# Statistical Comparison of Gamma Logs Between the Gearhart-Owen Mineral Logging System and the Mount Sopris System

Christopher Stohr

**Open File Series 2014-1**

ILLINOIS STATE
GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

**ILLINOIS STATE GEOLOGICAL SURVEY**
Prairie Research Institute
University of Illinois at Urbana-Champaign

***Cover photographs:*** *(a) Christopher Stohr operating the converted Gearhart-Owen Industries, Inc. Mineral Logging System (MLS). (b) Michael Barnhardt using a gamma log to aid in interpreting core. (c) Interpretation of three gamma logs for Quaternary sediments showing the relationship of gamma counts per second to amounts of silt and clay. (d) Antigone Dixon-Warren inserting an MLS gamma sonde into a newly drilled borehole for a water well. (e) Monitor and controls of the converted MLS logging system. (f) Gamma logs from the MLS and Mount Sopris systems for an ISGS test hole showing the peak at 265.67 foot depth of the test hole used for standardization alignment. (g) Keegan Gallagher, one of several students who performed geophysical logging using the two systems during summer field seasons, collecting single-frequency differential GPS for elevation and location of a water well. (h) Phil Reed initiated downhole logging at the ISGS operating the converted Gearhart-Owen Industries, Inc. MLS. Winch is in the foreground. (i) Andrew Stumpf using the Mount Sopris System to gamma log a new water well. (j) Geophysicist Timothy Young logging a well using a Mount Sopris system. (k) Eduard Breuer, one of several students who used a sieve to catch samples from newly drilled water wells and performed geophysical logging using the two systems during summer field seasons.*

<table>
<tr><td>a</td><td>b</td><td>c</td><td rowspan="2">d</td></tr>
<tr><td>e</td><td>f</td><td>g</td></tr>
<tr><td>h</td><td>i</td><td>j</td><td>k</td></tr>
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I L L I N O I S

**ILLINOIS STATE GEOLOGICAL SURVEY**
Prairie Research Institute
University of Illinois at Urbana-Champaign
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## Summary

Downhole natural gamma-ray logs provide important lithologic data based on radioactive decay and the proportions of potassium, uranium, and thorium contained in predominantly clay minerals. These data provide important information for many geologic uses in hydrogeology and three-dimensional geologic mapping.

A combined analog Gearhart-Owen Industries, Inc. Mineral Logging System (MLS) with a Widco winch was converted to a digital system by Mount Sopris Instrument Company, Inc. in 1995 for the Illinois State Geological Survey (ISGS). The MLS gamma (sodium iodide) sonde was used with the system to gather lithologic information for glacial and bedrock geology studies until 2004. This system was replaced in 2004 with a Mount Sopris 4MXC digital logging system, which uses a combination gamma, spontaneous potential (SP), and single point resistance (SPR) probe (serial no. 3342) for the same purposes. The observations recorded by the new system have greater counts per second (cps) values than those of the system it replaced despite having a smaller sodium iodide crystal.

A regression of downhole logs made by the two systems at the ISGS Test Hole on the South Farm of the University of Illinois at Urbana-Champaign compares the systematic difference in their measurements. Analysis indicated a high correlation ($R^2$, 0.97) between logs made with the Mount Sopris gamma 3342 and the MLS sonde/probe. The data from both logs were recorded at a rate of 10 feet per minute and adjusted to a common layer at a depth of 265.67 feet. In this study, we concluded that the cps values of the older MLS sonde/probe system should be multiplied by 1.66 to achieve an equivalent value for observations made with the newer Mount Sopris gamma 3342 probe.

## Background, Statistical Analysis, and Discussion

Downhole geophysical gamma logs measure the energy emitted from the radioactive decay of potassium, uranium, and thorium naturally occurring in lithologies, predominantly in clay minerals. Because the energy measured is largely proportional to the amount of clay minerals in a lithology, the logs indicate gradational or abrupt changes in the lithologic or mineralogical components of unconsolidated sediment and rock. Depending on the lithologic composition of the sediment or rock, natural gamma radiation can be used as a proxy for grain size. Interpretation of the magnitude of the measure of gamma radiation is used for setting screens for wells, delineating stratigraphic units for three-dimensional geologic mapping, and other geologic purposes (Keys 1990; Dixon-Warren and Stohr 2003; Bleuer 2004; Stohr et al. 2004).

Between 1989 and 1995, the Illinois State Geological Survey (ISGS) used an analog Gearhart-Owen Industries, Inc. Mineral Logging System (MLS) with a Widco winch, using the gamma lithology sonde for groundwater and mineral resource and geologic mapping studies. In 1995, the analog system was converted to a digital system by the Mount Sopris Instrument Company, Inc. (Denver, Colorado). The detector was replaced at the end of July 2003 with a crystal of the same size and diameter. Hundreds of wells in Illinois have been downhole logged using the MLS lithology sonde.

An invoice for the sodium iodide (NaI) or scintillation detector shows the dimensions of the detector crystal to be 1 inch in diameter by 4 inches in length (Appendix A). The volume of the MLS cylinder is 12.57 cubic inches or 205.93 cubic centimeters.

In 2004, the ISGS purchased a Mount Sopris 4MXC digital logging system to replace the aged converted analog downhole geophysical system. The Mount Sopris system uses a 2PGA-1000 poly-gamma combination gamma, spontaneous potential (SP), and single point resistance (SPR) probe (serial no. 3342).

Specifications for the Mount Sopris NaI gamma detector are 0.875 inches in diameter by 3.0 inches long (Appendix B). The volume of the Mount Sopris cylinder is 7.22 cubic inches or 118.25 cubic centimeters.

Sodium iodide crystals of different sizes and sondes having different electronic components will produce “markedly different count rates in the same well at the same depth” (Keys 1990, p. 80). Logging systems measure the amount of gamma radiation in counts per second (cps) based on the scintillation of the NaI crystal, which emits light in proportion to incident radiation, as described previously. The ratio of the crystal volumes of the older and newer systems is 1.74.

Counterintuitively, the new system, which has a smaller crystal, records higher cps than does the older system, which has a larger crystal. To standardize observations made by the two systems, a 314-foot-deep, 2-inch-diameter PVC-cased borehole was logged on August 4, 2004, using the converted MLS gamma sonde. The test hole is located on the South Farm of the University of Illinois at Urbana-Champaign south of Windsor Road and west of the Lincoln Street extension. Coordinates of the test well are 40.080395 m (±0.02 m) north, 88.218892 m (±0.01 m) west, 217.59 m (±0.06 m) NAD83/NAVD88.

Observations were compared with a log of the same test well made on September 7, 2004, using the newly acquired Mount Sopris Instrument Company, Inc. 4MXC combination gamma, SP, and SPR probe, serial no. 3342 (hereafter, Mount Sopris 3342). Both logs were made from the bottom to the surface at a rate of 10 feet per minute. The logs were found to be out of alignment by 1.23 feet when visually compared, and abrupt contacts were inspected both as plots and in the measured data. Relative depths were adjusted to a 0.9-foot-thick layer displaying a peak at 265.67 feet (Mount Sopris 3342).

Copies of both logs are found in Appendix C. Summary statistics of the two logs show that cps of the newer system are larger (Table 1). Analysis of the logs by simple linear regression was done to determine whether the difference between the two logs was systematic and whether data from the logs were directly comparable.

**Table 1** Summary statistics of gamma observations of a test hole using the Gearhart-Owen Industries, Inc. Mineral Logging System (MLS) and the Mount Sopris Instrument Company, Inc. probe no. 3342 (Mount Sopris 3342)

| Statistic | MLS, cps | Mount Sopris 3342, cps |
|---|---|---|
| Mean | 49.5 | 82.60 |
| Median | 38.9 | 65.50 |
| Mode | 36.4 | 87.62 |
| Standard deviation | 46.2 | 78.81 |
| Sample variance | 2,130.8 | 6,210.28 |
| Range | 446 | 803.33 |
| Minimum | 5.8 | 4.67 |
| Maximum | 451.8 | 808 |
| Count | 3,115 | 3,115 |

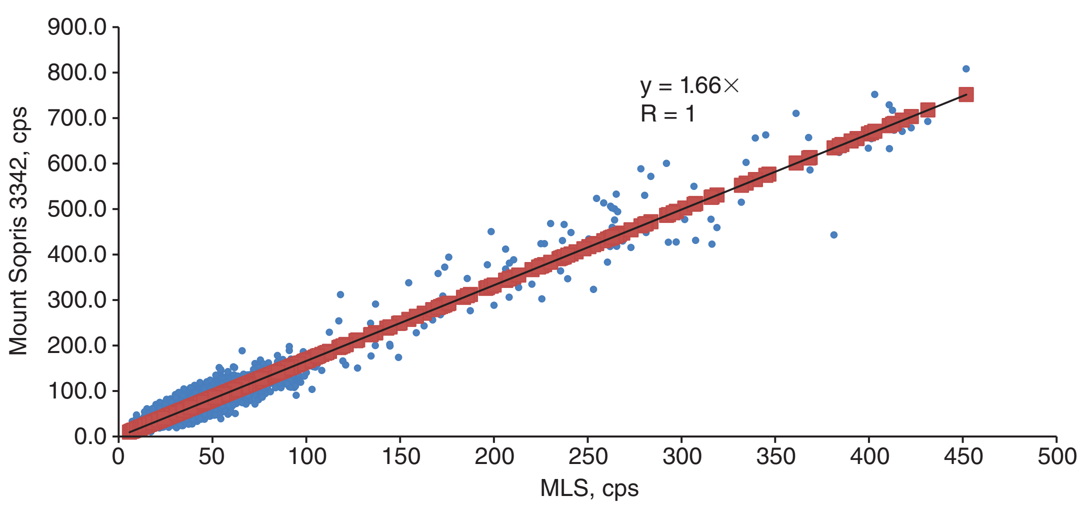



**Figure 1** Comparison of direct and predicted gamma observations for logs of a cased borehole using the Gearhart-Owen Industries, Inc. Mineral Logging System (MLS) and the Mount Sopris Instrument Company, Inc. probe no. 3342 (Mount Sopris 3342).

**Table 2** Summary regression statistics of gamma observations of a test boring using the Gearhart-Owen Industries, Inc. Mineral Logging System (MLS) and the Mount Sopris Instrument Company, Inc. probe no. 3342 (Mount Sopris 3342), with the Mount Sopris 3342 as the dependent variable

Regression statistics

| Statistic | Value |
|---|---|
| Multiple R | 0.986 |
| $R^2$ | 0.973 |
| Adjusted $R^2$ | 0.972 |
| Standard error | 18.860 |
| Observations | 3,115 |

One-way analysis of variance[1]

| Statistic | df | SS | MS | *F* | Significance *F* |
|---|---|---|---|---|---|
| Regression | 1 | 39,479,220 | 39,479,220 | 110,985.1 | 0 |
| Residual | 3,114 | 1,107,701 | 355.716 | | |
| Total | 3,115 | 40,586,920 | | | |

Regression coefficients with and without an intercept through the origin

| Statistic | Coefficient | Standard error | *t* | *P*-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 0 | NA | NA | NA | NA | NA | NA | NA |
| MLS, cps | 1.664 | 0.005 | 333.144 | 0 | 1.654 | 1.674 | 1.654 | 1.674 |

[1]df, degrees of freedom; SS, sums of squares for regression and error; MS, mean square of regression and error (i.e., SS/df); *F*, *F*-statistic; significance *F*, has a statistically meaningful correlation; *t*, *t*-statistic; NA, not applicable.

The Mount Sopris 3342 log was used as the dependent variable for simple regression analyses calculated by modeling without a constant. Analysis of 3,115 gamma observations along the 314-foot-deep, 2-inch-diameter boring yielded a coefficient of determination ($R^2$) of 0.97 without an intercept (i.e., the model was forced through the origin; Figure 1). The model was forced through the intercept to compare systematic differences in the radiation measured by the two sondes. The summary regression statistics (Table 2) show that observations of the two gamma logs were highly correlated, which was expected. The modest standard error was likely caused by natural variation of the earth materials and radioactive disintegration, which would be observed if the probes recorded data at a single depth for a length of time (Keys 1990).

The regression slope is calculated to be 1.66. Consequently, observations made with the Mount Sopris 3342 gamma probe would be approximately 1.66 times the value of observations made using the MLS gamma probe. This could be stated as

Mount Sopris 3342 observation (cps) ≈ 1.66 × MLS observation (cps).

Interpreters of natural gamma logs will recognize that direct numerical equivalency of logs is almost impossible for physical and operational reasons, such as (1) natural variation in gamma emissions of sediments; (2) differences in casing diameter, thickness, and materials; (3) borehole diameter; and (4) moisture inside the casing and in sediments, which can attenuate radiation (Keys 1990). The length, diameter, and sensitivity of NaI crystals used for radiation measurement and other variables complicate direct correlation of the records of gamma logs (Keys 1990). Although the original and replacement NaI crystals are not comparable, the common dimensions and electronics should yield similar cps measurements.

This exercise is intended to provide general guidance for comparison of the numerous logs made by these two systems that have been in general use by the ISGS.

## Acknowledgments

Timothy Young provided the historical chronology regarding modification of the Gerhart-Owen Industries, Inc. MLS by the Mount Sopris Instrument Company, Inc. and instructed the author and colleagues on gamma and other types of downhole geophysical logging and petrophysics. The author is indebted to Young for his continued advice and consultation on logging and interpretation of all types of logs. Ned Bleuer (Indiana Geological Survey) and Steven Brown (Indiana Geological Survey, ISGS) instructed the author on campaign downhole geophysical logging and sampling of water wells drilled by the mud rotary method as used for mapping glacial geology in Indiana. George Asquith, Texas Tech University, consulted with the author on standardizing the gamma logs by regression analysis.

