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Standard Guide for Conducting Borehole Geophysical Logging - Gamma[1]

This standard is issued under the fixed designation D 6274; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the general procedures necessary to conduct gamma, natural gamma, total count gamma, or gamma ray (hereafter referred to as gamma) logging of boreholes, wells, access tubes, caissons, or shafts (hereafter referred to as boreholes) as commonly applied to geologic, engineering, ground-water, and environmental (hereafter referred to as geotechnical) investigations. Spectral gamma and logging where gamma measurements are made in conjunction with a nuclear source are excluded (for example, neutron activation and gamma-gamma density logs). Gamma logging for minerals or petroleum applications are excluded.

1.2 This guide defines a gamma log as a record of gamma activity of the formation adjacent to a borehole with depth (See Fig. 1).

1.2.1 Gamma logs are commonly used to delineate lithology, correlate measurements made on different logging runs, and define stratigraphic correlation between boreholes (See Fig. 2).

1.3 This guide is restricted to gamma logging with nuclear counters consisting of scintillation detectors (crystals coupled with photomultiplier tubes), which are the most common gamma measurement devices used in geotechnical applications.

1.4 This guide provides an overview of gamma logging including general procedures, specific documentation, calibration and standardization, and log quality and interpretation.

1.5 To obtain additional information on gamma logs, see Section 13.

1.6 This guide is to be used in conjunction with Guide D 5753.

1.7 Gamma logs should be collected by an operator that is trained in geophysical logging procedures. Gamma logs should be interpreted by a professional experienced in log analysis.

1.8 The geotechnical industry uses English or SI units. The gamma log is typically recorded in units of counts per second (cps) or American Petroleum Institute (API) units.

1.9 *This guide does not purport to address all of the safety and liability problems (for example, lost or lodged probes and equipment decontamination) associated with its use.*

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.11 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

D 653 Terminology Relating to Soil, Rock and Contained Fluids

D 5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites

D 5608 Practice for Decontamination of Field Equipment Used at Low Level Radioactive Waste Sites

D 5753 Guide for Planning and Conducting Borehole Geophysical Logging

D 6167 Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper

3. Terminology

3.1 *Definitions*:

3.1.1 Definitions shall be in accordance with Terminology D 653, Section 13, Ref **(1)**, or as defined below.

[1] This guide is under the jurisdiction of ASTM Committee D18 on Soil and Rock and is the direct responsibility of Subcommittee D18.01 on Surface and Subsurface Characterization.

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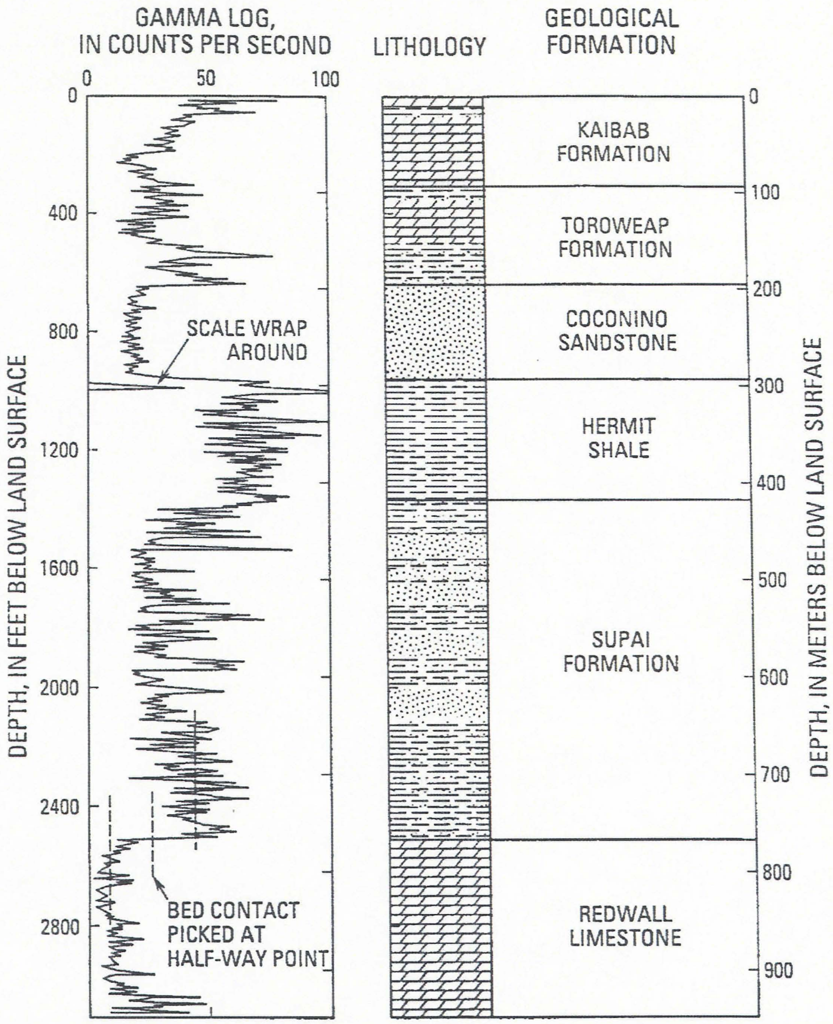
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



NOTE 1—This figure demonstrates how the log can be used to identify specific formations, illustrating scale wrap-around for a local gamma peak, and showing how the contact between two formations is picked to coincide with the half-way point of the transition between the gamma activities of the two formations.

FIG. 1 Example of a Gamma Log From Near the South Rim of the Grand Canyon

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *accuracy, n*—how close measured log values approach true value. It is determined in a controlled environment. A controlled environment represents a homogeneous sample volume with known properties.

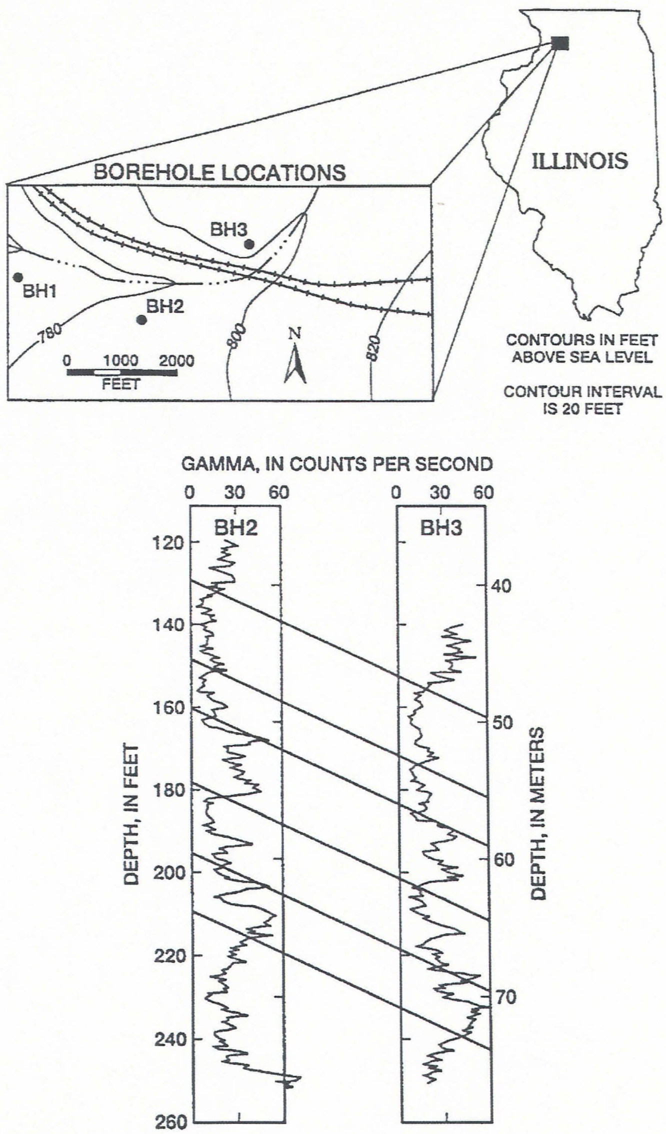
3.2.2 *dead time, n*—the time after each pulse when a second pulse cannot be detected.

