Louisiana Highway Research

NUCLEAR MOISTURE-DENSITY EVALUATION

Louisiana Department of Highways - Research Unit

LOUISIANA DEPARTMENT OF HIGHWAYS

IN REPLY PLEASE REFER TO
FILE NO.

Louisiana
DEPARTMENT OF HIGHWAYS
P. O. BOX 4245, CAPITOL STATION
BATON ROUGE, LA. 70804

November 24, 1964

NUCLEAR MOISTURE-DENSITY EVALUATION
Research Project No. 63-1S
Louisiana HPR 1(2)

Materials Engineers
American Association of State
Highway Officials

Enclosed is a report entitled, NUCLEAR MOISTURE-DENSITY EVALUATION.

This report discusses the results of a field evaluation of the Troxler Soil Moisture and Density Gauge with particular emphasis on the device itself and the results obtained therefrom as compared with the results of the two accepted conventional methods used by the Louisiana Department of Highways i.e. the volumeter and sand displacement methods.

Any comments or suggestions concerning this report will be invited.

Very truly yours,

L. W. Harrell
Testing & Research Engineer

VA:jk
Enclosure
cc: Mr. J. C. Breaux
Mr. R. E. Bollen, HRB
Mr. C. R. Foster
Mr. C. A. McKeogh
Mr. J. M. Griffith

Louisiana
DEPARTMENT OF HIGHWAYS
P. O. BOX 4245, CAPITOL STATION
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Mr. Lyman G. Youngs
Division Engineer
Bureau of Public Roads
3444 Convention Street
Baton Rouge, Louisiana

Dear Mr. Youngs:

Enclosed are 104 copies of the final report for the captioned project entitled, NUCLEAR MOISTURE-DENSITY EVALUATION.

We have made arrangements to distribute this report to the Materials Engineers of the AASHO.

This report discusses the results of a field evaluation of the Troxler Soil Moisture and Density Gauge with particular emphasis on the device itself and the results obtained therefrom as compared with the results of the two accepted conventional methods used by the Louisiana Department of Highways i.e. the volumeter and sand displacement methods.

By copy of this letter we are urging the Project Engineers and the District Laboratory Engineers to review this report.

Very truly yours,

L. W. Harrell
L. W. Harrell
Testing & Research Engineer

VA:jk
Enclosures
cc: Mr. E. J. James
Mr. T. W. Parish, Jr.
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Mr. Oren Baker
Mr. J. B. Carter
Section Heads - Engineering
Mr. C. W. Burns
All District Engineers
Mr. D. D. McDuff
All Project Engineers
All District Laboratory Engineers
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NUCLEAR MOISTURE-DENSITY EVALUATION

by

HARRY L. ROLAND, JR.
Geologist

Research Report No. 13

Interim Report No. 2

Research Project No. 62-1S

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research Unit
in Cooperation with
U.S. Department of Commerce
BUREAU OF PUBLIC ROADS

November 1964

SYNOPSIS

This report constitutes the results of a field evaluation of one of the several portable nuclear gauges for measuring soil moisture and density, namely, the Troxler Soil Moisture and Density Gauge manufactured by the Troxler Company of Raleigh, North Carolina.

The emphasis here is on the device itself and the results obtained therefrom as compared with the results from the two accepted conventional methods used by the Louisiana Department of Highways, i.e. the volumeter and sand displacement methods. Consequently, very little space has been devoted to theory nor has any attempt been made to determine or compare the relative accuracies of the conventional methods. Further, the work was performed by and under the immediate supervision of laboratory technicians with only general guidance at the professional level, as is ordinarily done for all routine testing and inspection work.

Operational characteristics have been described in some detail and calibration curves have been prepared utilizing the theory of least squares as processed by the LDH 1620 IBM Data Processing System.

In addition a test method has been prepared for the use of this equipment as an aide to compaction control (LDH designation 424-64T, Appendix). This test method has been prepared as a guide to successful test results, but it should be emphasized that utmost care must be taken in the initial calibration of any of these devices.

EVALUATION OF A NUCLEAR METHOD FOR DETERMINING SOIL MOISTURE AND DENSITY

INTRODUCTION

Quality control of highway materials is a highly desired objective concerning the Highway Engineer of today. In order to achieve this rather elusive phenomena, it becomes necessary to improve old methods and/or adopt new methods of testing and control.

With this idea of quality control becoming increasingly important, the Soils Research Unit initiated a research program in August, 1962, designed to investigate and evaluate one of the several portable nuclear moisture - density devices now on the market. The study was sponsored by the Louisiana Department of Highways in cooperation with the U.S. Department of Commerce, Bureau of Public Roads.

This report constitutes the results of a series of calibration curves prepared by comparing the Troxler Nuclear Density - Moisture Gauge count ratios with conventional densities as obtained by the Soiltest Volumeter and the sand displacement methods.

The disadvantages of the present conventional methods of obtaining in-place densities are well recognized with the time consuming element being among the more prominent of these disadvantages. In addition, the fact that conventional methods leave a great deal to be desired, as far as "accuracy" is concerned, is something which the engineer is more or less forced to accept.

Recent developments in the use of radioisotope techniques for the measurement of moisture and density offer a rapid method for obtaining in situ determinations of these particular engineering properties.

The measurement of density by radioisotope techniques is based on the ability of gamma photons to be scattered or absorbed in approximate proportion to the density of the material through which they are passed.

The measurement of moisture is based on the principle of thermalization (slowing down of fast neutrons) by the hydrogen contained within a given soil mass.

All of the calibration curves contained in this report are the direct result of field comparisons of the Troxler Gauge with conventional methods. These curves were derived by the Polynomial Curve Fitting method utilizing the theory of least squares as processed by the Louisiana Department of Highways 1620, IBM Data Processing System.

SCOPE

The research program was designed to investigate the following aspects of nuclear testing:

(a) Operational characteristics of the nuclear equipment.
(b) Durability of the nuclear equipment under field conditions.
(c) Development of a practical procedure for the use of this equipment in the field.
(d) Development of calibration curves for several soil types.

It was originally intended to investigate several increments of depth simultaneously with respect to density. However, when this became too time consuming, the emphasis was shifted to cover primarily a depth of six inches.

MATERIALS TESTED

This investigation covered a wide range of materials on construction projects over the entire state. It included determinations made on materials ranging from A-2-4 to A-6 and stabilized materials from A-2-4 to sand clay gravel and sand shell.

The testing program included nearly 400 individual observations under a rather wide range of climatic conditions.

TEST PROCEDURES

The soil samples and density determinations were tested in accordance with the following methods:

1. LDH TR 401-61 - Method of Test for the determination of In-Place Density.

2. LDH TR 407-63 - Method of Mechanical Analysis of Soils.
3. AASHO T 89-60 - Methods of Determining Liquid Limit of Soils.
4. AASHO T 90-56 - Methods of Determining the Plastic Limit of Soils.
5. AASHO T 91-54 - Method of Calculating the Plasticity Index of Soils.
6. Procedure for Nuclear Determinations - this is discussed fully under the heading of Discussion of Test Results.

DISCUSSION OF TEST RESULTS

For purposes of clarity and continuity the test results shall be discussed under approximately the same headings and order as listed under the section titled Scope.

OPERATIONAL CHARACTERISTICS OF THE TROXLER DEVICE

The Troxler Model 200 B scaler is a portable, battery-operated, transistorized instrument whose function is to supply and control voltage to the detectors, measure pulses from the detector tubes, and display the number of pulses per unit time. The power is supplied by a sealed nickel-cadmium, battery-pack which will charge up to about 21 votes. The manufacturer states that approximately 16 hours of operation may be obtained from a fully charged battery. However, after about 10 to 12 hours of constant field operation, the battery drops below the reliable operating voltage of approximately 17.5 volts. Figure 1 shows the rate of decrease in battery voltage with operating time. It is interesting to note that the voltage drops sharply the first hour, levels off for the next three hours and then drops rather rapidly again. The reliability count from the 275 minute mark to the 300 minute mark is about 80%; considerably less than the 90% or better obtained at 17.5 volts up. However, the effective operating time in the field proved to be sufficient so as to cause little difficulty in the operation.

In general, the scaler performed satisfactorily throughout the testing period. Malfunctions did occur occasionally due to the modular construction were usually corrected with very little difficulty. On one occasion, the scaler was returned to the factory due to a faulty timer, which was replaced and the equipment updated. Temperature apparently has little or no effect, at least within the temperature range of 30° F to 100° F. The instrument is relatively dustproof and sufficiently rugged for field use.

The Model 104-115 Surface Moisture Gauge is a lightweight, compact unit in which both the 3 mc Radium-Beryllium source and the detector are enclosed. The detector is an enriched boron-trifluoride moderated neutron detector which operates over a voltage range of approximately 1,300 - 1,500 volts. The

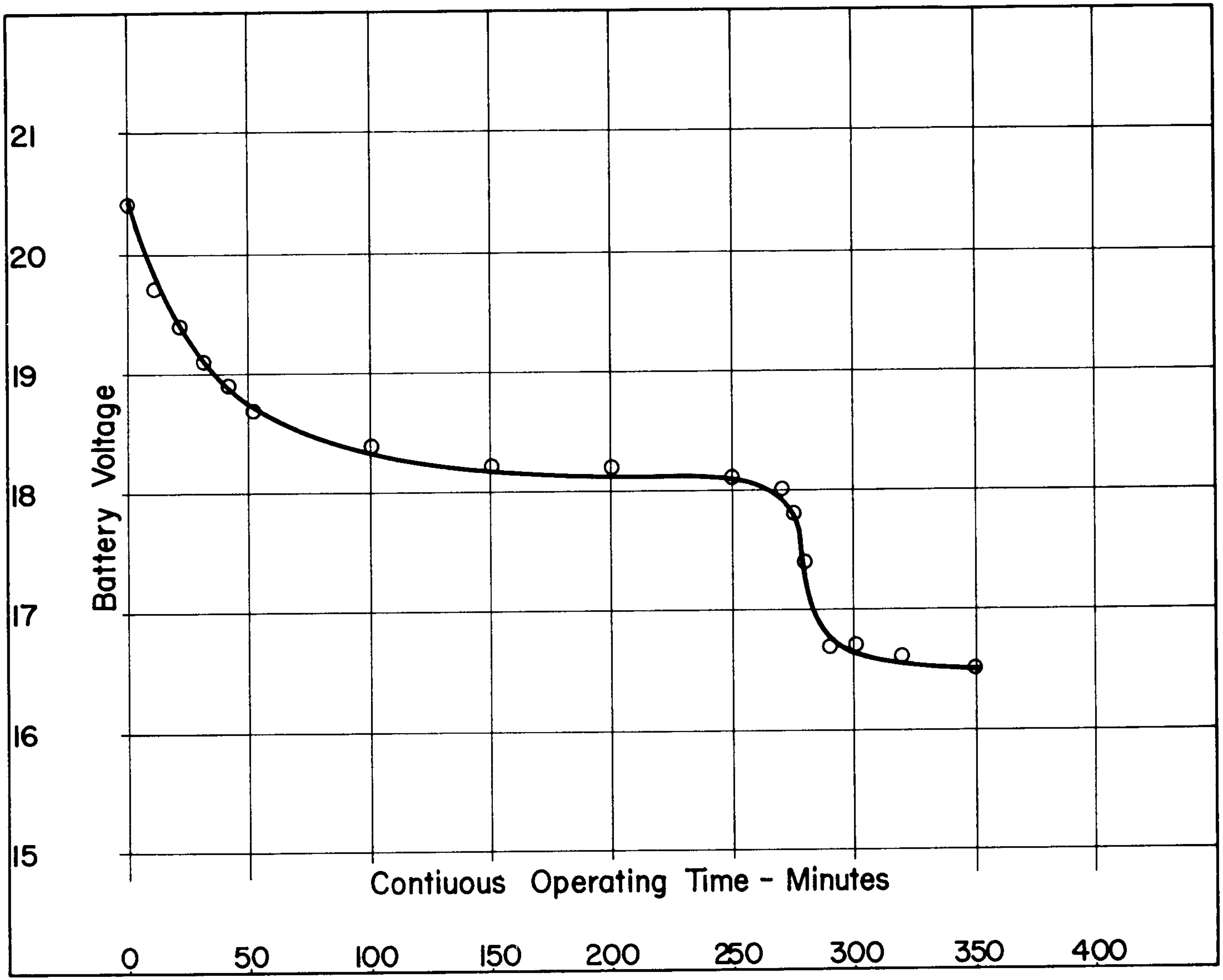

Figure 1 - Relationship of Continuous Operating Time to Battery Voltage.

volume measured is hemispherical in shape, the radius of which varies inversly as the moisture content. Figure 2 represents a plot of standard count rate versus time. There is a slight increase in the standard count rate after the first 6 months; then it becomes stable for the succeeding 7 months and again a rather large increase in count rate occurs. No attempt has been made to discuss the reasons for this variation in count rate, however, the effects of such variations can be eliminated by using a per cent of standard or count ratio, i.e., the actual count rate divided by the standard count. Figure 3 is a plot of several plateau curves extending over a period of some 16 months. Again this indicates a large change in count rate, which is attributed to the repair and updating of the equipment in January 1963. The primary purpose of this figure is to show that the "plateau", i.e., the area of the curve where a rather large fluctuation in voltage causes only a minor change in count rate, has remained constant over the entire 16 months time interval. This indicates that the boron-trifluoride tube is quite stable and should operate efficiently.

Table I shows that a one-minute warm up is sufficient to stabilize the count to within the permissible range of 1.5 times the square root of the average. However, it has been standard practice during this program to allow a minimum warm up time of at least 3 minutes.

The Model SC 120 Surface Density Gauge is a compact, portable unit which weighs approximately 20 pounds and contains a 3 mc radium-beryllium source in a variable depth probe which is capable of being inserted into the material to a controlled depth of up to 12 inches from the bottom of the gauge.

The detection unit consists of a halogen quenched Geiger-Müller tube with end window construction.

Due to the variable geometry of this device, separate calibration curves are required for the various thicknesses or depths to which density determinations are made.

Figure 4 shows several plateau curves prepared after the equipment was repaired in January 1963. The indication here is, that in the 6 months time interval represented by this figure, there has been a rather rapid deterioration of the Geiger-Müller tube. Thus, a higher voltage is required in order to stay well up on the plateau, which in turn tends to decrease the life of the tube.

