Low Activity Spectrometric Gamma-Gamma Borehole Logging Tool for the Metalliferous Industry

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Abstract. The low activity spectrometric gamma-gamma technique was applied to the quantitative determination of lead and zinc grades in boreholes well-logging. The tool was centralized and employed a γ-ray source of very low activity (1.8 MBq). The log tool was tested separately using (i) ^{133}Ba and (ii) ^{137}Cs with 37*75 mm NaI (TI) scintillation detector. Five source-detector configurations were studied and analyzed in the present work. The calibration equations for lead (Pb) and Zinc Metal Equivalent (ZME) prediction using Barium and Cesium sources have been quantitatively described for every studied configuration. The optimum configuration for the logging probe using a ^{133}Ba source is determined to be 52 mm source to detector spacing. This configuration gives the best results for both Pb and ZME grade. The r.m.s. deviation for Pb and ZME are 0.33 and 2.3% respectively. The optimum configuration for the logging probe using a ^{137}Cs source is determined to be 64 mm source to detector spacing. This configuration gives the best results for both Pb and ZME grade. The r.m.s. deviation for Pb and ZME are 0.36 and 2.2% respectively. The advantage of using low activity ^{137}Cs source is that this radioactive source does not need an extra source for spectrum gain stabilization, where the same source is used for both primary sources of radiation and gain stabilization. In addition, ^{137}Cs source is characterized by longer half- life and greater penetration effect of its gamma radiation. The low activity ^{133}Ba source however necessitates an additional ^{137}Cs microsource for gain stabilization. The tool is sensitive to changes in Zeq number of the matrix surrounding the borehole and could find application in the metalliferous mining industry for ore body delineation. Due to its very low γ-ray source activity and lightweight, the tool is ideal for use with portable logging systems and underground mining operations.

Introduction

The delineation of the ore body and determination of Pb and Zn concentrations in Pb-Zn deposits are important parameters both in the exploration and mine production stages of Pb-Zn mine. Prediction of these parameters translates into

reduced ore dilution. This increases the efficiency of the mine and reduces the operation costs, which can bring substantial financial saving to the mining company. The backscattered γ-technique is very well established in borehole logging in coal mining industry. Most of the commercial logging companies use the non-spectrometric γ-γ technique, which is adequate for density measurements of delineation of coal seams. However, the non-spectrometric γ-γ is not suitable for quantitative ore grade measurements. The more sophisticated technique γ-γ is spectrometric. It records the whole backscattered spectrum after each logging interval. The spectra are saved in a computer and processed at the end of logging.

Researches have been carried out in the last few years to develop spectrometric γ-γ technique for borehole logging, using very low activity sources. The availability of borehole logging equipment, using sources of activity lower than 3.7 MBq but capable of quantitative analysis, provides minimal risk to safety and environmental integrity. The fact that such systems do not require heavy shielding for the radioactive source makes them suitable to be portable logging systems, which are easier to be used in underground mining operations and do not require a dedicated logging vehicle. A nuclear well-logging, based on spectrometric backscattered γ-γ using low radioactivity source, has been applied in coal and iron mining (Charbucinski, 1993; Borsaru and Ceravolo, 1994; Borsaru *et al.,* 1995; Charbucinski *et al.,*1996). There are more applications for this technique in the metalliferous mining industry for ore body delineation (Charbucinski *et al.,* 1997; Asfahani, 1999). The present work deals with the laboratory investigation of the application of the backscattered technique γ-γ to the in site determination of Pb concentration in boreholes as Pb-Zn deposit.

The aim of this research work is to compare the achieved sensitivity and accuracy of Barium source with those obtained for the tool utilizing Cesium microsource. It was anticipated that lower energy [133]Ba source should provide better sensitivity for ZME and Pb grade determination than the applied ^{137}Cs source (Charbucinski *et al.,* 1997, Asfahani, 1999). It is well known that the low activity tool is sensitive to changes in equivalent atomic number (Zeq) and is applicable for ore body delineation due to the difference in Zeq number between the host rock and the ore body. Therefore, five source to detector distances (40, 52, 64, 76 and 88 mm) have been tested to obtain the adapted configuration to be applied in the field. The optimization of the source-detector configuration will always be needed for each particular mineralization in order to obtain best results. In the present work, the regression equations for these five configurations in case of Barium and Cesium sources are given in order to describe the characteristics of each studied configuration. This is done in an attempt to select the best configuration for both Barium and Cesium sources. The application of this described spectrometric γ-γ technique in the field of underground mining operations is also recommended.

Probe Configuration

The low activity tool, for lead and zinc quantitative determination, was tested in this research. The tool was fabricated from aluminum of 3 mm thickness and its external diameter is 60 mm, using 37*75mm NaI (TI) detector for detection of gamma radiation. The tool was centralized and used by ^{133}Ba and ^{137}Cs sources of 1.8 MBq activity. The detector was shielded from the gamma ray source by 30 mm lead. An extra Cd + Cu filter was placed between shielding and detector to further absorb unwanted X-rays. Because the gamma rays, originating from the ^{133}Ba source could not penetrate the lead shielding, an extra ^{137}Cs- source of 0.37 MBq activity was added in order to provide a 662 KeV gamma ray peak to stabilize the recorded backscattered gamma ray spectrum.

