CHAPTER 6

INSTRUMENTATION FOR GAMMA RAY LOGGING OF BOREHOLES, SHOT HOLES AND FACES IN MINES AND TRENCHES IN RADIOACTIVE OUTCROPS

6.0 Introduction

In the exploration program for radioactive metals, once an ore deposit has been inferred, the uranium or thorium resources are evaluated (i.e., finding tonnage and grade of ore) on the basis of drill-hole logging. Finally, if mining operations are started, they are continuously supported by radiometric methods for controlling ore grade.

System Borehole Logging version number 2A (SBL-2A) is available at the Atomic Minerals Directorate for Exploration and Research, Department of Atomic Energy, India and is a portable equipment to evaluate the grade of deposit at different depths in a borehole. It consists of a GM tube as detector and counting rate meter (CRM) to display the grade of the ore. The thickness of ore zones are obtained using depth recorder. This system can also be used for logging surface trenches in radioactive outcrops; mapping the mines faces and logging of shot holes for finding the direction a mines drive will move.

6.1 Gamma ray logging equipment

The block diagram of SBL-2A is shown in Fig.6.1 in which the logging sonde (probe) is connected to the CRM by an armored cable, which passes over a depth recording pulley and winch.

BNC connector makes winch to CRM connection. SBL-2A is a direct reading instrument, which records the grade as \(\%e\text{U}_3\text{O}_8\) at any point during the gross count gamma logging of the borehole. When this system is used for mapping the faces in uranium mines or trenches, a hemispherical lead shield (see sec. 6.7) is required to cover the G.M tube.
6.2 Logging probe

The probe housing (brass tube of approx. 1m length) contains an EHT (electrical high tension) circuit; a line driver circuit (i.e., emitter follower) and a GM tube (10cm long) as detector (Fig.6.2).

![Block diagram of logging probe](image)

Fig. 6.2 Block diagram of logging probe

The EHT circuit generates the bias voltage for the detector. This circuit consists of a blocking oscillator, step up transformer (Pulse transformer), voltage multiplier and regulator (Quadrupler and RC filter). It is also shown in Fig.6.2. The blocking oscillator has been wired around transistor (2N 2907) and a transformer to generate 2.2 kHz square wave and secondary voltage (output of transformer) of approx. 500 V peak to peak. The secondary voltage of the transformer is rectified and multiplied by a quadrupler circuit. 900 volts VR tube and two 50 volts neons to give 1000 volts then regulate the voltage. The required bias to the detector is supplied from the above-generated voltage, filtered by a RC combination and applied to the detector through a 2.2 MΩ load resistor.

The GM tube (EC 1015) gives negative pulses of about 80 µsec width. A line driver, which is an emitter follower circuit, transmits these pulses to the surface. The armored cable, which brings the DC supply (12 volt) to the probe, also carries pulses to CRM on the surface.

6.3 Counting Rate Meter (CRM)

The CRM circuit consists of an amplifier, monostable multivibrator, transistor inverter, integrator and a battery compartment to give DC power of 12V (Fig.6.3).

A common base amplifier amplifies pulses from the probe. The amplified pulses are fed to the monostable multivibrator (IC 74121) to get pulses of constant width. The supply voltage (5V) required for IC is derived from the 12V supply through a regulator (not shown in Fig.6.3) consisting of a 5.1V zener diode and a transistor (BC 107). The pulse width of the monostable can be adjusted by a 4.7 kΩ single turn carbon potentiometer (coarse control) located on CRM card which is in series with a 1 kΩ wire wound potentiometer (fine control). The later is brought out on the front panel as 'CALIBRATE' control. This pulse width variation is useful in calibrating the CRM for different GM probes.
Fig. 6.3 Block diagram of counting rate meter

The pulses from the monostable multivibrator are converted into 5V pulses by the transistor inverter and are fed to the integrator circuit built around transistor (2N 2907) for integration of pulses. The 5V pulses are brought out on the front panel through a BNC connector. The sensitivity of integrator circuit can be changed by selecting different emitter resistances of transistor (2N 2907) through the ‘Range’ switch provided on the front panel. The time constant of the integrating circuit can be changed by selecting different resistances by the ‘RC(sec)’ switch on the front panel. The grade display meter, which is a micro ammeter (0-50 µA) connected to the integrator circuit reads the grade of the ore as %$\text{U}_3\text{O}_8$ because the rate of current is calibrated with respect to a standard source of radiation (secondary standard at the drill site). The current flowing through the micro ammeter is directly proportional to the pulse width, pulse height, number of pulses and inversely proportional to the resistance in the emitter of 2N 2907 transistor. Varying the width of the monostable and changing the emitter resistor of the transistor 2N 2907, we can control the sensitivity of the CRM.

