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FIELD AND LABORATORY EVALUATION OF THE MICHIGAN NUCLEAR GAGE

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Synopsis

This report presents the results of a laboratory and field evaluation of the Michigan State Highway Department combination nuclear moisture and density gage, undertaken to determine the suitability of this equipment for routine compaction control.

Attempts were made to correlate nuclear gage readings with corresponding values obtained with the conventional Rainhart method and with absolute densities obtained from known volumes and weights of large laboratory samples. This phase of the work was performed using several types of soil and soil-aggregate combinations ranging from clay to 3/4-in. top-sized gravel. Comparison was made between the MSHD gage and commercial models in which separate sources were used to measure moisture and density.

Results of these studies showed that the MSHD nuclear gage was not yet ready for use under field conditions. Relationships between nuclear count rates and moisture and density were established but the instrument could not be calibrated to the degree of accuracy and consistency required. Best results were obtained with the moisture-indicating portion of the gage. Density readings were quite erratic, particularly with coarse aggregates. Laboratory tests indicated that the MSHD gage was as satisfactory as the commercial models and much easier to use.

During this work, several improvements were made in the gage system and considerable background information obtained concerning its use and operating characteristics. Calibration in the field against Rainhart results proved to be unsatisfactory and it is recommended that such attempts be discontinued. Instead, the emphasis of future work should be placed on obtaining an absolute calibration curve for the instrument by using samples of known characteristics, prepared under carefully controlled conditions. Until such calibration curves can be obtained, the MSHD combination nuclear gage must be considered still in the developmental stage.

Research Project 59 E-21, Application of Nuclear Methods for Measuring Soil Moisture and Density, was assigned to the Soils and Pavement Evaluation Unit of the Physical Research Section during November 1959. The primary purposes of the project were to improve the operating characteristics of the Department's nuclear moisture and density measuring equipment by laboratory and field study, to simplify the maintenance required, to develop controlled tests for positive calibration of the equipment, and to promote a better understanding of the potential of the nuclear method for field density control. The Michigan State Highway Department nuclear equipment was described in detail in Research Report No. 316 (1959).

The MSHD nuclear gage was first used by the Soils Unit during the construction of experimental test sections on M 46 between Newaygo and Howard City. The more important findings of this work were:

1. No usable relationship could be obtained between count rates of the nuclear gage and the densities and moisture contents obtained by conventional Rainhart tests.* Typical results of attempted correlations are shown in Fig. 1.

2. The proximity of certain automotive ignition systems seriously affected moisture and density count rates. This phenomenon was verified later in the laboratory and the gages were modified to eliminate this defect.

3. A new concept was developed for use of the gage in density control. In this method the gage could be used for qualitative rather than quantitative results. Fig. 2 shows results obtained when count rates were measured at a given location after successive passes of compaction equipment. This relationship suggests that the maximum density obtainable by a given compaction effort could be shown by count rate measurements of the density gage. This point would be indicated by the flat portion of the curve. With this compaction control method it would be unnecessary to know absolute density. It was suggested that a direct-reading dial (rate meter) be substituted for the more complicated decade scaler in obtaining the maximum density count rate position. This application of the nuclear gage should be an important future investigational phase of the work.

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* In this report, nuclear gage readings are expressed as counts per minute for both density and moisture content. Conventional density is expressed in pounds per cubic foot, wet basis, and moisture content in pounds of water per cubic foot as determined by drying the sample.

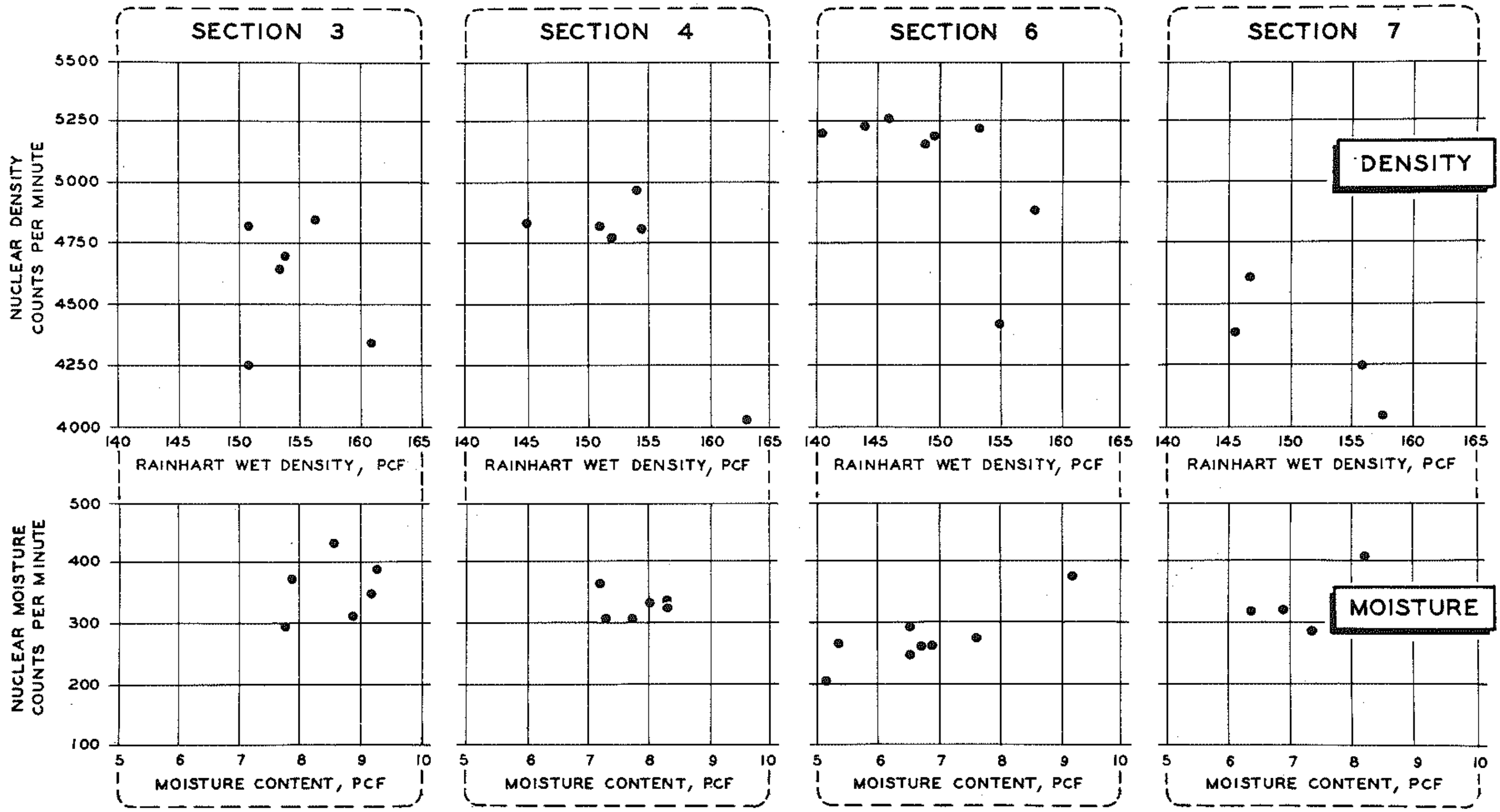

Figure 1. Attempted field correlations of the nuclear gage (M 46 test section--22A gravel).

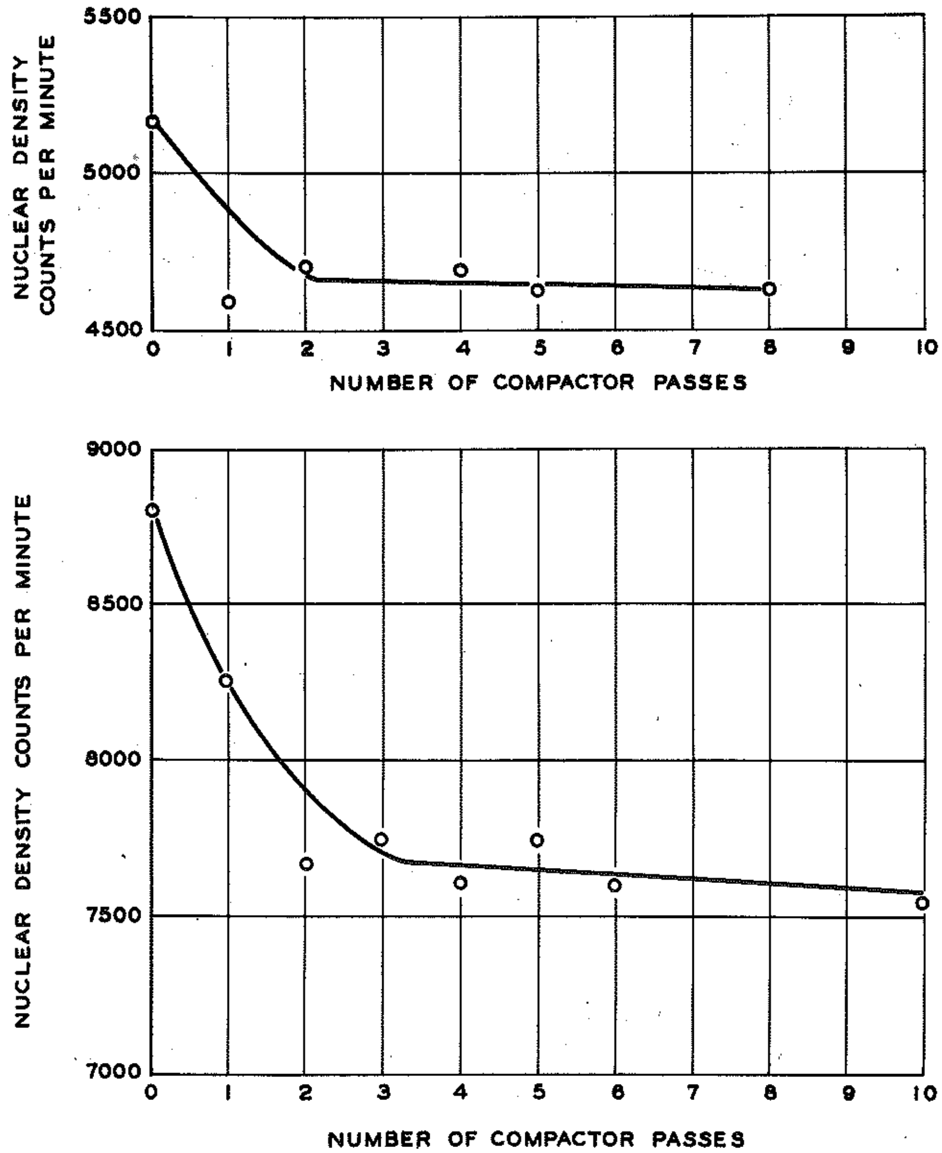

Figure 2. Effect of field compaction on nuclear gage count rates (M 46 test section--22A gravel).

The immediate concern of this project, however, was to obtain an absolute calibration of the MSHD nuclear gages so that a count rate value could be converted directly into pounds per cubic foot of density. Based on this work and that of other agencies working in this field, a program was set up for thorough evaluation of the characteristics of the gages under controlled laboratory conditions of test.

SCOPE OF LABORATORY TESTING

The laboratory testing program was set up to include: 1) calibration of the moisture and density gages with three soil types--22A gravel, sand, and clay*--under carefully controlled moisture and density conditions; 2) comparison of the MSHD combination gage with commercial models made by Nuclear-Chicago Corporation, in which separate gages are used for moisture and density measurements; and 3) study of the Rainhart method, which is the conventional method for measuring field density in Michigan. The commercial gages were borrowed from Dr. E. A. Erickson, Michigan State University College of Agriculture.

On February 25, 1960, a committee was formed within the Research Laboratory Division to direct all programs involving use of radioactive isotopes. At its first meeting, specific items of work were incorporated into the laboratory program and assigned to the Soils Unit. In addition to the laboratory work, supplemental field studies were planned at selected areas near the laboratory. On May 18 it was decided to place greater emphasis on the field portions of this work. For this reason, some laboratory results are fragmentary and inconclusive.

DETERMINATION OF SAMPLE SIZE

One of the first problems was determining the size of samples to be used in the laboratory tests. Space and handling limitations required that the container be as small as possible, but of sufficient size to prevent dimensional effects on the gage count rates.

Fig. 3 shows the results of a test in which the depth of the sample was increased by 3-in. increments until the count rate of the measuring gage became constant. This test indicated that a sample 9-in. deep should be satisfactory. The same figure includes the count rates obtained using an expandable box to determine satisfactory lateral dimensions. These results indicated that a gage's count rate was not affected appreciably by widths of 15 in. or more.

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* In this report "clay" is used to designate fine-grained plastic soil as contrasted to sand and gravel. It does not necessarily refer to a true clay.