The backscattered gamma-ray spectra in this research were recorded in a stationary case, while, these measurements in a motion case are carried out with speed logging of 2-3 m/min and stored directly on the hard disk of an IBM compatible PC for further analysis and interpretations.

Principle of Lead Quantitative Determination

Lead grade is determined from the 80 KeV X-ray, which is prominent in the backscattered gamma ray spectrum. The gamma ray, having energy above 88 KeV, can excite X-ray from lead, producing an 80 KeV peak. This peak is used to determine the Pb concentration, where the number of X- ray, recorded in this peak, is related to Pb concentration in the Pb-Zn ore. However, a linear relationship can not be assumed between the lead concentration and the peak area due to distortion of the gamma ray flux by the bulk ore sample. This variation must be taken in consideration during data interpretation.

Determination of Zinc Metal Equivalent (ZME)

Zinc Metal Equivalent units provide a useful measure of the response of the probe to the total composition of the material. The utility of introducing this parameter is related to the fact that γ-γ technique is not suitable to distinguish zinc from other heavy elements, such as Pb, Fe, and Mn, associated with Zn-Pb ores. ZME can be defined from the following equation:

$$ZME \ = \ \% \ Zn + \% \ Pb*Ef \ (Pb/Zn) \qquad [1]$$

where Ef(Pb/Zn) is a multiplier such that gamma radiation scattered and absorbed by a compound of a multi-heavy element medium and measured through a given spectral parameter results in the same value as that of the spectral parameter being measured in a mono heavy metal ore (e.g. Zn only). The value of Ef (Pb/Zn) has been determined as equals to 4, for which the best root mean square (r.m.s.) value between %ZME assayed and response tool has been obtained.

Laboratory Investigation

^{133}*Ba Source*

The γ-γ backscattered measurements, carried out in the laboratory, had the aim of determining the probe configuration providing the best sensitivity for logging measurements of lead and zinc concentrations. The separations between source and bottom end of the detector in the probe were selected to be 40, 52, 64, 76 and 88 mm using primary source of ^{133}Ba of 1.8 MBq. The detector is located at the top of the source. The measurements were carried out in 13 bore-hole geophysical models of 130 mm-diameter. Each model holding a volume of about 200 L of crushed Pb-Zn ore and the tool was centered in the hole through these models. The chemical composition of the 13 models is shown in Table 1.

TABLE 1. Chemical composition of the 13 geophysical models.

Geophysical model	Pb %	Zn %
1	4.27	4.71
2	3.83	4.32
3	5.81	5.86
4	0.52	0.52
5	7.10	19.08
6	5.02	6.03
7	5.40	6.52
8	5.06	6.42
9	5.74	12.48
10	7.87	9.40
11	0.65	0.87
12	7.77	9.47
13	6.66	9.2

Fig. 1(a) shows the spectra collected using the low activity 133Ba tool on three geophysical models (No 3, 4 and 10) having different quantities of lead (0.52, 5.81, 7.87%), (Asfahani, 1999). The peak, which corresponds to the 662 KeV gamma ray from ^{137}Cs, is used to gain stabilization. It is clear from Fig. 1(b), that the low energy region of spectra shows a differentiation in intensity between these three models. The intensity of the backscattered spectrum is determined by both the density of the medium and its chemical composition. The chemical composition affects mostly this low energy region. The high-energy region carries the information about the density of the matrix surrounding the borehole (Borsaru *et al.,* 1985). Fig. 2 presents low energy part of the spectra
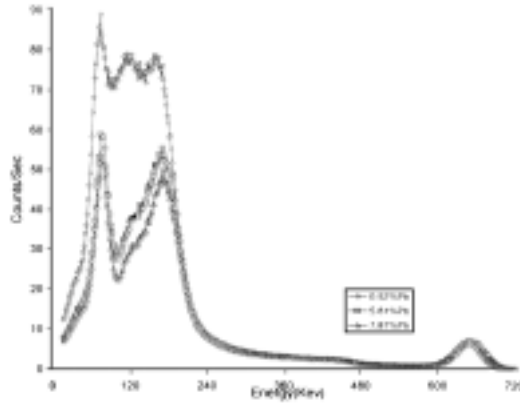
FIG. 1(a). Backscattered γ-γ spectra collected using [133]Ba source for different quantities of Pb (0.52, 5.81 and 7.87%).
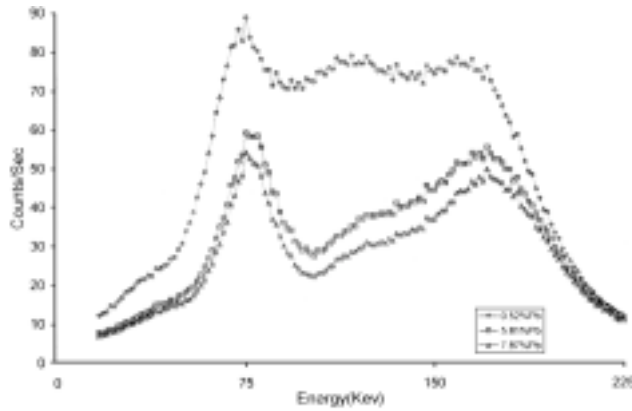

