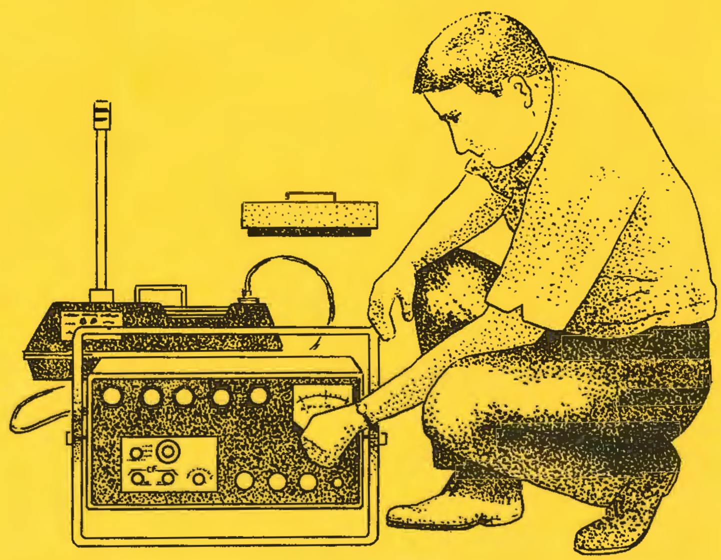
CALIBRATION AND EVALUATION OF A NUCLEAR DENSITY AND MOISTURE MEASURING APPARATUS



PREPARED BY
ARKANSAS STATE HIGHWAY DEPARTMENT
PLANNING AND RESEARCH DIVISION
IN COOPERATION WITH
U.S. DEPARTMENT OF COMMERCE
BUREAU OF PUBLIC ROADS

RESEARCH PROJECT 3

ARKANSAS STATE HIGHWAY DEPARTMENT
Highway Research Project No. 3
HPS 1-(20), F-426

CALIBRATION AND EVALUATION OF A NUCLEAR DENSITY AND MOISTURE MEASURING APPARATUS

IN-PLACE MEASUREMENT OF SOIL DENSITY AND/OR SOIL MOISTURE BY MEANS OF A NUCLEAR DEVICE USING LOW-LEVEL NEUTRON AND GAMMA RADIATION

FINAL REPORT
ON STUDIES TO

Develop Practical Techniques for Calibrating a Nuclear Measuring Device to Use in Determining Soils Densities and Soils Moisture Levels.
Evaluate the Practicability of the Device for Field Use and Appraise the Reliability of the Findings Produced by the Device in Comparison with the Currently Standard Sand-Cone Method.
Investigate Various Other Aspects of the Nuclear Measurement Technique and Explore Its Economic Value in the Highway Program, Particularly Its Potential for Reducing Lost Time in Field Tests.

Study Conducted by Jack R. Wofford,
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Report Prepared in Planning and Research Division

Little Rock, Arkansas
November 1963

FOREWORD

The testing and analysis of soils is a vital step in modern highway construction. The application of soils test results can effect great economic savings in the structural life and service of a roadway or bridge facility. Conversely, failure to apply the principles of soils mechanics can waste enormous sums of money.

The purpose of this project was an exploratory investigation of the use of radioactive materials in a nuclear apparatus for in-place field measurements of the densities and moisture contents of soils, particularly the in-place properties of highway embankment materials. Especial attention was to be directed to:

(a) The development of techniques by which standards of comparative reference might be applied to the results obtained by use of such a machine; that is, a scale of relative values for calibrating or gauging the results for comparative purposes.

(b) An appraisal of the instrument's adaptability for field use in varying situations and conditions, along with an evaluation of the accuracy and reliability of the findings of the instrument.

AUTHORITY

Highway Research Project No. 3 HRC 3, HPS 1-(20) F-426, HPR 1-(1) F426, HPR 1-(2) M426 was established May 24, 1962, under a joint agreement between the Arkansas State Highway Department, Planning and Research Division, and the U.S. Department of Commerce, Bureau of Public Roads, according to the provisions of Section 307, Title 23 - Highways, United States Code; and Section 522, Title 76 - Highways, Arkansas Statutes.

SUMMARY

The research objectives of this project were to investigate a new method of in-place determination of soils densities and moisture levels employing a nuclear physics principle of the gamma radiation function as the measurement technique, with specific emphasis upon:

a. The exploration and definition of the range of measurements which might be established as a uniform standard for calibration of the nuclear measuring device; and

b. An evaluation of the functional adaptation and utility of the device along with an appraisal of the reliability of the measurements produced.

Other areas of particular interest to be observed during the project were identified as follows: Time requirements per test, optimum probe depth, weather and/or temperature effects on test results, and undesirable aspects.

An apparatus manufactured by the Troxler Laboratories of Raleigh, North Carolina, was selected for use in the project. It comprised six elements housed in steel cases of various sizes and weights but all easily handled. The largest weight of any component was 29 pounds which is the uncrated weight of the surface density probe.

This selection was made for two basic reasons:

1. The device does not require an Atomic Energy Commission license; and

2. It provides greater flexibility in testing methods since it employs either directtransmission measurement or backscatter measurement or both.

The parameters established for deriving comparative values were the

findings furnished by the conventional sand cone test for soil density and the oven-dried test for soil moisture, at the same site and time.

Field investigation began in the summer of 1962 and was completed in September 1963. The first summer's work did not produce much in the way of useable data since mechanical difficulties, breakdowns, and equipment adaptation and modification consumed much time and rendered invalid or incompatible much of the data developed in the earlier weeks of the project. Of some 250 tests run, usability is largely limited to the last 100 tests.

The last 100 tests were within a reasonable range as compared to the sand-cone method, which is the standard method used by the Arkansas State Highway Department, and was much faster. The nuclear equipment is reliable enough for embankment density and moisture determinations, but the results indicate that the nuclear method is not as adaptable to stone base material density as to soil density determination.

DEFINITIONS

Regression Equation - The equation of a curve developed by use of the least squares analysis of the data. The best fitted curve.

95% Confidence Limit - The established parameter of deviation. Thus, the accuracy level must be such that the error in density and moisture measurements in 95 of every 100 tests will fall within less than the stated range of allowable error for sand cone test values, as determined from regression analysis. This range was selected as a reasonable value for the limit of significance in this project. The 95% level is equal numerically to ($\pm$) 2 times the standard error of estimate or standard deviation (all values rounded off).

Standard Error of Estimate - The value computed for each group of materials by the formula (S_x) -

$$S_x = \sqrt{\frac{(X_t - X_c)^2}{N}}$$

where:

X_t = test value of density.

X_c = corresponding regression curve value.

N = total number of tests.

Computed Dry Density - The Value derived from all the usable tests by the nuclear apparatus at given depths. It is computed by the square root of the sum of the squares of the standard error of estimates of moisture and wet density.

Reference Standard - A material selected for use as a standard reference to establish a reference count rate. The reference count rate is then used as the divisor in deriving the count ratio. The S-1 moisture standard is shown in PLATE I. The standard for density is, for this project, one particular concrete block 6" x 10" x 16", with 5/8" diameter access hole for density probe rod.

Count Ratio - The field count of the material divided by the standard reference count. It is used to compensate for weather influence in the test.

Calibrate - To establish a datum, scale, or standard of relative values by which the discrete indications of the nuclear apparatus may be converted into terms of comparable values with the findings of other devices for determining the density and moisture contents of soils.

Module - An electrical assembly comprising multi-circuits built into a complete unit.

Milli-curie - A measure of the intensity of a radio isotope.

Ra:Be - Radium-Beryllium nuclear source enclosed in stainless steel. When not in use contained in lead shield built into probe case.

Fast Neutrons - Particles of matter having a mass approximately equal to that of the hydrogen atom. They have high kinetic energy and show no change as they travel from a radioactive source.

Slow or "Thermal" Neutrons - Fast neutrons reduced to a much lower energy level as the result of many elastic collisions with atoms in the soil causing consequent loss of energy.

Moisture - Types or means of retention and movement in soils -

Gravitational - Water free to move downward from the force of gravity - water which will drain from the soil.

Capillary - Free water retained by surface tension in the soil capillaries overcoming gravity - water which will drain if the water table is lowered - also will evaporate.

Hygroscopic - Moisture retained by soil when air-dried. It can be driven off @ 230° F.

Adsorbed - Moisture held in by electrical charge on surface of soils.

Chemically Bound - Held in by chemical reaction of constituent materials.

Density - A measure of unit weight in pounds per cubic foot.

ABBREVIATIONS

pcf or $\#/ft^3$ - Pounds per cubic foot.

cpm - Count per minute.

S - Surface count position.

S-1 - A 3" polyethylene reference standard used in moisture measurements. This is the standard used in testing.

S-3 - A 1/2" polyethylene reference standard used in moisture measurements. This is used only as a secondary or complementary reference to check apparatus operation.

CONTENTS

IN-PLACE MEASUREMENT OF SOIL DENSITY AND/OR SOIL MOISTURE BY MEANS OF A NUCLEAR DEVICE USING LOW-LEVEL NEUTRON AND GAMMA RADIATION

PART I - INTRODUCTION

A. The Objectives of Soils Analysis

Soils have a tremendously important place in highway engineering economics. The importance of thorough exploration of the basic characteristics of soils used in highway construction is seldom over-emphasized. Inadequate initial information in this respect may result in increased costs through necessary design changes during the course of the project, or, later in structural failures through improper design. Knowledge of the pertinent soils density and moisture content is an essential prerequisite to design, and, during construction, an essential control for compliance with design. This knowledge can only be acquired by testing and analyzing the soils before design and construction of the project is begun and by continuing the testing program during construction.

In highway engineering design a major interest in soils is related to their load-bearing value or suitability for use, i.e., usually, the compressibility and stability of the soils which will support the roadway and bridge structures. Major factors in this value are density and moisture content. In the field of highway engineering these two, among the many, aspects of soils are possibly the most useful.

The basic characteristics of soils may be outlined broadly as: grain size, internal friction, cohesion, compressibility, elasticity, capillarity, and permeability. These primarily combine to indicate the mechanical and hydraulic properties which determine the suitability of soils for engineering usage and are usually expressed in load-carrying capacity and resistance to movement or consolidation in use. Drainage and volume-change aspects are important properties as well.

In view of this importance in highway engineering economy, it seems strange that one of the greatest areas of "un-development" and of potential impact upon progressive techniques in highway and airfield design and construction lies in today's limited reservoir of knowledge and methods which might permit an exact forecast of the action of soils involved during the physical or permanent life of a structure.

B. Current Methods for Determining Soils Density and Moisture

The speed of construction work has been steadily increasing for many years. Slowdowns can be disastrous to all concerned -- the contractor, the public administrative agency, the road-user, and the taxpayer.

However, the acquisition and the application of such knowledge as we do have is a time-consuming business with currently available testing techniques. Thus it is that the field engineer is often caught between the horns of the dilemma -- the need to take sufficient tests to reasonably assure compliance with the job specifications with their time consuming and meticulous application; and on the other hand, the willingness to perform tests at less frequent intervals to expedite job progress.

The testing of soils density during construction to assure compliance with specifications is done by the sand-cone method. Each of these tests takes about one hour. Soil moisture content is determined either by the lengthy oven-drying technique or the "Speedy Moisture" method. Any reliable testing technique which would reduce the time factor significantly would be used to great advantage in controlling the moisture content and density in earthfills during construction -- especially if "per test" costs are reasonable.

C. Research Objectives

In the search for such a new testing technique, the use of nuclear radiation apparatuses has been found promising. This project of report was initiated to explore and investigate this promise by determining the operational application and the reliability-comparability of its findings in terms of current testing procedures.

The purpose of this study was to evaluate and calibrate a nuclear device manufactured by the Troxler Laboratories of Raleigh, North Carolina for in-place measurement of density and moisture. The apparatus is intended for use to determine in-place densities and compaction of construction materials for embankments and base courses. The current method being used to make these determinations is "Density of Soil in Place by the Sand-Cone Method," ASTM 1556-58T.

A comparative study of the reproducibility and the reliability of the findings by the nuclear testing method and the standard method of testing was the primary objective of the project. A second major objective was the development of optimum techniques of use and performance. There were also other areas of particular interest, areas in which it was thought information could be collected during the project. These were identified as follows:

Average Time Requirement per Test. The average time consumed per moisture-density test by both sand-cone and nuclear method.

Optimum Probe Depth. To be derived by comparing readings and desities at 2", 4", 6", and 8" depths.

The effects, if any, of temperature or weather on nuclear test results. The identification of any modification or correlation required by materials that do not lend themselves readily to nuclear methods of testing.

The isolation and identification of any undesirable or unusual conditions which could affect the major studies.

The urgent need to minimize time-consumption in soil-testing operations, as well as to develop information on the other subjects, were felt, in view of the promising possibilities of the nuclear technique, to be sufficient to justify this investigation.

PART II - DESCRIPTION OF APPARATUS

The nuclear apparatus consisted of the following individual units, each a separately identifiable element of the apparatus (see PLATE I):

1. Model 200B Scaler. The counting device which records the number of pulses that are picked up by the detector tube. It provides for circuits of specific Modules to step up the output of the 18-volt battery to:

   a. The 825/925-volt range for density tests; or,

   b. The 1250/1350-volt range for moisture tests.

   It also incorporates a sensitivity element by which the selectivity in regulating voltage may be increased or decreased by means of the five Gain Scale settings.

   The Scaler is powered by an 18-volt internal rechargeable battery.

2. Model SC-120 Density Probe. This is the probe-rod containing the radioactive source. It is inserted in prepared apertures in the soil to a predetermined depth. Those nuclear pulses transmitted by the source, which succeed in reaching the detector tube about 11-inches distant in the same case, are then recorded as a direct measurement between the source and detector

tube. The detector tube is fixed in the apparatus and remains on the surface.