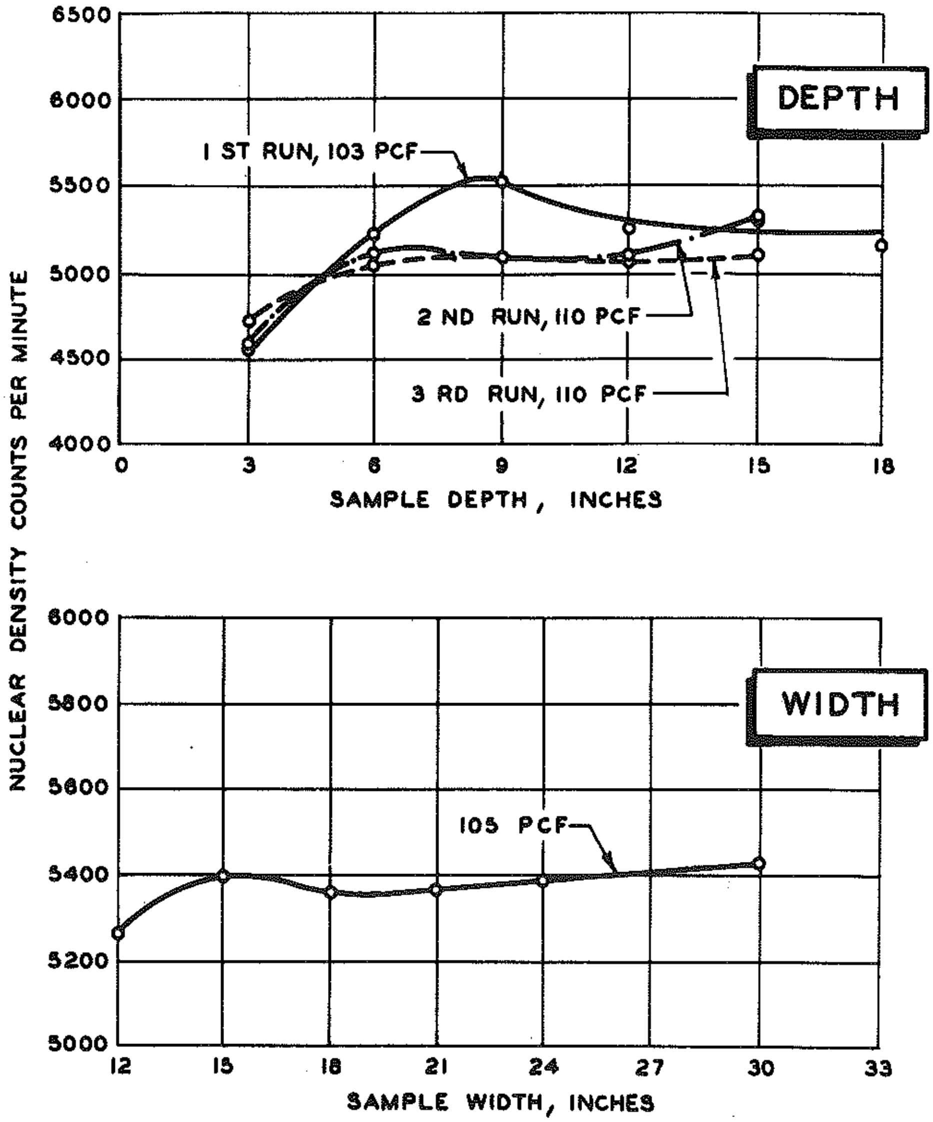


Figure 3. Variation in density counts with changes in dimensions of samples (laboratory calibration box).

On the basis of these tests a sample box 18-in. square by 12-in. deep was selected for the laboratory tests. The adequacy of these dimensions was checked by obtaining count rates as a gage was moved progressively in short increments across the surface of a compacted sample from one edge to another. The gage positions and corresponding count rates for moisture and density values are shown in Fig. 4. These data were obtained with only one orientation of the gage. When the gage was rotated to other positions, similar curves were obtained.

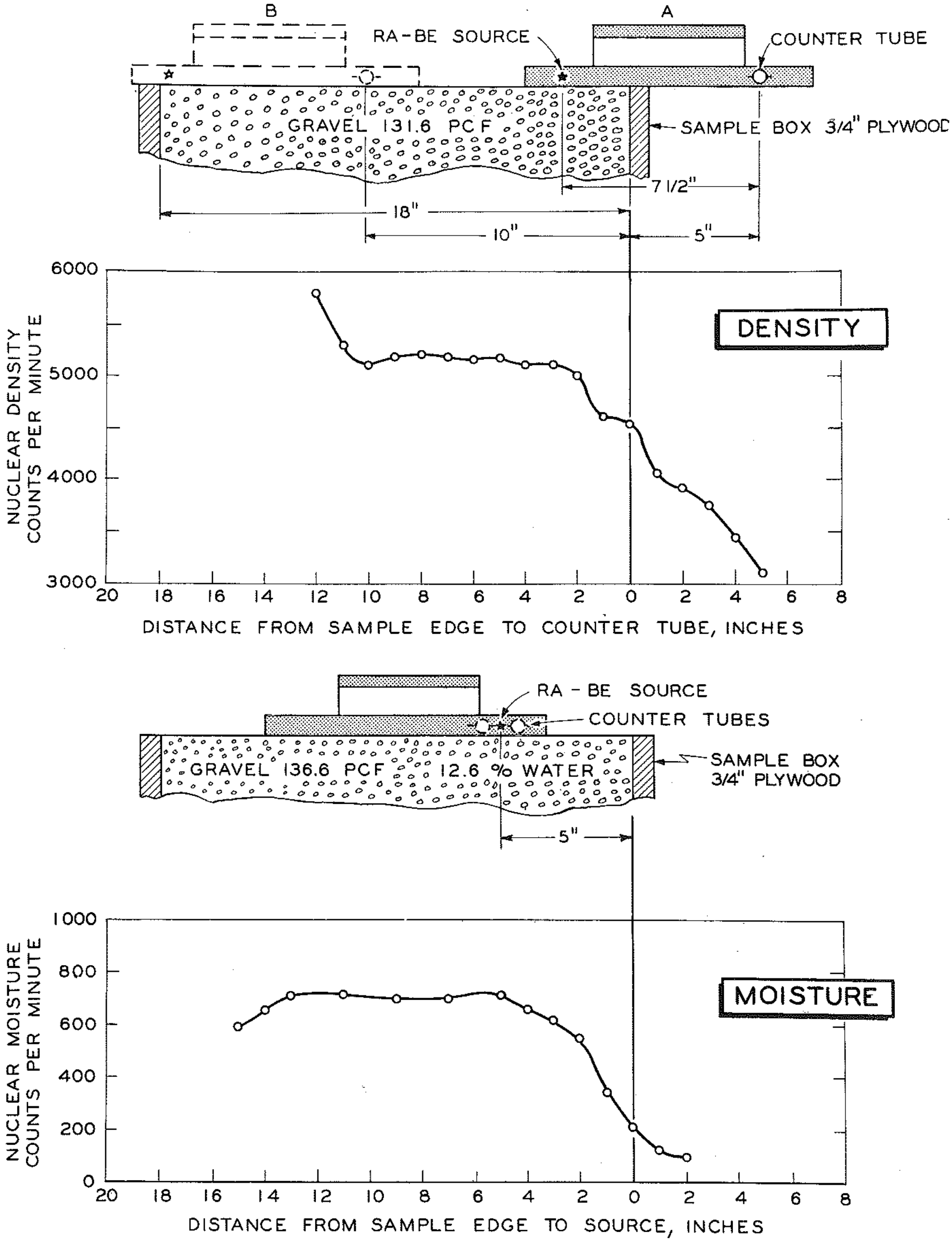


Figure 4. Moisture and density influence lines for standard size laboratory sample.

These tests confirmed the adequacy of the box dimensions and also indicated the approximate influence area for each source radiation. Fig. 5 shows the generally indicated sphere of influence for both the moisture and the density sources of the gage. Future studies are necessary to determine those portions of the sphere of influence which have the most effect on count rates, and whether the area of influence remains constant at all times.

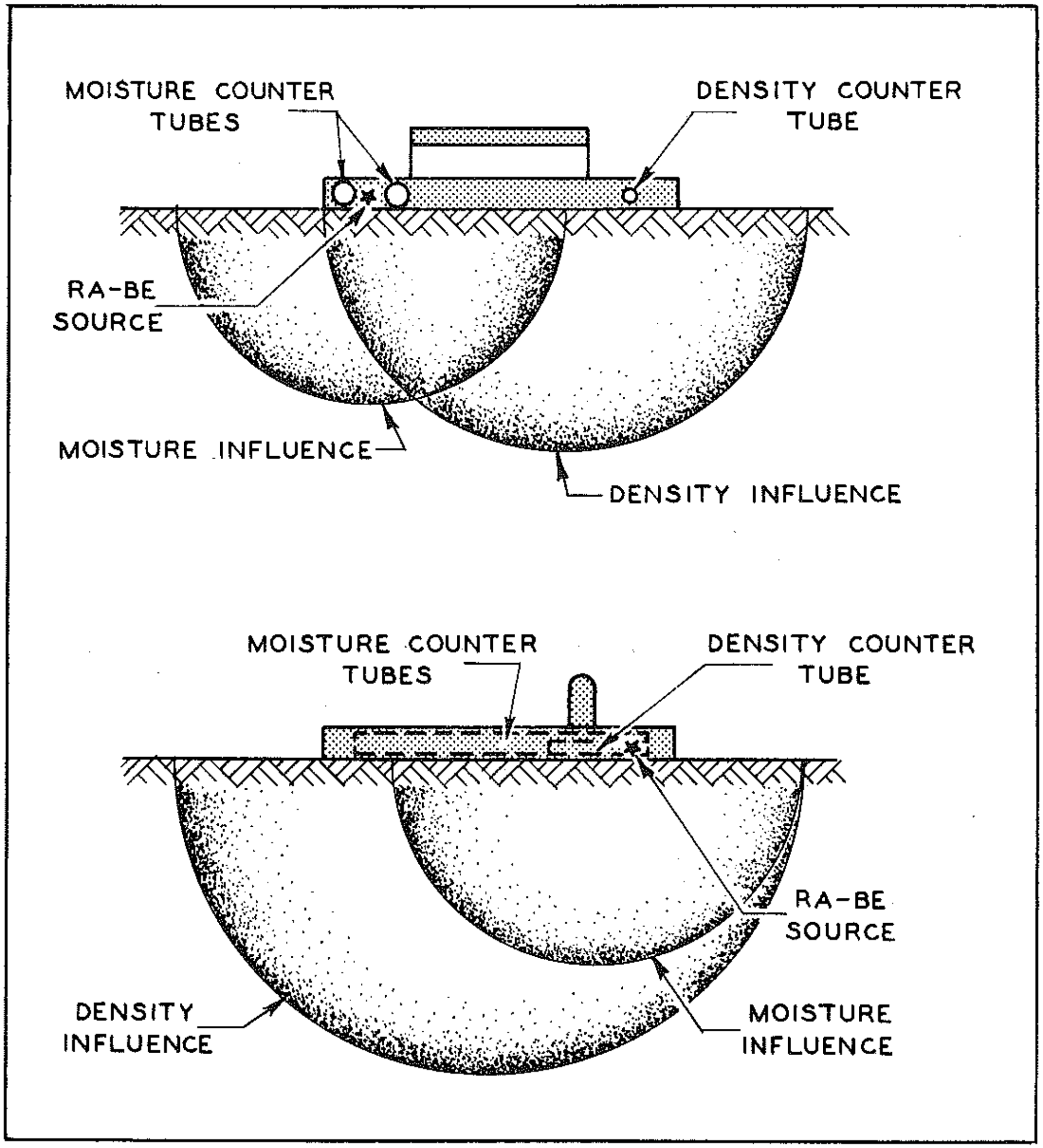


Figure 5. Spheres of influence of moisture and density measurements (two gage positions).

CALIBRATION TESTS

The nuclear gages were calibrated in the laboratory by measuring count rates obtained on prepared samples of materials compacted to known density and moisture content. The density of the sample as placed was determined on a weight-volume basis using the entire sample as placed in the box. Soil quantities of known weight were tamped into place in 3-in. layers until the box was filled to a depth of 12 in. Moisture samples were taken prior to placing the material and at the end of testing. In this manner the densities and moisture contents were as near absolute values as possible. Such densities are designated "absolute" values in this report.

Count rates were found to vary as a gage was rotated in a horizontal plane about a given point, probably due to the non-circular shape of the sphere of influence of the radioactive source. Except for special tests all gage readings represent an average of four 2-min counts taken at 90° intervals around the center of the area being measured.

Figs. 6 through 10 show the density and moisture calibration curves for three MSHD combination gages, the Nuclear-Chicago gages P-21 and P-22, and the density calibration curve for one of the single-source gages fabricated during early stages in the development of the MSHD nuclear equipment. These curves were developed using different materials which were placed to give a range in density and moisture content. To obtain uniformity in the sample, only the -1/4 fraction of a graded gravel was used. Concrete and granite blocks were included in the calibration of gage No. 4, which is the gage used for most of the field tests.

The general trend of the results was similar for all the gages tested. The moisture calibration curves were generally satisfactory, all gages giving good correlation between nuclear readings and oven-dry moisture determinations, expressed in pounds of water per cubic foot of material.

The density calibrations varied, however. In studying these data it should be noted that the same number of tests was not used in developing all curves. Commercial gages P-21 and P-22 were borrowed and not always available for specific tests. The slopes were best for the calibration curves for MSHD gage No. 4 and the commercial density gage. The cesium gage was least satisfactory in this respect.

