# Technical Report Documentation Page

**1. REPORT No.**
CA-DOT-TL-2908-3-75-30

**2. GOVERNMENT ACCESSION No.**

**3. RECIPIENT'S CATALOG No.**

**4. TITLE AND SUBTITLE**
Calibration Standards For Nuclear Gages- Density And Moisture Standards

**5. REPORT DATE**
December 1975

**6. PERFORMING ORGANIZATION**

**7. AUTHOR(S)**
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**8. PERFORMING ORGANIZATION REPORT No.**
19202-632908

**9. PERFORMING ORGANIZATION NAME AND ADDRESS**
Office of Transportation Laboratory
California Department of Transportation
Sacramento, California 95819

**10. WORK UNIT No.**

**11. CONTRACT OR GRANT No.**
F-4-22

**12. SPONSORING AGENCY NAME AND ADDRESS**
California Department of Transportation
Sacramento, California 95807

**13. TYPE OF REPORT & PERIOD COVERED**
Final

**14. SPONSORING AGENCY CODE**

**15. SUPPLEMENTARY NOTES**
Study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

**16. ABSTRACT**
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The research involved the selection of suitable nuclear moisture gage calibration standards which resulted in a recommendation to adopt a series of silica sand water mixtures as the moisture gage calibration standards. The investigation of several soils and materials revealed a greater understanding of moisture gage response to various soil minerals. The results of these laboratory tests indicated the magnitude of gage measurement errors that could occur during moisture determinations.

**17. KEYWORDS**
Calibrations, compaction control, gamma neutron logging, neutron counters, nuclear moisture density determinations, nuclear testing

**18. No. OF PAGES:**
54

**19. DRI WEBSITE LINK**
http://www.dot.ca.gov/hq/research/researchreports/1974-1975/75-30.pdf

**20. FILE NAME**
75-30.pdf

This page was created to provide searchable keywords and abstract text for older scanned research reports.
November 2005, Division of Research and Innovation

DIVISION OF CONSTRUCTION AND RESEARCH

TRANSPORTATION LABORATORY

RESEARCH REPORT

# CALIBRATION STANDARDS FOR NUCLEAR GAGES DENSITY AND MOISTURE STANDARDS

75-30

FINAL REPORT

CA-DOT-TL-2908-3-75-30

DECEMBER 1975

Prepared in Cooperation with the U.S. Department of Transportation, Federal Highway Administration

Caltrans

CALIFORNIA DEPARTMENT OF TRANSPORTATION

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TECHNICAL REPORT STANDARD TITLE PAGE

| | | |
|---|---|---|
| 1. REPORT NO. CA-DOT-TL-2908-3-75-30 | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENT'S CATALOG NO |
| 4. TITLE AND SUBTITLE CALIBRATION STANDARDS FOR NUCLEAR GAGES - DENSITY AND MOISTURE STANDARDS | | 5. REPORT DATE December 1975 |
| | | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) David R. Castanon, Ellsworth Chan, Jerry C. Chang, J. B. Hannon, and Raymond A. Forsyth | | 8. PERFORMING ORGANIZATION REPORT NO 19202-632908 |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Transportation Laboratory California Department of Transportation Sacramento, California 95819 | | 10. WORK UNIT NO |
| | | 11. CONTRACT OR GRANT NO F-4-22 |
| 12. SPONSORING AGENCY NAME AND ADDRESS California Department of Transportation Sacramento, California 95807 | | 13. TYPE OF REPORT & PERIOD COVERED Final |
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|---|---|
| 17. KEY WORDS Calibrations, compaction control, gamma neutron logging, neutron counters, nuclear moisture density determinations, nuclear testing. | 18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161. |

| 19. SECURITY CLASSIF. (OF THIS REPORT) | 20. SECURITY CLASSIF. (OF THIS PAGE) | 21. NO. OF PAGES | 22. PRICE |
|---|---|---|---|
| Unclassified | Unclassified | 54 | |

DH-TL 1242 (Rev. 3-74)

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

December 1975

FHWA No. F-4-22
TL No. 632908

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

CALIBRATION STANDARDS
FOR
NUCLEAR GAGES

Density and Moisture Standards

Study made by . . . . . Geotechnical Branch

Under the Supervision of . . . . . Raymond A. Forsyth, P.E.

Principal Investigator . . . . . Joseph B. Hannon, P.E.
Jerry C. Chang, P.E.

Co-Investigator . . . . . Ellsworth L. Chan

Report Prepared by . . . . . David R. Castanon
Ellsworth L. Chan

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

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## ACKNOWLEDGEMENTS

This work was accomplished by the Geotechnical Branch of the California Transportation Laboratory in cooperation with the United States Department of Transportation, Federal Highway Administration.

The authors would like to express their appreciation to Robert E. Smith and to Earl Shirley who were the original co-investigators on this study and were responsible for a major portion of this effort. The authors are especially indebted to Travis Smith, Principal Transportation Engineer, the former chief of the Foundation Section and to Donald L. Durr for their supervision.

Appreciation is also extended to Dale Sathre and Frank Champion who performed numerous technical operations with care and precision. Appreciation is also extended to the Materials personnel of the eleven districts for their cooperation in contributing to the evaluation of the standard density blocks, particularly to those who provided additional information to the questionnaires submitted to them.

The contents of this report reflect the views of the Transportation Laboratory which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.



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# INTRODUCTION

The official use of nuclear moisture-density gages by the California Department of Transportation began in 1966. Prior to this, the Sand Volume Method was the accepted measure of earthwork compaction. The adaption of this application of nuclear technology for compaction control required a personnel transition period of education, experimentation, and correlation between sand volume and nuclear gage measurements.

Development of field test procedures and the training of gage operators were major tasks. The confidence and reliability of the nuclear gage rested in the calibration procedure and the techniques applied by the gage operators. Several days were involved in gage calibration for compaction control at the beginning of each highway project. Soils sampled from the construction site were compacted in large molds at various densities and moisture contents and used for nuclear gage calibration purposes. Consideration of the validity of this procedure presented several questionable areas related to field conditions and gage performance consistency. The remolded soil standards limited the range of densities and water contents found under actual field conditions and did not account for the non-uniform character of soil types encountered on a construction project. Numerous soil types required additional time to produce a separate nuclear gage calibration for each soil.

By employing this calibration procedure, the number of calibration standards were as numerous as the number of highway projects in progress and as varied as the number of soil types tested. The soil standards also precluded a permanent calibration reference from being established. Moisture contents of the soil standards would also slowly diminish, thus resulting in a



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continuously changing moisture-density response from the nuclear gage. Reproduction or duplication of the soil standards were extremely difficult, if not impossible to achieve. Reproduction was usually necessary to monitor nuclear gage performance during the construction period.

The problems created by the soil standards necessitated the search for a more desirable and permanent set of calibration standards for all nuclear gages in service. To satisfy this requirement, a program to develop moisture-density standards was initiated as a state-financed research project in July 1967. A subsequent proposal was initiated to conduct the research as a FHWA participating project and was approved in September 1968.

As a result of this research authorization, a set of six master density gage calibration standards and two silica sand water moisture standards were established. The set, three calcareous standards and three siliceous standards, represent the predominant mineralogy of California highway soils. Three of the six density standards were quarried and cut to suitable size for effective use. The remaining three standards were cast of portland cement and selected aggregate. The moisture standards consist of silica sand water mixtures. One standard is kept dry in a sealed container and the second standard is fully saturated with water.

This report contains a brief summary of our experience with these standards. A detailed discussion on their selection and development is presented in the Interim Report for this study (1).

The major emphasis of this final report deals with the evaluation and development of neutron moisture gage calibration standards. Laboratory work, revealed several important facts concerning



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the effects of soil mineralogy on moisture gage response. Soil minerals containing hydroxyl ions in their structural lattice usually yield excessive moisture measurements. On the other hand, the presence of mineral elements which absorb thermal neutrons will yield deficient moisture measurements. A silica sand water mixture appears to be the most desirable materials to use as the moisture calibration standards. The absence of mineral hydroxyl ions and thermal neutron absorbing elements permits the moisture gage to respond to the true "free water" content of the soil water matrix. Two solutions to the mineral influence problem are discussed in detail.

Man made soil water substitutes were also explored, but proved to be unsuccessful in one or more aspects.

## CONCLUSIONS

### Density Gage Calibration Standards

1. The basic density calibration determined on the six stone master density standards is satisfactory for use in compaction control of California soils used in highway construction.

2. Over the range of densities comprised by the master density standards (96 to 173 pcf), the calibration curve appears to be slightly curvilinear when plotted on semilogarithmic paper.

3. The use of a high and a low density standard in each transportation district, in conjunction with the master standards, has greatly improved the uniformity and accuracy of nuclear gage calibration within the California Department of Transportation.



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4. The two transportation district reference standards can be satisfactorily fabricated of portland cement and selected aggregates. These reference standards are as stable and uniform as those cut from natural stone.

5. The master density standards have proved to be a satisfactory means of calibrating all nuclear density gages operated by the California Department of Transportation. In addition, the standards serve as an integral part of the specification criteria involved in gage procurement and can be used to determine gage performance.

Moisture Gage Calibration Standards

1. The nuclear moisture gages respond to the total water (Hydrogen) content of a soil. This includes bound or adsorbed water, inter-layer water, hydrates, and hydroxyl water. A water content estimated on the basis of an oven-dry moisture determination reflects only the free, or easily evaporable water.

2. For a given water content, the presence of slow neutron absorbing elements will decrease the response of the nuclear moisture gage. However, the presence of the absorbing elements appears to be a calibration constant.

3. The change in soil water during normal construction activities occurs almost entirely in the soil free water. The results of this research indicate that the free water calibration curves can be assumed to differ only by a constant, which depends on the sum of the effects of the structural water and absorbing elements present.

4. The slope of the nuclear moisture calibration curves is satisfactorily established by testing on reference standards of silica sand and water.



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## RECOMMENDATIONS

The standard density blocks and silica sand water moisture standard provide a uniform and relatively stable standard for calibration and evaluation of nuclear moisture density gages. The use of the standards has enabled the department to achieve improved accuracy, uniformity of test procedure, interchangeability of gages and monetary savings. On this basis we recommend that all gage users or potential gage users make available a series of permanent standards which are composed of materials which are both uniform and stable with respect to moisture and density. These standards should represent the range of density and mineral compositions which are expected to be encountered during normal use of the gage.