3. Model 104-115 Moisture Probe. The radiation source and detector tube are fixed in a single small case. This unit rests on the surface of the material and employs a back-scatter principle, counting the neturons returning to the detector on the surface. The source emits neutrons downward to be reflected back to the detector tube and registered on the scaler. It does not provide discrete measurements for each of the varying depths required in density measurement tests.
4. Model S-1 Reference Standard (Moisture). The pulses in field testing are counted and compared to reference counts taken on the S-1 Standard Reference to determine a ratio. The ratio is used to determine moisture content.
5. Model S-3 Reference Standard (Moisture). This is a smaller reference Standard and used only for the quick check of the moisture testing device prior to actual testing at each location.
6. Concrete Block (6" x 10" x 16") Reference Standard (Density). This block was made for a reference for the density ratio. It contains a 5/8"-inside-diameter aluminum tube for probe access. The probe is inserted to the designated depth and the count obtained is used as the denominator to produce the density ratio. (Not illustrated).
7. Probe Cable. The scaler and either probe are connected with a cable to relay the pulses. One cable will operate on both units.
8. Power Pack - Battery charger for 18-volt scaler battery.

PART III - THEORY OF OPERATION

The theory behind the operational method for measuring soil density by the use of radioactive materials is significantly different from the theory used in measuring soil moisture by the same radioactive materials. Density measurement depends upon a quantitative check on the flow of gamma-photons through the soil while moisture measurement depends upon a qualitative analysis of the neutron flow. Both measurements are relative. Yet the close inter-relationships in actual operational practices are so great that theoretical differences are apt to drop out of the picture. Economy and efficiency are greatly increased when both tests are made at each location and immediately subsequent one to the other but in a uniformly practiced order of precedence.

A. Density Measurement Theory

It has been known and reported in physics literature for many years that the energy loss by absorption of gamma-rays as they penetrate a material could be used to determine comparative degrees in the density of materials. The gamma-rays radiating from a source through matter will be slowed, absorbed, reflected, and scattered when they come in contact with the atoms of the medium in which they travel. The stronger this dispersion, the greater the number of electrons contained in this medium. The number of electrons being proportioned to the density of the medium, a heavy medium disperses more than a light one. Thus, the higher the density of a material, the lower the gamma-ray count returning to the source. This principle may be utilized to assign relative values to the density of materials. The distance traveled is also a function of the count. Therefore, the distance is predetermined or held constant.

NUCLEAR MOISTURE-DENSITY APPARATUS

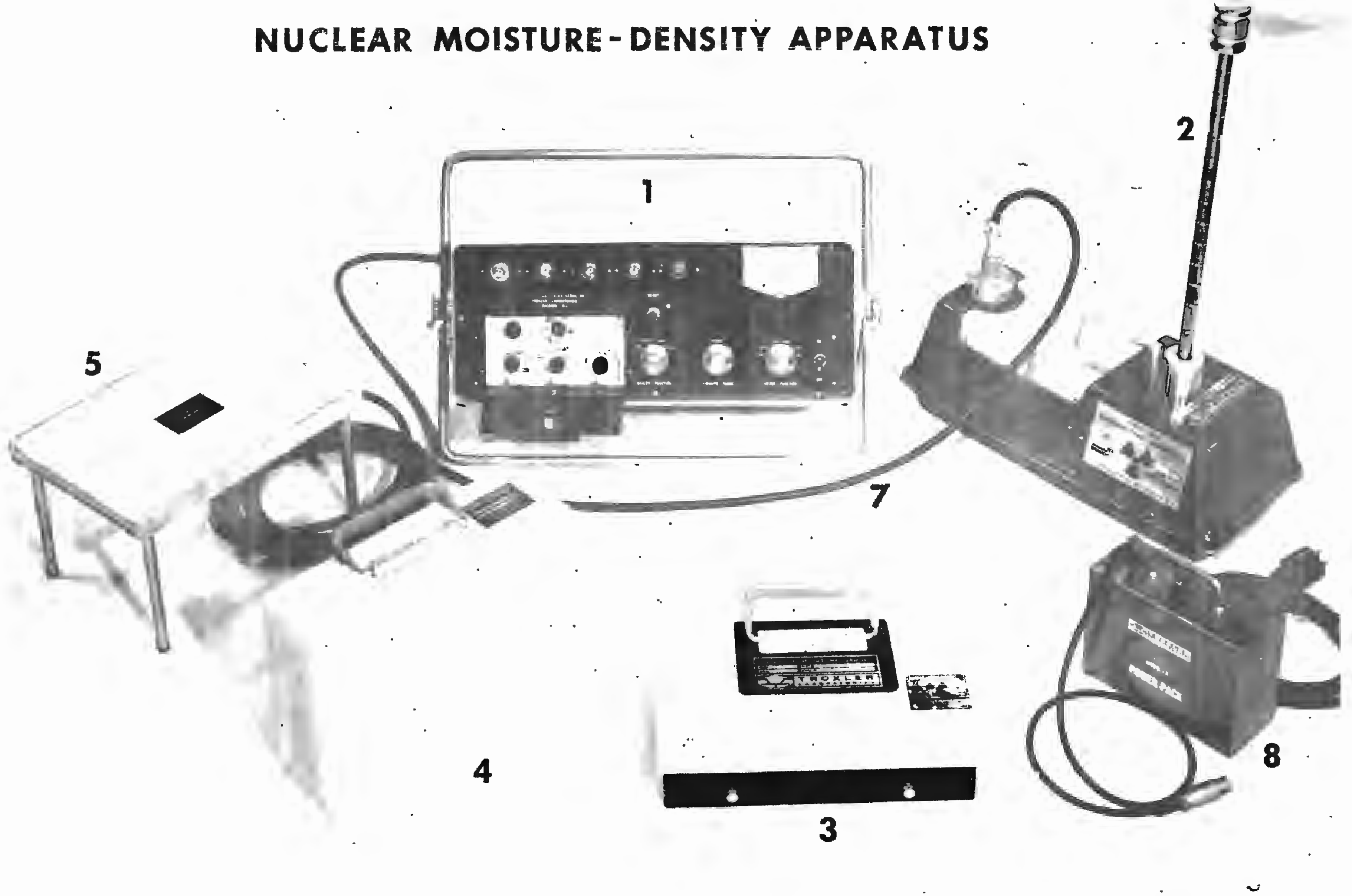

PLATE I

It seems readily apparent that when the gamma-ray source and the depth of the medium are also held constant, the method can be used to determine comparative or standard densities of materials.

These are the fundamental principles of the Troxler nuclear apparatus. The density probe-rod, i.e., source, (PLATE I), is marked off in one-inch increments for depth control. It contains a 3 millicurie source of radium-beryllium emitting gamma-rays (gamma-photons) and neutrons. The concomitant detector tube is fixed in position about 11 inches from the density probe rod.

B. Moisture Measurement Theory

The principle involved in making moisture determination is that the fast neutrons emitted by the Ra:Be source as they come in contact with hydrogen atoms lose considerable energy and are reduced to thermal neutron speeds (slow). This loss of energy is quite marked when the "fast" neutron collides with a hydrogen atom because they are very alike in mass and the neutron rebounds weakly from the collision, i.e., slowly, as a "slow" neutron having imparted roughly one-half of its energy or speed to the hydrogen atom. Thus, the number and presence of thermal or slow neutrons indicate the relative volume of hydrogen present. A high thermal neutron count shows a high rate of reduction of "fast" to "slow" and, consequently, indicates a higher hydrogen concentration. This moisture measurement does not differentiate between liquid, vapor and solid. Neither does it differentiate between the chemically bound hydrogen, hygroscopic moisture, or free water. However, the chemically bound hydrogen is very small and may be neglected for most purposes. (It was neglected in all cases for this project.) It is the free moisture which is the major focus of interest during the construction and compaction of earth fills or embankments.

PART IV - OPERATIONAL METHODS

A. General Operational Practices

The elements of the nuclear apparatus (See PLATE I) are so positioned on the ground surface at the site that they may function properly; primarily, that is, without radioactive interference with one another. The Scaler circuits require a warm-up period until the count rate becomes stable. Approximately five minutes must be allowed for this initial warmup of the Scaler and approximately one-half minute when changing probes.

See APPENDIX 3, Recommended Operating Procedure.

Caution: The moisture probe and density probe must always be kept at least 15 feet apart while either is in operation, or the unused unit will increase the count rate since both units are radioactive and throw off the same particles. Also, it seems advisable for purposes of accuracy and comparability to establish a consistently practiced order of precedence in the making of the two tests.

B. The Voltage Plateau.

After a warmup period for the Scaler, a selection must be made of that section of the voltage/count-rate curve providing the greatest stability and/or reproducibility in the data produced. This is done by a careful correlation of the two variables which may operate upon the count rate per minute. These two variables are:

1. The voltage range available; and,
2. The gain setting applied.

The Scaler uses two voltage ranges in the process of measuring the quantitative modifications to the gamma-photons emanating and the qualitative modifications to the neutrons emanating from the radioactive materials. For measuring the scatter, absorption, or dispersion of gamma-rays (gamma-photons) to determine relative density of the soil, a voltage range of 100 volts is used, increasing at 25-volt increments from 825-volts to 925-volts, and to measure the conversion of "fast" neutrons to thermal "slow" neutrons in moisture tests requires a range also of 100 volts; however, it lies between 1,250 and 1,350 volts.

The Scaler has an element designated as the Gain Scale which has a selection of five settings. This element provides a selection of five settings in the Gain Scale by which sensitivity in regulating the voltage being applied may be either increased or decreased to obtain the optimum stability and discreteness in the count rate readings.

The optimum operational voltage/gain setting is selected by varying the voltage level at 25 volt increments from the minimum to the maximum of the pertinent range for the test to be made, i.e., density or moisture, through each of the five Gain Scale Settings. At each combination the count rate is recorded. A family of five curves is prepared, one curve at each of the five settings on the Gain Scale. In this project, the curves were prepared by plotting voltage level on the X axis and the count rate per minute on the Y axis. The curve showing the greatest number of plateau values, that is, the longest consistent series of values with minimal change, is then selected. It will be, graphically, the flattest

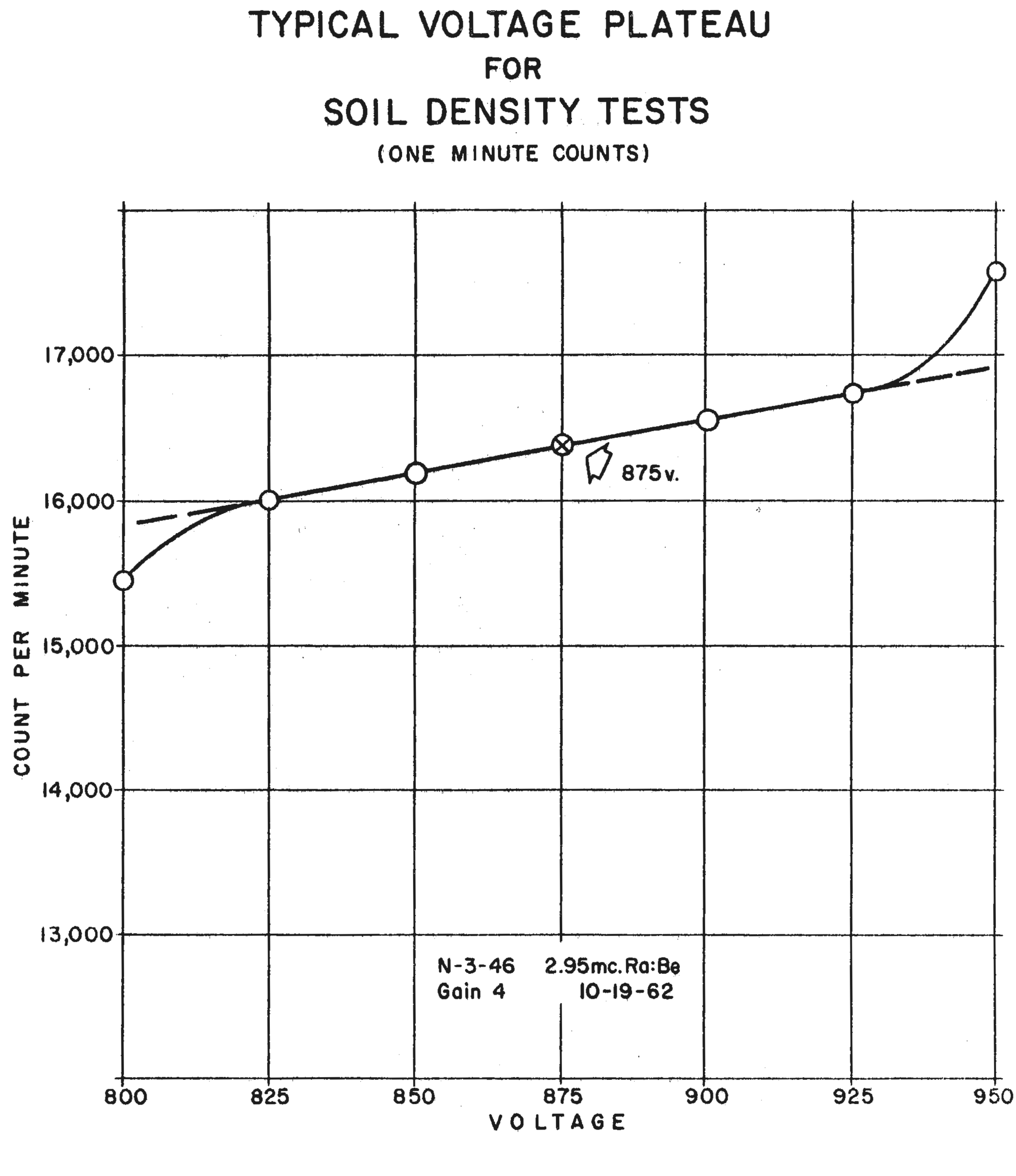
TYPICAL VOLTAGE PLATEAU
FOR
SOIL DENSITY TESTS
(ONE MINUTE COUNTS)
COUNT PER MINUTE
17,000
16,000
15,000
14,000
13,000
875v.
N-3-46 2.95mc. Ra:Be
Gain 4 10-19-62
800
825
850
875
900
925
950
VOLTAGE

PLATE II

TYPICAL VOLTAGE PLATEAU
FOR
SOIL MOISTURE TESTS
(ONE MINUTE COUNTS)

