Designation: D 6167 – 97 (Reapproved 2004)

Standard Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper[1]

This standard is issued under the fixed designation D 6167; 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 caliper logging of boreholes, wells, access tubes, caissons, or shafts (hereafter referred as boreholes) as commonly applied to geologic, engineering, ground-water, and environmental (hereafter referred as geotechnical) investigations. Caliper logging for mineral or petroleum exploration and development are excluded.

1.2 This guide defines a caliper log as a record of borehole diameter with depth.

1.2.1 Caliper logs are essential in the interpretation of geophysical logs since they can be significantly affected by borehole diameter.

1.2.2 Caliper logs are commonly used to measure borehole diameter, shape, roughness, and stability; calculate borehole volume; provide information on borehole construction; and delineate lithologic contacts, fractures, and solution cavities and other openings.

1.3 This guide is restricted to mechanically based devices with spring-loaded arms, which are the most common calipers used in caliper logging with geotechnical applications.

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

1.5 To obtain additional information on caliper logs see Section 9 of this guide.

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

1.7 This guide should not be used as a sole criterion for caliper logging and does not replace professional judgement. Caliper logging procedures should be adapted to meet the needs of a range of applications and stated in general terms so that flexibility or innovation is not suppressed.

1.8 The geotechnical industry uses English or SI units. The caliper log is typically recorded in units of inches, millimetres, or centimetres.

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.*

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

3. Terminology

3.1 *Definitions:* Definitions shall be in accordance with Terminology D 653, Section 12, Ref **(1)**,[3] or as defined below:

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

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

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

[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.

[3] The boldface numbers given in parentheses refer to a list of references at the end of the text.

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

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

3.1.6 *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 caliper 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 caliper logging.

5. Significance and Use

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

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

5.3 This guide applies to commonly used caliper 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 caliper technique, application, and interpretation methods.

6. Interferences

6.1 Most extraneous effects on caliper logs are caused by instrument problems and borehole conditions.

6.2 Instrument problems include the following: electrical leakage of cable and grounding problems, temperature drift, wear of mechanical components including the hinge pins and in the linear potentiometer (mechanical hysteresis), damaged or bent arms, and lack of lubrication of the mechanical components.

6.3 Borehole conditions include heavy drilling mud, borehole deviation, and drilling-related borehole irregularities.

7. Apparatus

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

7.2 Caliper logs may be obtained with probes having a single arm, three arms (averaging or summation), multiple independent arms (x-y caliper), multiple-feeler arms, bow springs, or gap wheels. Single-arm and three-arm averaging probes are most commonly used for geotechnical investigations.

7.2.1 A single-arm caliper commonly provides a record of borehole diameter while being used to decentralize another type of log, such as a side-collimated gamma-gamma probe (see Fig. 1). The caliper arm generally follows the high side of a deviated hole. The single-arm decentralizing caliper may not have the resolution needed for some applications.

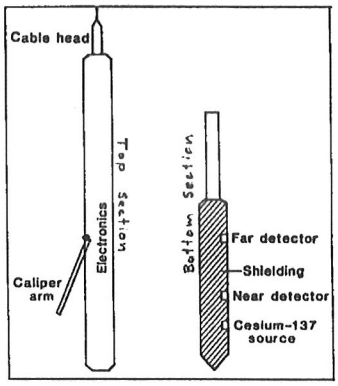

FIG. 1 Probe for Making Side-Collimated Gamma-Gamma Logs with Single-Arm Caliper (2)

7.2.2 The three-arm averaging or summation caliper has arms of equal length oriented 120° apart (see Fig. 2). All arms move together, which provides an average diameter measurement. This caliper provides higher resolution than the single-arm caliper measurement (see Fig. 3).

7.2.3 Multiple independent arm calipers generally have three or four independent arms of equal length; these arms are sometimes oriented. Horizontal resolution, that provides accurate borehole-diameter measurement regardless of borehole shape, is related to the number of independent arms. In general, calipers with four or more independent arms will have higher resolution than three-arm averaging (see Fig. 3). The four independent-arm caliper log may show borehole elongation (elliptical borehole shape) and better indicates the actual irregularity of the borehole.

