Designation: D 6727 – 01

Standard Guide for Conducting Borehole Geophysical Logging—Neutron[1]

This standard is issued under the fixed designation D 6727; 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 is focused on the general procedures necessary to conduct neutron or neutron porosity (hereafter referred to as neutron) 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. Neutron soil moisture measurements made using neutron moisture gauges, are excluded. Neutron logging for minerals or petroleum applications is excluded, along with neutron activation logs where gamma spectral detectors are used to characterize the induced gamma activity of minerals exposed to neutron radiation.

1.2 This guide defines a neutron log as a record of the rate at which thermal and epithermal neutrons are scattered back to one or more detectors located on a probe adjacent to a neutron source.

1.2.1 Induction logs are treated quantitatively and should be interpreted with other logs and data whenever possible.

1.2.2 Neutron logs are commonly used to: (*1*) delineate lithology, and (*2*) indicate the water-filled porosity of formations (see Fig. 1).

1.3 This guide is restricted to neutron logging with nuclear counters consisting of scintillation detectors (crystals coupled with photomultiplier tubes), or to He^3-tube detectors with or without Cd foil covers or coatings to exclude thermalized neutrons.

1.4 This guide provides an overview of neutron logging including: (*1*) general procedures; (*2*) specific documentation; (*3*) calibration and standardization, and (*4*) log quality and interpretation.

1.5 To obtain additional information on neutron logs see References section in this guide.

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

1.7 This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This guide should not be used as a sole criterion for neutron logging and does not replace education, experience, and professional judgment. Neutron logging procedures should be adapted to meet the needs of a range of applications and stated in general terms so that flexibility or innovation are not suppressed. 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 without consideration of a project's many unique aspects. The word standard in the title of this document means that the document has been approved through the ASTM consensus process.

1.8 The geotechnical industry uses English or SI units. The neutron log is typically recorded in units of counts per second (cps) or in percent porosity.

1.9 *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 requirements prior to use. The use of radioactive sources in neutron logging introduces significant safety issues related to the transportation and handling of neutron sources, and in procedures to insure that sources are not lost or damaged during logging. There are different restrictions on the use of radioactive sources in logging in different states, and the Nuclear Regulatory Agency (NRC) maintains strict rules and regulations for the licensing of personnel authorized to conduct nuclear source logging.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes[2]
D 653 Terminology Relating to Soil, Rock and Contained Fluids[2]
D 5088 Practice for Decontamination of Field Equipment at Non-Radioactive Waste Sites[2]
D 5608 Practice for Decontamination of Field Equipment Used at Low Level Radioactive Waste Sites[2]
D 5730 Guide for Site Characterization for Environmental Purposes with Emphasis on Soil, Rock, Vadose Zone, and Ground Water[2]
D 5753 Guide for Planning and Conducting Borehole Geophysical Logging[2]

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[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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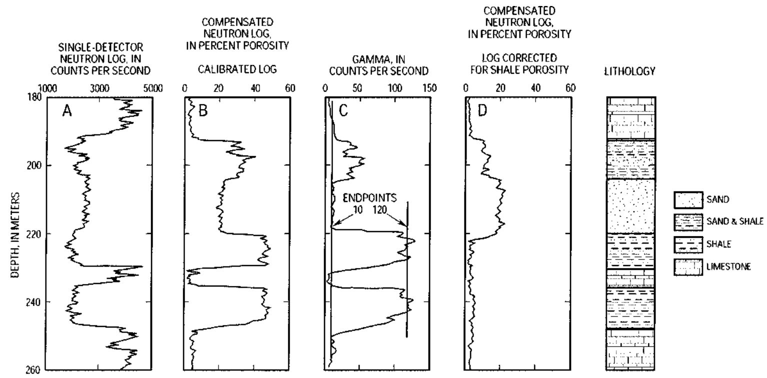
[2] *Annual Book of ASTM Standards*, Vol 04.08.



