	45	6	-20	-3
12300 - 12400	Dominan Calcite	70	15	10	5	35	8	-15	-2
12400 - 12500	Dominan Calcite	75	25	10	5	45	7	-15	-3
12500 - 12600	Dominan Calcite	75	25	10	0	45	9	-20	-3
12600 - 12700	Dominan Calcite dan Clay	70	25	10	5	40	8	-20	-3
12700 - 12800	Dominan Calcite	80	20	10	0	35	6	-25	-3
12800 - 12900	Dominan Calcite	80	20	10	0	30	6	-25	-3

Figure 4. Results of depth analysis per 100 ft (Source: PT. Schlumberger)

The depth column shows the 11,300–12,900 ft interval, representing a variety of subsurface rock formations. The dominant minerals in each interval include clay, quartz, and calcite, with clay being more abundant at shallow depths and calcite increasing to 50% at 12,000–12,200 ft. Quartz remains consistently present at an average of about 20%, while feldspar occurs only in small amounts (<5%),

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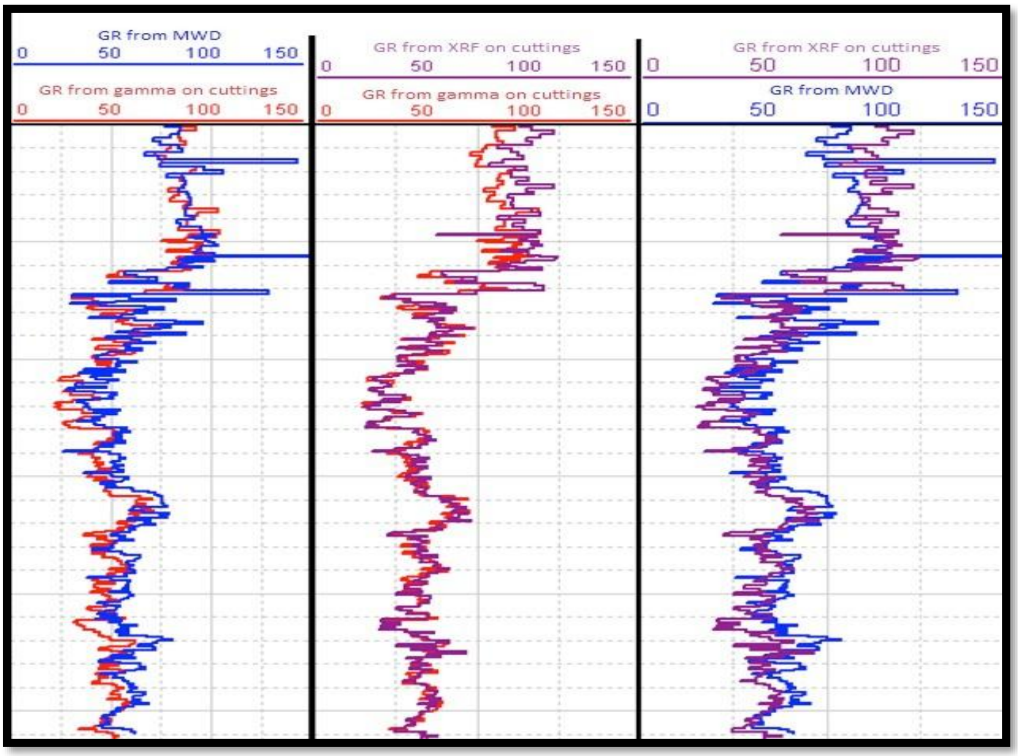
indicating it is not a major mineral in this formation. The percentages of these minerals indicate changes in lithology across the depth interval. Radioactivity parameters such as GR (35–110 API), uranium (3–9 ppm), thorium (-20 to -25 ppm), and potassium (generally low or negative) provide additional insight into the radioactive mineral content. High GR values in shallow intervals indicate a higher clay content. Variations in U, Th, and K were used for geochemical analysis, although negative values for Th and K are likely due to detection limits, background correction, or instrument calibration affecting the results.

Depth Analysis

Four depth intervals show variations in mineral composition and gamma ray characteristics that reflect changes in the geologic environment. At 11,300–11,400 ft, the formation is dominated by a quartz-clay mixture with a high GR (110 API) and relatively high uranium, indicating radioactivity due to the clay content. The 11,800–11,900 ft interval shows a transition to a carbonate-rich formation with calcite reaching 70%, a GR decreasing to 90 API, and lower uranium. At 12,100–12,200 ft, the clay-calcite mixture produces a low GR (35 API), indicating a more stable formation. The deepest interval, 12,500–12,600 ft, is dominated by up to 80% calcite with a consistently low GR (35 API) and a decrease in thorium, indicating an increasingly homogeneous carbonate formation.

Comparison with other Techniques

Gamma ray measurements on cutting samples were thoroughly validated to ensure accurate and consistent data. This process included comparing GR (API) values with MWD data and XRF analysis results to cross-check uranium, thorium, and potassium content. The evaluation also ensured adequate mud logging intervals and proper depth corrections to ensure samples matched their geological positions. Through cross-method verification and measurement procedure checks, more reliable gamma ray cutting data was obtained for geological interpretation and exploration planning.