## References

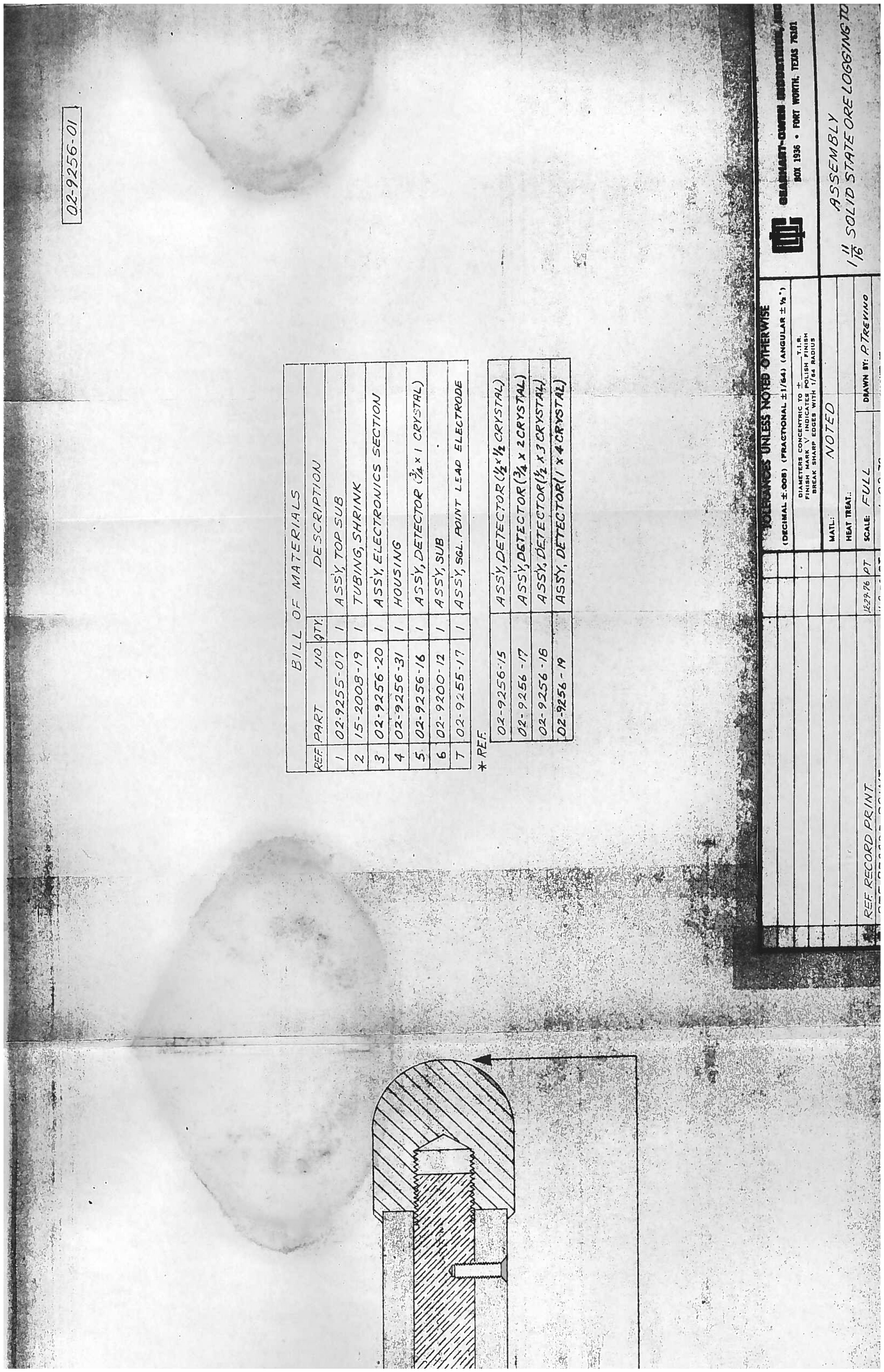
Bleuer, N.K., 2004, Slow-logging subtle sequences—The gamma-ray log character of glacigenic and other unconsolidated sedimentary sequences: Indiana Geological Survey, Special Report 65, 30 p.

Dixon-Warren, A., and C. Stohr, 2003, Downhole natural gamma-ray logging of quaternary sediments: The Professional Geologist, v. 40, no. 3, p. 2–5.

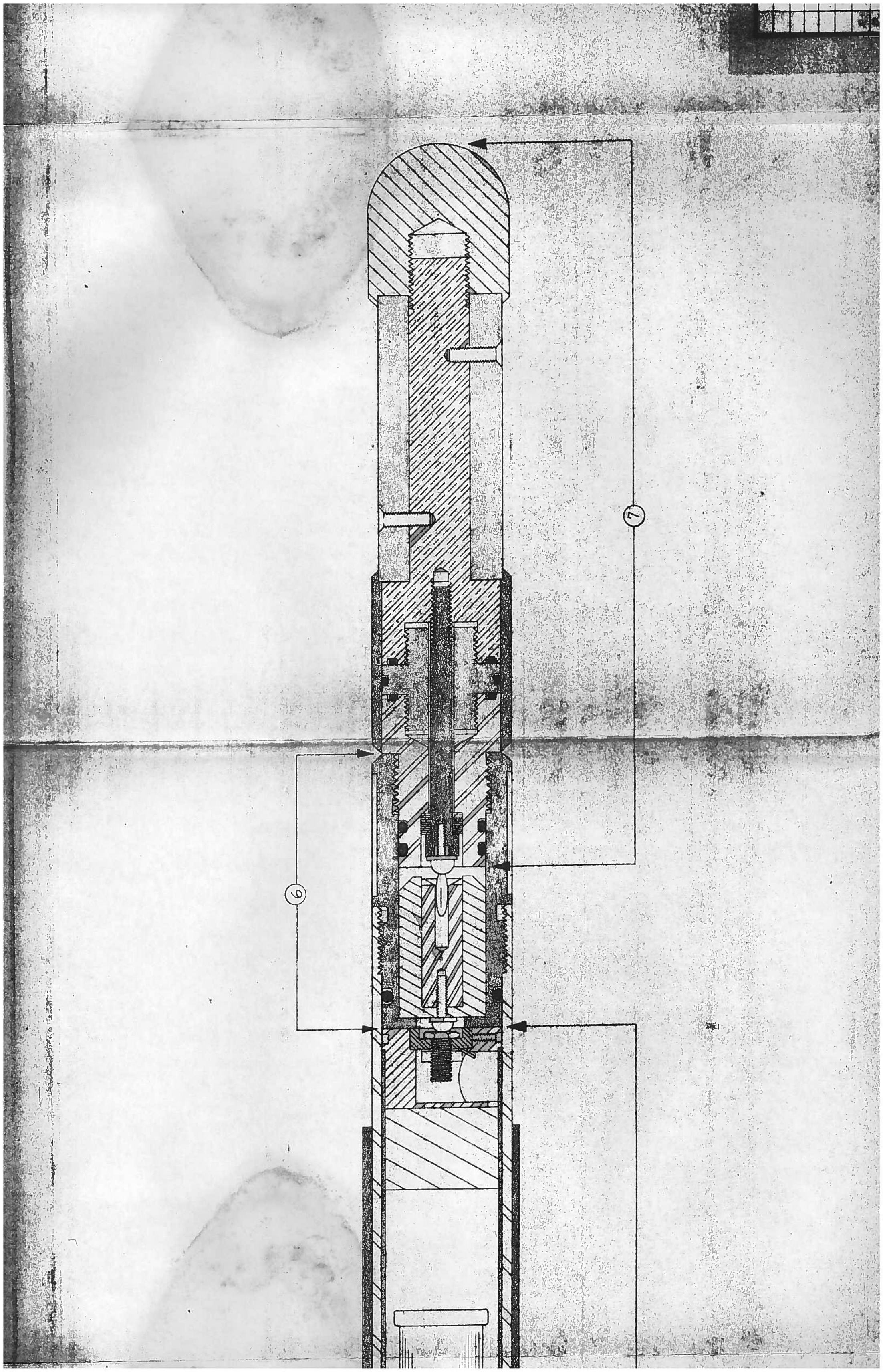
Keys, W.S., 1990, Borehole geophysics applied to ground-water investigations, *in* Techniques of Water-Resources Investigations: United States Geological Survey, Book 2, Chapter E2, 150 p.

Stohr, C.J., B.B. Curry, A.B. Dixon-Warren, M.L. Barnhardt, D.R. Larson, A. Phillips, A.J. Stumpf, J. Duval, B. Guttmann, and D. Korth, 2004, Downhole geophysical logging for Quaternary mapping applied to hydrogeologic and environmental issues: Geological Society of America, Abstracts with Programs, v. 36, no. 3, p. 44.

## Appendix A: Gerhart-Owen Industries Manual and Specifications




Provided courtesy of Haliburton.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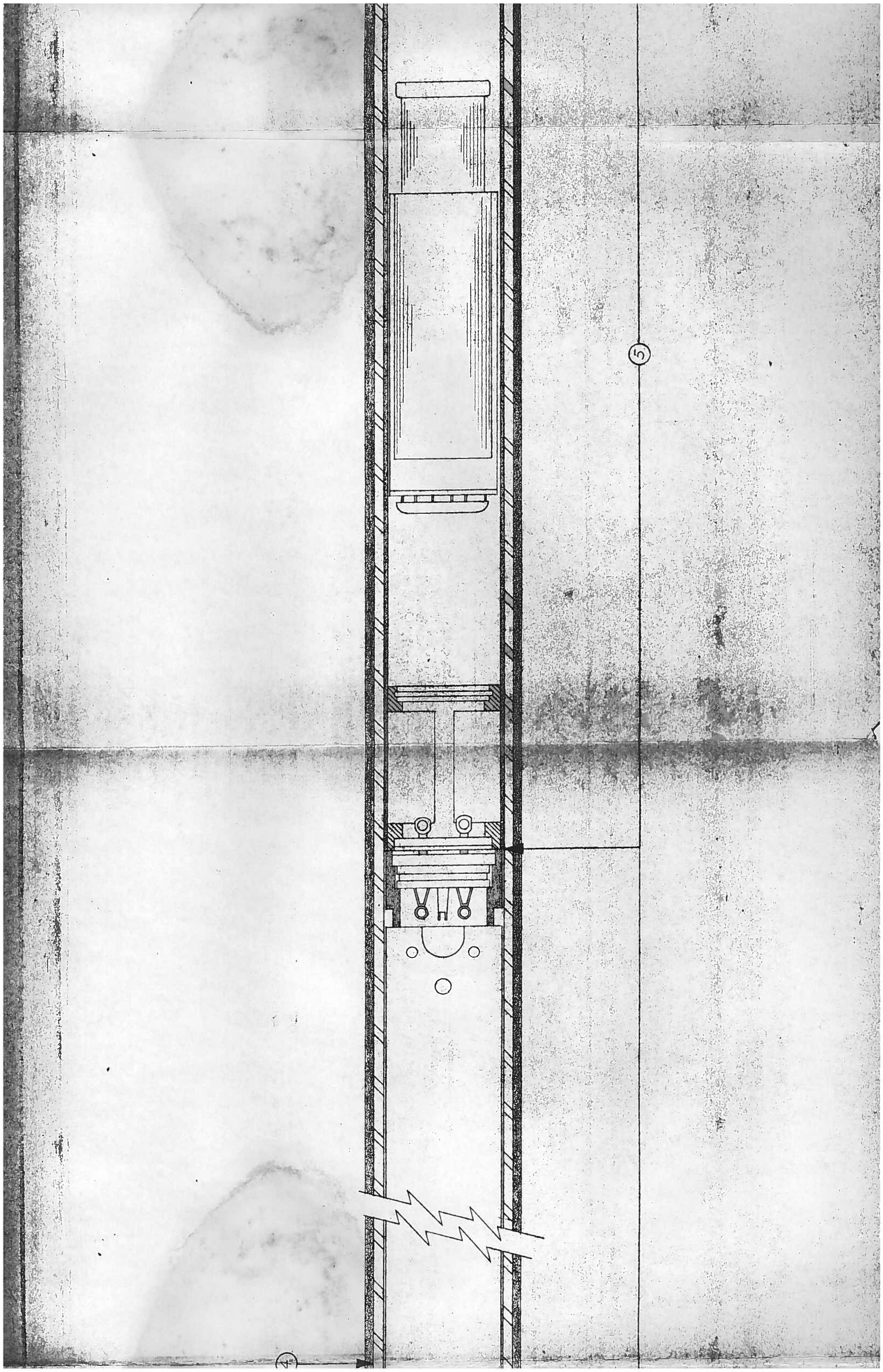
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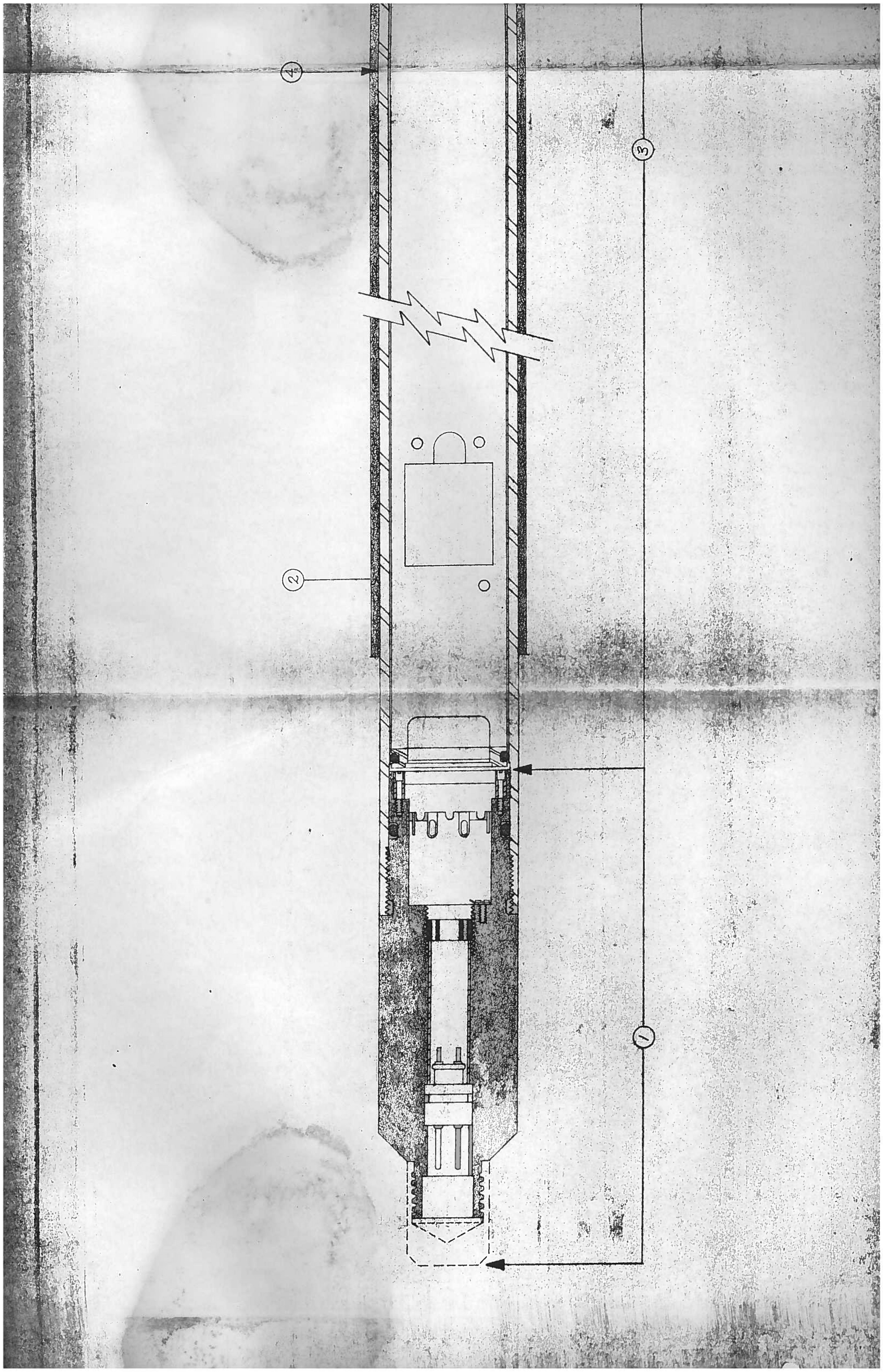
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3
2
1

GEARHART-OWEN INDUSTRIES, INC.