3.2.3 *dead time effect, n*—the inability to distinguish closely-spaced nuclear counts leads to a significant underestimation of gamma activity in high radiation environments and is known as the "dead time effect".

3.2.4 *depth of investigation, n*—the radial distance from the measurement point to a point where the predominant response may be considered centered, which is not to be confused with borehole depth (for example, distance) measured from the surface.

3.2.5 *measurement resolution, n*—the minimum change in measured value that can be detected.

3.2.6 *repeatability, n*—the difference in magnitude of two measurements with the same equipment and in the same environment.



NOTE 1—From a study site showing how the gamma logs can be used to identify where beds intersect each of the individual boreholes, demonstrating lateral continuity of the subsurface geology.

FIG. 2 Example of Gamma Logs From Two Boreholes

3.2.7 *vertical resolution, n*—the minimum thickness that can be separated into distinct units.

3.2.8 *volume of investigation, n*—the volume that contributes 90 % of the measured response. It is determined by a combination of theoretical and empirical modeling. The volume of investigation is non-spherical and has gradational boundaries.

4. Summary of Guide

4.1 This guide applies to borehole gamma logging and is to be used in conjunction with Guide D 5753.

4.2 This guide briefly describes the significance and use, apparatus, calibration and standardization, procedures, and reports for conducting borehole gamma logging.

5. Significance and Use

5.1 An appropriately developed, documented, and executed guide is essential for the proper collection and application of gamma logs. This guide is to be used in conjunction with Guide D 5753.

5.2 The benefits of its use include improving selection of gamma logging methods and equipment, gamma log quality and reliability, and usefulness of the gamma log data for subsequent display and interpretation.

5.3 This guide applies to commonly used gamma logging methods for geotechnical applications.

5.4 It is essential that personnel (see the Personnel section of Guide D 5753) consult up-to-date textbooks and reports on the gamma technique, application, and interpretation methods.

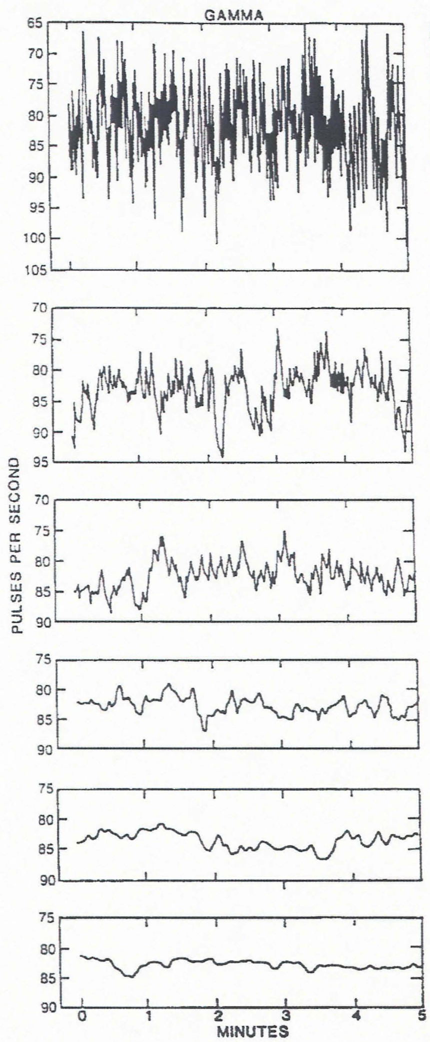
6. Interferences

6.1 Most extraneous effects on gamma logs are caused by logging too fast, instrument problems, borehole conditions, and geologic conditions.

6.2 Logging too fast can significantly degrade the quality of gamma logs. Gamma counts originating at a given depth need to be averaged over a time interval such that the natural statistical variation in the rate of gamma photon emission is negligible (see Fig. 3).

6.3 Instrument problems include electrical leakage of cable and grounding problems, degradation of detector efficiency attributed to loss of crystal transparency (fogging) or fractures or breaks in the crystal, and mechanical damage causing separation of crystal and photomultiplier tube.

6.4 Borehole conditions include changes in borehole diameter (especially in the fluid-filled portion); casing type and number; radioactive elements in drilling fluid in the borehole, or in cement or slurry behind casing; and steel casing or cement in the annulus around casing, and thickness of the annulus.



TIME CONSTANT	MEAN	STANDARD DEVIATION
1 second	Not calculated	
3 seconds	83.0	4.7
5 seconds	82.9	2.5
10 seconds	83.1	1.5
15 seconds	83.8	1.4
20 seconds	83.0	0.8

NOTE 1—The fluctuations in gamma activity in counts per second is shown to vary by progressively smaller amounts as the averaging period (time constant) is increased from 1 to 20 s.

FIG. 3 Example of Natural Statistical Fluctuation of Gamma Counts From a Test Source of Given Strength

6.5 Geologic conditions include high levels of radiation which can degrade the efficiency of gamma counting through the dead time effect, energy level of emitted gammas, formation density, and lithologic bed geometry.

7. Apparatus

7.1 A geophysical logging system has been described in the general guide (the Apparatus section of Guide D 5753).

7.2 Gamma logs are collected with probes using scintillation detectors.

7.2.1 The most common gamma detectors are sodium iodide (NaI).

7.2.2 Other gamma detectors include cesium iodide (CsI) and bismuth germanate (BGO).

7.3 Gamma probes generate nuclear counts as pulses of voltage that are amplified and clipped to a uniform amplitude.

7.3.1 Gamma probes used for geotechnical applications typically can be logged inside of a 2-in. (5-cm) diameter monitoring well.

7.4 The volume of investigation and depth of investigation are determined by the density of the material near the probe, which controls the average distance a gamma photon can travel before being absorbed.

7.4.1 The volume of investigation for gamma logs is generally considered spherical with a radius of 0.5 to 1.0 ft (15 to 30 cm) from the center of the detector in typical geological formations. The volume becomes elongated when detector length exceeds approximately 0.5 ft (15 cm).

7.4.2 The depth of investigation for gamma logs is generally considered to be 0.5 to 1.0 ft (15 to 30 cm).

7.5 Vertical resolution of gamma logs is determined by the size of the volume from which gammas can reach a nuclear detector suspended in the borehole. In typical geological formations surrounding a fluid-filled borehole, this is a roughly spherical volume about 1 to 2 ft (30 to 60 cm) in diameter. Excessive logging speed can decrease vertical resolution.

