NUCLEAR BOREHOLE LOGGING TECHNIQUES DEVELOPED BY CSIRO-EXPLORATION AND MINING FOR IN SITU EVALUATION OF COAL AND MINERAL DEPOSITS

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Abstract
A range of nuclear spectrometric techniques for quantitative borehole logging and surface quantitative analysis for the coal and metalliferous mining industries. The paper reviews the latest developments of this technology.

1. INTRODUCTION
Geophysical techniques are well established in the resource industries like oil, gas, uranium, coal and minerals. Nuclear borehole logging which represents a subset of this group has been widely used in the oil, gas and uranium industries for a long time. Due to the deep penetration of neutrons and gamma rays, nuclear techniques are suitable for borehole logging applications and they are making inroads in other industries like coal and minerals. Many holes drilled in the coal and metalliferous mining industries are cored and the core is sent to the laboratory for chemical analysis. The chemical analysis of the core provides all the information which is usually extracted from a borehole. However, this does not make nuclear borehole logging redundant. The benefits which can be derived from nuclear logging are:

i. It samples a much larger volume of the material surrounding the borehole than the core sample and therefore provides better sampling statistics especially in heterogeneous deposits.

ii. The results are instantaneous.

iii. The cost of drilling open holes is cheaper than the cost of cored holes.

Considering that the full information provided by the laboratory analysis is not always needed and that in some mineral deposits the core cannot be fully recovered, nuclear logging and the laboratory analysis of the core are complementary.

The Commonwealth Scientific and Industrial Research Organisation, Division of Exploration and Mining has developed the spectrometric nuclear logging system, SIROLOG, based on natural-gamma, gamma-gamma and neutron-gamma techniques. In this system the whole gamma ray spectrum is recorded for each preset logging interval. By recording and analysing the whole gamma-ray energy spectrum from a spectrometric measurement one can extract more information from the logging data. A dedicated software package for spectrometric data analysis and interpretation has also been developed. The SIROLOG logging system was developed for both the coal and metalliferous mining industries. However, the data interpretation and the source/detector configuration is usually specific to the type of application, ie, it is tuned for each specific application.

The SIROLOG logging system and its application to the coal and metalliferous mining industries was described in a previous paper (1). This paper deals mostly with new developments and applications of SIROLOG. A Coal Face Analyser was also developed recently and is described in this paper.

2. INSTRUMENTATION
Being spectrometric, gain stabilisation is an essential part of the system. The upgraded SIROLOG is fully digitised. Pulses produced by the gamma-ray detector are processed in the probe and transmitted to the uphole PC computer. The transmission of the signal is noise proof and is not susceptible to attenuation in the cable as was the case with the previous analogue system. A CPU is incorporated in the probe and all the software is written in C. The whole system consists of the probe, winch and a laptop computer. When low activity sources are used and a source transporter is not required, the system is portable and does not require a dedicated logging vehicle. This makes SIROLOG suitable for logging in areas where the only way of access is by helicopter.

The standard logging probe has a diameter of 60 mm and can accommodate a scintillation detector of 37 mm diameter. The length of the probe is about 2 m. When logging large diameter boreholes it is advantageous to use larger volume detectors which are more efficient for gamma ray detection. Larger diameter probes are constructed for these applications. Scintillation detectors are used in the SIROLOG system. The most common scintillator used in the gamma-gamma tool is NaI(Tl), while
BGO (bismuth germanate) is the preferred scintillator for natural-gamma and neutron-gamma logging.

### 3. APPLICATIONS

#### 3.1 Coal

The spectrometric gamma-gamma technique was developed for the determination of ash content of coal (2). The ash determination is based on the correlation which exists between $Z_{eq}$ (atomic equivalent number) of coal and ash. The technique works well in both dry and waterfilled boreholes.

A combined gamma-gamma/natural-gamma probe was developed for borehole lithology logging for brown coal (3). The identification of the three basic components - sand, clay and coal - is possible because they have different densities and intrinsic natural radioactivities. The combination probe employs one BGO detector and a $^{137}\text{Cs}$ gamma-ray source. The gamma-gamma and natural-gamma responses are recorded simultaneously due to the spectrometric feature of the probe. A technique based on the prompt neutron-gamma method was also developed for the determination of ash in coal seams intersected by boreholes (4). The technique works both in waterfilled (4) and dry (5) holes, and uses a $^{252}\text{Cf}$ neutron source and a BGO detector. Apart from sampling larger volumes of coal, neutron-gamma can also measure some of the major constituents of coal ash.