P. O. BOX 1936
FORT WORTH, TEXAS 76101
TELEPHONE 817-293-1300
CABLE ADDRESS GO OILTOOL FTW
TELEX NO. 75-8252

QUOTATION

COPY

TO: Northern Illinois Gas Company
P.O. Box 190
Aurora, Illinois 60507

ATTN: Bruce Engquist

OUR REFR. 6-205
CUSTOMER REFR.

DATE: October 8, 1976
VALIDITY PERIOD: 60 days

| ITEM NUMBER | QUANT. | PART NUMBER | DESCRIPTION | UNIT PRICE | TOTAL |
|---|---|---|---|---|---|
| 1 | 1 | 06-3000-00 | Basic Model 3200 Drawworks | | 3,950.00 |
| 2 | 1 | 15-1654-31 | Slip Ring 4-Conductor | | 564.00 |
| 3 | 2000' | | 3/16" O.D. 4-conductor cable | .51 | 1,020.00 |
| 4 | 1 | 04-9705-00 | 1" O.D. Cablehead 4-conductor | | 160.00 |
| 5 | 1 | | Electronic Equipment Cabinet w/weather resistant front cover & Internal wiring | | 495.00 |
| 6 | 1 | 02-9821-03 | NBP 504 Nims Main Frame Assy w/low voltage power supply | | 975.00 |
| 7 | 1 | 02-9857-00 | PSA 003 Power Supply 300 VDC at 170 MA | | 285.00 |
| 8 | 1 | 02-9822-03 | LPM 203 Line Power & CCL Module | | 475.00 |
| 9 | 1 | 02-9823-07 | RMM 208 Ratemeter Module | | 795.00 |
| 10 | 1 | 02-9825-03 | RSM 204 Resistivity & S.P. Module | | 675.00 |
| 11 | 1 | 02-9856-01 | WIP 202 Weight Indicator & A/C Voltmeter Panel | | 275.00 |
| 12 | 1 | 02-9852-01 | MRP 501 Recorder 3 pen with built in line speed, time drive & LoZ Input | | 3,550.00 |
| 13 | 1 | 02-9256-00 | 1-11/16" O.D. Gamma Ray Tool & Resistivity S.P. Adapter w/1" x 4" scintillation detector (Lithology) | | 2,795.00 |
| 14 | 1 | 06-1700-00 | Well Head Tripod & Sheave Wheel | | 135.00 |
| 15 | 3 | 02-9821-16 | 2 Width Blank Nims Panels | 15.20 | 45.60 |
| | | | | | 16,194.60 |
| | | | Crate Unit for Shipment | | 175.00 |
| | | | F.O.B. Ft. Worth | | 16,369.60 |
| | | | TERMS: Net 30 days<br>DELIVERY: 30 days after receipt of order | | |

PAGE 1 OF 1 PAGES

G-014 (Rev.) 5/75

*This Quotation is Subject to General Terms and Conditions Printed on the Reverse Side.*

GEARHART - OWEN INDUSTRIES, INC.
P. O. BOX 1936 FORT WORTH, TEXAS 76101
PHONE 817 - 293-1300

_______________

.ED: _______________

| ORDERED BY | CUSTOMER ORDER NO. | DATE RECEIVED | DATE PROMISED | RECEIVED BY |
|---|---|---|---|---|
| Bruce Engquist | Quote # 7-053 | 3-1-77 | 4-20-77 | L. Wyatt |
| DATE SHIPPED | SHIPPED VIA | | TERMS | |

TO:
Northern Illinois Gas
P. O. Box 190
Aurora, Illinois 60507

SHIPPED TO:

| ITEM | QUANTITY ORDERED | BACK ORDER | PART NO. | DESCRIPTION | QUANTITY SHIPPED | UNIT PRICE | CODE | AMOUNT |
|---|---|---|---|---|---|---|---|---|
| 24. | 1 | | 02-9823-08 | RMM 209 Ratemeter Mod. | | | | 845.( |
| 25. | 1 | | 02-9825-03 | RSM 204 Res & SP Module | | | | 675.( |
| 26. | 1 | | 02-9826-02 | PGM 103 Pulse Generator Mod. | | | | 350.( |
| 27. | 1 | | 02-9900-14 | 18" BNC Cable | | | | 17.5 |
| 28. | 2 | | 02-9815-19 | 1 3/4 Blank 19" | | 6.00 | | 12.C |
| 29. | 1 | | 02-9821-15 | 1 Width Nims Blank | | | | 14.7 |
| 30. | 2 | | 02-9821-16 | 2 Width Nims Blank | | 15.20 | | 30.4 |
| 31. | 1 | | 15-1651-82 | Chart Paper | | | | 8.7 |
| 32. | 1 | | 02-9856-00 | Ore Tool with SP & Res Electrode "0" | | | | |
| | | | | dead time with 1 x 4 crystal | | | | 2,795.0 |
| 33. | 1 | | 02-9256-14 | N-3 Calibrator | | | | 125.0 |
| 34. | 1 | | 06-1825-19 | Res & SP test box | | | | 49.50 |
| | | | | | | | | 20,213.75 |

| | |
|---|---|
| TOTAL | |
| SALES TAX | |
| TOTAL OF INVOICE | |

5938

5937

Page 3 of 3

ORIGINAL

# Ore Logging System

## OPERATOR'S MANUAL

G-478 11-76

1. Check all power
   A. Tool Power    80 ma @ 40V≈w
   B. Nims Bin ± 12, ± 24
   Note: ± 6 V has no power in This type of Bin.

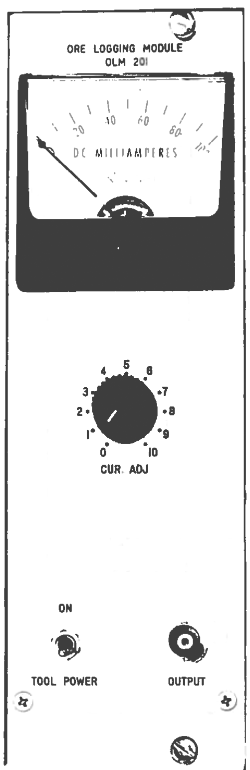
2. Check Rate Meters for correct switch and Knob positions.

Apply know signal to RMM and check That Recorder is working.

## ORE LOGGING MODULE OLM-201

### DESCRIPTION

This module was designed for use with the Ore Logging Tool. An adjustable, regulated power supply furnishes tool operating current. A special signal processing circuit requires no operator adjustments. Output signals from the module are further processed by a standard RMM-type Ratemeter Module.



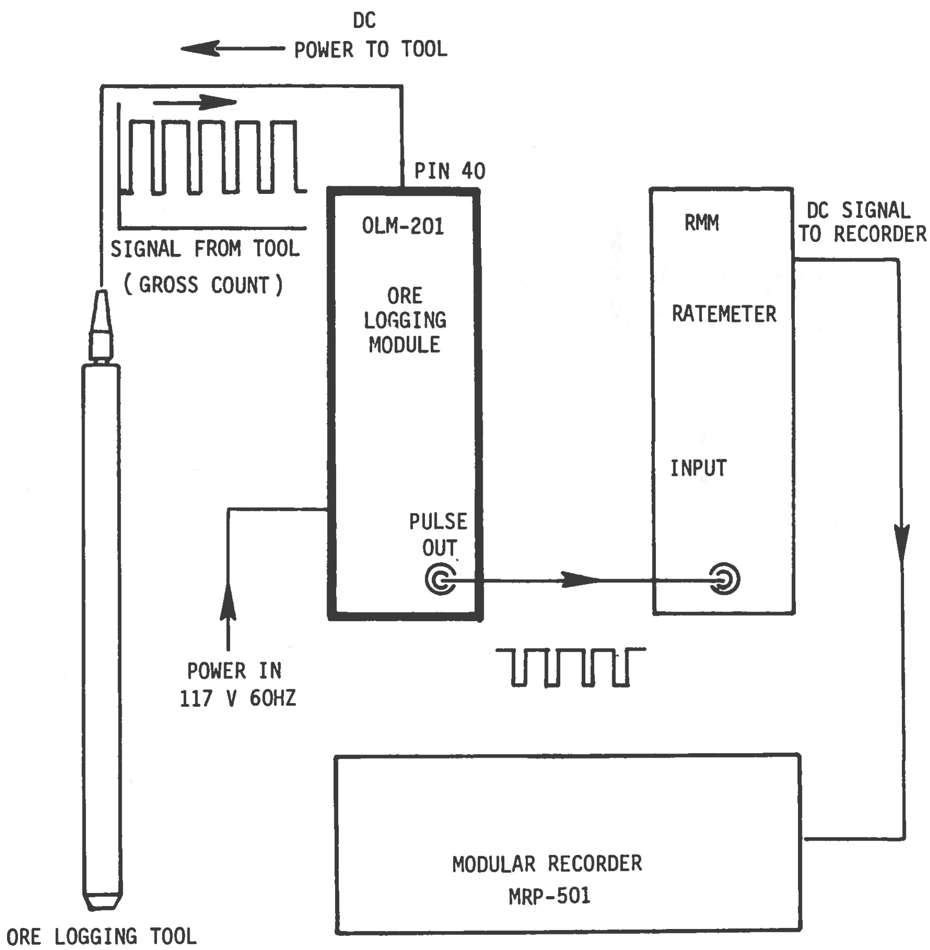

### SPECIFICATIONS

| | |
|---|---|
| DIMENSIONS: | The module is designed for the NIMS-Cabinet. Module width is 2 Units. |
| POWER REQUIREMENTS: | 117 V, 60 Hz<br>+12 V DC and -12 V DC<br>(Furnished by the NIMS Cabinet Power Supply) |
| SIGNAL INPUT: | Negative pulses from the Ore Logging Tool |
| SIGNAL AMPLITUDE: | ~~Typically 1 Volt, depends on cable length~~<br>Dependent on cable length |
| SIGNAL FREQUENCY: | 100,000 pulses per second (MAX) |
| OUTPUT SIGNAL: | Negative pulses, approximately 4 V amplitude |
| DISCRIMINATOR: | |
| TYPE | Automatic 50% |
| SETTING | Preset at ~~25%~~ of AVERAGE Signal Pulse Amplitude |

OLM-201 ORE LOGGING MODULE

SYSTEM DIAGRAM

The simplified diagram on this page shows the typical connection of the module for an ore logging application. An additional ratemeter module can be connected to the Ore Logging Module to run a lithology (correlation) log.



## ORE LOGGING PRINCIPLES

This supplement provides general and specific data related to the special field of ore logging.

The material is arranged as follows:

A.) GENERAL BACKGROUND

B.) GLOSSARY OF TERMS

C.) LOGGING PRACTICES

D.) LOG INTERPRETATION

The supplement cannot present all the information that applies to this field. a review of technical information in trade publications is necessary to keep abreast with the changing requirements and techniques in this field.

### A.) GENERAL BACKGROUND

Ore logging is mainly concerned with the determination of the exact location, the extent and the grade of uranium ores. Typically, logs are run in shallow holes of the shothole type. If additional resistivity and S.P. logs are run the borehole must of course be fluid filled. The Gamma Ray log alone can be run in dry hole. Depth is rarely more than 3000 feet. The Gearhart-Owen Portable Loggers Model 3200 or 3500 are well suited to this type of logging operation. They can be operated by a crew of two men. The equipment is mounted in rugged, all-terrain vehicles of small size. Operating costs are therefor kept low.

Uranium, in its different ore forms, has been found in many different types of rock and over a wide range of geologic settings throughout the United States. Two types of deposits are economically important: Sandstone beds and veins. The former account for about 95% of the total known reserves.

Uranium in sandstones generally occurs in undulating, irregular layered deposits. Such deposits have been profitable mined to depths of about 1500 feet. Deposits range in size from a few tons to several million tons. The average grade of ore in sandstone deposits is in the order of 0.25% or 5 pounds of $U_3O_8$ per ton of ore.

## ORE LOGGING PRINCIPLES

### REQUIREMENTS FOR AN ORE LOGGING SYSTEM

The logging tool must be small (borehole size). It must accurately process the high count rates associated with ore logging. The tool must be rugged and be easily adapted to different gross count conditions. The circuits must be stable over a wide range of operating conditions. Calibration must be simple and the whole logging system must have a high degree of repeatability. The Gearhart-Owen Ore Logging Tool and the associated surface equipment meets these requirements very well.