A–Single detector epithermal neutron log plotted in counts per second.
B–Dual-detector neutron log calibrated in limestone porosity units.
C–Gamma log showing maximum and minimum values used as endpoints for the gamma activity scale.
D–Dual detector neutron log plotted in porosity units corrected for the non-effective porosity of clay minerals using the equation:

$$N_c = N_0 - C_{sh} \cdot \Phi_{sh}$$

where:
N_c = corrected neutron log,
N_0 = original neutron log,
C_{sh} = computed shale fraction based upon the gamma log position between the endpoints of 10 and 120 cps, and
Φ_{sh} = estimate of shale non-effective porosity of about 40 % picked from intervals on the log where Φ_{sh}= 1.0.

FIG. 1 Typical Neutron Logs for a Sedimentary Rock Environment

D 6167 Guide for Conducting Borehole Geophysical Logging: Mechanical Caliper[3]
D 6235 Practice for Expediated Site Characterization of Vadose Zone and Ground Water Contamination at Hazardous Waste Contaminated Sites[3]
D 6274 Guide for Conducting Borehole Geophysical Logging—Gamma[3]
D 6429 Guide for Selecting Surface Geophysical Methods[3]

3. Terminology

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

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 *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.

3.2.3 *effective porosity*, *n*—the volume percent of connected pore spaces within a formation that are capable of conducting ground-water flow.

3.2.4 *epithermal neutron*, *n*—neutron with kinetic energy somewhat greater than the kinetic energy associated with thermal lattice vibrations of the surrounding formation; such neutrons have been slowed enough by collisions with formation minerals to interact with the detector, but the population of epithermal neutrons is not strongly affected by absorption cross-sections of trace minerals in the geologic environment.

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

3.2.6 *neutron generator*, *n*—a device which includes a particle accelerator to generate a flux of high-energy neutrons, and which can be turned on and off through connection with an external power supply.

3.2.7 *neutron slowing distance*, *n*—the distance traveled by a neutron within a formation over the time required for the neutron to be slowed to half of its original velocity by repeated collisions with the atoms in the formation.

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

3.2.9 *thermalized neutron*, *n*—neutron that has been slowed to a kinetic energy approximately equal to that of the thermal kinetic energy of the surrounding formation.

3.2.10 *total porosity*, *n*—the total amount of pore space expressed as a volume fraction in percent in a formation; this total consists of effective pore space which can conduct ground-water flow, and additional unconnected pores that will not conduct ground-water.

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

3.2.12 *volume of investigation*, *n*—the volume that contributes 90 percent 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 neutron logging and is to be used in conjunction with Standard Guide D 5753.

4.2 This guide briefly describes the significance and use, apparatus, calibration and standardization, procedures, and

[3] *Annual Book of ASTM Standards*, Vol 04.09.

reports for conducting borehole neutron logging.

5. Significance and Use

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

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

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

5.4 It is essential that personnel (see Section 8.3.2, Standard Guide D 5753) consult up-to-date textbooks and reports on the neutron technique, application, and interpretation methods.

6. Interferences

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

6.2 Logging too fast can significantly degrade the quality of neutron logs, especially when neutron detectors are designed to exclude thermalized neutrons, resulting in relatively low counting rates. Neutron counts measured at a given depth need to be averaged over a time interval such that the natural statistical variation in the rate of neutron emission is negligible.

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; borehole wall roughness whenever neutron logs are run decentralized; and steel casing or cement in the annulus around casing, and thickness of the annulus.

6.5 Geologic conditions include the presence of clay minerals with significant non- effective porosity (Fig. 2), and the presence of minerals such as chlorine with relatively large neutron absorption cross-sections.

6.6 Neutron log response is designed to measure water-filled pore spaces so that neutron logs do not measure unsaturated porosity.

7. Apparatus

7.1 A geophysical logging system has been described in the general guide (Section 6, Standard Guide D 5753).

7.2 Neutron logs are collected with probes using He^3 detectors, which may be coated with Cd to exclude thermalized neutrons, or may be un-coated to detect both thermal and epithermal neutrons; neutron logs may occasionally be collected using detectors using lithium-iodide scintillation crystals coupled to photomultiplier tubes (Fig. 3).

7.2.1 A neutron shield is needed for the storage of the neutron source during transport to and from the logging site.

7.2.2 A secure storage facility is needed for neutron source during the time between logging projects when the source cannot be left in the shield in the logging truck.

