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Date Received: 12/8/2005 ***Processor:*** YCA ***Page Count:*** 12

Privileged: (Y/N) N ***Record Category:*** P ***Administrative Record: (Y/N)*** Y

FileFolder: N/A

Miscellaneous Comments: REFERENCE CITED. SUBMITTED BY MEENA SACHDEVA.

Record Documents:

Start Pg	*Doc Type*	*Doc Date*	*Title*	*Box*	*Package*
1	REPORT	11/1/1999	SUBSURFACE MOISTURE MEASUREMENTS USING NEUTRON PROBES DOP-FMU64-023,R0 N/A N/A		

14347

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90803

DOP-FMU64-023, R.0

Subsurface Moisture Measurements Using Neutron Probes

Effective Date: _____

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HISTORY OF REVISIONS

Document Number	Issue Date	Action	Description
DOP-FMU64-023, R.0	November 1999	New Document	

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1.0 PURPOSE

This procedure enables neutron probe logging technicians to properly and safely operate the CPN 503DR Hydroprobe Moisture Depth Gauge (the moisture probe) for subsurface investigations in and under disposal units and of the vadose zone.

2.0 SCOPE

This document provides instructions for using the 503DR Hydroprobe to evaluate subsurface moisture levels at TA-54 and specifies the requirements for the maintenance of this instrument. Appendix B in this document also provides information on the theory of neutron probe technology and generalized information on the calibration of the Hydroprobe.

Troubleshooting methods and operating instructions that apply more generally to the use of this instrument under other circumstances and at other locations are beyond the scope of this procedure and are provided in the factory operating manual.[1]

This procedure does not include operating instructions for the CPN 501 Depthprobe Density Moisture Gauge.

3.0 PREREQUISITES

None.

4.0 DEFINITION AND ACRONYMS

4.1 DEFINITIONS

Moisture gauge, moisture probe, instrument, neutron probe: The entire instrument assembly.

Probe: The logging tool containing the radioactive source and detector that is physically emplaced in the subsurface.

Surface assembly: The shielded casing that contains the instrument electronics and that houses the probe when not in use .

Cable: The depth-incremented cable that attaches the probe to the surface assembly.

Downhole: The position of the probe relative to the ground surface. When the probe is physically emplaced into the subsurface, it is said to be downhole.

Authorized user: A person who has successfully met the training requirements outlined in this DOP.

Logging technician: An authorized user who performs subsurface moisture logging using the moisture gauge.

Vadose Zone: The unsaturated geological media between the surface and the ground water (saturated zone).

Casing stick-up: The distance a borehole casing extends above the ground surface.

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[1] *503DR Hydroprobe Moisture Depth Gauge. June 16, 1983. CPN Corporation.*

4.2 ACRONYMS

ALARA as low as reasonably achievable

CPN Campbell Pacific Nuclear Corporation

5.0 PRECAUTIONS AND LIMITATIONS

The neutron probe emits ionizing radiation from a sealed, non-registerable source. See Appendix A.

Exposure should be limited as follows:

- Keep the probe as far away from the body as possible when it is necessary to remove the probe from the housing for any reason.
- Minimize the length of time the probe spends on the surface when unshielded by the surface assembly.
- Transport the instrument in its case by the handle.
- Require personnel not necessary to the operation to maintain a minimum distance of 10 ft from the probe when the probe is not downhole.
- In general, minimize the number of persons in the vicinity of the instrument and the time spent near the instrument.

Do not transport probes with any observed or suspected damage until source integrity has been verified by the Source Custodian and ESH-1.

Only authorized personnel may use the neutron probes at FMU-64. Authorization requires Laboratory radiation worker training (I or II) and training on this procedure.

6.0 RESPONSIBILITIES

Team Leader	◆ Appoints the logging technician. ◆ Ensures that the logging technician is trained as an Authorized User.
Logging technician	◆ Follows this procedure. ◆ Ensures instrument is locked in the cabinet in the cage area of TA-54-33 when not in use. ◆ Ensures instrument is in good working order.
Source Custodian	◆ Responsible for radioactive source control requirements as outlined in AR 3-4.

7.0 PROCEDURE-SPECIFIC EQUIPMENT

- Moisture Probe
- Cable
- Logbook
- Miscellaneous hand tools, as needed

8.0 PROCEDURE

8.1 TAKING THE FIELD STANDARD COUNT

The logging technician follows the instructions below.

Take a standard count with the instrument at the beginning of each sampling day.