## IMPLEMENTATION

The six master density standards and the two silica sand water moisture standards are currently in use by the State of California, Department of Transportation as an integral part of the annual nuclear gage calibration and gage specification compliance test procedures. Each district has been provided with two density standards and two silica sand water moisture standards. On an annual basis the six master density standards are taken to each of the eleven transportation districts for calibration of district gages. This service is also provided to the various cities and counties that employ nuclear gages. For the detailed calibration procedure refer to Transportation Laboratory Test Method No. Calif. 911 which is appended.



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## DISCUSSION

### Evaluation of Gamma-Density Calibration Standards

Since the publication of the Interim Report, procedures for calibrating all Department of Transportation nuclear density gages on the six standard density blocks have been established and are outlined in Test Method No. Calif. 911 (see Appendix). As described by this method, all nuclear density gages are initially calibrated on the six density standards maintained by the Transportation Laboratory at Sacramento, California. The gages are then recalibrated once annually with the six density standards. Between annual calibrations, the gages may be recalibrated on the two reference standards kept by each Transportation District. The two reference standards are also used during the annual calibration procedure, and their location on the standard calibration curve is determined. One reference standard is located in the high density region of the calibration curve (150 to 155 lbs. per cu. ft.) and the other standard is located in the low density region 110 to 115 lbs. per cu. ft. Dense and light weight concrete serve as the district reference standards.

Over 150 nuclear density gages are being used by the California Department of Transportation. In addition, city, county, and private engineering laboratories utilize these standards for their gage calibrations. For the purpose of evaluating the usability of the standard density blocks, questionnaires, concerning the use of the standards, were submitted to each of the eleven District Materials Engineers. On the basis of their replies, it is felt that the original intent of the standards had been accomplished. Improved accuracy, uniformity, flexibility, and monetary savings had been achieved.



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Accuracy has been achieved because the standard density blocks are relatively homogeneous materials with stable moisture conditions, enabling accurate density determination. The remolded soil standards previously used varied considerably and proved to be undesirable. Since all gages are now calibrated in a designated manner on the six standards, calibration uniformity was realized. This aspect also helped unite the gage operators to adopt a common procedure for gage use. Due to the common calibration standards, any nuclear density gage in service can be interchanged with any other gage without concern for calibration differences, that is, within the limits of the calibration test variability. Gage substitutions or relocations pose no difficulty to gage reliability, thus gage flexibility was secured. The elimination of the need to compact soil specimens for gage calibration reflects a major savings in man-hours expended. The two permanent reference density standards kept by each district provide a means to monitor gage performance.

Achievement of the goals mentioned above reflect the general comments made by the Transportation Laboratory personnel, who assist and consult with district personnel in nuclear gage maintenance and test procedures throughout the California Department of Transportation. This technical assistance includes the annual gage calibration.

Several correlation studies were also performed to determine the validity of the six density standards and each pair of reference standards maintained by the District Materials Engineers. Compaction control tests, conducted with gages calibrated by the six density standards and gages calibrated by the reference standards indicated similar test results. During the 1972 construction season, tests were performed on five highway projects throughout California. The comparison



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of limited test data between the two gage calibrations showed good correlation. Previous comparisons made with gages calibrated on different sets of remolded soil standards indicated very poor correlation results.

Conclusions by Smith, et.al. (2), in their research report "Relative Compaction Study," indicate that standard density blocks calibration curves correlate well with volumetric box (remolded soil) calibration curves for the 6-inch and 8-inch direct transmission mode. In reference to the backscatter mode, they conclude that, "The standard density blocks calibration curve is offset about 2 or 3 pcf from the volumetric box curve in the backscatter mode." Tests recently conducted on another research project displayed very good correlation between gages calibrated on the standard density blocks and gages calibrated on volumetric box standards. These statements indicate that the six standard density blocks are adequate for the densities and compositions of soils used in California highway construction.

The standard density blocks serve as an intergral part of the specification compliance testing procedure for all Department gages. The standards are used to determine gage sensitivity to changes in soil density as well as determine, to some degree, gage sensitivity to mineral composition when different soil mineralogy is encountered. The gage's performance, concerning these two major parameters, is clearly defined by the standard density blocks, and provides an important measure of gage quality.

The favorable comments received and the general satisfaction with the standard density blocks, including the nuclear gage procedures and specifications structured around them, indicate that they are providing a valid method for utilization of our nuclear density gages for earthwork compaction control. As



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for future use, in addition to gage calibration, the standard density blocks will be used, where applicable, to evaluate suggestions submitted by nuclear gage personnel and the normal changes which come about in the nuclear gage state-of-the-art.

## The Moisture Calibration Problem

### 1. Field Moisture Correlation

In the fall of 1967, research directed at development of calibration standards for nuclear moisture-density gages was undertaken by the California Department of Transportation at the Transportation Laboratory, 5900 Folsom Boulevard, Sacramento, California. Temporary moisture standards having high and low water contents were prepared by compacting a local river sand in molds cut from steel drums. Before compaction, the sand was allowed to attain air-dry equilibrium moisture. It was then compacted similarly in each of the tubs, and the bulk densitites of both were calculated.

One tub was constructed with a piezometer and a plastic tube leading to the bottom to permit saturation of the specimen. This sample was flooded until the free water surface was at the sand surface, and all voids were considered saturated. The amount of water added was measured, and checked by weighing the tub and contents before and after adding water. The initial water content of the sand was estimated from oven-dry moisture samples and as a result, the total water content of the saturated moisture standard was known.

The tub containing air-dry sand with no further water added was used as a low moisture standard. Subsequent weighing of this sample indicated little change in moisture content. When the tub was dismantled, the top one to two inches was found



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to be slightly drier than at greater depth. However, this had a negligible effect on the nuclear moisture tests taken on that sample.

When a calibration curve established on these standards was compared with one (for the same gage) developed using "oven-dry" field moistures, the two were found to be displaced by about 3 lb. per cu. ft. of water. That is, the indicated water content of a site using the oven-dry calibration was lower than if the sand water calibration was used. It was very evident, however, that the estimated regression through the field data points was essentially parallel to the laboratory calibration. Since these curves were developed independently, it was concluded that the relationship between the two methods of calibration should be investigated further.

2. "Structural" Soil Water

The observed discrepancy of the offset in the parallel moisture calibration curves discussed above was concluded to be due to the presence of moisture, especially in the clay minerals, which was not removed in the oven-dry test. The nuclear moisture gage response is proportional to the hydrogen contained in any form. This may include in addition to the free water: inter-layer water, hydrates, and hydroxyl water. It is easily demonstrated that all of these forms of "structural" soil water are not evaporated at temperatures of 105-110°C. For example, Nutting (3) reports that the kaolin minerals lose an additional 14 percent by weight (approximately) of hydroxyl water between 400 and 800°C, with the ensuing destruction of the kaolinite. The number of hydrogen atoms in hydroxyl water is one half that of the corresponding quantity of free water molecules. Consequently, the nuclear moisture gage would respond to the free water equivalent of the hydroxyl water in kaolinite; or, about 7 percent by weight.



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Typical data for some clay minerals are summarized in Table 1.

These are approximate average values showing the trend toward additional water loss at temperatures above 100°C. For the portion of this loss considered to be hydroxyl water, the equivalent free water (one half) is tabulated.

Hydrates such as the zeolites and serpentines also contain significant amounts of water which are not driven off by temperatures of 105-110°C. Also, Lambe reported that a diatomaceous earth retained significant amounts of water at temperatures above 105°C (4). This is apparently caused by the attractive forces of the very large internal surface area of this soil. This water should be similar in behavior to the bound water of the clay minerals.

3. Thermal Neutron Absorption

In 1964, Burn published a report, "Calibration of a Neutron Moisture Meter in Leda Clay" (5). Figure 1 is a reproduction of a graph from that paper showing moisture correlation data for a nuclear gage used on the Leda clay. The plot of nuclear readings versus oven-dry moisture contents of the soil is nearly 6 lbs. per cu. ft. to the right of the reference curve. This is at the opposite extreme of the California field calibration data. Burn's reference curve is based (in part) on silica sand and water standards having known total water content which generally correspond to the California Department of Transportation standards previously described.

Burn speculated that the discrepancy between the two calibrations was due to the presence of iron in the clay which absorbed the neutron flux. He observed, as is apparent in the figure, that the displacement between the two curves appears to be a constant for that soil.



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## 4. Summary

It has been shown that if the nuclear gage is calibrated by oven-dry moisture determinations, it can indicate a water content of field soils as much as plus or minus 6 lbs. per cu. ft. of water from that based on an inert system such as silica sand and water, Figures 1 to 5. However, in earth construction, the free soil moisture is the factor which requires control. This has been shown to be a variable percentage of the total soil water to which the nuclear gage responds. Consequently, unless a consistent relationship can be demonstrated to exist between a calibration based on standards of known water content and the free water content of individual soils, the users of the gages are forced to calibrate by field correlation. This is difficult, and in some cases impossible to do, since a sufficient range of data is often not available to establish the slope of the curve with any degree of confidence.

## Experimental Procedure

The experimental procedure involved the careful fabrication, and testing with nuclear moisture gages of four soil water systems in large molds. They were:

1) A commercial silica sand
2) A commercial kaolin clay
3) A typical clayey field soil
4) An expanded shale

The approximate structural water content of the soils was determined on the basis of high temperature evaporative tests, mineral identification, and differential thermal analysis (DTA), Tables 2 to 5. Therefore, by exercising careful control of the amount of water added, both the free water and total (equivalent) water content of the individual samples were closely estimated.



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The physical data concerning the dimensions, volumes, densities, and water contents of all samples tested with the nuclear moisture gages in the experimental program are presented in Table 6. The dimensions and volumes of the samples were of sufficient size to ensure that they would essentially represent infinite soil mass for testing with the gages.

The top surfaces of most of the samples were protected by covering them with a layer of polyethylene plastic. The plastic was tested and found to have a negligible effect on test results by taking readings with and without the covering.

1. Silica Sand Samples

Silica sands from two sources were obtained, which were 99.7 to 99.9 percent pure $SiO_2$. The approximate grading of the sands is given in Table 2.