7.2.3 Radiation monitoring equipment is needed for checking of radiation levels outside the neutron shield and in working areas during use of the neutron source to verify that radiation hazards do not exist.

7.3 Neutron logging probes generate neutron fluxes using a chemical radioactive source such as Ca^{252} or a combination of Am and Be; or by using a neutron generator.

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

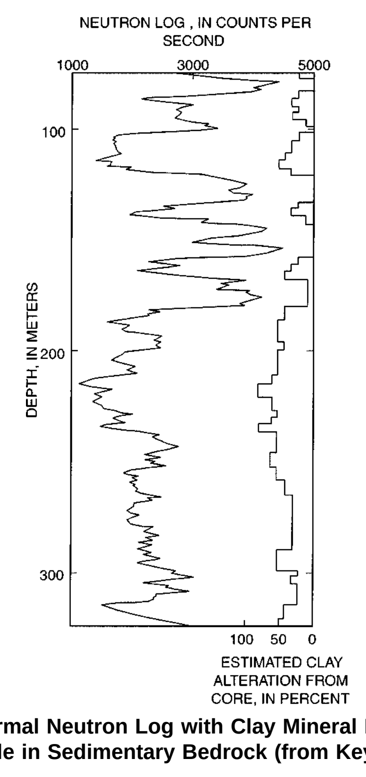
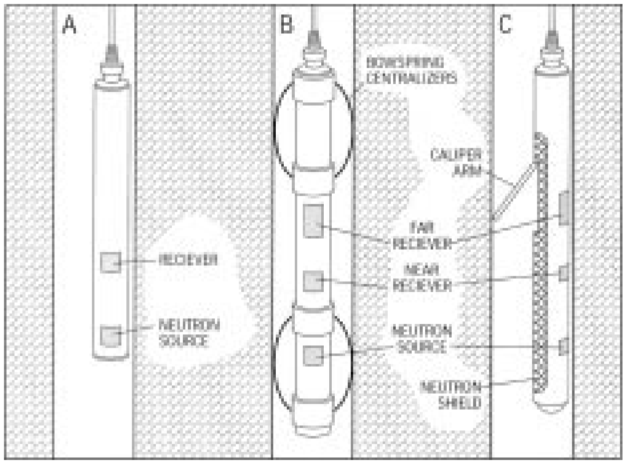


FIG. 2 Comparison of Single Detector Epithermal Neutron Log with Clay Mineral Fraction Determined Form Core Samples for a Borehole in Sedimentary Bedrock (from Keys, 1990)



A–Single detector run without centralization in a fluid-filled borehole.
B–Pair of detectors run with borehole centralization in a fluid-filled borehole.
C–Pair of detectors in a decentralized and collimated probe run in a fluid-filled borehole.

FIG. 3 Schematic Illustration of Neutron Logging Probes

7.4.1 Neutron probes used for geotechnical applications can be run centralized or decentralized (held against the side of the borehole); decentralized probes can be collimated (shielded on the side away from the borehole wall to reduce the influence of the borehole fluid column). However, collimation requires an impracticably heavy, large-diameter logging probe, and such probes are rarely used in geotechnical logging (Fig. 3C).

7.4.2 Neutron probes can have a single detector (Fig. 3A), or a pair of detectors located at different separations from the neutron source. When logging probes contain two detectors, the far detector is significantly larger than the near detector to compensate for the decreasing population of neutrons with distance from the neutron source, as indicated in Fig. 3B.

7.4.3 Neutron probes are designed with source-to-receiver spacing such that measured neutron counts are proportional to the slowing down distance of the neutrons, which is assumed to be inversely proportional to the water-filled porosity of the formation.

7.5 The Volume of Investigation and Depth of Investigation are primarily determined by the moisture content of the material near the probe which controls the average distance a neutron can travel before being absorbed.

7.5.1 The Volume of Investigation for neutron logs is generally considered spherical with a radius of 1.5 to 2.5 ft (40 to 70 cm) from the midpoint between the neutron source and detector(s) in typical geological formations.