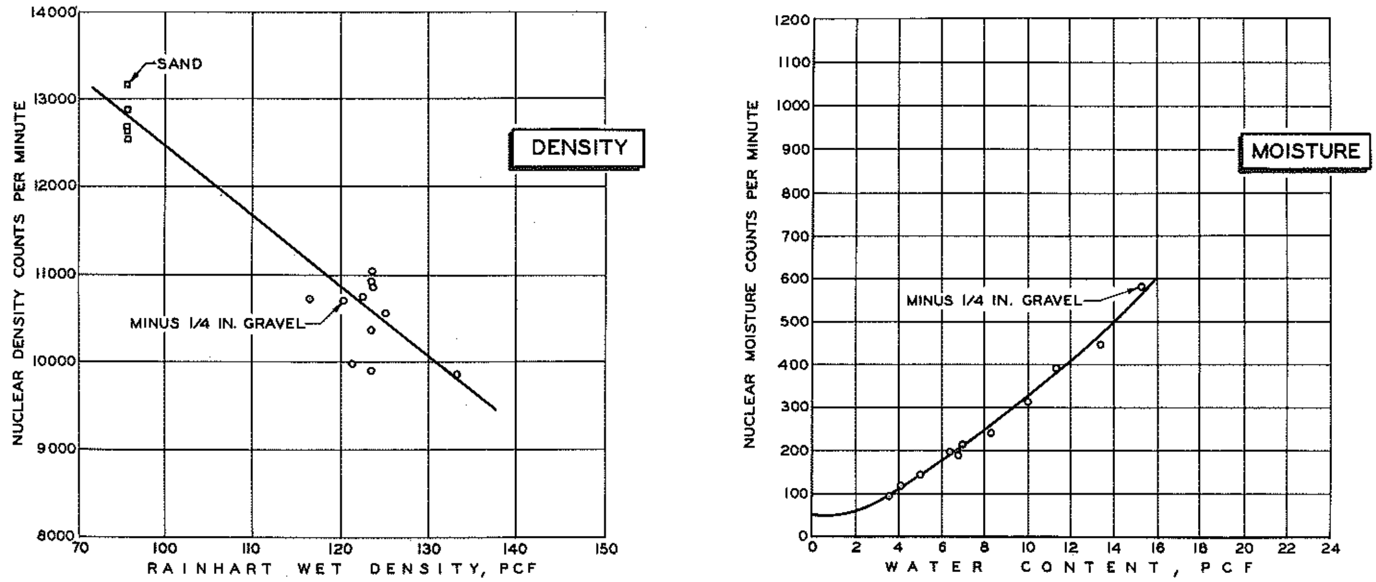


Figure 6. Laboratory calibration curves:
MSHD gage No. 1.

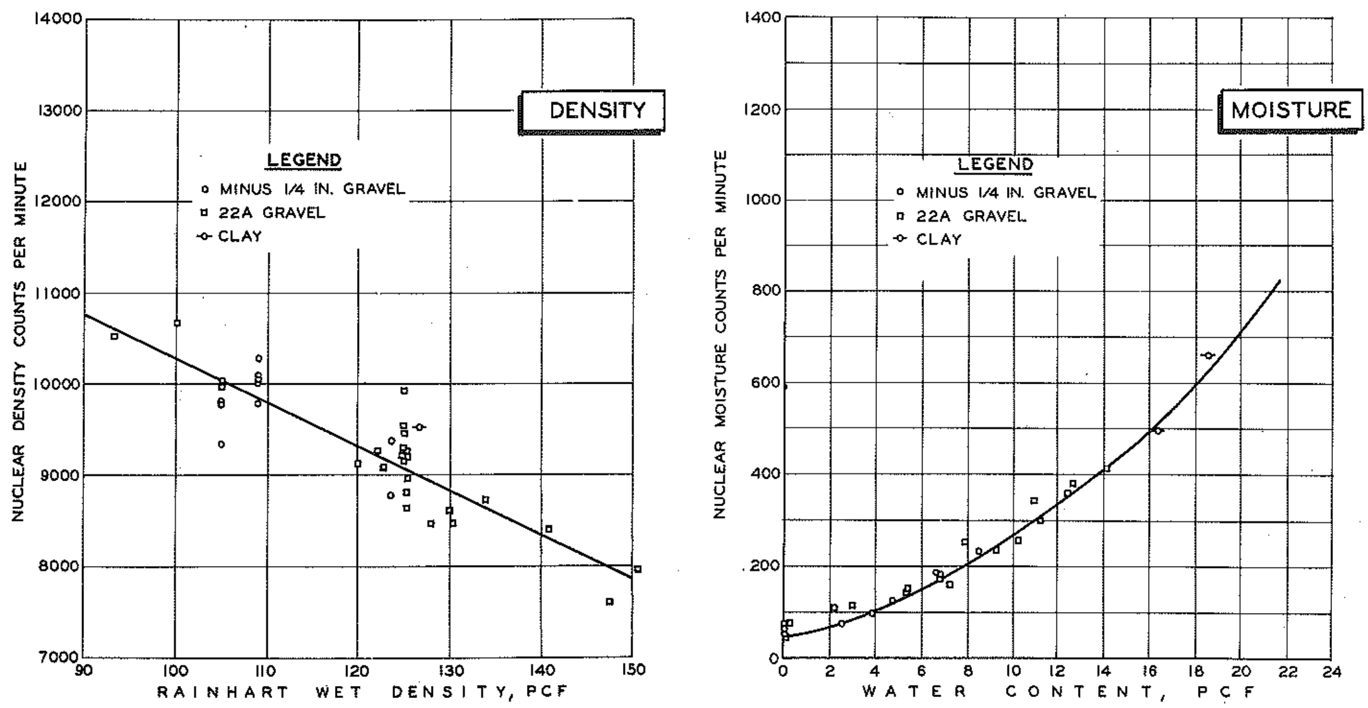
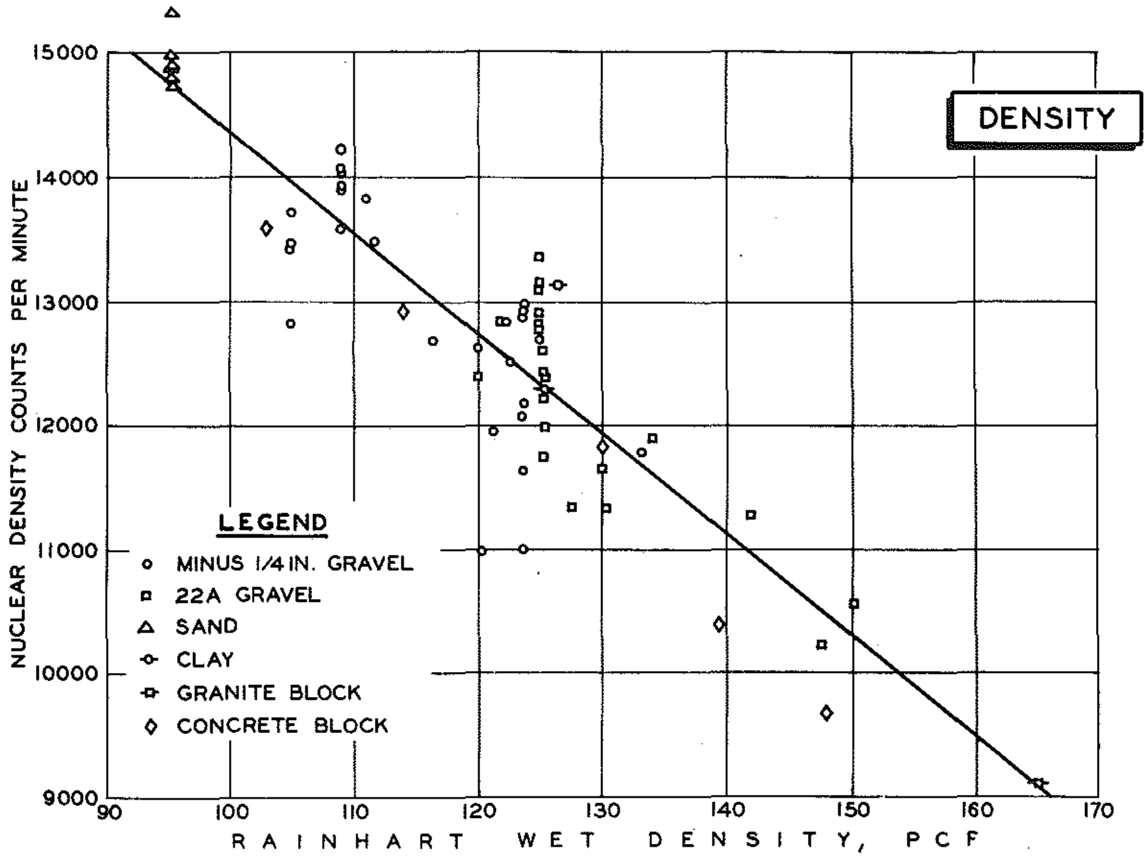


Figure 7. Laboratory calibration curves:
MSHD gage No. 3.



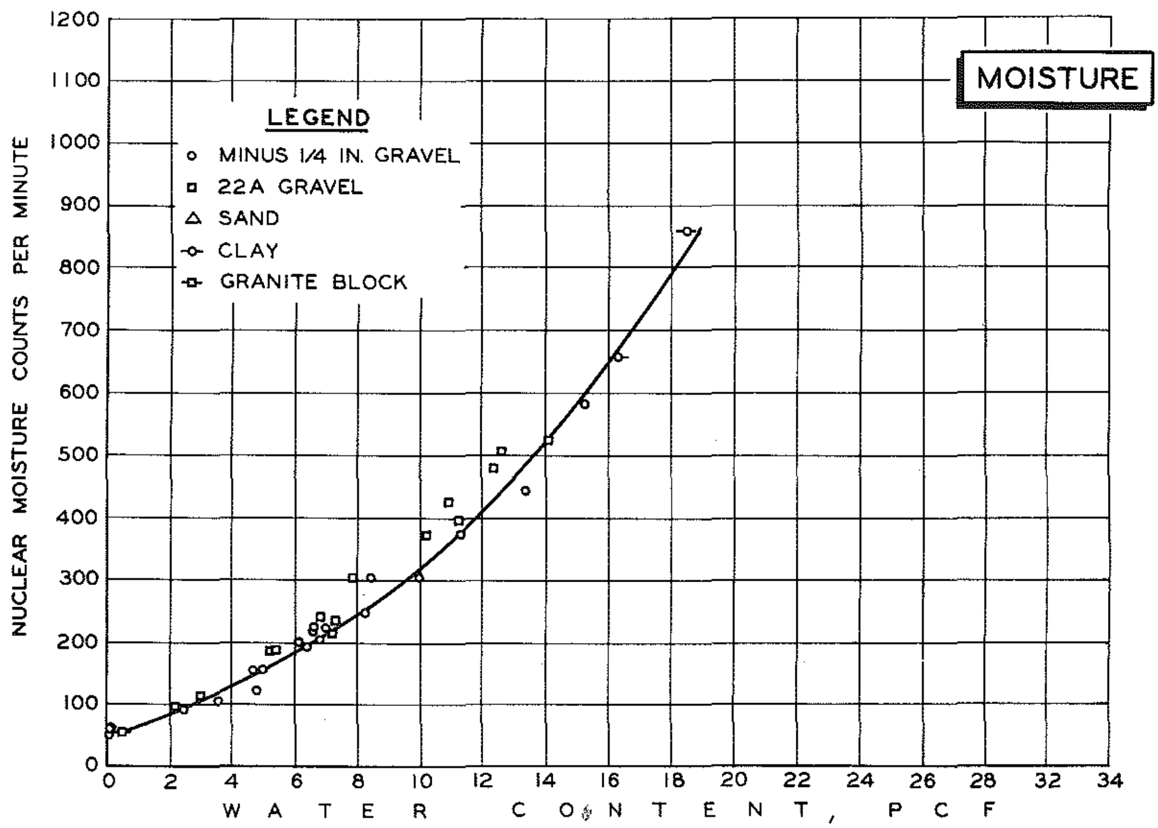


Figure 8. Laboratory calibration curves: MSHD gage No. 4.

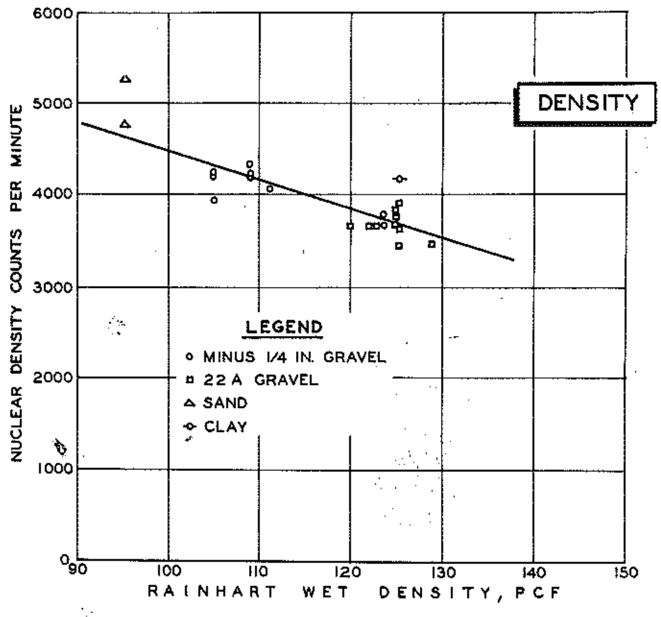


Figure 9. Laboratory calibration curve: MSHD single-source cesium gage.