Four samples were fabricated from these sands. They were:

1) A-70-W. This sample was compacted dry in approximately 2-inch lifts with an electric impact hammer using a plywood disc to confine the sand. The sample was provided with a piezometer and a perforated plastic tube to prevent saturation from within. The (W) in the notation indicates a "wet" or saturated sample.

2) E-25-W. This sample was prepared similarly, except that the No. 25 sand was used.

3) A-70-200-W. A ground silica sand (No. 200 flour) was uniformly mixed with the No. 70 sand to reduce the void space, so that a lower saturated water content was obtained.



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4) E-25-D. The dry silica sand standard (D) was fabricated with the No. 25 sand. The moisture content of this sand when initially compacted was hardly detectable. After exposure to the atmosphere in the test area for a period of several months, the moisture increase was upward to 0.2 percent.

An attempt was also made to fabricate a partially saturated sample by compacting the moistened sand in increments. Polyethylene plastic was used to prevent migrations of water. However, sufficient intra-layer water movement was found to occur in the layers which affected the gage readings and made this type of specimen unsatisfactory.

2. Kaolin Samples

A kaolin clay of high purity was obtained from Ione, California. The physical properties and chemical analysis provided by the producer are shown in Table 3.

An independent analysis of a sample of this clay using X-ray diffraction and differential thermal analysis (DTA), was conducted at the Transportation Laboratory. The clay was identified as a typical kaolin, with little or no indication of the presence of other clay minerals.

High temperature evaporation tests were conducted with oven-dry samples of the Ione Kaolin. These samples lost 0.1 percent by weight between 105 and 400°C, and 12.2 percent by weight between 400 and 600°C. This loss in weight was considered to be primarily hydroxyl water, and an equivalent water loss between 105 and 600°C of 6 percent was presumed for the purposes of the study.



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Two samples of the kaolin were then prepared in large molds for testing. The dimensions and volumes of the samples are given in Table 6. These two samples were prepared similarly, except that different amounts of free water were added to each. The intent was to obtain as high (H) and as low (L) a water content as possible, with uniform compaction, and not too great a difference in the dry density of the two. The amount of free water to add was estimated from preliminary tests. Representative oven-dry samples were also taken and checked when the sample was dismantled after completion of the testing. One of the kaolin samples (the Kaolin-H) was dried in a 105-110°C oven, and then retested with the nuclear moisture gages.

3. Field Soil Samples

Two samples of a typical field soil were prepared and tested similarly at a high and low free water content. A third sample was fabricated by compacting the material in an oven-dry condition. The grading and mineralogy of the soil are presented in Table 4.

High temperature evaporation tests were also conducted on oven-dry samples of the field soil. A loss of 0.5 percent by weight was recorded between 105 and 400°C, and 2.2 percent between 400 and 600°C. The loss in weight between 105 and 600°C was assumed to indicate an equivalent water content of 1.5 percent by weight.

4. Expanded-Shale Sand Samples

Five samples were prepared of an expanded-shale sand. This material is manufactured by expanding sand-sized particles of montmorillonitic shale by heating in a rotary kiln to temperatures of approximately 2,000°F. The grading of the expanded shale sand, and the manufacturer's chemical analysis is given in Table 5.



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One of the expanded-shale sand samples (ES-20.6, Table 6) was prepared by compacting, and then saturating. The (ES-dry) sample was left in a dry or "as compacted" state. The remaining three expanded-shale sand samples were prepared by moistening the shale sand to intermediate water contents, and then compacting. Due to the absorbent nature of the calcined shale, the procedure appeared to work satisfactorily, with little discernible migration of water during the period of testing. The water contents of several of the shale sand samples were checked by removing the material in layers, and oven drying the entire increments.

5. Concrete Blocks

Consideration was also given to the prototype concrete density gage calibration standards. The high quantity of hydrated compounds present in these standards provided sufficient hydrogen content to satisfy both low and high water content equivalents. More data, however, remains to be gathered on their ability to maintain a constant degree of hydration.

Other materials considered for use as a moisture standard included phenolic resin and silica sand, polyethylene and glass, and epoxy are described below.

6. Phenolic Resin and Sand

Phenolic resin coated sand was placed in two different molds and each mold heated so as to fuse the sand together. The molds, 1.2' height by 1.9' diameter, consisted of metal barrel ends whose approximate individual volumes were 3.25 cubic feet. The amount of resin content was varied in both molds so as to represent, in terms of hydrogen content, high and low water equivalents. The reason for abandoning the phenolic resin and



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sand combination was because the equivalent $H_2O$ content in the high moisture sample was too low and the vendor could not fabricate a sample with a higher phenolic resin content.

7. Epoxy

Testing with 4" thick epoxy and sand blocks was conducted but these were found to be too thin and larger masses of epoxy and sand were difficult to control.

8. Polyethylene and Glass

This combination of materials was considered but was not tested.

Nuclear Moisture Gage Data

The soil samples were not necessarily fabricated or tested with the nuclear gages in the order presented, nor was it possible to retain all samples so that they could be tested concurrently.

To compensate, as each new sample was being tested, all available samples were read. The average of these readings on each available sample was then plotted against the sample free water in Figures 2 and 3 and against the estimated total water content in Figures 4 and 5.

Two nuclear soil gages were used during this study. Gage A is an older unit that has been found to be relatively stable over an extended period of time. The source contained in this gage is 4.5 mc Radium 226-Beryllium. Gage B is of more recent manufacture, and contains a 50 mc Americium 241-Beryllium neutron source.



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1. Free Water Correlation Data

Figures 2 and 3 illustrate the response of Gages A and B plotted against the free water content of the samples. The curves are drawn by visual "best fit". For Gage A, the calibration curves for the four soil water systems are essentially parallel, except for the expanded shale at the lower water contents. The readings taken with Gage B indicate a somewhat greater variation in the slope of the individual calibration lines for the four soil water systems than did those of Gage A.

The data for the expanded-shale water system reflects a high degree of neutron flux absorption. A report by the Oklahoma Department of Highways presents a similar datum point for an expanded-shale water sample tested by them (6). The chemical analysis of the shale sand indicates a total of about 6 percent of iron and potassium present in the material, which would not seem sufficient to cause the amount of absorption shown.

The oven-dry expanded shale sample (ES-dry) plotted very closely to the dry silica sand sample (E-25-D) in Figures 2 and 3. This suggests that a certain level of thermal neutron activity is required before the capacity of the material to absorb thermal neutrons becomes saturated. At some water content, this absorptive capacity of the soil begins to be satisfied. Thereafter, the production of thermal neutrons with change in water content is almost as though the absorptive elements were not present. Above this critical water content, the calibration curves for soils with absorptive elements for thermal neutrons appear to be reasonably parallel to the silica sand calibration curve.

The assumption that the net effect of the presence of structural water, and slow neutron absorbing elements in a soil, is a calibration constant; is undoubtedly an over-simplification. However, it is concluded that the slope of a calibration curve



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determined using standards of silica sand and water should be satisfactory for nuclear gage moisture determinations on most soils. An exception may have to be made for those containing highly absorptive elements, especially at water contents below 6 lbs. of water per cu. ft. The extent to which such materials may be encountered in soils used in highway construction is not known.

2. Total Water Correlation Data

Figures 4 and 5 show the average nuclear gage count ratio readings plotted with respect to the estimated total water content of the samples. Most of the moisture data for the clay soils now plot either on, or to the right of the silica sand calibration curve. It is concluded that nuclear moisture measuring instruments do respond to the structural water, as well as to the free water. However, the effect of the hydroxyl water does not appear to be directly proportional to the hydrogen content. This is to be expected, since the bonding of the hydrogen atom to the soil minerals probably reduces its capacity to thermalize the fast neutrons emitted by the radioisotope in the gage (7, 8).

## Mineralogical Effects on Moisture Measurements

A need to determine the amount of influence exerted by soil mineralogy on moisture measurements was identified during our laboratory experiments. Once the influence was established, experimental means to correct moisture gage behavior could be attempted. Four soil types, having the physical and chemical properties listed on Tables 7, 8 and 9, were fabricated in round containers (Photos 1 & 2 and Figures 6 & 7) similar to those used for the silica sand moisture calibration standards (Photo 3). Each air-dry soil type, placed in 2-inch lifts, was consolidated with an electric impact hammer. A plywood disc covering the entire surface of the lift confined the soil during compaction.



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The clay minerals have an abundance of hydrate compounds and hydroxyl ions, which generally cause a neutron moisture gage to indicate a higher water content than actually exists in the soil. The bound water held in the mineral lattice effectively thermalize the fast neutrons entering the soil. A container of bentonite and a container of kaolinite were fabricated to determine the bound water effects on moisture gage measurements. In their air-dry state, the bentonite water content, as determined by the 105°C gravimetric method was 6.9 pcf. Similarly, the kaolinite air-dry moisture was found to be 0.4 pcf. The nuclear moisture gage count rates were recorded for these clays using an experimental gage (9,10) and plotted on the silica sand calibration curve (Figure 8) above their respective air-dry moisture contents.

The bentonite contains hydrates and hydroxyl ions which would tend to give a higher thermal neutron count rate and therefore signify a higher moisture content. However, this bentonite contains other elements which act as thermal neutron absorbers. The absorption effect, in this case, appeared to override the thermalizing effect. As a result, the data point on Figure 8 plots below the silica sand calibration curve. The opposite was observed from the kaolinite test. The amount of thermal absorbers (iron) present in the kaolinite was approximately one-tenth the amount present in the bentonite. Therefore, the increased neutron thermalization exceeded the absorption, resulting in an increased thermal neutron count rate. The data point in this instance plotted above the silica sand calibration curve.

Tables 10 and 11 are abridged listings of elements which thermalize fast neutrons and capture thermal neutrons respectively. A brief inspection of these tables, in addition to a review of the element oxides tabulated for the kaolinite and bentonite (Table 8) substantiate this line of reasoning.



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Thermal neutron absorption was also investigated by placing an expanded shale, containing 5 percent iron, under the moisture gage. The large amount of iron compounds and oxides of this soil, sold under the trade name, "basalite", was expected to absorb a noticeable quantity of thermal neutrons. As noted by the bentonite test results, the basalite data point should plot below the silica calibration curve. Water was added to the basalite container producing a 17.7 pcf water content. Moisture gage measurements were not made on the air-dry basalite soil prior to saturation of the container.

The test results verified our hypothesis; however, the presence of the high water content probably overshadowed the full effect of the iron. Figure 8 shows the data point below the silica curve. A lesser water content would possibly have revealed a greater absorption influence.