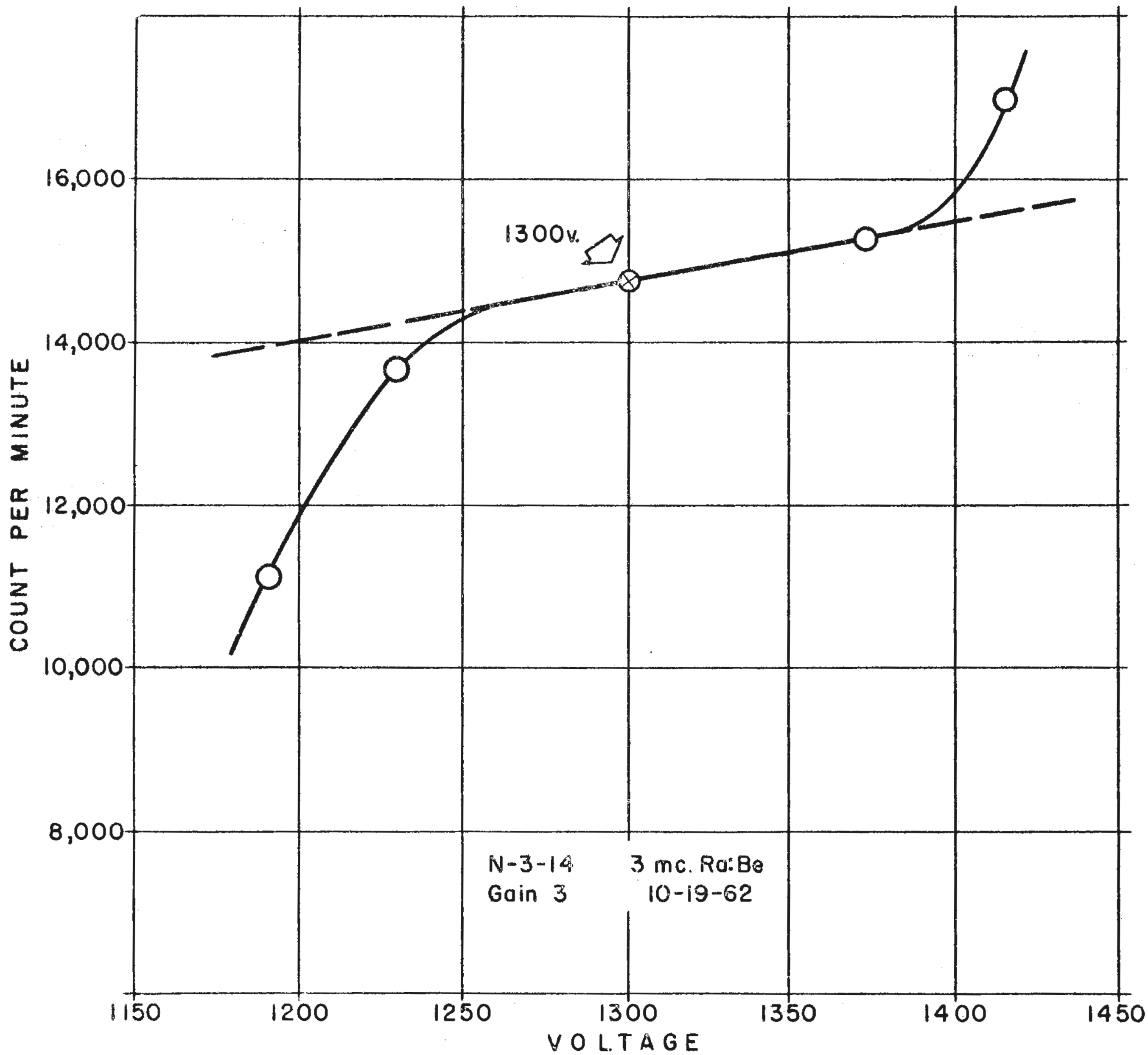

PLATE III

curve with the greatest number of values between the usable voltage levels at a certain Gain Scale setting (see Plates II & III). The voltage found at the midpoint of the straight line best fitted to the "plateau" segment of the curve will furnish the most stable and consistently uniform count rate readings. It will be the optimum voltage and Gain Scale setting to be used in the pertinent tests to follow for density and for moisture. Plate II illustrates a voltage setting of 875 and a Gain Scale setting of 4 as being the optimum coordinates for soil density tests during October 1962. Plate III indicates that the voltage and Gain Scale coordinates for moisture testing would be 1300 volts at a Gain Scale setting of 3.

The flat slope tends to limit the error in voltage setting by minimizing the change in count rate caused by small voltage fluctuations. Plate II shows, for example, that a fluctuation of 25V changes the count rate approximately 180 counts per minute in this flattest section of the soil density curve. These values are used for each test and should be checked monthly.

The Scaler uses two voltage ranges in evaluating emanations from the nuclear sources: 825V - 925V, for measuring the gamma rays to determine density; and 1250V - 1350V, for measuring neutrons to determine moisture.

C. The Density Test Procedure

The density probe-detector unit is attached to the Scaler and allowed to warm up approximately five minutes before testing. During this warm-up period, the site is prepared for testing. This preparation consists of little more than smoothing the surface and driving a 3/4" pin to make an access hole for the probe rod.

First, after the warm-up period, Reference Standard (Density) Counts are taken in the concrete block "standard" at 4" depth and at 'S', i.e., surface, position. These results are recorded on data sheets. The 4" cpm is divided by the 'S' cpm for a quick check to detect any irregularity or malfunction in the apparatus. In this study it was found that when operating properly the ratio $\frac{4\text{" cpm}}{\text{'S' cpm}}$ falls between 1.10 and 1.20. (See Appendix I for data sheets.)

The probe is placed in the prepared access hole on the site and field counts are taken in three positions to average out any large voids or stones. This is done by rotating the Density Probe Unit around the access hole, using the probe rod as a pivot. Each of these field counts is recorded on a data sheet. The ratio is determined by dividing the field count by the Reference Standard (Density) 'S' Count.

D. Moisture Test Procedure

The moisture tests are made in the same location as the density tests. A series of three counts is taken in rotation at each location and the three counts are averaged to compensate for any large stones or voids.

After the warm-up but prior to testing at each location a quick check is made of the moisture unit. Three tests each are taken on the S-1 and the S-3 Reference Standards (Moisture) and averaged. The ratio of the S-3 cpm divided by the S-1 cpm falls between a range of 0.554 to 0.566 when the apparatus is functioning properly. This check is made to detect any irregularities or maladjustments which might occur in the unit. The S-1 Reference Count is used as the denominator in deriving the field count ratio.

As with the density tests, the field counts for the moisture tests are recorded on data sheets and the ratio is found by dividing the field count by the S-1 Reference Standard (Moisture) Count.

E. Correlation with Standard Method of Tests

Sand cone tests are taken immediately in the test site to establish the assumed absolute values for the wet density and the moisture of the material. These values derived from the sand cone tests are then used as parameters in the calibration curves.

The density field count ratio is plotted versus the density as determined by sand cone test on semi-logarithmic graph paper. The ratio is plotted on the log scale, and the wet density assumed absolute value is plotted on the standard scale. A smooth curve is drawn when sufficient points have been plotted. The curve will be a straight line on the semi-log paper for a range of 100 pcf to 160 pcf. The curve may be transferred to regular graph paper for ease of reading.

The moisture curve is prepared on regular graph paper. The count ratio is plotted versus moisture content in pcf units, and a smooth curve is drawn when sufficient points are plotted. The wet density or moisture can then be determined from the curves when only the field count ratio is known. The dry density can be determined by subtracting the moisture from the wet density since they have the same units.

The percent moisture content can be calculated from the formula:

$$\left(\frac{\text{Wet Density}}{\text{Dry Density}} - 1.0 \right) \times 100.$$

This is pointed out here because in most cases the density is reported as dry density and the moisture content as a percentage of the oven-dry density.

For the original trial calibration in the laboratory, three boxes were constructed, 12" deep, and filled with soil. The soil was weighed and compacted into the boxes for a given density to be used as a parameter for the calibration process. The soils used in the boxes were a heavy red clay, a silty clay, and a stone base material (Class SB-4). Five tests were made by sand cone and twelve by nuclear methods per box of material. These tests were averaged and plotted on semi-log paper. They produced a straight line.

These calibration charts were then used in the field densities in-place measurement. <u>They did not give comparable results with sand-cone tests made in the field</u>. This was due to the fact that the soil boxes did not have sufficient volume to contain the volume of influence of the nuclear apparatus. It was realized that a high order of reliability would require calibration of the apparatus during actual use in the field. The field method was found to be more valid than the laboratory method.

PART V - ANALYSIS OF DATA

A. Usable Data

The information presented in this report is based upon the soil density and moisture data collected after all necessary modifications and repairs to the apparatus were completed. The data used were compiled from actual field-testing operations and are limited to those data developed during the later stable stage of the work. The shifting conditions caused by equipment modification and/or malfunction and personnel's lack of familiarity yielded highly erratic results. Data from this earlier stage of the project are included <u>but only for purposes of illustration</u>.

It should be kept in mind that these data are referred in every instance to the 95% confidence limit, so that they can be presented with uniformity and clarity -- especially for comparative purposes. The confidence limit is the indication of the level of accuracy to be expected in making future tests.

<u>Example:</u>

"95% Confidence Limit = $\pm$ 2.0 pcf"

This statement indicates that in 95 out of every 100 soil density tests made should not have an error (i.e., deviation) greater than plus or minus two pounds per cubic foot from the findings derived by sand cone tests of the same material.

In this situation, the sand cone field test data on soils densities constitute the fixed values, and the nuclear apparatus field test data are to be correlated with them. The same correlation is made in the case of the soils moisture tests except only that the fixed values are derived from oven-dried soil moisture samples.

The variable values for dry density are calculated by the square root of the sum of the squares of the individual standard error of measurement values for density and moisture, then projected to the 95% level. The comparative data are compiled from (as stated earlier) the last 30% of the tests made after more stable applications had been established for the use of the nuclear apparatus. Summaries of the compiled data are tabulated on the following page and all these tabulated data are shown as the variance of the information produced by the nuclear device when such information is related to the sand cone parameter or benchmark information:

Probe Depth	4"	6"	8"
Calibration Data Results			
Wet Density (pcf)	± 4.7	± 4.8	± 5.7
Moisture (pcf)	± 3.0	± 3.0	± 3.0
Moisture (%)	± 2.2	± 2.2	± 2.2
Computed Dry Density (pcf)	± 5.6	± 5.6	± 6.5
Field Data Results			
Wet Density (pcf)	± 4.7	± 6.8	± 8.7
Moisture (pcf)	± 4.4	± 4.4	± 4.4
Computed Dry Density (pcf)	± 6.4	± 8.1	± 9.8
Combined Calibration and Field Data Results			
Wet Density (pcf)	± 4.5	± 5.5	± 7.1
Moisture (pcf)	± 4.0	± 4.0	± 4.0
Computed Dry Density (pcf)	± 6.0	± 6.8	± 8.2
Stone Base Materials - Field Data Results			
Wet Density (pcf)	± 8.5	± 6.1	±11.1
Moisture (pcf)	± 6.0	± 6.0	± 6.0
Computed Dry Density (pcf)	±10.5	± 8.6	±12.7

The apparent stability in Moisture Values has no significance. It is due simply to the fact that moisture measurement by this device (using the "back-scatter" principle of the Ra:Be Neutrons) is not discrete for the minor differences in depth at which density testing is done.

The Tests yielding the preceding summary data were made on stone base material that was 7" to 8" in depth and constructed over select sand material.

The 2" depth results are not shown in the tabulations because testing at this depth was found to be useless.

The 4" depth results are higher in comparison to 6" depth due to lower moisture in the upper 2" of the material.

The 6" depth results are more reliable, in that they average out the moisture and depth of the layer of material.

The 8" depth results indicate that the lower stratum (a less dense select sand) was penetrated by the nuclear volume of influence, which would give erroneous results when compared to the sand-cone results.

It is pointed out that the number of stone base tests was limited by the completion date of the project. The limited number of tests may tend to influence the results to a point that they appear unrealistic. At least 50 tests should be made for analytic purposes and to establish validity for use.

The random scatter of the results (see Fig. A5, A6, and A7) indicates that the curve would not smooth out if a larger number of samples were taken. The results were determined by least-square regression analysis and standard error of estimates.

B. Unusable Data

The discarded data derived in the earlier exploratory phases of the project were very erratic. For example, the following results of the correlation for the 95% confidence limit indicates the widely fluctuating range of these results:

95% Confidence Limit

Results Prior to Parts Replacement

Probe Depth	4"	6"	8"
Wet Density (pcf)	± 9.6	± 7.0	± 7.5

This is probably due to the low voltage limit in the high voltage module. This situation would reduce the count rate per unit of depth. The 4" depth would show a greater loss percentagewise, which would result in a higher error in the density indicated; i.e., an erroneously high density. Consequently, these moisture and dry density test data have been omitted because the reliability of the essential wet density test data was so widely erratic. The validity of the data prior to the repairs was far too questionable for its inclusion as the summary above shows. In every case the repairs caused a change in count rates.

PART VI - FINDINGS

After the "shakedown" period had run its course many comparative tests were made and analyzed. From this accumulated reservoir of experience data certain findings became clear.

A. Major Studies

The closing paragraphs of the Introduction to this report stated that the primary objective of this project was a comparative investigation of the reproducibility and reliability of the data furnished by:

1. The nuclear low-level radiation testing method; and,
2. The currently standard sand cone testing method.

Of only slightly less importance was an interest in developing optimum techniques of use and optimum levels of performance of the nuclear device for in-place measurement of soil density and/or soil moisture.

As to the findings on these two major objectives, it was found in the comparative study that:

1. The measurement-in-place of soil density and soil moisture by means of a nuclear low-level radiation testing device provides:

    a. For subgrade soil embankment materials, data on the order of that furnished by the standard sand cone method, of reasonable reliability and reproducibility.

    b. For base materials, data of questionable reliability and erratic reproducibility.