It should be realized that this particular density device is not designed primarily for backscatter measurements, but rather for direct transmission measurements and is, therefore, not a completely non-destructive measuring device. It has been fairly well established that the direct transmission measurements are more sensitive than backscattering measurements and in addition, the

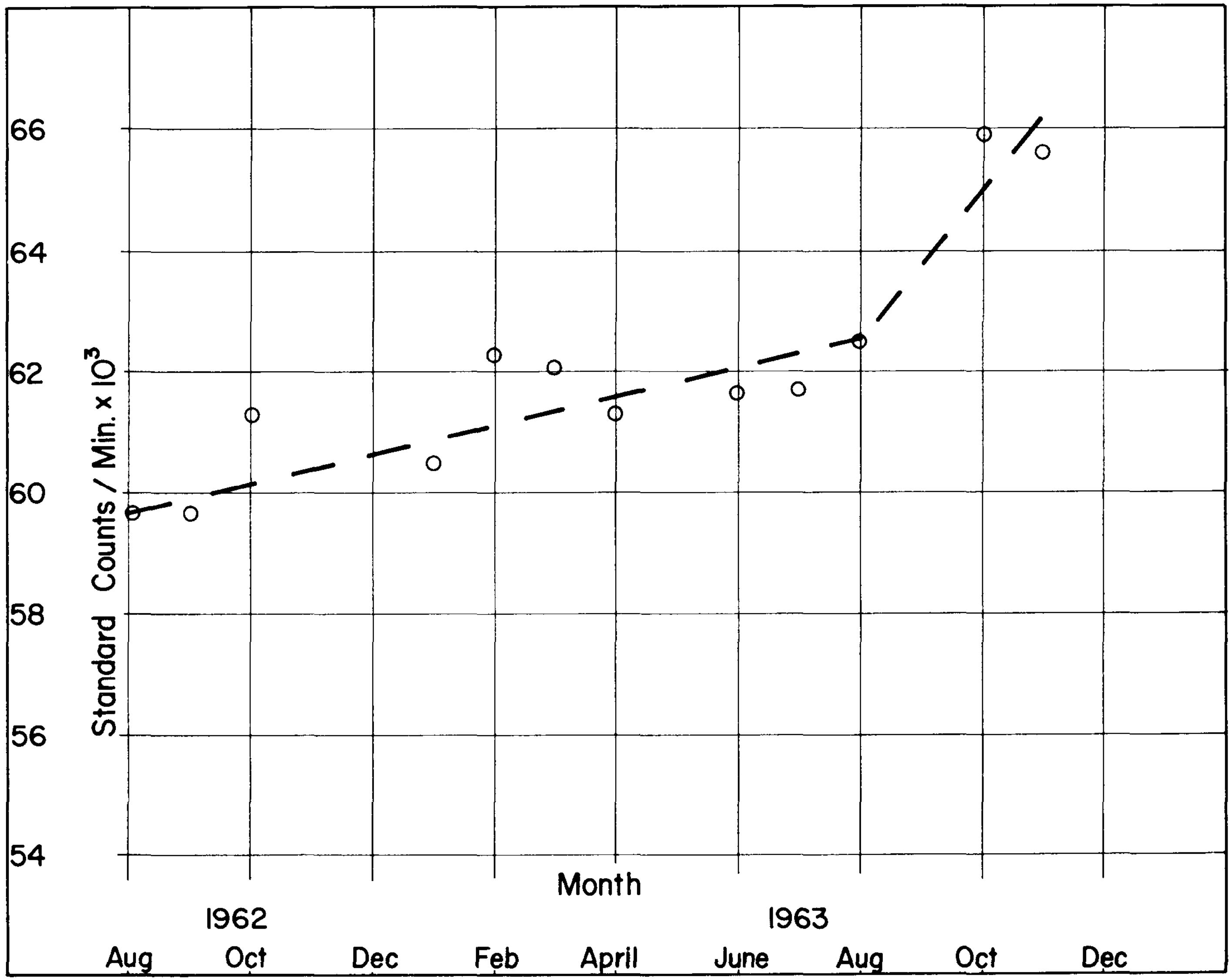

Figure 2 - Relationship of Standard Count Rate to Time.

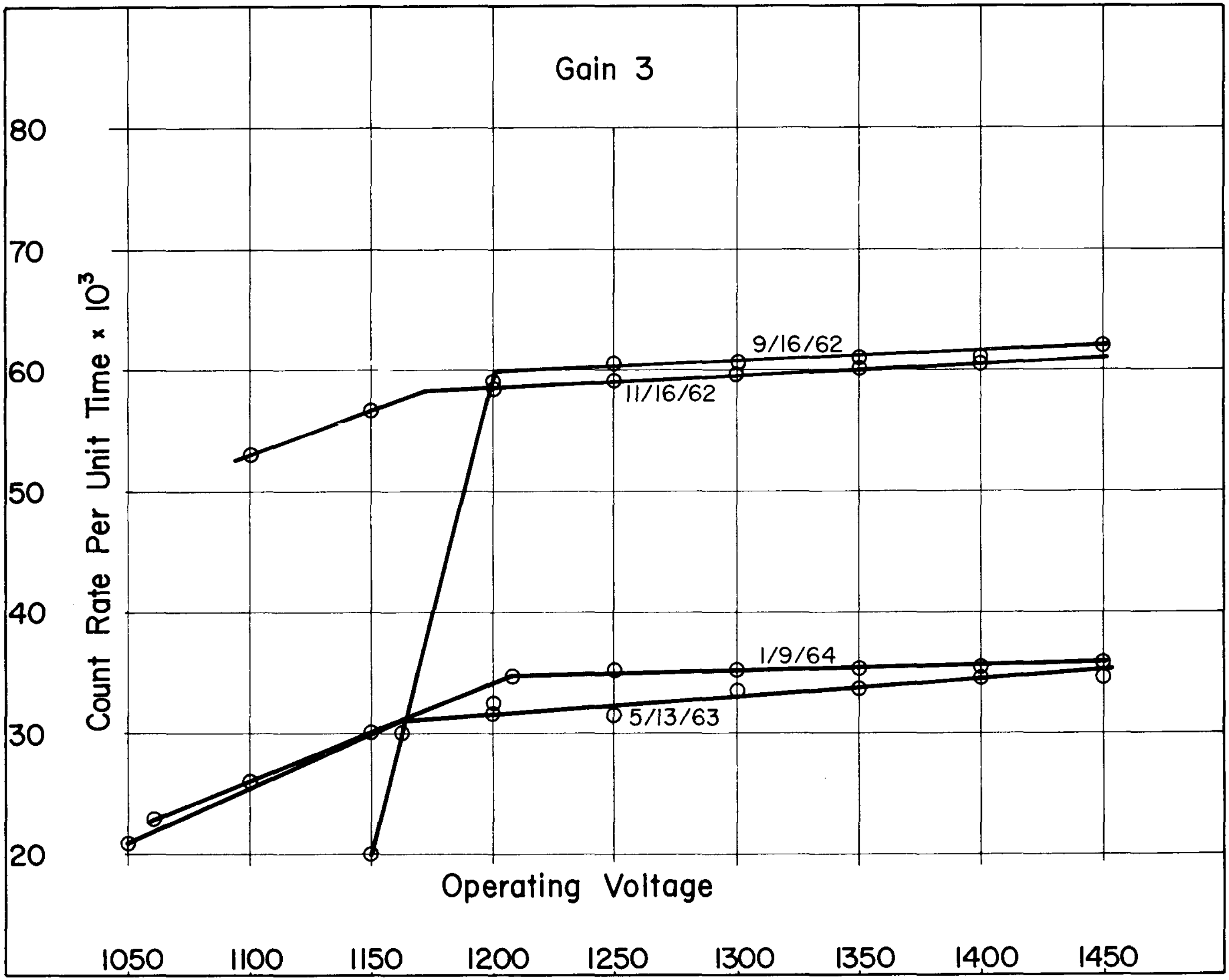

Figure 3 -Moisture Gauge Plateau Curves--Relationship of Count Rate to Operating Voltage.

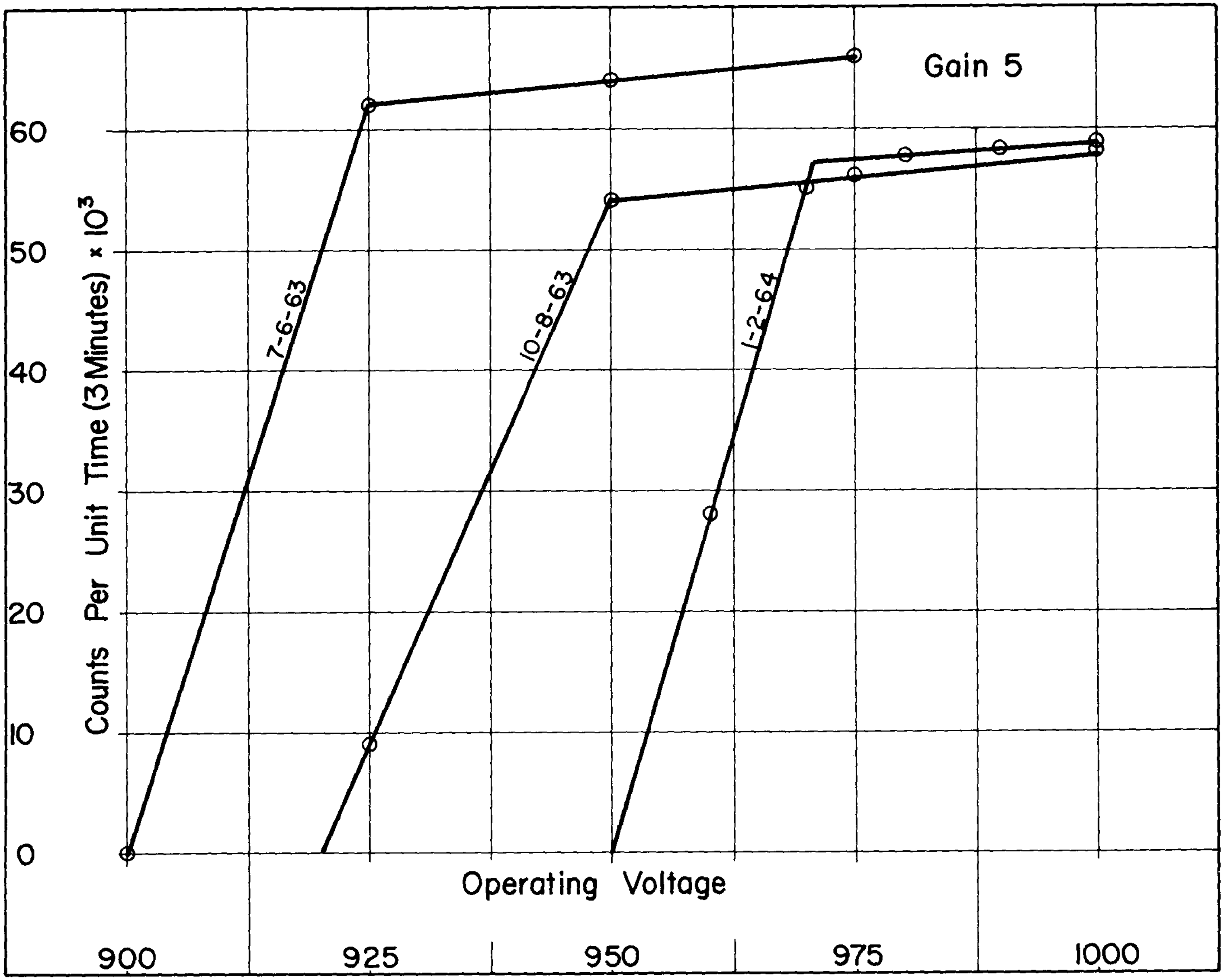

Figure 4 -Density Gauge Plateau Curves - Relationship of Count Rate to Operating Voltage.

variable depth probe allows the measurement of photons through a known or predetermined thickness.

Table II shows the warm up time required for the density gauge. Here the second one-minute count does not fall within the permissible range of ± 214 counts per minute which further indicates that at least 3 minutes should be allowed for warm up time.

The final point to consider under this section concerns the use of the steel spike to provide a hole for the density depth probe. It was felt that the driving of this spike into the surface of the material to be tested could have an adverse affect upon the density determinations; at best, it could introduce an unknown into the evaluation. For these reasons it was decided, after some experimentation, to use a 5/8 inch modified wood auger in conjunction with a brace to drill the necessary holes. This method proved very satisfactory, with a minimum of disturbance in the material to be tested.

DURABILITY OF NUCLEAR EQUIPMENT UNDER FIELD CONDITIONS

The original equipment, as purchased in August 1962, contained certain imperfections which caused some delay during the first 6 months of operation. For example, the scaler was not dustproof, which may or may not have led to a faulty timer and/or a faulty meter. At any rate these items were corrected in January, 1963. In addition, the original cables were replaced with a better type in August 1963, after being in service for 1 year. Also several of the modules were replaced during the first 6 months.

In general, this equipment is sufficiently durable for extended field usage, but it is subject to minor breakdowns which are sometimes difficult to correct without the services of qualified electronics personnel.

It should be pointed out that one of the big items in question at this writing concerns the life of the Geiger-Müller tube in the density device. As mentioned previously there are indications that the tube is deteriorating, however, it is not known how long it will function properly.

DEVELOPMENT OF PRACTICAL PROCEDURE FOR FIELD USE

The primary objective of this study is to determine the equivalent accuracy of this instrument as compared to established methods in relation to the moisture and density of soils and further, to develop a procedure for its use in the field.

Two approaches to this problem were readily available; either a comprehensive laboratory evaluation or a field evaluation. Since any curve or curves derived by a laboratory procedure would, of necessity, have to be checked in the field, it was decided to send the equipment to the field without any unnecessary delay.

The general procedure used for the development of the curves is as follows:

1. The scaler is connected to the surface moisture gauge and allowed to warm up.

2. The test location is leveled and, if necessary, a very thin sand blanket applied to reduce any large air voids which might be present.

3. A minimum 3 minute standard count is run on the polyethlene block with the moisture device. (Figure 5(a)).

4. The moisture device is then firmly seated (Figure 5(b)) and "readings"* taken in 3 positions rotating 120° each time (Figure 6). These readings are then averaged and divided by the standard count to give count ratio or per cent of standard.

5. The density gauge is then connected to the scaler, allowed to warm up for 3 minutes, and a standard count run either with the probe in self-standard position or with the probe extended to some depth in some other standard reference (Figure 5(c)).

6. A hole approximately 5/8 inch in diameter is then drilled into the material using the modified 5/8 inch wood auger. The density probe is inserted into the hole to the desired depth and set firmly against the side of the hole and readings (Figure 5(d)) taken again in the 3 positions (Figure 6) which are averaged and divided by the standard count.

7. A conventional density, using either the Soiltest model CN 980 volumeter or the standard sand cone, is obtained at one or more of the 120° locations.

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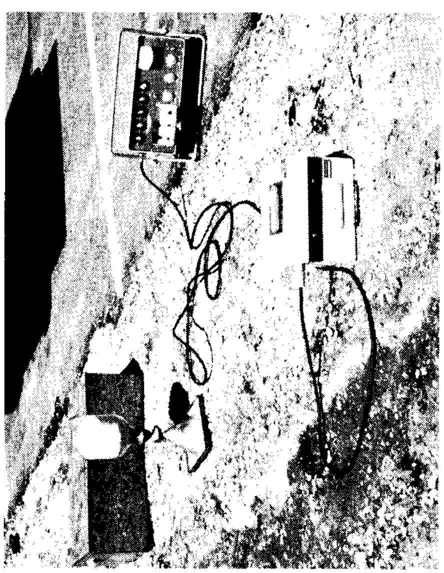
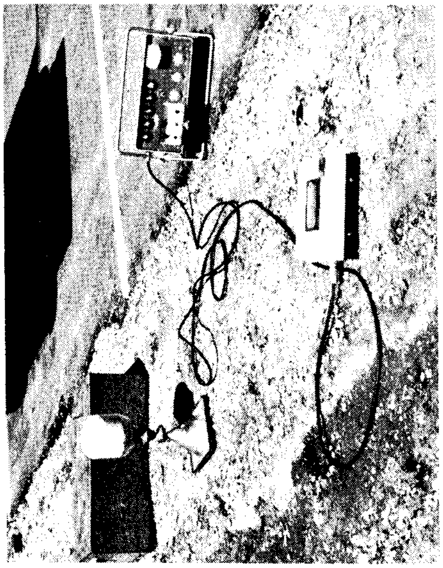
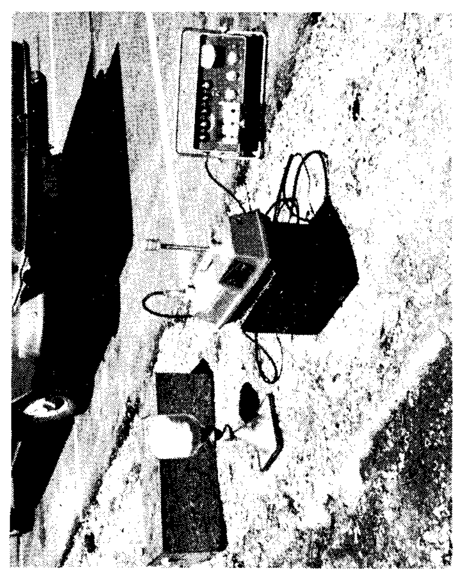
* It shall be henceforth understood that a nuclear "reading" consist of a minimum of 3 one-minute counts, all of which must fall within the statistical range of 1.5 times the square root of the average.