FIG. 1(b). Detailed spectra of Fig. 1(a) recorded in low energy regions.
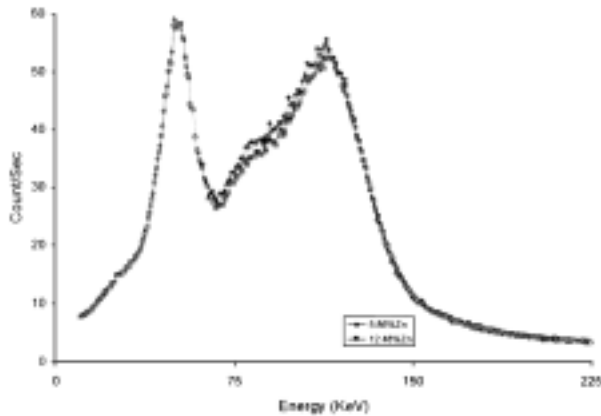

FIG. 2. Elargated spectra recorded in low energy regions and collected in two geophysical models of the same Pb% but different quantities of Zn% (5.86, 12.4%).

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recorded and collected in two geophysical models (No. 3 and 9), having approximately the same quantity of lead (5.8%), but different quantity of zinc (5.86 and 12.48% respectively), (Asfahani, 1999).

Linear regression analysis was used to analyze and interpret the experimental data obtained from the 13 geophysical models. This regression was applied for the five probe configurations (40, 52, 64, 76, and 88mm). The results of this regression analyses are summarized in Table 2. The various regression analyses for each of the probe configuration gave high values of the correlation coefficient (Rc > 0.95) between assayed Pb contents and the various spectral ratios based on spectral windows and P_z parameters. P_z is the ratio between count rate in two windows at high and low energies. The r.m.s. deviations between laboratory assays and the tool's prediction vary between 0.33 and 0.41. These regression analyses gave also high values of the correlation coefficient (Rc > 0.92) between assayed Zinc Metal Equivalent (ZME) and the various spectral and P_z parameters considered. The r.m.s. deviations between laboratory assays and the tool's prediction vary between 2.3 and 2.88.

TABLE 2. Regression analysis results for the five-tested probe configurations using [133]Ba source.

S-D spacing	133Ba source					
	% Pb			% ZME		
	r.m.s.	Rc		r.m.s.	Rc	
40 mm	0.41	0.96	2.3	2.88	0.949	13.47
52 mm	0.33	0.97	2.3	2.3	0.961	13.47
64 mm	0.39	0.96	2.3	2.6	0.94	13.47
76 mm	0.34	0.98	2.3	2.72	0.93	13.47
88 mm	0.34	0.98	2.3	2.78	0.94	13.47

Fig. 3 shows cross-plots of calibration data between the chemical assay of Pb and the low activity [133]Ba tool prediction for the five probe configurations. The regression analysis generates the following equations:

$$[40 \text{ mm}] \quad \% \text{ Pb} = -0.02 \text{ Roi3} + 2.66 \text{ Rat1} - 3.483 \qquad [2]$$
$$[52 \text{ mm}] \quad \% \text{ Pb} = -0.024 \text{ Roi2} + 13.377 \text{ Rat2} - 7.158 \qquad [3]$$
$$[64 \text{ mm}] \quad \% \text{ Pb} = -0.0276 \text{ Roi2} + 10.618 \text{ Rat2} - 2.338 \qquad [4]$$
$$[76 \text{ mm}] \quad \% \text{ Pb} = -0.0205 \text{ Roi2} + 10.67 \text{ Rat2} - 5.97 \qquad [5]$$
$$[88 \text{ mm}] \quad \% \text{ Pb} = -0.024 \text{ Roi2} + 9.40 \text{ Rat2} - 6.147 \qquad [6]$$