7.3 Caliper probes using arms are typically spring loaded. The arms are retracted and opened with an electric motor and

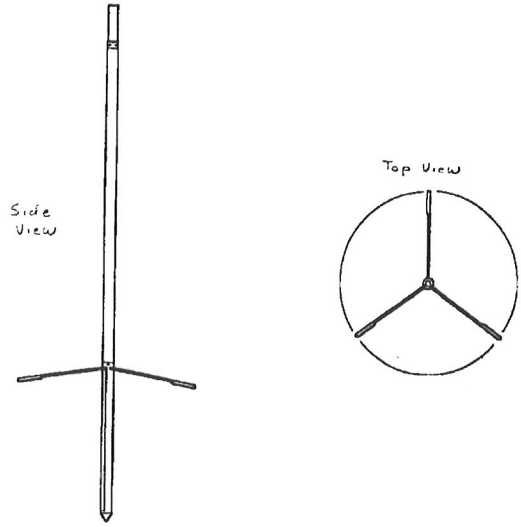

FIG. 2 Three-Arm Averaging Caliper

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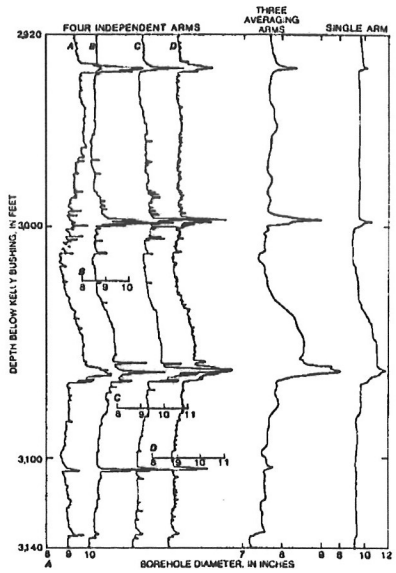

FIG. 3 Caliper Logs From Probes Having Four Independent Arms, Three Averaging Arms, and a Single Arm, Madison Limestone Test Well 1, Wyoming (2)

retention spring. The arms and gears are lubricated. Caliper probes closed by hand are held closed with an electric solenoid or weighted retention ring that is released with a sudden drop. Typically, the caliper arms are mechanically connected to a linear or rotary potentiometer such that changes in the angle of the arms causes changes in resistance. These changes in resistance are proportional to average borehole diameter. In some probes, the voltage changes are converted to a varying pulse rate or digitized downhole to eliminate or minimize cable transmission noise. Different arm length can be used to optimize sensitivity for the borehole-diameter range expected.

7.4 The concepts of volume of investigation and depth of investigation are not applicable to caliper logs since it is a surface-contact measurement.

7.5 Vertical resolution of caliper measurements is a function of the size of the contact surface (arm tip or pad), the response of the mechanical and electronic components, and digitizing interval used. The theoretical limit of vertical resolution is equal to the width of the caliper pad or tip. Selection of arm lengths and angle, and tip diameter will affect sensitivity. Shorter arms generally will provide more detail of the rugosity (borehole roughness as defined by Ref. **(2)**) of the borehole wall than longer arms. However, size of caliper probe and borehole diameter may also determine arm lengths used.

7.6 Measurement resolution of typical caliper probes is 0.05 in. (0.13 cm) of borehole diameter.

7.7 A variety of caliper 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 Caliper Logs

8.1 *General:*

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

8.1.2 Caliper logs can be used in a qualitative (for example, comparative) or quantitative (for example, borehole diameter corrections) manner depending upon the project objectives.

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

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

8.2 Calibration is the process of establishing values for caliper response and is accomplished with a physical model of a known diameter. Calibration data values related to the physical properties (for example, borehole diameter, roughness) may be recorded in units (for example, counts per second), that can be converted to units of length (for example, inches, millimetres, or centimetres.)