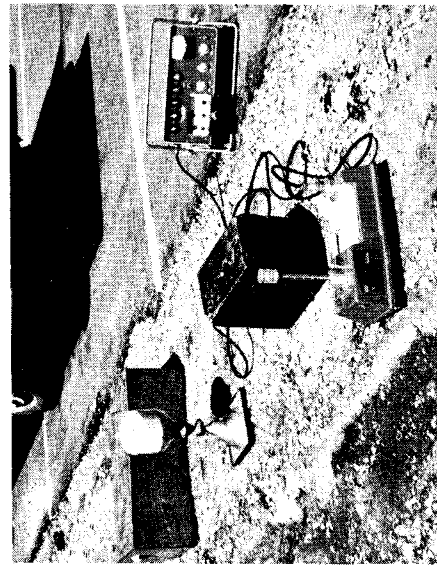
(a) Moisture Standard Determination



(b) Moisture Determination



(c) Density Standard Determination



(d) Density Determination

Figure 5 - Pictorial Nuclear Determinations

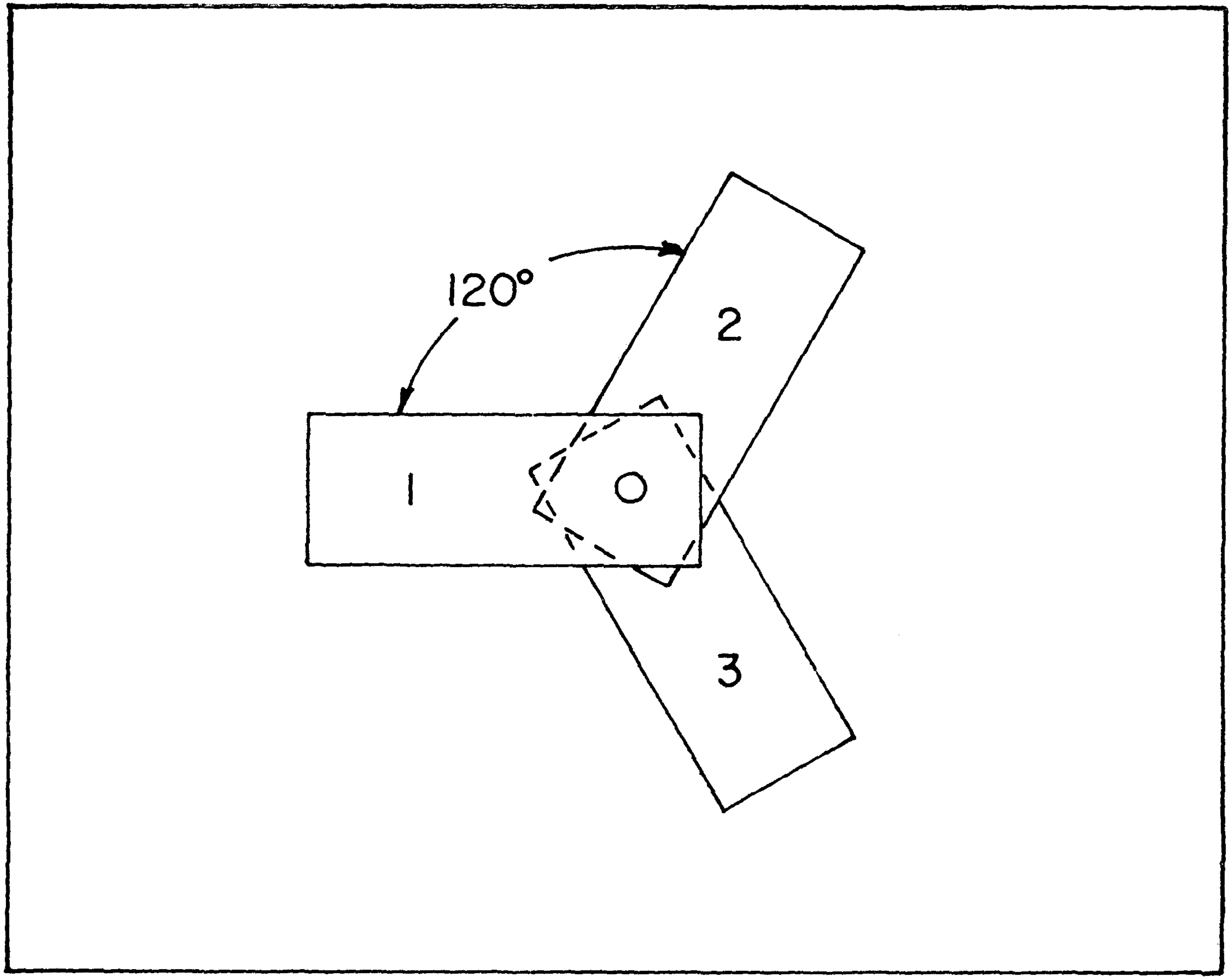


Figure 6 -Schematic Diagram of Positioning Arrangement for Nuclear Gauges.

The preceeding discussion has been concerned with the method used to derive the basic calibration curves. However, at the present time, there seems to be little reason for changing any of the procedure for field use except the elimination of the conventional methods. Using this technique, one operator can arrive at a complete density determination in approximately 20 to 30 minutes and in emergency cases this time can be trimmed to as little as 10 minutes.

One other item that should be included in any standard procedure concerns a short, weekly "ritual" to check the electronics of this equipment. Each Monday morning a reliability count should be performed for both moisture and density. This consists of 25 one-minute counts and any count that is not within the range of 1.5 times the square root of the average is subtracted from the total number of counts (25) and this number divided by 25 and multiplied by 100 to give % reliability. For example:

Average of 25 counts = 20,482
$1.5\sqrt{20,482} = 214$ counts per minute (cpm)
Two of the 25 counts were outside the limits of -214 cpm.

Therefore, $25 - 2 = 23$; $\frac{23}{25} \times 100 = 92\%$ reliability

In addition to the reliability checks, an actual density determination is performed on a concrete block of known density. If the reliability check is 88% or better and the density of the block checks within ± 1.5 lbs./cu. ft., it is assumed that the equipment is in proper working order.

Figure 7 is self explanatory and shows the major components of the equipment used for this research.

Figure 8 (a) shows the equipment ready to be placed in the carrying case and Figure 8 (b) shows the equipment ready to be moved to a new location.

DEVELOPMENT OF CALIBRATION CURVES FOR SEVERAL SOIL TYPES

A summary of test results is presented in Tables III - VI.

The preceding discussion has been concerned with the methods and procedures used to obtain data for the development of the calibration curves. This section is devoted to the actual development of the curves.

The materials tested have been combined into 2 groups; namely, raw compacted materials and stabilized compacted materials. The stabilized

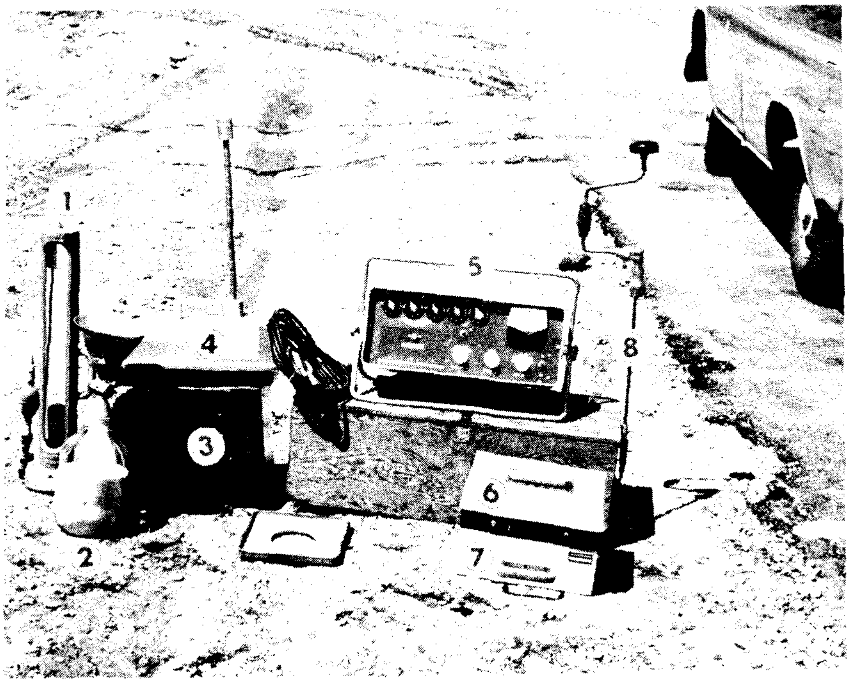
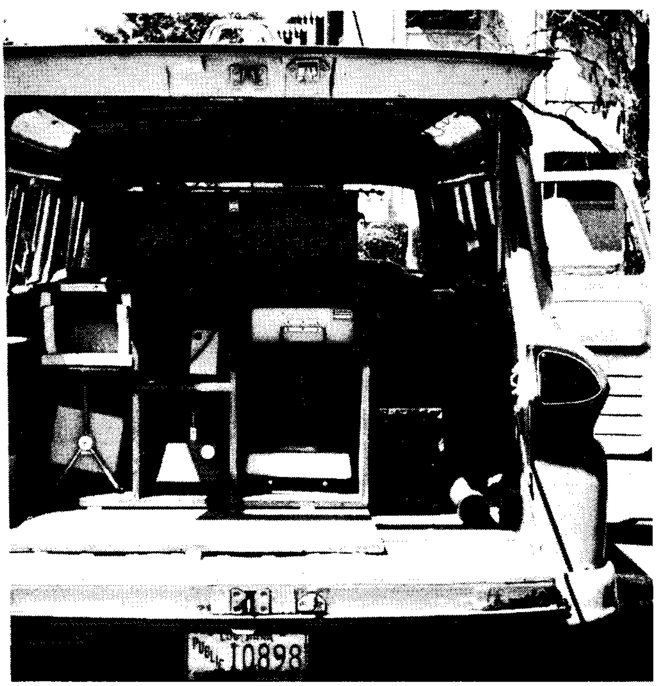


Figure 7 - Equipment

1. *Soiltest Volumeter Model CN 980*
2. *Sand Cone Apparatus*
3. *Concrete Standard*
4. *Density Probe, Troxler Model SC 120*
5. *Scaler, Troxler Model 200B*
6. *Surface Moisture Gauge, Troxler Model 104-115*
7. *Polyethlene Moisture Standard*
8. *Brace, 5/8 inch Auger, and Extension*

(a)



(b)

Figure 8 - Equipment Loading Arrangement

material includes both cement stabilized and lime-treated-cement stabilized materials.

The results were analyzed using statistical concepts and the resulting curves were derived by the Polynomial curve fitting method (theory of least squares) as processed by the Louisiana Department of Highways 1620 IBM Data Processing System. Pertinent data is recorded on each figure including the index of correlation, standard deviation, standard error of estimate and the type of curve (degree). The degree selected is based upon the curve showing the highest index of correlation and the least standard error. An index of correlation of zero indicates no correlation and unity indicates perfect correlation. It should be kept in mind that the accuracy figures shown are based on a large volume of soil measured by the nuclear device as compared to a relatively small volume measured by the conventional methods.

Figure 9 illustrates the relationship of count ratio to wet density for stabilized soils at a density depth of 4 inches. The dashed lines represent plus or minus 2, 3, and 4 lbs. per cubic foot respectively. It is readily apparent that the manufacturer's calibration curve is almost parallel to and approximately 3.0 lbs. per cubic foot lower than the curve derived for this material. This derived curve shows that 58% of the observations are within plus or minus 2.0 lbs. per cubic foot; 75% are within plus or minus 3.0 lbs. per cubic foot; and 83% are within plus or minus 4.0 lbs. per cubic foot.

Figure 10 represents the relationship of count ratio to wet density for stabilized soils at a density depth of 8 inches. This figure shows that, for the portion of the curve represented, no parallelism exists and the deviation between them grows progressively greater as lower densities (and higher count ratios) are approached. For 34 observations, 68% fall within plus or minus 2.0 lbs. per cubic foot; 82% within plus or minus 3.0 lbs. per cubic foot; and 88% within plus or minus 4.0 lbs. per cubic foot.

The first degree equation was utilized in plotting the 2 aforementioned curves due to the fact that the indices of correlation were highest and the standard errors were lowest. However, the accuracies of the second degree curves were determined to be within approximately 3% of the first degree curves, i. e., the accuracy is higher in some cases and lower in some cases, but within 3%.

The remaining figures relative to density correlations (Figures 11, 12, and 13) all represent the 6 inch depth level. Each curve used in a second degree curve since this equation represents the best fit of the data.

Figure 11 illustrates the curve derived for all raw compacted materials. The

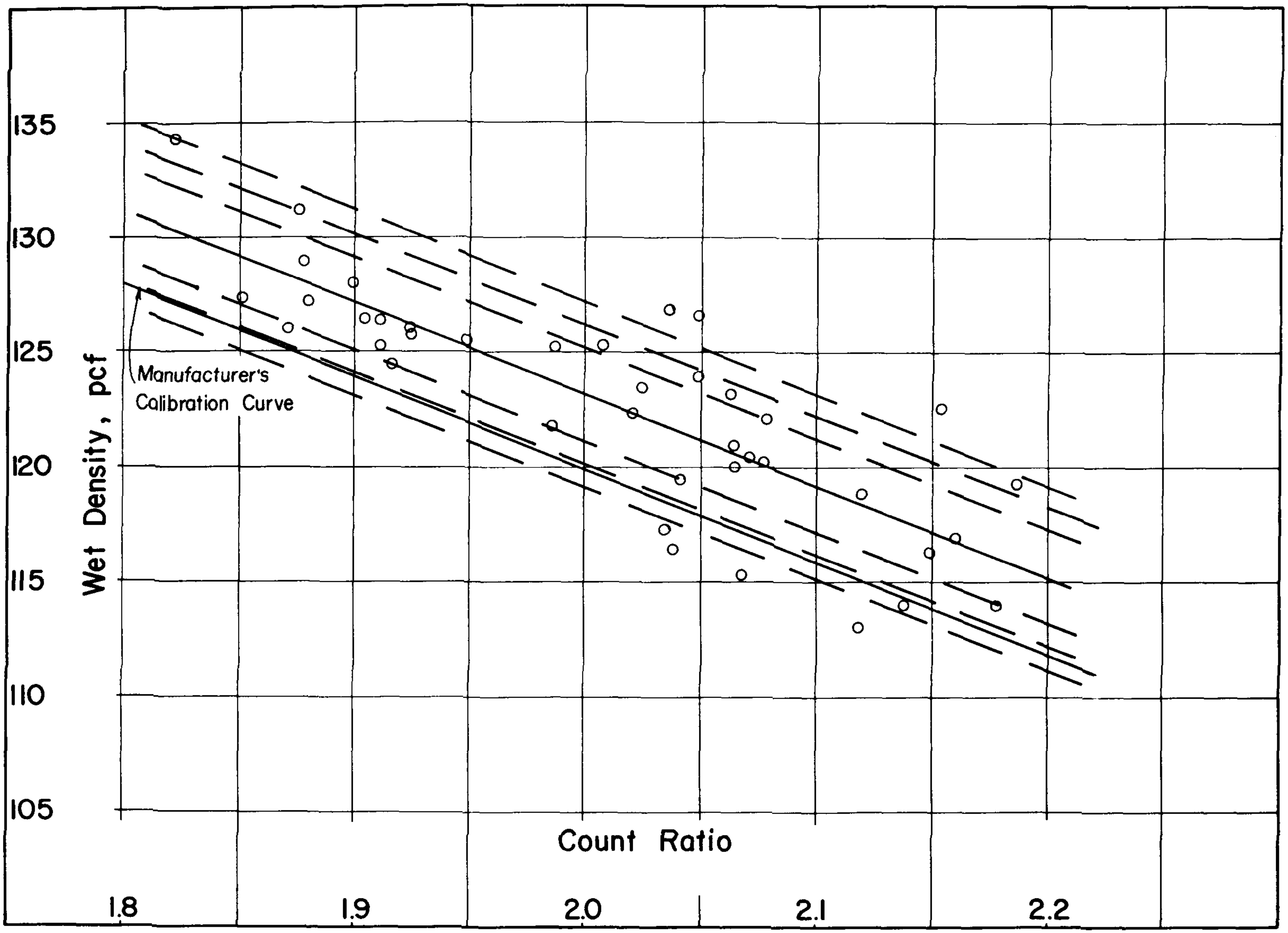


Figure 9 - Relationship of Count Ratio to Wet Density (pcf) for Stabilized Soils at a Depth of Four Inches. No. of Observations - 40, Degree 1st, Mean 122.7, Standard Deviation 4.830, Standard Error 2.796, Index of Correlation 0.815.