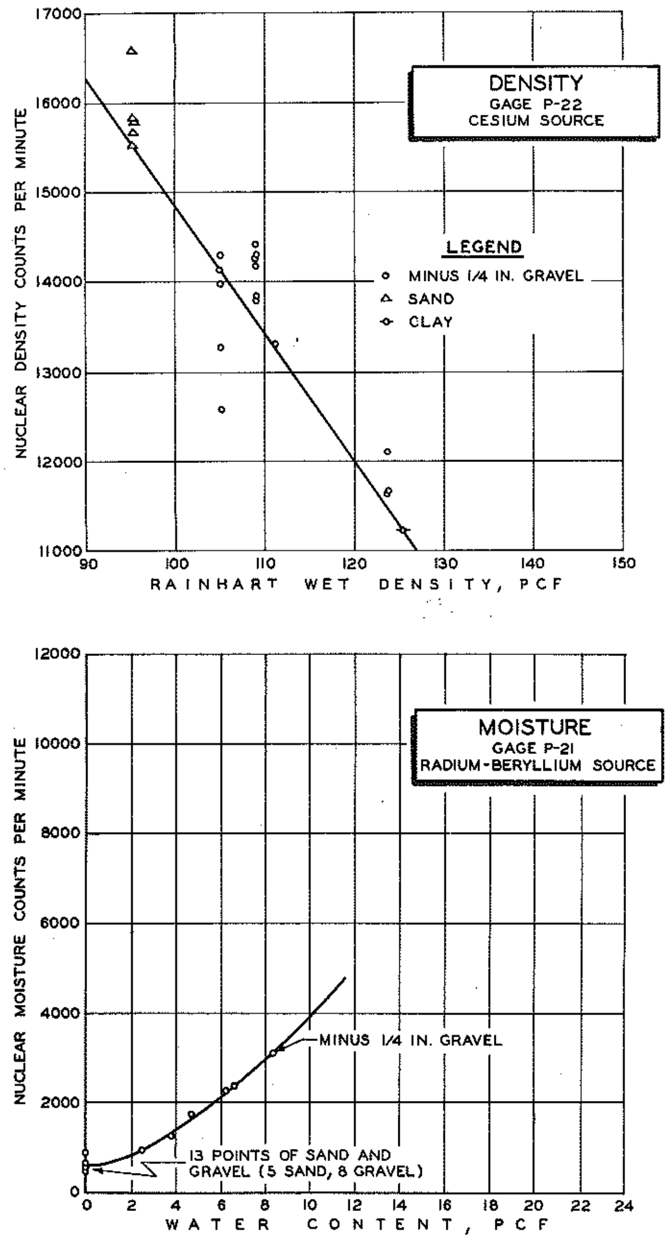


Figure 10. Laboratory calibration curve: commercial gages.

Although the density curves show a correlation between gage count rates and measured density, there is a wide range in the values for particular densities. For example, with gage No. 4 the range in the count rates at 125 pcf is equal to approximately 2500 counts, which from the average slope of the calibration curve is equal to about 30 pcf. An average value, however, appears to be $\pm$ 7 pcf.

These curves indicate that the gages definitely measure changes in density over a wide range, but that more emphasis should be placed on calibrating the gages for a given material within the range of moisture and density values normally encountered in the field.

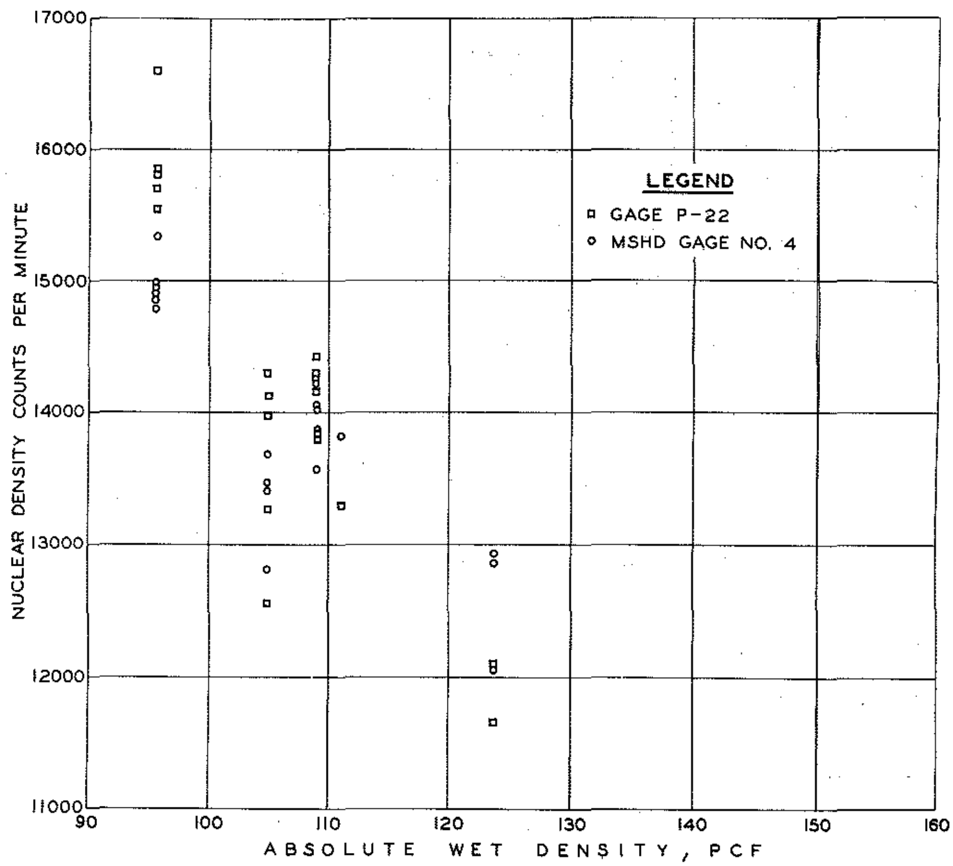


Figure 11. Density calibration comparison of two gages (laboratory box samples).

Limited tests show that the commercial P-22 gage gave no better calibration curves than did the MSHD combination gage. This is shown in Fig. 11, which compares the density reading obtained with MSHD gage

No. 4 and with commercial gage P-22. The range in values at each density shows no significant difference favoring either gage.

Fig. 12 shows the calibration curve developed for gage No. 4 (Fig. 10) applied to density determinations for four concrete blocks, bare and covered with sand. The effect of the sand cover was quite pronounced in the gage readings, showing that caution should be used when sand or other materials are used as leveling courses for seating gages on irregular surfaces. This curve also shows clearly that although density values for the blocks fall close to those of soils, they are consistently lower. This indicates that concrete blocks might be useful for calibrating the gages, but would not give the same calibration curve as soil or gravel.

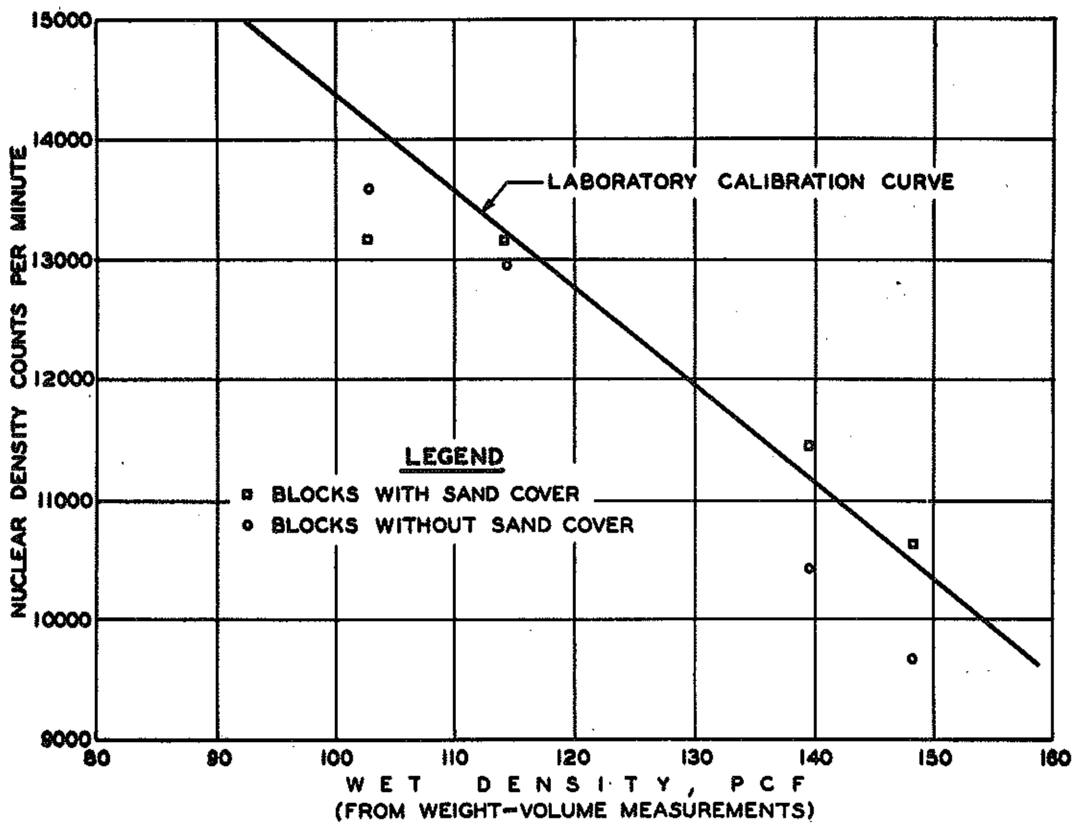


Figure 12. Density of concrete blocks with and without sand cover: MSHD gage No. 4.

Fig. 13 shows a comparison between nuclear gage values of moisture and density and corresponding values obtained by conventional methods. A laboratory test sample was used in this comparison.

A few tests were made using gravel treated with 6 lb of calcium chloride per ton as used in normal field construction without noticeable effect on results. Changes in chemical characteristics of the samples apparently have too little effect on results to be detected within the present limits of accuracy of the gage. The effect of chemical composition should be considered when more accurate and consistent calibrations can be made.

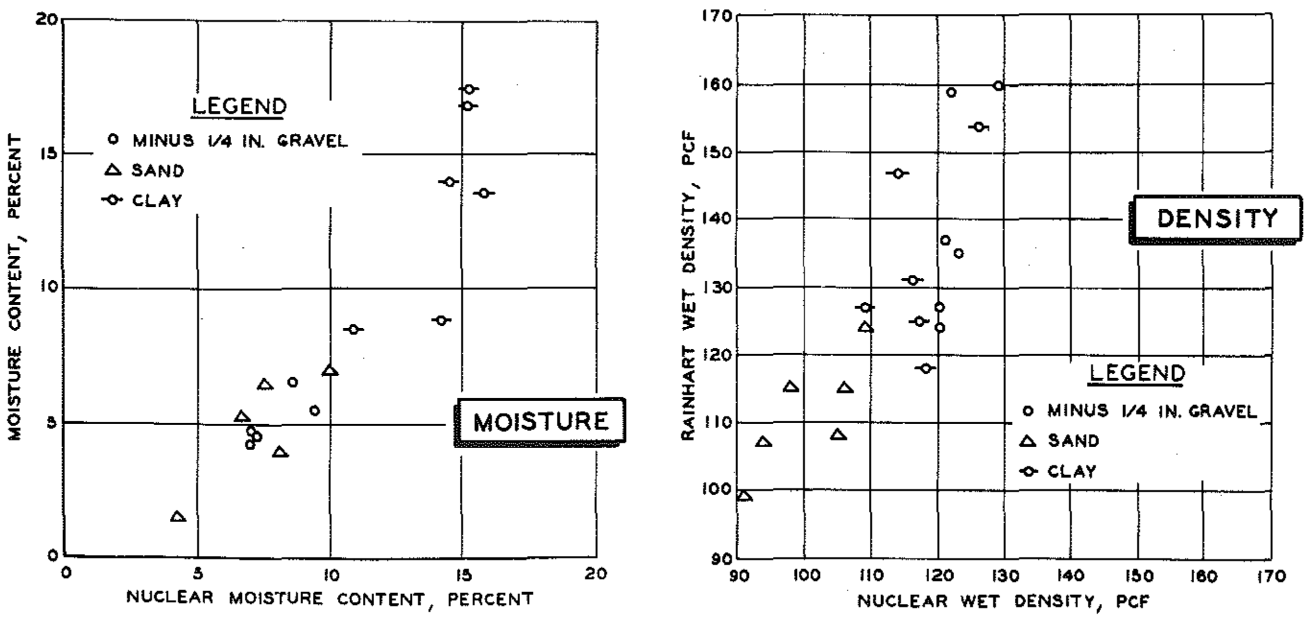


Figure 13. Comparison of nuclear and Rainhart methods for measuring moisture and density using MSHD gage No. 4 (with laboratory calibration curve for nuclear values).

EFFECT OF MOISTURE CONTENT

During the calibration tests there were indications that variation in moisture contents of samples of equal wet density had some effect on the count rates of nuclear gages (Fig. 14). This appears logical considering that the calibration curves are different for different materials. Soil is a three-phase system containing solids, liquid, and air, and consequently can have many different dry densities for the same wet density. In soils engineering the term "soil density" is used to express the concentration of solids within a given mass of soil rather than to define mass per unit volume as normally related to a single homogeneous or isotopic material. For example, a cubic foot of soil containing 120 lb of solids and 10 lb of water has the same wet density as a soil containing 125 lb of solids and 5 lb of water. Both have a wet density of 130 pcf.