The meaning of the variables, used in these equations, is explained in Table 3.
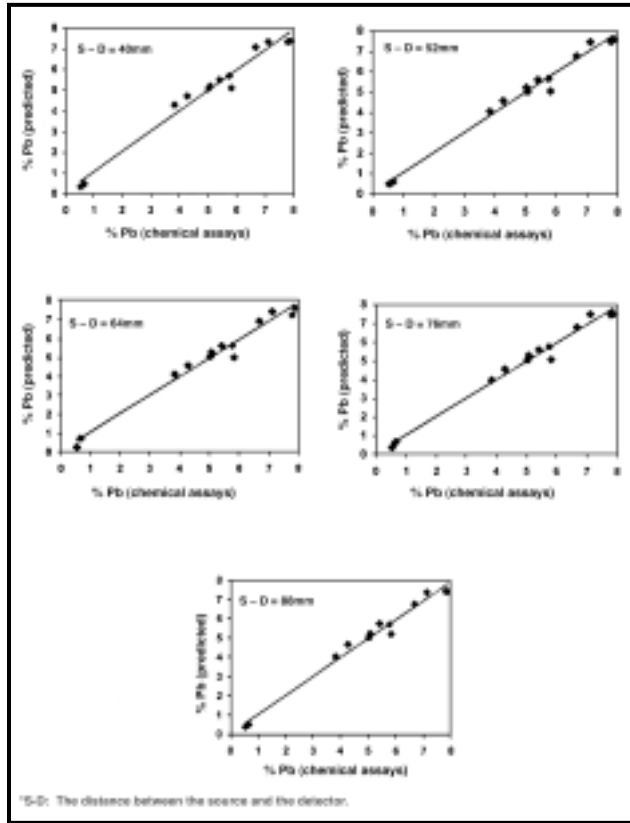
F<small>IG</small>. 3. Comparison of Pb% determined by chemical analysis and ^{133}Ba tool prediction, for the five probe configurations.

T<small>ABLE</small> 3. Variables used for Pb determination using ^{133}Ba source.

Roi	Rat
Roi2 (52.5-108KeV)*	Rat1 (51-100.5)/(97.5-105 KeV)
Roi3 (51-100.5 KeV)	Rat2 (51-100.5) / 105-135 (KeV)

*The count rate in the spectral window

The ratios in these equations take into account the variation of gamma-ray flux in the bulk sample and represent the normalization of the count rate of lead peak to the gamma-rays of energies just above the γ-ray peak.

Fig. 4 shows cross-plots of calibration data between chemical ZME and the low activity ^{133}Ba tool predictions for the five configurations. The regression analysis gives the following equations:
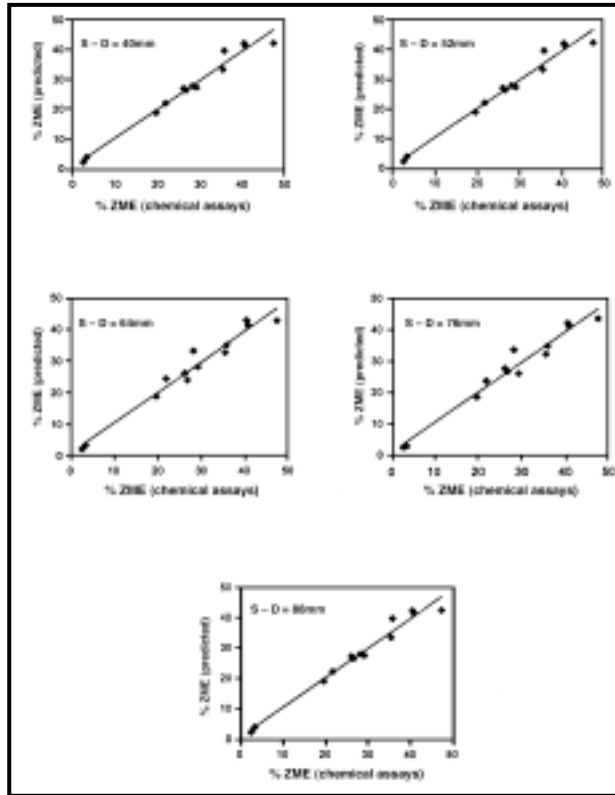
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Fɪɢ. 4. Comparison of ZME% determined by chemical analysis and ^{133}Ba tool prediction, for the
five probe configurations.

[40 mm]   % ZME = $-$ 0.062 Roi6 $-$ 102.33 Rat2 + 270   [7]

[52 mm]   % ZME = $-$ 0.041 Roi3 + 1827.73 Rat3 $-$ 182.28   [8]

[64 mm]   % ZME = $-$ 0.094 Roi6 $-$ 98.28 Rat1 + 295.59   [9]

[76 mm]   % ZME = $-$ 0.011 Roi6 $-$ 121.37 Rat1 + 319.92   [10]

[88 mm]   % ZME = $-$ 0.3 Roi7 $-$ 121.05 Rat8 + 309.1   [11]

The meaning of the variables, used in these equations, is explained in Table 4.

Tᴀʙʟᴇ 4. Variables used for ZME determination using ^{133}Ba source.

Rai	Rat
Roi6 (135-180 KeV)	Rat2 (225-300)/(75-105 KeV)
Roi3 (150-180 KeV)	Rat3 (225-300)/(45-120 KeV)
Roi7 (180-232.5 KeV)	Rat1 (135-210)/(60-105 KeV)
	Rat8 (135-180)/(51-100.5 KeV)

^{137}*Cs Source*

The five probe configurations were also tested, using primary source of ^{137}Cs of 1.8 MBq. Fig. 5 shows the spectra collected on three geophysical models (No. 3,4 and 10), (Asfahani, 1999). The peak, which corresponds to the 662 KeV gamma ray, is used for gain stabilization.