2. The desirable procedure for operation is set out in Appendix No. 3.

B. Minor Studies

The areas of secondary or minor interest for study and observation in the project as set out in the Introduction were:

1. Optimum Probe Depth
2. Average Time Requirement per Test
3. Temperature and Weather Factors
4. Refactory or Unmanageable Materials
5. Undesirable Aspects

The Optimum Probe Depth seems to be four inches. This finding is supported by the lower numerical range of the confidence level results presented in Part V, Analysis of Data, table on page 18 .

The four inch depth compares well with the average depth of four to five inches used for sand cone testing. It seems probable that a finding of greater comparative reliability would be shown if a condition of controlled depth, for comparative tests could be established and equipment were available.

Testing at the two inch probe depth was deleted from the study. Crusting of the materials in the top two inch stratum prohibits the production of any usable test data for this depth by either method of testing.

The Average Time Requirement per Test with the nuclear apparatus is 15.4 minutes. This average is based upon testing times ranging from 10 minutes to 35 minutes. Tests requiring more than 20 minutes will be rather unusual. This average includes the time expended for the triple position readings taken at each test location to offset the effects of large stones and/or voids. Sand cone tests, on the other hand, ranged between 50 and 127 minutes per test and averaged 89.2 minutes per test.

The establishment of an Average-Time-Requirement-Per-Test for the sand cone method was not an objective of this project. The difficulties in separating time between the sand cone test and the nuclear apparatus test when performed at the same site were too great to use for the Average-Time-Requirement-Per-Test comparison. These difficulties are caused by the numerous interrelationships at test locations when both tests are performed. The sand cone test, immediately following the nuclear apparatus test, with the focus of interest upon the comparative relationship of the moisture and density data produced, loses the routine efficiency of an ordinary sand cone test. In view of this the time study on sand cone testing was conducted by a survey of Resident Engineers in the process of making routine sand cone tests on construction projects. (See the Field Density Time Study Specimen form in Appendix 1.)

Temperature and Weather Factors operate upon the data produced by the nuclear testing apparatus; however, the influence is small and lacks any real significance. Their influence is reflected in the count rates for moisture and density -- the higher the temperature, the higher the count rate. The increase in count rate is small and is compensated by taking count rates on the reference standard. The consequent ratio would negate the effect of temperature. Weather, other than temperature, has no pertinence since testing is only relevant when done during construction weather.

No Refractory or Unmanageable Materials were discovered and no detrimental effects due to testing with the nuclear apparatus were observed. However, an unusual condition was observed when different materials were placed in layers. The depth of the layer has an effect on the nuclear test. This is because the nuclear volume of influence penetrates both materials and the readings are a function of both densities. This effect is probably considerably greater where stone base material is placed over selected material.

C. Performance of Apparatus

The overall performance of the apparatus has been plagued with malfunctions of the equipment components.

1. The density probe case was damaged during shipment and was returned for replacement.

2. The original apparatus was furnished with a 5 mc. Ra:Be

nuclear source. This was later replaced with 3 mc. source. The more intense source furnished a high count rate and would over-run the count rate scale. It was thought that the 5 mc. source would be more ideal for backscatter testing. It was also considered that the direct measurement would be more accurate than backscatter; therefore, the 3 mc. source would be used and the backscatter method omitted.

3. It was necessary to replace this density probe with another unit. The lead shielding was improperly positioned. The unit was replaced with the latest model that had a self-reference position on the prove.

4. It was also necessary to replace a high-voltage module in the scaler to raise the voltage to proper operating range for the density unit.

5. The original one-minute mechanical timer in the scaler was erratic, and it required replacement. It was replaced with a later-developed electronic timer.

6. Two buffer condensers vibrated loose during the regular field testing and were repaired by re-soldering and securing. This did not require assistance from the manufacturer.

7. In the operation of the equipment during cold weather, the battery voltage did not function properly. It was decided that a static charge would build up across the voltage meter, and erroneous voltage readings would occur. This made the moisture tests invalid and accounted for the replacement of the moisture pre-amplifier tube.

8. Finally, the detector tube for the density unit had to be

replaced.

In all cases, it was necessary to re-calibrate the apparatus after the repairs were made. In some cases, more than one repair or replacement was made at the same time. A total of six series of tests, one calibration, and five re-calibrations, have been made. The compiling of reliable data began about March 1963 and was terminated September 1, 1963. The final calibration has been the most reliable, as shown in PART V, ANALYSIS OF DATA.

D. Safety Aspect

The safety of nuclear density testing devices has been previously established; however, the personnel were monitored by film badges. The film badges did not show any measurable radiation exposure to operators of the apparatus.

PART VII - CONCLUSIONS AND RECOMMENDATIONS

A. The nuclear tests are within a reasonable range as compared to sand-cone testing. The sand cone test is the standard method used by the Arkansas State Highway Department; however, the reliability of this method depends upon several factors, both human and mechanical. Consequently, the use of test findings by the sand cone method as parameters of absolute value is only assumptive for the purposes of this research project.

B. The results indicate that the nuclear method is more adaptable to soil density determination than to stone base material determination.

C. <u>The Nuclear method is faster, much faster!</u> It requires about one-sixth of the time per test as that required by conventional methods.

D. The radiation resulting from useage of the machine is negligible. In this project the film badge reports have been negative.

E. The depth of material has an effect on the density readings, especially where the volume of influence penetrates different materials. This would require a special calibration for individual cases with the probe depth equal to approximately 2" less than the material depth.

F. The nuclear equipment is reliable enough for embankment density and moisture determinations, but it must be realized that the equipment has not proven to be completely reliable and dependable with respect to mechanical and electrical functions. It is recommended that it be used by qualified personnel on preliminary embankment construction; the final results to be taken with standard methods of tests.

In the future, all testing will probably be done by some sort of nuclear radiation apparatus. At the present time, the nuclear equipment is new and not yet "bug-free" but with time and experience it will undoubtedly offer reasonably reliable relative data at tremendous savings in lost time and, consequently, money. It is the value of time saved which will stimulate the greatest interest in and use of the apparatus - at least in the near future. However, in addition to the time saving another great advantage of the nuclear process is its non-destructive testing technique by which the soil itself is almost undisturbed and free from unnatural influences.

On the theoretical level there is a distinct analogy, an analogy of measurement techniques between:

a. The two techniques (1) sand cone testing and (2) nuclear radiation testing; for guaging the density and moisture content of soils; and,

b. The use of (1) exploratory surgery as contrasted to (2) X-ray for locating and diagnosing internal situations of mammals.

But there remains much to be done in perfecting the application of the nuclear technique before the theoretical promise becomes a practical tool.

APPENDIX 1

SPECIMEN FORMS

ARKANSAS STATE HIGHWAY DEPARTMENT
DIVISION OF MATERIALS AND TESTS
LITTLE ROCK, ARKANSAS

NUCLEAR MACHINE FIELD DENSITY CALIBRATION

SPECIMEN

Job No. 6663 Date 7/22/63

Station 855+45 Rt.Ln. 8' Lt. Test No. 65 A

Sample Location & Elev. Finish Subgrade Tested by Smith

Type Material Sandy Silt Weather Clear 95°

FIELD DENSITY COUNT

Hole No. A

Count Cycle (Minutes) (1) 2 3 4 5
(Circle One)

Time Study
Finish 11:30
Start 10:20
Net 70 (Min) (2) 35 Min Tests

Standard Daily Count 13, 910

Standard Daily Count 25,550

Density Gauge (Scint)

H.V. 875 Gain 4

Probe Depth 4"	6"	8"
24,050	13,700	7380
24,100	13,900	7690
24,000	13,800	7690
3) 72,150	41,400	22,760 Total
Avg. 24,050	13,800	7580

Moisture Gauge (G.M.)

H.V. 1300 Gain 3

16,940
16,940
17,110
17,050
3) 68,040 Total
17,010 Avg. Field Count

Count Ratio = Field Count / Std. Count

1.73 0.99 0.55

% Relative = Field Count / Std. Count X 100 = 67

Count Ratio = 0.67

126.1 128.1 128.8 Lb/Cu.Ft. Wet Density (From Graph)

14.9 Lb/ Cu.Ft. Moisture (From Graph)

111.2 113.2 113.9 Lb/ Cu.Ft. Dry Density

Lab. Density	Field Density	Rel. Compaction
117.5 Lb/Cu.Ft.	113.7 Lb/Cu.Ft.	96.8 %

Wet Density (Sandcone) 128.8 lb/C.F.

Moisture (Sandcone) 15.2 lb/C.F.

10-18-62

ARKANSAS STATE HIGHWAY DEPARTMENT
DIVISION OF MATERIALS AND TESTS
LITTLE ROCK, ARKANSAS

SPECIMEN

STANDARD COUNT DETERMINATION

WORK SHEET

JOB NO. 6663 DATE 7/22/63

TYPE MATERIAL Sandy Silt STA. 855+45 Rt.Ln. 8' Lt.

TEST NO. 65 A TESTED BY Smith

PREVIOUS STANDARD DAILY COUNT 13,880

DAILY STANDARD COUNT

DATE 7/22/63

PREVIOUS STANDARD DAILY COUNT 25,670

"S" (AM) DENSITY	"4" (PM) DENSITY	(AM) S-1 MOISTURE	(PM) S-3 MOISTURE
13,940	15,570	25,730	14,280
13,730	15,830	25,400	14,480
14,050	15,240	25,510	14,280
41,720	46,040	76,640	43,040
13,910 Avg.Count	15,540 Avg.Count	25,550 Avg.Count	14,350 Avg.Count

4"/S = 1.11

S-3/S-1 = 0.56

6-12-62

ARKANSAS STATE HIGHWAY DEPARTMENT
DIVISION OF MATERIALS AND TESTS
LITTLE ROCK, ARKANSAS

SOIL DENSITY DETERMINATION
WITH BEAM BALANCE

SPECIMEN

Job No. 6663 Date 7/22/63

Station 855+45 Rt.Ln. 8'Lt. Test No. 65 A

Type Material Sandy Silt Tested by Smith

SAND CALIBRATION	HOLE VOLUME DETERMINATION
1. Weight Jar Filled 16.60 Lb.	7. Weight Jar + Sand before 13.05 Lb.
2. Weight Jar Empty 3.61 Lb.	8. Weight Jar + Sand After 6.99 Lb.
3. Weight Sand 12.99 Lb.	9. Weight Sand 6.06 Lb.
4. Volume of Jar 0.139 C.F.	10. Weight Sand in Funnel 3.55 Lb.
5. Calibrated Density(3÷4) 93.5 Lb/CF	11. Weight Sand in Hole(9-10) 2.51 Lb.
6. Weight Sand in Funnel 3.55 Lb.	12. Volume of Hole(11÷5) 0.02684 Cu.Ft.

MOISTURE AND DENSITY DETERMINATION Pan #34 1660

13. Wet Wt. Sample + Pan 4.07 Lb.	16. Dry Wt. Sample + Pan(14) 3.66 Lb.
14. Dry Wt. Sample + Pan 3.66 Lb.	17. Wt. Pan 0.61 Lb.
15. Moisture Loss(13-14) 0.41 Lb.	18. Dry Wt. Sample(16-17) 3.05 Lb.
	19. Water Content(15 ÷ 18)X100 13.4 %

20. Wet Wt. Sample + Pan 4.07 Lb.

21. Wt. Pan 0.61 Lb.

22. Wet Wt. Sample (20-21) 3.46 Lb. (Not to be used for calculating compaction)

23. Wet Density(22÷12) 128.9 Lb/CF 15.2 lbs. of moisture / ft^3

24. Dry Density of Material in Roadway (18÷ 12) 113.8 Lb/Cu.Ft.

25. Compaction (24÷AASHO Density)X100 96.8 %

Rev.6-13-62
JRW-jmh

ARKANSAS STATE HIGHWAY DEPARTMENT
DIVISION OF MATERIALS AND TESTS
LITTLE ROCK, ARKANSAS

FIELD DENSITY TIME STUDY

SPECIMEN

Fill & Weigh 1 gal. sand jug	8	minutes
Compute density of sand in jug	4	minutes
Prepare test site, dig hole and drop sand	20	minutes
Weigh wet samples from hole and weigh used sand jug	16	minutes

Drying Time of Sample (Use only one)

A. By Cook-off method on Hot plate or Oven

time finish	8:00 A.M.	minutes
time start	9:30 A.M.	minutes
time required	1:30	minutes

B. By Speedy Moisture Tester

time finish	10.55 A.M.	minutes
time start	10.30 A.M.	minutes
time required	25	minutes

Time required to calculate moisture and density data 20 minutes

TOTAL TIME ELAPSED

Time and date of test request	4:30 P.M. JAN. 7, 1963
Time and date of available test results	8:15 A.M. JAN 8, 1963
	100.9
time required	2:30

Approximate round-trip mileage from field lab to test hole site 2.5 Miles

Emb. Matl. ______________

Base Matl. ______________

Select Matl. ✓

Other ______________ (specify)
(check one)

Return to J. R. Wofford
Materials & Tests Div.

12-3-62

APPENDIX 2

GRAPHIC AND TABULAR DATA

LIST OF TABLES

LIST OF CHARTS

TABLE 1

4" PROBE DEPTH FIELD CALIBRATION DATA

WET DENSITY (P.C.F.) (SAND CONE)	4" DEPTH COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE WET DENSITY (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
147.8	1.30	147.0	+0.8
147.2	1.32	146.0	+1.2
129.4	1.54	134.8	−5.4
131.0	1.58	132.8	−1.8
131.3	1.57	133.5	−2.2
131.7	1.62	130.8	+0.9
119.2	1.82	122.5	−3.3
116.2	1.86	121.0	−4.8
121.5	1.88	120.0	+1.5
123.5	1.83	122.0	+1.5
123.3	1.82	122.5	+0.8
124.3	1.82	122.5	+1.8
121.5	1.79	123.6	−2.1
126.2	1.77	124.5	+1.7
110.8	2.18	109.0	+1.8
111.8	2.16	109.5	+2.3
119.1	1.94	117.6	+1.5
120.6	1.97	116.5	+4.1
131.9	1.61	131.4	+0.5
129.9	1.63	130.5	−0.6
124.9	1.72	126.1	−1.2
132.7	1.65	129.5	+3.2
128.6	1.69	127.6	+1.0
125.8	1.67	128.5	−2.7
130.0	1.54	134.8	−4.8
134.0	1.55	134.5	−0.5
129.9	1.61	131.4	−1.5
129.2	1.69	127.6	+1.6
130.0	1.66	129.0	+1.0
130.4	1.63	130.5	−0.1

S_x = 2.37 P.C.F.