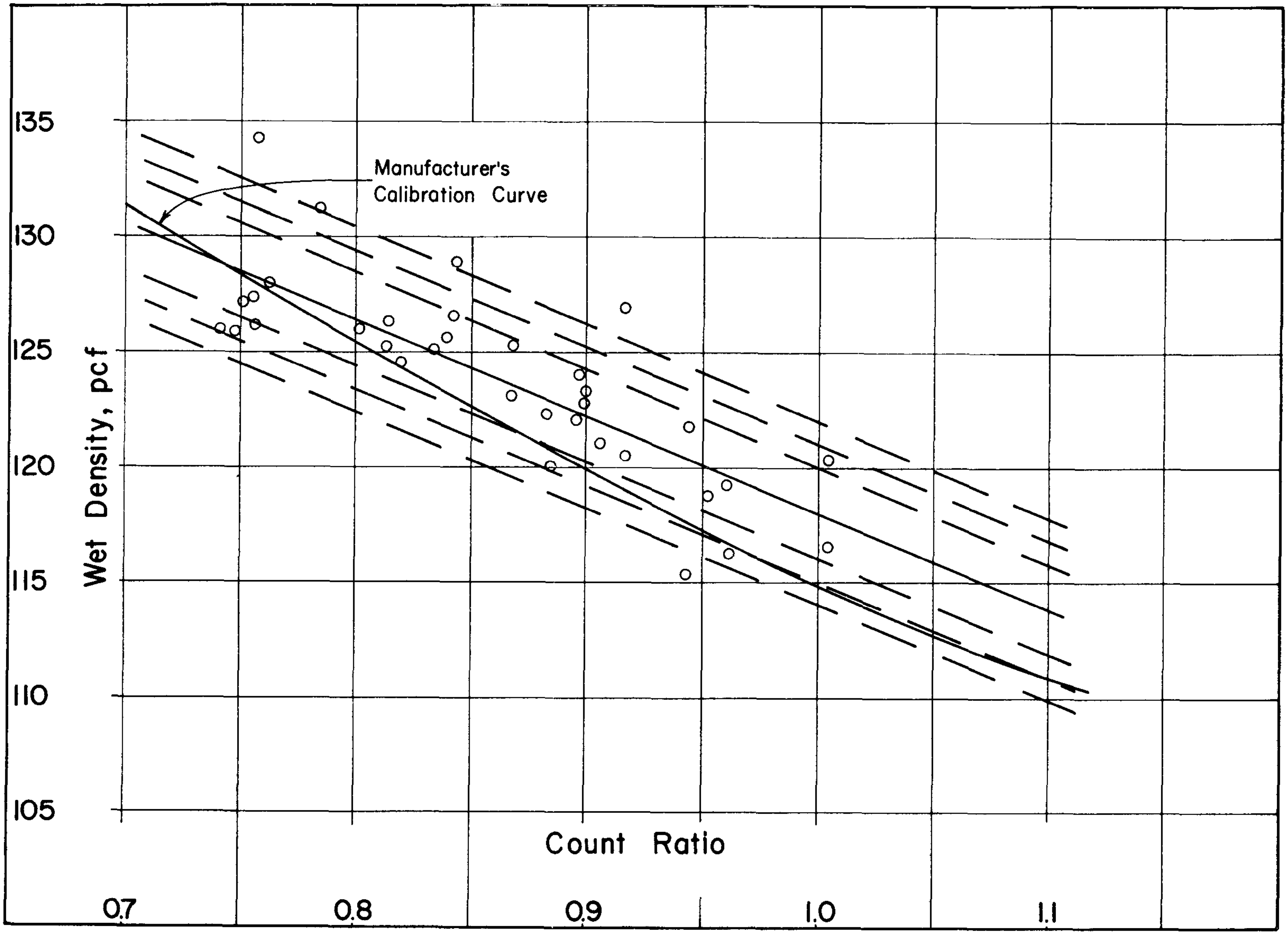


Figure 10 - Relationship of Count Ratio to Wet Density (pcf) for Stabilized Soils at a Depth of Eight Inches. No. of Observations - 34, Degree 1st, Mean 123.9, Standard Deviation 4.075 Standard Error 2.456, Index of Correlation 0.798.

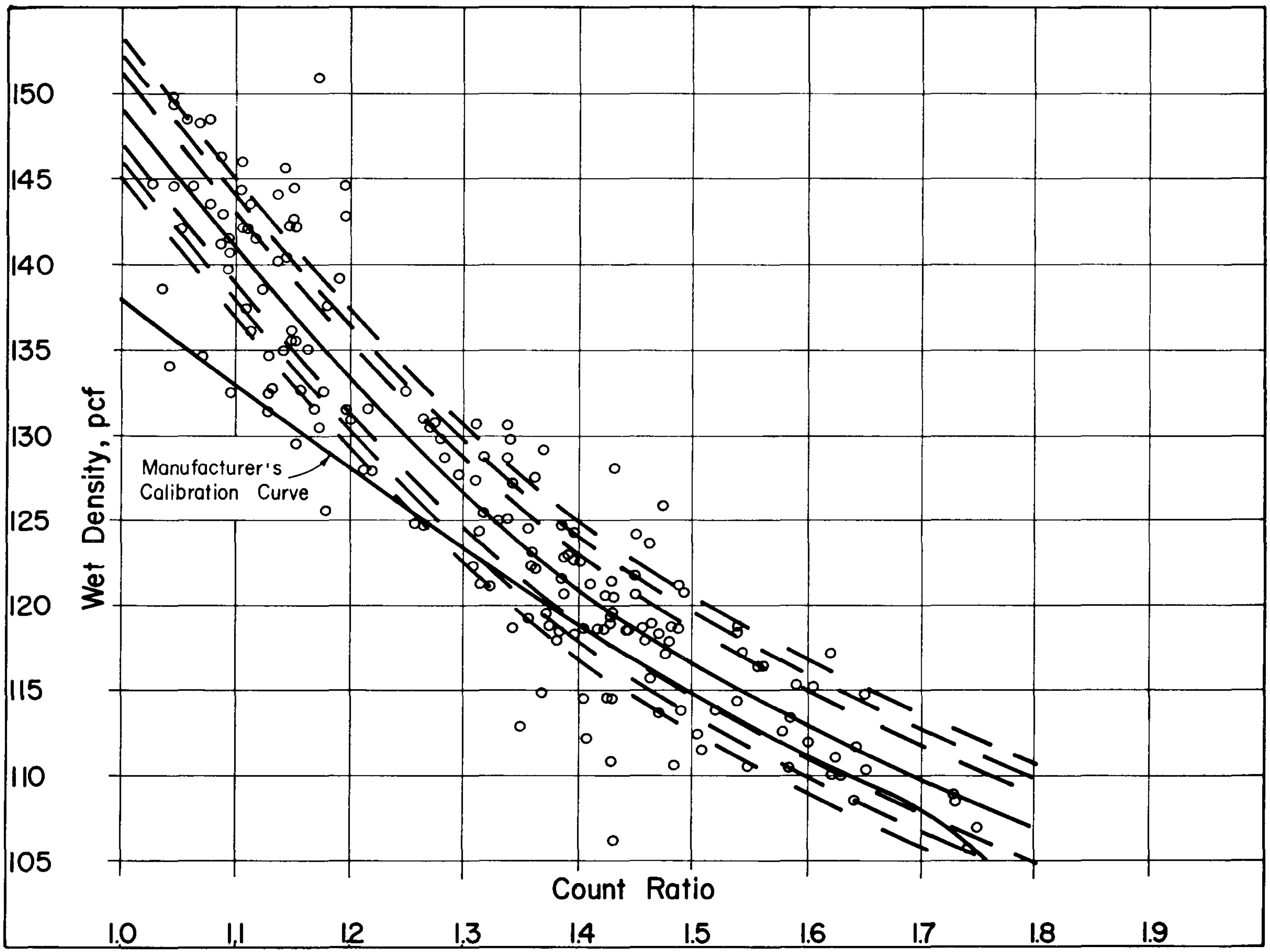


Figure 11 - Relationship of Count Ratio to Wet Density (pcf) for Raw Soils at a Depth of Six Inches. No. of Observations ; 174, Degree 2nd, Mean 126.4, Standard Deviation 11.367 , Standard Error 4.459, Index of Correlation 0.919.

maximum deviation from the manufacturer's curve occurs in the higher density range and is of a magnitude of nearly 11 lbs. per cubic foot. The minimum deviation occurs in the 110 lbs. per cubic foot to 120 lbs. per cubic foot range and is from 1.5 to 2 lbs. per cubic foot. The resulting accuracy of the 174 observations contained in this curve is as follows: 39% within plus or minus 2.0 lbs. per cubic foot; 58% within plus or minus 3.0 lbs. per cubic foot; and 69% within plus or minus 4.0 lbs. per cubic foot.

The curve derived for stabilized materials is represented by Figure 12. This curve contains 219 observations with a maximum deviation from the manufacturer's curve of approximately 9.0 lbs. per cubic foot and a minimum deviation of less than 1.0 lbs. per cubic foot. The accuracy range of this curve is approximately the same as for Figure 3 except that 46% of the observations fall within plus or minus 2.0 lbs. per cubic foot.

The final density calibration curve is shown by Figure 13. Here all observations for density at the 6 inch depth are included regardless of type of material or method of stabilization. The 393 observations incorporated in this curve show 42% within plus or minus 2.0 lbs. per cubic foot, 56% within plus or minus 3.0 lbs. per cubic foot, and 68% within plus or minus 4.0 lbs. per cubic foot. Maximum deviation from the manufacturer's calibration curve is approximately 9.5 lbs. per cubic foot and minimum deviation is 1.0 lbs. per cubic foot.

It is interesting to note that the maximum deviation between either the stabilized materials curve or the raw materials curve and the curve containing all observations is 2.7 lbs. per cubic foot and this deviation occurs at the higher ranges of density. This indicates that it is possible to utilize a "general" curve for density determinations, at least for the materials and conditions of this study.

Further, it may be noted that by calculating the accuracy from a point where the two calibration curves (manufacturer's curve and derived curve) begin to deviate rather widely (i.e. a count ratio of 1.06) the accuracy figures are approximately 10% better than those noted above.

The next 3 curves (Figures 14, 15, 16) are calibration curves for the surface moisture gauge. These curves were obtained by comparing an average of the 3 nuclear readings with the results obtained by oven-drying the total material excavated for the in-place density determinations.

Figure 14 illustrates the relationship between count ratio and moisture content in lbs. per cubic foot for compacted raw soils. The curve includes some 165 observations which show an accuracy of 54% within plus or minus 2.0 lbs. per

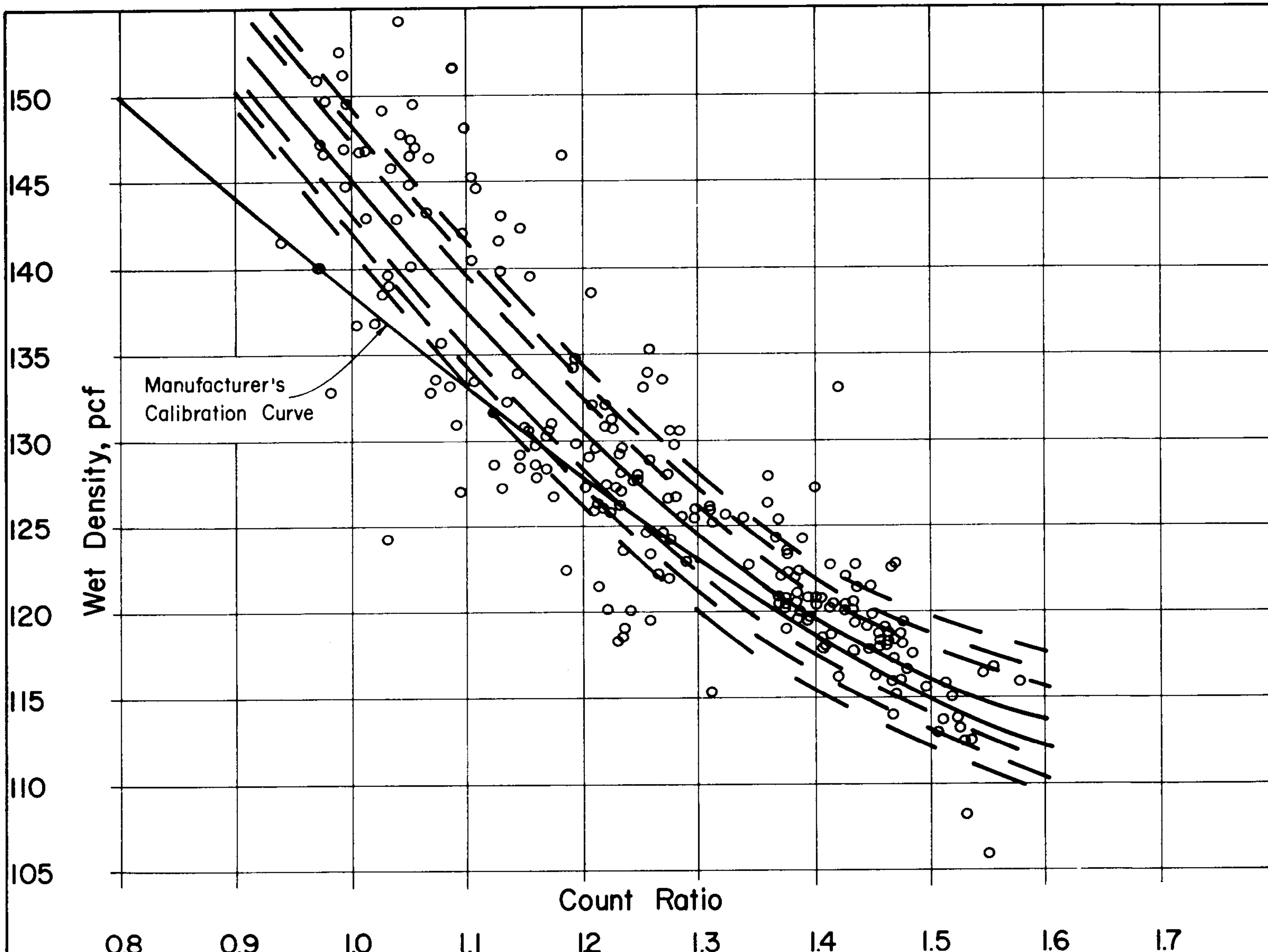


Figure 12 - Relationship of Count Ratio to Wet Density (pcf) for stabilized soils at a Depth of Six Inches. No. of Observations - 219, Degree 2d, Mean 128.1, Standard Deviation 10.469, Standard Error 4.758, Index of Correlation 0.890.