Picture5.Blind test comparison between GR from measurements onCuttingduring drilling, the theoretical MWD and GR gamma ray logs reconstructed from XRF measurements at Cutting. (Source:PT. Schlumberger)

Figure 5 is a graph showing a comparison between Gamma Ray (GR) logs taken from various measurement methods. There are three graphs that illustrate the relationship between GR from MWD (Measurement While Drilling), GR from gamma rays in Cutting, and GR from XRF in Cutting.

The following is a more in-depth analysis of Figure 5:

- Vertical Axis (Depth): All of these graphs indicate the depth of the well or formation being analyzed. Each graph shows the change in gamma radiation concentration at various depths. This data is obtained from measurements taken at different depth intervals.
- Horizontal Axis (Gamma Ray - API): On each graph, the horizontal axis shows the Gamma Ray readings in API (American Petroleum Institute) units, which are used to measure the intensity of natural radiation detected by an instrument. Higher values usually indicate a higher presence of radioactive minerals, especially clay, which tends to be more radioactive.

Three Chart Analysis

This graph compares three gamma radiation measurement methods for assessing radioactive elements in geological formations: MWD, Cutting gamma ray measurements, and XRF. The first graph displays real-time MWD gamma ray data during drilling, demonstrating the consistency and variation of GR readings at specific depths. The second graph shows GR measurements from Cutting samples, providing additional verification of the MWD data and a more detailed picture of the distribution of radioactive minerals within the rock sample. The third graph displays GR calculated from Cutting XRF analysis, providing more specific information about the chemical composition and radioactive elements within the sample. Comparison of these three graphs allows for evaluation of data consistency, validation of measurement results, and improved accuracy of subsurface formation interpretation.

Comparison and Validation

The graphs shown provide an opportunity to directly compare three measurement methods used to detect gamma radiation: MWD (Measurement While Drilling), gamma rays in Cuttings, and XRF in Cuttings. Each of these three methods has its own characteristics, advantages, and disadvantages, which depend heavily on the purpose of the measurement and the prevailing field conditions.

MWD (Measurement While Drilling)

This method allows for live data collection during the drilling process. With the ability to record changes in real time, MWD is extremely useful in providing timely information about geological conditions while drilling is in progress. This allows engineers and geologists to quickly adjust drilling methods or select more interesting layers for further analysis. However, this method can be affected by changing drilling conditions, such as changes in drilling speed, variations in the tool used, or the presence of mechanical disturbances that can affect gamma-ray readings. Additionally, other factors such as high background radiation or fluctuations in the instrument system can also affect the accuracy of the measurements.

MWD excels at providing real-time data during drilling, invaluable for quick decisions but vulnerable to changing drilling conditions.

Gamma Rays in Cutting

The gamma-ray measurement method in Cutting provides more stable data and can be analyzed in-depth in the laboratory, because the sample is already at the surface and is not affected by dynamic drilling conditions. While it offers a more consistent representation of the formation, this method has a time lag, making it less ideal for real-time decisions, and is also susceptible to contamination or sampling errors that can affect the accuracy of the results.

***XRF* on Cutting**

Cutting's X-ray fluorescence (XRF) technique offers deeper analysis and high accuracy in detecting specific radioactive elements in a sample. XRF can provide more specific and detailed elemental composition, including the ability to identify minor or trace elements that other methods might miss. XRF's advantage also lies in its ability to detect heavy elements such as uranium and thorium with very high accuracy. While XRF provides more in-depth analysis, it often requires a more intensive and expensive laboratory setup than other methods. The sample collection and preparation process for XRF can also be more time-consuming, which can delay the rapid decision-making often required in a drilling context. Cutting's XRF offers high accuracy in elemental analysis and provides more in-depth data, although at a higher cost and with a more complex sample preparation process.

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CONCLUSIONS AND SUGGESTIONS

The application of Spectral Gamma Ray (SGR) in Advanced Mud Logging (AML) functions to analyze gamma radiation in Cutting in real-time using a detection system consisting of a lead shield, scintillation detector, and photomultiplier tube (PMT), thus being able to provide accurate formation characterization. This accuracy is strengthened by the use of a thallium-doped NaI(Tl) detector and data verification through comparison with X-Ray Diffraction (XRD) results, which allows analysis of the relationship between mineral content and rock physical properties. In addition, the use of SGR in Cutting has been proven to reduce interpretation ambiguity, as seen at a depth of 11,300–11,400 feet which shows a Gamma Ray value of 110 API and a Uranium content of around 6.5 ppm, thus providing a clearer lithological picture and producing more stable, consistent, and reliable data for geological analysis.

Based on the results of the research analysis, the application of Spectral Gamma Ray (SGR) technology in Advanced Mud Logging (AML) can be improved through several important steps, namely expanding the integration of SGR into the AML system to improve drilling efficiency and accuracy, ensuring proper calibration and equipment settings through operator training and regular monitoring, and conducting a more in-depth cost-benefit evaluation so that the use of this technology remains optimal even in projects with limited budgets.

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