TABLE 2

6" PROBE DEPTH FIELD CALIBRATION DATA

WET DENSITY (P.C.F.) (SAND CONE)	6" DEPTH COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE WET DENSITY (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
147.8	0.73	147.2	+0.6
147.2	0.73	147.2	0.0
129.4	0.94	131.2	−1.8
131.0	0.97	129.2	+1.8
121.5	1.12	120.0	+1.5
123.5	1.11	120.7	+2.8
131.3	0.92	132.6	−1.3
131.7	0.94	131.2	+0.5
119.2	1.11	120.7	−1.5
116.2	1.11	120.7	−4.5
123.3	1.03	125.5	−2.2
124.3	1.02	126.1	−1.8
121.5	1.08	122.4	−0.9
126.2	1.10	121.2	+5.0
110.8	1.32	109.0	+1.8
111.8	1.32	109.0	+2.8
119.1	1.15	118.5	+0.6
120.6	1.18	116.8	+3.8
131.9	0.95	130.5	+1.4
129.9	0.97	129.2	+0.7
124.9	0.98	128.6	−3.7
132.7	0.98	128.6	+4.1
128.6	0.99	128.0	+0.6
125.8	0.97	129.2	−3.4
130.0	0.90	134.0	−4.0
134.0	0.93	132.0	+2.0
129.9	0.93	132.0	−2.1
129.2	0.97	129.2	0.0
130.0	0.96	130.0	0.0
130.4	0.94	131.2	−0.8

S_x = 2.38 P.C.F.

TABLE 3

8" PROBE DEPTH
FIELD CALIBRATION DATA

WET DENSITY (P.C.F.) (SAND CONE)	8" DEPTH COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE WET DENSITY (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
147.8	0.40	147.5	+0.3
147.2	0.38	152.0	+4.8
129.4	0.55	129.0	+0.4
131.0	0.56	127.6	+3.4
121.5	0.65	119.0	+2.5
123.5	0.65	119.0	+4.5
131.3	0.53	131.0	+0.3
131.7	0.52	132.2	-0.5
119.2	0.61	122.6	-3.4
116.2	0.60	123.6	-7.4
123.3	0.58	125.6	-2.3
124.3	0.56	127.6	-3.3
121.5	0.64	120.0	+1.5
126.2	0.66	128.1	-1.9
110.8	0.75	110.6	+0.2
111.8	0.76	110.0	+1.8
119.1	0.63	120.8	-1.7
120.6	0.68	116.3	+4.3
131.9	0.55	129.0	+2.9
129.9	0.53	131.0	-1.1
124.9	0.58	125.6	-0.7
132.7	0.57	126.6	+6.1
128.6	0.58	125.8	+2.8
125.8	0.56	127.6	-1.8
130.0	0.52	132.2	-2.2
134.0	0.54	130.0	+4.0
129.9	0.53	131.0	-1.1
129.2	0.56	127.6	+1.6
130.0	0.53	131.0	-1.0
130.4	0.52	132.2	-1.8

S_x = 2.86 P.C.F.

TABLE 4

FIELD CALIBRATION DATA DRY DENSITY

DENSITY (P.C.F.) (SAND CONE)	PROBE DEPTH DENSITY 4"	6"	8"
114.2	112.4	113.4	114.4
114.9	113.9	114.7	115.4
116.1	116.4	117.0	116.0
115.3	113.8	115.3	113.3
120.5	117.0	114.5	112.5
116.9	118.2	117.4	115.4
114.8	121.3	122.0	120.0
118.2	119.6	119.6	117.1
119.0	117.0	116.2	114.0
111.6	114.1	116.2	113.0
116.3	116.3	115.3	116.8
118.0	116.4	115.5	113.8
106.2	102.3	102.1	102.1
105.9	104.3	104.7	107.4
99.9	98.7	98.2	99.2
98.4	96.4	96.5	98.3
110.1	109.5	106.2	103.0
106.1	107.0	105.8	103.4
111.9	110.8	114.5	115.8
109.6	109.2	112.3	112.2
111.1	114.1	112.1	114.1
108.9	114.3	113.8	116.8
115.2	113.8	116.2	117.0
114.4	117.7	117.8	115.2
111.0	109.5	108.0	106.5
109.5	107.5	107.5	106.5
115.2	118.6	116.2	113.3
114.7	122.3	118.7	116.3
142.8	141.8	142.9	147.3
143.6	141.9	142.0	142.9
	S_x 2.79 (P.C.F.)	S_x 2.90 (P.C.F.)	S_x 3.54 (P.C.F.)

TABLE 5

MOISTURE CALIBRATION

MOISTURE (P.C.F.) (SAND CONE)	COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE MOISTURE (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
4.5	0.55	5.1	−0.6
4.4	0.54	4.3	+0.1
14.7	0.64	12.5	+2.2
15.8	0.66	14.1	+1.7
12.0	0.64	12.5	−0.5
12.5	0.64	12.5	0.0
16.9	0.68	15.8	+1.1
16.5	0.67	14.9	+1.6
7.3	0.57	6.7	+0.6
8.1	0.59	8.4	−0.3
2.6	0.52	2.6	0.0
3.8	0.52	2.6	+1.2
13.7	0.65	13.3	+0.4
12.4	0.63	11.7	+0.7
15.4	0.69	16.6	−1.2
16.1	0.67	14.9	+1.2
12.4	0.64	12.5	−0.1
11.9	0.62	10.8	+1.1
13.3	0.65	13.3	0.0
14.2	0.66	14.1	+0.1
13.9	0.67	14.9	−1.0
13.6	0.66	14.1	−0.5
13.3	0.64	12.5	+0.8
13.7	0.64	12.5	+1.2
10.4	0.59	8.4	+2.0
11.0	0.57	6.7	+4.3
13.2	0.69	16.6	−3.4
13.5	0.70	17.4	−3.9
13.9	0.66	14.1	−0.2
13.8	0.67	14.9	−1.1
15.5	0.69	16.6	−1.1
15.8	0.68	15.8	0.0

S_x = 1.5 P.C.F. or 2.2%

4" PROBE DEPTH CALIBRATION CURVE
FOR WET DENSITY

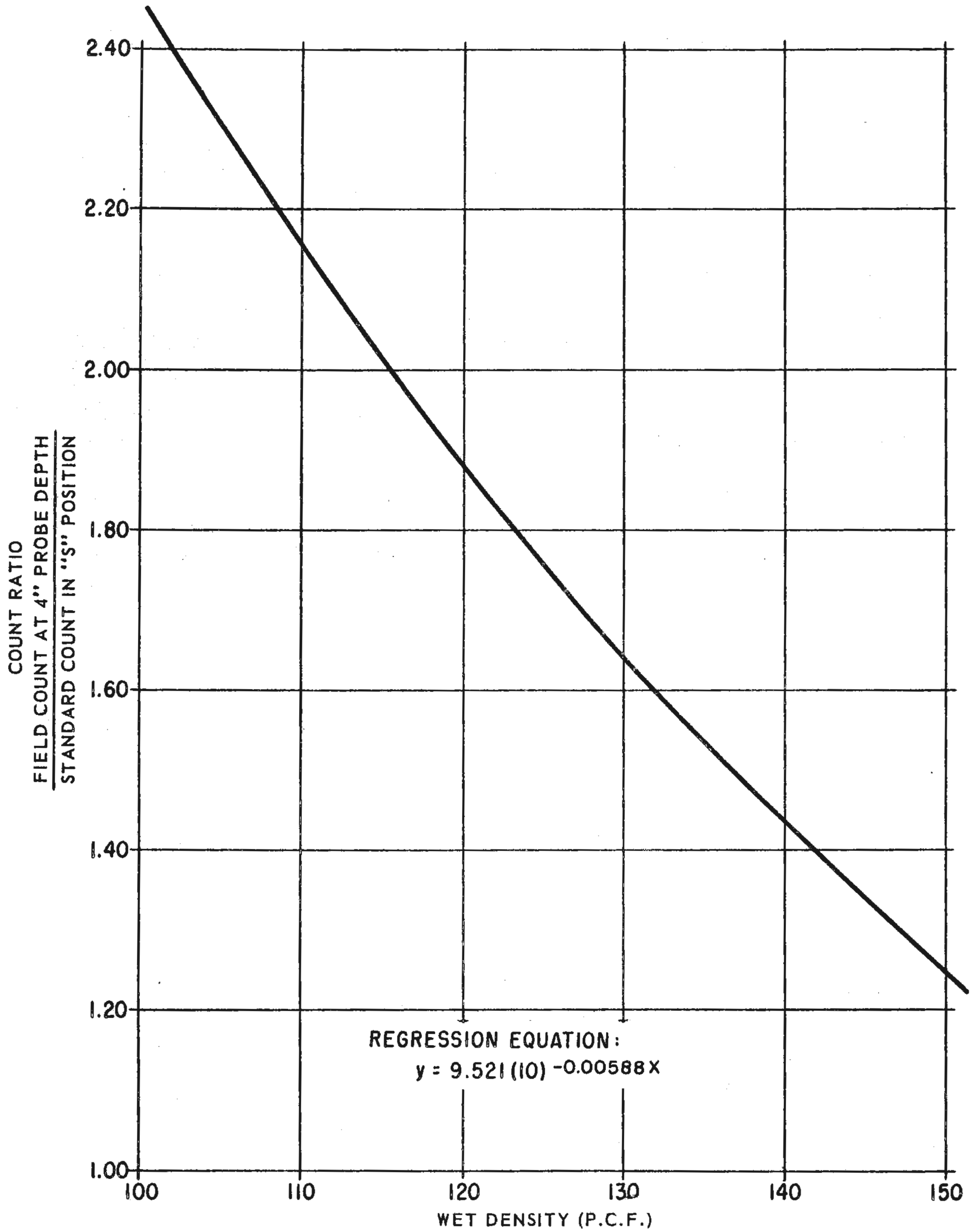

FIG. A-1

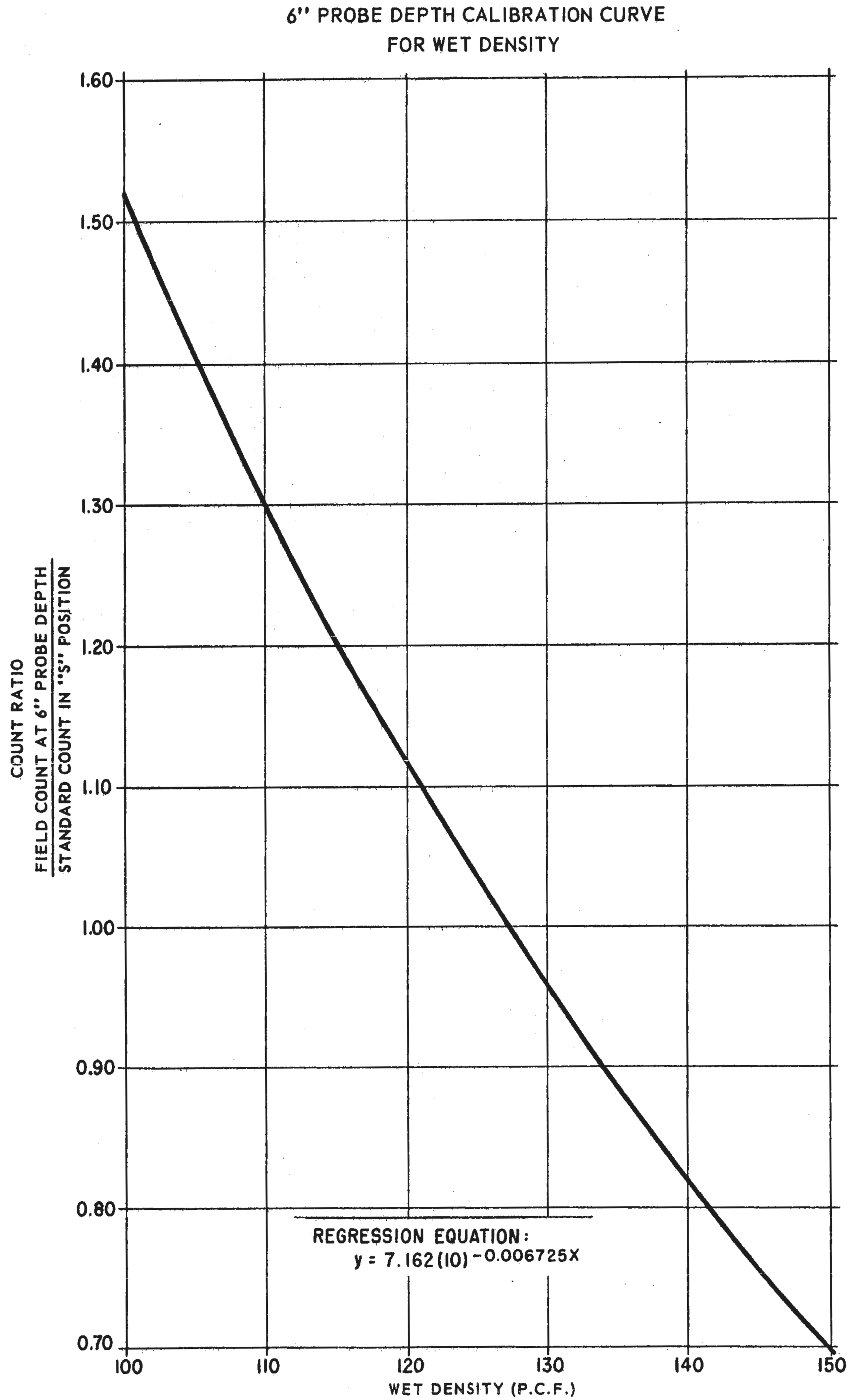
6" PROBE DEPTH CALIBRATION CURVE
FOR WET DENSITY
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
COUNT RATIO
FIELD COUNT AT 6" PROBE DEPTH / STANDARD COUNT IN "S" POSITION
100
110
120
130
140
150
WET DENSITY (P.C.F.)
REGRESSION EQUATION:
y = 7.162 (10) -0.006725X