8.2.1 At least two, and preferably more, values, which approximate the anticipated operating range, are needed to establish a calibration curve (for example, 4- and 10-in. (10.2- and 25.4-cm) rings) if the borehole diameter to be logged is 5 in. (12.7 cm)).

8.2.2 Physical models of measured diameter that may be used to calibrate the caliper response may include rings or bars made of rigid materials that are not easily deformed and resist wear.

8.2.2.1 Calibration of caliper probes is done most accurately in rings of different diameters.

8.2.2.2 A calibration bar is a plate that is drilled and marked at regular intervals and machined to fit over the body of the probe (see Fig. 4). One arm is placed in the appropriate hole for the range to be logged.

8.2.2.3 Calibration can be checked by using casing of measured diameter logged in the borehole.

8.3 Standardization is the process of checking logging response to show evidence of repeatability and consistency.

8.3.1 Calibration serves as a check of standardization.

8.3.2 A representative borehole may be used to periodically check caliper response providing the borehole environment does not change with time. Caliper response may not repeat exactly because the probe may rotate, causing the arms to follow slightly different paths within the borehole.

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.

9.2 Caliper specific information (for example, arm length) should be documented.

9.3 Identify caliper logging objectives.

9.4 Select appropriate equipment to meet objectives.

9.4.1 Caliper 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). Some materials commonly used for caliper-arm lubrication may be environmentally sensitive.

9.5 Select the order in the logging sequence in which the caliper probe is to be run (see 8.2.2.1 of Guide D 5753).

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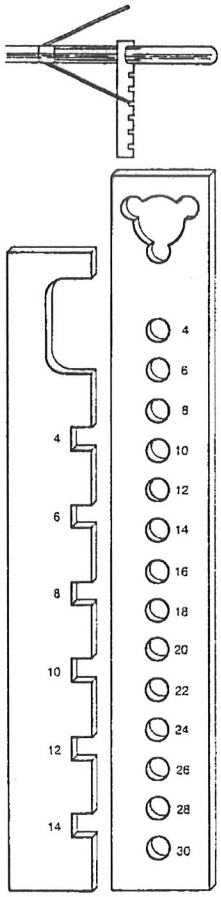

FIG. 4 Calibration Bars for Caliper Probes (3)

9.5.1 Caliper probes are run before any probe utilizing nuclear sources and more expensive centralized probes.

9.5.2 Caliper probes are run after any television camera and fluid property probes are run.

9.6 Caliper operation and calibration are checked at the start of each borehole or at an interval consistent with project objectives. (see the Procedure section of Guide D 5753). After calibration, the caliper arms are closed before lowering.

9.7 Select and document the depth reference.

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

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

9.8.1 The measurement point of a caliper is the end of caliper arms and it changes as the arms open and close with the sine of arm angle multiplied by length of arm. Typically, the measurement point varies less than a few tenths of a foot (a few centimetres).

9.8.2 The measurement point will change if the arm length is changed.

9.9 Select horizontal and vertical scales for log display.

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

9.10.1 Maximum vertical resolution requires the selection of a digitizing interval at least as small as the arm tip contact height.

9.10.2 Typically, this interval is no larger than 0.1 ft (0.03 m) for high-resolution applications.

9.11 The caliper probe is lowered to the bottom of the borehole.

9.11.1 Any time the caliper probe is lowered in the borehole, the arms should be closed to avoid damaging equipment or borehole.

9.11.2 Selection of probe speed while lowering is based on knowledge of borehole depth, stability, and other conditions.

9.12 Open caliper arm(s).

9.13 Select logging speed.

9.13.1 A logging speed of approximately 15 ft (5 m) per min is recommended for high-resolution applications. Faster logging speeds may induce noise due to the caliper probe bumping the borehole wall. Slower logging speeds will not enhance measurement resolution for most systems.

9.14 Collect caliper data while the probe is moving up the borehole.

9.15 When the probe reaches the top of the borehole:

9.15.1 If surface casing is present, compare and document caliper measurement.

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

9.15.3 Determine if ASDE meets project objectives.

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

9.16 Selected borehole intervals should be repeated (that is, relogged) under similar logging parameters as the initial log. Repeat logs provide information on the stability of the caliper equipment. The interval repeated should have enough variability, if possible, to check repeatability and resolution.