### B.) GLOSSARY OF TERMS

#### ORE

Mineral material that occurs in the necessary quantity and grade (concentration) and is accessible for economic recovery.

#### URANIUM ORE

Contrary to popular belief, uranium is not exceedingly rare. It is actually more abundant than such metals as tin, mercury or cadmium. It never occurs in its metallic form. It is always combined with other elements to form uranium containing minerals. There are more than one hundred such minerals.

The principal uranium mineral ores are the uraninite and the pitchblende. The latter is an amorphous variety of uranium oxide.

#### URANIUM ORE GRADES

The industrial useful component in uranium ores is the $U_3O_8$ compound. The percentage of $U_3O_8$ determines the general grading of the ore as follows

| | |
|---|---|
| EXTRA HIGH GRADE: | 2% or higher (40 pounds per ton) |
| HIGH GRADE: | 0.5 to 2% (10-40 pounds/ton) |
| MEDIUM GRADE: | 0.1 to 0.5 (2-10 pounds/ton) |
| LOW GRADE: | 0.05-0.1% (1-2 pounds/ton) |

## ORE LOGGING PRINCIPLES

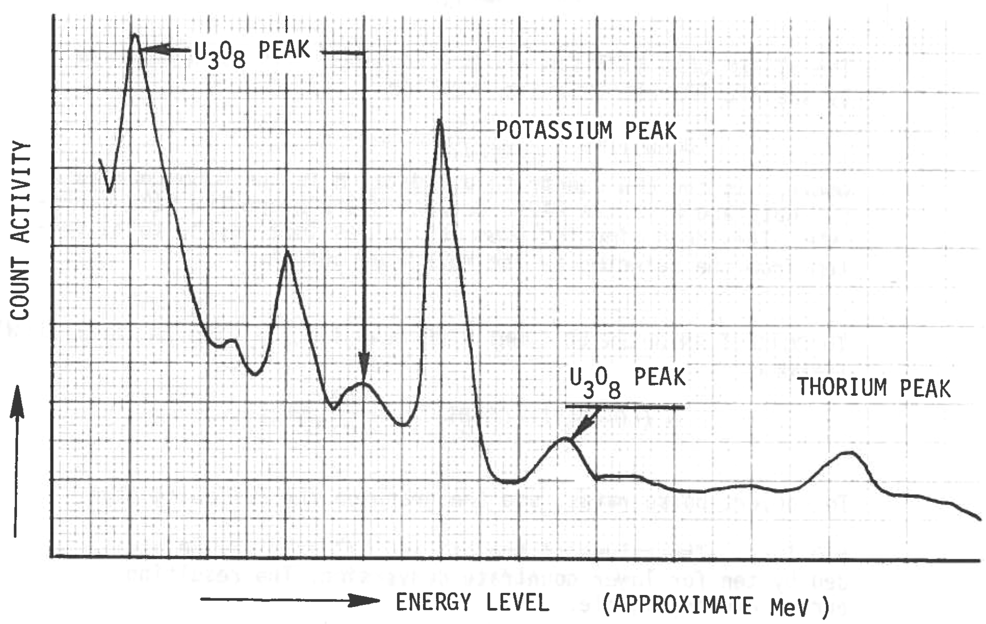
GLOSSARY OF TERMS, CONTINUED

### CUT-OFF GRADE

The MINIMUM grade of material which may be mined without monetary loss.

### GROSS COUNT

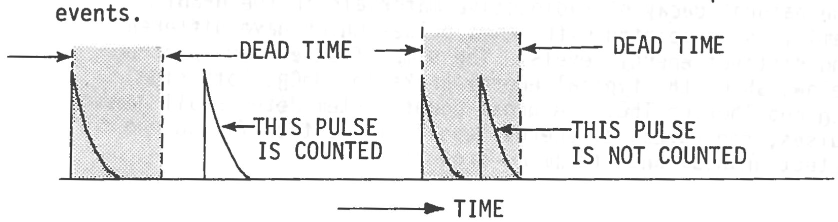
The natural decay of radioactive materials in the uranium family is associated with gamma pulses which have different and distinct energy levels. The simplified energy spectrum below, shows the typical energy peaks for $U_3O_8$, Potassium $K_{40}$ and Thorium $ThO_2$. A gross count system detects all gamma pulses, regardless of energy level. It is therefor suited to detect uranium and its decay products.



GLOSSARY OF TERMS, CONTINUED

## DEAD TIME

The "dead time" of a gross count logging system must be small in order to avoid large counting errors. Dead time is the actual time interval immediately following a counted event (pulse) during which the counting circuits are unable to accept another count. This is shown in the figure below. Dead time causes the observed number of pulses always to be lower than the actual number of pulse events.




The SYSTEM DEAD TIME for all Ore Logging Tools is determined by the AEC TWO PIT TEST and EQUATION

$$\text{DEAD TIME} = \frac{L - HR}{LH(1-R)} = t$$

where L is the LOW countrate pit data, H is the HIGH countrate pit data and R is the RATIO between the LOW and the HIGH countrate. This dead time includes ALL pulses lost in the total system from the detector to the ratemeter output.

TO CORRECT AN OBSERVED COUNT, THE DEAD TIME IS USED IN THE FOLLOWING FORMULA:

$$\text{N (CORRECTED COUNT)} = \frac{1}{1 - nt}$$

To convert pulse rates, use the graph on the following page.

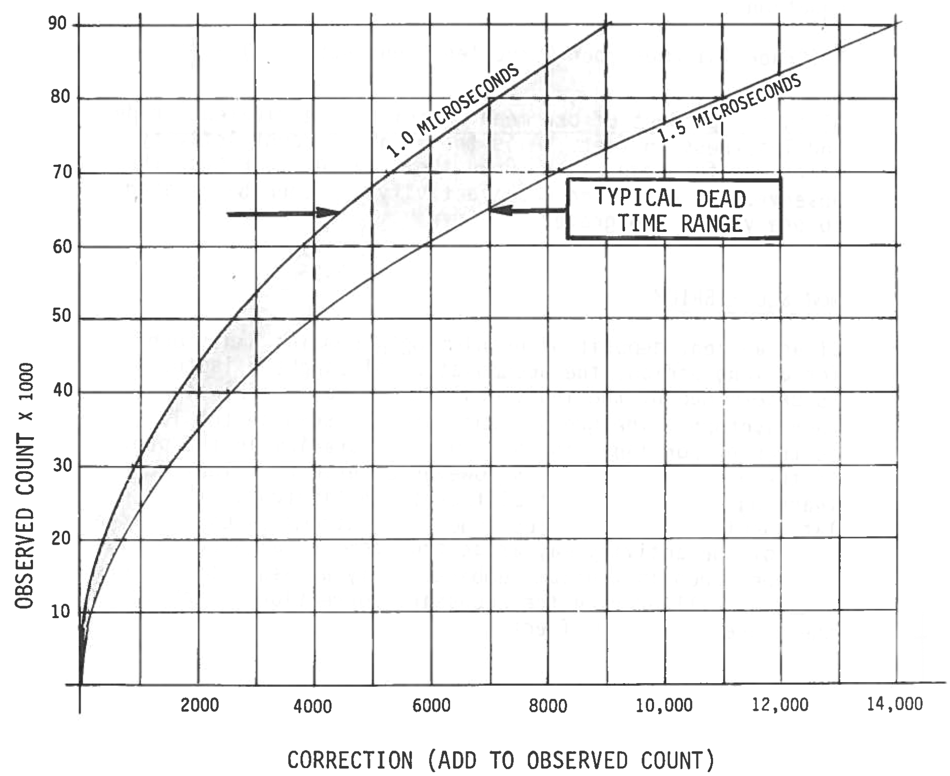
N O T E : The values of the "X" and "Y" axis may be divided by ten for lower countrate conversion. The resulting errors are negligible.

GLOSSARY OF TERMS, CONTINUED

DEAD TIME: (Continued)

For convenience, the calculation for correcting an observed count rate has been plotted on the graph below. Enter the graph on the left with the observed count to intersect the applicable dead time curve. Follow the intercept down to the X-axis to obtain the corrected count.

NOTE: The graph shows clearly the increasingly large effect of dead time as the count rate goes up. Below 10,000 counts the correction for most dead times is negligible.



GLOSSARY OF TERMS, CONTINUED

## K-FACTOR

Gross count logging systems are commonly calibrated in test pits maintained by the Atomic Energy Commission. The logging tool is exposed to ore material in a simulated borehold environment. This primary calibration allows the actual observed count of a particular logging system to be related to ore grade and quantity. The calibration procedure requires that the system "dead time" is determined beforehand (see definition of "dead time" in this glossary).

The K-Factor is calculated in principle by using the equation

$$K \text{ (Grade-Thickness per Corrected Count Activity)} = \frac{GT}{A}$$

GT is the product of ore mean radiometric equivalent Grade and Thickness in feet. A is the observed count Activity corrected for dead time. Once the K-Factor is known, the observed and corrected count activity can then be related to ore volume and grade.

## NON-EQUILIBRIUM

If an ancient deposit of uranium $U_{238}$ remains undisturbed for a long period, the accumulation of daughter isotopes is determined by the individual decay (half life) of each isotope. The gross count rate, as seen on the log, is then proportional to the amount of uranium in the ore. If the original deposit is however altered by selective leaching or migration of different constitutents, this relationship no longer holds true. In extreme cases, a large part of the activity may arise from commercially worthless isotopes such as thorium members. Only an assay of the ore material will provide the necessary correction factor for the non-equilibrium effect.

## GLOSSARY OF TERMS, CONTINUED

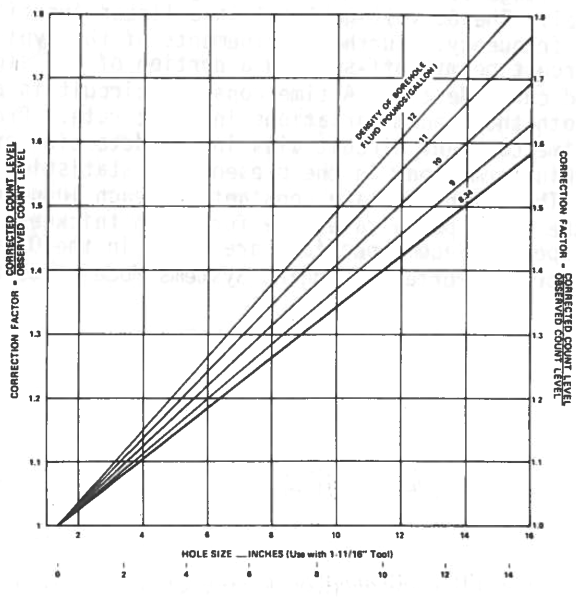
### BOREHOLE EFFECT

The borehole effect is quite pronounced, particularly in larger boreholes. It must always be applied to gross count logs to preserve log integrity. Typically this correction factor is in the range of 1.0 for a 2.25 inch diameter borehole, 1.1 and 1.2 for a 4.0 inch and 6.0 inch diameter borehole respectively. The above values are based on a 3/4 x 1 inch detector.

The graph on this page is for a decentralized tool. If a larger diameter tool is used, the graph must be entered on the auxiliary scale. The same graph is also contained in the Formation Evaluation Handbook, a Gearhart-Owen Publication, on page 175.

NOTE: No correction is required in a gas filled borehole.

GAMMA RAY CORRECTION FACTORS TO REMOVE THE EFFECTS OF HOLE SIZE AND BOREHOLE FLUIDS. (UNCASED HOLE, TOOL DECENTRALIZED, 1-11/16" O. D. GROSS COUNT PROBE)



## ORE LOGGING PRINCIPLES

GLOSSARY OF TERMS, CONTINUED

### DETECTORS

The preferred detector for ore logging is the scintillation crystal coupled to a photomultiplier tube. This detector combines small size (to keep the gross count within the limits imposed by the counting system) with fast response time (to keep the dead time to the lowest practical level). The Gearhart-Owen Ore Logging Tool may be equipped with different detector sizes to meet the requirements of a particular logging environment. The recommended size, based on the ore grade is:

| | |
|---|---|
| EXTRA HIGH OR HIGH GRADE: | 1/2 x 1/2 (inch) |
| MEDIUM OR LOW GRADE ORE: | 3/4 x 1 (inch) |

### RATEMETER:

A ratemeter transforms the pulses from the logging tool into a scaled DC voltage suitable for recording on a chart recorder channel. The DC voltage level is a linear function of the pulse frequency. Further refinements of the typical ratemeter circuit permit off-setting a portion of the signal for increased curve detail. A time constant circuit is provided to smooth the random variations in count rate. Proper use of the time constant circuit aids in the detection of relatively thin formations in the presence of statistical variations. The amount of time constant for each logging job depends on the total pulse rate, the formation thickness and the logging speed. Recommendations are given in the Operators Manual for the Portable Logging Systems Model 3200 and 3500.

## ORE LOGGING PRINCIPLES

### C.) LOGGING PRACTICES

A typical ore log is run with two curves. The GROSS COUNT curve is used to establish the location (depth) and count intensity of ore bearing formations. The second curve (using a separate ratemeter) is used for lithology correlation. This curve is run at a much higher sensitivity and recording pen goes off-scale when the tool traverses the ore interval.

If a simultaneous Resistivity-S.P. log must be run to get additional formation data, the tool is equipped with the optional Single Point Resistivity-S.P. probe. A multi-conductor (usually the standard 4-conductor) cable must be used and the two curves are logged with the NIMS-type RSM-204 Resistivity-S.P. Module. The borehole must of course be filled with conductive liquid. A mud pit electrode is required for the S.P. circuit.

Specific recommendations about the calibration and logging procedures for both curves, using this module, is found in the Operator Manual for the Model 3200 and 3500 Portable Logging Systems.

Additional log interpretation data may be gathered by logging, in addition to Gross Count and Lithology curves, a borehole Caliper, a Sonic or a Density curve or any combination of the above. Small diameter tools are available for these services. The associated surface equipment is easily incorporated in the modular NIMS-Cabinet system.