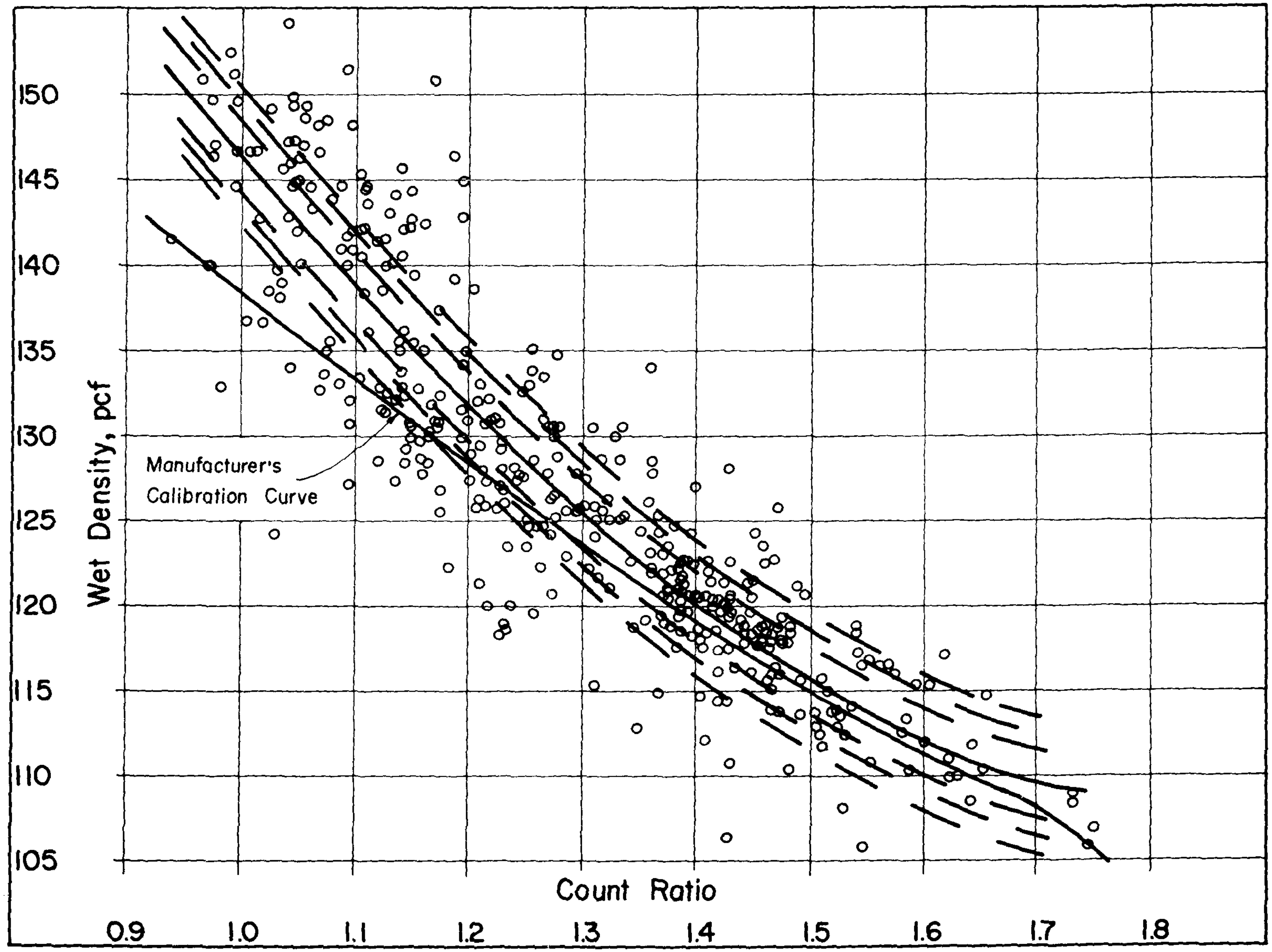


Figure 13 - Relationship of Count Ratio to Wet Density (pcf) for both Stabilized and Raw Soils at a Depth of Six Inches. No. of Observations - 393, Degree 2d, Mean 127.3, Standard Deviation 10.908, Standard Error 4.757, Index of Correlation 0.899.

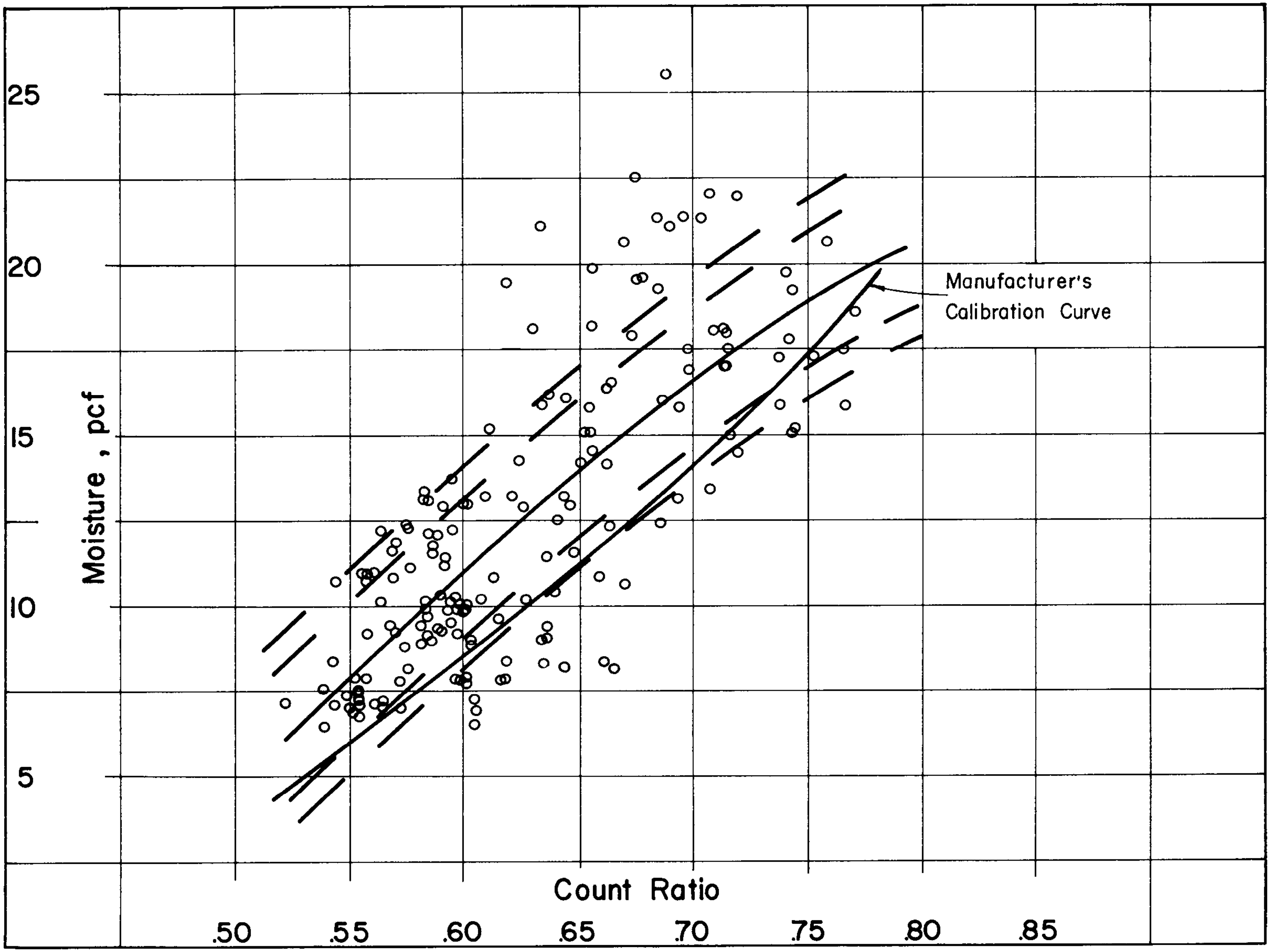


Figure 14 - Relationship of Count Ratio to moisture Content (pcf) for Raw Soils. No of Observations -165, Degree 2nd, Mean 12.426, Standard Deviation 4.371, Standard Error 2.877, Index of Correlation 0.752.

cubic foot and 73% within plus or minus 3.0 lbs. per cubic foot.

It should be mentioned at this time that since the surface moisture gauge measures the relative hydrogen content on a volumetric basis, it is necessary to convert either the oven dry moisture (% of dry-wt.) to a volume basis or the nuclear moisture to a per cent of dry weight basis. Since the basis of comparison is the conventional method, these values for moisture were converted to the volumetric determinations (lbs. moisture per cubic foot).

Figure 15 shows the curve derived for the moisture content determination of compacted stabilized materials. This curve seems to have a much steeper slope than either of the other curves for moisture content, which means that, with a lesser change in count ratio, there is a greater change in moisture content. However, this curve agrees fairly well with the raw moisture curve (Figure 14) in the range of 15-20 lbs. per cubic foot. The accuracy of this curve is on the order of 54% within plus or minus 2.0 lbs. per cubic foot and 73% within plus or minus 3.0 lbs. per cubic foot.

The combination of the stabilized moisture and raw moisture points constitutes the curve shown in Figure 16. This curve is the more or less "general" curve containing some 335 observations with an accuracy of 51% within plus or minus 2.0 lbs. per cubic foot and 72% within plus or minus 3.0 lbs. per cubic foot.

Figure 17 illustrates the curves derived for raw compacted soils, stabilized compacted soils, the "general" curve and the manufacturer's calibration curve. The "general" curve and the raw materials curve agree fairly well with only approximately 1 lb. per cubic foot deviation.

RADIOLOGICAL SAFETY

The radioactive sources used in this study were nominal 3 mc Radium - Berylluim sources which do not require the possession of an Atomic Energy Commission license. This does not suggest that this type of radiation is any less dangerous than those which require licenses. However, any agency using or comtemplating the use of such materials should set up and follow some standard safety procedures.

The following general rules were set up for and observed by all personnel assigned to this project:

1. Do not remove or tamper with the radioactive sources.

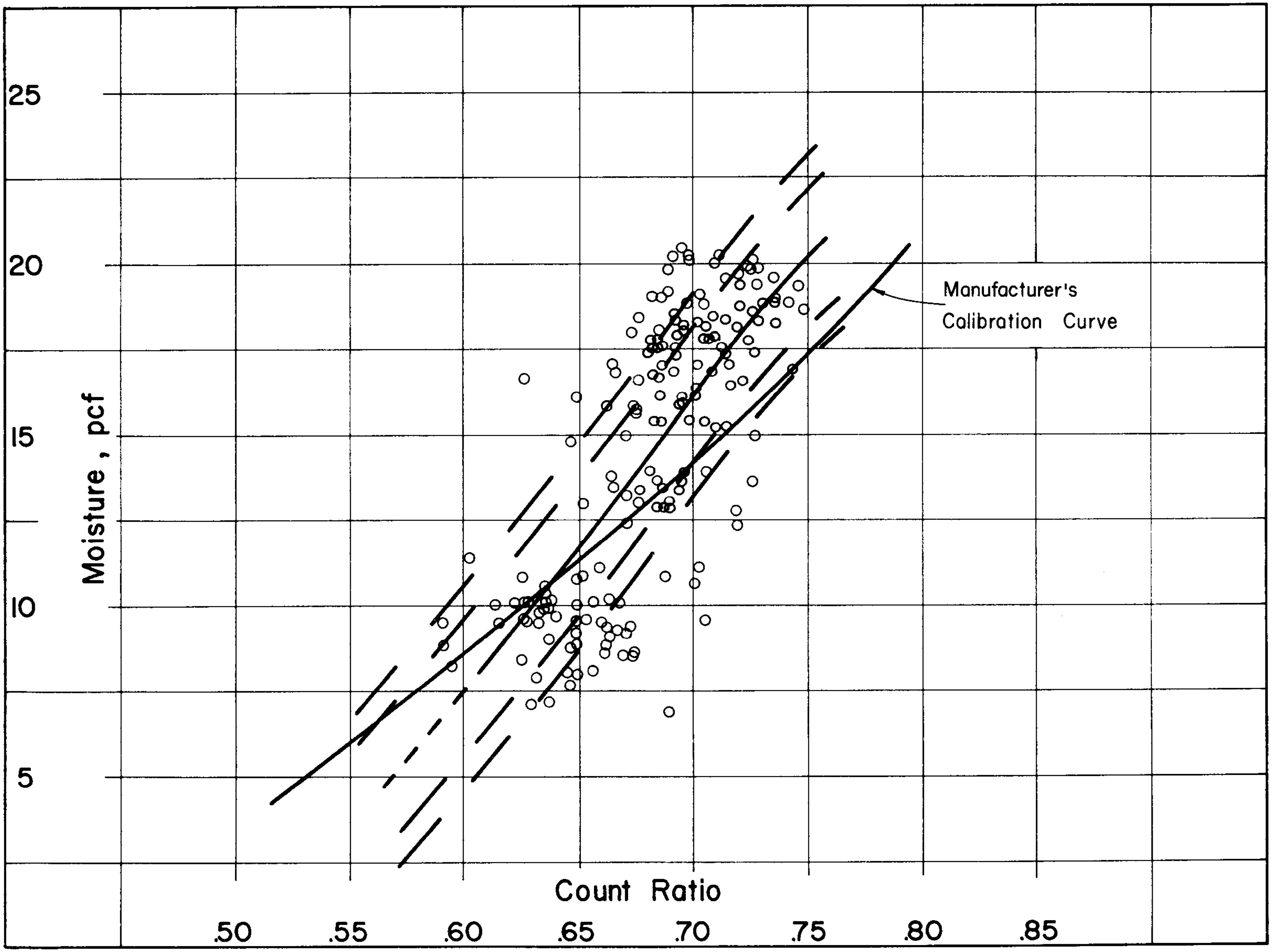


Figure 15 -Relationship of Count Ratio to Moisture Content (pcf) for Stabilized soils. No. of Observations -165, Degree 2d, Mean 14.390, Standard Deviation 4.026, Standard Error 2.751, Index of Correlation 0.730.

