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

This standard is issued under the fixed designation D6274; 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, groundwater, 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 and Fig. 2).

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. 3).

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 This guide is to be used in conjunction with Guide D5753.

1.6 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.

1.7 The values stated in either SI units or inch-pound units [given in brackets] are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Reporting of test results in units other than SI shall not be regarded as nonconformance with this standard.

1.7.1 The gamma log is typically recorded in units of counts per second (cps) or American Petroleum Institute (API) units. The gamma ray API unit is defined as 1⁄200 of the difference between the count rate recorded by a logging tool in the middle of the radioactive bed and that recorded in the middle of the nonradioactive bed" recorded within the calibration pit. A calibration facility for API units currently exists at the University of Houston and is the world standard for the simple Gamma Ray tool, however the validity of the calibration pit has been called into question in recent years.

1.8 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *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.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[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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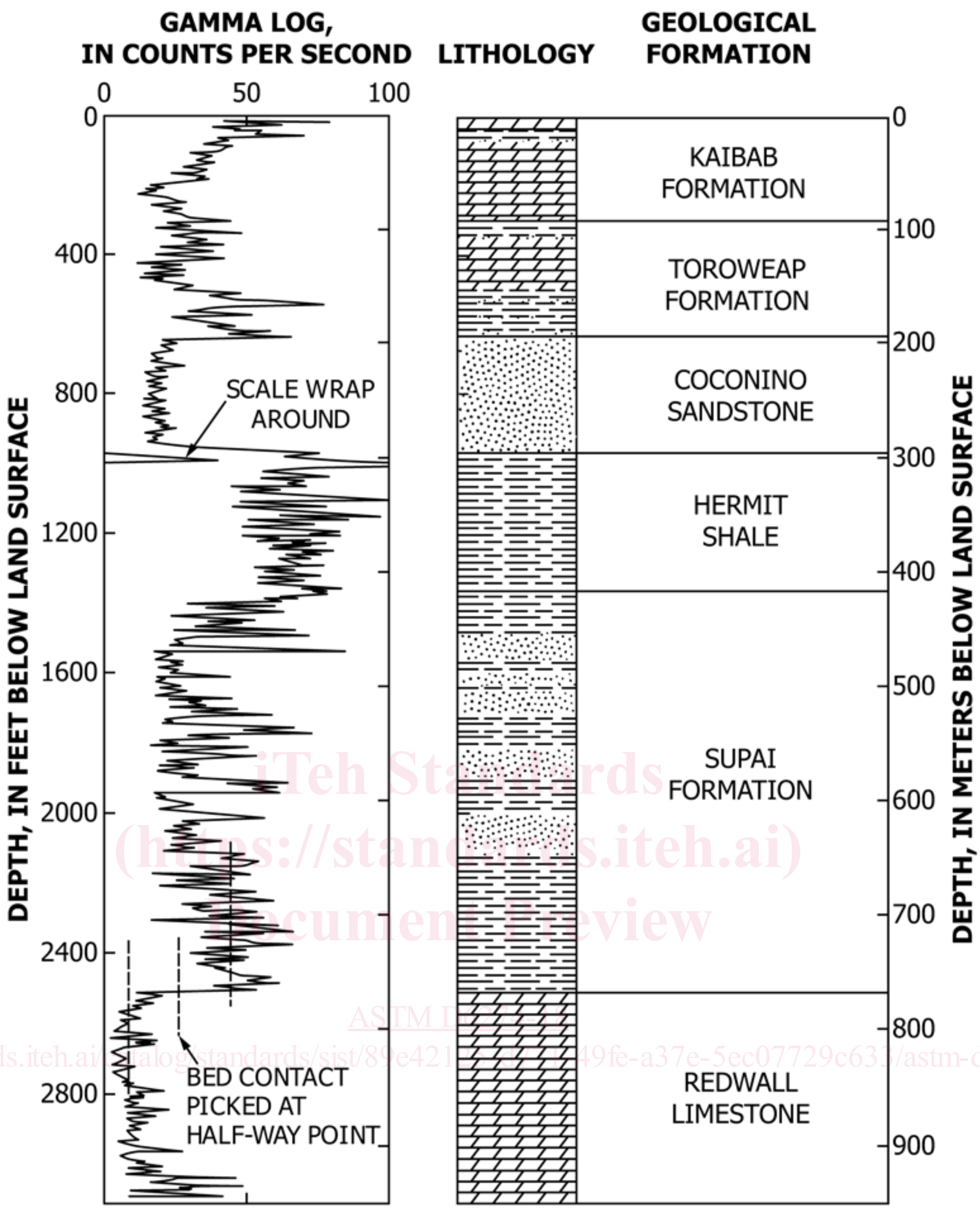