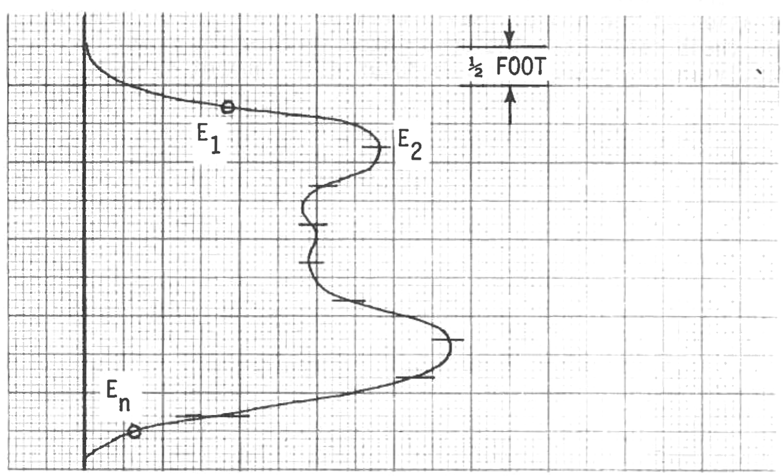
## ORE LOGGING PRINCIPLES

### D.) LOG INTERPRETATION

The Gamma Ray Gross Count curve gives a quantitative survey of the ore bearing strata. The curve is calibrated in COUNTS PER SECOND units. The standard practice is to correct count-rates over the ore section at 1/2 foot intervals (see Figure below). Each rate is corrected to True rate using the system dead time (Use graph on Page 5).

The upper data point (E1) is at the half point of the first curve excursion ($E_1$). The last data point ($E_n$) is taken 1/2 foot below the lowest intermediate value which is considered the lower boundary of the ore section. Data points $E_1$ and $E_n$ are multiplied by the factor 1.4 to account for the "TAIL EFFECT".

All corrected countrates at the 1/2 foot intervals are then summed and the borehole correction factor (see page 7) applied. The GRADE-THICKNESS product (See K-Factor description in Glossary of Terms) is derived by multiplying the resulting value with the system K-factor and other applicable factors.
This grade-thickness product must be corrected for non-equilibrium effects (See Glossary) and divided by the zone thickness in order to arrive at the particular ore grade.



## 1.1 INTRODUCTION

Throughout the world, the name GEARHART-OWEN is connected with oilwell logging equipment which is designed and built to meet the high standards and ever changing needs of the industry.

The ORE LOGGING TOOL and the companion ORE LOGGING MODULE Type OLM-201 have been developed to overcome some of the difficulties relating to logging jobs where very high count-rates are common.

## 1.2 ABOUT THIS MANUAL

This manual will provide the operator with the necessary practical and theoretical background about the tool and associated surface equipment.

The operator who takes the time to study the information in this manual will make consistently better logs, experience less down time and he will also be able to remedy equipment problems faster.

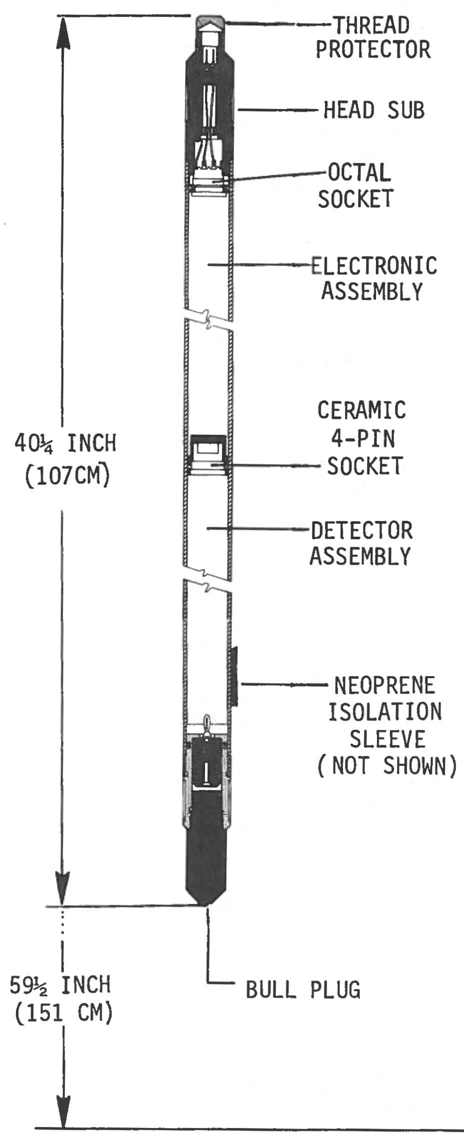
## 1.3 SYSTEM FEATURES

The signal processing circuits in both the tool and the logging module are designed to handle the very high count-rates found in ore logging jobs. Three different detector sizes are also available to match the logging system even better to the existing conditions.
The proprietary pulse processing circuits are able to count nearly all incident pulses and transmit pulses efficiently to the surface electronics. The socalled "Dead Time" has been reduced to a very low value.

The tool is extremely rugged. The detector crystal and the photomultiplier tube are unitized in a shock resistant molded assembly.

A simultaneous S.P. and Single Point Resistivity curve can be logged when the optional Probe Assembly is attached to the tool bottom sub. A multi-conductor cable must be used for this combination tool. A RSM-204 Resistivity - S.P. Logging Module is required in addition.

## 1.4 TOOL ASSEMBLY - DESCRIPTION

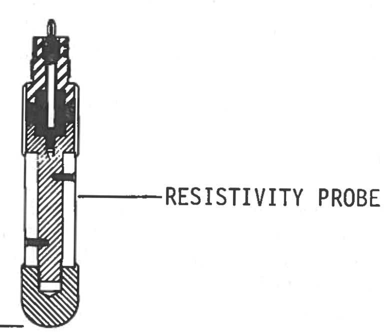



The HEADSUB connects the tool to the standard 4-conductor cable head. Simultaneous Resistivity-S.P. logs can be run when using the 4-conductor logging cable.

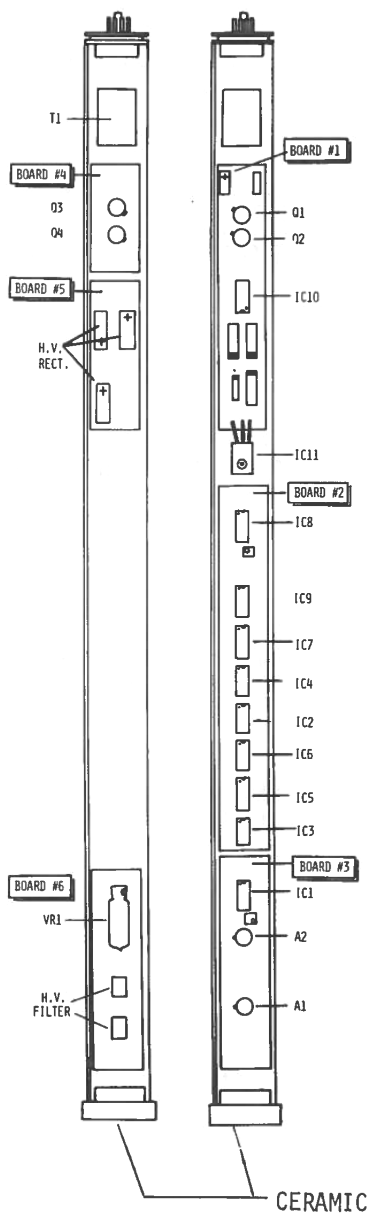
The tool housing is covered by a neoprene sleeve to provide isolation for the Resistivity-S.P. signals.

In the upper part of the housing, a Z-shaped steel chassis contains all signal and power circuits. Connectors at the top and bottom of this chassis make tool disassembly simple.

The lower housing protects the detector/photomultiplier assembly. A bull plug covers the threaded lower end, unless the S.P.-Resistivity probe is connected.



## 1.5 ELECTRONIC CHASSIS-MAJOR COMPONENTS




A total of SIX printed circuit boards are mounted on the Z-shaped steel chassis.

BOARD #1 contains the pulse shaping and line driver circuits IC10, Q1, Q2 and filter components.

BOARD #2 holds the logic circuits IC2 through IC9 and associated components.

BOARD #3 includes the signal shaping amplifiers A1 and A2 as well as integrated circuit IC1.

BOARD #4 is the DC-DC converter power supply with transistors Q3 and Q4.

BOARD #5 contains high voltage rectifiers and filter components.

BOARD #6 contains the high voltage regulator tube VR1 and associated filter components.

A regulator, integrated circuit C11, is mounted to the chassis between BOARD #1 and #2.

The photomultiplier/detector assembly plugs into the four-pin ceramic socket at the downhole end of the electronics assembly.

## 1.6 TOOL SPECIFICATIONS

### MECHANICAL

| | |
|---|---|
| LENGTH WITH RES. PROBE | 59.5 inches (151 cm) |
| LENGTH WITHOUT RES. PROBE | 42.25 inches (107 cm) |
| DIAMETER, [redacted] without sleeve material | 1-11/16 inches ( 44 mm) |

### OPERATIONAL LIMITS

| | | |
|---|---|---|
| TEMPERATURE | 200° F | ( 79° C) |
| PRESSURE | 15,000 PSI | (1040 atm) |
| MAXIMUM CABLE LENGTH | 6,000 feet | (2000 m) |

### DETECTOR OPTIONS

DETECTOR SIZE

| | |
|---|---|
| FOR HIGH GRADE ORES | 1/2 x 1/2 inch CRYSTAL |
| FOR MEDIUM OR LOW GRADE | 3/4 x 1 inch CRYSTAL |

### TOOL POWER

| | |
|---|---|
| POLARITY | POSITIVE |
| CURRENT | 70 mA DC (UP TO 4000 FEET)<br>80 mA DC (OVER 4000 FEET) |

### OUTPUT SIGNAL

| | |
|---|---|
| PULSE SIGNAL, POLARITY | NEGATIVE |
| REPETITION RATE, MAXIMUM | UP TO 100,000 PPS |

SPECIAL SIGNAL PROCESSING
ASSURES ZERO TRANSMISSION SIGNAL LOSS
(RANDOM DETECTOR PULSES ARE REGROUPED
FOR EVEN SPACING)

### SYSTEM DEAD TIME

| | |
|---|---|
| AS DETERMINED BY THE<br>AEC TWO-PIT METHOD | 1.5 MICRO-SECONDS (TYPICAL) |

### ACCESSORIES

N-3 TYPE CALIBRATION SLEEVE

## 1.7 SYSTEM PERFORMANCE DATA

The data contained in the following summary are based on tests performed at the AEC test facility in Grand Junction, Colorado. When test data are received (Form EL-1), you may wish to enter them in this page for future reference.

TOOL SERIAL NUMBER: ______________________

N-3 CALIBRATOR SERIAL NUMBER: ______________

SYSTEM K-FACTOR: _________________________ (Crystal Size ___X__)

(NOTE: This K-Factor is based on the average results of three test logs in the N-3 Test Pit.)

SYSTEM DEAD TIME: _________________________

(NOTE: Dead time is calculated from the average test results of two test runs each in the U-1, U-2 and U-3 Test Pits in addition to the results of the N-3 series of tests.)

HOLE SIZE - WATER FACTORS:

0-2.25 Test Model: ______________
0-4.50 Test Model: ______________
0-6.50 Test Model: ______________
0-8.50 Test Model: ______________

CASING FACTORS:

CASTING THICKNESS (INCH)

| | |
|---|---|
| 1/16: ______________ | 1/4: ______________ |
| 1/8 : ______________ | 3/8: ______________ |
| 3/16: ______________ | 1/2: ______________ |

## 2.0 OPERATION

### 2.1 INTRODUCTION

This section provides general equipment calibration and operation recommendations. The information is intended to supplement the specific procedures practiced by your company. Tool performance and calibration, the determination of correction factors and the log interpretation is well standardized by the AEC procedures.

**NOTE** IF YOU ARE NOT FAMILIAR WITH THE OPERATION OF ANY SURFACE EQUIPMENT, REVIEW THE SUPPLEMENTS IN SECTION 2. THE FUNCTION OF EACH CONTROL IS DESCRIBED IN THESE SUPPLEMENTS.

### 2.2 EQUIPMENT PREPARATION

1.) Install the necessary modules in the NIMS-cabinet. Connect all cabling between modules and the recorder channels (Refer to the diagrams on Page 5 and 6 Section 2.)

**NOTE** It is recommended that the system is assembled and a quick functional check made BEFORE you go to the job site. At this time go over your spares and tool kit to see if it is complete.

2.) Check the recorder. Enough paper? Pens working? Ink reservoirs filled?

3.) Do not turn on any power switches until the tool is connected to the cable.

4.) Turn ON: truck power, NIMS MAIN power, recorder MAIN power.

**NOTE** THE OPERATING INSTRUCTIONS REFER TO THE RMM-207 RATEMETER MODULE. IF THE LATER MODEL RMM-208 RATEMETER IS USED, THE DISCRIMINATOR ADJUSTMENTS ARE NOT REQUIRED BECAUSE THIS MODEL HAS THE AUTOMATIC DISCRIMINATOR CIRCUIT. DISCRIMINATION IS AT THE 50% LEVEL OF THE RECEIVED PULSE HEIGHT

## 2 .2 EQUIPMENT PREPARATION, CONTINUED

### 2.2.1 CHART TRACK ARRANGEMENT

Logging companies use different log arrangements. For this reason, no recommendations are made with respect to trace placement on the chart tracks.

Gamma ray and resistance scales ALWAYS increase toward the RIGHT. The pen deflection is correct if ratemeter PEN DRIVE is set to NORMAL.

### 2.2.2 PEN DEPTH SETTINGS

Set all pens as close as possible to the same depth line. The off-set between the Gamma Ray detector and the center of the Resistance Probe is less than 1 foot and may be neglected.