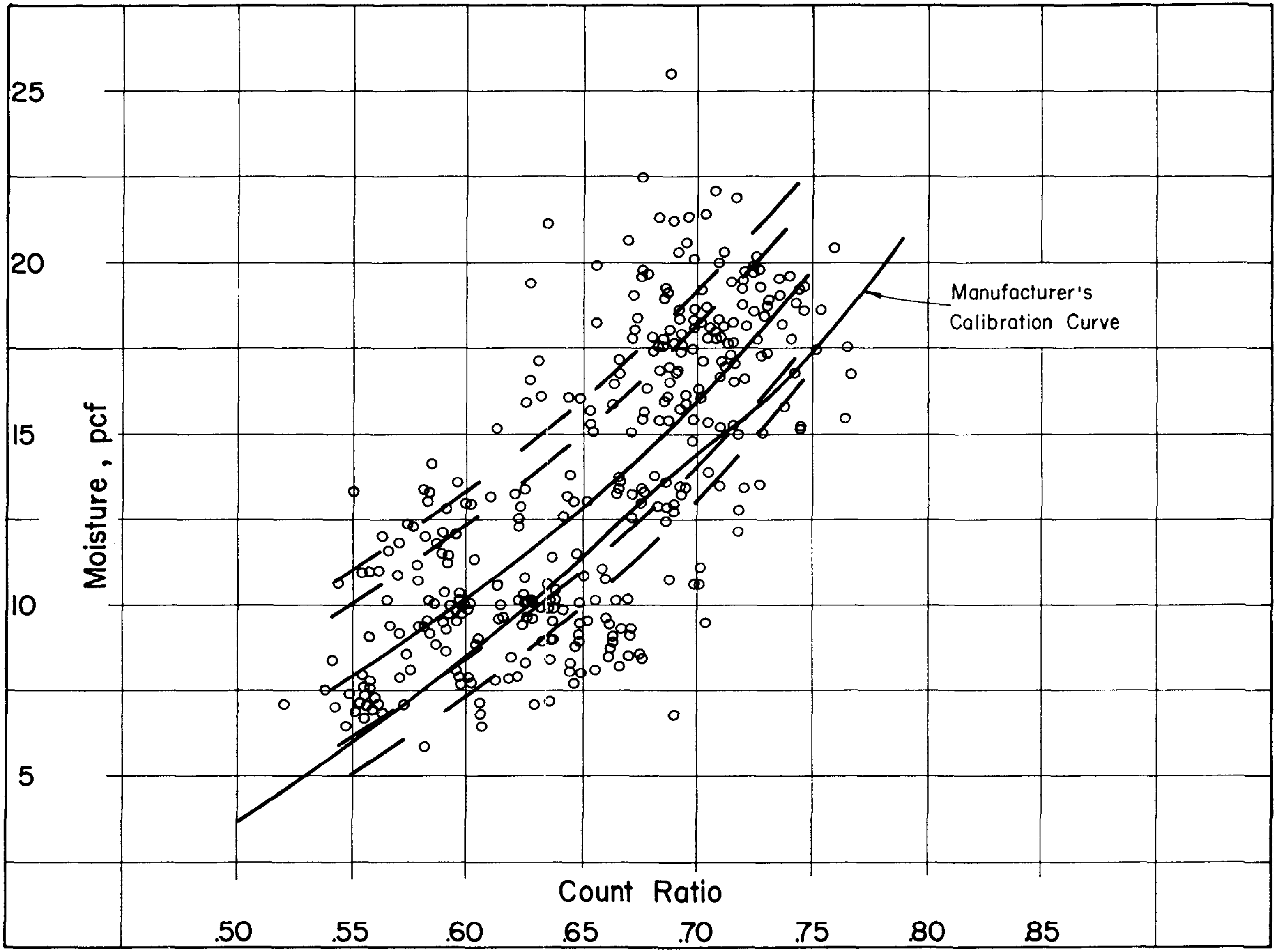


Figure 16 - Relationship of Count Ratio to Moisture Content (pcf) for all Moisture Determinations. No. of Observations - 335, Degree 2nd, Mean 13.423, Standard Deviation 4.313, Standard Error 2.937, Index of Correlation 0.732.

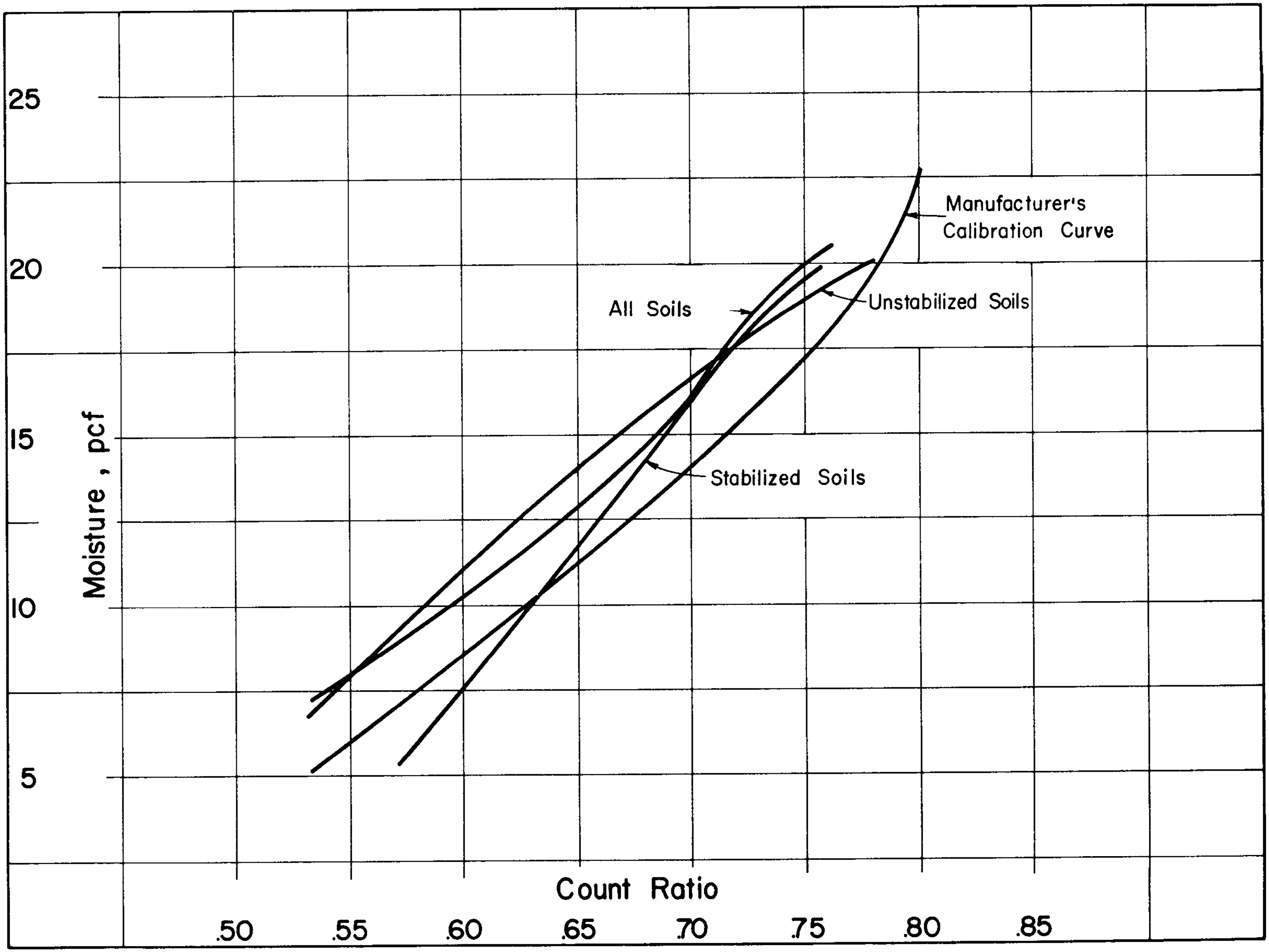


Figure 17 - Graphical Illustration of the Derived Calibration Curves as Compared to the Manufacturer's Calibration Curve in Relation to Moisture Content.

2. Film badges or other monitoring devices must be worn at all times when using the equipment.

3. Operators are to remain as far from the soures as possible. In no event should an operator be closer than 3 feet for any extended period of time.

4. Keep sources in the shielded position when not in use.

5. Keep equipment under lock and key when not in use.

6. Perform a leak test periodically on the equipment.

The above procedure should provide a safe environment for the use of this type of equipment. A periodic processing of the film badges worn by the personnel assigned to this project showed a consistent minimal dosage. Dosimeters were issued to personnel not permanently assigned to the project. The leak tests performed on the equipment have indicated no leakage during the 18 months of operation.

CONCLUSIONS:

The following conclusions are based on non-selective data obtained under a variety of field conditions by sub-professional personnel.

1. The equipment used in this program is sufficiently rugged for field usage with little more than normal care.

2. The battery voltage should be maintained at not less than 17.5 volts and should be recharged after each normal day of operation.

3. The moisture detection tube has appeared to be quite stable over the 18 month period, whereas, the Geiger-Muller Tube appears to be deteriorating to some extent.

4. A general procedure has been developed as a guide for the use of this equipment in the field, including certain laboratory check procedures. These are given in the Appendix.

5. Calibration curves for several materials have been derived and accuracy ranges estabilished for both moisture and density determinations.

6. In general the calibration curves for density do not coincide with the manufacturer's calibration curve, although they seem to approach it in the 110-130 lbs. per cubic foot range.

7. The calibration curves for moisture content do not coincide with the manufacturer's calibration curve.

8. The nuclear equipment is safe enough for use by the average construction worker, so long as he is properly instructed as to the hazards involved.

9. The so-called accuracy figures may be improved by measuring a greater volume of material by conventional methods.

RECOMMENDATIONS:

1. It is recommended that several units be purchased for further evaluation and use under actual construction conditions.

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APPENDIX

METHOD OF TEST FOR THE DETERMINATION OF IN-PLACE DENSITY BY USE OF NUCLEAR INSTRUMENTATION LDH DESIGNATION TR 424-64T

SCOPE

This method of test is intended to determine the density of soil, sand-clay-gravel, soil-lime and soil cement courses in the natural state or after compaction in an embankment by counting a proportional number of events occuring as a consequence of the interaction of a radioactive substance with the material to be tested.

APPARATUS

1. Scaler - Troxler Model 200B with a maximum counting rate of 25 kilocycles per second, equivalent to a resolution time of 40 microseconds and associated electronic equipment.

2. Surface Moisture Gauge - Troxler Model 117 (w/source) and Reference Standard. Any Louisiana Department of Highways accepted standard method of determining moisture content may be used in lieu of the surface moisture gauge.

3. Surface Density Gauge - Troxler Model SC - 120 (w/source).

4. A 5/8 Inch Wood Auger With Extension - The auger cutting edges to be filed down so as to make approximately 45° with the horizontal.

5. Brace

6. A hard steel spike 3/4 inches in diameter by 15 inches long.

7. Concrete block with dimensions of approximately 15 inches x 6 inches x 12 inches of known density and painted with epoxy paint. This block should have a 3/4 inch hole centered 2 inches from one end of the block. This hole must be vertical.

8. A supply of dry fine sand to use as a sand blanket when needed.

9. Hand Tools - Such as a 3 lb. hammer, shovel, etc., for leveling and smoothing the test area.

PROCEDURE

After selection of the test location, an area approximately 30 inches square is very carefully leveled and smoothed. If necessary, a very thin (1/8 inch or less) sand blanket is applied to reduce any large air voids.

The moisture device is connected to the scaler for a 3 minute warm up period (careful attention must be given to the manufacturer's instructions). A standard count is then run on the Polyethlene Block near the test location. It is important that the density gauge be at least 25 feet removed from the moisture device during this and subsequent operations. The moisture device is then firmly seated on the test location and 3 one minute counts obtained all of which must fall within the range of 1.5 times the square root of the average. The moisture device is rotated 120° (Figure 1) and the counts repeated, then rotated again 120° and the counts repeated. The 3 readings are then averaged and divided by the standard count, as previously determined, to get count ratio. The count ratio is plotted on the calibration chart (Figure 2) and the moisture content in pounds per cubic foot is read on the ordinate.

The moisture device is then disconnected and removed 25 feet or more from the test location. The density device is connected to the scaler and allowed to warm up for 3 minutes. A standard count is run, either with the probe in self-standard position or with the probe extended into some other standard medium. A vertical hole is then drilled into the test location to the required depth using the modified auger (the steel spike is used where it is difficult or impossible to use the brace and bit). The density device is placed on the test location and the probe lowered to the desired depth. The device is then pulled against the side of the hole and firmly seated. Three 1 minute readings are taken in each of the 3 positions at 120° (Figure 1). These are averaged and divided by the standard count to give count ratio which is plotted on the appropriate chart (Figure 3) to give wet density pounds per cubic foot.

Dry density in pounds per cubic foot is obtained by simply subtracting the moisture content in pounds per cubic foot from the wet density in pounds per cubic foot; for example if the wet density were determined to be 126.6 lbs. per cubic foot and the moisture content were 13.6 lbs. per cubic foot then, 126.6 minus 13.6 = 113.0 lbs. per cubic foot dry density. Further, if the moisture