7.6 Measurement resolution of gamma probes is determined by the counting efficiency of the nuclear detector being used in the probe. Typical measurement resolution is 1 cps.

7.7 A variety of gamma logging equipment is available for geotechnical investigations. It is not practical to list all of the sources of potentially acceptable equipment.

8. Calibration and Standardization of Gamma Logs

8.1 *General*:

8.1.1 National Institute of Standards and Technology (NIST) calibration and standardization procedures do not exist for gamma logging.

8.1.2 Gamma logs can be used in a qualitative (for example, comparative) or quantitative (for example, estimating radioisotope concentration) manner depending upon the project objectives.

8.1.3 Gamma calibration and standardization methods and frequency shall be sufficient to meet project objectives.

8.1.3.1 Calibration and standardization should be performed each time a gamma probe is suspected to be damaged, modified, repaired, and at periodic intervals.

8.2 Calibration is the process of establishing values for gamma response associated with specific levels of radioisotope concentration in the sampled volume and is accomplished with a representative physical model. Calibration data values related to the physical properties (for example, radioisotope concentration) may be recorded in units (for example, cps), that can be converted to units of radioactive element concentration (for example, ppm Radium-226 or percent Uranium-238 equivalents).

8.2.1 Calibration is performed by recording gamma log response in cps in boreholes centered within volumes containing known homogenous concentrations of radioactivity elements.

8.2.2 Calibration volumes should be designed to contain material as close as possible to that in the environment where the logs are to be obtained to allow for effects such as gamma energy level, formation density, and activity of daughter isotopes on the calibration process.

8.3 Standardization is the process of checking logging response to show evidence of repeatability and consistency, and to ensure that logging probes with different detector efficiencies measure the same amount of gamma activity in the same formation. The response in cps of every gamma detector is different for the same radioactive environment.

8.3.1 Calibration ensures standardization.

8.3.2 The American Petroleum Institute maintains a borehole in Houston, Texas, where two formations have been fabricated to provide homogeneous levels of gamma activity so that probes can be standardized on the basis of the response in these boreholes. 1 API gamma unit is 1/200th of the full scale response in the representative shale model in this borehole (see Guide D 5753).

8.3.3 For geotechnical applications, gamma logs should be presented in API units for standardization.

8.3.4 A representative borehole may be used to periodically check gamma probe response providing the borehole and surrounding environment does not change with time or their effects on gamma response can be documented.

8.3.5 A small radioactive source(s) (thorium-treated lantern mantles, small bottles of potassium chloride, laboratory radioactive test sources, or sleeves containing natural radioisotopes (phosphate sands, etc.)) placed over the gamma detector can be used to check calibration if the sources have been related to a calibration facility.

8.4 Gamma log output needs to be corrected for dead time when logging in formations with unusually large count rates, such as uranium-rich pegmatites or phosphatic sands, and areas contaminated with radioactive waste.

8.4.1 Dead time corrections are usually negligible under typical logging conditions when measured gamma counts are less than a few hundred counts per second.

8.4.2 Dead time corrections are estimated by comparing the gamma log response under the influence of two similar radioactive sources. The measured count rate would approximately double over that with one source when both sources are placed in the sample volume of the logging tool. The dead time causes the count rates to be slightly less than double. Dead time is given by the formula:

$$\text{Dead Time} = t_0 = 2(N_1 + N_2 - N_{12})/(N_{12}(N_1 + N_2)) \tag{1}$$

$$\text{Corrected count rate} = N^* = N/(1 - N\,t_0)$$

where:

N_1, N_2 = the count rates measured using each of the two similar sources,
N_{12} = the count rate obtained using both of the similar sources in counts per second,
t_0 = the dead time correction in seconds,
N = the measured count rate in a formation in counts per second, and
N^* = the count rate after correction for the dead time effect.

t_0 is usually found to be a few microseconds for most gamma logging equipment.

9. Procedure

9.1 See the Procedure section of Guide D 5753 for planning a logging program, data formats, personnel qualifications, field documentation, and header documentation.

9.1.1 Document gamma specific information (for example, crystal size, type, and location).

9.2 Identify gamma logging objectives. Select appropriate equipment to meet objectives.

9.3 Gamma logs are commonly run with other logging measurements in combination probes for correlation purposes. This is most often done by equipping other classes of logging probes (electric, indication, neutron porosity, etc.) with gamma detectors (see Fig. 4).

9.3.1 Detector location on the probe needs to be appropriate to meet the project objectives. Long combination probe strings with the gamma detector located at a significant distance from the bottom of the probe may be inappropriate. Gamma detection position on the logging probe is especially important in shallow boreholes where over drilling the borehole is not possible.

9.3.2 Gamma probes are usually run free-hanging where the probe lies against one side of the borehole that is, as a mandrel. However, gamma detectors are sometimes included with combination probes that are run centralized or decentralized in the borehole. Gamma response may be somewhat different depending upon the method used (for example, free-hanging or centralized) in a given geologic environment.

9.3.3 Gamma equipment decontamination is addressed according to project specifications (see Practice D 5088 for non-radioactive waste sites and Practice D 5608 for low level radioactive waste sites).

9.4 Select when the gamma probe is to be run in the logging sequence (see 8.2.2.1 of Guide D 5753).

9.4.1 Gamma probes are run after or in combination with any television camera and fluid property probes to insure that there is minimum disturbance to the borehole fluid that can degrade those logs.

9.4.2 Gamma probes are run before any probe utilizing nuclear sources and more expensive centralized probes to ensure borehole stability possible.

9.4.3 Whenever possible, gamma probes should be run open hole or through the least amount of completion material to minimize well construction effects and to provide a base line for comparing subsequent logs.

9.5 Gamma probe operation is typically checked before the start of each run to insure that equipment is operating and that nuclear counters are producing output.

9.5.1 Gamma operation may be checked by placing a small radioactive source over the gamma detector. Common materials, such as thorium-treated lantern mantles, small bottles of potassium chloride, laboratory radioactive test sources, or sleeves containing natural radioisotopes (phosphatic sands, etc.), are frequently used.

9.6 Select and document the depth reference point.

9.6.1 The selected depth reference needs to be stable and accessible (for example, top of borehole casing).

9.7 Determine and document probe zero reference point (for example, top of probe or cablehead) and depth offset to gamma measurement point.

9.7.1 The measurement point of the gamma logging probe is the distance along the probe corresponding with the center of the crystal within the logging tool; this position is not visible unless the position is marked on the outside of the tool or the operator has information specifying that position with respect to a prominent reference point on the probe housing.

9.7.2 Position the probe zero reference point to the depth reference point (ground level, top of casing, etc.) and initialize depth recording/display systems.

9.8 Select horizontal and vertical scales for log display to meet project objectives.

9.8.1 Preferred horizontal scale divisions are multiples of two or five inches, such that the log value is easily determined on the plot (for example, 0 to 100, 0 to 200, 50 to 150, etc.).

9.8.2 Preferred vertical scales are multiples of two or five, such that depth can be easily determined on a log plot (for example, 1/5, 1/10...1/100, etc.).

9.9 Select digitizing interval (or sample rate if applicable) to meet project objectives (see 8.3.1.2 of Guide D 5753).

9.9.1 Digitizing interval needs to be at least as small as the vertical resolution of the gamma probe, that is typically about 1 ft (30 cm).

