MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

DATA SUMMARIES ON NUCLEAR METHODS REPORTED ON SOILS

Based on 12 reports on the neutron scattering method for moisture and 11 reports on the gamma ray scattering method for density.

by

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Table 1

List of Reports Investigated

A. Reports Covering the Neutron Moisture Method

1. Belcher, D. J.; Cuykendall, T. R.; and Sack, H. S.; *The Measurement of Soil Moisture and Density by Neutron and Gamma-Ray Scattering*. Technical Development Report No. 127, Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana, October, 1950.

2. Belcher, D. J.; Cuykendall, T. R.; and Sack, H. S.; *Nuclear Meters for Measuring Soil Density and Moisture in Thin Surface Layers*. Technical Development Report No. 161, Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana, February, 1952.

3. Carlton, Paul F.; Belcher, D. J.; Cuykendall, T. R.; and Sack, H. S.; *Modifications and Tests of Radioactive Probes for Measuring Soil Moisture and Density*. Technical Development Report No. 194, Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana, March, 1953.

4. Spinks, J. W. T.; Lane, D. A.; and Torchinsky, B. B.; "A New Method for Moisture Determination in Soil". *Canadian Journal of Technology*, Vol. 29, April 3, 1951, pp. 371-4.

5. Swanson, R. W.; *Instrumentation of a Field Survey Meter for Soil Moisture Determination.* Thesis, M. S. in Nuclear Engineering, North Carolina State College (Underwood, Van Bavel), 1954, 59 pp.

6. Gardner, Wilford; and Kirkham, Don; "Determination of Soil Moisture by Neutron Scattering," *Soil Science*, Vol. 73, No. 5, May, 1952, pp. 391-401.

7. Pieper, G. F., Jr.; *The Measurement of Moisture Content of Soil by the Slowing of Neutrons*. Thesis, Cornell University, June, 1949.

8. U. S. Army Corps of Engineers, *Field Tests of Nuclear Instruments for the Measurement of Soil Moisture and Density*. Miscellaneous Paper No. 4-117, Vicksburg Infiltration Project, Forest Service, U. S. Department of Agriculture, for Waterways Experiment Station, Vicksburg, Mississippi; March, 1955.

9. Yates, E. P., *Soil Moisture Determination by Neutron Scattering*. Thesis, Cornell University, September, 1950.

10. Hood, E. E., Jr.; Determination of Soil Moisture Content by Measurement of Neutron Scattering. Thesis, North Carolina State College, June, 1953.

11. Goldberg, Irving; Trescony, Louis J.; Campbell, James S., Jr.; and Whyte, Gordon J.; Measurement of Moisture Content and Density of Soil Masses Using Radioactivity Methods. Paper prepared for presentation at the 1954 Pacific Coast Regional Conference on Clays and Clay Technology, June 25-6, 1954, University of California, Berkeley.

12. Horonjeff, Robert; Goldberg, Irving; and Trescony, Louis J.; The Use of Radioactive Material for the Measurement of Water Content and Density of Soil. Paper prepared for presentation at the Sixth Annual Street and Highway Conference, February 3-5, 1954, University of California, Los Angeles.

B. Reports Covering the Gamma Ray Density Method

1. Belcher, D. J.; Cuykendall, T. R.; and Sack, H. S.; The Measurement of Soil Moisture and Density by Neutron and Gamma Ray Scattering. Technical Development Report No. 127, Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana, October, 1950.

2. Belcher, D. J.; Cuykendall, T. R.; and Sack, H. S.; Nuclear Meters for Measuring Soil Density and Moisture in Thin Surface Layers. Technical Development Report No. 161, Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana, February, 1952.

3. Carlton, Paul F.; Belcher, D. J.; Cuykendall, T. R.; and Sack, H.S.; Modifications and Tests of Radioactive Probes for Measuring Soil Moisture and Density. Technical Development Report No. 194, Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana, March, 1953.

4. Vomocil, J. A., "In Situ Measurement of Soil Bulk Density," Agricultural Engineering, Vol. 35, No. 9, September,, 1954, pp. 651-4.