## 2.3 GROSS COUNT CHANNEL CALIBRATION

| EQUIPMENT | OPERATION |
|---|---|
| OLM-201 | CUR. ADJ.: Fully CCW<br>TOOL POWER: ON<br>CUR. ADJ.: Turn CW until meter indicates specified current level. 70 mA for less than 4000 feet of logging line. 80 mA for 4000 feet or more. |
| RMM-207 | |

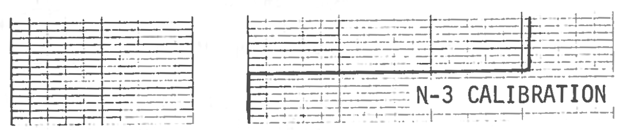
(Both GROSS COUNT and LITHOLOGY). Preset controls as follows:

| | |
|---|---|
| MODE SWITCH: | INPUT |
| DISCR.: | Full CCW |
| REVERSE-NORMAL: | NORMAL |
| POS.-NEG.: | NEGATIVE |
| RECORDER OUTPUT: | Full CW |
| SUPPRESSION: | Full CW (1000) |
| T.C.: | 1 or 2 seconds |

| | |
|---|---|
| CALIBRATOR | Slide over tool end (single point probe must be in place). The Calibrator will give a tool output of approximately 5000 CPS. The exact value is determined in the N-3 Test Pit calibration for each tool. |
| RMM-207 (GROSS COUNT) | Set CPS selector switch to 10K. Slowly advance DISCR. until meter indicates a pulse count. Set control 2 dial markings higher. |
| RECORDER GROSS COUNT CHANNEL | Turn channel ON. Adjust GAIN until pens oscillate, then back off for stable and solid pen drive. When set correctly, the pen will not overshoot when deflected by hand and released. |

## 2.3 CALIBRATION, CONTINUED

| | |
|---|---|
| RECORDER SPAN | NOTE: All new model recorders have preset SPAN controls. Pen deflection (scale) is controlled with the ratemeter OUTPUT controls. |
| RMM-207 (GROSS COUNT) | Press and hold ZERO pushbutton for the next step. |
| GROSS COUNT CHANNEL ZERO | With ZERO control move pen to desired GROSS COUNT ZERO (BASELINE). Release the ZERO button. |
| RMM-207 GROSS COUNT CALIBRATION | Turn REC. OUT control until pen deflects the correct number of scale divisions for the N-3 calibrator count. |




| | |
|---|---|
| RECORDER | Move chart by hand to record about 1 inch of trace. Push ZERO button on RMM-207 and check ZERO. Adjust if necessary. Record 1 inch of ZERO trace. |
| RMM-207 | Release button and check calibration CPS pen position. Adjust if necessary then record 1 inch of trace. |

## 2.4 LITHOLOGY CHANNEL CALIBRATION

In most logging situations, a LITHOLOGY (Correlation) log is run with the GROSS COUNT log. When the 3/4 x 1 inch detector is used the sensitivity is sufficient to make a log with good bed definition. Across an ore zone the lithology pen is allowed to go off-scale. A precise calibration of the log (in API units) is usually not required. If an API calibration is needed refer to the procedures in the 1-11/16 GAMMA RAY-NEUTRON Operator Manual.

LITHOLOGY SCALE

A 0-100 CPS scale may be used in most locations. Use the RMM-207 "100 CPS CAL" setting to set this scale.

| EQUIPMENT | OPERATION |
|---|---|
| CALIBRATOR | Remove the Calibrator Sleeve |
| RMM-207 (LITHOLOGY) | Set MODE switch to CAL 100. Set CPS selector to 100. Slowly advance DISCR. control until meter reads 100 CPS. Advance DISCR. one more dial marking. |
| RECORDER (LITHOLOGY CHANNEL) | Turn channel on and adjust GAIN as described before. |
| RMM-207 (LITHOLOGY) | Press and hold the ZERO pushbutton. |
| RECORDER (LITHOLOGY) | Use the ZERO control to move the pen to the required ZERO position on the chart. Release the ZERO button. |
| RMM-207 | Turn the REC. OUT control to deflect the pen 10 chart divisions to the right. Push the ZERO button and check the pen ZERO. Adjust if required. Release and check the 10 chart division pen deflection. Adjust with the REC. OUT control if necessary. |

## 2.4 LITHOLOGY CHANNEL CALIBRATION, CONTINUED

| | |
|---|---|
| RECORDER | Move the chart drum by hand to record about 1 inch of both pen settings (ZERO button pushed and released). |
| RMM-207 | Return the MODE switch to the INPUT position. |
| | The two GAMMA channels are now calibrated. The CPS and the T.C. settings on both ratemeters may be reset for optimum log quality. Observe the pens while going into the hole. |

## 2.5 RESISTANCE - S.P. CALIBRATION

The Mode 3200/3500 and Model 1200 Portable Logging Systems Operator Manuals describe the principles of Single Point Resistance and S.P. logs in detail. The operator is referred to these publications if he requires this information. The log calibration is simple. Refer to Supplement #112 in Section 2 for a description of the RSM-204 Module.

| EQUIPMENT | OPERATION |
|---|---|
| MUDPIT ELECTRODE | Position the electrode in a water-filled shallow hole, at least 50 feet (16 meters) from the borehole. Connect the mud pit cable to the receptacle on the RSM-204 front panel. |
| | The two curves are usually calibrated after the tool has been lowered to just below the water level in the borehole. Alternately the Test Box may be used to check and calibrate the two circuits with the tool still at the surface. Only the first method is shown here. |
| RSM-204 | Check the position of the logging line selector switch at the rear of the module. |
| | Turn the OFF-ON switch to ON. |
| | Set both SCALE selectors to 100. |
| | Set the CAL 100 OHM-LOG switch to CAL 100 OHM. |

## 2.5 RESISTANCE - S. P. CALIBRATION, CONTINUED

| | |
|---|---|
| RECORDER RES. CHANNEL | Turn the recorder RESISTANCE channel ON and adjust the GAIN as outlined before. |
| RSM-204 | Press the RES.ZERO switch and hold it during the next step. |
| RECORDER RES. CHANNEL | With the recorder ZERO control, move the pen to the RESISTANCE scale ZERO position. |
| RSM-204 | Release the RES.ZERO switch. The pen should move 10 chart divisions to the right if the preset recorder SPAN control presetting has not been up-set. |

**NOTE** There is probably some interaction between the two settings. Repeat the steps to achieve a correct pen span.

| | |
|---|---|
| RECORDER | Set the S.P. pen to the S.P. BASE LINE (at the right edge of the chosen track). Use the recorder ZERO control. |
| RSM-204 | Press the S.P. 100 mV CAL switch. The S.P. pen should move 10 chart divisions to the left. |
| | Set the CAL-LOG switch to the LOG position. You are now ready to log. |
| SCALE SELECTION | If, during logging, the pens do not deflect enough or move out of the track, adjust the SCALE selectors to a lower or higher value. |

## 2.6 LOGGING RECOMMENDATIONS

HOW TO LOG HIGH COUNT RATES IF NO RMM-208 RATEMETER IS AVAILABLE

The Ore Tool, with the correct detector installed, can transmit up to 100,000 counts per second when logging through high grade ores. The 50K setting on the RMM-207 is able to handle this count. The output will linearly increase. Adjust the REC.OUTPUT during calibration to get a 100,000 scale if such high rates are expected.

SATURATION

If the detector is too sensitive (too large) for the ore grade to be logged, the curve will show a "flat" top. Install a smaller detector and recalibrate the gross count channel.

TIME CONSTANT AND LAG

The best T.C. setting is a function of countrate and logging speed. Refer to the published data in the GEARHART-OWEN Operator Manuals for the 3200/3500 Portable Logging System and the 1 - 11/16 INCH GAMMA RAY - NEUTRON TOOL.

LOG DIRECTION AND SPEED

Logs are normally run coming out of the hole. Logging speed is adjusted to get good detail across thin beds. A speed of 30-40 feet per minute is typical.

CALIBRATION AFTER LOGGING

After the required interval has been logged and the tool is back on the surface, make another calibration sequence. Attach the calibration chart to the log package.

## 2.7 EQUIPMENT SHUTDOWN

After each logging job, take the time to perform routine, preventive maintenance. Equipment performance and service life will be improved when these simple steps are taken care of before major problems occur.

### CLEANING

When the tool is back at the surface, shut system power off, then clean the exterior surface of tool and cable head to remove all borehole residues. Wipe dry, then remove the cable head.

### INSPECTION

Inspect the surface of the tool for any sign of damage. Check the contact area for signs of moisture entry due to O-Ring failure. Check the condition of the seal O-rings. Rings with flat spots or cracks should be replaced immediately.

### PREVENTIVE MAINTENANCE

Install the protective caps on both the tool and the cable sub. Apply corrosion protective oil or aerosol spray (WD-40 or equivalent)

### SURFACE EQUIPMENT

Periodically wipe the surface of the electronic cabinet and all plug-in modules with a mild detergent moistened rag. Check all knob set screws for tightness. See that all meter pens are mechanically zeroed.
Check the condition of all system cables and connectors for abrasion, freedom from kinks, damaged insulation, loose wiring or damaged connector pins.

## 2.8 LOG INTERPRETATION

Ore logs are analyzed to determine the location, extent and grade of ore deposits. The logging probe and the associated surface equipment is calibrated at the Grand Junction research facility operated by the AEC. The system dead time and K-Factor are then used to determine ore grade from the log data.

Samples of lithology and resistivity/S.P. logs are included for reference. A detailed discussion of the interpretation for these logs is found in other Gearhart-Owen publications (See list at the end of this section).

### 2.8.1 GROSS COUNT LOG

The log interpretation (see Figure on next page) requires that the area A under the interval of interest is calculated.

STEP 1 Locate and record the CPS value at the half point $E_1$ of the first (top) peak.

STEP 2 Record additional CPS values at 1/2 foot intervals.

> NOTE: If a log is run with a metric depth measurement, the data points are located at intervals of 10 centimeters.

STEP 3 The LAST CPS value $E_n$ is the first data point that falls lower than the half point value of the last (bottom) peak.

STEP 4 Correct ALL values for system dead time (Convert n to N). Use the system dead time for your equipment and enter the graph on page 5 of Supplement #200 in Section 3.

> N O T E: If count rates fall below 10,000, the correction for dead time in the order of 1 to 1.5 microseconds is very small. The graph may be used by divising the "X" and "Y" axis values by 10. The resulting errors are negligible.

STEP 5 Multiply the SUM of $E_1$ and $E_n$ by 1.4. This is the TAIL FACTOR.

STEP 6 Add ALL corrected values $E_2$ through $E_{n-1}$ and then add the TAIL FACTOR. This is the Area A.

## 2.8.1 GROSS COUNT LOG INTERPRETATION, CONTINUED

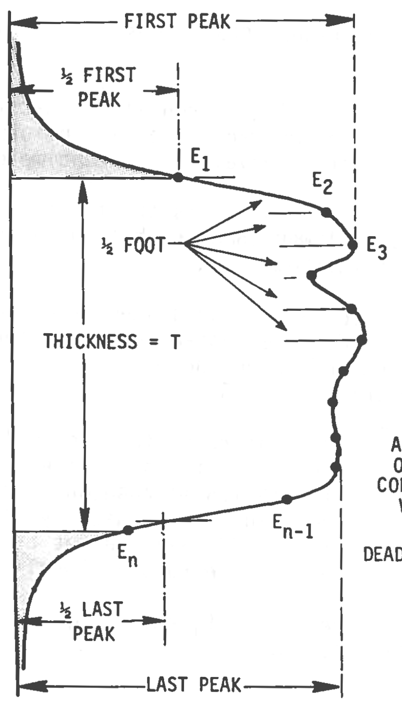
The grade thickness product (GT) is calculated with the area (A), found in the previous steps, the system K-factor, the borehole fluid correction (SF) and the casing correction (CF):

$$GT = K \times A \times WF \times CF$$

The ORE GRADE (G) is then

$$G = \frac{K \times A \times WF \times CF}{T}$$

T is the ore bed thickness shown in the figure below.

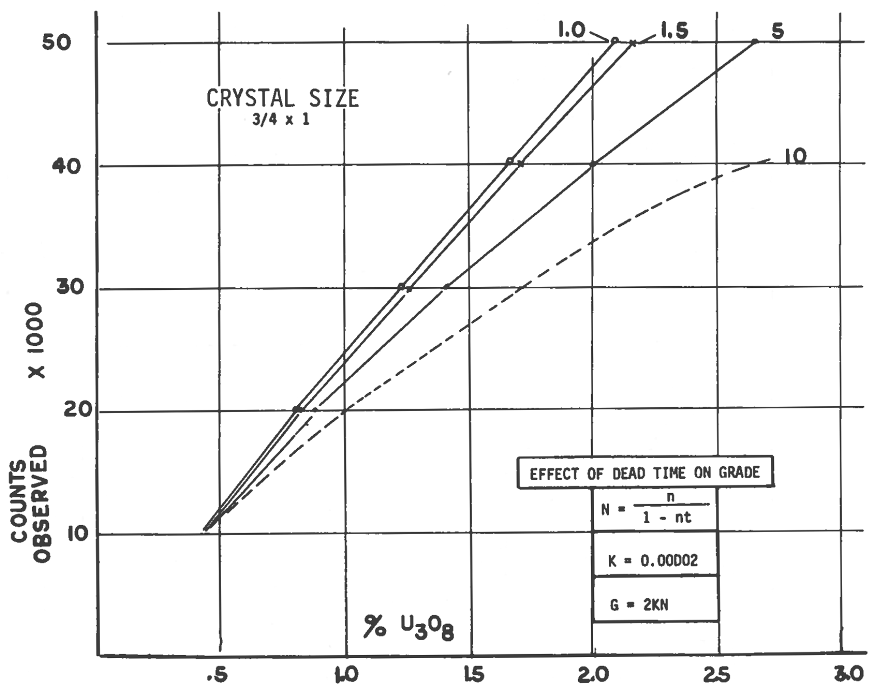



| | OBSERVED n | CORRECTED N |
|---|---|---|
| $E_1$ | 2,285 | 2,293 |
| $E_n$ | 1,000 | 1,002 |
| $E_1 + E_n$ → | | 3,295 |
| $1.4x(E_1 + E_n)$ → | | 4,612 |
| $E_2$ | 4,000 | 4,024 |
| $E_3$ | 4,450 | 4,479 |
| $E_4$ | 3,850 | 3,872 |
| ⋮ | ⋮ | ⋮ |
| $E_{n-1}$ | 3,500 | 3,518 |
| A = SUM OF ALL CORRECTED VALUES → | | 39,378 |