9.9.2 Typically, this interval is no larger than 0.5 ft (15 cm) to ensure that the optimum vertical resolution is achieved.

9.9.3 Even though field plots may be generated with smoothing, the rawest (non-filtered) form of the data should be recorded.

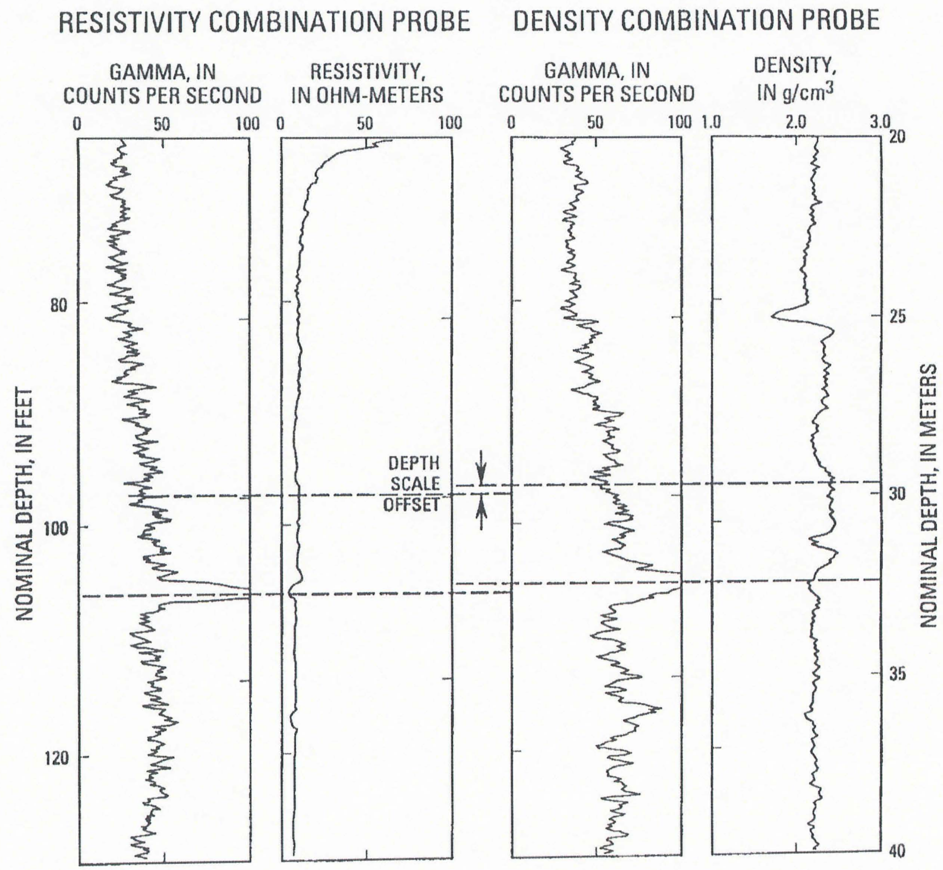
9.10 The gamma probe is lowered to the bottom of the borehole.

9.10.1 Gamma counts should be monitored as the probe is lowered because knowledge of the average count rates produced by the formation is important in determining proper logging speed. Gamma value range is also needed to determine proper horizontal scale and with some instrumentation, to determine sensitivity/gain settings.

9.10.2 Selection of probe speed while lowering is based on knowledge of borehole depth, stability, and other conditions; tension on the measuring wheel and smoothness of probe descent should be monitored to ensure that depth errors are not being introduced.

9.11 Select logging speed.

9.11.1 Logging speed should be determined by the application of the data acquired to meet project objectives.



NOTE 1—This figure shows a small depth offset that should be removed by adjusting the depth scale on one of the logs; note that the average count rates for the two different gamma detectors differ as a result of different detector efficiencies.

FIG. 4 Example of Gamma Logs From Gamma Detectors in Two Different Logging Tools (Electrical Resistivity on Density)

9.11.2 Typical gamma logging speed is approximately 20 ft/min (6 m/min), but slower speeds may be needed if formation gamma activity is low.

9.11.3 Proper logging speed is indicated by gamma logs that show distinct beds, which correlate with other information such as core descriptions or driller's logs, and where there is relatively little random fluctuation within beds (see Fig. 1).

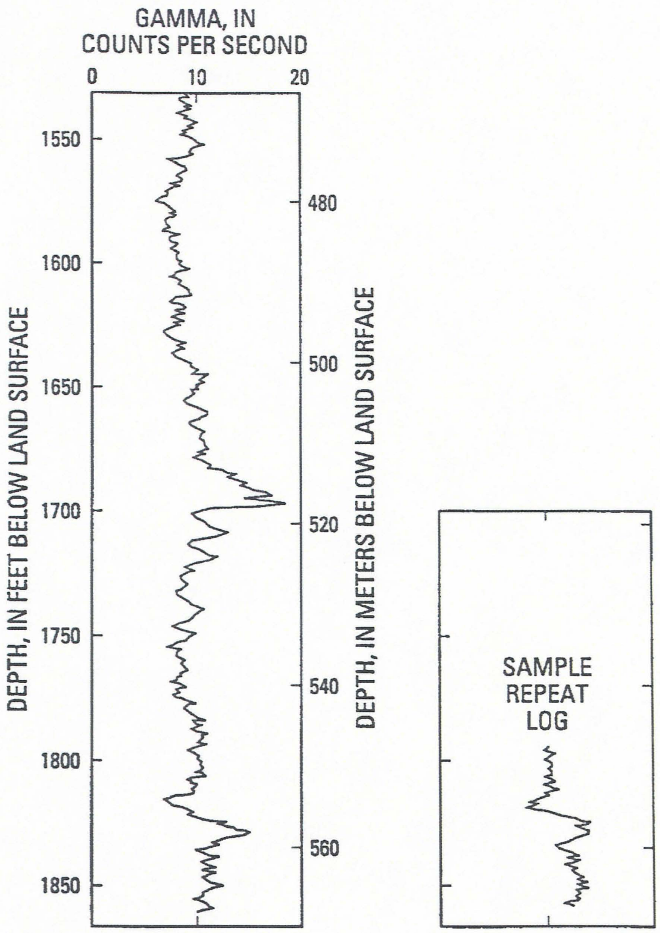
9.11.4 If the operator is concerned about whether logging speed is affecting the quality of the gamma log, the operator should repeat a representative section of the log (representative of the geologic variation in the borehole) using the same speed; if the log reproduces interpreted bed boundaries that agree with other log and geologic data and the initial run, then the logging speed is adequate. If there are significant changes in the interpreted bed boundaries or if bed boundaries (lithologic contacts) are not indicated, the operator should try logging at a reduced speed.

9.11.5 In situations where gamma activity is extremely low, such as in many basalts and some carbonate and quartzite formations, the operator can estimate the maximum logging speed from the formula:

$$S_f < 0.50G \quad \text{or} \quad S_m < 0.15G \tag{2}$$

where:
S_f = the logging speed in feet per minute,
S_m = the logging speed in metres per minute, and
G = the average measured gamma activity of the interval or intervals of interest in counts per second.

