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Development of Spectral gamma-ray logging probe using $LaBr_3(Ce)$ detector and testing of its application in geophysical prospecting for uranium

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ABSTRACT

Spectral gamma ray logging is a useful technique for uranium exploration during the large-scale borehole drilling stage. It can detect sub-surface uranium-bearing formations, quantify uranium concentration, and map geological structures. Traditionally, NaI(Tl) crystal is used as a detector in spectral logging probes. The coring boreholes drilled for uranium exploration have a limited diameter, necessitating smaller detectors in Spectral gamma ray logging probes. This limitation resulted in reduced sensitivity, increased high-energy thorium contributions in uranium and potassium channels, and thus pose challenges in accurately quantifying uranium content with the NaI(Tl) detector. Advances in detector technology, such as $LaBr_3(Ce)$, $CeBr_3$ and CsI(Tl) scintillation detectors, offer improved energy resolution and sensitivity in smaller form factors. The $LaBr_3(Ce)$ detector has various advantages over standard NaI(Tl) detectors of the same size, such as high density, superior light output, good linearity, faster response time, and improved energy resolution. In this regard, an attempt was made to use a $LaBr_3(Ce)$ detector in the spectral gamma-ray logging probe. A spectral gamma-ray logging probe using a small 1-inch diameter x 1-inch height $LaBr_3(Ce)$ detector was developed to perform gamma-ray spectroscopy in slim borehole environments. The probe was attached to a vehicle-mounted multi-para borehole logging system. The probe was calibrated using gamma-ray sources of known energies and standard boreholes with known uranium, thorium, and potassium concentrations. The spectral gamma-ray logging was performed in a borehole with a radioactive zone around the Sarangapalli area, Guntur district of Andhra Pradesh (India). The logging results were compared with laboratory core sample analysis results to confirm the credibility of the probe's ability to measure K, U, and Th concentrations in a drilled borehole.

Keywords: $LaBr_3(Ce)$ detector, Spectral logging, Probe calibration, Uranium exploration, Radioactive zone

INTRODUCTION

In mineral exploration, drilled boreholes are crucial to assess the presence of minerals in the subsurface. Various logging probes are employed to log the drilled boreholes and evaluate the subsurface information. These probes provide important information regarding the geological formations, mineral composition, fluid content and other properties crucial to assessing potential mineral deposits. A spectral gamma-ray logging probe is one such critical probe, used in uranium exploration. This probe measures the natural gamma radiation, emitted by radioisotopes of elements, mainly potassium (K), uranium (U), and thorium (Th) in the subsurface. It helps to identify and quantify radioactive minerals, especially uranium-bearing minerals, which indicate potential ore bodies. In order to perform the logging activity in the drilled borehole, the probe's diameter must be smaller than the borehole diameter so that it may be lowered into the borehole freely and perform measurements effectively. The diameter of coring boreholes varies significantly depending on the geological formation, drill depth, and exploration objective. Therefore, small-size NaI(Tl) detectors were used in traditional spectral gamma-ray logging probes resulting in reduced sensitivity and increased contributions from high-energy thorium in uranium and potassium channels (Jegannathan et al., 2018). The $LaBr_3(Ce)$ detector has several advantages over NaI(Tl) detectors of the same size. The improved energy resolution of the $LaBr_3(Ce)$ detector, results in sharp energy peaks compared to the NaI(Tl) spectra (ORTEC, 2023). This reduces the high-energy thorium contributions in uranium and potassium channels. The $LaBr_3(Ce)$ scintillator exhibits a high density (5.2 g/cm^3), high light yield (~ 68000 photons/MeV), energy resolution (3-4% at 662 keV), decay time (16 ns), excellent thermal stability and higher detection efficiency than the NaI(Tl) scintillator (epic-crystal.com). Many researchers have studied the application of $LaBr_3(Ce)$ scintillation detector for gamma-ray spectrometry (Dias et al., 2009; Saizu and CATA-DANIL, 2011; Loher et al., 2012) and found it suitable. As a result, the $LaBr_3(Ce)$ detector was selected to develop a suitable spectral gamma-ray probe for spectral logging of drilled cored boreholes for uranium exploration. Indigenously developed spectral logging systems are economical and have full control over the system for repair, maintenance, and calibration.

High-purity Germanium (HPGe) detectors offer superior energy resolution, compared to $LaBr_3$ and NaI detectors. HPGe detectors require cryogenic cooling and operate at temperatures between 90-120 K. This cooling is achieved using a combination of a cryostat, dewar, and liquid nitrogen. Therefore, the HPGe detector is not preferable for borehole logging applications. The comparison of LaBr3(Ce), NaI(Tl), and HPGe spectra is illustrated below (Figure 1).

DEVELOPMENT OF SPECTRAL GAMMA-RAY LOGGING PROBE USING $LaBr_3(Ce)$ DETECTOR

In order to achieve a smaller probe diameter, including the detector protective enclosure and metal probe case diameters, a hermetically sealed $LaBr_3(Ce)$ crystal of diameter 1-inch x 1-inch length (EPIC make), coupled with a suitable photo