**EHT card** – This card consists of a DC to DC converter (see Fig.6.2) and an amplifier to amplify the pulses coming from the detector. The EHT bias voltage required by the external detector, like the one in shielded probe and in shot hole probe, is generated by this EHT card.

The specifications of CRM are as follows.

(i) Range : Six ranges viz., CONF, 0.015, 0.05, 0.15, 0.5 and 1.5 %$\text{U}_3\text{O}_8$ are selectable through a switch.
(ii) Time Constant : 1, 2, 5 and 10 sec switch selectable.
(iii) Sensitivity : about 4.5 pulses per second for 0.01 %$\text{U}_3\text{O}_8$.
(iv) Power requirement : 12 V DC, 45 mA.

### 6.4 Logging a hole

CRM is calibrated for direct reading only where the geometry is $4\pi$ (see sec. 6.5) i.e., in borehole or shot hole logging but not for shielded probe logging where geometry is $2\pi$. At the drill site, first of all, probe is connected to the CRM and is kept at a place having low radiation background. Then the instrument is switched on and a range appropriate to the value of secondary standard is selected. The background reading is noted by selecting a time constant (RC) of 10 sec. With the probe in the same place the secondary standard is slid over the probe to obtain the maximum reading on the meter. Generally probe shell has marking indicating the location of the detector. Then the ‘CALIBRATE’ potentiometer is adjusted with a screwdriver to bring the meter reading to a value equal to the value of the secondary standard plus the background reading noted earlier. While calibrating at least 10 readings separated by regular time intervals equal to 5 times...
the time constant of the CRM should be taken and averaged. Now the instrument will be ready to
read %eU₃O₈ directly. The probe is lowered to a measuring point in the borehole and held
stationary while the reading at the point is recorded. The distance between the measuring points is
usually 10 cm in active zones and 20 cm in inactive zones. In this way the whole borehole is
logged on point – to – point basis.

6.5 Geometry

The solid angle subtended by a spherical surface of radius r, at its center is given by;
spherical surface area/(radius)^2 \Rightarrow 4\pi r^2/r^2 \Rightarrow 4\pi.

Here any radius drawn, is perpendicular to the tangent at the point where it cuts the
surface. This means that the angle between the direction of 'r' and perpendicular to an element of
surface (\delta s) taken at that point is zero. If this angle is \theta, then solid angle amount will be given by;
\[ d\Omega = (\delta s \cos(\theta))/r^2. \]

In spherical coordinate system (r,\theta,\phi); it assumes an expression of the following form (Fig.
6.4):
\[ d\Omega = [rd\theta rSin(\theta) d\phi]/r^2. \]

Fig. 6.4 Diagram showing the solid angle subtended by an element of surface dAₛ in spherical polar
coordinate system
As the shielded probe is allowed to receive the source–radiation from a hemispherical volume, the solid angle subtended at the detector-point is $2\pi$.

### 6.6 Shot hole logging

The detector is a GM tube (10cm long), which is kept in a brass housing of length 15 cm (Fig.6.5) and is fixed to a 5 ft long conduit pipe.

![Diagram of shielding and detector](image)

**Fig. 6.5 Schematic diagram for logging systems**

At the other end of this conduit pipe some more pipes are connected depending upon the length of shot hole (varying between 10 and 15 meter). The high voltage bias to the detector is given through a long tough rubber sheathed cable passing through the conduit pipes and connected to the counting rate meter. For proper functioning in the humid environment of the mines, the CRM is made moisture proof. The analog display in the meter is calibrated against a secondary standard. The shot hole logging results, when presented in the form of a plan, help to delineate the ore body on the mines face.