This formula gives the logging speed required to ensure that the standard nuclear statistical error is less than about 5 %. In some situations, the available time and budget and the length of borehole to be logged may indicate that a trade-off be made between statistical errors and log resolution; an effective trade-off for a given situation can be made by experimenting



NOTE 1—In this figure, experimentation with logging speed demonstrates that a 10 ft (m) per minute logging speed generates useful and repeatable gamma logs with statistical errors somewhat greater than 5 %, but where beds can be effectively detected.

FIG. 5 Example of a Gamma Log From a Basalt Formation of Very Low Gamma Activity

with repeat logging runs over representative intervals containing bed contacts (see Fig. 5).

9.12 Collect gamma log data while the probe is moving up the borehole; data collection while logging upward ensures that the probe is retrieved smoothly and continuously.

9.12.1 In unstable boreholes, it is sometimes advantageous to collect data both while probe is being lowered and being pulled up the borehole.

9.13 When the probe reaches the top of the borehole:

9.13.1 Check depth reference and document after survey depth error (ASDE).

9.13.2 Determine if ASDE meets project objectives.

9.13.3 Typical tolerance for ASDE is ±0.4 per 100-ft interval logged (±0.4 m per 100-m).

9.13.4 Typical depth tolerance for repeat logs is within 0.4 %.

9.14 Selected borehole intervals should be repeated (that is, relogged) under similar logging parameters as the initial log. Repeat logs verify that the gamma electronics are functioning correctly, and that the logging speed (effect of nuclear statistical fluctuations) is adequate for project objectives. The interval repeated should have enough variability, if possible, to check repeatability and resolution; also note that nuclear statistical noise is most likely to affect intervals with relatively low gamma count rates.

9.14.1 Repeat logs should be compared with the original log to ensure correct operation of the probe prior to ending a logging event.

9.14.2 Repeat sections may not repeat exactly because of the statistical nature of nuclear activity that introduces some random fluctuation into the measured count rate. Individual log values should typically repeat within one standard deviation, and the character and shape of the logs should be similar. Note that the importance of high count rates to reduce the statistical variations between log runs.

9.14.3 Repeat sections may not repeat exactly due to a different orientation of the logging probe on the repeat run or changes in the borehole between logging runs (see Section 6, Interferences).

9.15 Evaluate the quality of field logs and compare logs with drilling and completion information.

9.16 Gamma logs are usually smoothed by filtering (in hardware or software) with an N-point averaging window (for example, running average, weighted average, etc.) to minimize the effects of statistical variation caused by radioactive decay. The window width:

$$(N-1)\Delta z \tag{3}$$

where:

N = the number of points, and
Δz = the digitizing interval, which should correspond with the vertical resolution, which is typically about 1 ft (30 cm) in most geological formations.

9.16.1 Larger filters are frequently applied to gamma logs for presentation purposes (compression of the vertical scale); however, this filtering generally results in loss of some log information.

9.16.2 The rawest form of the gamma data and the filtered data should be saved.

9.17 Post-acquisitions calibration checks may be required to meet the objectives of the logging program to verify gamma log standardization and dead time correction.

10. Interpretation of Results

10.1 See the Log Interpretation section of Guide D 5753 for procedures on log interpretation.

10.2 A valid gamma log is important to establish the distribution of lithology and bedding within a borehole for correlation purposes, for different logs run in the same borehole (see Fig. 4), and for the extrapolation of results between boreholes (see Fig. 2).

10.2.1 Except at sites contaminated by radioactive waste, the measured gamma photons originate from the radioactive decay of naturally-occurring isotopes of Potassium-40 and daughter products of Uranium-238 and Thorium-232 (see Fig. 6).

10.2.2 Gamma logs can be analyzed individually (that is, borehole lithology).

10.2.3 Gamma logs can be analyzed as part of a suite to take advantage of the synergistic nature of log data.

10.3 The gamma log should be depth correlated with the other geophysical logs as the first step to interpretation. This is especially important for logs that use the gamma data for depth adjustment.

10.3.1 The gamma log data may be filtered, edited, combined, and merged with other log values.

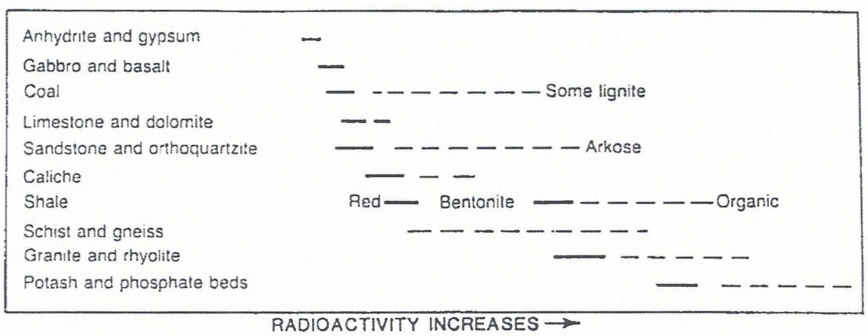


FIG. 6 Range of Relative Gamma Activity of Common Rocks

10.3.2 Final log headers are filled out and attached to the data.

10.3.3 The gamma log may be plotted at different scales for the purpose of interpreting, summarizing, and presenting the final data.

10.4 Other pertinent information, including borehole construction (casing size), drilling history (hole size, drill method, penetration rate, core loss, fluid loss, etc.), and geologic information should be integrated with the gamma log data.

10.4.1 Many of the borehole effects on the gamma log, such as correction for attenuation of steel casing and borehole fluid, can be normalized with empirical data to facilitate interpretation. This is especially important in comparing gamma logs from boreholes logged with different completion designs.

10.4.2 It is also possible to normalize the gamma log for well construction if it is possible to log a similar borehole prior to completion and again after a similar scheme.

10.5 Gamma logs commonly are the primary indicator of geologic structure and stratigraphy to be used as a guide in installing well screens, positioning cement plugs, bentonite seals or packers, etc.

10.5.1 When gamma logs are used as indicators of bed boundaries, the bed contact is usually identified as the point where the log measures half of the total change in amplitude across the bed contact (see Fig. 5).

10.6 Gamma logs obtained for depth correlation on logging runs using different probes may not produce the same count rates at each depth because of differences in detector efficiencies and probe designs.

10.7 Gamma logs may be applied to correlate lithology between boreholes based upon the characteristic gamma activity of specific beds or formations (See Fig. 6). Gamma logs can be used to determine the continuity of lithology, strike, and dip of beds between boreholes, and to infer the existence of faults and other discontinuities.

10.8 The primary application of gamma logs for geotechnical applications assumes a correlation between gamma activity and the proportion of fine-grained material in the formation. The gamma log may be used to calculate a clay volume or percentage. This assumption is frequently not valid (for example, phosphatic sands, arkosic sands, non-sedimentary environments, areas of natural radioactive mineralization, etc.) and should be tested in the project area. This testing may consist of cross plots, principal component analysis, and other multivariate statistical techniques. The application of gamma log analysis in the estimation of clay fraction may also be complicated by the presence of more than one clay type, each of which has a distinctly different level of gamma activity.

10.9 Gamma logs can be used to detect the presence of radioisotopes in borehole tracer studies, calibrated in units of radioisotope concentration to assess the degree of radioisotope contamination at radioactive waste sites, and used to locate source rocks in natural radium and radon hazard assessment studies.