Another strong thermal neutron absorber, boron, produced a significant amount of thermal neutron absorption. The soil contained 2.08 percent boron, in addition to other less effective absorbers. The chemical analysis is listed in Table 8. Water, in this case, was not added to the soil. The air-dry moisture determined by the 105°C gravimetric method was 2.7 pcf. The data point from the moisture gage measurement reduced the expected thermal neutron count rate by approximately 35 percent. Note the position of the boron soil data point on Figure 8.

Our definition of moisture gage measurement error is graphically defined by the horizontal distance in pcf water content of the data point from the silica sand calibration curve. Three nuclear gages, each having a different moisture gage design, were used to measure the water content of the four soil types employed to explore mineral induced error. The measurement errors recorded from each gage are presented in Table 9.



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The experiments have clearly shown that mineral composition of the soil is extremely influential in deciding the credibility of moisture gage measurements. Further consideration is being given to this area of study. Recommendations may be advanced for adopting some soil mineral as a standard for determining the measurement error of commercial gages, as well as define error limitations acceptable for our procedurement specifications.

## Application

### 1. "Offset" Method

For specific soils, where an equivalent oven-dry moisture calibration curve for the nuclear gage is desired, a moisture sample is taken at the site of a nuclear moisture reading. The density of the location must be determined by nuclear or other means. The oven-dry moisture in lbs. per cu. ft. of water is calculated, and plotted against the nuclear gage moisture reading. A calibration curve for that soil is drawn through the point and parallel to the sand water reference calibration.

This procedure has two disadvantages: 1) It is only good for the particular soil and 2) any errors in the estimates of moisture or density are reflected in the calculated moisture. An alternate and preferred method is discussed as follows.

### 2. "Approximate Wet-Weight" Method

A practical method of compaction control utilizing only a wet density correction based on the slope of the moisture calibration curve can be demonstrated. The procedure is especially applicable to structural section materials, for which it is often possible to pre-establish a satisfactory compaction standard. The concept is similar to that of the so-called



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"wet-weight" method of compaction control used by California (11) and others. This procedure is predicated on expressing the wet density of a soil, and the laboratory control density, in terms of the same moisture content. The above procedure contains a slight approximation, but the percentage is close to that calculated on the basis of the "exact" wet or dry weight methods.

As an example, suppose that it has been established that a certain soil should have a wet density of 135 lbs. per cu. ft. at some definite (but unknown) water content. This unknown water content was present in the material when it was obtained for laboratory compaction testing. Assume also that a nuclear moisture gage had been used to test the location where the soil was obtained. At the time of removal it was found to have a water content of (x) lbs./cu.$^3$. At a later time, a site with similar soil is tested, and found to have a wet density of 140 lbs. per cu. ft. with (x+3) water content. The wet density of the site in terms of the water content at which the control had been established is (140 - 3), or 137 lbs. per cu. ft. This equivalent wet density is greater than the 135 lbs. per cu. ft. previously established as a minimum control density. Thus, if the slope of the nuclear moisture calibration curve is correct, it has been found that the density of the site is satisfactory without knowing its actual water content.



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TABLE 1

APPROXIMATE WATER LOSS OF VARIOUS MINERALS, 100 TO 800°C

| Mineral | Temperature °C (100, 200, 300, 400, 500, 600, 700, 800) | Structural Water Total (equiv) $H_2O$ loss |
|---|---|---|
| Kaolin Halloysite | Little loss; Approx. 14% by wt. $OH^-$ (equiv. $H_2O$ loss = 7%) | 7% |
| Montmorillonite Smectite | Approx 3% loss inter-layer $H_2O$; Approx 5% loss $OH^-$ (equiv. $H_2O$ = 2½%) | 5½% |
| Vermiculite | Approx. 8% loss inter-layer, cation hydrates; Approx. 3% $OH^-$ (equiv. $H_2O$ = 1½%) | 9½% |
| Illite (Mica group) | Gradual loss 2% (presumed $H_2O$); $OH^-$ loss est. 4½% (equive. $H_2O$ approx. 2%) | 4% |
| Chlorite | Little loss; $OH^-$ loss approx. 12% (equiv. $H_2O$ = 6%) | 6% |
| Sepolite | Gradual loss to 10% (presumed $H_2O$); $OH^-$, gradual loss to 6% (equiv. $H_2O$ = 3%) | 13% |

Clay mineral data estimated from Grim (12)



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TABLE 2

SILICA SAND GRADING

| Identification | E-25 | E-85 | No. 200 | A-70 |
|---|---|---|---|---|
| Fineness | 25.88 | 84.42 | --- | 65 |
| Sieve | (Percent Retained) | | | |
| 20 | 2.2 | | | |
| 30 | 38.6 | | | |
| 40 | 57.6 | 0.2 | | 0.6 |
| 50 | 1.4 | 2.4 | | 3.9 |
| 60 | | | | 9.3 |
| 70 | 0.2 | 10.0 | | 20.5 |
| 80 | | | | 22.1 |
| 100 | | 45.0 | | 31.2 |
| 140 | | 20.0 | 1.0 | 11.6 |
| 200 | | 11.0 | 4.0 | 0.7 |
| 270 | | 2.4 | 6.0 | |
| 325 | | 1.0 | 9.0 | |

TABLE 3

IONE KAOLIN, PHYSICAL AND CHEMICAL DATA

Physical Properties:

| | |
|---|---|
| Specific Gravity | 2.60 |
| Moisture (max.) % | 0.5 - 1.0 |
| Particle Size, % | |
| Minus 2 microns | 50 - 55 |
| Plus 5 microns | 20 - 25 |
| pH | 4.5 - 5.5 |
| Water of Plasticity, % | 31.9 |
| Average Particle Size | 2.2 microns |

Chemical Analysis:

| | |
|---|---|
| Silica, % | 45.0 - 47.0 |
| Alumina, % | 37.5 - 39.0 |
| Iron Oxide, % | 0.3 - 0.5 |
| Titanium Dioxide, % | 1.5 - 2.0 |
| Ignition Loss, % | 13.0 - 14.0 |



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TABLE 4

FIELD SOIL, GRADING AND MINERALOGY

| Grading | | Mineral Identification | |
|---|---|---|---|
| Size | % Passing | Mineral | *Approx. % |
| 3/4 | 100 | Quartz | 25 - 30 |
| 1/2 | 84 | Feldspar | 10 - 15 |
| 3/8 | 73 | Chlorite | 10 - 15 |
| #4 | 52 | Mica | 5 |
| 8 | 41 | Hornblende | 5 |
| 16 | 31 | Misc. Clay | 5 - 10 |
| 30 | 23 | Talc | 2 - 3 |
| 50 | 18 | Augite | 2 - 3 |
| 100 | 15 | Other Xtaline | 5 |
| 200 | 13 | Amorphous | 15 |
| 5 micron | 8 | | |
| 1 micron | 6 | | |

*These percentages are estimated from X-ray diffraction data.

TABLE 5

EXPANDED SHALE-SAND, GRADING & CHEMICAL ANALYSIS

| Sieve | Percent Passing (Basalt Rock Co.) | Percent Passing Translab |
|---|---|---|
| #4 | 99 | |
| 8 | 82 | 82.6 |
| 12 | | 52.6 |
| 16 | 56 | |
| 30 | 36 | 33.3 |
| 50 | 23 | 22.1 |
| 100 | 12 | 13.5 |
| 200 | | 6.5 |

| | Chemical Analysis "Raw" Shale | Chemical Analysis Calcined Shale |
|---|---|---|
| $SiO_2$ | 59.2 | 62.8 |
| $Al_2O_3$ | 20.0 | 21.7 |
| CaO | 2.6 | 3.2 |
| $Fe_2O_3$ | 3.3 | 4.4 |
| MgO | 2.7 | 3.3 |
| $Na_2O$ | 2.6 | 2.6 |
| $K_2O$ | 1.6 | 1.6 |
| $H_2O$ | 8.0 | 0.0 |
| Ignition Loss | Trace | 0.4 |



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TABLE 6

PHYSICAL DATA FOR THE EXPERIMENTAL SOIL-WATER SAMPLES

| Sample | Physical Description | | | | Density (lbs/cu ft) | | Water Content (lbs $H_2O$/cu ft) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Shape | "D" (ft) | Depth (ft) | Volume (cu ft) | Wet | Dry | Free | Struct.* | Total | Legend** |
| A-70-W | Cylindrical | 1.87 | 0.94 | 2.63 | 125.4 | 100.9 | 24.5 | - | 24.5 | 0 |
| E-25-W | " | " | 0.92 | 2.55 | 130.2 | 110.9 | 19.2 | - | 19.2 | 0 |
| A-70-200-W | " | " | 0.87 | 2.43 | 123.9 | 109.6 | 14.3 | - | 14.3 | 0 |
| E-25-D | " | " | 1.19 | 3.31 | - | 111.7 | - | - | - | 0 |
| Kaolin-H | Octagon | 1.50 | 1.17 | 2.31 | 97.1 | 77.9 | 19.2 | 4.7 | 23.9 | |
| Kaolin-L | Rectangular | 1.00 | 1.50 | 2.25 | 80.1 | 70.7 | 9.4 | 4.2 | 13.6 | |
| Kaolin-H(dry) | Octagon | 1.5 | 1.17 | 2.31 | - | 77.9 | - | 4.7 | 4.7 | |
| Field Soil-H | Octagon | 1.50 | 1.17 | 2.31 | 146.0 | 131.9 | 14.1 | 2.0 | 16.1 | |
| Field Soil-L | Rectangular | 1.00 | 1.50 | 2.25 | 137.4 | 129.8 | 7.6 | 2.0 | 9.6 | |
| Field Soil(dry) | Cylindrical | 1.87 | 1.22 | 3.29 | 89.9 | 89.9 | - | 1.4 | 1.4 | |
| ES-20.6 | Cylindrical | " | 0.95 | 2.76 | 109.2 | 87.0 | 22.2 | - | 22.2 | x |
| ES-17.4 | " | " | 0.94 | 2.64 | 94.4 | 77.0 | 17.4 | - | 17.4 | x |
| ES-12.0 | " | " | 0.94 | 3.62 | 93.8 | 81.8 | 12.0 | - | 12.0 | x |
| ES-6.0 | " | " | 1.14 | 3.27 | 88.2 | 82.1 | 6.1 | - | 6.1 | x |
| ES-(dry) | " | " | 1.19 | 3.29 | 88.6 | 88.2 | 0.4 | - | 0.4 | x |

* Equivalent water content
** As used in Figures 2 and 3

NOTE: The dimension "D" is the least top surface dimension.