Linear regression analysis was carried out in order to interpret the experimental data obtained from the 13 geophysical models. The results of this regression analysis for the five probe configurations are summarized in Table 5.

The regression analysis for each of the probe configuration indicates high values of the correlation coefficient (Rc > 0.97) between assayed Pb contents and the various spectral ratios based on spectral windows and P_z parameters.
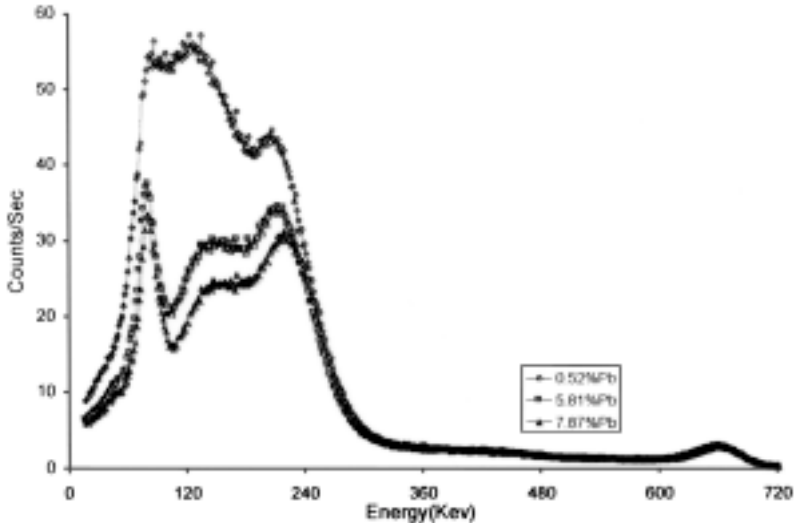

F$_{IG}$. 5. Backscattered γ-γ spectra collected using ^{137}Cs source for different quantities of Pb% (0.52, 5.81, 7.87%).

The r.m.s. between laboratory assay and the tool prediction varies between 0.29 and 0.37 percent lead. This regression analysis indicates also high values of the correlation coefficient (Rc > 0.89) between assayed ZME and the various spectral parameters considered in the calibration equations. The r.m.s. deviation between laboratory assays and the tool prediction varies between 2.20 and 2.83 percent ZME.

Fig. 6 presents cross-plots of calibration data between the chemical assay of Pb and the low activity ^{137}Cs tool prediction for the five probe configurations. The regression analysis gives the following calibration equations:
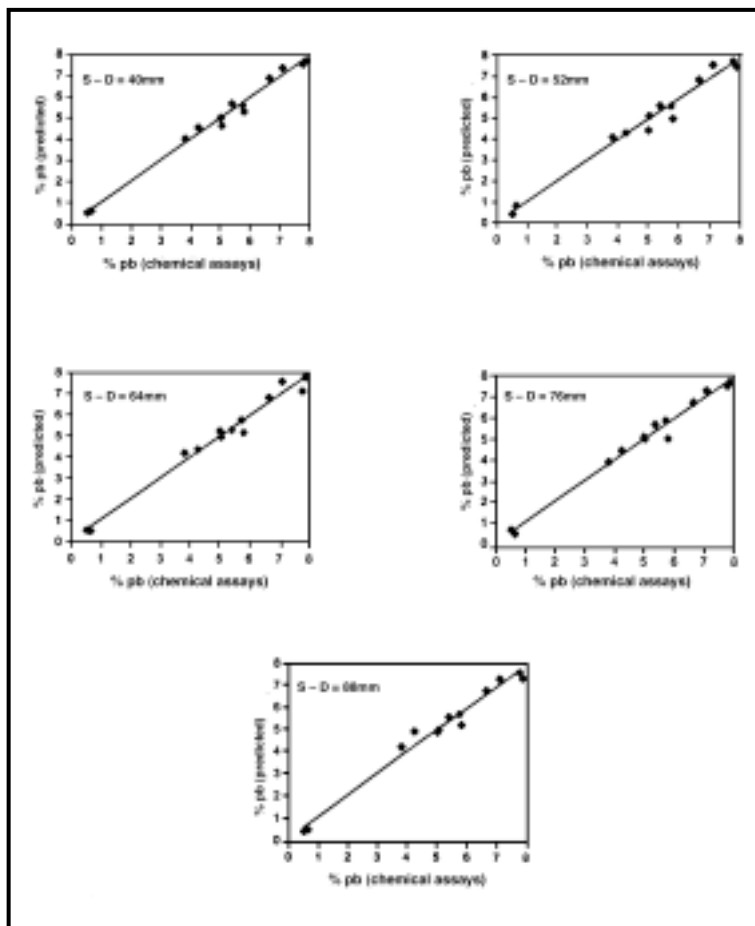
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F<small>IG</small>. 6. Comparison of Pb% determined by chemical analysis and ^{137}Cs tool prediction, for the
five probe configurations.