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

9.16.2 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).

9.16.3 Close caliper arms prior to lowering the probe down the borehole for a repeat section.

9.17 Evaluate the field log quality and compare log with drilling and completion information.

9.17.1 A reduction in borehole diameter over large depth sections may be indicative of borehole deviation on three-arm averaging caliper logs.

9.17.1.1 The magnitude of borehole deviation that causes this effect depends upon the length of the caliper arms being used and the strength of the tensioning spring within the caliper. Typically, a borehole deviation of greater than 15° is likely to produce this effect.

9.17.1.2 Converting the three-arm averaging caliper by removing two of the caliper arms may allow a good log to be obtained in these types of boreholes.

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9.17.2 Mud can prevent caliper arms from opening fully, and thick mud cake may prevent accurate measurement of drilled diameter. Lack of caliper arm movement, especially in the bottom of a mud drilled borehole, may be indicative of arm sticking due to heavy mud.

9.17.2.1 If mud interferences are suspected, the borehole may be reconditioned, the caliper probe cleaned and lubricated, and the caliper log repeated.

9.18 Post-acquisition calibration checks may be required (surface casing or calibration standard) to meet the objectives of the logging program. Typical tolerances between pre- and post-calibration are ±0.2 in. (0.5 cm).

10. Interpretation of Results

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

10.2 A valid caliper log is essential in the interpretation of the logs that are affected by changes in borehole diameter, including those logs that are labeled 'borehole compensated.' It is not always possible to compensate logs for substantial differences in borehole diameter.

10.2.1 Caliper logs can be analyzed individually (that is, borehole volume).

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

10.3 The caliper 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 caliper data for borehole correction and depth adjustment.

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 caliper-log data.

10.5 Interpretations based on changes in borehole diameter may be related to changes in drilling, mud cake, mud rings, borehole construction, lithology and structure, fractures and solution openings, and stress-induced breakouts.

10.6 The measured borehole diameter may be significantly different than the drilled diameter because of plastic formations extruded into the borehole and friable formations enlarging the borehole. A series of caliper logs may also show increases or decreases in borehole diameter with time.

10.6.1 Caliper logs are useful for determining what other logs can be made and what range of borehole diameters will be accepted by centralizers or decentralizers.

10.7 Fractures and solution openings may be obvious on a caliper log; however, their character may not be uniquely defined.

10.7.1 The single-arm caliper log may completely miss a feature or indicate only a small anomaly.

10.7.2 The three-arm averaging caliper log of a fracture dipping at an angle such that the three arms enter the opening at different depths will indicate three separate anomalies rather than one.

10.8 Borehole-diameter information is essential for calculation of volumetric rate from flowmeter logs.

10.9 Caliper logs provide useful information for borehole completion and testing.

10.9.1 Caliper logs are used to locate the optimum placement of inflatable packers for borehole testing. Inflatable packers can only form an effective seal within a specified range of borehole diameters, and can be damaged if they are set in rough or irregular parts of the borehole.

10.9.2 Caliper logs are used to estimate the volume of borehole completion material (cement, gravel, etc.) needed to fill the annular space between borehole and casing(s) or well screen.

10.10 Caliper logs may be applied to correlate lithology between boreholes based upon enlargements related to lithology.

11. Report

11.1 Consult the Report section, Guide D 5753 for requirements of the report.

11.2 Reports presenting caliper logs shall describe the components of the caliper logging system, the principles of the methods used, and their limits, methods and results of calibration and standardization, and performance verification (for example, diameter of surface casing, correlation with other logs, repeat sections, ASDE, etc.).

11.3 Information on the software and algorithms used should be included in the report.

11.4 Any deviations from this guide should be justified with documentation.

11.5 Presentation of caliper 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 (see Fig. 3). There may be a difference between presentations of data collected in the field versus in final report. Any scale "wraps" should be clearly marked.