NOTE 1—This figure demonstrates how the log can be used to identify specific formations, illustrating scale wrap-around for a local gamma peak, and showing how the contact between two formations is picked to coincide with the half-way point of the transition between the gamma activities of the two formations.

FIG. 1 Example of a Gamma Log From Near the South Rim of the Grand Canyon in the USA (in cps)

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D5088 Practice for Decontamination of Field Equipment Used at Waste Sites

D5608 Practices for Decontamination of Sampling and Non Sample Contacting Equipment Used at Low Level Radioactive Waste Sites

D5753 Guide for Planning and Conducting Geotechnical Borehole Geophysical Logging

D6167 Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of common technical terms used in this standard, refer to Terminology D653.

[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.

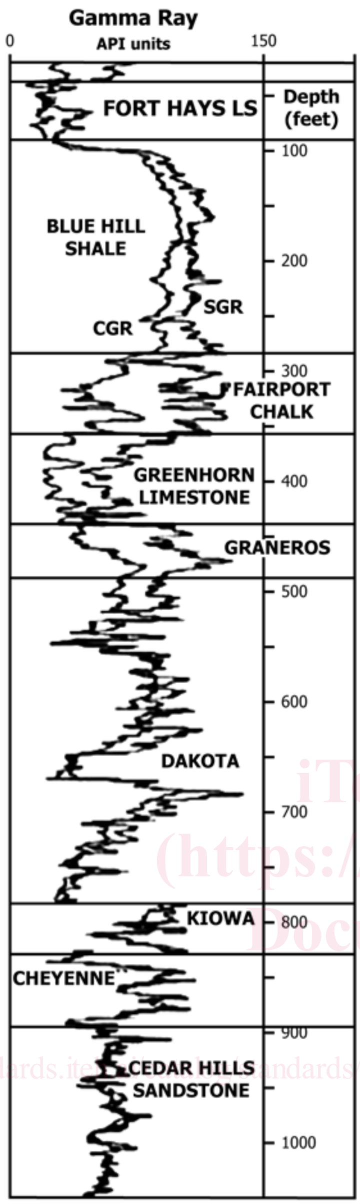


FIG. 2 Example of a Gamma Log for the Hydrologic Observation Well KGS #1 Braun located near Hays, Kansas in the USA (in API units whereby SGR reflects the derived total gamma ray log (the sum of all the radiation contributions), and CGR reflects the computed gamma ray log (the sum of the potassium and thorium responses, leaving out the contribution from uranium).

3.2 *Definitions of Terms Specific to This Standard:*

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

3.2.2 *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".

3.2.3 *depth of investigation, n*—the radial distance from the measurement point to a point where the predominant measured response may be considered centered.

3.2.3.1 *Discussion*—The depth of investigation for borehole logging is a radial distance from the borehole and is not to be confused with borehole depth or any depth measured from the surface.

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

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

3.2.6 *volume of investigation, n*—the volume that contributes 90 % of the measured response.

3.2.6.1 *Discussion*—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 D5753.

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 D5753.

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 D5753) consult up-to-date textbooks and reports on the gamma technique, application, and interpretation methods.