NOTE: The standard count serves as an instrument check to ensure that the instrument source, detector, and electronics are operating within the manufacturer's specifications.

To Perform the field standard count:

1. Place the carrying case on the ground.
2. Verify that no other radioactive sources are within 30 ft.
3. Verify that no significant sources of hydrogen are within 10 ft.
4. Remove the moisture probe from the carrying case.
5. Place the probe on the metal plate located on the lid of the carrying case.
6. Attach the cable to the probe.
7. Attach the cable to the surface assembly.
8. Press "Std"; the instrument will display the stored current standard count.
9. Press "Step"; the instrument will display the stored previous standard count.
10. Press "Step" again; the instrument will display the chi value for the stored standard count.
11. Press "Step" again; the instrument will display "NEW STD?"
12. Press "Enter," which is equivalent to "Yes."

CAUTION
Stand back at least 10 ft during standard count.

13. The instrument will now collect 32 counts and average them. This is the standard count.
14. When the count is complete, the instrument will display "S ####," where "####" is the standard count.
15. Press "Enter" to store the standard count.
16. Press "Step"; the previous standard count is displayed.
17. Press "Step" again; the current chi value is displayed.
18. Record the standard count in the logbook (see Section 8.3.1).

If	Then
The chi value is not between 0.75 and 1.25.	Return to Step 8, above.
The chi value is between 0.75 and 1.25.	Proceed to Section 8.2.
The instrument consistently returns chi values outside of the acceptable range.	The instrument requires servicing by the manufacturer.

NOTE: Pressing "Clear" at any time during the standard counts will abort the standard count. "Clear" can be used to clear the instrument display and return to the "Ready" mode.

8.2 Configuring the Neutron Probe for Borehole or Access Tube Types

Prior to collecting data from a specific monitoring location, the instrument must be set up to collect or interpret data that is consistent with the type of borehole or access tube. The steps for instrument set up at the types of boreholes and access tubes currently in use are as follows:

8.2.1 Five or Nine-inch Uncased Boreholes

1. Push "Units" on instrument panel.
2. Press "Step" until the display reads "CNT."
3. Press "Enter"; the instrument returns to the "Ready" mode.

8.2.2 Two-inch Aluminum Casing

1. Push "Units" on instrument panel.
2. Press "Step" until it reads "%V."
3. Press "Enter."
4. Push "Cal" on the instrument panel; it will display the current calibration (for example, "mcal 2").
5. Use the "Step" button or the numbers on the keypad to change to "mcal 1."
6. Press "Enter"; it will display "mcoeff."
7. Press "Enter" to display coefficient "A," record in logbook.
8. Press "enter" to display "B," record in logbook

NOTE: These coefficients can be edited, if necessary.

9. Press "Enter"; instrument returns to "ready" mode.

8.2.3 Four-inch Schedule 40 PVC Casing

1. Push "Units" on instrument panel
2. Press "Step" until it reads "%V."
3. Press "Enter."
4. Push "Cal" on the instrument panel; it will display the current calibration (for example, "mcal 1").
5. Use the "Step" button or the numbers on the keypad to change to "mcal 2."
6. Press "Enter"; it will display "mcoeff."
7. Press "Enter" to display coefficient "A", record in logbook; Press "enter" again to display "B", record in logbook.

NOTE: These coefficients can be edited if necessary.

8. Press "enter"; instrument returns to "ready" mode.

8.3 FIELD MEASUREMENTS

The Moisture Probe and cable are designed for use in vertical holes. As designed, the instrument is placed over a borehole or access tube casing and the probe and cable are deployed directly from the surface assembly into the subsurface. When used in this way, the probe is not removed from the surface assembly or handled directly.

The cable is marked in one foot increments, but the first mark on the cable indicates a depth of 2 ft. This marking assumes the probe and cable are being deployed directly from the surface assembly and so takes into account the 1-ft height of the surface assembly itself.

When the probe is not deployed from the surface assembly, this correction to the probe depth is not necessary. The logging technician must add 1 ft to the depth indicated on the cable; for example, if the cable increment reads 20 ft, record a depth to the probe of 21 ft. Similarly, the use of different cables may require different corrections to derive the correct depth of the probe from the surface.