Shot holes or blast holes drilled in the mine faces are radiometrically logged before the blasting operation. Mines face, line of foliation, shot holes and long holes in a mines drive face are illustrated in Fig.6.6. A coordinate system is marked on the face and the average foliation dip is measured with respect to this coordinate system. Lines (2 cm apart) parallel to the foliation are drawn to cover all the holes above the cut off value of selected $\%eUO_2$. This gives rise to bands. Values that fall in each band are averaged and the average value is assigned to each band. The area of each of these bands is calculated and multiplied by its assigned value. In the case where waste is also there, bands are drawn likewise and area grade is calculated. The sum of all these products divided by the total area gives the grade of the blast. There may be considerable differences in grades as obtained by shot hole logging and channel sampling (Table 6.1). This may happen due to inhomogeneous distribution of mineral grains in sampling volumes. In channel sampling the sample drawn represents a very small depth of the ore body whereas shot hole log gives the average value of the ore body to a depth of a few meters.
However, in general, the average values obtained by the two methods over considerable lengths of the drives are normally found to be in agreement.

Fig. 6.6 Illustration of mines drive face
Table 6.1. Comparison of shot hole logging and channel sampling data.

<table>
<thead>
<tr>
<th>Average of the blast</th>
<th>Number of tubs</th>
<th>Radiometric logging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiometric logging(%)</td>
<td>Scoop sampling(%)</td>
<td>Thickness of lode(”)</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>0.054</td>
<td>0.050</td>
<td>15</td>
</tr>
<tr>
<td>0.061</td>
<td>0.054</td>
<td>15</td>
</tr>
<tr>
<td>0.081</td>
<td>0.084</td>
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</tr>
<tr>
<td>0.079</td>
<td>0.072</td>
<td>18</td>
</tr>
<tr>
<td>0.074</td>
<td>0.070</td>
<td>12</td>
</tr>
<tr>
<td>0.098</td>
<td>0.070</td>
<td>20</td>
</tr>
<tr>
<td>0.067</td>
<td>0.058</td>
<td>6</td>
</tr>
<tr>
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<td>0.071</td>
<td>10</td>
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<tr>
<td>0.063</td>
<td>0.055</td>
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<tr>
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<td>0.063</td>
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<tr>
<td>Total</td>
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<td>231.5</td>
</tr>
<tr>
<td>Average</td>
<td>0.069</td>
<td>0.068</td>
</tr>
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</table>

Ave.Assay x Width = \[ \sum (\text{Assay x width x length})/ \text{Total length} \]

\[ = [(78\times 0.060\times 4) + \ldots]/64 = 6.8. \]

6.7 Shielded probe logging of trenches or mine faces

The radioactive material surrounding the detector influences the response of the detector. This mass effect is pronounced in trenches, pits or inside the mines. To cut off the gamma rays from all other sides except the viewing side, the detector, usually a GM tube (10cm long) is mounted inside a semi cylindrical lead shield of about 1” thickness (cutting off 86% of 1 MeV gamma rays) and 23cm length (inner end to end). It is shown in Fig.6.5. The background is taken by covering the opening of the shield by another rectangular lead shield. This way the detector is completely surrounded by lead shield.

The detector response is calibrated against a flat secondary standard. In this case, CRM will not read directly in terms of %e\text{U}_3\text{O}_8 instead the reading has to be multiplied by a constant factor. The high voltage bias to the detector is given through a long tough rubber sheathed cable from the counting rate meter. This shielded probe is used in the logging of trenches and mapping of mines faces. Manual excavation like pitting and trenching followed by shielded probe logging paves the way for exploratory drilling. Khedkar in 1950s located a large number of surface anomalies by this method in the Singhbhum area of Jharkhand state, covering a distance of 200 km.

An illustrative example for the presentation of the log data for purposes of radioactive metal exploration is shown in Fig.6.7. Shielded probe \(\gamma\) ray log data are presented in terms of grade and thickness product coupled with the radiometric assay values of samples collected from the areas
Sample assay values are shown in the form of ratios such as \( \text{eU}_3\text{O}_8/\text{U}_3\text{O}_8 \) and \( \text{ThO}_2/\text{U}_3\text{O}_8 \) (chem.) side by side. At some places (denoted by *) \( \text{U}_3\text{O}_8 \) values are strikingly different than logged ones. Disequilibrium in uranium series prevails in these cases.