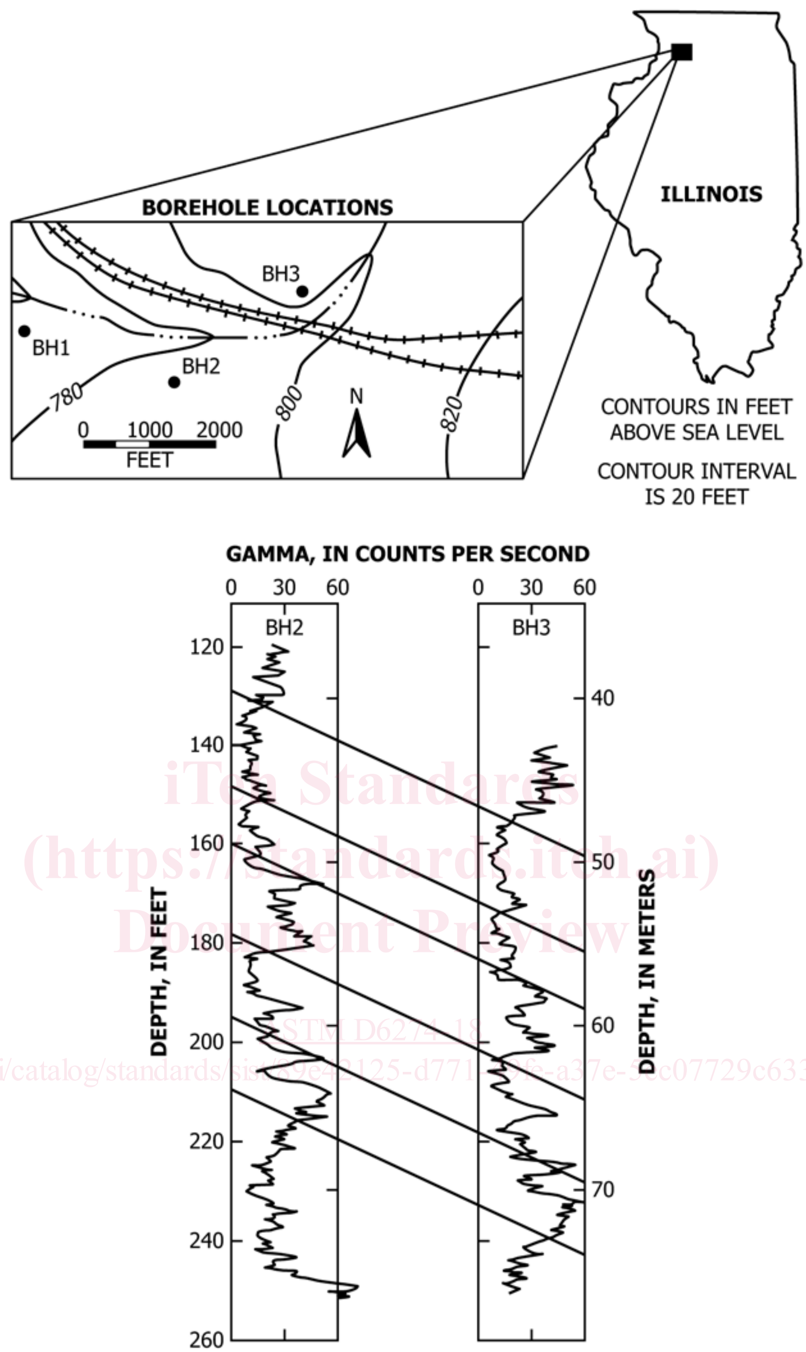
6. Interferences

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. 4).