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Table 7

PHYSICAL DATA FOR CHEMICAL ERROR PRONE

MOISTURE TUBS

| Moisture Tub | Dia.(ft) | Height(ft) | Volume($ft^3$)* | Wet Density ($lbs./ft^3$) | Moisture ($lbs./ft^3$) |
|---|---|---|---|---|---|
| Silica(Wet) | 1.996 | 1.2144 | 3.800 | 130.46 | 18.8 |
| Silica(Dry) | 1.997 | 1.2186 | 3.817 | 112.22 | 0 |
| Bentonite | 1.994 | 1.3296 | 4.138 | 69.8 | 6.9 |
| Boron | 1.994 | 1.259 | 3.913 | 98.8 | 2.7 |
| Basalite | 1.998 | 1.150 | 3.581 | 112.5 | 17.7 |
| Kaolinite | 1.979 | 1.168 | 3.62 | 50.8 | 0.4 |

* Volume was determined by use of water.



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Table 8

CHEMICAL ANALYSIS FOR CHEMICAL ERROR PRONE MOISTURE TUBS

| Kaolinite Tub* | % |
|---|---|
| $SiO_2$ | 45-47 |
| $Al_2O_3$ | 37.5-39 |
| $Fe_2O_3$ | 0.3-0.5 |
| $TiO_3$ | 1.5-2.0 |
| $Na_2O_3$ | 0.0-0.2 |
| $K_2O_3$ | 0.1-0.3 |
| Ignition Loss | 13.0-14.0 |

| Bentonite Tub* | % |
|---|---|
| $SiO_2$ | 56.42 |
| $Al_2O_3$ | 23.62 |
| $Fe_2O_3$ | 1.64 |
| $Mn_3O_4$ | 0.04 |
| CaO | 0.62 |
| MgO | 4.24 |
| $Na_2O$ | 0.07 |
| $K_2O$ | 0.01 |
| $H_2O$ (@ 110°C) | 6.13 |
| Ignition Loss | 7.18 |

| Boron Tub* | % |
|---|---|
| B | 2.08 |
| Cd, Fe, H | 0.47 |
| Quartz | 57 |
| Mixed Layer Clays | 15-20 |
| Feldspars | 10-15 |
| Calcite | <5 |
| Biotite | <5 |

| Basalite Tub** | % |
|---|---|
| Quartz | 20-25 |
| Feldspar | 5-10 |
| Fe | 5 |

*Chemical analysis by wet laboratory analysis and mineral analysis by Differential Thermal Analysis (DTA) and X-ray Defraction.

**Analysis by Differential Termal Analysis (DTA) and X-ray Defraction. Remaining percentages could not be determined because the crystallinity of this sample was largely destroyed by the high temperature it had been subjected to.



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Table 9

MINERAL INDUCED ERROR OF MOISTURE GAGE MEASUREMENTS

| Fast Neutron Moisture Gage | Soil Type** | | | |
|---|---|---|---|---|
| | Boron | Bentonite | Kaolinite | Basalite |
| Commercial Gage "A" | -2.9 | -1.8 | +0.6 | -0.6 |
| Commercial Gage "B" | -2.6 | -1.7 | +1.4 | -0.5 |
| Experimental Gage* | -2.5 | -0.5 | +0.9 | -0.5 |

* The experimental gage was designed and constructed by Transportation Laboratory personnel

** Units are lbs. of $H_2O$/cu. ft.



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Table 10

Relative Effectiveness of Elements in Slowing Down Fast Neutrons (13)

| Element | Average number of collisions required for thermalization | Element | Average Number of collisions required for thermalization |
|---|---|---|---|
| Hydrogen | 18.2 | Silicon | 262 |
| Boron | 104.5 | Phosphorus | 288 |
| Carbon | 115.4 | Sulfur | 298 |
| Nitrogen | 133.5 | Chlorine | 329 |
| Oxygen | 152 | Potassium | 362 |
| Sodium | 215 | Calcium | 371 |
| Magnesium | 227 | Iron | 514 |
| Aluminum | 251 | Cadmium | 1028 |
| | | Uranium | 2169 |

Table 11

Relative Absorption of Capability of Some Elements for Thermal Neutrons (13)

| Element | *Barns | Element | *Barns |
|---|---|---|---|
| Cadmium | 2450 | Sulfur | 0.520 |
| Boron | 755 | Sodium | 0.505 |
| Indium | 196 | Calcium | 0.44 |
| Gold | 98.8 | Hydrogen | 0.332 |
| Lithium | 71.0 | Aluminum | 0.230 |
| Silver | 63.0 | Phosphorus | 0.200 |
| Chlorine | 33.6 | Silicon | 0.160 |
| Iron | 2.53 | Magnesium | 0.063 |
| Potassium | 2.07 | Carbon | 0.0034 |
| Nitrogen | 1.88 | Oxygen | 0.0002 |

* A "burn" or "Fermi" is a measure of the probable cross-sectional target area.



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CALIBRATION CURVE FOR LED A CLAY (5)