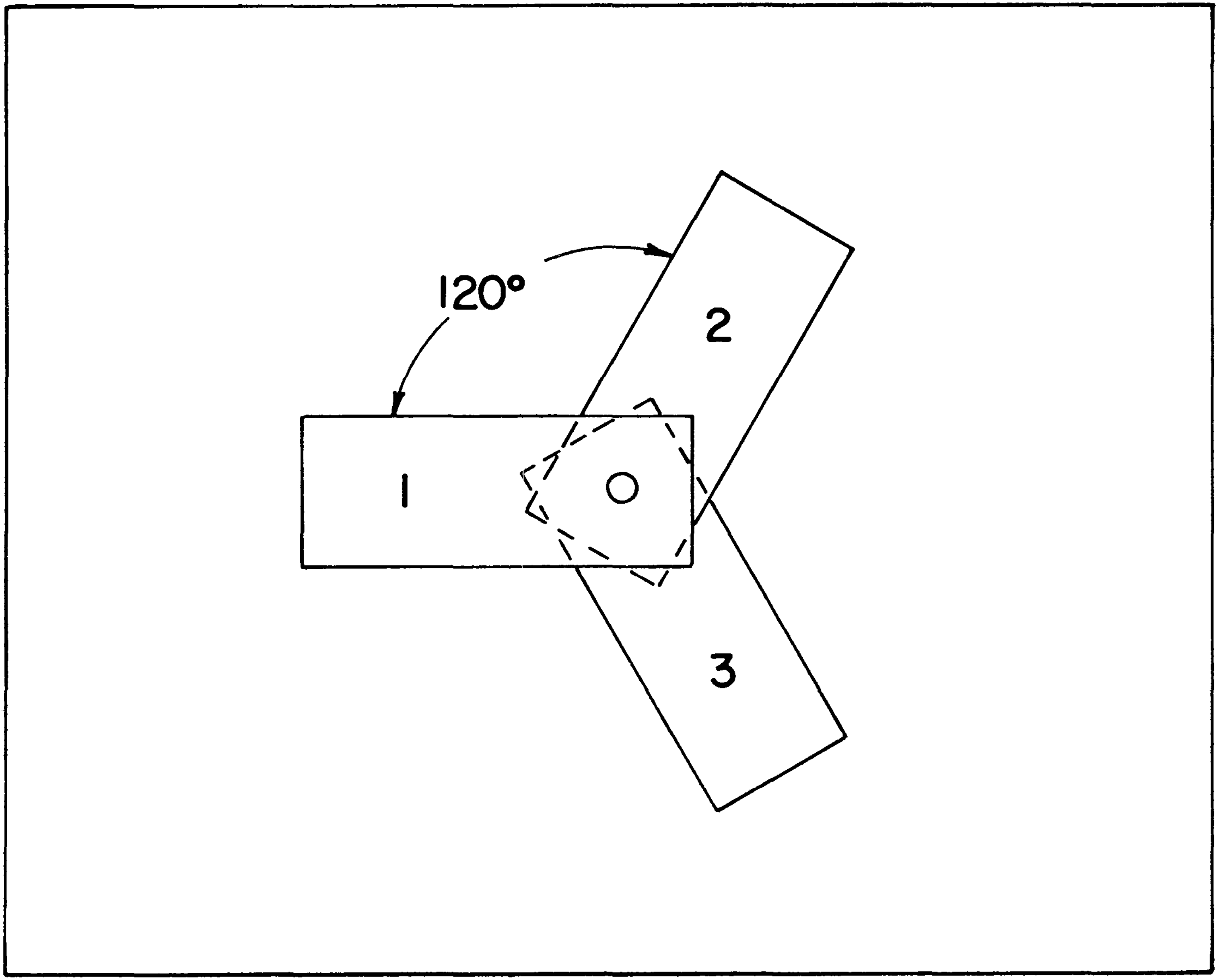

Figure 1-A - Schematic Diagram of Positioning Arrangement for Nuclear Gauges

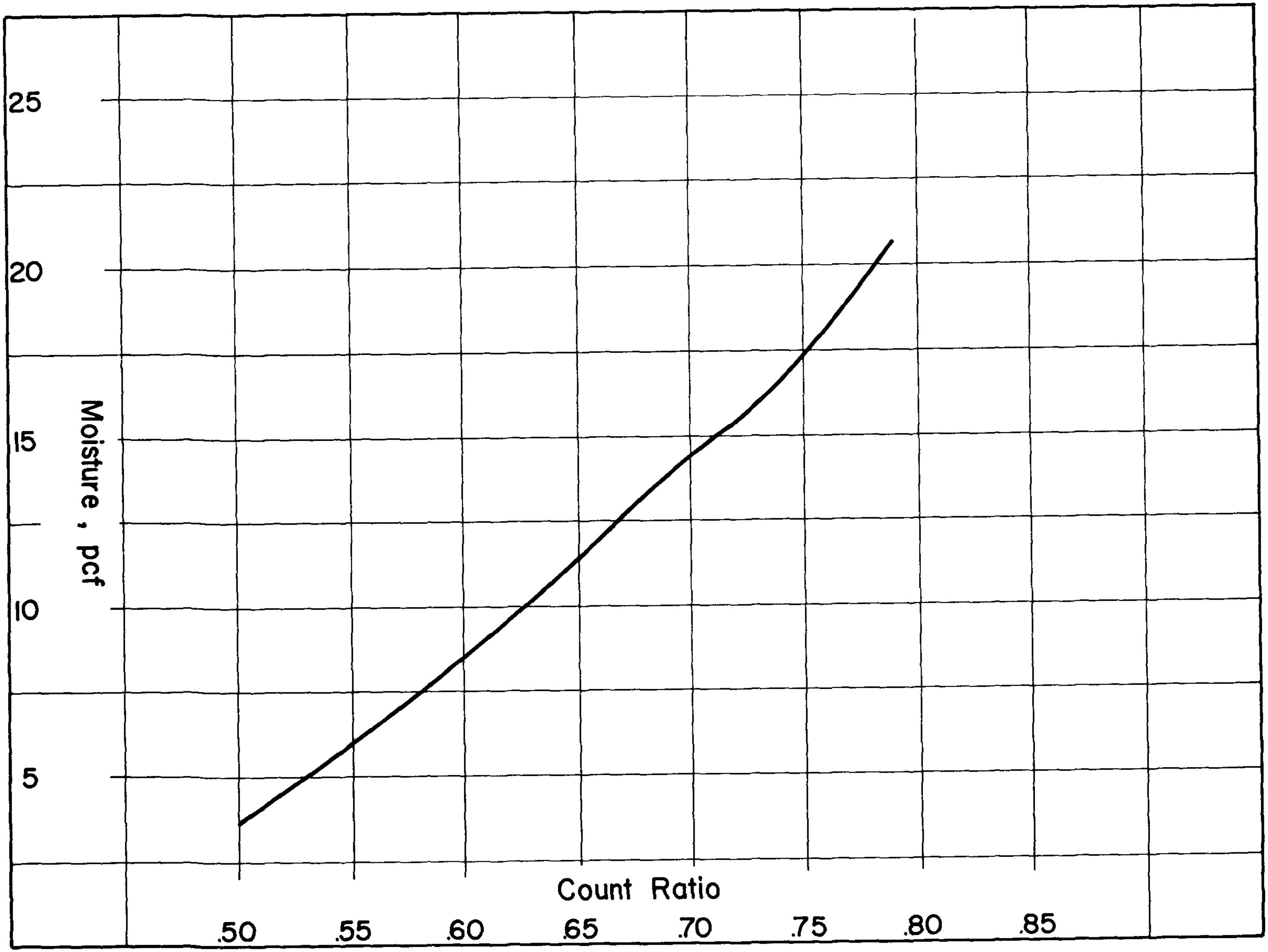

Figure 2A - Calibration Curve for Moisture Content (pcf) Determinations by Nuclear methods.

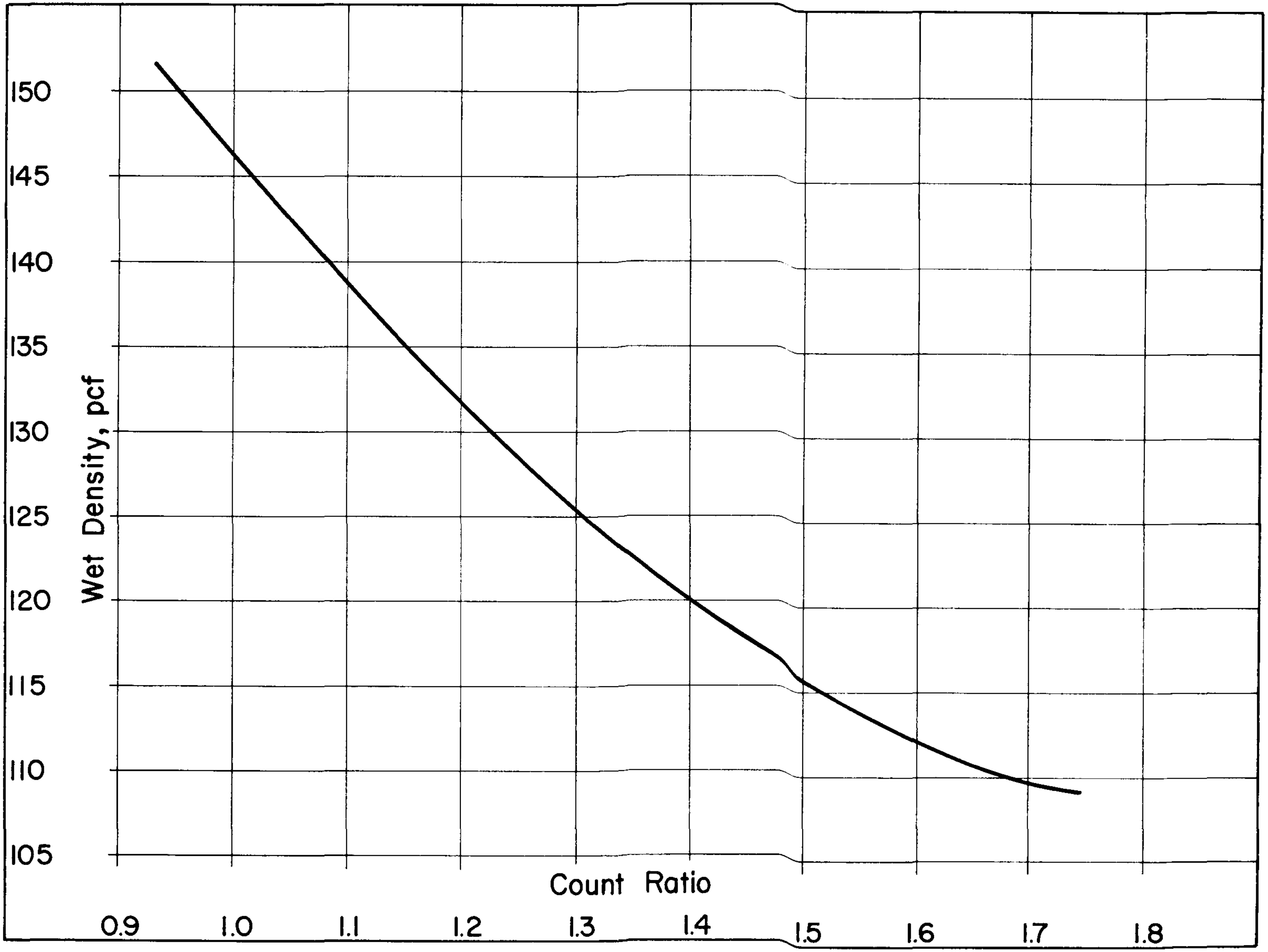

Figure 3A - Calibration Curve for Wet Density (pcf) Determinations by Nuclear Methods for a Density Depth of Six (6) Inches.

content must be expressed in per cent, then, 13.6 lbs. per cubic foot divided by 113.0 lbs. per cubic foot times 100 = 12.0%.

TABLE I

Operating Time (Minutes) vs Battery Voltage

Operating Time, Minutes	Battery Voltage
0	20.4
10	20.0
20	19.4
30	19.1
40	18.9
50	18.8
60	18.6
70	18.6
80	18.5
100	18.4
120	18.3
140	18.2
160	18.2
200	18.2
220	18.2
240	18.1
260	18.0
280	17.4
290	16.7
300	16.7
320	16.6
340	16.5
350	16.5

TABLE II

WARM UP TIME

SURFACE MOISTURE GAUGE

Operating Time No. of one min. counts	Standard Count	High Voltage	Gain No.
1	21,471		
2	21,793		
3	21,605		
4	21,620		
5	21,663		
6	21,917	1350	3
7	21,842		
8	21,803		
9	21,624		
10	21,676		

Total 217,014

Average 21,701

$1.5\sqrt{21,701} = \pm 220$ cpm

SURFACE DENSITY GAUGE

Operating Time No. of one min. counts	Standard Count	High Voltage	Gain No.
1	20,624		
2	20,157		
3	20,533		
4	20,286		
5	20,519		
6	20,603	1000	5
7	20,689		
8	20,419		
9	20,419		
10	20,574		

Total 204,823

Average 20,482

$1.5\sqrt{20,482} = \pm 214$ cpm

TABLE III

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 4 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 803-17-03 Type of Material - Sandy Loam			
125.6	1.949	15.0	.728
123.3	2.024	14.8	.697
119.3	2.187	12.9	.686
122.0	2.079	12.9	.682
122.7	2.154	17.7	.726
123.1	2.063	16.8	.742
126.5	2.049	12.1	.719
125.2	2.008	12.7	.719
125.1	1.987	12.7	.689
125.2	1.911	13.0	.698
122.3	2.020	10.6	.700
120.5	2.072	9.5	.704
120.9	2.065	11.1	.702
Project No. 424-02-12 Type of Material - Silty Clay A-6			
120.2	2.077	19.1	.703
118.8	2.120	18.0	.683
120.0	2.066	18.3	.702
128.9	1.877	18.5	.691
134.2	1.821	17.7	.683
131.1	1.875	18.3	.696
126.4	1.904	20.2	.726
127.1	1.879	19.4	.720
127.9	1.899	19.7	.725
125.9	1.924	20.1	.699
124.5	1.916	20.3	.690
126.2	1.911	20.6	.695
125.9	1.870	19.2	.686
127.3	1.851	20.2	.711
125.8	1.924	19.7	.677
Project No. 713-08-84 Type of Material - Silty Clay A-6			
123.9	2.049	19.4	.738
126.8	2.036	19.3	.738
121.8	1.986	17.2	.706
115.3	2.068	18.5	.714
116.2	2.149	17.0	.717
116.5	2.038	17.8	.687
Project No. 450-02-12 Type of Material - Silty Clay A-6			
119.5	2.041	15.6	.673
113.0	2.119	16.6	.676
117.3	2.035	17.3	.678
116.9	2.162	16.5	.686
113.9	2.179	17.2	.687
114.0	2.138	18.1	.698

TABLE IV

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 8 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 424-02-12 Type of Material - Silty Clay A-6			
120.2	1.005	19.1	.703
118.8	.951	18.0	.683
120.0	.884	18.3	.702
128.9	.843	18.5	.691
134.2	.756	17.7	.683
131.1	.783	18.3	.696
126.4	.813	20.2	.726
127.1	.750	19.4	.720
127.9	.761	19.7	.725
125.9	.801	20.1	.699
124.5	.819	20.3	.690
126.2	.756	20.6	.695
125.9	.740	19.2	.686
127.3	.754	20.2	.711
125.8	.747	19.7	.677
Northeast Front Rd. Traffic Circle Type of Material - Sandy Loam			
125.6	.839	15.0	.728
123.3	.899	14.8	.697
119.3	.960	12.9	.686
122.0	.895	12.9	.682
122.7	.898	17.7	.726
123.1	.867	16.8	.742
126.5	.841	12.1	.719
125.2	.867	12.7	.719
125.1	.833	12.8	.689
125.2	.813	13.0	.689
122.3	.883	10.6	.700
120.5	.916	9.5	.704
120.9	.905	11.1	.702
123.9	.896	19.4	.738
126.8	.916	19.3	.738
121.8	.944	17.2	.706
115.3	.943	18.5	.714
116.2	.961	17.0	.687
116.5	1.043	17.8	.717

TABLE V

RAW MATERIALS

DEPTH OF DENSITY - 6 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Interstate 410 Type of Material - Silty Clay Loam A-4			
121.1	1.317	17.1	.713
124.8	1.255	15.5	.664
124.2	1.353	16.0	.685
118.5	1.483	14.5	.668
118.9	1.458	15.1	.654
118.1	1.397	14.3	.650
127.8	1.293	17.0	.709
127.1	1.340	15.7	.692
119.0	1.425	10.6	.669
118.6	1.415	17.5	.716
121.5	1.388	17.5	.698
122.7	1.385	17.3	.738
122.8	1.393	17.7	.740
120.9	1.383	19.3	.743
124.3	1.395	19.7	.740
Project No. 278-03-07 Type of Material - Silty Clay A-6			
130.5	1.268	14.4	.720
131.1	1.263	13.5	.707
128.7	1.280	15.0	.717
125.0	1.330	17.3	.752
129.9	1.339	18.6	.752
130.6	1.336	15.8	.737
128.9	1.316	15.2	.744
130.4	1.309	16.9	.766
132.6	1.156	17.5	.765
128.5	1.336	13.1	.692
134.0	1.369	15.2	.742
134.9	1.279	17.0	.712
127.4	1.360	20.6	.759
Project No. 450-02-26 Type of Material - Sandy Loam A-2-4			
135.4	1.147	12.8	.624
128.0	1.213	13.2	.620
131.0	1.200	15.7	.652
129.8	1.151	12.5	.641
Project No. 450-02-26 Type of Material - Silty Clay A-6			
135.0	1.140	13.2	.644
131.6	1.195	14.3	.624
135.0	1.160	14.1	.662
132.3	1.175	13.0	.646
131.3	1.127	21.1	.634
131.9	1.169	10.4	.639

TABLE V (cont.)