7.5.2 The Depth of Investigation for neutron logs is generally considered to be 1.5 to 2.5 ft (40 to 70 cm).

7.6 Vertical Resolution of neutron logs is determined by the size of the volume over which neutrons are scattered back towards the detector after being emitted by the source. 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.

7.7 Measurement Resolution of neutron probes is determined by the counting efficiency of the nuclear detector or detectors being used in the probe. Typical Measurement Resolution is 1 cps.

7.8 A variety of neutron 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 Neutron Logs

8.1 *General*:

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

8.1.2 Neutron logs can be used in a qualitative (for example, comparative) or quantitative (for example, estimating water-filled porosity) manner depending upon the project objectives.

8.1.3 Neutron 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 neutron probe is suspected to be damaged, modified, repaired, and at periodic intervals.

8.2 Calibration is the process of establishing values for neutron response associated with specific values of water-filled porosity in the sampled volume and is accomplished with a representative physical model. Calibration data values related to the physical properties (for example, formation porosity) may be recorded in units (for example, cps), which can be converted to units of percent, water-saturated porosity.

8.2.1 Calibration is performed by recording neutron log response in cps recorded by one or a pair of detectors in boreholes centered within volumes containing a uniform, fully water-saturated medium of known porosity and mineral composition.

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 borehole diameter, formation density, and formation chemical composition.

8.2.3 Neutron log calibration is especially sensitive to borehole diameter in water-filled boreholes because the neutron flux from the logging probe interacts with water in the borehole as well as that in pore spaces; therefore, neutron log calibration is only accurate when applied to logs obtained in boreholes of nearly the same diameter as that of the calibration environment.

8.2.4 Neutron log calibration procedures depend upon whether single-detector or dual detector data are used.

8.2.4.1 Neutron log calibration fails above the water level where neutrons streaming along the air-filled annulus around the probe dominate the measured response of the equipment.

8.2.4.2 When counts from a single neutron detector are used, the measured counts are assumed to be inversely proportional to the logarithm of porosity.

8.2.4.3 When counts from a pair of detectors are used, the ratio of the counts from the near (short-spaced) to the far (long-spaced) detector are assumed to be linearly proportional to porosity.

8.2.5 Neutron logs can also be calibrated using porosity data obtained from core, provided the following conditions are satisfied:

8.2.5.1 Depth scales on log and core are adjusted by cross-correlation to insure there are no depth offsets related to depth scale errors.

8.2.5.2 The core measurement technique either measures total porosity equivalent to that inferred from neutron log measurements, or calibration is only applied to intervals where effective porosity is expected to equal total porosity (for example, clay-free sandstone).

8.2.5.3 Enough measurements are used to statistically overcome the size mismatch between core plugs and the sample volume of the neutron log measurement.

8.3 Standardization is the process of checking logging response to show evidence of repeatability and consistency, and to insure that logging probes with different detector efficiencies measure the same neutron slowing flux attenuation in the same formation. The response in cps of every neutron source/detector pair is different for the same environment.

8.3.1 Calibration insures standardization.

8.3.2 The American Petroleum Institute maintains a calibration facility in Houston, Texas, where a borehole has been constructed to provide access to three fully-saturated blocks of quarried limestone of unusually constant porosity; the borehole is 6 in. (15 cm) in diameter, and the known porosity values are 1.88, 19.23, and 26.63 percent (Fig. 4).

8.3.3 For geotechnical applications, neutron logs can be presented in either cps or calibrated limestone porosity.

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

8.3.5 An approximate neutron log field calibration can be made using rough estimates of the largest and smallest porosity values for the geological formations sampled by the log. This is done by identifying the maximum log value in cps with the minimum porosity, and the minimum log value in cps with the maximum porosity, and then extrapolating the porosity scale between these endpoints using a logarithmic scale (Fig. 5).

9. Procedure

9.1 See Section 8, Guide D 5753 for planning a logging program, data formats, personnel qualifications, field documentation, and header documentation.