Fig. 15 shows the results of a test using gravel in which wet density was held constant at 105 pcf but the soil to water ratio was varied. The soil to water ratios in pounds per cubic foot were: 105.0/0, 102.5/2.5, 101.2/3.8, 100.3/4.7, and 98.4/6.6.

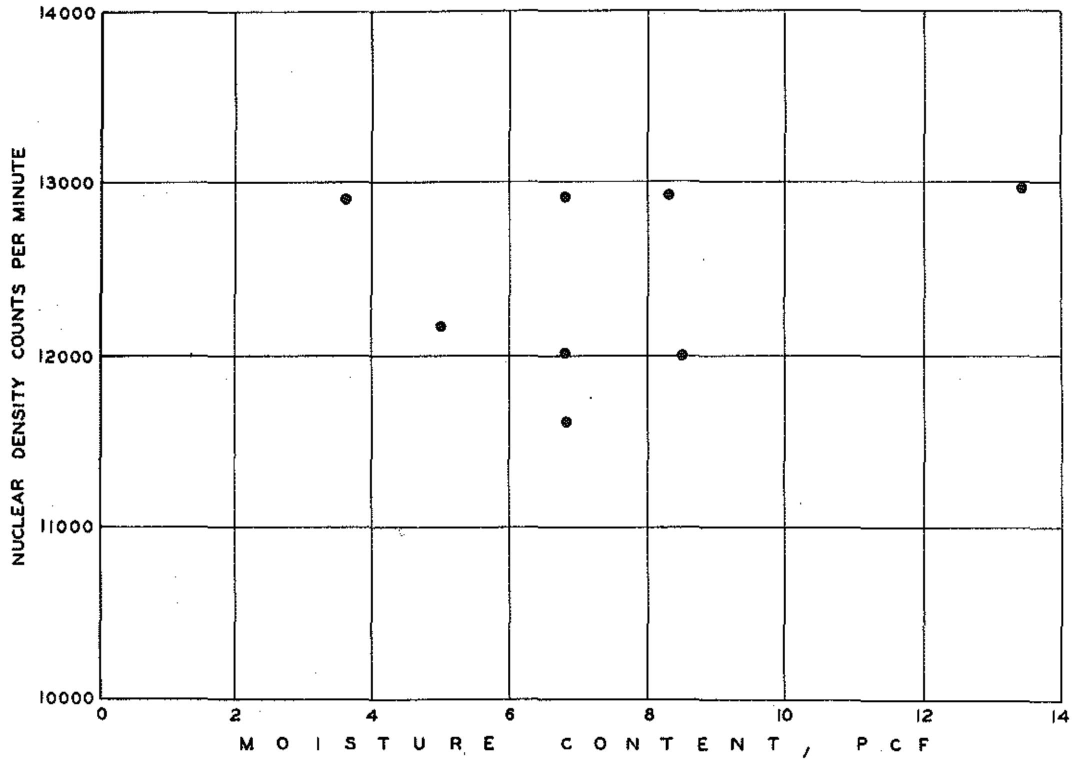


Figure 14. Density counts for different moisture contents using MSHD gage No. 4 (-1/4 in. gravel sample at constant wet density of 123 pcf).

For all three gages there was a wide and non-uniform variation in count rates as the soil to water ratio varied, indicating that gage readings might be affected by this ratio. Additional tests are required for full evaluation of this important characteristic of the density gage.

VARIATION IN VALUES OBTAINED BY CONVENTIONAL METHODS

Part of this program was designed to check Rainhart as well as nuclear values against the "absolute" box densities. One such plot is shown in Fig. 16. These data show that the conventional Rainhart test does not check well against the box densities. In this work the old-style 4-in. Rainhart device was used, but the results are still significant.

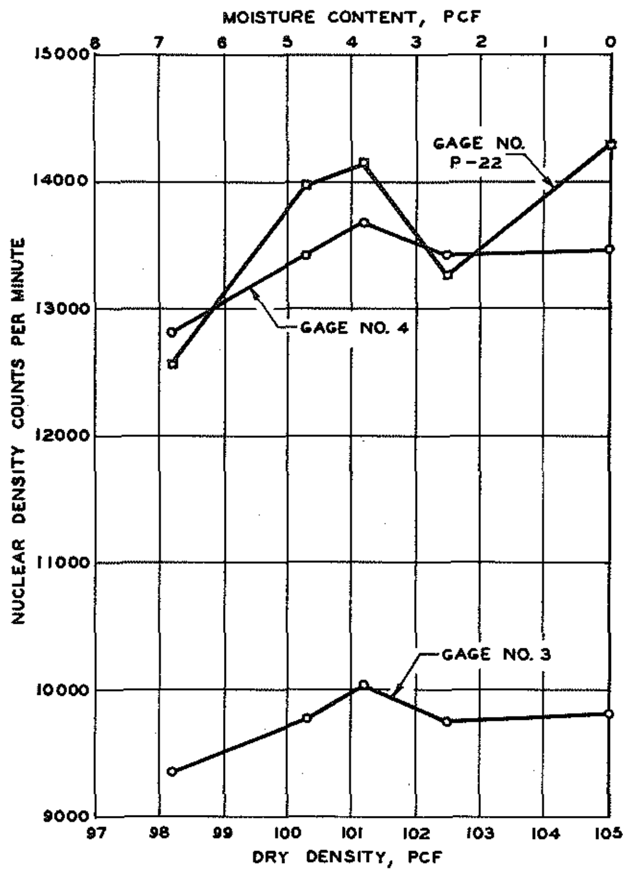


Figure 15. Density counts for different moisture contents using three gages (sample at constant wet density).

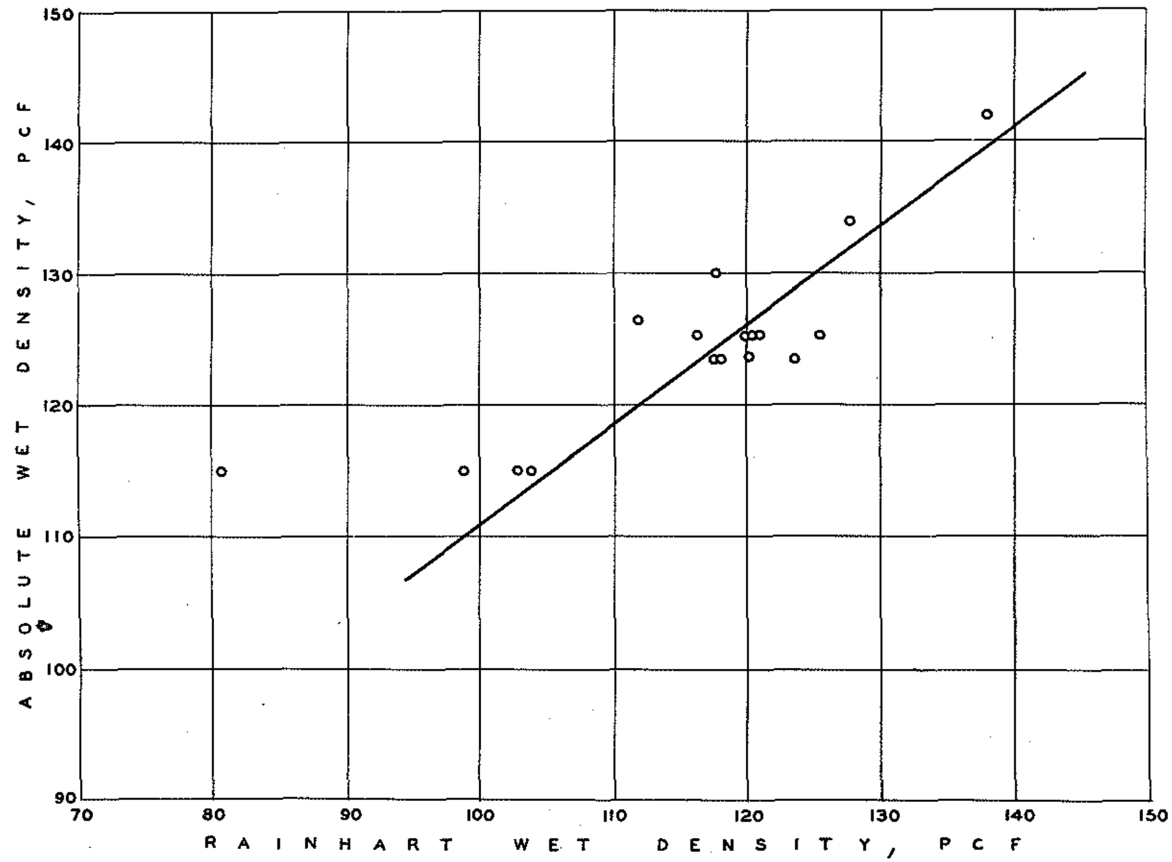


Figure 16. Comparison of Rainhart and laboratory box densities (-1/4 in. gravel using 4-in. Rainhart).

The tests were limited but indicate that more work should be done calibrating the Rainhart as well as the nuclear device if the two methods are to be used as checks against each other.

REPEATABILITY OF GAGES

Among the tests recommended by the nuclear committee were those to determine the repeatability of gages on identical samples, to compare various gages on samples of given density but remixed after each test, and on samples of varying dry density but the same wet density.

TABLE 1
REPEATABILITY OF GAGES
UNDER DIFFERENT TEST CONDITIONS

Gage No.	Test Sample Characteristics				No. of 2-Min Readings per Sample	Average Counts per 2-Min	Range Max-Min Counts per 2-Min	Standard Deviation	
	Material	Density, pcf	Water Content, percent	No. and Type				σ Counts per 2-Min	Density, pcf***
MSHD 1	Undisturbed gravel	123.6	7.2	1 box	8*	22,143	508	301.5	1.9
MSHD 4						25,876	344	122.3	0.6
P-22	Undisturbed sand	95.3	0.0	1 box	8*	33,168	1096	305.9	0.9
MSHD 1						25,081	536	162.4	1.0
MSHD 4						29,525	488	152.3	0.7
P-22	Remolded gravel	95.3	0.0	5 boxes	4*	31,756	2134	738.2	2.0
MSHD 1						25,546	1242	447.0	3.4
MSHD 4						29,906	1102	612.0	4.2
P-22	Remolded gravel	109.0	0.0	6 boxes	4*	28,262	1224	469.2	1.5
MSHD 3						20,092	964	284.2	2.9
MSHD 4						27,876	1262	396.6	2.7
P-22	Remolded sand	105.0	0.0 - 6.7 (variable)	5 boxes	4*	27,300	2052	1292.6	3.6
MSHD Cesium						8,336	698	258.9	4.1
MSHD 3						19,456	1436	465.8	4.9
MSHD 4						26,728	1758	585.0	4.0
P-22	Undisturbed sandy gravel	132.0	7.0	1 area in situ	10*	20,722	2463	720.7	2.1
MSHD 4						25,151	2060	547.9	3.8
P-22	Undisturbed sandy gravel	132.0	7.0	1 area in situ	10**	22,327	513	141.5	0.4
MSHD 4						25,048	558	185.9	0.9
P-22	Undisturbed sandy loam	128.0	7.0	1 area in situ	10**	22,666	722	195.3	0.6
MSHD 4						25,102	254	89.0	0.5

* Gages rotated between readings
** Gages stationary between readings
*** Converted from counts per 2-min values by use of calibration curves

A summary tabulation of these test results is shown in Table 1. The work was quite limited and conclusions should not be drawn without additional tests. However, the results do indicate a trend in favor of commercial gage P-22. Less variations were found, as would be expected, using one undisturbed sample for the tests. The remolded samples showed a higher value of deviation and slightly higher variations were found when the dry densities were varied, but this change was reflected by all the gages.

Much of this work was done with dry samples. It is felt that more significant results could be obtained from these tests if higher, more realistic moisture contents were used. It should also be noted that all gravel samples contained only -1/4-in. material which should minimize variability as compared to normal gravel mixtures of 3/4-in. maximum size.

COMPARISON OF INDOOR AND OUTDOOR BACKGROUND COUNTS

To check the possible effects of interference of surrounding equipment with gage operation, a study was made to compare readings obtained both in the laboratory and the field by means of readings taken from the plywood standard.* Fig. 17 shows comparisons obtained from 210 outdoor and 79 indoor tests for both moisture content and density. Only a few consecutive individual tests are plotted but these are sufficient to indicate typical variations relative to the arithmetical mean $\bar{x}$ and standard deviation σ shown for the total number of tests. Differences were noticeable between moisture readings for the two conditions. This could be due to atmospheric or other outdoor effects on either the standard or the gage. Density counts were slightly lower outdoors than in the laboratory.

A further comparison was made by testing the hypothesis that the mean of indoor standard readings was equal to the mean of the outdoor standard readings. The difference between means was significant, indicating that the gage may not operate the same indoors as out, even though the standard beneath the gage is constant.

Further tests are planned to see if this is also true for larger soil samples. Differences between laboratory and field calibration could seriously affect nuclear gage operations and it may be necessary to conduct all calibration tests outdoors.

* The standard used in this study consisted of a wooden box (20-in. long by 15-in. wide by 7-in. deep) completely filled with sheets of plywood. These sheets were treated with a water repellent to prevent variations in moisture content. For durability, the box was capped with 1/4-in. Masonite. The same standard was used for both moisture and density measurements.