FIG. A-2

8" PROBE DEPTH CALIBRATION CURVE
FOR WET DENSITY

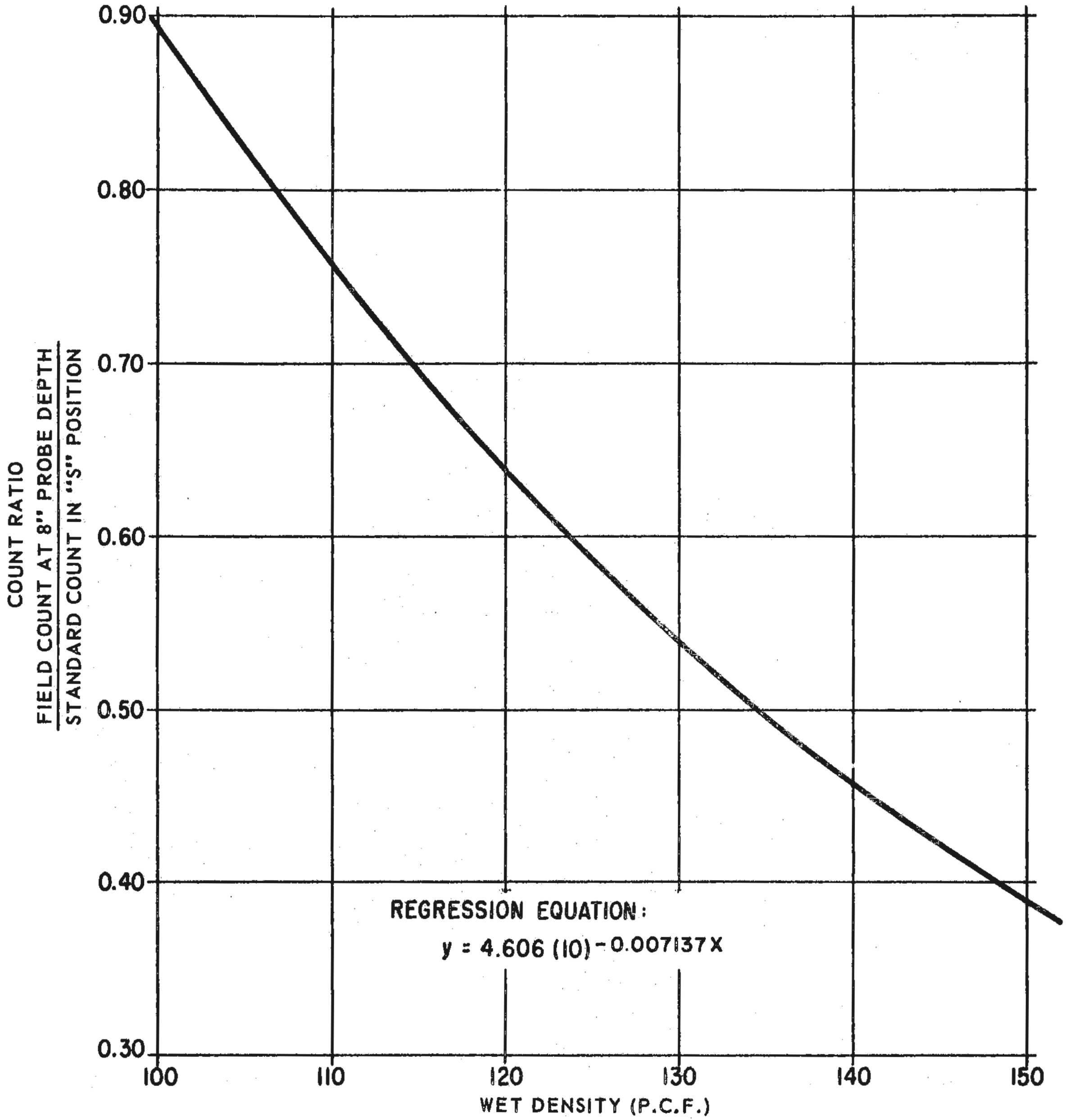

FIG. A-3

MOISTURE CURVE
CALIBRATION POINTS

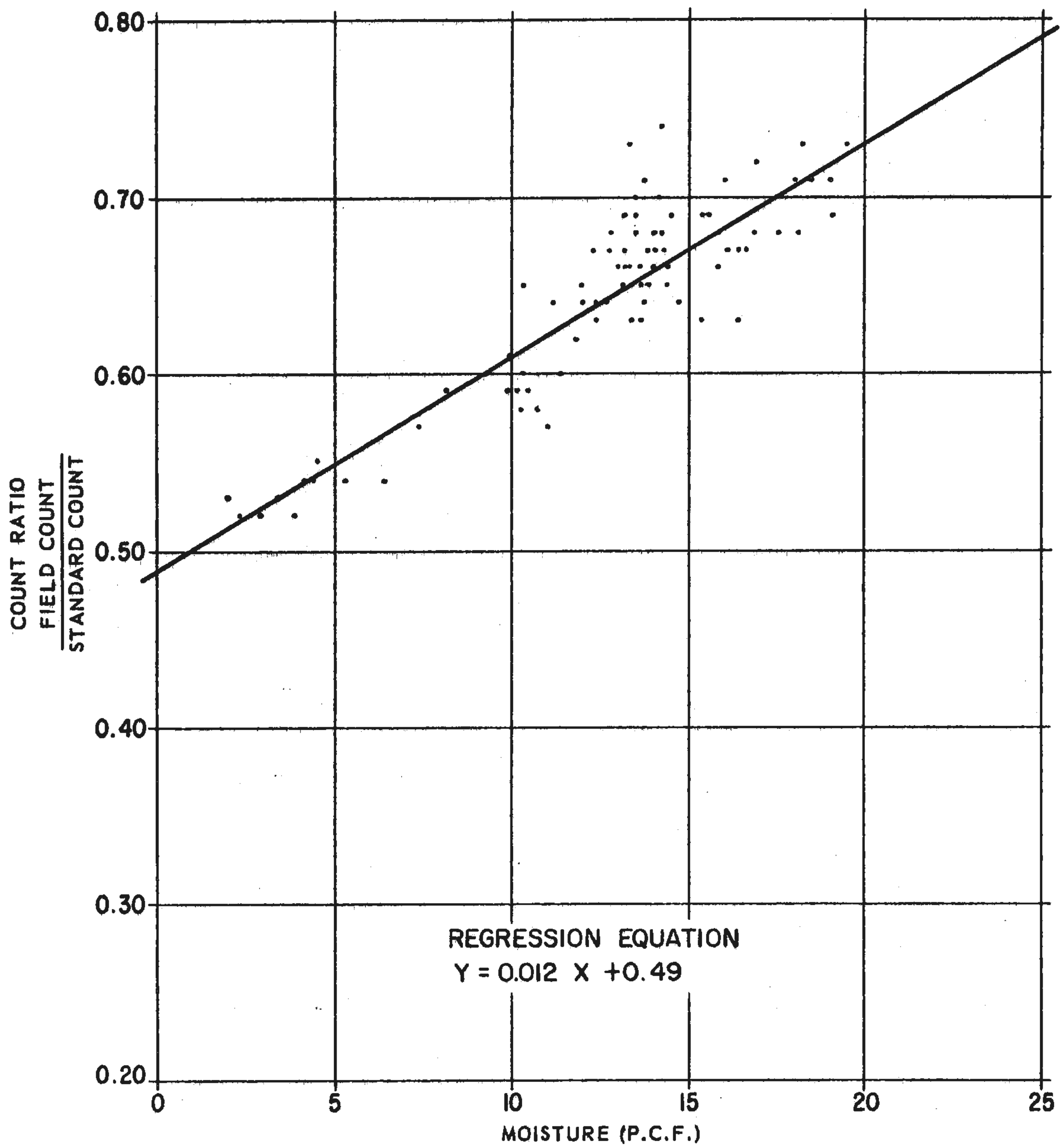

FIG. A-4

TABLE 6

4" PROBE DEPTH FIELD TEST DATA

WET DENSITY (P.C.F.) (SAND CONE)	4" DEPTH COUNT RATIO	CALIBRATED CURVE VALUE	DIFFERENCE (COL. 1 MINUS COL. 3)
121.0	1.82	122.5	-1.5
119.0	1.85	121.5	-2.5
113.0	2.08	112.2	+0.8
112.6	2.12	111.0	+1.6
126.6	1.76	125.0	+1.6
129.0	1.73	126.3	+2.7
120.7	1.88	120.0	+0.7
121.5	1.93	118.0	+3.5
116.5	1.93	118.0	-1.5
118.2	2.01	115.0	+3.2
124.0	1.72	126.6	-2.6
123.5	1.75	125.5	-2.0
125.0	1.77	124.6	+0.4
125.3	1.80	123.2	+2.1
122.9	1.90	119.2	+3.7
123.6	1.91	119.0	+4.6
121.5	1.85	121.5	0.0
122.9	1.83	122.0	+0.9
118.7	1.87	120.6	-1.9
114.8	1.93	118.0	-3.2
112.1	2.09	112.0	+0.1
112.2	2.10	111.5	+0.7
109.9	2.17	109.2	+0.7
111.1	2.18	109.0	+2.1
106.5	2.34	103.6	+2.9
108.3	2.19	108.5	-0.2
128.6	1.74	126.0	+2.6
127.5	1.75	125.5	+2.0
126.5	1.90	119.1	+7.4
128.6	1.76	125.0	+3.6
146.2	1.29	147.5	-1.3
150.0	1.25	150.0	0.0
141.5	1.37	143.2	-1.7
146.6	1.33	145.5	+1.1
147.0	1.34	145.0	+2.0
146.2	1.30	147.0	-0.8
147.8	1.33	145.5	+2.3
124.4	1.74	126.0	-1.6
127.6	1.73	126.3	+1.3
147.0	1.26	149.1	-2.1
140.5	1.42	140.6	-0.1
121.9	1.77	124.5	-2.6
132.7	1.61	131.3	+1.4
127.6	1.60	131.8	-4.2
128.1	1.69	127.8	+0.3
129.8	1.65	129.5	+0.3
130.0	1.65	129.5	+0.5
113.5	1.91	119.0	-5.5
116.6	1.94	117.6	-1.0
124.9	1.72	126.6	-1.7
129.2	1.70	127.4	+1.8
126.7	1.71	127.0	-0.3
128.2	1.69	128.0	+0.2
131.6	1.68	128.2	+3.4
128.6	1.70	127.4	+1.2
130.3	1.68	128.2	+2.1
124.1	1.77	124.5	-0.4
124.8	1.75	125.5	-0.7
124.6	1.74	126.0	-1.4
121.9	1.87	120.6	+1.3
121.5	1.88	120.0	+1.5
127.0	1.74	126.0	+1.0
125.6	1.76	125.0	+0.6
129.0	1.73	126.3	+2.7
127.4	1.69	127.8	-0.4
129.0	1.74	126.0	+3.0

S_x = 2.25 P.C.F.

TABLE 7

6" PROBE DEPTH FIELD TEST DATA

WET DENSITY (P.C.F.) (SAND CONE)	6" DEPTH COUNT RATIO	CALIBRATED CURVE VALUE	DIFFERENCE (COL 1 MINUS COL. 3)
121.0	1.06	123.6	-2.6
119.0	1.10	121.2	-2.2
113.0	1.24	113.0	0.0
112.6	1.29	110.4	+2.2
126.6	1.03	125.6	+1.0
129.0	0.99	127.1	+1.9
120.7	1.16	117.5	+3.2
121.5	1.21	114.6	+6.9
116.5	1.12	120.0	-3.5
118.2	1.18	116.3	+1.9
124.0	1.02	126.2	-2.2
123.5	1.04	125.0	-1.5
125.0	1.02	126.2	-1.2
125.3	1.03	125.6	-0.3
122.9	1.14	118.7	+4.2
123.6	1.20	115.2	+8.4
121.5	1.12	120.0	+1.5
122.9	1.12	120.0	+2.9
118.7	1.10	121.2	-2.5
114.8	1.11	120.6	-5.8
112.1	1.31	109.4	+2.7
112.2	1.31	109.4	+2.8
109.9	1.35	107.6	+2.3
111.1	1.36	107.1	+4.0
106.5	1.42	104.5	+2.0
108.3	1.33	108.5	-0.2
128.6	1.07	123.0	+5.6
127.5	1.08	122.4	+5.1
126.5	1.13	119.4	+7.1
128.6	1.09	121.8	+6.8
146.2	0.70	150.0	-3.8
150.0	0.69	151.0	-1.0
141.5	0.74	146.3	-4.8
146.6	0.71	149.0	-2.4
147.0	0.72	148.0	-1.0
146.2	0.73	147.0	-0.8
147.8	0.72	148.0	-0.2
124.4	1.00	127.5	-3.1
127.6	1.00	127.5	+0.1
147.0	0.67	153.4	-6.4
140.5	0.77	143.7	-3.2
121.9	1.07	123.0	-1.1
132.7	0.99	128.1	+4.6
127.6	0.99	128.1	-0.5
128.1	1.05	124.3	+3.8
129.8	0.96	130.0	-0.2
130.0	0.94	131.3	-1.3
113.5	1.18	116.3	-2.8
116.6	1.22	114.0	+2.6
124.9	1.03	125.6	-0.7
129.2	1.04	125.0	+4.2
126.7	1.01	126.9	-0.2
128.2	1.03	125.6	+2.6
131.6	0.98	128.7	+2.9
128.6	0.99	128.1	+0.5
130.3	1.00	127.5	+2.8
124.1	1.07	123.0	+1.1
124.8	1.08	122.4	+2.4
124.6	1.06	123.6	+1.0
121.9	1.08	122.4	-0.5
121.5	1.07	123.0	-1.5
127.0	1.03	125.6	+1.4
125.6	1.03	125.6	0.0
129.0	0.99	128.1	+0.9
127.4	0.98	128.7	-1.3
129.0	1.00	127.5	+1.5

S_x = 3.16 P.C.F.