$$[40 \text{ mm}] \quad \% \text{ Pb} = -0.033 \text{ Roi2} + 19.07 \text{ Rat2} - 13.36 \quad [12]$$

$$[52 \text{ mm}] \quad \% \text{ Pb} = -0.0318 \text{ Roi2} + 15.87 \text{ Rat2} - 9.70 \quad [13]$$

$$[64 \text{ mm}] \quad \% \text{ Pb} = -0.0459 \text{ Roi2} + 13.35 \text{ Rat2} - 2.94 \quad [14]$$

$$[76 \text{ mm}] \quad \% \text{ Pb} = -0.024 \text{ Roi2} + 13.66 \text{ Rat2} - 10.52 \quad [15]$$

$$[88 \text{ mm}] \quad \% \text{ Pb} = -0.0278 \text{ Roi2} + 12.65 \text{ Rat2} - 9.04 \quad [16]$$

The significance of the Roi2 and Rat2, used in these equations, is the same as
presented in Table 5.

TABLE 5. Regression analysis results for the five-tested probe configurations using ^{137}Cs source.

S-D Spacing	^{133}Cs source					
	% Pb			% ZME		
	r.m.s.	Rc	σ	r.m.s.	Rc	σ
40 mm	0.29	0.987	2.33	2.48	0.95	13.46
52 mm	0.35	0.98	2.33	2.73	0.9	13.46
64 mm	0.36	0.971	2.33	2.2	0.95	13.46
76 mm	0.306	0.988	2.33	2.83	0.94	13.46
88 mm	0.377	0.98	2.33	2.79	0.89	13.46

Fig. 7 shows cross-plots of calibration data between chemical assay of ZME and the low activity ^{137}Cs tool for the five probe configurations. The calibration equations for ZME prediction have the following forms:
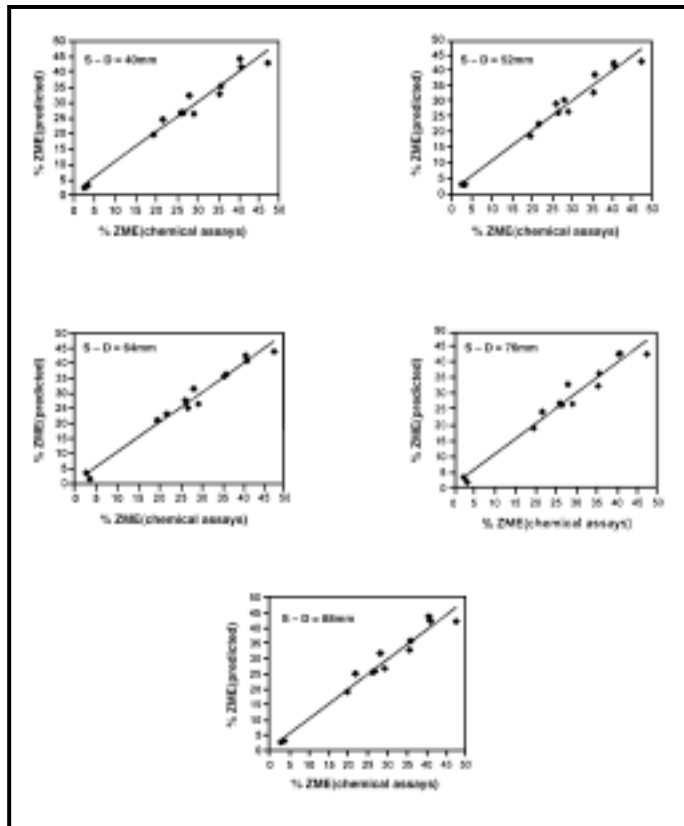

FIG. 7. Comparison of ZME% determined by chemical analysis and ^{137}Cs tool prediction, for the five probe configurations.

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[40 mm]   % ZME =   0.083 Roi14 + 238.14 Rat7 – 231.35   [17]

[52 mm]   % ZME = – 0.478 Roi1 – 189.84 Rat8 + 333.21   [18]

[64 mm]   % ZME = – 0.21 Roi7 – 78.26 Rat5 + 414.17   [19]

[76 mm]   % ZME = – 0.082 Roi6 – 138.27 Rat8 + 235.72   [20]

[88 mm]   % ZME = – 0.466 Roi11 – 241.16 Rat8 + 341.37   [21]

The explanation of the variables, used in these equations, is shown in Table 6.

TABLE 6. Variables used for ZME determination using ^{137}Cs source.