11. Report

11.1 The Report section of Guide D 5753 should be consulted for requirements of the report.

11.2 Providers of gamma logs shall describe the components of the gamma logging system, the principles of the methods used, methods and results of calibration and standardization, performance verification (repeat sections, ASDE, correlation with other logs and key features such as bottom of steel casing, etc.), and uniqueness of interpretation.

11.3 Information on the software and algorithms used should be documented.

11.4 Any deviations from this guide should be documented.

11.5 Presentation of gamma logs should be designed to meet project objectives. At a minimum, depth (y-axis) and units of measurement (x-axis) scales should be clearly marked. There may be a difference between presentations of data collected in the field versus in the final report. Any scale "wraps" should be clearly marked (see Fig. 1).

11.5.1 Gamma logs are typically displayed with linear scales in counts per second or API units (see Fig. 1).

11.5.2 The digital data should be provided in ASCII format and include depth referenced gamma values and all pertinent header and calibration information; for example, Log ASCII Standard format (LAS).

11.5.3 Field plots typically are generated at the time of logging or immediately upon completion of data acquisition. These plots may be delivered in the field or may be discarded at some point later in the project. They are not typically included in the report.

11.5.4 Final log plots are typically generated post acquisition. They consist of the filtered and edited gamma data combined and merged with logical combinations of other log data. Final log plots are typically plotted in an industry standard format such as API format and may be included in the report.

11.5.5 Summary log plots may be generated (typically at reduced scales) to incorporate other logs, relevant data, and interpretations. These plots are generally included in the report.

12. Keywords

12.1 borehole geophysics; dead time correction; gamma log; natural gamma log; nuclear statistics; radioisotope; well construction; well logging

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GEOVision
geophysical services

December 4, 2006

GEOVision Project Number 6285

Mr. Matthew Cooke
MACTEC Engineering and Consulting
720 Gracern Road
Suite 132
Columbia, SC 29210

Subject: **Final Report - Four Electrode Wenner Resistivity Tests**
VC Summer Nuclear Station
SCE&G COL Project – MACTEC Job Number 6234-06-3534

Dear Mr. Cooke

A geophysical survey was conducted between July 11 and 13 2006 at the SCE&G COL site near the VC Summer Nuclear Power Plant at Jenkinsville, South Carolina. The purpose of the geophysical survey was to measure soil resistivity according to ASTM standard G57-95a. Site conditions consisted of very dry soil that had been disturbed during path clearing activities.

METHODOLOGY

Resistivity equipment used during this investigation included a MiniRes HP earth resistivity meter coupled to 1/4- inch stainless steel electrode stakes with 22 gauge insulated copper wire. A test resistor rated at 19.935 ohms (at 72 degrees Fahrenheit) was used to verify the MiniRes HP was operating within calibrated levels. The MiniRes HP operates at two selectable power levels: "Low Power" with a 1 mA output current and 730 V peak to peak, and "High Power" with an output current of 10 mA and 530 V peak to peak.

FIELD PROCEDURES

Each day before conducting the geophysical survey the battery level was checked on the resistivity meter and found to be within acceptable limits. Ambient temperature and soil conditions were recorded on the field log. Electrode spacing was pre-determined based on information provided by the client.

A test resistor rated at 19.935 ohms was connected to the positive and negative current and potential leads on the MiniRes HP immediately before the first sounding and immediately after the final sounding, at each of the survey locations. The resistance value across the test resistor and the time of the test measurement was recorded on the field log.

Resistivity measurements (soundings) were made at six locations (R-1 to R-6) at the selected intervals using a surveyor's measuring tape for spatial control. See Attachment A of the MACTEC Geotechnical Data Report for surveyed locations of the six locations R-1 to R-6.

Ten soundings were made on each line. For each resistivity sounding, four stainless steel electrodes were placed at equal distances (*a* spacing) in a straight line. A current was applied from the outer electrodes, and a potential reading (voltage) was measured across the inner electrodes. The MiniRes HP displays the resistance value, which was recorded along with the *a* spacing on a field data sheet and later transferred to a spreadsheet. Two or more measurements were recorded at each station for quality control. If there was significant variation between the first and second measurements the control leads, electrode cable and electrode coupling were field checked to ensure proper survey conditions. After each sounding, the electrodes were moved to the next *a* spacing and another set of measurements was taken. Typically, for shorter *a* spacings, the instrument was operated at the lower power setting. The power level was increased at greater *a* spacings, or when the measured resistance range required more power, whichever condition occurred first.

DATA REDUCTION

Six spreadsheets were generated from the collected resistivity data. Probe spacing (*a*) and resistance reading (ΔV/I), were entered for each Wenner sounding. A generalized form of the four-electrode array is shown in Figure 1.

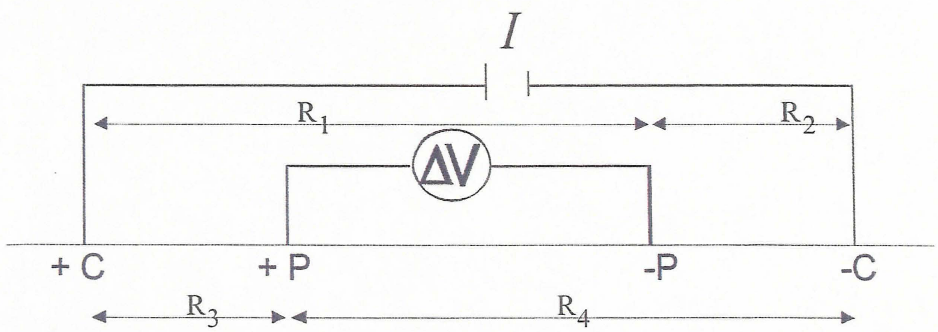

Figure 1: The generalized form of the four electrode array

When the material upon which the current is induced is uniform, the resistivity calculated will be constant independent of electrode configuration. However, in a field investigation where subsurface heterogeneities exist, the calculated resistivity values will vary with electrode array. This calculated resistivity is referred to as apparent resistivity (ρ_a), and can be calculated using the relationship:

$$\rho_a = \frac{2\pi\Delta V}{I\left\{(\frac{1}{R_3} - \frac{1}{R_4}) - (\frac{1}{R_1} - \frac{1}{R_2})\right\}}$$

For the Wenner array, where $R_1 = R_4$; $R_3 = R_2$ and $R_1 = 2*(R_2) = 2a$, it can be shown that the formula for calculated apparent resistivity can be reduced to the following form:

$$\rho_a = 2\pi a\left(\frac{\Delta V}{I}\right)$$

RESULTS

Data collected from the four Wenner resistivity arrays are attached as Tables 1-6. Electrode *a* spacing was converted to meters in order to provide an average soil resistivity (ρ_a) in ohm-meters. According to ASTM Standard G57-95a, data is also presented in the ohm-centimeter unit.

All completed data processing forms are retained in project files. All files generated during the processing sequence were archived on CD-ROM.

SUMMARY

Four-electrode soil resistivity measurements were made at the VC Summer nuclear power plant according to ASTM standard G57-95a. Soil and rock resistivity values were made at six locations, at *a* spacings determined by the client. Field measurements and calculated values were consistent and repeatable at all locations.