TABLE 8

8" PROBE DEPTH FIELD TEST DATA

WET DENSITY (P.C.F.) (SAND CONE)	8" DEPTH COUNT RATIO	CALIBRATED CURVE VALUE	DIFFERENCE (COL. 1 MINUS COL. 3)
121.0	0.61	122.5	−1.5
119.0	0.65	119.0	0.0
113.0	0.72	113.0	0.0
112.6	0.76	109.8	+2.8
126.6	0.57	126.5	+0.1
129.0	0.54	129.8	−0.8
120.7	0.66	118.0	+2.7
121.5	0.67	117.1	+4.4
116.5	0.61	122.5	−6.0
118.2	0.66	118.0	+0.2
124.0	0.58	125.5	−1.5
123.5	0.58	125.5	−2.0
125.0	0.57	126.5	−1.5
125.3	0.58	125.5	−0.2
122.9	0.66	118.0	+4.9
123.6	0.69	115.5	+8.1
121.5	0.66	118.0	+3.5
122.9	0.67	117.1	+5.8
118.7	0.62	121.5	−2.8
114.8	0.62	121.5	−6.7
112.1	0.76	109.9	+2.2
112.2	0.78	108.3	+3.9
109.9	0.77	109.0	+0.9
111.1	0.81	106.0	+5.1
106.5	0.81	106.0	+0.5
108.3	0.78	108.3	0.0
128.6	0.63	120.6	+8.0
127.5	0.65	119.0	+8.5
126.5	0.67	117.1	+9.4
128.6	0.63	120.6	+8.0
146.2	0.39	150.0	−3.8
150.0	0.37	153.5	−3.5
141.5	0.40	148.0	−6.5
146.6	0.42	145.0	+1.6
147.0	0.39	149.8	−2.8
146.2	0.40	148.0	−1.8
147.8	0.39	149.8	−2.0
124.4	0.56	127.5	−3.1
127.6	0.57	126.5	+1.1
147.0	0.36	156.0	−9.0
140.5	0.42	145.0	−4.5
121.9	0.62	121.5	+0.4
132.7	0.60	123.5	+9.2
127.6	0.59	124.5	+3.1
128.1	0.62	121.5	+6.6
129.8	0.54	130.0	−0.2
130.0	0.52	132.0	−2.0
113.5	0.69	115.5	−2.0
116.6	0.74	111.5	+5.1
124.9	0.59	124.5	+0.4
129.2	0.59	124.5	+4.7
126.7	0.57	126.5	+0.2
128.2	0.59	124.5	+3.7
131.6	0.57	126.5	+5.1
128.6	0.56	127.5	+1.1
130.3	0.57	126.5	+3.8
124.1	0.62	121.5	+2.6
124.8	0.62	121.5	+3.3
124.6	0.62	121.5	+3.1
121.9	0.62	121.5	+0.4
121.5	0.61	122.5	−1.0
127.0	0.58	125.5	+1.5
125.6	0.57	126.5	−0.9
129.0	0.55	128.7	+0.3
127.4	0.55	128.7	−1.3
129.0	0.57	126.5	+2.5

S_x = 4.08 P.C.F.

TABLE 9

FIELD MOISTURE DATA

MOISTURE (P.C.F.) (SAND CONE)	COUNT RATIO	NUCLEAR CURVE VALUE	DIFFERENCE (COL. 1 MINUS COL. 3)
12.5	0.64	12.5	0.0
11.8	0.62	10.8	+1.0
13.4	0.69	16.6	−3.2
13.7	0.71	18.2	−4.5
13.5	0.68	15.8	−2.3
14.1	0.68	15.8	−1.7
11.1	0.64	12.5	−1.4
10.4	0.65	13.3	−2.9
9.3	0.60	9.2	+0.1
11.3	0.60	9.2	+2.2
16.3	0.63	11.7	+4.6
15.3	0.63	11.7	+3.6
13.7	0.65	13.3	+0.4
14.4	0.65	13.3	+1.1
10.1	0.59	8.4	+1.7
9.9	0.59	8.4	+1.5
9.9	0.61	10.0	−0.1
10.1	0.60	9.2	+0.9
10.6	0.58	7.6	+3.0
10.3	0.58	7.6	+2.7
18.0	0.71	18.2	−0.2
19.1	0.69	16.6	+2.5
16.0	0.71	18.2	−2.2
16.9	0.72	19.0	−2.1
19.0	0.71	18.2	+0.8
18.5	0.71	18.2	+0.3
14.3	0.67	14.9	−0.6
13.2	0.67	14.9	−1.7
12.8	0.67	14.9	−2.1
13.3	0.66	14.1	−0.8
6.4	0.54	4.3	+2.1
5.2	0.54	4.3	+0.9
4.1	0.54	4.3	−0.2
2.9	0.52	2.6	+0.3
2.3	0.52	2.6	−0.3
3.4	0.53	3.5	−0.1
2.0	0.53	3.5	−1.5
16.4	0.67	14.9	+1.5
17.6	0.68	15.8	+1.8
14.5	0.68	15.8	−1.3
18.1	0.68	15.8	+2.3
13.3	0.64	12.5	+0.8
13.4	0.63	11.7	+1.7
18.3	0.73	19.9	−1.6
19.5	0.73	19.9	−0.4
14.1	0.70	17.4	−3.3
14.5	0.69	16.6	−2.1
13.4	0.73	19.9	−6.5
14.1	0.74	20.7	−6.6
12.8	0.68	15.8	−3.0
13.0	0.66	14.1	−1.1
13.4	0.65	13.3	+0.1
13.1	0.66	14.1	−1.0
13.4	0.65	13.3	+0.1
13.6	0.63	11.7	+1.9
12.3	0.67	14.9	−2.6
11.9	0.65	13.3	−1.4
14.9	0.66	14.1	+0.8
15.3	0.66	14.1	+1.2
15.2	0.67	14.9	+0.3
10.7	0.66	14.1	−3.4
10.7	0.64	12.5	−1.8

S_x = 2.01 P.C.F.

TABLE 10

4" STONE BASE

WET DENSITY (P.C.F.)	4" DEPTH COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE WET DENSITY (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
141.5	1.46	142.0	-0.5
143.1	1.42	145.3	-2.2
138.0	1.41	146.2	-8.2
142.0	1.43	144.5	-2.5
146.3	1.43	144.5	+1.8
138.3	1.49	139.3	-1.0
142.9	1.42	145.3	-2.4
147.8	1.38	149.0	-1.2
138.8*	1.57	133.0	+5.8
143.3*	1.56	133.6	+9.7
140.0*	1.43	144.5	-4.5
139.5*	1.46	142.0	-2.5
139.0	1.55	134.3	+4.7
137.0	1.56	133.6	+3.4
139.0	1.46	142.0	-3.0
138.8	1.48	140.2	-1.4

* 3½ inches of stone base placed over 7½ inches of crushed stone subbase.

6" STONE BASE

WET DENSITY (P.C.F.)	6" DEPTH COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE WET DENSITY (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
141.5	0.84	137.5	+4.0
143.1	0.82	141.5	+1.6
138.0	0.81	143.0	-5.0
142.0	0.83	140.0	+2.0
146.3	0.79	146.6	-0.3
138.3	0.86	135.0	-3.3
142.9	0.80	145.0	-2.1
147.8	0.78	148.1	-0.3
138.8*	0.85	136.6	+2.2
143.3*	0.84	137.5	+5.8
140.0*	0.80	145.0	-5.0
139.5*	0.81	143.0	-3.5
139.0	0.83	140.0	-1.0
137.0	0.84	137.5	-0.5
139.0	0.85	136.6	-2.4
138.8	0.85	136.6	-2.2

*3½ inches of stone base placed over 7½ inches of crushed stone subbase.

8" STONE BASE

WET DENSITY (P.C.F.)	8" DEPTH COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE WET DENSITY (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
141.5	0.48	138.0	+3.5
143.1	0.46	142.2	+0.9
138.0	0.44	146.8	-8.8
142.0	0.47	140.0	+2.0
146.3	0.44	146.8	-0.5
138.3	0.49	136.0	+2.3
142.9	0.46	142.2	+0.7
147.8	0.45	144.5	+3.3
138.8*	0.46	142.2	-3.4
143.3*	0.47	140.0	+3.3
140.0*	0.44	146.8	-6.8
139.5*	0.43	149.0	-9.5
139.0	0.54	126.5	+12.5
137.0	0.52	130.0	+7.0
139.0	0.49	136.0	+3.0
138.8	0.49	136.0	+2.8

*3½ inches of stone base placed over 7½ inches of crushed stone subbase.

TABLE 11

MOISTURE (STONE BASE)

MOISTURE (P.C.F.)	COUNT RATIO FIELD COUNT / REF. COUNT	CALIBRATION REGRESSION CURVE VALUE MOISTURE (P.C.F.)	DIFFERENCE (COL. 1 MINUS COL. 3)
4.9	0.54	11.0	−6.1
5.0	0.53	9.0	−4.0
4.1	0.52	7.0	−2.9
4.0	0.51	5.0	−1.0
3.7	0.50	3.0	+0.7
3.5	0.50	3.0	+0.5
2.9	0.50	3.0	−0.1
2.6	0.50	3.0	−0.4
4.7	0.48	−0.4	+5.1
5.2	0.50	3.0	+2.2
4.8	0.50	3.0	+1.8
4.1	0.49	0.8	+3.3
3.6	0.49	0.8	+2.8
3.9	0.49	0.8	+3.1
2.3	0.52	7.0	−4.7
2.4	0.50	3.0	−0.6