9.1.1 Neutron specific information (source identity, detector

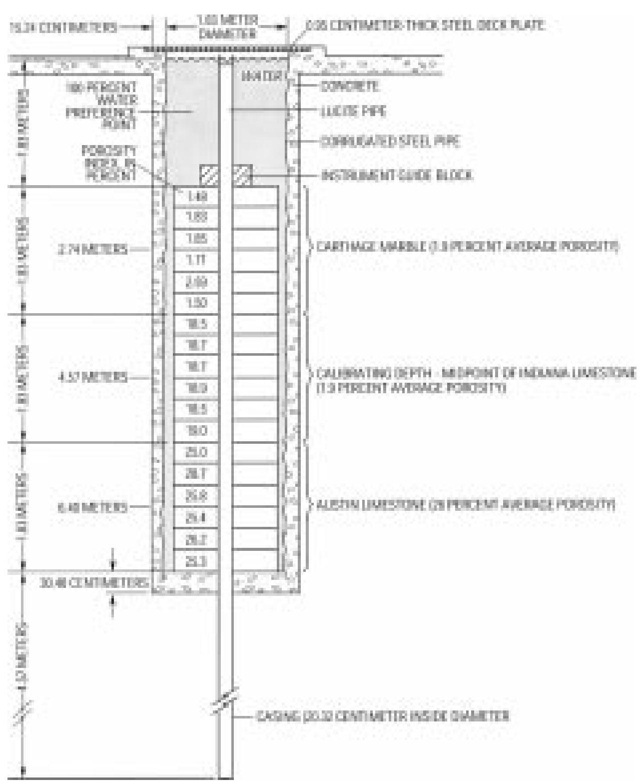


FIG. 4 Construction Plan of the American Petroleum Institute Neutron Porosity Calibration Pit, Illustrating the Presence of Three Calibration Environments Composed of Cylindrical Sections Quarried from Three Different Natural Geologic Formations (from Keys, 1990)

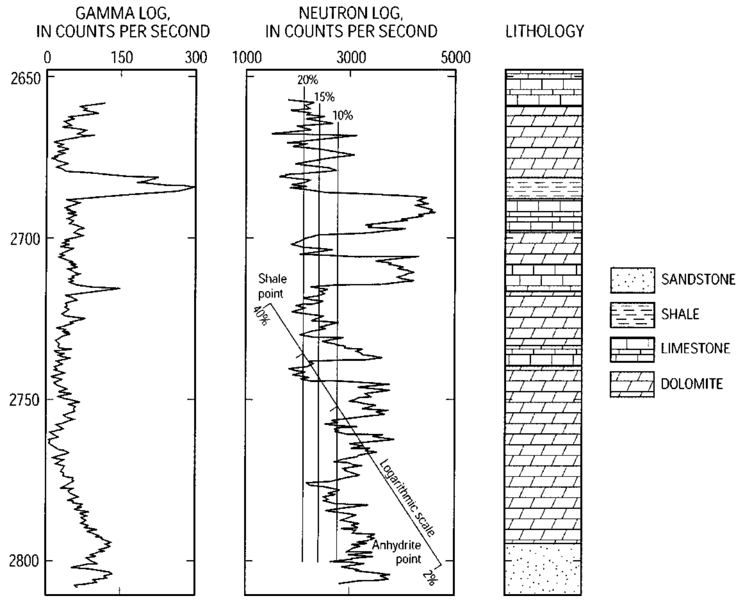


FIG. 5 Example of Single-Detector Epithermal Neutron Log Presented in Counts Per Second and Given an Approximate Field Calibration in Porosity Units Using Assumed Endpoints of 2 % for Anhydrite, a Dense, Low Porosity Mineral, and 40 % for a Shale Known from Previous Experience to Contain Approximately that Amount of Non-Effective Porosity in the Form of Bound Water (modified from McCary, 1980)

spacing, etc.) should be documented.

9.2 Identify neutron logging objectives.

9.3 Select appropriate equipment to meet objectives.

9.3.1 Neutron logs may be run either centralized or free-hanging where the probe lies against one side of the borehole (that is, as a mandrel), depending upon project objectives, borehole diameter, and logging probe design.

9.3.2 Neutron 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 neutron probe is to be run in the logging sequence (see Section 8.2.2.1, Guide D 5753).