5. Berdan, D.; and Bernhard, R. K.; Pilot Studies of Soil Density Measurements by Means of X-Rays. Presented at the Fifty-third Annual Meeting of the American Society for Testing Materials, June 26-30, 1950.

6. U. S. Army Corps of Engineers, Field Tests of Nuclear Instruments for the Measurement of Soil Moisture and Density. Miscellaneous Paper No. 4-117, Vicksburg Infiltration Project, Forest Service, U. S. Department of Agriculture, for Waterways Experiment Station, Vicksburg, Mississippi, March, 1955.

7. Hosticka, Harold E.; "Radioisotopes and Nuclear Reactions Applied to Soil Mechanics Problems," Symposium on the Use of Radioisotopes in Soil Mechanics, ASTM Special Technical Publication No. 134, American Society for Testing Materials, Presented at a meeting of Committee D-18 on Soils for Engineering Purposes, Cleveland, Ohio, March 5, 1952.

8. Bernhard, R. K.; and Chasek, M.; Soil Density Determination by Direct Transmission of Gamma Rays. Presented at the Fifty-eighth Annual Meeting of the American Society for Testing Materials, June 26-July 1, 1955; 18 pp.

9. Miles, M. E.; Energy Distribution of Gamma Rays Scattered Around a Soil Density Probe. Thesis, Cornell University, June, 1952.

10. Goldberg, Irving; Trescony, Louis J.; Campbell, James S., Jr.; and Whyte, Gordon J.; Measurement of Moisture Content and Density of Soil Masses Using Radioactivity Methods. Paper prepared for presentation at the 1954 Pacific Coast Regional Conference on Clays and Clay Technology, June 25-6, 1954, University of California, Berkeley.

11. Horonjeff, Robert; Goldberg, Irving; and Trescony, Louis J.; The Use of Radioactive Material for the Measurement of Water Content and Density of Soil. Paper prepared for presentation at the Sixth Annual Street and Highway Conference, February 3-5, 1954, University of California, Los Angeles.

Table 2

Advantages of the Neutron Moisture Method Cited by Authors

	Number of authors citing
Determinations are made *in situ* (it is unnecessary to remove samples for analysis).	12
Continuous readings are possible at the same point.	8
Method determines total water regardless of physical or chemical state.	7
Moisture contents at various depths can be determined.	8
Continuous and automatic recording is possible.	4
Accuracy and precision equal or exceed those of standard procedures.	7
Movement of moisture in soils may be followed.	3
The method possesses equal sensitivity over the entire range of moisture.	2
The method is more rapid than conventional methods.	7
Both surface and depth measurements are possible.	5
Equipment is readily portable.	6
Method yields moisture content per unit volume directly.	3
Method is independent of soil type.	7

Method is independent of soil temperature.	3
Method is independent of soil texture.	2
Method is independent of soil composition.	1
Method is independent of soil compaction.	1
Method is independent of soil structure.	1
Method is independent of the concentration of soil solution (salts).	2
Volume of soil being measured is likely to assure a representative sample.	3
The method is simple.	1
Desired vertical or horizontal precision can be attained by effective design of shielding geometry.	1
The same procedure can be used to determine the asphalt content of a bituminous pavement mix.	1

Table 3

Advantages of the Gamma Ray Density Method Cited by Authors

	Number of authors citing
Determinations are made *in situ* (it is unnecessary to remove samples for analysis).	11
Continuous readings are possible at the same point.	7
Densities at various depths can be determined.	9
Continuous and automatic recording is possible.	4
Accuracy and precision equal or exceed those of standard procedures.	4
Changes of density with compaction may be followed.	7
The method is more rapid than conventional methods.	8
The method is independent of soil type.	4
The method is independent of soil temperature.	2
Both surface and depth measurements are possible.	4
Equipment is readily portable.	5
The method yields bulk density directly.	2
The volume of soil being measured is likely to assure a representative sample.	3
The method is simple.	1
Desired vertical or horizontal precision can be attained by effective design of shielding geometry.	1