DEAD TIME USED : 1.5 MICROSECONDS

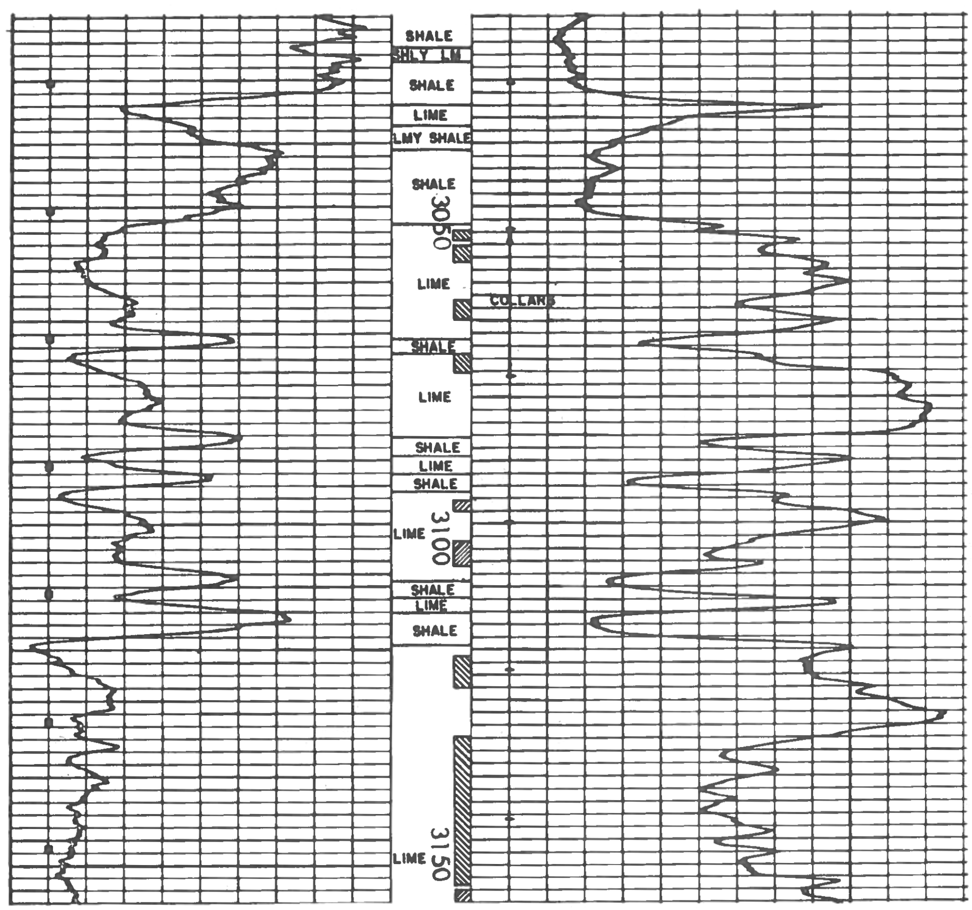
2.8.1 GROSS COUNT INTERPRETATION, CONTINUED

The graph on this page shows the effect of dead time on the ore grade. The curve is typical. Do not use without additional corrections. It is based on a K-factor of 0.00002 and a detector size of 3/4 x 1 inch. It is quite apparent from the graph, that dead times in the order of 1.5 microseconds allow a nearly linear countrate versus Percent $U_3O_8$ analysis over the countrate range of 10,000 to 50,000 counts per second.



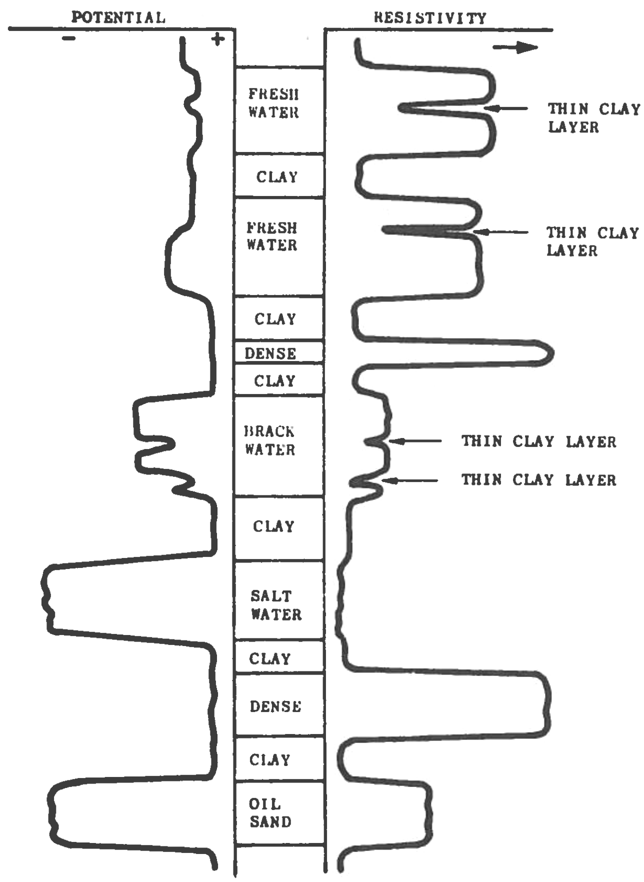
2.8.2 <u>LITHOLOGY LOG SAMPLE</u>

The sample log shows typical gamma responses opposite different lithologies. As a rule, count rates are higher in shale and high shale content formations.



2.8.3 RESISTIVITY-S.P. LOG SAMPLE (IDEALIZED)

This idealized Resistivity-S.P. log indicates the general trends of the two curves opposite different formations containing both fresh or salt water. For a more detailed discussion of the two curves and their interpretation, see the Operator Manuals for either the Model 1200 or Model 3200/3500 Portable Logging Systems.




IDEALIZED ELECTRIC LOG

## REFERENCE SOURCES

The following Gearhart-Owen Publications may be useful to the operator of the Ore Logging System:

1) FORMATION EVALUATION DATA HANDBOOK 1974
2) GAMMA RAY - NEUTRON LOGGING SYSTEM OPERATORS MANUAL
3) MODEL 1200 PORTABLE LOGGING SYSTEM OPERATORS MANUAL
4) MODEL 3200/3500 PORTABLE LOGGING SYSTEM OPERATORS MANUAL

**Appendix B: Mount Sopris Manual and Specifications**

# 2PGA-1000
# POLY- GAMMA PROBE

Permission to publish from Mount Sopris Instrument Company, Inc.

# Table of Contents

## General Information

### Overview

The 2PGA-1000 Poly-Gamma is a combination probe providing natural gamma, spontaneous potential (SP), and single point resistance (SPR), measurements. The operator must make these measurements in two separate runs. i.e. the gamma is made in one run and the S.P. , and SPR are made together on the second run. The Poly-Gamma probe is also the base foundation for the Poly series of probes. The Poly-Gamma when connected to a Poly-Resistivity probe is capable of making multiple Normal resistance measurements along with the, above-mentioned, Poly Gamma measurements, all in one run. The Poly-Gamma probe can be operated as a stand-alone probe on an MGX II or MATRIX logging system.

The SP and SPR measurements must be run in open (uncased), fluid filled, boreholes. The natural gamma may be run in any borehole conditions within specifications.

### Controls, Connectors, and Layout

Connectors for the tool are as follows. The probe top described below is a Mount Sopris standard single conductor probe top. Other variations of probe tops and wiring can be accommodated at the factory but will not be discussed in this document.

### PROBE TOP CONNECTOR:

| Pin | Signal | Origin |
|---|---|---|
| Probe top housing | Tool power ground | Armor |
| Center pin in probe top | Tool power positive | Center conductor |

### BOTTOM CONNECTOR:

This connector is made of rings and the numbering of the rings begins from the inner most ring.

| Ring | Signal | Origin |
|---|---|---|
| 1 | SP, SPR or 64" Normal | Electrode below probe top |
| 2 | Center conductor | Center pin on probe top |
| 3 | Pulse return | Returns Gamma pulse to center cond. |
| 4 | Pulse | Output from Gamma circuit |
| 5 | Armor | Armor of probe top |
| 6 | Gate | From Poly Electric tool |

Layout for the tool in general is as follows starting at the bottom of the tool. The bottom connector is below the scintillation crystal and Photo multiplier. Next is the electronic section for the gamma and electric measurements, followed by the electrode and probe top.

## Theory of Operation

SINGLE POINT RESISTANCE

The single point resistance measurement is made by passing an AC current between a surface electrode or (mud plug), and the probe electrode. The probe electrode is located just below the probe top and should be the only piece of metal exposed during the logging process. The surface electronics rectifies the AC voltage between these two electrodes and by using Ohms law the system calculates the resistance between them.

Ohms law: $r = E / I$

r = resistance in ohms;
E = potential in volts;
I = current in amperes.

The SPR measurement is the sum of cable resistance, and the resistance based on the composition of the medium, the cross sectional area and length of the path through the medium. Therefore the single point resistance log is not quantitative.

SPONTANEOUS POTENTIAL

The spontaneous potential, also known as self-potential or SP uses the same electrodes as the SPR measurement. This natural potential, which originates from electrochemical differences between borehole and formation fluid, or electro-kinetic "streaming" is measured by the surface electronics. The circuit measures a DC voltage between the surface electrode and the probe electrode. This potential may be positive and /or negative with respect to the surface electrode.

GAMMA

The natural gamma measurement is made by the use of a Sodium Iodide crystal, which when struck by a gamma ray emits a pulse of light. This pulse of light is then amplified by a Photo multiplier tube, which outputs a current pulse. These pulses are then detected, shaped and transmitted up the cable line. The center of the Sodium Iodide crystal is approximately 20 inches, or 508 mm below the center of the R & SP electrode. The approximate location of the gamma detector is referenced by a band of colored tape on the housing of the probe. The user must maintain this band of tape, or marker, as it may tend to degrade with use of the tool. When a Poly Gamma tool is used in conjunction with the Poly Electric tool, the pulses are sent down to the circuitry in the Poly resistivity and sent up the cable in a digital format.

The Poly Gamma tool is capable of using a power source that is positive or negative with respect to the armor. This gives the tool more flexibility and reduces the risk of damage to the tool due to a wrong switch position or the choice of a wrong probe file. Worthy of note is the crystal detector and the Photo multiplier tube. Both of these devices are fragile at best and are quite costly to replace. Sopris has taken steps to afford these items as much protection as possible. These items are subject to be damaged by sudden shock so when shipping or transporting the tool ensure it has proper protection from vibration and shock to reduce the chances of damage.

## 2PGA-1000: Specifications:

### Power Requirements
DC. voltage + or - at probe top. MIN. 52 VDC MAX. 88 VDC@ 35mA nominal, 100mA start up.

### Tool Output
Positive pulse, 1.25uS wide, adjustable if required.

### Gamma Detector
NaI (tl) .875" dia X 3.0" long 22.22mm dia. X 76.2mm long

### Gamma Detector location
Using the center of the R & SP electrode measure towards the bottom of the tool 20", or 508 mm.

### Measurement Range
0-100K CPS Gamma, Accuracy 1% FS, Resolution 0.02% FS
± 1500 mV SP, Accuracy 1% FS, Resolution 0.02% FS
0-5000 Ohms SPR, Accuracy 1% FS, Resolution 0.02% FS

### Operating temperature range
14 to 120 degrees F -10 to 50 degrees C

### Pressure rating
2000 PSI 13789 k PASCAL

### Dimensions

| | | | |
|---|---|---|---|
| Length | 31.3 inches | 79.5 cm | |
| Diameter | 1.63 inches | 4.1 cm | with neoprene heat shrink and PVC electrical tape |
| Weight | 7 lbs | 3.2 kg | |

## Installation

### Installing the Poly - Gamma and support equipment

Before operating the Poly - Gamma probe, determine if the probe will be used as a stand-alone probe, or if it will be used in conjunction with a Poly Series probe.

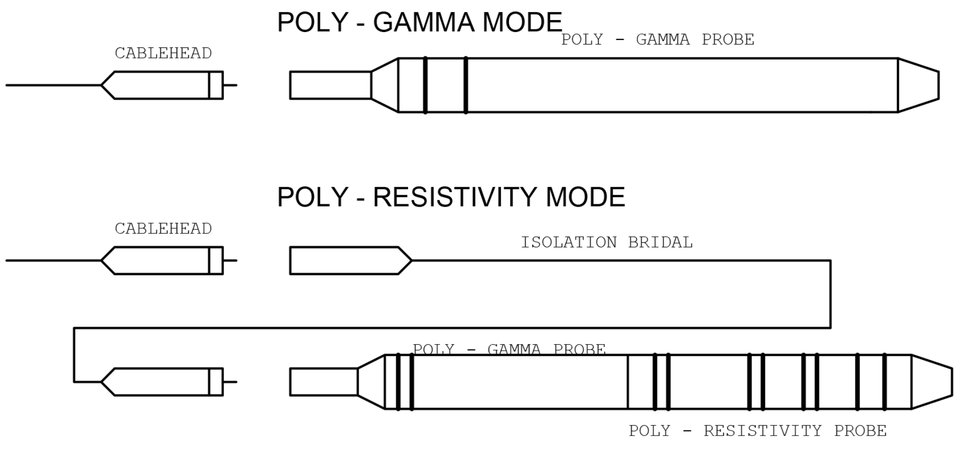
### Poly - Gamma stand alone mode

In order to operate the probe in the borehole the lower thread protector must be installed in the bottom of the probe. This thread protector seals out any borehole fluid and shorts two of the rings on the bottom connector of the probe, to send the pulses from the gamma circuitry up the cable line. Remove the thread protector from the probe top then thread the probe top onto the cablehead of the winch assembly. Inspect the o-ring on the cablehead for cuts or abrasions before each use to ensure an adequate seal. If you are going to run a Spontaneous Potential log, the probe top and cablehead, including the spring, must be taped at least 2 feet above the measure electrode. Follow the operating instructions in this manual or in the logging software before logging in regards to this tool.