8.3.1 Logbook Entry

Once the standard count is complete and the instrument has been set up for the borehole or access tube of interest, subsurface measurements can be collected. The data is recorded by the operator in a field logbook. At a minimum, the logbook should contain the following information:

- Date
- Location
- Standard Count
- Previous Standard Count
- Chi value
- Surface casing stick-up (if any)

- Calibration number and A and B coefficients
- Depth with units (generally feet)
- Data with units identified (i.e., counts, vol%)

The logbook is a controlled SWO document and conforms to standard SWO logbook entry procedures. Follow the requirements of POLICY-FMU64-005, "Controlled Logbook," by observing the standard procedures outlined below.

- Avoid personal or editorial remarks.
- Make entries legibly and in indelible ink.
- Correct errors by lining out, entering the correction, signing, and dating the entry.
- When all pages are used or the logbook terminated, write "End of Log" after the last entry.
- When the logbook is no longer in use as a reference, submit the logbook to Records Management and Document Control for maintenance.

8.3.2 Collecting Data from Vertical Boreholes and Tubes

The steps for collecting subsurface data are as follows:

1. Lower the probe through the surface assembly with the cable to the desired depth.
2. Press "Start"; the instrument will count for 16 seconds.
3. At the "beep", the instrument will display the value for that depth. Record the data.
4. Record the measurement in the logbook (see Section 8.3.1).
5. Repeat Steps 1 through 4 until the required measurement are complete.

8.3.3 Collecting Data from Non-vertical Boreholes and Tubes

Because the surface assembly will not sit over a non-vertical hole, the probe must be removed from the surface assembly and placed in the borehole or access tube manually. In this case, a correction must be made in the depth measurements (see Section 8.3).

All non-vertical boreholes currently being logged are sufficiently steep such that the probe will slide down the hole or tube. Logging can proceed following these steps:

CAUTION

In the steps below, minimize the time the probe is outside of the surface assembly and not downhole.

1. Using the cable, remove the probe from the surface assembly.
2. To confirm the true downhole depth, measure the distance from the detector in the probe to the first measurement tab on the cable. This should be approximately 1 ft deeper than the cable's depth designation.

3. Lower the probe down the borehole or access tube with the cable to the desired depth.
4. Press "Start"; the instrument will count for 16 seconds.
5. At the "beep", the instrument will display the value for that depth. Record the data.
6. Record the data in the logbook (see Section 8.3.1).
7. Repeat Steps 3 through 6 until the required measurements are complete.

8.4 INSTRUMENT MAINTENANCE

The logging technician shall follow the instrument care and maintenance procedures detailed in the manufacturer's manual.[2]

9.0 RECORDS

The logbook used to record the data generated by this procedure is designated as a controlled document as of the issue date of this procedure. Subsurface monitoring logbooks are submitted to Records Management and Document Control for archival when they no longer serve as reference documents for the Low-Level Waste Operations team.

Logbook data are entered into an appropriate spreadsheet and stored electronically by the team leader or designee.

Electronic data does not constitute a controlled record. The data should be stored on a hard drive or equivalent (for example,. Zip or Jazz disk), and be backed up on the appropriate FMU-64 server.

10.0 DEVELOPMENTAL REFERENCES

501 Depthprobe Density/Moisture Gauge Operating Manual. June 16, 1983. CPN Corporation.

AP-FMU64-001, "Records Management." Solid Waste Operations.

11.0 ATTACHMENTS AND APPENDICES

Appendix A. Estimated Neutron Probe Personnel Exposure

Appendix B. Neutron Probe Calibration

[2] *503DR Hydroprobe Moisture Depth Gauge. June 16, 1983. CPN Corporation.*

APPENDIX A. ESTIMATED NEUTRON PROBE PERSONNEL EXPOSURE

Radioactive Sources in the Moisture and Moisture/Density Probes

Instrument	Source	Curies[a]	Activity[b]	Serial #	LANL PN #
503DR	^{241}Am/Be	50 mCi	<50 µCi	H310700379	858976
501	^{241}Am/Be, ^{137}Cs	50 mCi, 10 mCi	<50 µCi	D73115093	693792

[a] Maximum source activity as provided by manufacturer

[b] Activity based on surface dose (LANL Health Physics 1995/1996)

Estimated Exposure

This exposure estimate is for the 503DR Hydroprobe, which is the instrument currently in routine use at TA-54.

The ^{241}Am/Be source produces low-energy gamma shielded internally by lead sheathing. Gamma emission at the surface of the probe is approximately 1 mrem/h, a dose of less than 0.05 mrem/h at 2 ft from the probe. Thermal neutron output is approximately 0.2 mrem/h at the surface of the probe. Fast neutron output is about 4 mrem/h at the probe's surface. Total gamma and neutron radiation at mid-trunk height of an average human body, when the instrument is being carried by its handle, is approximately 0.3 mrem/h.