11.5.1 Caliper logs are typically displayed with linear scales in inches, millimetres, or centimetres.

12. Keywords

12.1 borehole correction; borehole diameter; borehole geophysics; borehole volume; caliper log; ground water; single-arm caliper; three-arm caliper; well construction; well logging

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(1) *Glossary of Terms and Expressions Used in Well Logging*, 2nd Ed., Society of Professional Well Log Analysts, Houston, TX, 1984.

(2) Keys, W. S., *Borehole Geophysics Applied To Ground-Water Investigations, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 2*, Chapter E2, 1990.

(3) Hodges, R. E., Calibration and Standardization of Geophysical Well-Logging Equipment for Hydrologic Applications, *U.S. Geological Survey Water Resources Investigations Report 88-4058*, 1988.

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Designation: D 6274 – 98 (Reapproved 2004)

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.

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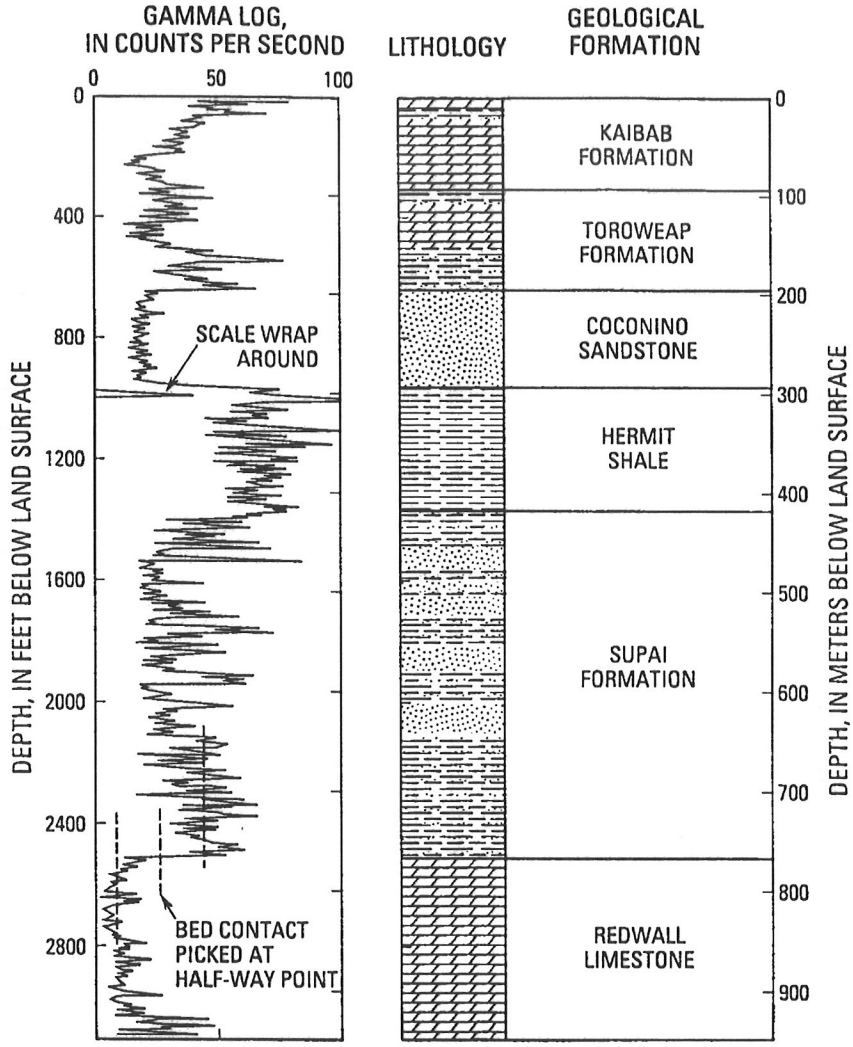

NOTE 1—This figure demonstrates how the log can be used to identify specific formations, illustrating scale wrap-around for a local gamma peak, and showing how the contact between two formations is picked to coincide with the half-way point of the transition between the gamma activities of the two formations.