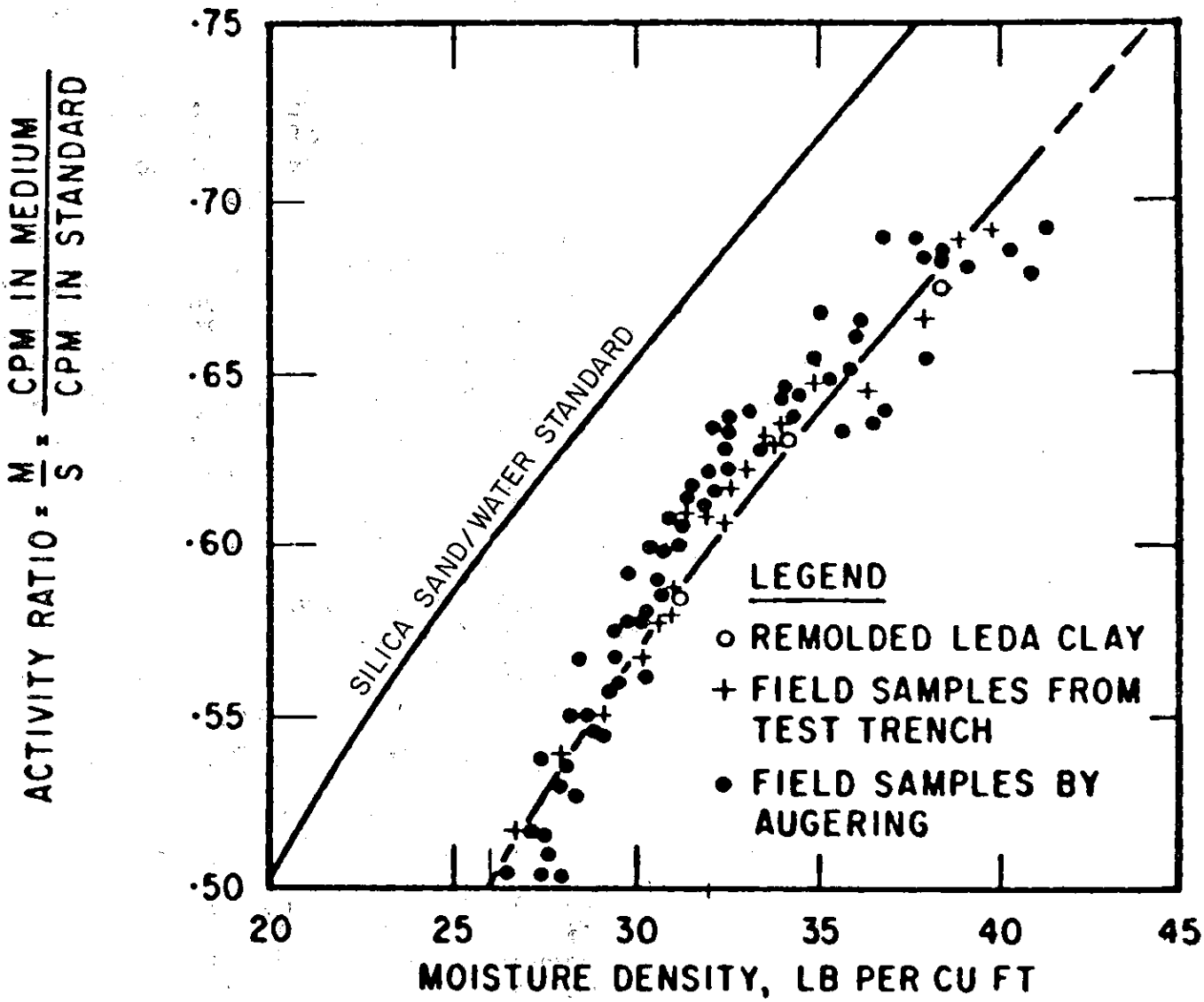


Figure I



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# NUCLEAR FREE MOISTURE CORRELATION
## TEST DATA
### GAGE A

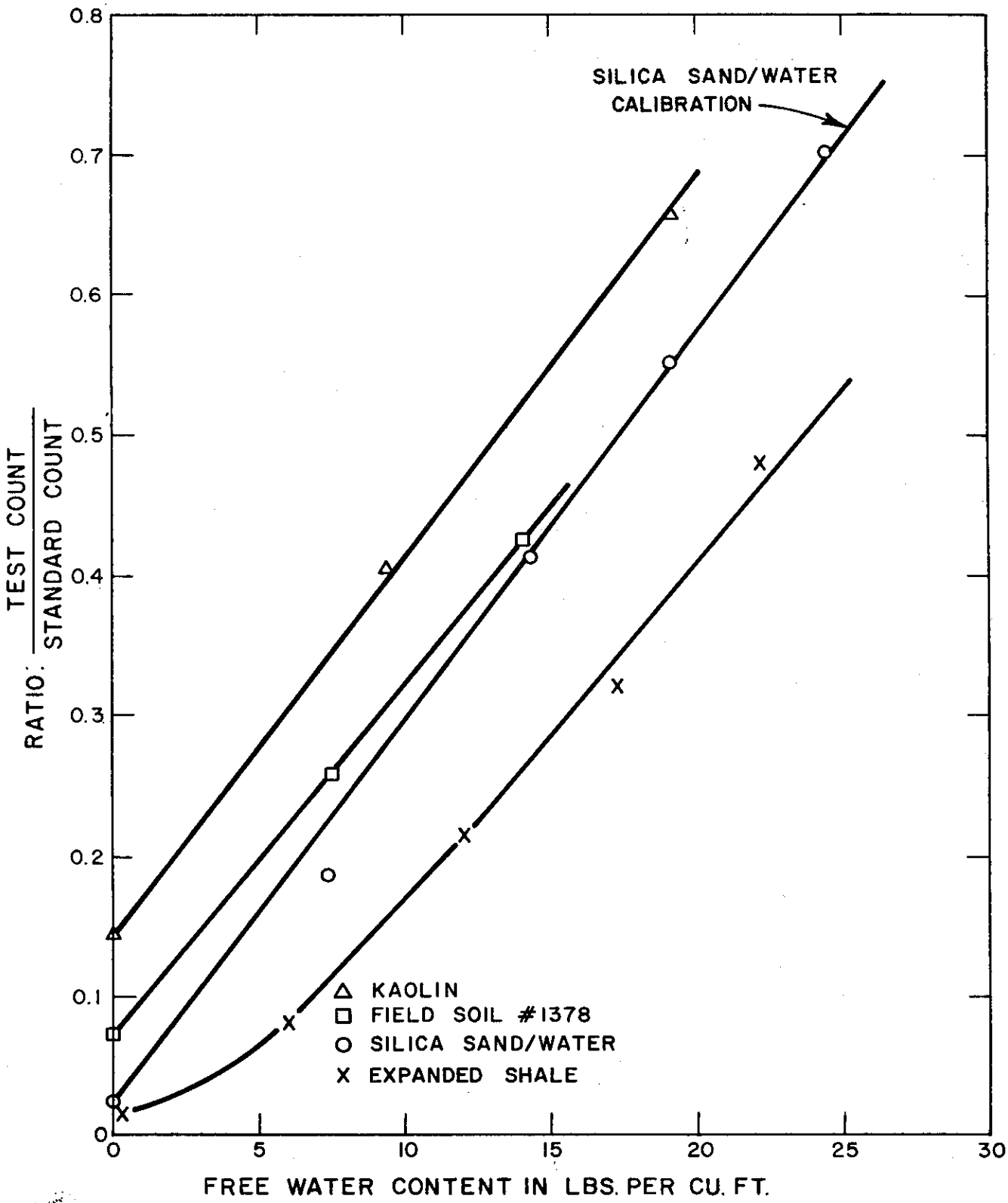


Figure 2



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# NUCLEAR FREE MOISTURE CORRELATION TEST DATA

GAGE B

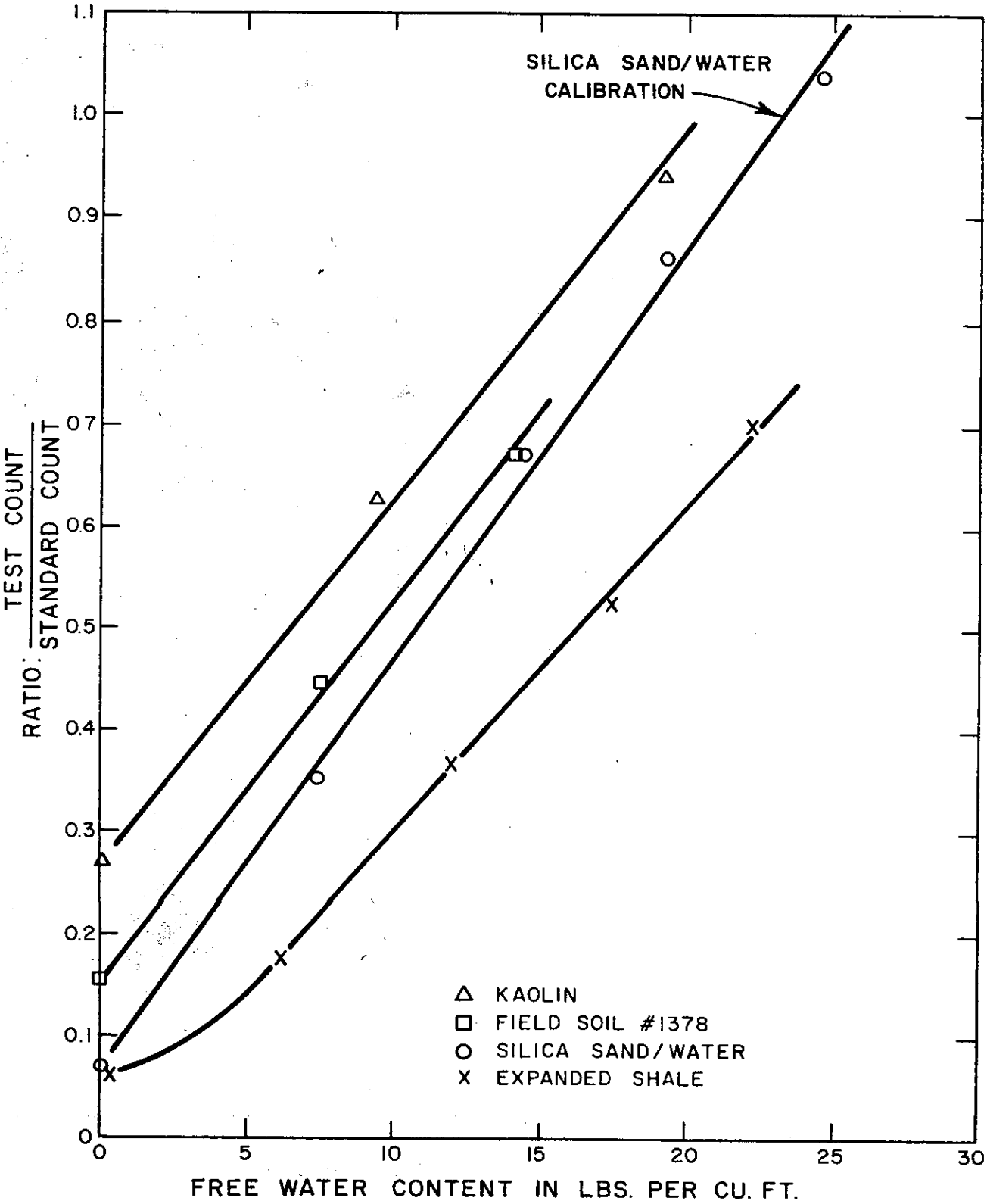


Figure 3



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# NUCLEAR TOTAL MOISTURE CORRELATION