An anticipated duty cycle in close proximity to the neutron probe is about 2 hours/day over a full 8 hour work day. The estimated maximum dose rate is:

(2 h/day)(5 days)(0.3 mrem/h) = 3.0 mrem/week.

The estimated annual dose from routine logging activities, assuming one full week of logging every other month, is **18 mrem**.

APPENDIX B. NEUTRON PROBE CALIBRATION

Theory

The CPN 503DR Hydroprobe contains a ^{241}Am/Be neutron generator. The ^{241}Am decays by emitting an alpha particle that interacts with beryllium to produce fast neutrons. When these neutrons leave the probe and encounter the surrounding media (soil, rock, fill), they are slowed by collisions until their energies fall within the probe's range of detection. They are considered thermal neutrons when in this energy state.

Hydrogen atoms are approximately the same mass as neutrons and dramatically slow neutrons upon collision. The vast majority of thermalized neutrons detected by the probe are produced by collisions with hydrogen. Because the only significant source of hydrogen in most media is water, the number of thermal neutrons detected is proportional to the water content of the media. A specific calibration that relates media moisture content to thermal neutron flux can be developed for any specific type of media.

The radius of influence of the fast neutrons produced by beryllium alpha absorption/neutron emission is limited. Among the variables that affect the relationship between detected thermal neutron flux and media moisture concentration are the diameter of the access hole and the borehole casing material. The elevated hydrogen content of a material like PVC produces a baseline thermal neutron flux that must be factored into the calibration.

Calibration

Several types and sizes of boreholes and access tubes are in use at FMU-64 for neutron probe logging. These include:

- 5-in. diameter, uncased boreholes in the Bandelier Tuff
- 9-in. diameter, uncased boreholes in the Bandelier Tuff
- 2-in. diameter, aluminum pipes in waste media in disposal units
- 4-in. diameter, schedule 40 PVC pipes in waste media and in the Bandelier Tuff

Five and Nine-Inch Boreholes

During the drilling of the 5- and 9-in. boreholes, borehole cores were collected and analyzed for gravimetric moisture content and density. The boreholes were then logged with the 503DR Hydroprobe and the raw counts were recorded at one-ft intervals.

Gravimetric moisture content in the core was converted to volumetric moisture content using the bulk density of the samples. The intervals of core measured for moisture content were correlated with the number of counts collected by the neutron probe. The assumption was made that the volumetric moisture content in the one-ft interval of the borehole logged by the neutron probe was equal to that in the associated collected core. Separate calibration curves for the 5- and 9-in. holes were developed in this way, and are as follows:

Borehole Designation	Vol% H_2O Derivation
5 inch	$0.0002 \times \text{counts}^{1.3404}$
9 inch	$0.00008 \times \text{counts}^{1.537}$

The relationship between neutron count and moisture content is expressed as an exponential function in order to avoid negative numerical moisture level outcomes when the calculations involve extremely low moisture-level regions of tuff. These exponential functions do not diverge significantly from the associated linear relationship at the relatively dry conditions found at Area G (< 20 volume %). At 20 % moisture by volume, the 5-in. power calibration diverges from the linear relationship by 1 volume %. The 9-in. power calibration diverges approximately 3 volume % from the linear at 20 volume % moisture. These calibrations diverge more significantly as the moisture content nears saturation (~50% by volume); at high moisture contents, a linear calibration may be more appropriate.

Four- and Two-in. Access Pipes and Boreholes

Because core moisture data for the 4- and 2-in. access pipes and boreholes are not available, calibration functions were supplied by Campbell Pacific Nuclear Corporation, the probe manufacturer. These calibrations are linear relationships established for a sand media in the form

$$\text{soil moisture} = A \times \text{counts} + B$$

These neutron flux to media moisture conversions are performed directly by the instrument's electronics for the 4- and 2-in. access pipes and boreholes.

The instrument can provide moisture data in various units, including moisture expressed as a percent of the total or moisture expressed by volume. The calibration number on the instrument and the coefficients entered into the instrument are as follows:

Calibration 1 (2-in. Al pipes): A = 17.4556 B = -1.2378

Calibration 2 (4-in. PVC): A = 29.0912 B = -1.2361

Other Borehole Types

If current neutron logging efforts change to include boreholes or access tubes that are of different sizes or cased with different materials, new calibrations will have to be obtained.