Roi	Rat
Roi14 (75-105 KeV)	Rat7 (190.5-210)/(105-142.5 KeV)
Roi1 (30-52.5 KeV)	Rat8 (135-180)/(51-100.5 KeV)
Roi7 (180-232.5 KeV)	Rat5 (165-262.5)/(45-105 KeV)
Roi6 (135-180 KeV)	
Roi11 (37.5-60 KeV)	

Results and Discussion

The comparison between the backscattered γ-γ results, obtained by using [133]Ba and ^{137}Cs sources, can be enumerated as follows:

1. It is observed that changing the separation between the source and detector from 40 mm to 88 mm does not have a big influence on the recorded spectra.

2. It was found from Table 2 that the 52 mm configuration is considered to be the best that is adapted for both Pb and ZME quantitative determinations (Asfahani, 1999). For that configuration, the smallest r.m.s and highest Rc were obtained, using very low radioactivity of 133Ba source. The r.m.s. deviations between γ-γ prediction and laboratory assay was 0.33% Pb. This r.m.s represents a measure of the accuracy in determining the average grade based on the laboratory chemical assay of the core sample. The standard deviation (σ) for the population were 2.3% Pb and 13.4% ZME. In general the standard deviation σ is defined as:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}} \qquad [22]$$

where, x_i are the core values chosen in the calibration equation, $\bar{x}$ is the mean and n is the number of samples.

The r.m.s. deviation between laboratory assay and the tool prediction was 2.3% ZME. The two variables, used in equation 8, have physical meanings. Rat3 considered as P_z ratio is related to the chemical composition of Zn e.g. %ZME, while Roi3 is almost related to the density of ore material.

3. It is evident from Table 5 that 64 mm probe configuration is considered as compromise for both Pb and ZME prediction using very low radioactivity of ^{137}Cs source, (Asfahani, 1999). For this configuration, the r.m.s. deviation between γ-γ prediction and laboratory assay was 0.36 % Pb. The r.m.s deviation between laboratory assay and the tool prediction was 2.2% ZME.

The standard deviation for the population σ was 2.33 % for Pb. The standard deviation for the population σ was 13.465% for ZME. The two variables used in equation 19 have the same physical meaning as that used in equation 8.

4. The spectral parameters, used in regression analysis for both [133]Ba and ^{137}Cs sources, are statistically significant and have physical meaning.

5. The variables, used in the calibration equations for Pb prediction (Roi2, Rat2) are the same for [133]Ba and ^{137}Cs sources.

6. The sensitivity of tool logging, using both [133]Ba and ^{137}Cs sources, were also tested and compared. The sensitivity S is defined as :

$$S = \frac{\frac{Y2-Y1}{\overline{Y}}}{\frac{X2-X1}{\overline{X}}} \qquad [23]$$

where   Y1, Y2 : are the predicted values for two data points 1,2.

   $\overline{Y}$: the predicted average of 13 data points.

   X1, X2 : are the chemical values for two data points 1,2.

   $\overline{X}$: the chemical average of 13 data points.

The absolute and relative average errors $\overline{E}$, $\overline{E}$ for the determination of a given Vk, are calculated from the following formulae:

$$\overline{E} = \frac{\sum_{i=1}^{n}\left[V_{k,i}^c - V_{k,i}^p\right]}{n} \qquad [24]$$

$$\overline{Er} = \frac{\sum_{i=1}^{n}\frac{\left[V_{k,i}^c - V_{k,i}^p\right]}{V_{k,i}^c}}{n} \qquad [25]$$

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where: $V^c_{k,i}$ and $V^p_{k,i}$ = i^{th} value of the chemical and predicted k^{th} parameter Vk.

n: number of data points.

The values of $\overline{E}$ and $\overline{E}r$ were calculated from 13 data points for all the studied configurations.

Results of S, $\overline{E}$ and $\overline{E}r$ are tabulated in Table 7. One can notice that there is a slight difference in sensitivity when ^{133}Ba source is used compared to ^{137}Cs source. However, if we compare this sensitivity in the case of 52 mm-probe configuration for both ^{133}Ba and ^{137}Cs sources, we notice that the sensitivity of 133Ba source is slightly better than that of ^{137}Cs one.

TABLE 7. Sensitivity of tool logging using ^{137}Cs and ^{133}Ba source.

| S-D Spacing | ^{133}Ba source | | | | | | ^{137}Cs source | | | | | |
| | % Pb | | | % ZME | | | % Pb | | | % ZME | | |
	S	E(%pb)	Er(%)	S	E(%ZME)	Er(%)	S	E(%pb)	Er(%)	S	E(%ZME)	Er(%)
40 mm	0.764	0.30	8.6	0.954	2.014	9.2	0.917	0.212	4.3	1.07	1.781	7.6
52 mm	0.876	0.230	5.2	1.057	1.392	5.9	0.837	0.269	7.9	1.04	1.742	5.4
64 mm	0.861	0.29	9.3	1.069	1.666	6.6	0.881	0.241	5.8	0.924	1.59	11.5
76 mm	0.872	0.236	6.3	1.062	1.805	7.0	0.944	0.204	7.2	1.1	1.99	11.6
88 mm	0.84	0.249	7.3	1.050	1.785	6.5	0.770	0.257	7.7	1.09	1.850	6.7

7. Taking into account the r.m.s. Rc, and the sensitivity obtained using ^{133}Ba and ^{137}Cs sources for the five probe configurations, it appears that the performances of tools with ^{133}Ba and ^{137}Cs sources are comparable.