## TEST DATA
### GAGE A

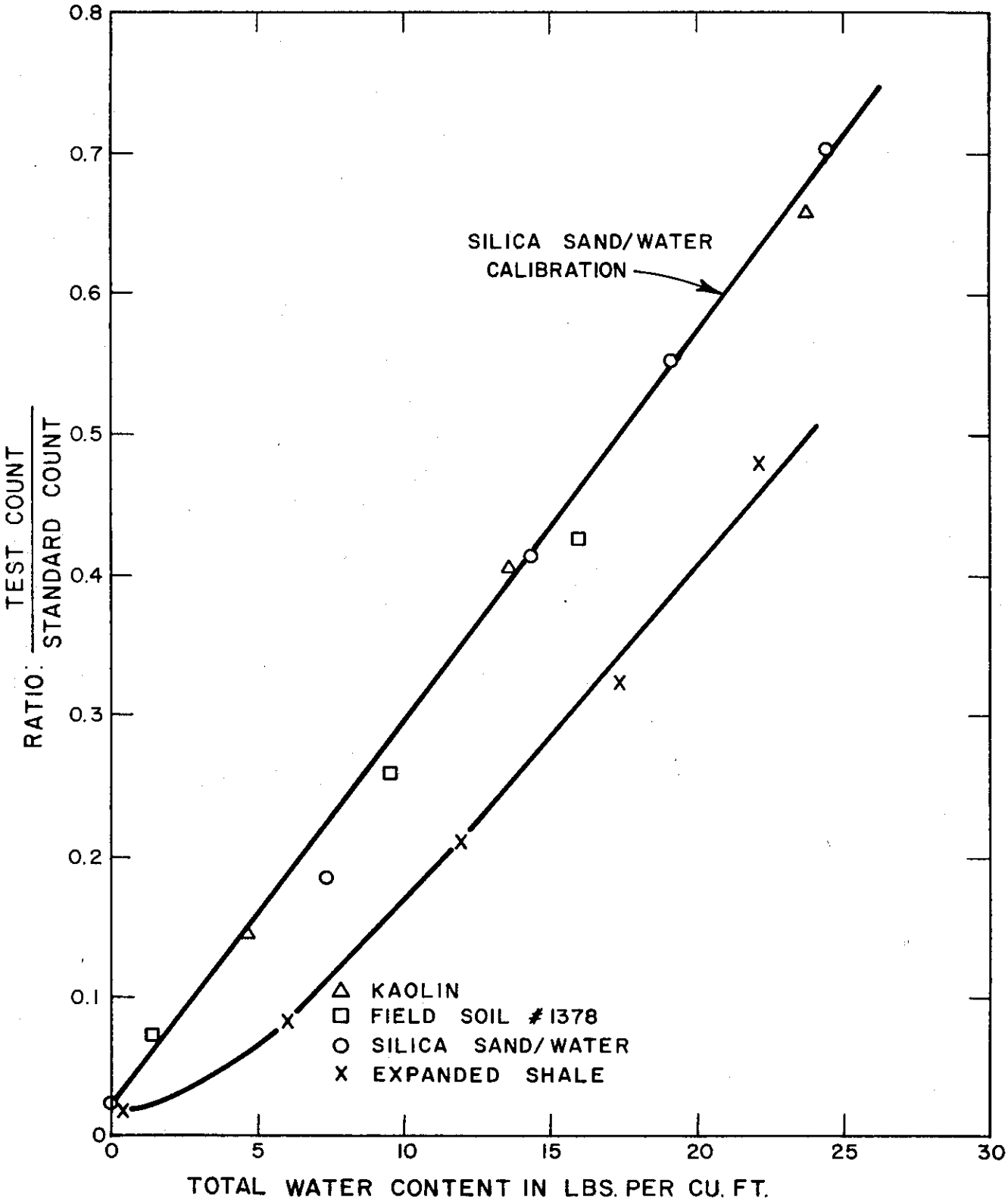


Figure 4



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# NUCLEAR TOTAL MOISTURE CORRELATION TEST DATA

GAGE B

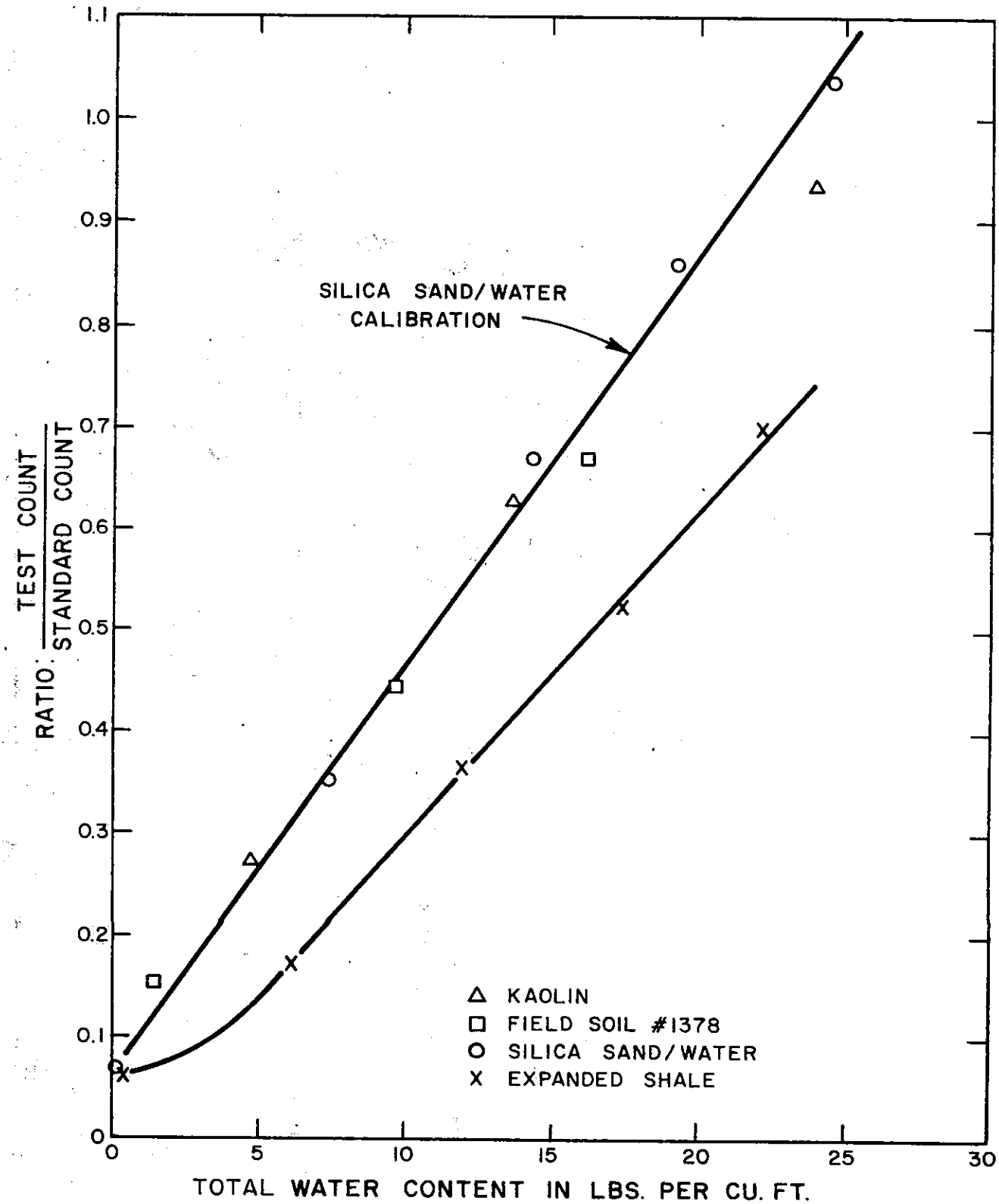


Figure 5



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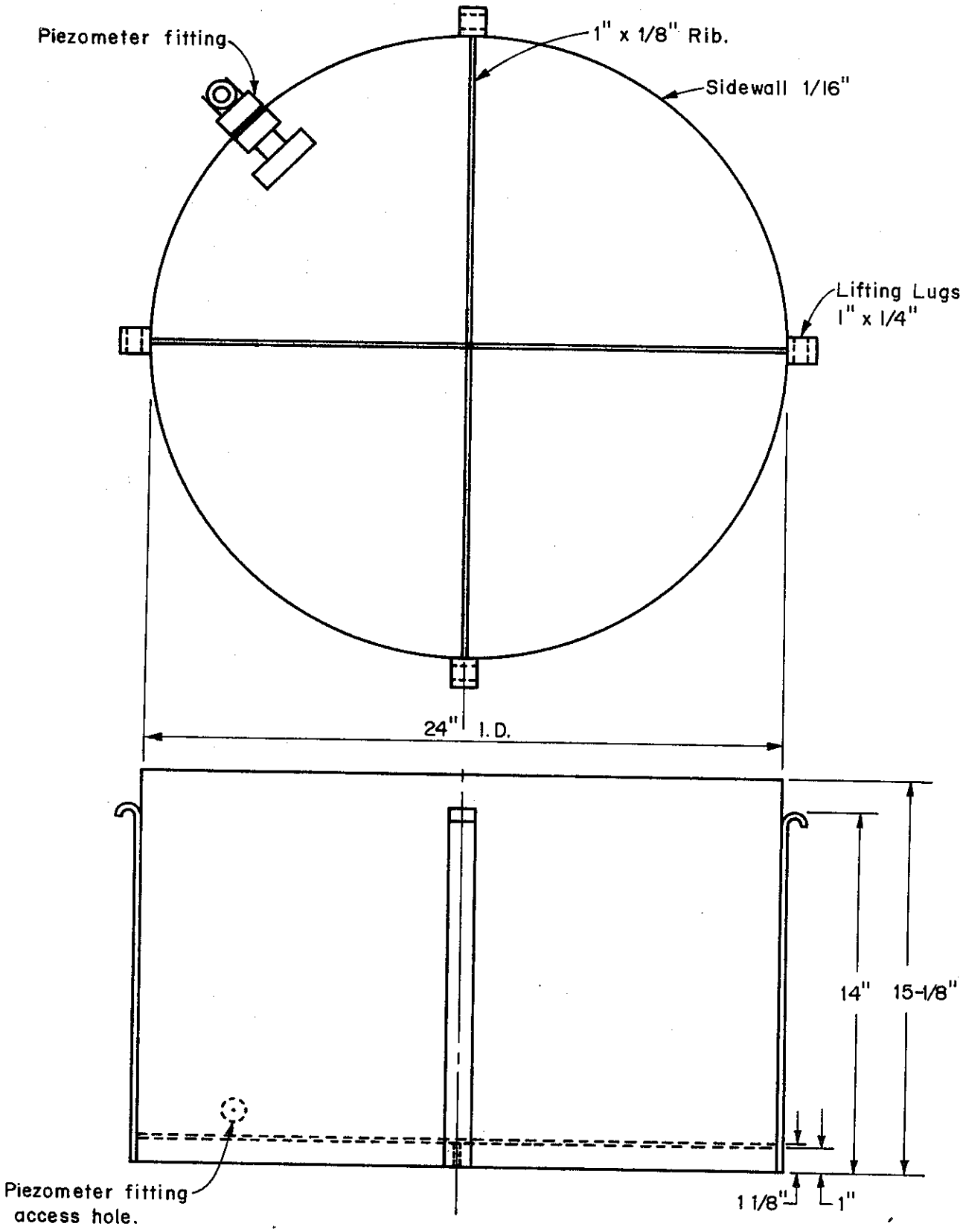


**MOISTURE STANDARD TUB**

Scale 3/16" = 1"

Figure 6



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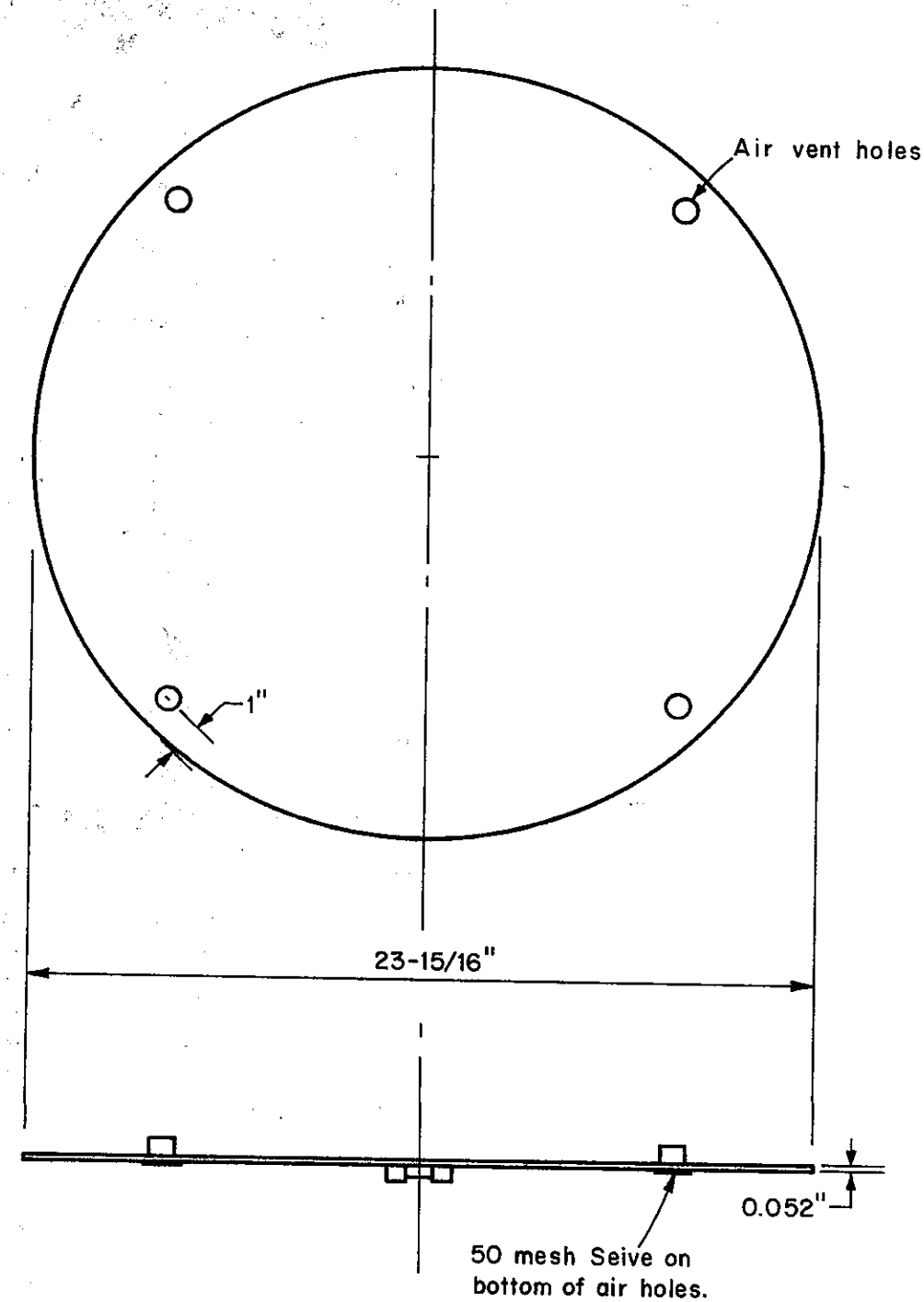