9.4.1 Neutron logs are almost always run towards the end of the logging program after previous runs with other equipment have indicated that the borehole is stable, and no constrictions or other potential hazards have been encountered.

9.4.2 Whenever possible, neutron probes should be run open hole or through the least amount of completion material to minimize well construction affects and to provide a base line for comparing subsequent logs; however, useful data can be obtained from neutron logs run in cased boreholes if casing is required to insure borehole stability, or to meet state requirements pertaining to the use of radioactive sources in formations containing potable water supplies.

9.5 Neutron probe operation is typically checked before the start of each run to insure that equipment is operating and that nuclear counters are producing output; this check-out can usually be performed with the source still in its shield and the detector placed near the outside of the shield (for example, at a location where a small neutron flux is likely to be detected).

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 neutron measurement point.

9.7.1 The measurement point of the neutron logging probe is the distance along the probe corresponding with the midpoint between source and receiver (far receiver if there are two receivers); 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.

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

9.8.1 Preferred horizontal scale divisions are multiples of 2 or 5 such that the log value is easily determined on the plot (for example, 0-100, 0-200, 50-150, etc.).

9.8.2 Preferred vertical scales are multiples of 2 or 5 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 Section 8.3.1.2, Standard Guide D 5753).

9.9.1 Digitizing interval needs to be at least as small as the Vertical Resolution of the neutron probe, which is typically about 2 ft (60 cm).

9.9.2 Typically, this interval is no larger than 1.0 ft (30 cm) to insure 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 neutron source is removed from its shield and attached to the probe by NRC licensed operators observing all NRC required procedures, and the probe lowered into the borehole so that the source is at least several feet below ground level.

9.10.1 The source is lowered far enough into the borehole to shield site personnel from radiation; the output from the probe can then be checked to insure that the probe and uphole electronics are functioning properly.

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

9.11.1 Neutron counts should be monitored as the probe is lowered because knowledge of the average count rates recorded by the detector or pair of detectors is important in determining proper logging speed, and in verifying proper operation of the logging equipment. Neutron count range is also needed to determine proper horizontal scale and with some instrumentation, to determine sensitivity/gain settings.

9.11.2 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 insure that depth errors are not being introduced.

9.12 Select logging speed.

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

9.12.2 Typical neutron logging speed is approximately 20 ft per minute (6 m per minute), but slower speeds may be needed if measured count rates are unusually low.

9.13 Collect neutron log data while the probe is moving up the borehole; data collection while logging upward insures that the probe is retrieved smoothly and continuously.

9.13.1 When the probe reaches the top of the borehole:

9.13.2 Check depth reference and document After Survey Depth Error (ASDE).

9.13.3 Determine if ASDE meets project objectives.

9.13.4 Typical tolerance for ASDE is $\pm$ 0.4 ft per 100 ft interval logged ($\pm$ 0.4 m per 100 m).

9.13.5 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 neutron measurement 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 neutron count rates.

9.14.1 Repeat logs should be compared with the original log to insure 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 which introduces some random fluctuation into the measured count rate. However, the neutron source normally provides count rates which are large enough to suppress such statistical variation, which should only appear when count rates are unusually low.

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 Neutron 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 $(N - 1)\Delta z$ where N is the number of points and Δz is the digitizing interval, should correspond with the Vertical Resolution, which is typically about 2 ft (60 cm) in most geological formations.

9.16.1 Larger filters are frequently applied to neutron 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 neutron log data and the filtered data should be saved.

9.17 Post acquisition calibration checks may be required to meet the objectives of the logging program to verify neutron log standardization and calibration.

10. Interpretation of Results

10.1 See Section 8.5, Guide D 5753 for procedures on Log Interpretation.

10.2 The neutron log should be depth correlated with the other geophysical logs as the first step to interpretation.

10.2.1 The neutron log data may be filtered, edited, combined and merged with other log values.

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

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

10.3 Although neutron logs are often run to obtain a profile of porosity in situ, neutron log measurements respond to total rather than effective porosity, and may be influenced by mineralogy of the formation (Fig. 1, Fig. 3); comparison with other logs is often needed to distinguish qualitatively or quantitatively the effective porosity signal from that associated with non-effective porosity and lithologic effects.