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 measured 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.

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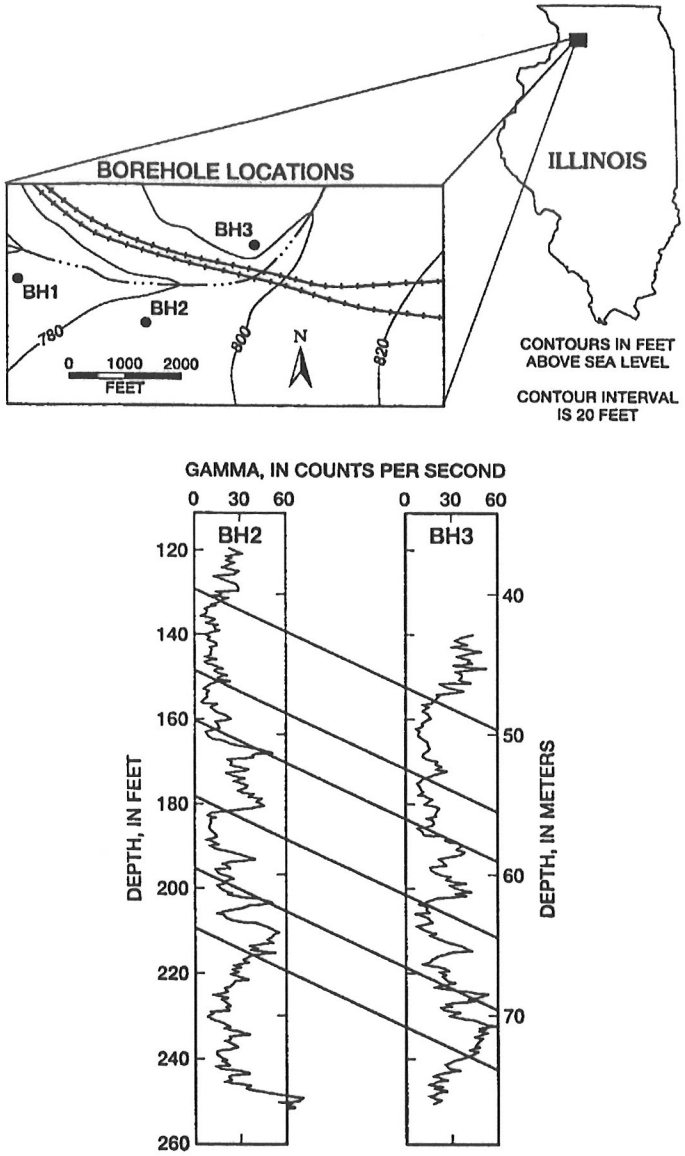

NOTE 1—From a study site showing how the gamma logs can be used to identify where beds intersect each of the individual boreholes, demonstrating lateral continuity of the subsurface geology.

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

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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.