#### 3.2 Metalliferous Mining

The three nuclear borehole logging techniques, natural gamma, gamma-gamma and neutron gamma have found applications in the iron ore mining industry. Natural-gamma can be used for delineating the iron ore body based on the big difference in natural gamma radiation between the iron ore (low in natural gamma radiation) and the shaly rock. It can also provide a means for determining alumina contamination of iron ore based on the correlation between alumina and the kaolinitic material of the ore matrix (6). Neutron-gamma logging can provide both the iron ore grade and the silica content (7, 8).

### 4. IN-SITU ANALYSIS USING ULTRA-LOW RADIATION INTENSITY GAMMA-RAY SOURCES

Although nuclear techniques are widely used in the mining industry, some mines are still reluctant to use them due to the extra care required when working with radioactive sources. Work has been carried out over the last years to develop environmentally friendly techniques for in-situ analysis using ultra-low radiation intensity gamma-ray sources. Equipment for in-situ analysis using low activity sources significantly simplifies safety procedures and reduces to a minimum the source radiation risk. Logging systems using very low activity sources are much more likely to be accepted by the mining industry. Two instruments have been developed: i. a borehole logging probe and ii. a coal face analyser.

**i. Logging probe.** Two source - shield - detector configurations were tested for the logging probe. The one source configuration (9) comprises a 1.8 MBq $^{137}\text{Cs}$ gamma-ray source placed along the axial centreline of the detector with a conical 30 mm thick lead shield between the source and the detector. The three source configuration (10) comprises three 0.36 MBq $^{137}\text{Cs}$ gamma-ray sources placed circumferentially (at a distance of 22.5 mm from the bottom end of the detector) around a cylindrical iron/lead shield. Due to the very short source to detector distance the probes provide the best possible delineation of coal seams.

**ii. Coal Ash Face Analyser.** Coal ash determination on the coal face falls into the category of in-situ measurement, which is mainly applicable to the production phase in open-cut pits and underground. Two coal face analysers have been developed. One coal face ash analyser was based on natural gamma radiation and utilises the existence of a correlation between the natural gamma radiation of coal and its ash content (12). In the second coal face ash analyser, the determination of the ash content of coal on the coal face was based on the backscattered gamma-gamma technique in a $2\pi$ geometry (12). The instrument is portable, hand held, weighs 2 kg and does not expose the user to unacceptable levels of radiation.

#### 4.1 Applications

**4.1.1 Coal.** Both the logging probe and the face analyser were developed primarily for the coal mining industry. The laboratory and field tests demonstrated that both the single source and three source configurations were suitable for delineation of coal seams and ash determination in wet and dry boreholes. The face analyser using the $^{133}\text{Ba}$ gamma-ray source was developed for quantitative measurements of ash on the coal face.
4.1.2 Iron ore. The single source probe was tested in an iron ore deposit (13). The probe proved suitable for delineation of the ore body and also for predicting its grade.

4.1.3 Pb-Zn ores. Both single source and three source configurations were tested for orebody delineation and grade control of Pb-Zn ore (14,15). Lead grade is determined from the 80 keV K X-Ray peak excited by the multiscattered gamma-rays. The probes were field tested in two cored holes, reamed later to a diameter of 142 mm. The holes were water-filled. The r.m.s. deviation given by the regression equation was 0.3 %Pb and the standard deviation of the population was 1.7 %Pb. The gamma-gamma probe is not able to measure the concentration of zinc directly. The probe's response is related to the overall contributions given by the major components with high atomic number which are present in the Pb-Zn ore, eg Pb, Zn, Fe and Mn. Because Pb concentration can be measured directly, the determination of Zn is possible if the Fe and Mn concentrations in the ore are constant, or can be estimated in a different way.

5. CONCLUSIONS
The spectrometric SIROLOG system for in-situ analysis developed by CSIRO has proved itself in the Australian mining industry. The new fully digitised, portable systems using ultra-low radiation intensity gamma-ray sources will make the system even more competitive. The system has great potential in both the coal and metalliferous mining industries.

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