**6.8 Statistical analysis of the counting rate meter**

The counting rate meter is a pulse integrating and averaging instrument with an electrical, exponentially decaying memory. The average current to the output meter is proportional to the counting rate for constant sources or for decaying sources whose mean life is significantly greater than the time constant \( RC \) of the output tank circuit. This \( RC \) is analogous to a radioactive mean life and may be regarded as the mean memory time. While the output current depends only on the output resistance \( R \), and not on the output capacitance \( C \) (except for very rapidly decaying sources), the statistical fluctuations in the output current depend upon \( RC \), and are equivalent to the fluctuation expected in a time interval of \( 2RC \). Expressions are given for the condenser charge \( Q \), or output current \( Q/RC \), for constant source of radiation, as well as for the expected fractional statistical fluctuations.

A condenser \( C \) shunted by a resistance \( R \) (Fig.5.14, chap.5), so arranged that a charge \( q \) is placed on the condenser each time the instrument receives a pulse. The current in the output meter is always proportional to the total charge on the condenser.
6.8.1 Theory for Constant Source

a. Average output

We shall first assume that the average or expected number of pulses received per unit time has the constant value $x$. The pulses are assumed to arise individually and collectively at random from a source of constant strength; they are therefore distributed in time according to Poisson's law. The number expected during the time interval $t$ to $t+dt$ is $xdt$, and the expected increment of charge on the condenser in this interval is $qxdt$. If now a reading is taken at a later time $t_0$, this charge will have decayed to $qxe^{-\frac{(t_0-t)}{RC}}dt$.

Assuming that the instrument has been operating for a time long compared to $RC$, the expected value of the charge at the time of reading ($t = t_0$) is given by an integral over $t$, the lower limit of which is effectively $-\infty$. Thus the expected charge $Q$ at any time is

$$Q = \int_{-\infty}^{t_0} qxe^{-\frac{(t_0-t)}{RC}} dt = qxRC \quad (6.1)$$

This relation can also be obtained from a more intuitive picture. When a steady state is reached, the average current through the resistance $R$ must equal that flowing into the tank circuit, or $q$. This produces an average potential drop $qR$ across the resistance, which must equal the average voltage drop $Q/C$ across the condenser if the system is to be in equilibrium. This gives Eq.(1) immediately since the reading of the output meter is proportional to $Q$, we see that the expected value of this reading is proportional to the average counting rate $x$.

It is obvious that Eq.(1) holds for either statistically distributed or periodic counts, thus a periodic source of known frequency can be used to calibrate the instrument.

b. Statistical fluctuations in a single observation

In finding the expected standard deviation (S.D.) of a single reading we use the statistical result that this quantity is $N^{1/2}$ if $N$ events are expected in a given time interval; provided that the events are distributed at random, that is according to Poisson's law. Thus the expected S.D. of the charge placed on the condenser between $t$ and $t+dt$ is $q(xdt)^{1/2}$, and the contribution of this deviation to the deviation of the condenser charge observed at a time $t_0$ is $q(xdt)^{1/2}e^{-\frac{(t_0-t)}{RC}}$. Since all these contributions are independent they arise from independent intervals $dt$, we sum (or integrate) their squares to obtain the square of the deviation of the whole reading. This gives for the expected S.D. squared of a single condenser charge reading observed at any time:

$$(\delta Q)^2 = \int_{-\infty}^{t_0} q^2xe^{-\frac{(t_0-t)}{RC}} dt = q^2xRC/2 \quad (6.2)$$

The expected fractional S.D. of a single reading is then

$$\sigma_1 = \delta Q/Q = (2xRC)^{-1/2} \quad (6.3)$$

The corresponding fractional probable error being $p_1 = 0.6745\sigma_1$.

At 0.10% eU$_3$O$_8$ of material grade, $x$ is 5 c.p.s (for GM tube detector). Taking a value of RC = 5 sec, 1$\sigma$ r.s.d becomes 14%. Minimum detection limit of log equipment is therefore taken to be 100 ppm at 14% precision of data.

For scintillation probe having $3/4" \times 2"$ NaI(Tl) crystal, a different system named SBL-4A is used for recording gamma counts in integral mode (i.e., without any differentiation among Th, $^{40}$K
and U emitted gamma energies) in a specified time. With this probe, grade level up to 10 ppm can be estimated with the same precision as that provided by the GM probe for 100 ppm eU$_3$O$_8$.

**Bibliography**

Instruction manual for System Borehole Logging (SBL-2A) from Department of Atomic Energy, Atomic Minerals Directorate for Exploration and Research, Hyderabad.