### Poly - Resistivity mode

If the Poly - Gamma is to be used in conjunction with the Poly - Resistivity probe you will need to remove the thread protector from the bottom of the Poly - Gamma probe. Then remove the thread protector from the top of the Poly - Resistivity probe. Thread the two probes together and hand tighten this connection. With a roll of PVC electrical tape, cover all exposed metal surfaces at this connection, not the electrode located just below this connection. Next you will need to install the isolation bridal. This bridal comes as an accessory to the Poly - Resistivity probe and must be used in order to achieve a valid measurement. Install the bridal on the cablehead first by only rotating the bridal and not the cablehead. This is easily done by extending the bridal to its full length. Damage to the cablehead may occur if any other methods are used. Next remove the thread protector from the probe top of the Poly - Gamma and thread the probe onto the bridal assembly, rotating only the probe assemblies. Cover all exposed metal surfaces at this connection, but not the electrode, with PVC electrical tape. Follow the operating instructions in the Poly - Resistivity manual or in the logging software before logging.

CONNECTIONS FOR POLY - GAMMA



## Operating Procedure

## Operation

**GAMMA-GAMMA MEASUREMENTS**

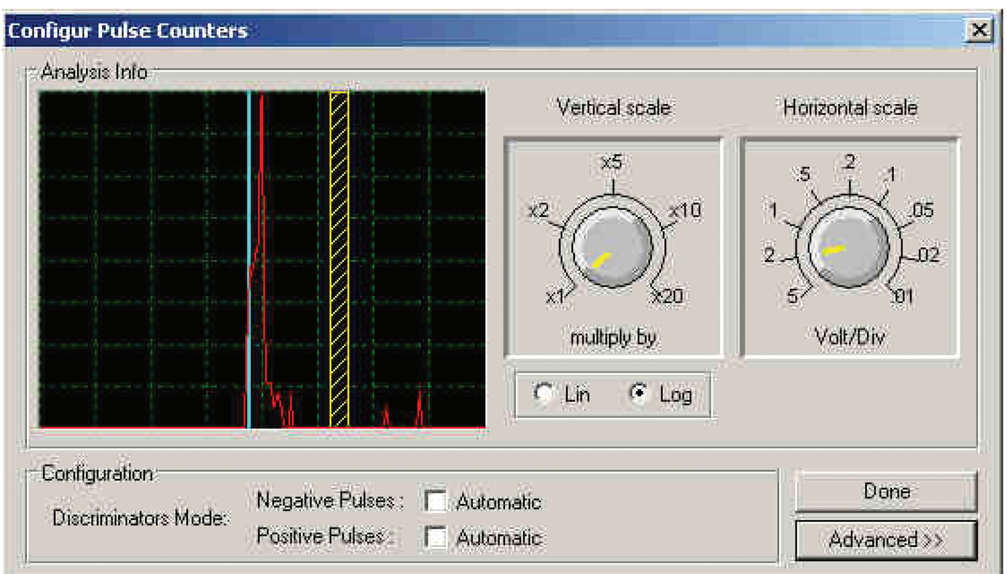
To use the Poly - Gamma with the 2GGA 1000 density sub, you will need to remove the bull nose from the bottom of the probe and install a 2ADM-1020 adapter. This adapter will allow you to connect the GG-375 gamma-gamma source sub or the newer version 2GGA-1000 source sub to the bottom of the 2PGA. The 6” spacer can be used if necessary. Consult Mount Sopris Instrument Company for more information.

**USE WITH AN MGX II SYSTEM**

To use the Poly - Gamma with the MGX II logging system, make sure the correct tol files have been installed in the C:\MSLOG\tol\current directory. This should be done by using the MSLConfig program, using the ADD Tol Files function. Failure to use the MSLConfig program may result in incorrect power and pulse discriminator settings. ALWAYS use MSLConfig to install tol files when using the MGX II logger. Select the proper tol file (for gamma or SP/SPR mode) and follow the standard MSLog logging procedures.

**USE WITH A MATRIX LOGGING SYSTEM**

To use the Poly - Gamma with the MATRIX logging system, make sure the correct tol files are installed in the C:\Matrix\tol\current directory. The files are most easily installed using the MTXFileConfig.exe file supplied with the software. The 2PGA files are normally already installed in the correct directory during installation. In the case of the Matrix logger, the power settings are automatically handled by the logger, and depend on the wireline type and length settings entered during logger setup, using the MatrixSettings program. Different wirelines will have specific settings for pulse discrimination for the gamma function. The user can observe the discriminator settings and make changes as necessary using the “Settings” button in the Telemetry window on the dashboard. The pulse discriminator bar should be placed in the middle of the pulse display, as shown in the following figure. Once the correct discriminator setting is made, SAVE the configuration, and the settings will be recorded in the tol file for future use. In general, the settings supplied with the “factory” tol file will not need adjustment.



## Performance Checks and Calibrations

Calibrations are performed at the factory and require a basic knowledge and understanding of the tool. In the event the user feels the tool needs to be calibrated it is advisable to speak with a representative of Mount Sopris. Performance checks for the gamma measurement can be made on the surface before logging. With the tool powered on and viewing data on the computer screen a small source of natural gamma radiation can be placed in close proximity to the detector area about 6 inches above the bottom of the probe. An increase in gamma counts will then be observed on the computer screen if the tool is working properly. To verify the electric measurements are working the user may use a calibration box, available from Mount Sopris, which when connected properly to the system, provides different resistance and voltage values for calibration. To check the Electrode of the tool for connection place an Ohmmeter set to read ohms on the center conductor of the probe top. Place the other meter lead on the electrode. The meter should read approximately 620 ohms.

## Preventative Maintenance

The 2PGA-1000 Poly - Gamma requires little maintenance other than washing the probe off after each use. ***Never take the probe apart. This probe is very difficult to disassemble and requires special steps to be taken in order to gain access to the inside of the probe without damaging the electronics. If you have read this after attempting to disassemble the probe chances are the probe has experienced damage and will need repaired.*** Inspecting o-rings occasionally and keeping the threads on both ends of the probe clean, will minimize problems in the future. The heart of the gamma section is the Photo multiplier tube and the Sodium Iodide crystal. Both units are very fragile and can be damaged if the probe is dropped or sees very abrupt shock. Take great care while handling or packing the probe for transportation.

# Troubleshooting

## Problems with the Tool

In the event the tool develops a problem, follow the troubleshooting procedure listed below.
***NEVER DIS-ASSEMBLE THE PROBE WITHOUT KNOWLEDGE OF PROCEDURE***

### GAMMA Problems

No counts from the probe.

1. Are the MGX switches set correctly? **PULSE 2** and **ON** positions.
2. Are the PROBE CURRENT and PROBE POWER LED's on?
3. Is the correct probe file being used? MGX and MGX II versions.
4. Check cable for conductive leakage across the center conductor to ARMOR. (20 Meg MIN.)
5. Is the thread protector installed in the bottom of the probe in the stand-alone mode?
6. Is the logger supplying the correct voltage as specified in this document?
7. If no result from the above , consult Mount Sopris.

### SP & SPR Problems

Troubles with electric logs.

1. Check that the MGX or MGX II is connected properly.
2. Ensure surface electrode is placed in the ground and add some water to this area if possible.
3. Check switch setting on the logger, **ELECTRIC** and **ON** positions, and ensure the correct probe file is in use.
4. If no response from the above, remove the probe from the cablehead and with a DVM set to read ohms check the resistance from the center pin in the probe top to the electrode located below the probe top. The meter should read 620 Ohms.
5. While cablehead is disconnected from step 4 check the cable line for leakage from the center conductor to the ARMOR. (20 Meg MIN.)
6. If no result from the above consult Mount Sopris.

## Disassembly Instructions

The 2PGA-1000 Poly -Gamma Probe should **never be disassembled** unless service is necessary. This is a very difficult probe to disassemble, and is highly recommended that any service be performed by Mount Sopris or a qualified technician. An M3 socket head cap screw has been placed near the top of the probe to prevent the housing from being accidentally turned off the probe top. If probe must be entered first remove the bull-nose from the bottom of the probe. Use a long M3 screw and anchor it into the center of the slip-ring connector in the bottom of the probe. Pull the slip-ring connector straight out and remove the connector from the rear. Now remove the M3 socket head screw from joint of the housing and probe top. Unscrew the housing from the probe top and slide housing off. Use care with the fragile PMT and crystal inside. Reverse steps to re-assemble.

## Schematics

Available upon request

2PGA-1000

| | | | |
|---|---|---|---|
| Drawing # | 500S-2094 | 50002094A.S01 | Title: Power Supply, Disc, Pulse Driver |
| Drawing # | 500S-2094 | 50002094A.S02 | Title: High Voltage Osc. And Dynode Multiplier |
| Drawing # | 500S-2067 | 50002067A.S01 | Title: High Voltage Interface |
| Drawing # | 500K-2074 | 50002074A.S01 | Title: Signal Cable Poly Gamma |

## Appendix

### Suggested QA Procedure

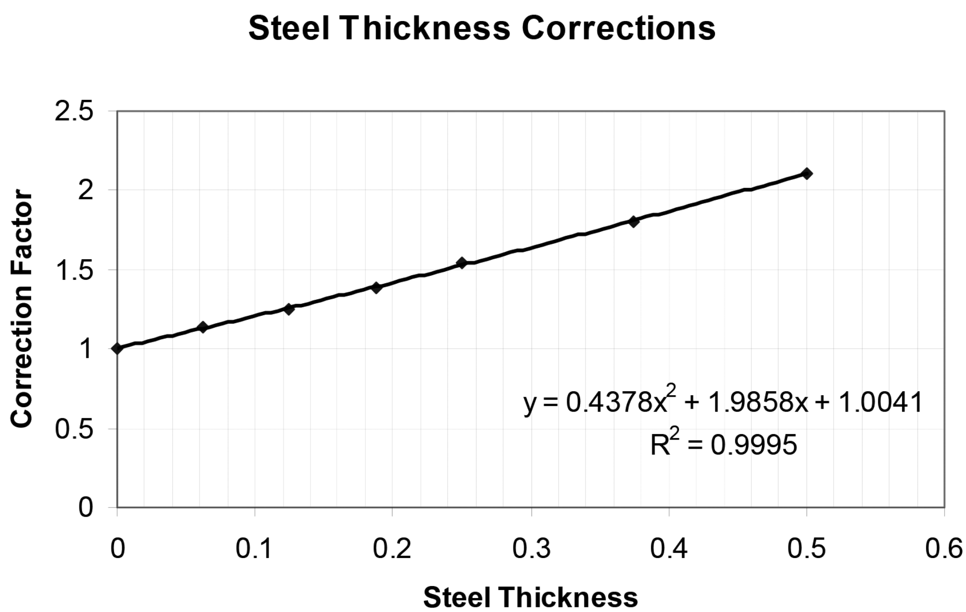
General notes for Quality Assurance are presented here for users who need to utilize these techniques when collecting data. These users will need to periodically calibrate their equipment using equipment whose calibration is traceable to an approved standard. Details of these calibrations must be recorded.

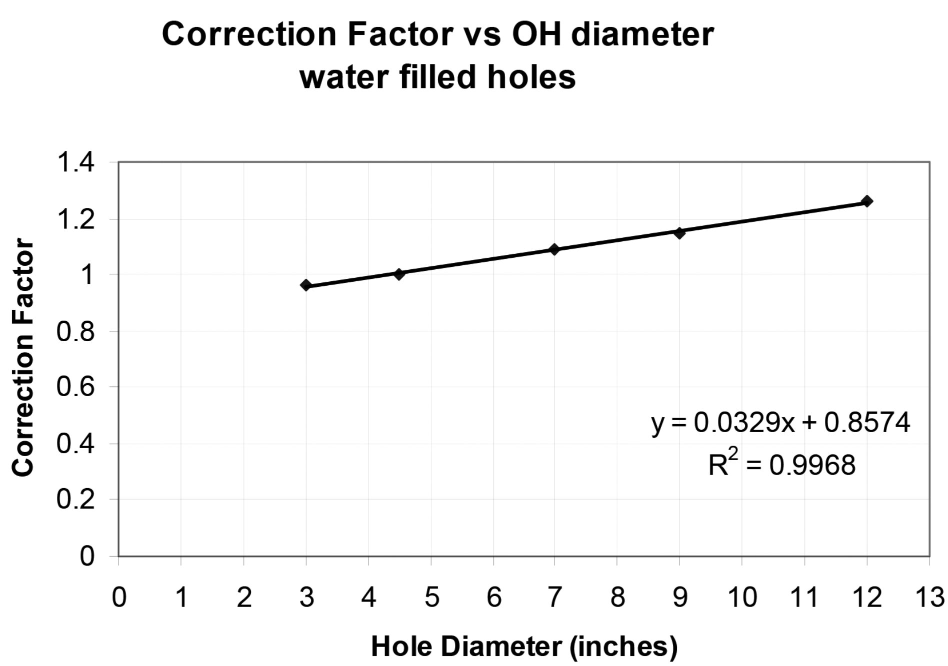
When an instrument is calibrated, records need to be kept regarding the calibration standard(s) used and what was changed on the instrument to calibrate it. Typically, the corrections made to the instrument involve changing constants that are used to scale the raw instrument reading so that the proper value is reported. The constants must be recorded during a calibration procedure. The Mt. Sopris family of Acquire programs records the calibration constants that were used to acquire the data. This aids the QA process, but does not replace the need for recording these constants at the time of calibration. The reason for this is that the length of time since the last calibration is unknown with only this information.

The device providing the standard must be traceable to an accepted standard. Examples of organizations providing standards for measuring instrumentation are: The U. S. National Bureau of Standards; The American Petroleum Institute; and the American Society for Testing Materials. For example, if the voltmeter or the density standard used for calibration is not traceable to an approved organization, such as those listed above, the calibration should not be considered valid. Records should be kept indicating the last time that standard being used for calibration was calibrated or checked against an approved standard. The QA procedure necessary for some programs mandate that the calibration standards be periodically checked against a standard approved by a proper agency.

A QA procedure may dictate that data taken from a given locale be associated with records indicating the exact time and location that the data was collected. The data itself may have to be collected in a certain format to meet requirements. Often, QA procedure specifies that surveys must be repeated and the data from the successive surveys compared. This technique is used to eliminate poor or invalid data.

**Casing and Water Factors for 2PGA-1000**



# Appendix C: Gamma Ray Logs of ISGS Test Boring

Gamma log of the Gearhart-Owen Industries, Inc. Mineral Logging System (MLS) is shown in blue on the left. Gamma log of the Mount Sopris Instrument Company, Inc. 4MXC combination gamma, SP, and SPR probe (serial no. 3342) is shown in red on the right.