Table 4

Limitations of Neutron Moisture Method Cited by Authors

	Number of authors citing
Soils containing large quantities of chlorides require special calibration.	2
Temperature range is 35 to 90 degrees F.	1
Chemically bound water is included.	1
One thousand counts are required for less than 2% counting error. This takes 100 minutes at low moisture contents.	1
Mucks require special calibrations.	1
Different metals for access tubing require special calibrations.	1
Too much time is required for moisture tests.	1
The method is worthless for thin layers.	1
The equipment costs too much.	1
The equipment is difficult to procure.	1
The equipment is difficult to operate.	1
Maximum depth is only 30 ft.	1
None reported.	6

Table 5

Limitations of Gamma Ray Density Method Cited by Authors

	Number of authors citing
The equipment costs too much.	1
The equipment is difficult to procure.	1
The equipment is difficult to operate.	1
The method is worthless for thin layers.	1
Maximum depth is only 18 inches.	1
Maximum depth is only 30 feet.	1
The equipment is too sensitive to "minor disturbances" close to the counter tube.	1
The equipment is not sensitive enough.	1
Too little is known about the effects of surface irregularities.	1
The presence of rocks affects the results.	1
Temperature range is 35 to 90 degrees F.	1
None reported.	5

Table 6

Frequency of Laboratory and Field Use

	Number of authors citing
A. Moisture	
Laboratory use only.	2
Field use only.	2
Both.	8
B. Density	
Laboratory use only.	1
Field use only.	2
Both.	6
Not stated.	1

Table 7

Types of Sources Employed

	Number of authors citing
A. Moisture	
Radium-beryllium	7
Radium D-beryllium	4
Polonium-beryllium	4
B. Density	
Cobalt 60	9
Radium	2
X-Rays	1

Table 8

Strengths of Moisture Sources Used

	Number of authors citing
A. Radium-Beryllium	
6 millicuries	1
9 millicuries	1
100 millicuries	2
B. Radium D-Beryllium	
25 millicuries	2
C. Polonium-Beryllium	
100 millicuries	1
150 millicuries	1

Table 9

Strengths of Density Sources Used

		Number of authors citing
	A. Cobalt 60	
1	millicurie	3
1.5	millicurie	1
2	millicuries	1
70	millicuries	1
	B. Radium	
4	millicuries	1

Table 10

Types of Access Tubing

	Number of authors citing
A. Moisture	
Aluminum	7
Stainless Steel	3
No tubing (auger hole)	2
Not reported	1
B. Density	
Aluminum	3
Stainless steel	3
No tubing (auger hole)	1
Not reported	4

Table 11

Types of Detectors

	Number of authors citing
A. Moisture	
Rhodium foil	2
Silver foil	4
Indium foil	2
Boron 10 trifluoride filled tube	3
Boron 10 lined counter tube	1
B. Density	
Victoreen 1B85 Geiger tube	6
Anton 106 counter tube	2
X-Ray film	1
Scintillation counter	1
Pocket Dosemeter	1
Boron 10 trifluoride	1

Table 12

Dimensions of Moisture Probes

	Number of authors citing
Less than 2" OD, 1.76" ID	1
1 1/32" OD	2
1" ID	1
9" x 1" OD	1
63/64" OD	1
Less than 15/16" OD	1
29/32" ID	1
3/4" OD, 3/4" less 0.050" ID	1
7 5/8" x 6 1/4" x 2 1/2" surface type	1
Not reported	3

Table 13

Dimensions of Density Probes

	Number of authors citing
14" x 1" OD	1
1" ID	1
63/64" OD	3
0.90" OD, 0.83" ID brass tubing	1
9 1/4" x 8" x 1 11/16" surface type	1
Not reported	5

Table 14

Types of Reference Standards

	Number of authors citing
A. Moisture	
Water	6
Paraffin	2
Aluminum-lead-paraffin sphere	1
Not reported	3
B. Density	
Concrete	2
Aluminum-lead-paraffin sphere	1
Fixed distance from known source	1
Not reported	6