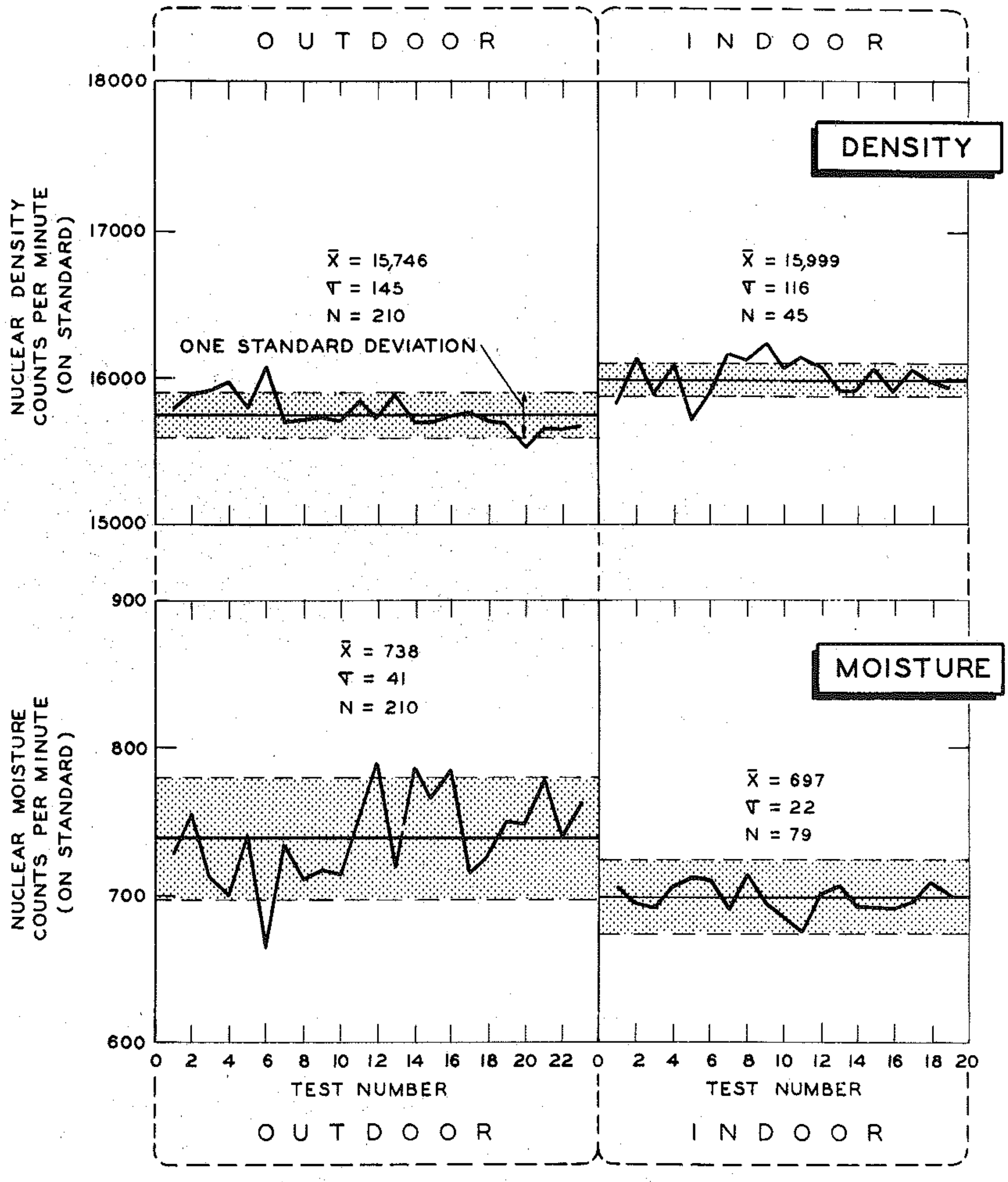


Figure 17. Comparison of indoor and outdoor gage readings for moisture and density, using MSHD gage No. 4 with standard (partial data).

CONTROLLED FIELD TEST SECTION

On May 20, 1960, a special study was initiated to evaluate nuclear and Rainhart methods for measuring moisture content and density, on the basis of a statistical survey and analysis of results similar to those used for quality control in some industrial operations. With such methods, it is not necessary to know the absolute quality of the material being tested. Instead, an average of many readings is considered to be the actual value sought and individual values can be compared to this mean. The deviation of individual readings from the mean indicates the control obtainable by the operation. In these tests the values sought were density and moisture content.

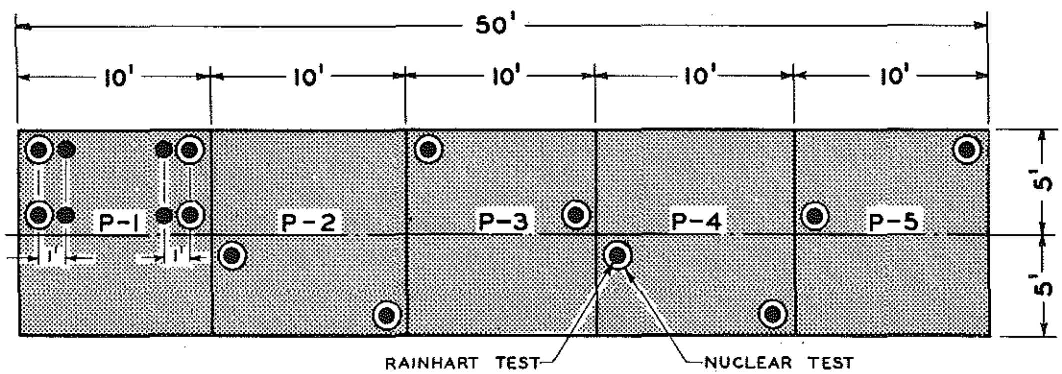


Figure 18. Layout of typical field control section.

In order that data might be obtained by a uniform procedure, standard dimensions and methods were established for testing selected areas. The section measured 50 by 10 ft and was subdivided into ten numbered subareas. Half of these subareas were selected at random for test. In the first area chosen, four nuclear and four Rainhart tests were made by the usual method (Rainhart and nuclear tests at the same spot), supplemented by four additional Rainhart tests taken within a foot of the others to check for any deviations in the test method or in soil characteristics. In each of the other four selected subareas, two nuclear and two Rainhart tests were made. The total tests for one standard section were 16 Rainhart and 12 nuclear. Fig. 18 shows the general arrangement of a typical test area. All nuclear readings represented an average of four count rates taken at 90^{o} intervals around the test point for both density and moisture. Gage No. 4 was used in these tests.

At least six sections each of sand, gravel, and clay soil were included. All these test areas were selected during construction operations on US 27 and M 46 in the general area north and west of St. Louis. In addition two different sections of a lime-flyash (Poz-O-Pac) shoulder stabilization project were included in this work, located on the US 10 Bypass in Midland County.

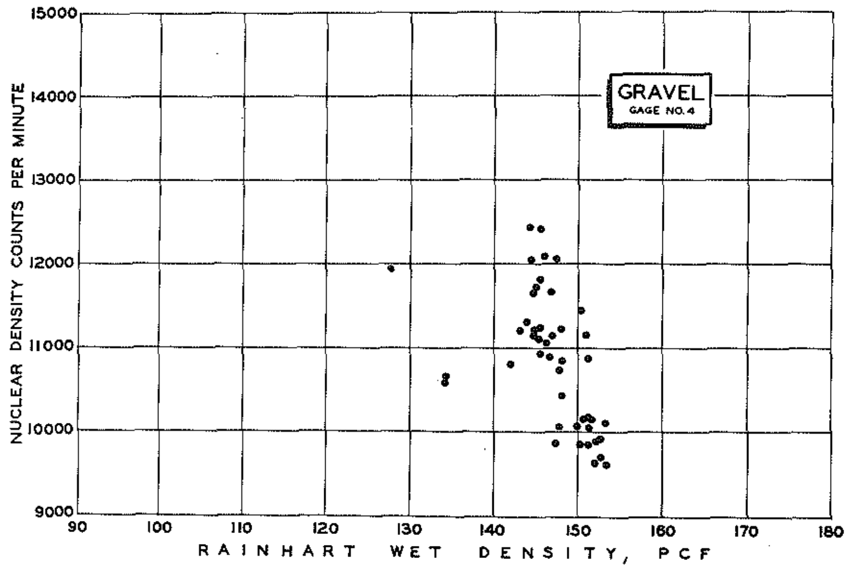
Results of these tests, plotted as density count rate of the nuclear gage against conventional values, showed no usable correlation between the two methods when used with gravel or clay soil. With sand there was an indication of a usable curve with the points falling within an area bounded by densities of $\pm$ 7 pcf. The density results obtained from the control sections for each material are plotted in Figs. 19 and 20.

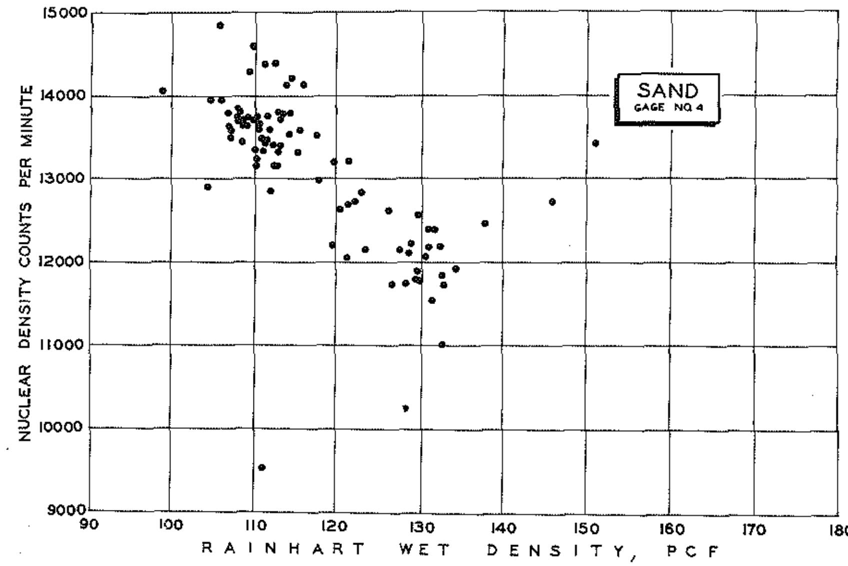
Composite calibrations of density and of moisture for all the control sections using gravel, sand, and clay are shown in Fig. 21. The Poz-O-Pac points were not included in this plot but the general area in which they would fall is outlined. This shows that Poz-O-Pac, although a processed material, still reacted to the nuclear gage in much the same manner as natural materials.

Fig. 22 shows the variation in density and moisture found in one 50-ft test section of the Poz-O-Pac mixes (20 B gravel plus Poz-O-Pac and fine sand plus Poz-O-Pac) when nuclear counts per minute were compared with corresponding conventional values. Variation seemed to be in about the same order for both methods.

Fig. 23 shows another method of presenting differences in density within given control sections as measured both by the Rainhart and by nuclear counts per minute. In studying these data it should be remembered that counts per minute of the nuclear gage vary inversely with density. Variations shown could be either in the method of measurement or actual field differences. The control sections had all been compacted but had not necessarily been inspected for acceptance. The tests were made during construction operations and the test sections were located at various positions within a given job or even on different jobs. For these reasons, variations in actual field density could be expected.

To check as nearly as possible the ability of the Rainhart method to yield repetitive results, the values of the densities measured 1 ft apart were plotted as shown in Fig. 24. These represent random sections for gravel, sand, and clay. Generally the repeatability of the Rainhart test was good. Largest individual variations were found in sections 16 and 21. These could be due to operational error.