RAW MATERIALS

DEPTH OF DENSITY - 6 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Krotz Springs Fill			
119.2	1.357	20.6	.669
119.3	1.370	19.3	.683
117.4	1.420	16.4	.660
117.8	1.381	22.0	.708
114.7	1.426	16.9	.690
113.8	1.472	18.1	.714
121.4	1.414	21.3	.704
118.3	1.386	21.3	.682
118.0	1.477	25.5	.688
121.1	1.321	21.9	.718
122.2	1.308	22.5	.675
125.0	1.337	19.6	.675
122.1	1.361	18.2	.655
114.6	1.426	19.4	.628
112.5	1.502	16.1	.643
110.5	1.482	15.9	.633
118.7	1.342	19.6	.675
125.4	1.318	21.1	.689
113.0	1.349	19.9	.656
114.9	1.367	21.3	.697

TABLE V (cont.)

RAW MATERIALS

DEPTH OF DENSITY - 6 inches

Volumeter Sand Cone* Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Interstate Baton Rouge Type of Material - Select			
130.4	1.276	16.2	.638
123.0	1.359	17.1	.630
124.2	1.453	17.8	.674
Krotz Springs Fill Type of Material - Sand Shell			
132.5*	1.095	7.1	.560
134.6*	1.127	7.0	.572
136.1*	1.112	7.2	.562
134.9*	1.075	7.0	.556
134.1*	1.042	7.1	.553
135.6*	1.151	8.4	.542
149.3*	1.042	7.9	.553
138.2*	1.036	7.3	.553
132.5*	1.123	6.4	.548
142.0*	1.049	7.8	.571
124.8*	1.382	6.9	.562
127.3*	1.304	6.9	.551
124.8*	1.261	7.1	.520
124.1*	1.311	6.7	.554
132.7*	1.246	7.3	.549
128.0*	1.210	7.5	.555
125.6*	1.761	7.0	.557
137.5*	1.174	7.5	.538
130.7*	1.175	7.0	.542
139.2*	1.188	7.5	.557
140.7*	1.086	5.6	----
141.3*	1.091	5.5	----
141.3*	1.118	5.6	----
144.3*	1.103	6.3	----
138.5*	1.122	6.4	----
140.4*	1.141	6.5	----
142.1*	1.159	6.1	----
142.8*	1.087	6.1	----
132.8*	1.123	5.8	----
140.1*	1.134	6.5	----

TABLE V (cont.)

RAW MATERIALS

DEPTH OF DENSITY - 6 inches

Volumeter Sand Cone* Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio

TABLE V (cont.)

RAW MATERIALS

DEPTH OF DENSITY- 6 inches

Volumeter Sand Cone* Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. Grangeville 254-31-05 Type of Material - Sand-Clay-Gravel			
140.9*	1.095	8.4	.636
150.7*	1.170	9.0	.636
149.7*	1.041	8.2	.643
144.7*	1.025	8.2	.664
148.2*	1.065	9.4	.636
148.5*	1.073	8.4	.619
143.7*	1.077	7.8	.617
144.8*	1.045	8.3	.660
142.2*	1.149	7.2	.606
142.6*	1.150	6.5	.606
137.3*	1.107	6.9	.606
143.5*	1.111	7.7	.598
146.2*	1.085	7.7	.601
142.0*	1.106	7.9	.601
148.5*	1.058	7.7	.598
144.5*	1.060	6.8	.580
Project No. Gonzales East 803-23-02 Type of Material - Sand-Clay-Gravel			
139.9*	1.091	5.2	.615
145.6*	1.140	4.5	.603
144.0*	1.135	4.1	.604
144.3*	1.150	4.8	.591
146.0*	1.104	4.0	.579
144.7*	1.195	3.7	.576
142.1*	1.109	4.2	.597
Project No. 803-22-06			
131.7*	1.214	7.9	.614
136.1*	1.143	12.4	.686
142.8*	1.192	10.8	.657
Lake Bisteau - Elm Grove Type of Material - Select A-4			
118.7	1.541	11.4	.637
117.2	1.543	12.3	.662
118.5	1.541	11.5	.648
116.5	1.563	10.1	.628
116.5	1.570	10.1	.627
115.2	1.592	9.8	.591
114.7	1.656	9.3	.590
112.0	1.600	9.4	.596
115.2	1.604	9.6	.584
111.8	1.645	9.2	.571
105.9	1.743	9.9	.598
109.0	1.732	9.4	.568

TABLE V (cont.)

RAW MATERIALS

DEPTH OF DENSITY- 6 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Lake Bisteau - Elm Grove Type of Material - Select A-4			
108.5	1.731	9.2	.583
107.0	1.753	8.6	.573
110.4	1.655	9.4	.580
114.2	1.539	10.0	.602
118.7	1.480	10.7	.612
113.8	1.520	10.1	.596
109.9	1.624	10.3	.596
110.5	1.588	9.7	.600
113.4	1.588	12.1	.589
109.9	1.631	10.0	.600
111.0	1.625	9.9	.602
110.6	1.554	9.9	.584
108.6	1.642	8.8	.633
Interstate Baton Rouge Washington Street Type of Material - Select			
122.9	1.388	13.4	.582
128.1	1.431	14.2	.584
121.2	1.488	12.7	.590
117.9	1.459	12.2	.595
122.2	1.360	14.0	.601
106.4	1.429	11.2	.578
118.7	1.378	13.0	.600
117.7	1.479	13.1	.582
125.7	1.473	13.6	.595
121.3	1.427	10.0	.584
120.4	1.432	12.3	.575
118.4	1.441	12.2	.575
118.6	1.405	11.7	.570
112.1	1.409	10.9	.553
114.6	1.404	10.9	.558
120.3	1.422	10.7	.579
115.6	1.465	10.3	.590
119.5	1.429	13.2	.609
119.0	1.464	11.5	.587
118.5	1.443	12.1	.582
118.4	1.471	10.8	.569
121.7	1.454	11.0	.560
123.5	1.461	12.1	.562
120.7	1.493	11.7	.586
120.5	1.452	11.4	.592
119.3	1.433	10.6	.544
122.5	1.400	11.6	.568
111.5	1.514	7.9	.557
117.1	1.620	10.1	.563
112.6	1.580	9.1	.557
113.8	1.492	15.1	.612
110.8	1.429	15.2	.651

TABLE VI

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 6 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 424-02-12 Type of Material - Silty Clay A-6			
120.2	1.417	19.1	.703
118.8	1.461	18.0	.683
120.0	1.414	18.3	.702
128.9	1.258	18.5	.691
134.2	1.197	17.7	.683
131.1	1.222	18.3	.696
126.4	1.274	20.2	.726
127.1	1.227	19.4	.720
127.9	1.271	19.7	.725
125.9	1.301	20.1	.699
124.5	1.268	20.3	.690
126.2	1.232	20.6	.695
125.9	1.208	19.2	.686
127.3	1.202	20.2	.711
125.8	1.226	19.7	.677
Northeast Front Rd. Traffic Circle Type of Material - Sandy Loam A-2-4			
125.6	1.295	15.0	.728
123.3	1.377	14.8	.697
119.3	1.475	12.9	.686
122.0	1.413	12.9	.682
122.7	1.431	17.7	.726
123.1	1.374	16.8	.742
126.5	1.322	12.1	.719
125.2	1.367	12.7	.719
125.1	1.313	12.8	.689
125.2	1.279	13.0	.689
122.3	1.384	10.6	.700
120.5	1.401	9.5	.704
120.9	1.409	11.1	.702
Project No. 450-02-26 Type of Material - Loam			
121.0	1.385	15.4	.681
115.9	1.512	13.0	.651
119.5	1.385	15.6	.673
113.9	1.523	17.6	.687
114.0	1.467	18.1	.698
116.5	1.547	18.4	.672
116.4	1.478	18.0	.671
116.1	1.450	17.5	.682
127.1	1.400	19.0	.670

TABLE VI (cont.)

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 6 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 450-02-26 Type of Material - Sandy Loam			
117.3	1.467	17.3	.679
113.0	1.504	16.6	.676
116.9	1.554	16.5	.686
120.6	1.399	17.7	.680
119.0	1.443	17.0	.686
122.0	1.369	17.5	.682
116.0	1.476	18.7	.704
118.2	1.403	17.9	.691
120.6	1.432	16.8	.665
121.5	1.448	19.0	.686
113.4	1.527	18.3	.691
116.0	1.578	18.7	.698
Project No. 450-02-26 Type of Material - Clay Loam			
113.8	1.503	16.1	.649
106.0	1.548	16.2	.684
108.1	1.532	17.2	.664
Project No. 424-02-12 Type of Material - Loam			
118.8	1.476	19.3	.746
112.7	1.527	17.4	.732
118.5	1.454	18.8	.742
119.0	1.373	19.5	.715
120.8	1.373	17.1	.702
117.7	1.482	16.9	.701
Project No. 424-02-12 Type of Material - Silty Loam			
119.7	1.385	18.9	.734
118.3	1.468	17.6	.715
117.7	1.443	17.7	.704
116.2	1.420	17.8	.707
115.0	1.468	16.7	.709
Project No. 424-02-12 Type of Material - Sandy Loam			
120.5	1.371	18.9	.730
112.5	1.531	15.7	.662
118.0	1.404	18.4	.709

TABLE VI (cont.)

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 6 inches

Volumeter Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 424-02-12 Type of Material - Soil Cement			
120.5	1.369	16.3	.701
115.0	1.519	16.1	.702
115.6	1.493	16.8	.681
Ferriday-Vidalia Type of Material - Soil Cement			
119.6	1.391	20.0	.710
120.8	1.391	18.2	.721
122.8	1.343	19.7	.720
120.9	1.375	18.2	.736
124.4	1.367	18.6	.747
125.3	1.339	19.6	.735
119.6	1.388	14.4	.663
122.1	1.373	14.3	.678
126.2	1.359	15.4	.698
119.0	1.460	17.5	.692
120.2	1.428	17.4	.692
120.2	1.373	14.9	.706
117.9	1.456	14.6	.693
116.0	1.468	16.4	.716
118.1	1.468	16.6	.721
122.7	1.412	15.9	.693
119.9	1.424	13.6	.728
117.5	1.433	18.4	.729
118.4	1.410	18.6	.726
119.7	1.449	19.0	.735
122.8	1.469	16.2	.695
120.0	1.430	18.3	.715
119.3	1.433	18.2	.706
116.3	1.436	17.3	.715
118.0	1.460	17.8	.710
120.3	1.384	19.3	.728
117.6	1.404	18.8	.720
121.9	1.383	19.9	.724
122.6	1.463	19.8	.727
117.2	1.438	17.1	.717

TABLE VI (cont.)

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 6 inches

Sand Cone Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 84-07-07 Type of Material - Sand Clay Gravel			
133.0	1.142	9.5	.632
130.1	1.168	10.3	.633
129.6	1.211	9.6	.652
129.9	1.196	9.5	.649
123.6	1.235	9.3	.661
127.7	1.247	7.8	.632
132.1	1.219	16.6	.628
134.8	1.197	11.3	.602
130.4	1.274	8.4	.625
130.8	1.223	8.2	.594
132.0	1.207	8.7	.590
126.3	1.211	9.5	.614
124.9	1.255	9.5	.590
133.9	1.140	11.1	.659
126.8	1.176	8.8	.661
130.4	1.170	8.6	.660
129.0	1.205	10.8	.650
121.4	1.212	10.8	.649
133.1	1.086	10.1	.635
130.7	1.150	10.0	.649
129.1	1.146	10.8	.625
127.3	1.137	10.1	.625
128.6	1.159	10.1	.653
122.3	1.185	9.8	.631
130.9	1.173	10.1	.628
129.8	1.159	7.0	.629
128.2	1.166	10.1	.622
127.8	1.160	10.0	.613
129.2	1.231	10.6	.635
123.4	1.257	9.5	.628
115.2	1.313	9.9	.635
122.9	1.287	9.7	.640
118.5	1.234	9.9	.636
127.8	1.246	10.1	.638
127.6	1.242	8.1	.655
127.4	1.218	9.6	.625
126.6	1.275	8.0	.649
119.5	1.258	7.2	.637
126.0	1.214	8.9	.647
130.5	1.280	8.7	.646
133.3	1.267	9.3	.666
133.0	1.253	9.5	.659
122.2	1.265	8.6	.673
134.0	1.257	9.0	.662
129.8	1.278	9.3	.671
135.2	1.255	9.2	.670

TABLE VI (cont.)

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 6 inches

Sand Cone Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Project No. 84-07-07 Type of Material - Sand Clay Gravel			
125.9	1.312	8.5	.669
125.8	1.299	8.5	.674
128.1	1.230	10.2	.662
119.0	1.231	6.8	.688
120.0	1.239	9.0	.637
120.0	1.219	9.2	.648
129.5	1.230	10.1	.668
124.2	1.277	7.6	.646
127.7	1.361	8.1	.645
Project No. 740-00-36 Type of Material - Sand Shell			
147.6	1.042	15.7	.673
149.6	0.995	15.3	.685
151.3	1.089	12.4	.670
139.0	1.035	14.2	.670
139.5	1.033	15.0	.670
152.3	0.989	10.9	.686
149.7	0.974	13.8	.680
147.0	1.055	13.7	.664
146.4	1.066	15.3	.705
148.1	1.099	14.6	.684
150.8	0.967	15.2	.710
142.9	1.040	14.7	.646
151.1	0.993	15.2	.714
141.9	1.098	14.3	.693
144.9	1.050	14.0	.673
142.9	1.129	13.4	.676
Causeway - Veteran Exchange - New Orleans Type of Material - Sand Shell			
139.9	1.127	6.8	----
124.2	1.030	5.9	----
118.2	1.229	4.7	----
127.1	1.095	5.1	----
136.8	1.018	6.4	----
130.9	1.218	9.6	----
125.3	1.285	5.3	----
127.0	1.231	6.0	----
132.7	1.069	7.4	----
144.5	0.996	6.6	----
133.3	1.073	6.0	----
140.1	1.051	8.2	----
141.4	1.128	6.4	----
132.9	0.983	6.5	----
130.6	1.150	5.0	----
146.7	1.008	6.6	----
138.4	1.024	5.7	----
146.7	1.014	6.9	----

TABLE VI (cont.)

CEMENT STABILIZED MATERIALS

DEPTH OF DENSITY- 6 inches

Sand Cone Wet Density	Nuclear Wet Density Count Ratio	Oven Dry Moisture Lbs./cu.ft.	Nuclear Moisture Count Ratio
Causeway - Veteran Exchange - New Orleans Type of Material - Sand Shell			
140.0	0.971	6.8	----
141.4	0.939	9.6	----
140.0	0.971	9.6	----
142.8	1.014	11.7	----
146.4	1.183	11.3	----
144.6	1.109	11.5	----
157.4	0.974	13.8	----
131.5	1.124	10.5	----
145.7	1.034	13.5	----
147.1	0.976	12.6	----
154.1	1.040	12.6	----
149.3	1.053	12.8	----
138.4	1.205	11.1	----
121.9	1.277	9.0	----
135.5	1.078	11.4	----
128.5	1.122	10.4	----
146.8	0.994	11.9	----
136.8	1.006	10.8	----
128.3	1.147	9.8	----
133.4	1.105	10.8	----
Bonnerville Intersection New Orleans Type of Material - Sand Shell			
139.4	1.152	11.7	.667
140.3	1.103	12.4	.656
142.2	1.143	11.8	.642
146.4	1.050	12.8	.686
130.8	1.093	10.6	.654
132.2	1.135	10.6	.666
147.3	1.048	12.6	.655
143.1	1.062	12.7	.664
145.1	1.105	12.9	.630
146.4	0.976	11.6	.684
149.2	1.024	13.5	.689

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