If you have any questions concerning this investigation, please call us at 951-549-1234.

Sincerely,
GEO*Vision* Geophysical Services

JB Shawver

Antony J Martin

Submitted by:
JB Shawver
Senior Project Geophysicist

Reviewed and Approved by:
Antony J. Martin
Technical Director

Attachments:

Table 1: Resistivity Soundings R-1
Table 2: Resistivity Soundings R-2
Table 3: Resistivity Soundings R-3
Table 4: Resistivity Soundings R-4
Table 5: Resistivity Soundings R-5
Table 6: Resistivity Soundings R-6
Applied Technical Services, Incorporated Certificate of Calibration
Applied Technical Services, Incorporated Calibration Data Sheet

TABLE 1 ELECTRICAL RESISTIVITY SOUNDING R-1

Job Number 6285 Date 12-Jul-06

19.938 ohm Test Resistor Reading

19.918 ohm at 1430 19.914 ohm at 1520

A-Spacing [ft.]	Resistance Reading [Ohm]	Geometric Multiplier [2(pi)A]	Calculated Magnitude [Ohm-ft.]	Converted Magnitude [Ohm-m]	Calculated to Ohm-cm [Ohm-cm]	Repeat Resistance [Ohm]	Repeat Magnitue [Ohm-ft.]	Repeat Conversion [Ohm-m]	Repeat Calculation to Ohm-cm [Ohm-cm]
3.0	119.900	18.850	2260.062	688.867	68886.682	119.900	2260.062	688.867	68886.68229
5.0	72.300	31.416	2271.371	692.314	69231.403	72.300	2271.371	692.314	69231.40297
7.5	45.900	47.124	2162.987	659.278	65927.830	45.900	2162.987	659.278	65927.8298
10.0	37.600	62.832	2362.478	720.083	72008.320	37.600	2362.478	720.083	72008.31955
15.0	27.900	94.248	2629.513	801.476	80147.558	27.900	2629.513	801.476	80147.5578
30.0	12.914	188.496	2434.232	741.954	74195.381	12.914	2434.232	741.954	74195.38074
50.0	6.923	314.159	*2174.925*	662.917	66291.702	6.922	2174.610	662.821	66282.12605
100.0	5.629	628.319	3536.805	1078.018	107801.817	5.629	3536.805	1078.018	107801.8167
200.0	6.259	1256.637	7865.291	2397.341	239734.081	6.259	7865.291	2397.341	239734.0809
300.0	5.937	1884.956	11190.981	3411.011	341101.112	5.940	11196.636	3412.735	341273.4719

TABLE 2 ELECTRICAL RESISTIVITY SOUNDING R-2

Job Number 6285 Date 12-Jul-06

19.938 ohm Test Resistor Reading

19.924 ohm at 0920 19.918 ohm at 1330

A-Spacing [ft.]	Resistance Reading [Ohm]	Geometric Multiplier [2(pi)A]	Calculated Magnitude [Ohm-ft.]	Calculated to Ohm-m [Ohm-m]	Calculated to Ohm-cm [Ohm-cm]	Repeat Resistance [Ohm]	Repeat Magnitue [Ohm-ft.]	Repeat Calculation to Ohm-m [Ohm-m]	Repeat Calculation to Ohm-cm [Ohm-cm]
3.0	123.900	18.850	2335.460	711.848	71184.820	123.900	2335.460	711.848	71184.82015
5.0	86.500	31.416	2717.478	828.287	82828.719	86.500	2717.478	828.287	82828.71863
7.5	52.700	47.124	2483.429	756.949	75694.916	52.700	2483.429	756.949	75694.9157
10.0	37.600	62.832	2362.478	720.083	72008.320	37.600	2362.478	720.083	72008.31955
15.0	25.900	94.248	2441.017	744.022	74402.213	26.000	2450.442	746.895	74689.48038
30.0	14.190	188.496	2674.752	815.264	81526.441	14.191	2674.940	815.322	81532.18586
50.0	8.816	314.159	2769.628	844.183	84418.264	8.816	2769.628	844.183	84418.26398
100.0	6.450	628.319	4052.655	1235.249	123524.910	6.449	4052.026	1235.058	123505.7587
200.0	5.457	1256.637	6857.468	2090.156	209015.638	5.457	6857.468	2090.156	209015.6382
300.0	4.087	1884.956	7703.814	2348.122	234812.236	4.088	*7705.698*	2348.697	234869.6891

TABLE 3 ELECTRICAL RESISTIVITY SOUNDING R-3

Job Number 6285 Date 13-Jul-06

19.938 ohm Test Resistor Reading

19.925 ohm at 0800 19.925 ohm at 0900

A-Spacing [ft.]	Resistance Reading [Ohm]	Geometric Multiplier [2(pi)A]	Calculated Magnitude [Ohm-ft.]	Converted Magnitude [Ohm-m]	Calculated to Ohm-cm [Ohm-cm]	Repeat Resistance [Ohm]	Repeat Magnitue [Ohm-ft.]	Repeat Conversion [Ohm-m]	Repeat Calculation to Ohm-cm [Ohm-cm]
3.0	112.500	18.850	2120.575	646.351	64635.127	113.100	2131.885	649.798	64979.84793
5.0	79.900	31.416	2510.133	765.088	76508.840	79.900	2510.133	765.088	76508.83952
7.5	55.300	47.124	2605.951	794.294	79429.390	55.400	2610.663	795.730	79573.02333
10.0	49.700	62.832	3122.743	951.812	95181.210	49.700	3122.743	951.812	95181.20962
15.0	34.100	94.248	3213.849	979.581	97958.126	34.100	3213.849	979.581	97958.1262
30.0	21.200	188.496	3996.106	1218.013	121801.306	21.200	3996.106	1218.013	121801.3065
50.0	15.425	314.159	4845.907	1477.032	147703.235	15.424	4845.593	1476.937	147693.6597
100.0	10.447	628.319	6564.044	2000.721	200072.052	10.447	6564.044	2000.721	200072.0517
200.0	7.967	1256.637	10011.627	3051.544	305154.405	7.967	10011.627	3051.544	305154.4052
300.0	7.015	1884.956	13222.963	4030.359	403035.927	7.015	13222.963	4030.359	403035.9268

TABLE 4 ELECTRICAL RESISTIVITY SOUNDING R-4

Job Number 6285 Date 13-Jul-06

19.938 ohm Test Resistor Reading

19.924 ohm at 0940 19.922 ohm at 1100

A-Spacing [ft.]	Resistance Reading [Ohm]	Geometric Multiplier [2(pi)A]	Calculated Magnitude [Ohm-ft.]	Converted Magnitude [Ohm-m]	Calculated to Ohm-cm [Ohm-cm]	Repeat Resistance [Ohm]	Repeat Magnitue [Ohm-ft.]	Repeat Conversion [Ohm-m]	Repeat Calculation to Ohm-cm [Ohm-cm]
3.0	126.000	18.850	2375.044	723.913	72391.343	126.100	2376.929	724.488	72448.79597
5.0	79.100	31.416	2485.000	757.428	75742.794	79.100	2485.000	757.428	75742.79357
7.5	61.400	47.124	2893.407	881.910	88191.040	61.400	2893.407	881.910	88191.0403
10.0	50.800	62.832	3191.858	972.878	97287.836	50.900	3198.141	974.793	97479.34747
15.0	38.700	94.248	3647.389	1111.724	111172.419	38.700	3647.389	1111.724	111172.4189
30.0	21.400	188.496	4033.805	1229.504	122950.375	21.400	4033.805	1229.504	122950.3754
50.0	14.800	314.159	4649.557	1417.185	141718.501	14.800	4649.557	1417.185	141718.5012
100.0	11.930	628.319	7495.840	2284.732	228473.205	11.930	7495.840	2284.732	228473.2054
200.0	8.107	1256.637	10187.557	3105.167	310516.727	8.106	10186.300	3104.784	310478.4246
300.0	8.673	1884.956	16348.220	4982.937	498293.741	8.673	16348.220	4982.937	498293.7411