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

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



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. 3 Example of Gamma Logs From Two Boreholes

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

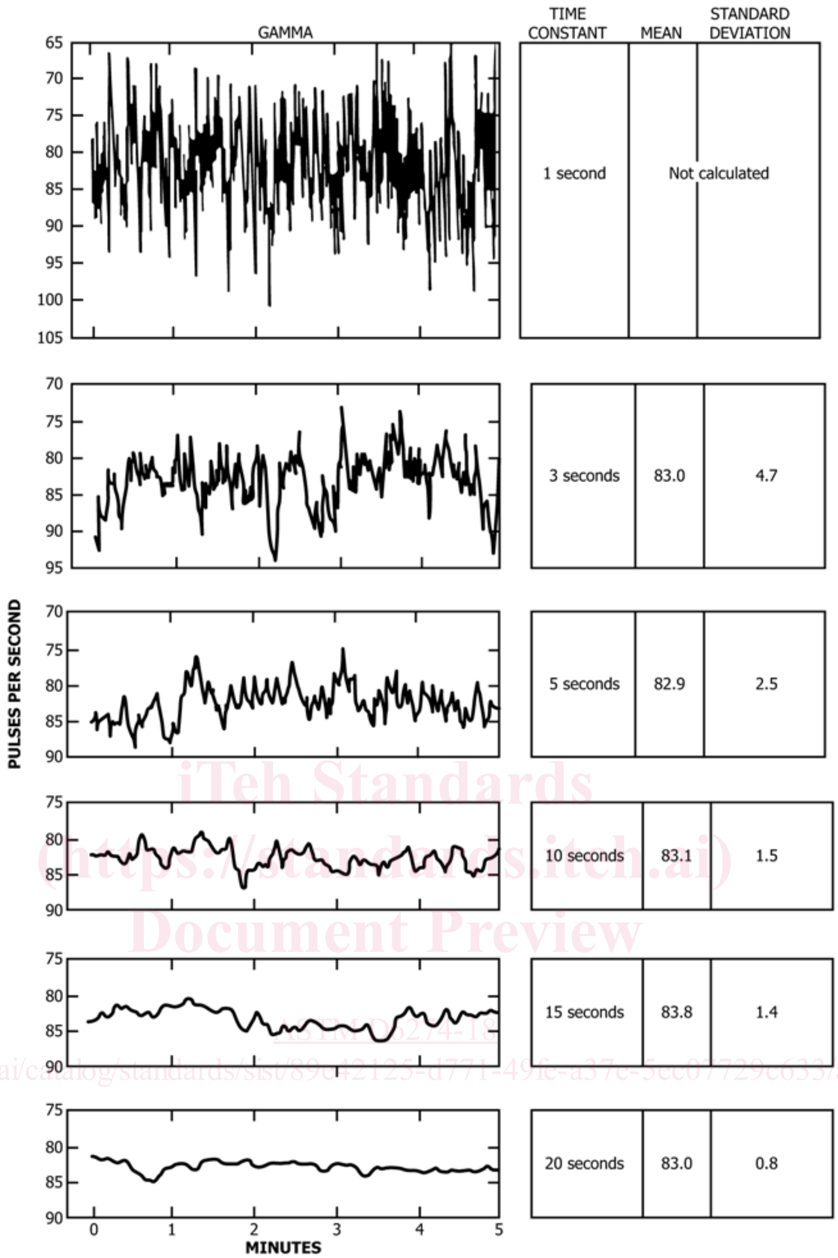
7.1 A geophysical logging system has been described in the general guide (the Apparatus section of Guide D5753).

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.



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

7.3.1 Gamma probes typically used for geotechnical applications can be logged inside boreholes as small as 5 cm [2-in.] in diameter.

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 15 to 30 cm [0.5 to 1.0 ft] from the center of the detector in typical geological formations. The volume becomes elongated when detector length exceeds approximately 15 cm [0.5 ft].

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

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 30 to 60 cm [1 to 2 ft] 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. A calibration facility for API units currently exists at the University of Houston and is the world standard for the simple Gamma Ray tool.

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, but at least once a year.

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. To be able assess the temperature impact on the results, it is suggested that a temperature log is maintained during the calibration.

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 serves as a check of standardization.

8.3.2 A representative borehole may be used to periodically check gamma probe response, provided the borehole and surrounding environment do not change with time or the effects of such changes on gamma response can be documented.

8.3.3 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 the gamma probe response if the level of gamma activity in the source(s) has been certified.

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 D5753 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. 5).

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.