Table 15

Sizes of Samples Used for Calibration

	Number of authors citing
A. Moisture	
55 gallons	5
25 gallons	2
Less than 25 gallons	1
Calibrated in field	1
Not reported	1
B. Density	
55 gallons	4
Less than 55 gallons	3
Varied	1
Not reported	2

Table 16

Radii of Moisture Measurement

	Number of authors citing
A. Minimum	
4 inches	1
6 inches	6
10 inches	1
B. Maximum	
6 inches	1
8 inches	2
12 inches	2
15 inches	3
18 inches	1
C. Not reported	2

Table 17

Radii of Density Measurement

	Number of authors citing
A. Minimum	
6 inches	1
13 inches	1
B. Maximum	
8 inches	1
9 inches	2
18 inches	1
C. Not reported	5

Table 18

Methods of Varying Moisture Parameter

	Number of authors citing
Air drying, adding known amounts of water, and mixing thoroughly.	2
Saturating, then drying little by little in sacks in oven.	1
Moistening soil to desired degree, weighing, drying, and weighing again.	3
Hand shoveling ("best and fastest method").	1
From 1000 to 1200 lb. soil mixed in Lancaster. Range from oven-dry to 27 lb. water per cubic foot.	1
"Batch mixer".	1
Tests run in field under natural soil conditions.	1
"Conventional method".	1
Not reported.	1

Table 19

Methods of Varying Density Parameter

	Number of authors citing
Vibrating soil with concrete vibrator.	1
Hand tamping.	2
"Using soils of different moisture content".	1
Varying wet density in pounds per cubic foot by varying soil type.	1
From 1000 to 1200 lb. soil mixed in Lancaster. Range from 75 to 133 pounds per cubic foot.	1
Varying bulk density ("Known mass and known volume") as well as water content.	1
Tests conducted in field under natural soil conditions.	1
Not reported.	3

Table 20

Time Required for Measurement

	Number of authors citing
A. Moisture	
3 minutes	3
5 minutes	2
9 minutes	1
30 minutes	2
Several hours	1
B. Density	
3 minutes	4
C. Not reported	10

Table 21

Control Tests Used for Neutron Moisture Method

	Number of authors citing
Use of "loss on heating" samples.	5
Oven-drying 1500 g. from center of drum.	2
Oven-drying 4 samples at 4 different levels.	1
Weighing and drying duplicate 100-g. samples, then returning these to gross sample.	1
Core sampling, weighing, then oven-drying.	1
Not reported.	2

Table 22

Control Tests Used for Gamma Ray Density Method

	Number of authors citing
"Weighing samples."	1
"Volume change."	1
"Weight and volume measurements."	1
Net weight and volume of drum contents.	2
Core sampled, volume and weight determined.	1
Sand cone method.	1
"Conventional 'sand' method."	1
"Weight/volume plus sand density tests."	1
"Standard samples."	1
Not reported.	4

Table 23

Special Features and Observations

Associated with Moisture Equipment

	Number of authors citing
Employed telemetering.	2
Base plate design for surface measurements.	1
Different methods of placement of access tubes were tried out.	1
The closer the source to the counter tube, the better. Intimate contact is best.	1
None reported.	7

Table 24

Special Features and Observations

Associated with Density Equipment

	Number of authors citing
Employed telemetering.	1
Base plate design for surface measurements.	1
Different methods of placement of access tubes were tried out.	1
Source and detector in two separate probes.	1
Apparatus "very simple;" measures depths to 60 feet.	1
Energy distribution studied.	1
None reported.	5

Table 25

Effects of Soil Type, Condition, Amendments, etc., on Moisture Determinations

	Number of authors citing
Texture or composition has negligible effect.	1
Humus, rich in organic material, had no effect on determinations.	1
Effect of sand was negligible.	1
Effect of glacial drift was negligible.	1
Influence of soil type was negligible (sand, clay loam, silt, gravelly clay sand).	1
All soil textures used (quartz sand, Onslow fine sandy loam, Cecil clay) fell on same curve when expressed on volume basis.	1
Effect of organic material must be considered but may be negligible.	1
Effect of organic material is compensated for by the large moisture contents of these soils.	1
Chlorides may exert an effect if present in large quantities.	1
No effects reported.	7