TABLE 5 ELECTRICAL RESISTIVITY SOUNDING R-5

Job Number 6285 Date 11-Jul-06
19.938 ohm Test Resistor Reading
19.930 ohm at 1100 19.920 ohm at 1500

A-Spacing [ft.]	Resistance Reading [Ohm]	Geometric Multiplier [2(pi)A]	Calculated Magnitude [Ohm-ft.]	Converted Magnitude [Ohm-m]	Calculated to Ohm-cm [Ohm-cm]	Repeat Resistance [Ohm]	Repeat Magnitue [Ohm-ft.]	Repeat Conversion [Ohm-m]	Repeat Calculation to Ohm-cm [Ohm-cm]
3.0	121.700	18.850	2293.991	699.208	69920.844	121.700	2293.991	699.208	69920.84433
5.0	80.700	31.416	2535.265	772.749	77274.885	80.700	2535.265	772.749	77274.88547
7.5	51.300	47.124	2417.456	736.840	73684.045	51.300	2417.456	736.840	73684.04507
10.0	42.500	62.832	2670.354	813.924	81392.382	42.500	2670.354	813.924	81392.38247
15.0	29.600	94.248	2789.734	850.311	85031.101	29.600	2789.734	850.311	85031.10074
30.0	15.444	188.496	2911.125	887.311	88731.103	15.443	2910.937	887.254	88725.35735
50.0	9.614	314.159	3020.327	920.596	92059.572	9.614	3020.327	920.596	92059.57236
100.0	8.628	628.319	5421.132	1652.361	165236.112	8.628	5421.132	1652.361	165236.112
200.0	5.984	1256.637	7519.716	2292.009	229200.949	5.984	7519.716	2292.009	229200.949
300.0	5.415	1884.956	10207.035	3111.104	311110.413	5.420	10216.459	3113.977	311397.6798

TABLE 6 ELECTRICAL RESISTIVITY SOUNDING R-6

Job Number 6285 Date 13-Jul-06
19.938 ohm Test Resistor Reading
19.901 ohm at 1230 19.908 ohm at 1350

A-Spacing [ft.]	Resistance Reading [Ohm]	Geometric Multiplier [2(pi)A]	Calculated Magnitude [Ohm-ft.]	Converted Magnitude [Ohm-m]	Calculated to Ohm-cm [Ohm-cm]	Repeat Resistance [Ohm]	Repeat Magnitue [Ohm-ft.]	Repeat Conversion [Ohm-m]	Repeat Calculation to Ohm-cm [Ohm-cm]
3.0	120.800	18.850	2277.026	694.038	69403.763	120.600	2273.256	692.889	69288.85642
5.0	74.100	31.416	2327.920	709.550	70955.006	74.100	2327.920	709.550	70955.00636
7.5	37.700	47.124	1776.571	541.499	54149.873	38.000	1790.708	545.808	54580.77413
10.0	38.500	62.832	2419.026	737.319	73731.923	38.500	2419.026	737.319	73731.92294
15.0	20.800	94.248	1960.354	597.516	59751.584	21.100	1988.628	606.134	60613.386
30.0	15.400	188.496	2902.832	884.783	88478.308	15.400	2902.832	884.783	88478.30753
50.0	11.800	314.159	3707.079	1129.918	112991.778	11.800	3707.079	1129.918	112991.778
100.0	8.700	628.319	5466.371	1666.150	166614.995	8.700	5466.371	1666.150	166614.9947
200.0	5.015	1256.637	6302.035	1920.860	192086.023	5.016	6303.292	1921.243	192124.3249
300.0	5.470	1884.956	10310.707	3142.704	314270.352	4.475	8435.176	2571.042	257104.1729

APPLIED TECHNICAL SERVICES, INCORPORATED
1280 Field Parkway, Marietta, GA 30066 (770) 514-3288

CERTIFICATE OF CALIBRATION

ATS Reference No.: M502064-1 **Date:** October 24, 2006

Purchase Order: 66252

MACTEC Engr. & Consult.
396 Plasters Avenue, N.E.
Atlanta, GA 30324

Test Instrument: Low Resistivity Meter **Manufacturer:** LRI

Model No: Unknown **Asset No.:** 107 **Serial No:** 107

Status When Received: *IN TOLERANCE* **Location:** In-Lab

Calibration Environmental Conditions: Temperature: 70 °F **Relative Humidity:** 40 %

Date of Calibration: July 10, 2006 **Calibration Due:** July 10, 2007

This certificate attests that the calibration was performed in compliance with ANSI/NCSL Z540-1 and ISO/IEC 17025 and is traceable to the National Institute of Standards and Technology. Applied Technical Services, Inc., certifies that the above named instrument has been calibrated by comparison standards traceable to the National Institute of Standards and Technology through the following test numbers and is certified and returned within required tolerance/accuracy.

Master Shunt Box **Due:** February 25, 2007 **Trace:** 02014

Calibrated by: John C O'Toole

John O'toole
Senior Calibration Technician

APPLIED TECHNICAL SERVICES, INCORPORATED

1280 Field Parkway, Marietta, Georgia 30066 • (770) 514-3288 Fax (678) 819-1055

CALIBRATION DATA SHEET

Customer: MACTEC Engr. & Consult., Atlanta
Purchase Order No.: 66252
Item Name: Low Resistivity Meter
Asset No.: 107
ATS Reference No.: M502064-1
Manufacturer: LRI
Model No.: Unknown
Proc. No.: 1032
Rev.: 1
Serial No.: 107
Calibration Date: 07-10-06
Calibration Due Date: 07-10-07

Reason For Service: ☒ Initial Calibration ☐ Due For Calibration ☐ Repair and Calibration

Equipment Used: ATS-02014 Due: 02-25-07 Guildline Master Shunt Box
Due:
Due:
Due:
Due:
Due:

Calibrated By: *John O'Toole*

Customer Instrument Under Test

UNCERTAINTY (SEE NOTE)	RANGE	ATS STANDARD	TOLERANCE	AS FOUND READING	AS CALIBRATED READING
± .01	Auto	1.000	.92 to 1.08	1.0	1.0
± .01	Auto	10.000	9.65 to 10.35	10.0	10.0
± .01	Auto	100.000	96.95 to 103.05	100.1	100.1
± .01	Auto	1000.000	965 to 1035	1000.1	1000.1
± .01	Cal resistor	19 Ohms	As Found data only	19.939	19.939

* Indicates out of tolerance readings.

Remarks: Measurement Uncertainty reported at coverage factor K = 2 or 95% confidence level.