10.3.1 The gamma log or other logs which indicate the amount of clay mineral or other source of non-effective porosity can be used to separate the portion of neutron log response related to effective porosity from the total porosity response given by the raw neutron log (Fig. 1).

10.3.2 Calibrated neutron logs are usually given in porosity units for an assumed limestone lithology, so the calibration may need to be modified for other lithologies; for example, neutron counts calibrated at 4 and 40 percent porosity would actually represent about 0 and 38 percent respectively for a formation composed of silica and water (sandstone lithology).

10.3.3 Neutron logs obtained with a single epithermal detector are sometimes calibrated in API units, which are standardized neutron log counts based on readings obtained in a standardized logging environment maintained by the American Petroleum Institute.

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 neutron log data.

10.4.1 Many of the borehole effects on the neutron 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 neutron logs from boreholes logged with different completion designs.

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

10.4.3 Borehole diameter can have a significant effect on neutron logs through the effect of the borehole water column on the neutron flux from the source in logging probe.

10.4.3.1 If the borehole diameter is significantly different from the diameter at which the probe was calibrated, a correction to the calibrated neutron log may be required.

10.4.3.2 The neutron log should be compared with the caliper log to identify depths where borehole enlargement or wash outs have affected the log so that these anomalous neutron log responses can be corrected or edited out of the data.

10.5 Neutron logs are sometimes the primary indicator of formation permeability in situ, usually in situations where clay aquitards are not present and formation permeability is determined by the distribution of porosity and the degree of cementation in the formation.

10.5.1 Neuron logs can be used as a guide in installing well screens, positioning cement plugs, bentonite seals or packers, etc.

10.5.2 When neutron 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.

10.6 Neutron logs may be applied to correlate lithology between boreholes based upon the neutron log character of specific beds or formations.

10.7 Neutron logs may be used in unsaturated formations to monitor changes in saturation and the infiltration of water in the formation adjacent to the borehole.

10.7.1 Neutron logs obtained at different times may be compared to give a qualitative indication of the changes in moisture in situ over time.

10.7.2 Conventional porosity calibration data cannot be applied to neutron logs obtained in unsaturated formations, and borehole conditions may not produce the expected linear inverse correlation between neutron counts and the logarithm of water-filled porosity unless source-to-receiver spacings are significantly increased.

10.7.3 When neutron logs are run in air filled boreholes and surrounded by formations with very small water contents the average distance traveled by neutrons before they reach the detectors may be relatively large, significantly increasing the depth of investigation in comparison with values typical of logging in fully saturated formations.

10.7.4 When neutron logs are run in a water or drilling-mud filled borehole surrounded by unsaturated or partially saturated formations, the neutron log may be influenced by invasion of the formation with borehole fluid, and may not indicate the natural saturation of the formation.

11. Report

11.1 Section 9, Guide D 5753 should be consulted for requirements of the report.

11.2 Providers of neutron logs shall describe: (*1*) the components of the neutron logging system, (*2*) the principles of the methods used, (*3*) methods and results of calibration and standardization, (*4*) performance verification (repeat sections, ASDE, correlation with other logs and key features such as bottom of steel casing, etc.), and (*5*) uniqueness of interpretation.

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

11.4 Any deviations from this guide should be documentation.

11.5 Presentation of neutron 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.

11.5.1 Neutron logs are typically displayed with linear scales in counts per second or percent porosity for an assumed limestone lithology.

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 neutron data combined and merged with logical combinations of other log data. Final log plots are typically plotted in percent porosity corrected to a given lithology and may be included in the report.

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

11.5.6 When calibration data is not available, neutron logs plotted in units of counts per second represent a non-linear porosity scale; approximate field estimates of porosity at two representative points (for example, estimates of maximum and minimum porosity in a given section) can be used to generate an approximately calibrated log where the scale varies linearly with formation porosity.

12. Keywords

12.1 borehole geophysics; neutron log; neutron porosity log; well construction; well logging

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