Table 26

Effects of Soil Type, Condition, Amendments, etc., on Density Determinations

	Number of authors citing
Independent of soil type	2
Rocks may affect the readings	2
No effects reported	8

Table 27

Improvements in Moisture Method Suggested by Author

	Number of authors citing
Use boron type counters.	3
Use scintillation counters.	2
Use a weaker source (less than 250 millicuries radium-beryllium).	1
Use a stronger source (greater than 25 millicuries radium D - beryllium).	2
Use a longer counting time.	1
Use a compact, battery-operated scaler. Make field improvements.	3
Study the size of the sphere being measured.	1
Improve the geometry used (better probe design).	2
Develop an instrument for depth measurement from the surface.	1
None suggested.	2

Table 28

Improvements in Density Method Suggested by Author

	Number of authors citing
Use boron type counters.	1
Use scintillation type counters.	2
Use compact, battery-operated scaler.	1
Use smaller, more rugged equipment.	2
Use count rate meter.	1
Decrease crystal height-diameter ratio to increase ratio of low gammas.	1
Improve design of probe.	1
Use absorber around detector to limit gamma energies.	1
Increase the sensitivity.	1
Eliminate the effect of rocks.	1
Study the effect of soil moisture on the density readings.	2
Study the size of the sphere being measured.	1
None suggested.	3

Table 29

Accuracy of Moisture Measurements

	Number of authors citing
± 0.13 to 0.15 lb/cu ft.	1
± 0.8 lb/cu. ft.	2
± 0.9 lb/cu. ft.	1
± 1 lb/cu. ft.	2
± 2.0% by volume or 1.4% by weight.	1
± 2%	1
± 10%	1
Not reported.	3

Table 30

Accuracy of Density Measurements

	Number of authors citing
0.5 lb/cu. ft.	1
1.60 to 1.74 lb/cu. ft.	1
2 lb/cu. ft.	1
3 lb/cu. ft.	1
4 lb/cu. ft.	1
5 lb/cu. ft.	1
5.5 lb/cu. ft.	1
0.7% by weight	1
1.5%	1
Not reported	2

Table 31

Safety Precautions for Moisture Tests

Other Than Film Badge, Monitor, and Health Examinations

	Number of authors citing
3-ft. distance, not shielded, for short intervals.	3
6-ft. distance for longer intervals when using drums.	1
30-inch distance.	1
2-ft. distance.	1
Wire cages.	2
2 1/2-inch lead container for probe.	1
2-inch lead container for probe.	1
"Only a few obvious precautions."	1
Not reported.	2

Table 32

Safety Precautions for Density Tests

Other Than Film Badge, Monitor, and Health Examinations

	Number of authors citing
3-ft. distance, not shielded, for short intervals.	1
6-ft. distance for longer intervals when using drums.	1
2-ft. distance.	1
Wire cages.	3
1 1/2 inches of lead.	1
Not reported.	5

Table 33

Frequency of Soils Used

	Number of authors citing
Memphis silt loam	3
Briensburg silt loam	1
Clarion silt loam	1
Monona silt loam	1
Wabash silt loam	1
Norfolk fine sandy loam	1
Onslow fine sandy loam	1
Quartz sand	2
River sand	1
Fine river sand	1
O'Neil sand	1
Sand, not specified	2
Sandstone fill	1
Gumbo clay	1
Cecil clay	1
Sandy clay	3
Silty clay	3
Commerce silty clay	1
Putnam clay	1
Clay loam	1
Silt, not specified	2
Glacial drift	1

Table 34

Frequency of Soil Textures Used

	Number of authors citing
Sand	7
Silt	2
Clay	3
Silt loam	7
Silty clay	4
Sandy loam	2
Sandy clay	3
Clay loam	1
Sandstone	1
Glacial drift	1