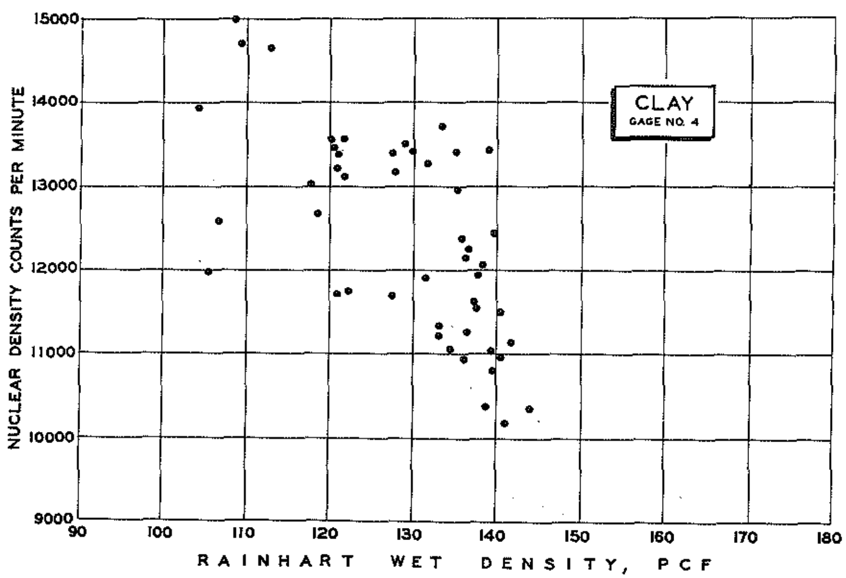
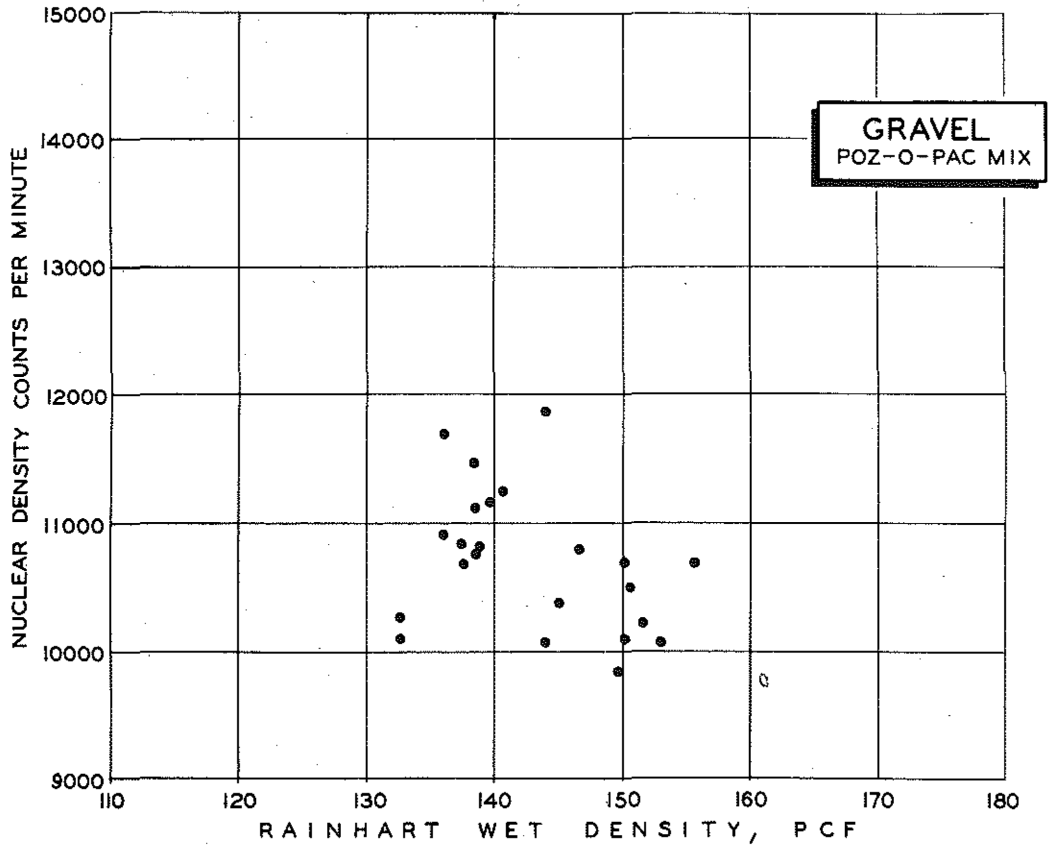


Figure 19. Field density calibrations for gravel, sand, and clay.



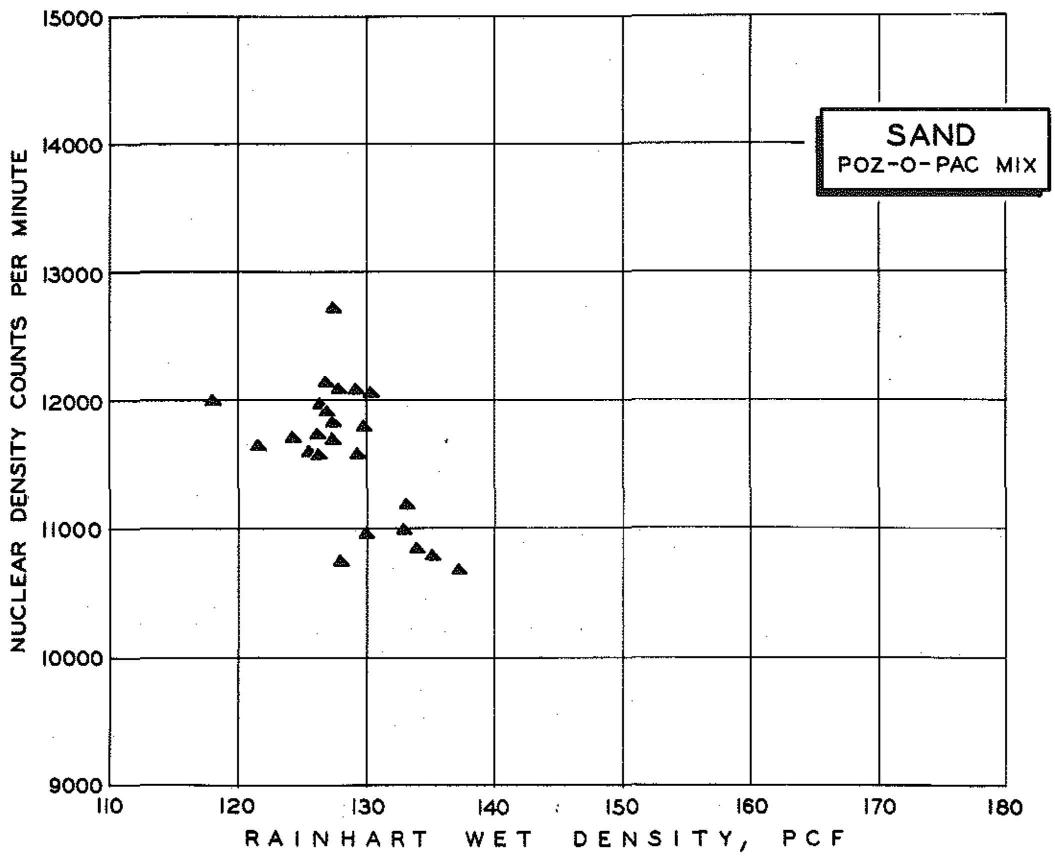


Figure 20. Field density calibrations for Poz-O-Pac mixes using MSHD gage No. 4.

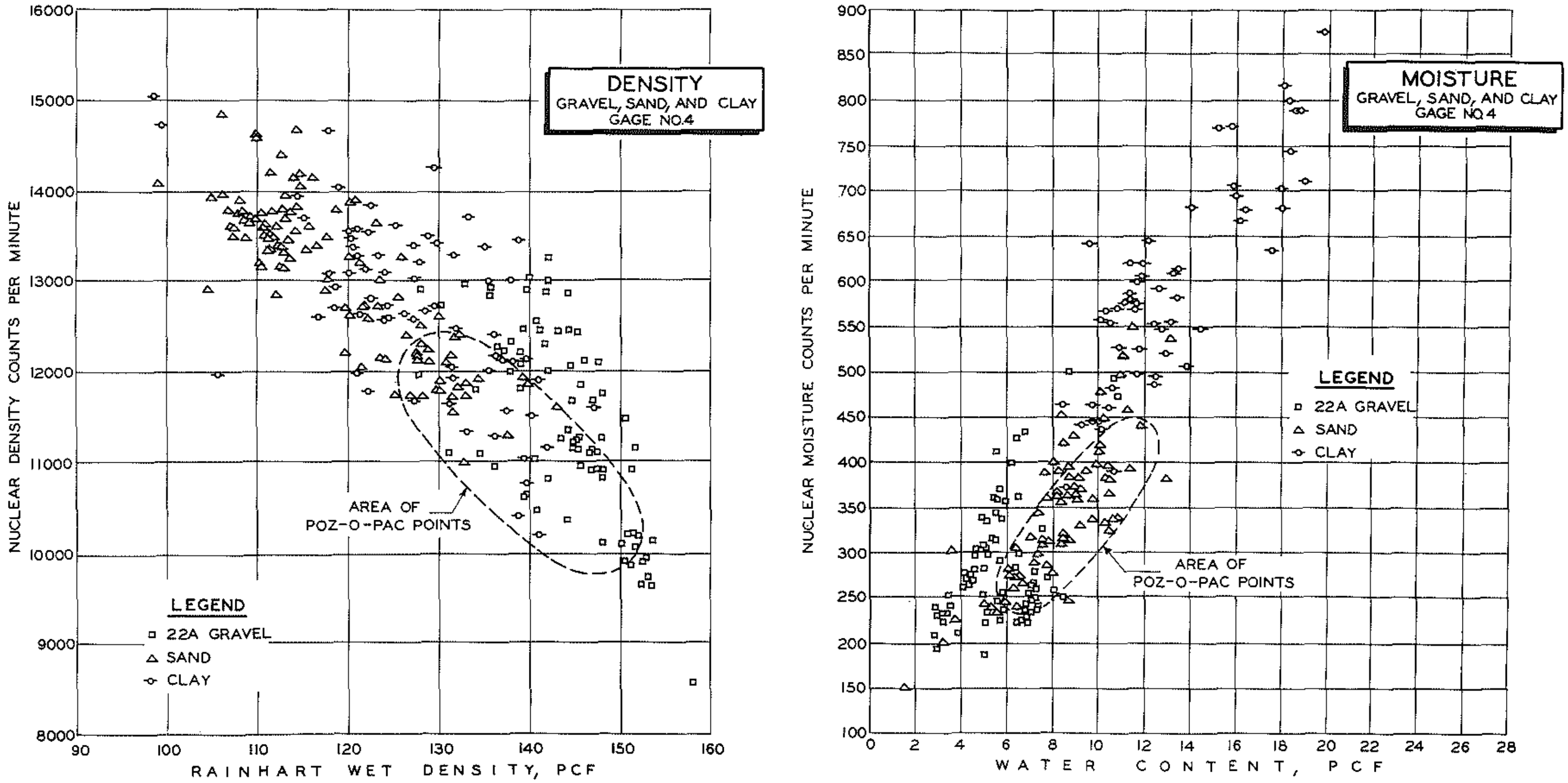
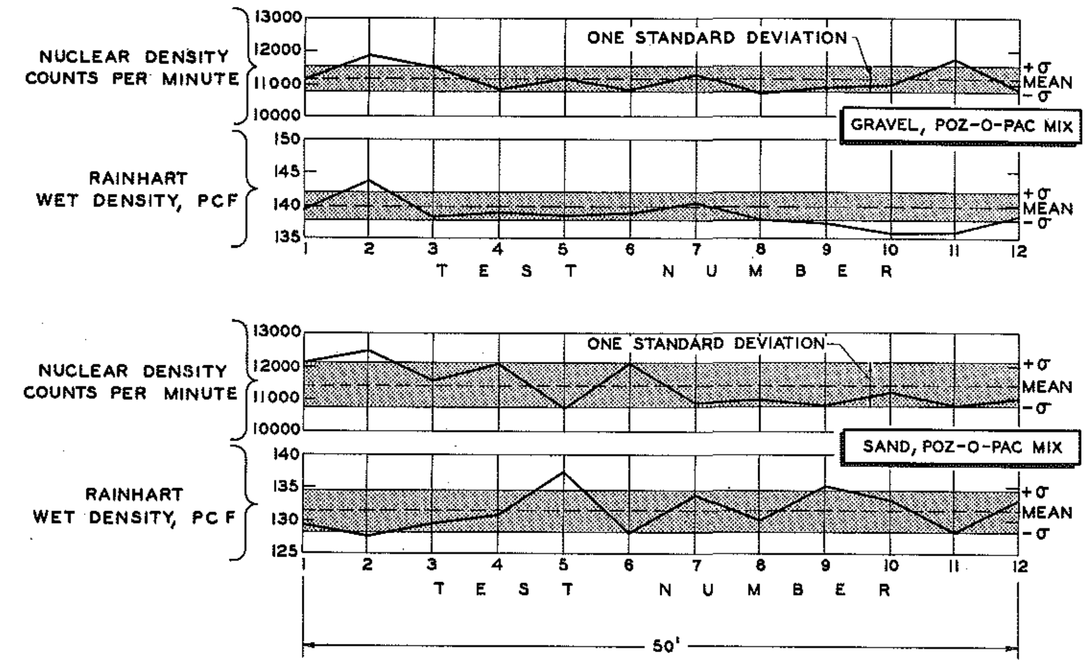
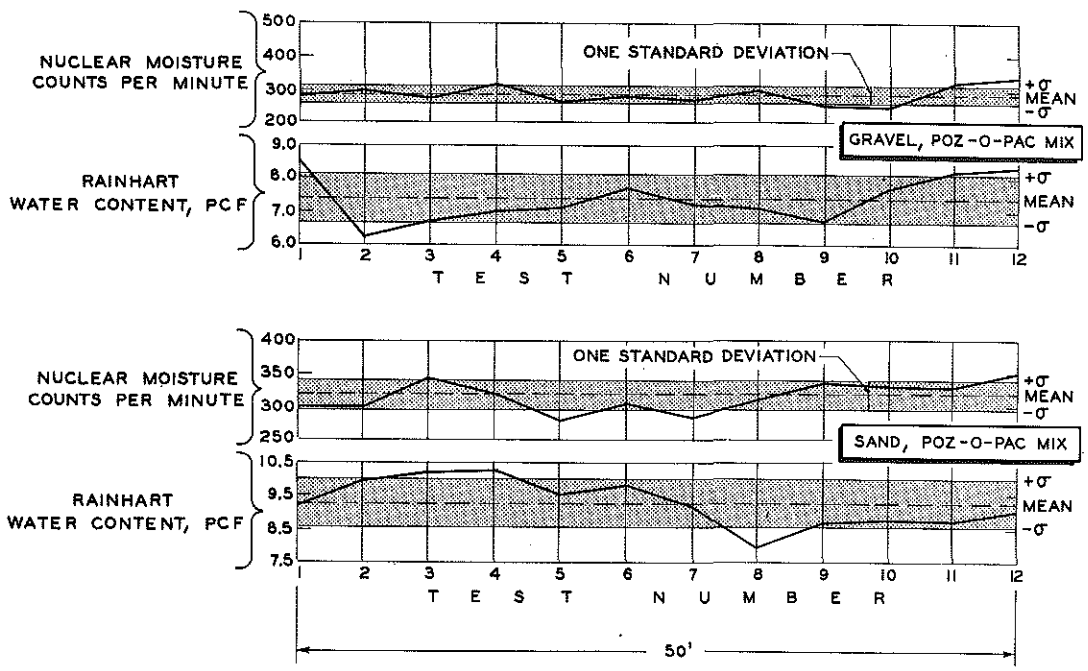


Figure 21. Composite density and composite moisture calibrations.