PROBE DEPTH FOR
4" STONE BASE MATERIAL

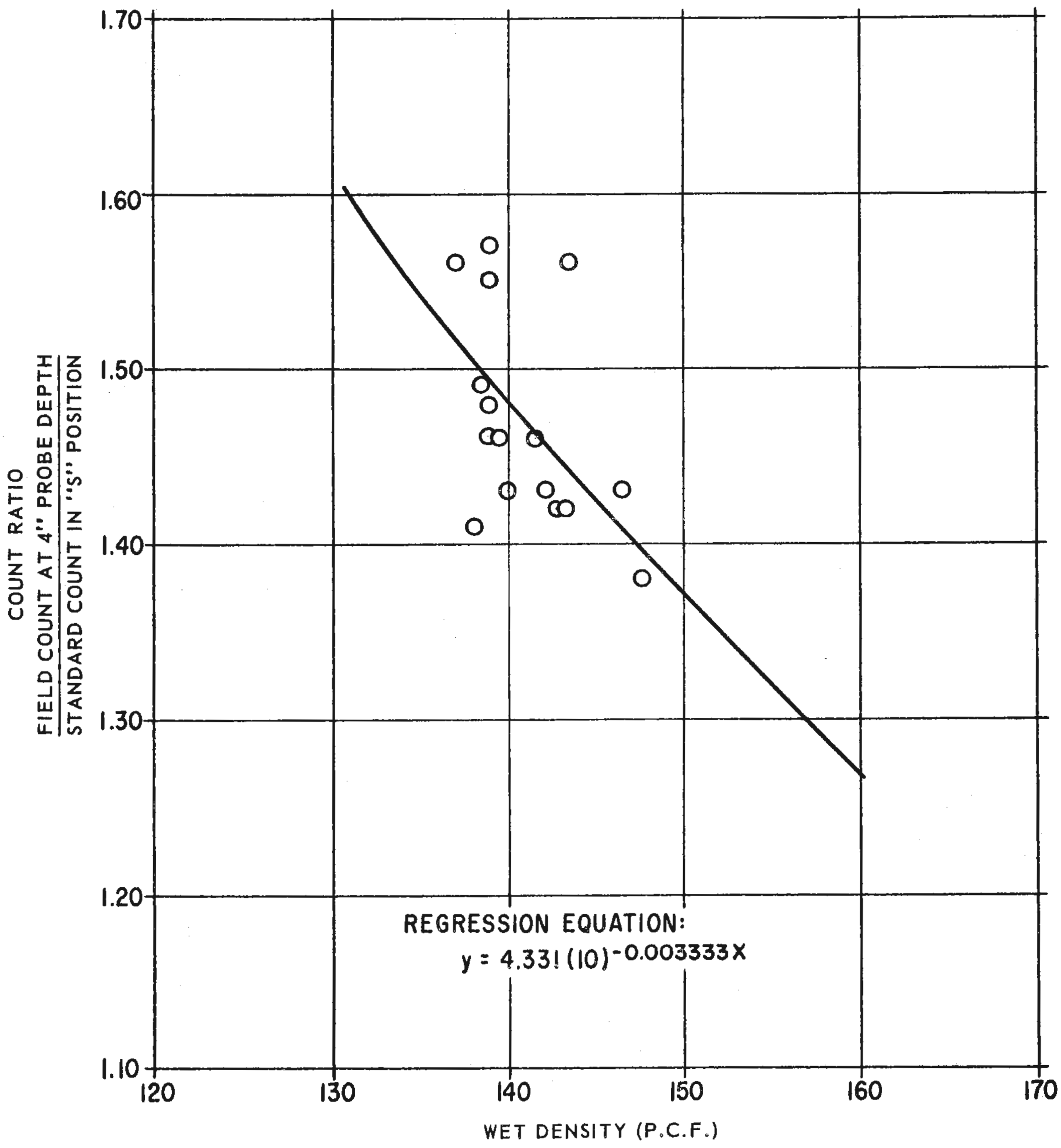

FIG. A-5

PROBE DEPTH FOR
6" STONE BASE MATERIAL

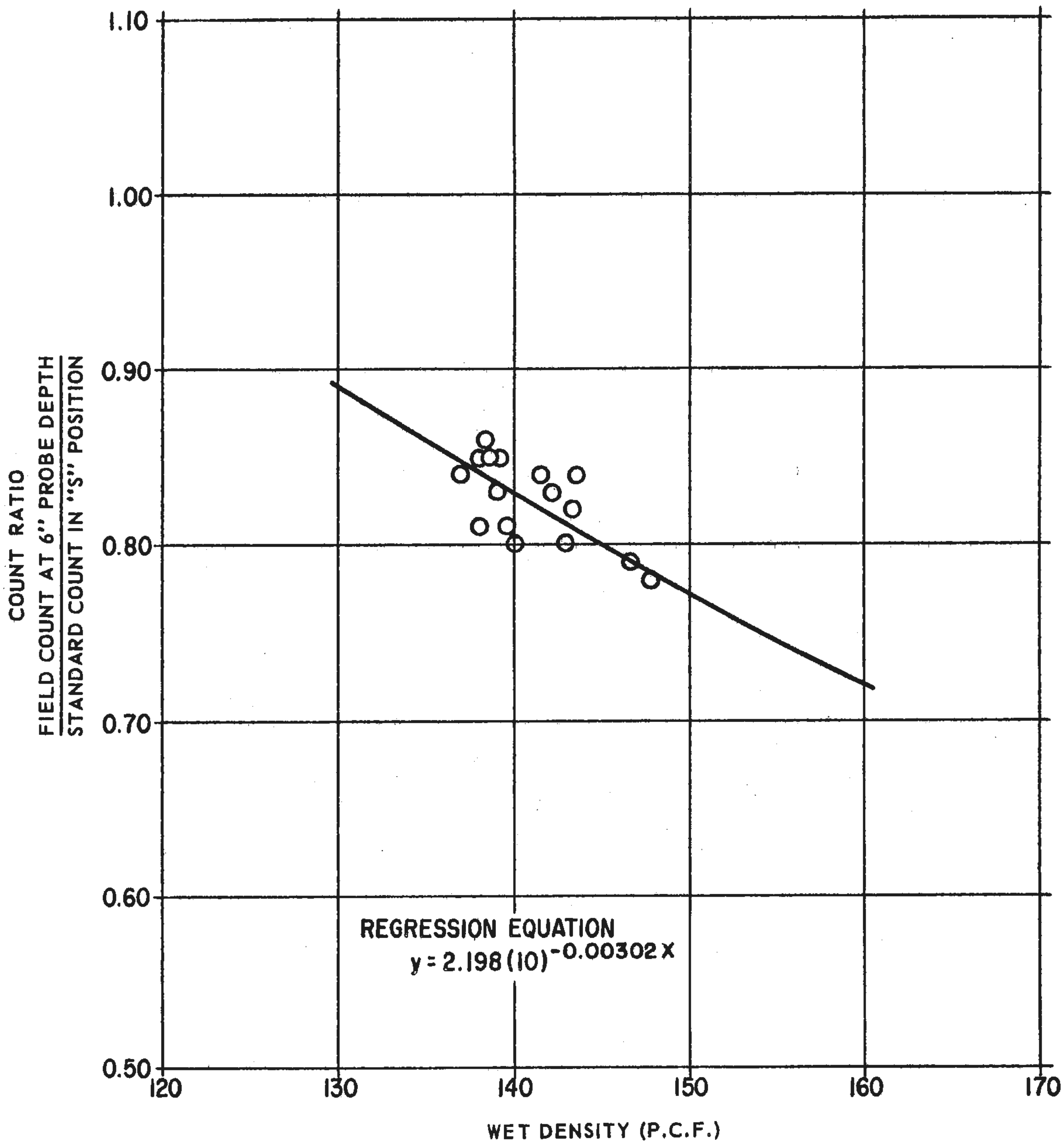

FIG. A-6

PROBE DEPTH FOR
8" STONE BASE MATERIAL

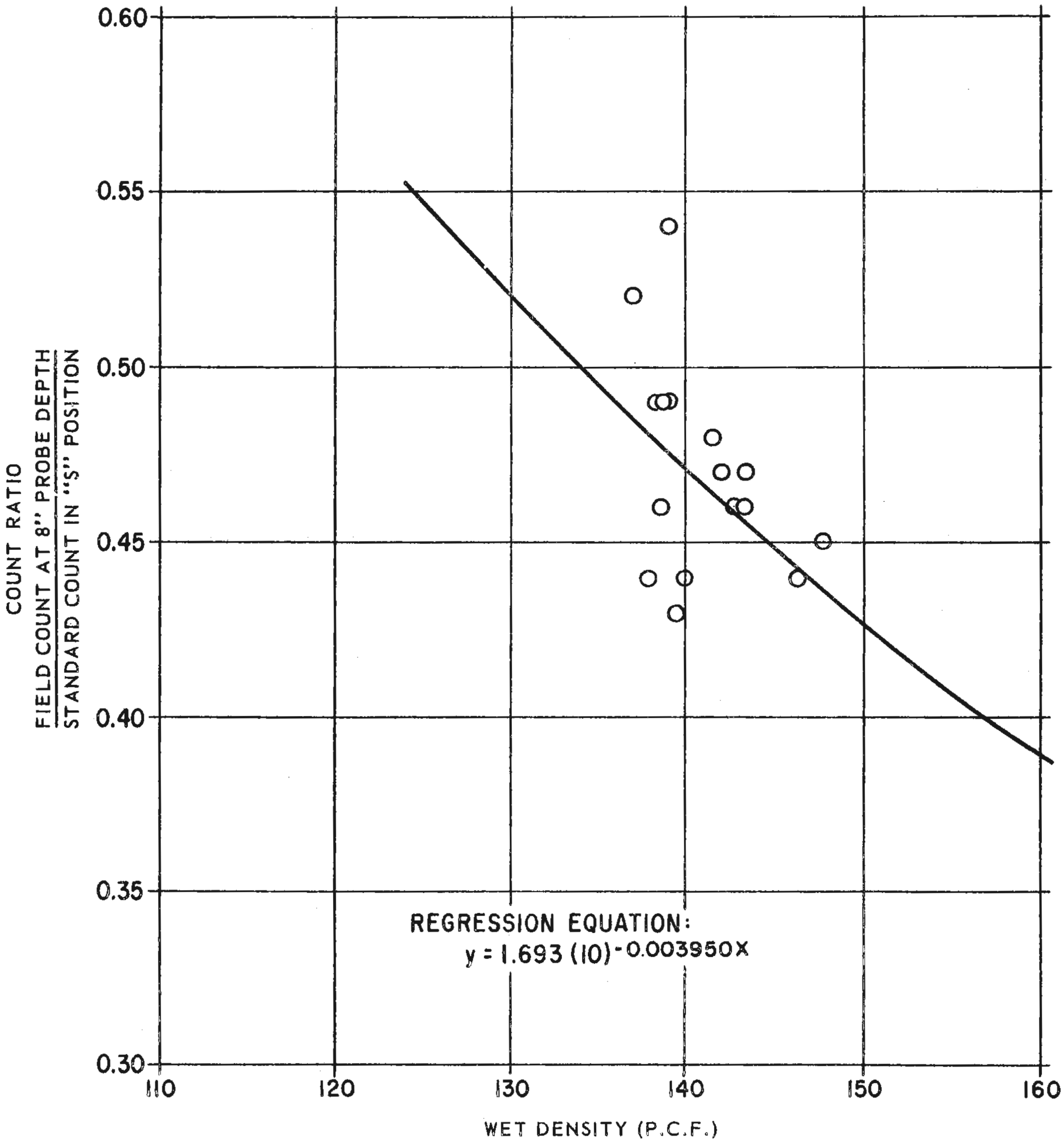

FIG. A-7

MOISTURE CURVE
(STONE BASE MATERIAL)

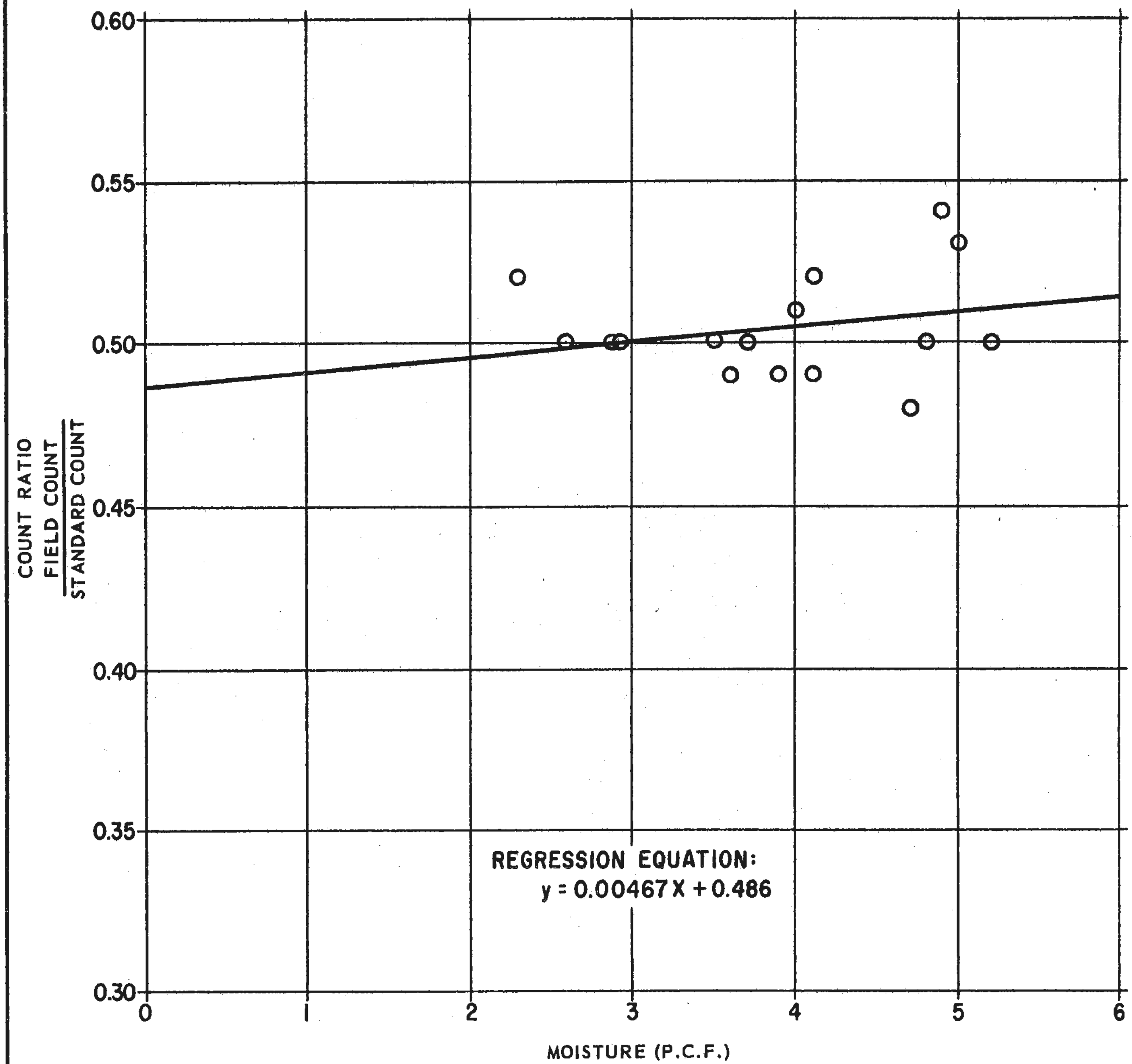

FIG. A-8

APPENDIX 3

RECOMMENDED OPERATING PROCEDURE

RECOMMENDED OPERATING PROCEDURE FOR MAKING NUCLEAR MOISTURE-DENSITY DETERMINATIONS

Preliminary Operation

1. Connect scaler and moisture probe.
2. Set "High Voltage Select" to moisture range of 1500 volts.
3. Set "Scaler Function" to "Count" position and "Meter Function" to "H.V.", set gain to desired number, place master switch to "ON", set H.V. Adjustment to desired voltage on voltmeter, and allow scaler to warm up approximately 5 minutes.

   The same procedure applies to density, with the following exceptions --

1. H.V. Select positioned to 1000 volts.
2. If scaler is prewarmed, allow only about 1/2 minute additional warming period after changing probe units.

   Caution: Always turn all switches to "OFF" before changing probe units.

Standard Count Determination (Moisture)

1. Place probe unit on reference standard (S-1).
2. Switch scaler function to TIMED and push RESET button firmly to set decade tube register to zero.
3. Turn one-minute timer clockwise until contact points click; release gently.
4. Record count of decade tubes. Repeat until a minimum of three counts are recorded. They should not vary more than approximately ± 300 cpm from the average. This S-1 value is the denominator for count ratio.
5. Repeat procedure for S-3 reference standard.
6. Divide S-3 cpm by S-1 cpm and record. This value is useful in

further checks to determine if operation is proper. It is a quick-check.

7. The density quick-check is made by dividing the 4" depth count by the 'S' position count on the concrete block standard. The 'S' position is the denominator for density count-ratio.

Field Counts

1. The field counts are made on a prepared test site in the same operational manner as described for Standard Count Determination.
2. Approximately three tests should be made, spaced 120° apart; the results to be recorded and averaged.

Calibration Curves

1. Perform nuclear tests at test site and determine count-ratios for moisture and density.
2. Take sand-cone tests in same site locations.
3. Plot wet sand-cone density versus nuclear count ratio on semi-logarithm paper. Plot count ratio on log scale and the wet density on the arithmetic scale and connect with a straight line. A minimum of 10 tests is needed; five on low density end and five on high density end.
4. Moisture is plotted on standard graph paper. The points are connected with a smooth curve.

   The scaler should be put on the battery charger overnight to insure high-type battery performance.

Results

1. Enter count ratio in density curve to obtain wet density in pounds per cubic foot.
2. Enter count ratio in moisture curve and read moisture in pounds per

cubic foot.

3. Subtract water from wet density to obtain dry density in pounds per cubic foot.

4. Divide water content by dry density and multiply by 100 to obtain moisture content expressed as a percentage.

Testing for Field Samples

It is necessary to prepare calibration curves prior to field sample testing.

The field testing is carried out in the same manner as the calibration, except that the sand cone test is deleted.

The nuclear apparatus should be checked against a sand-cone test periodically to insure accurate performance.

APPENDIX 4

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