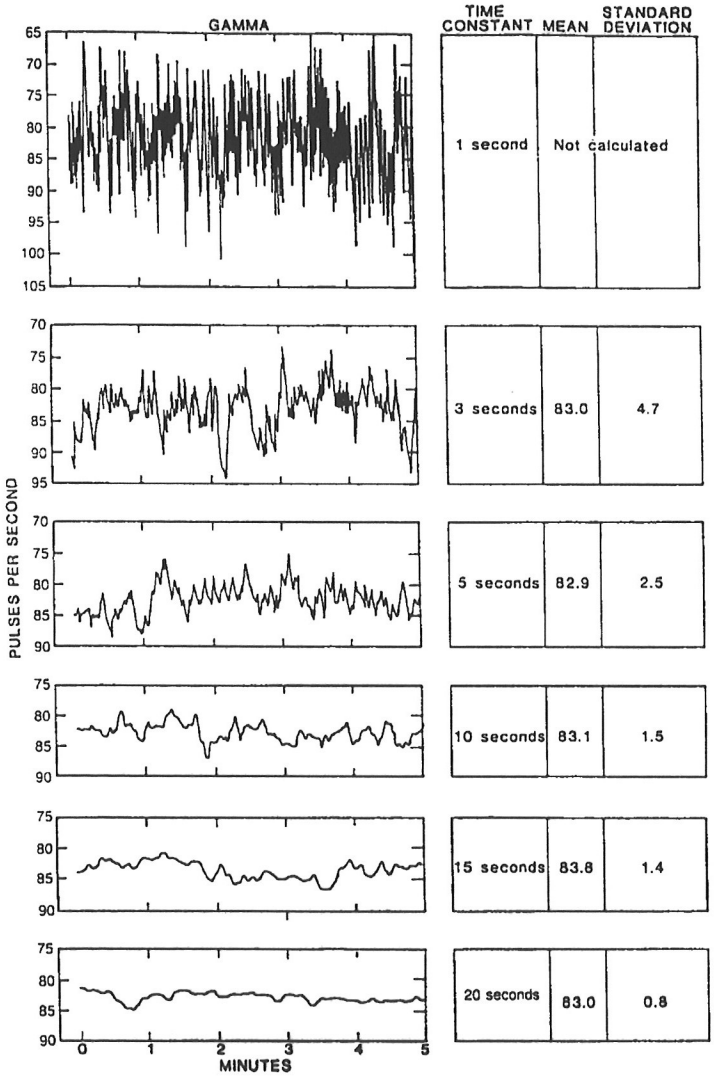
6. Interferences

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

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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 $1/200^{th}$ 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:

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

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

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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.

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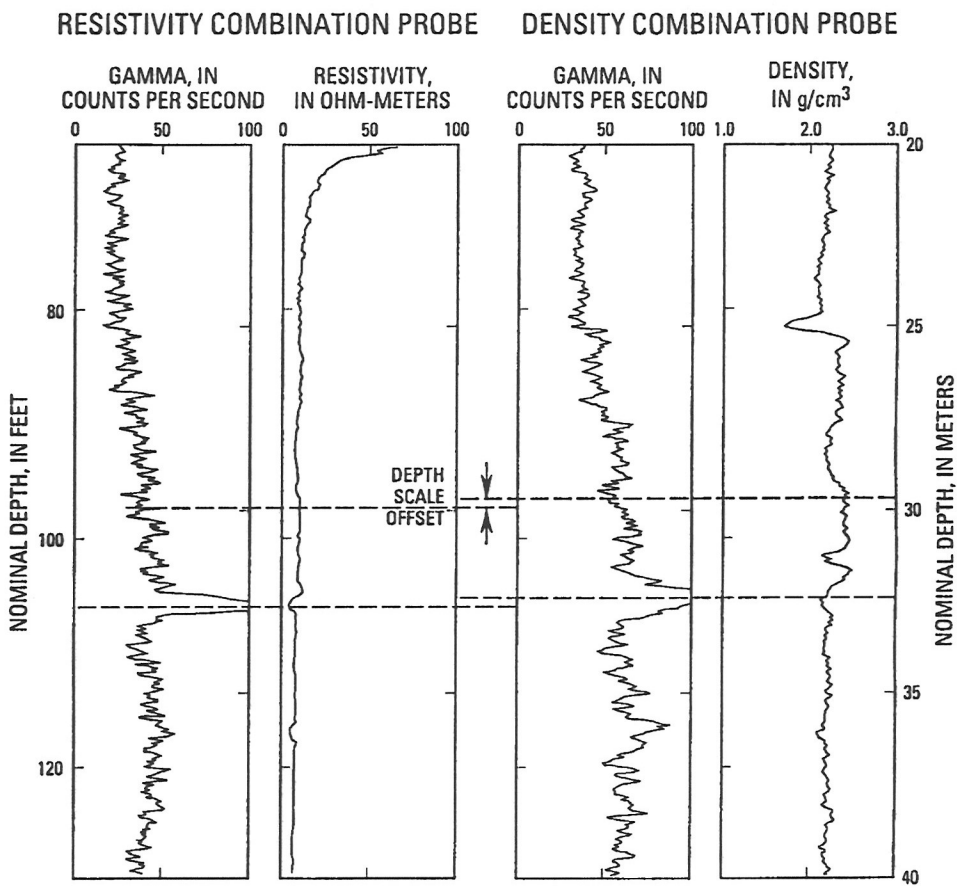

NOTE 1—This figure shows a small depth offset that should be removed by adjusting the depth scale on one of the logs; note that the average count rates for the two different gamma detectors differ as a result of different detector efficiencies.