DENSITY



MOISTURE

Figure 22. Variations in density and moisture readings within one control section, by Rainhart and nuclear methods.

Overall study of data from the field control sections indicates that both the Rainhart and nuclear methods were subject to considerable variation, which was accentuated when the methods were used with coarse materials. It should be realized, however, that the statistical analysis used includes all the variables encountered in obtaining field density (materials, instrumentation, operators, etc.) and thus does not necessarily reflect the absolute accuracy of either method. As normally used,

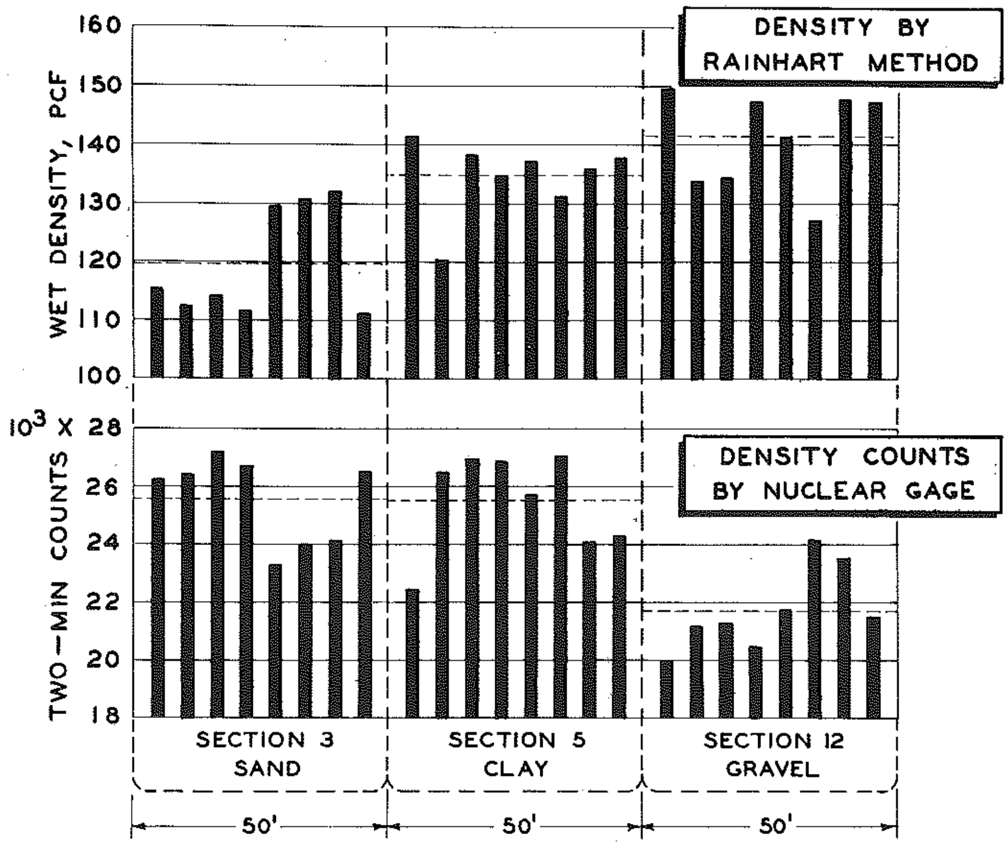


Figure 23. Variations in density within three control sections, by Rainhart and nuclear methods.

the statistical method of quality control presupposes that one of two variables is of known controllability. Unfortunately, in this case neither the uniformity of the material tested nor the accuracy of the instruments were known, so variability between two operations was compared without knowing where the variations arose. By using a large amount of such data, much useful information might be obtained by statistical analysis, but such information should be used with caution until all factors are understood.

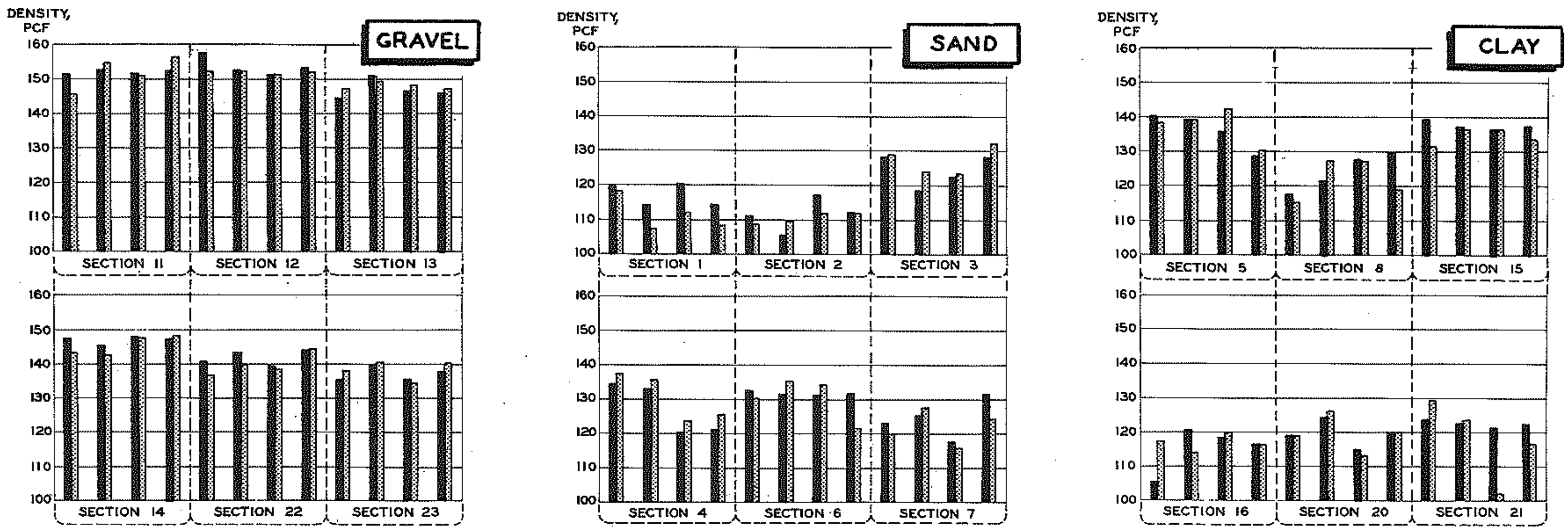


Figure 24. Comparison of Rainhart densities--two values obtained 1 ft apart--in random sections of gravel, sand, and clay.

To differentiate between variations in material and variation in testing methods, the Laboratory plans to return to its original procedure of calibrating the density equipment against absolute density of the material. This will be done in outdoor calibration boxes and will include samples of the same material used in the control test areas. This should provide good supplemental information to the statistical analysis.

CONCLUSIONS AND RECOMMENDATIONS

The evaluation tests completed so far on the MSHD nuclear gages have been comprehensive and varied. More than 60 large samples have been built and tested in the laboratory and thousands of field tests have been made at different locations in an effort to calibrate the nuclear gage in terms of standard Rainhart results. On the basis of this work, the following conclusions and recommendations are made:

1. No usable correlation between nuclear and Rainhart densities has been obtained in the field. A general correlation was obtained with sand, but the relationship was quite broad, being in the order of $\pm$ 7 pcf wet density. It is recommended that attempts to correlate Rainhart and nuclear densities in the field be discontinued.

2. Results obtained with the nuclear gages have been variable and often unpredictable. It is not known whether these conditions are due to characteristics of the gage, the methods of measuring the qualities of the gage, the effect of variation in the samples being studied, or a combination of these factors. Separating these variables requires a systematic, uninterrupted program of laboratory investigation and it is recommended that such a program be reactivated and concluded before additional field work is considered.

3. The work completed to date should provide a good background for expanded studies. Specific indications obtained from the present work are:

a. The type of material being tested affects the calibration of the nuclear gage. It is hoped that a few general calibration curves can be developed which will be applicable over a wide range of soil conditions.

b. The density gage count rate might be affected by the ratio of the solid to the liquid phases of soil systems even when wet densities are kept constant. This problem needs further study before definite statements can be made.

c. Variations in Rainhart density and the corresponding method used for determining moisture content in the field were significant enough to warrant further study of these methods before accepting them as a basis for evaluating the acceptability of new methods of test.

d. Laboratory and field tests showed much better correlations between moisture content and nuclear count rates than for density and nuclear count rates. Much better correlation was obtained in the laboratory than in the field. Some of the field variations could have been magnified by errors made in obtaining the dry weight of samples.

e. Count rates of the density gage, measured on the standard, were different outdoors than indoors. Fluctuations were higher indoors. Moisture readings showed a possible effect of humidity, or other atmospheric conditions, on outdoor readings of the gage. This problem requires further analysis before definite conclusions can be reached.

f. Based on limited laboratory tests, the MSHD nuclear gage compared favorably with the commercial models manufactured by Nuclear-Chicago. This comparison, however, cannot be firmly established without additional testing. The MSHD single-source cesium gage similar to Nuclear-Chicago's density gage had the poorest slope in its calibration curve.

g. Laboratory samples of sufficient size to eliminate edge and floor effects are satisfactory for establishing performance characteristics of the gages if used outdoors or away from excessive background interference. The possible effect of background disturbances should be constantly checked, however, and it may be necessary to use larger samples for some materials.

h. A calibration curve on which different materials (wood, gravel, concrete, etc.) each appear as a single point or a small group of points may not be suitable for normal highway field use. Such a curve shows that the gage will differentiate between the densities of different materials, but does not indicate that the gage can differentiate between densities within a multiple-phase system, such as soil or gravels, to the accuracy required for construction purposes.

i. It has been necessary to average at least four readings around a single location (at 90° apart) in order to obtain satisfactory nuclear gage readings. This increases the time of operation per test to approximately that of the Rainhart method. This condition might be improved by modifying the sphere of influence of the gage to approach a circular shape.

4. Future studies of the nuclear method for measuring moisture and density of soils should be divided into two general phases:

a. Study of gage characteristics to determine positively if such equipment can be used successfully for measuring density and moisture contents, and

b. Development of calibration curves and techniques for satisfactory use of the instrument for field operations. The latter phase would be a continuation of work already started and should include the following:

(1) Using larger laboratory test samples to conduct multiple sampling of each test condition and to minimize possible dimensional effects when using a variety of densities and materials. This work should be performed away from background interferences, preferably outdoors.

(2) Securing data for all tests in sufficient quantity and such a manner that results will have statistical significance.

(3) Carefully programming comparison tests of the MSHD, Nuclear-Chicago, or other available gages. This may require purchase or rental of commercial gages.

(4) Evaluating the Rainhart method for obtaining moisture content and density, using laboratory control samples to determine the limitations of this method.

(5) Developing a positive calibration curve, if possible, of count rate against density in the laboratory or a controlled field test area. If such a curve can be developed it could be used directly in the field (with slight adjustment) without having to check against the Rainhart or other field tests.

(6) Determining if the gage can actually be calibrated to express moisture content directly in both pounds per cubic foot of wet mixture and percent based on the dry weight of soil. If moisture can be measured by both of these methods, the gage is functioning as more than an indicator of hydrogen atoms and is including density effects in the results. How this is done should be the subject of further study. If the moisture gage can measure water content of soils directly in both pounds

per cubic foot and percent dry weight, the results could be used to obtain dry density without using the density gage. The accuracy of such a procedure, however, might not be as good as that obtained by direct density gage readings.

5. As a result of these studies of the nuclear methods, several new concepts of field density control have been considered. One of these concerns the use of the gage, on a qualitative basis, to measure change in density under field compaction effort. The point at which additional passes of the compaction equipment cause little or no change in count rate would represent the maximum density possible for a given weight of roller. No calibration curves will be required if the gage is used in this manner.

Another concept suggested is the use of quality control methods for controlling compaction. In this method, statistical analysis, based upon a large number of tests, would be used to control the desired limits. For such work, the nuclear methods of measurement would be well suited.

Such methods may eventually be used in compaction control. However, it should be realized that these are concepts of density control that are not limited to any one method of measuring moisture and density. Before such ultimate uses of the nuclear gage are considered it must be proved that the gage is a functional device. This is yet to be done.

ACKNOWLEDGMENTS

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W. H. Schwartje of the Isotopes Section modified the electrical systems of the gage to eliminate automotive ignifion interferences, and has otherwise maintained the nuclear equipment in good working order.