8 . The fact that the tool can predict ZME suggests that there is a potential for the quantitative determination of the % Zn content in the samples, provided that supplementary physical techniques are used to assess the Fe content while the Pb content could be readily determined concurrently from spectral response at the Pb X-ray peak.

Summary and Conclusions

The present work demonstrates that the low activity logging tools with the configuration described in this paper can be successfully employed in the metalliferous mining industry for the determination of Pb and ZME in bulk Pb-Zn ore samples. The activities of the gamma-ray sources used with the present tools are so low that they do not require special shielding. This makes the tools suitable

for underground mining operations in horizontal borehole or for portable logging systems particularly where weight is an important consideration. The tool configuration was chosen so that it enhances the contribution of the low energy region in the backscattered γ-ray spectrum.

Experimental results show that the optimum configuration is 52 mm source-detector spacing when [133]Ba source is used, and is 64 mm when ^{137}Cs source is applied.

The low activity ^{137}Cs does not need an extra source for spectrum gain stabilization, where the same source is used for both primary sources of radiation and gain stabilization. In addition, ^{137}Cs source is characterized by longer half-life and greater penetration effect of its gamma radiation.

The low activity [133]Ba source however necessitates an additional ^{137}Cs microsource for gain stabilization.

This technique has considerable potential for the determination of Zn grade in special cases when the concentration of elements with high atomic number like Fe, Mn, Cu is constant or can be estimated by other methods

Acknowledgements

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سابرة غاما–غاما الطيفية البئرية للصناعة التعدينية باستخدام مصادر إشعاعية منخفضة

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هيئـة الطاقـة الذريـة ، قسم الجيولوجيا
دمشق– سوريا

المستخلص .   طبقت تقانة غاما–غاما الطيفية البئرية بشدات إشعاعية منخفضة لتحديد محتوى الرصاص والتوتياء (الزنك) كميا واستخدمت سابرة ممركزة ومصدر من أشعة غاما ذو شدة إشعاعية منخفضة من مرتبة ١٫٨ ميغـا–بيكرل (MBq). اختبرت السـابرة البئريـة بشكل منفصل باستخـدام البـاريوم ١٣٣ والسـيزيوم ١٣٧، وكاشف عبـارة عن بلورة الصوديوم المشعة بالتنتاليوم أبعادها ٣٧مم × ٧٥مم .

تم في هذا البحث دراسـة خمسـة تشكيلات مـابين المنبع والكاشف ، كمـا تم أيضـا التوصيف الكمي لمعادلات المعايرة للرصاص والزنك المعدني المكافئ (ZME) للتشكيـلات المدروسـة باستـخدام السـيزيوم والباريوم . ووجد أن التشكيل الأمثل في حالة استخدام مصدر الباريوم هو ٥٢مم بين المنبع المشع والكاشف . يعطي هذا التشكيل أفضل النتائج من حيث تحديد محتوى Pb و ZME ، فقد كانت الانحرافات المعيارية (r.m.s) لكل من Pb و ZME من ٣٣٫ ٠٪ إلى ٢٫٣٪ على التوالي . كما وجد أن التشكيل الأمثل في حالة استخدام مصدر السيزيوم هو٦٤مم بين المنبع والكاشف ، وهذا التشكيل يعطي أفـضل النتـائج إذ كـانت الانحـرافـات المعيـاريـة لكل من Pb و ZME ٣٦٫ ٠٪ و٢٫٣٪ على التوالي. تكمن ميزة استخدام السيزيوم كمصدر مشع بحيث أنه لاحاجة إلى مصدر آخر للحصول على القمة عند ٦٦٢KeV ، والتي تستخدم لاستقرار الأطياف عند تنفيذ القياسـات البئرية . إضـافة إلى ذلك فإن مصـدر السيزيوم المستخدم يتصف بنصف عمر أكبر ، كما أن إشعاعات غاما الصادرة عنه تتميز بعمق اختراق أكبر. في حين يتطلب استخدام

الباريوم كمصدر مشع وضع مصدر مشع إضافي من السيزيوم ، وذلك
للحصول على استقرارية الأطياف .

تعتبر السابرة المستخدمة حساسة تجاه تغيرات العدد الذري Zeq للمواد
الصخرية المحيطة بالبئر، وبالتالي يمكن استخدام هذه السابرة في عدة
تطبيقات في مجال الصناعة المنجمية التعدينية من أجل تحديد الأجسام
الخامية. تعتبر هذه السابرة مثالية للاستخدام كنظام بئري محمول وفي
العمليات المنجمية تحت السطحية، بسبب وزنها الخفيف من جهة ،
وللشدة الإشعاعية المنخفضة جدا لمصدر غاما من جهة أخرى .