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

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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.

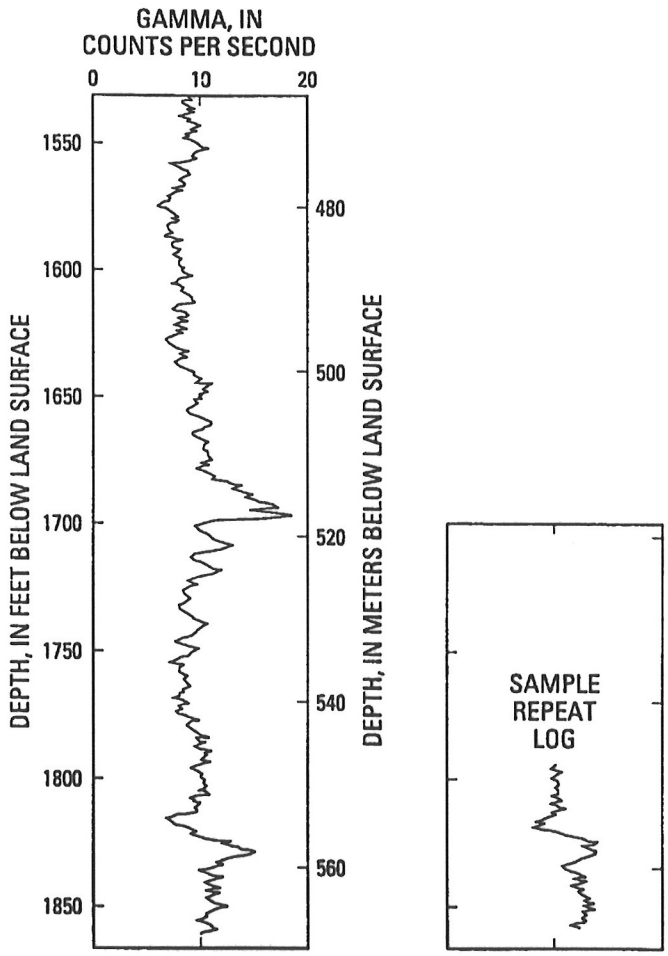
9.11.5 In situations where gamma activity is extremely low, such as in many basalts and some carbonate and quartzite formations, the operator can estimate the maximum logging speed from the formula:

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

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

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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.

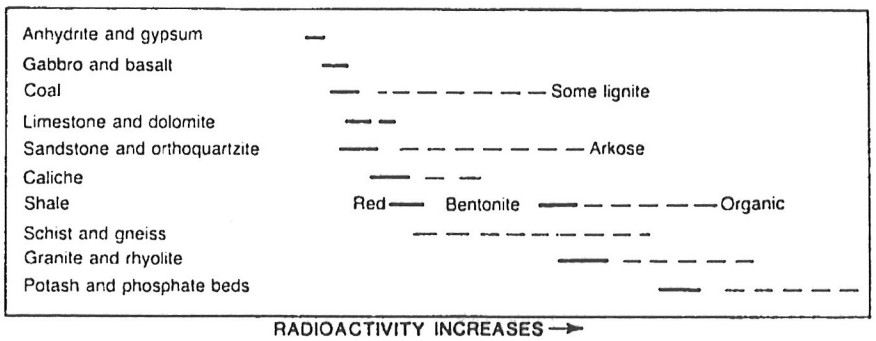

FIG. 6 Range of Relative Gamma Activity of Common Rocks

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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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