MOISTURE STANDARD TUB COVER

Scale 3/16" = 1"

Figure 7



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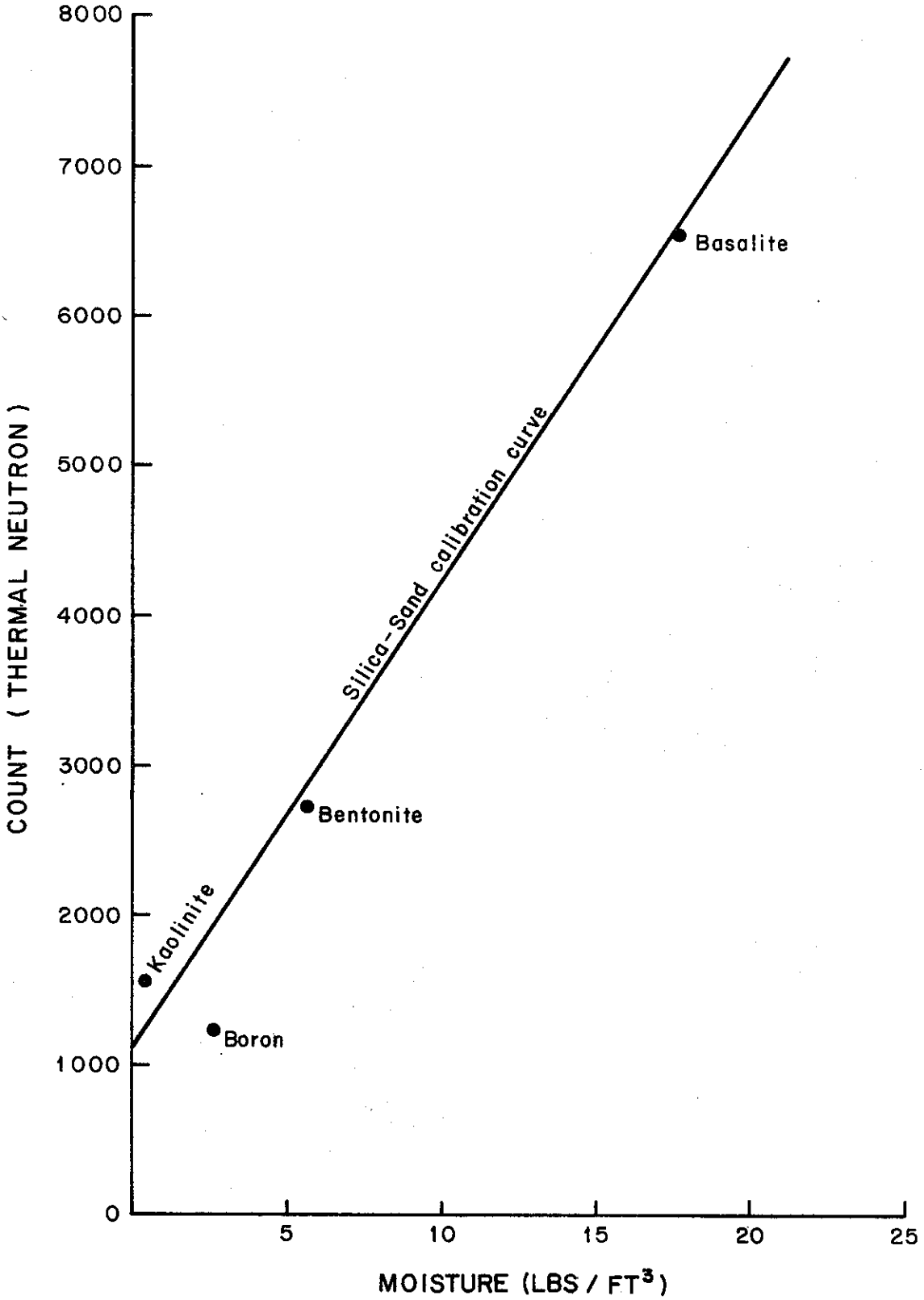


AUTOPROBE MOISTURE CALIBRATION CURVE
EXPERIMENTAL GAGE

Figure 8



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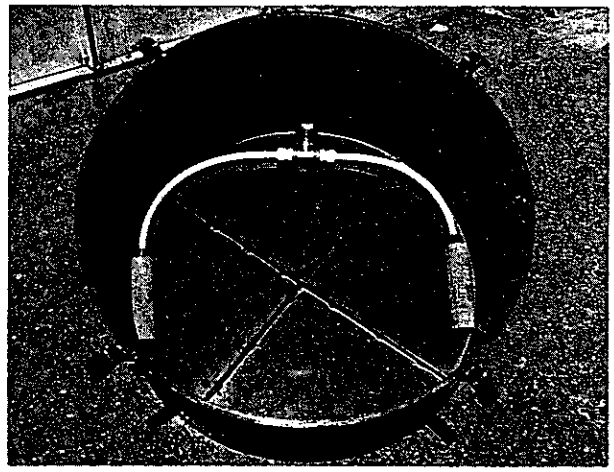
Photo 1 Top view of empty tub for moisture standard.



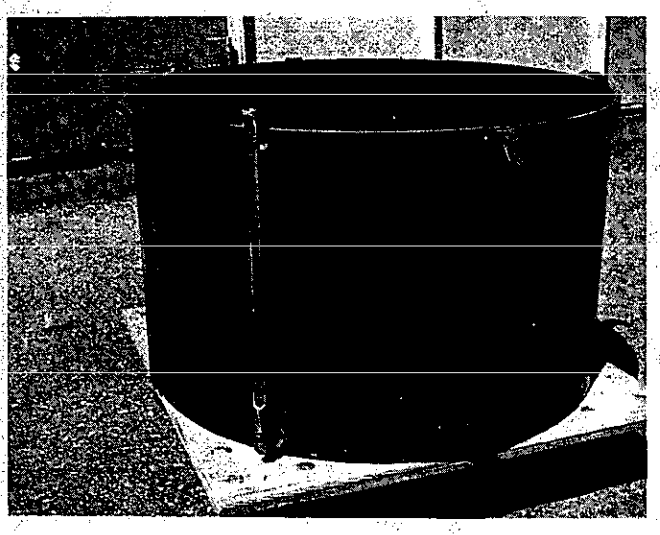
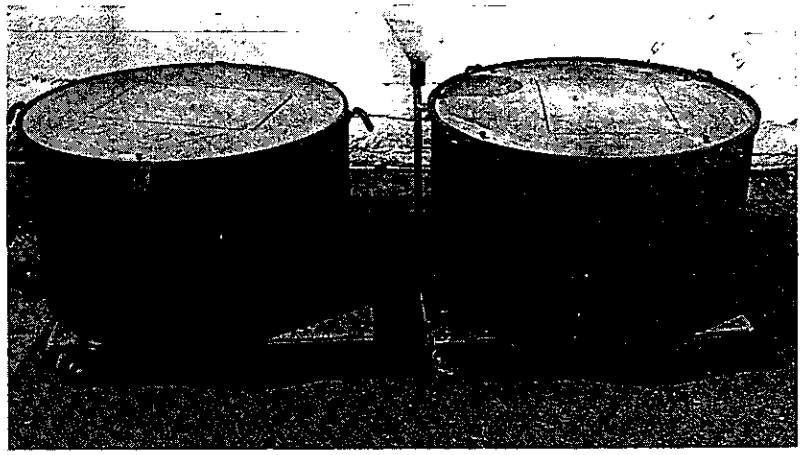


Photo 2 Side View of empty tub.

Photo 3 Dry Silica Tub and 18.8 #/ft$^3$ Silica Tub moisture standards.





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State of California
Department of Transportation
Division of Highways

TRANSPORTATION LABORATORY

Test Method No. Calif. 911-C
October 7, 1974
(12 pages)

# METHOD OF DEVELOPING DENSITY AND MOISTURE CALIBRATION TABLES FOR THE NUCLEAR GAGE

## Scope

This is a procedure for developing density and moisture calibration tables for nuclear gages. Gage count ratios are related to six California Transportation Laboratory Master Standard Density Blocks (CTLMSDB), located in Sacramento, California. These blocks are the standard reference blocks for the California Department of Transportation.

Density calibration tables may also be developed by relating gage count ratios to two reference standard blocks located in each of the eleven Transportation Districts of the Department of Transportation. Each district block is correlated to the six CTLMSDB at least once every 15 months as described in this procedure.

Moisture calibration tables can be developed by relating gage count ratios to the two moisture standards located at the Transportation Laboratory in Sacramento or to the two moisture standards in each of the eleven Transportation Districts. Correlations to oven dry moistures may be necessary where this relationship is desired.

This method is divided into the following three parts:

Part I. Procedure For Correlating The Six Transportation Laboratory Master Standard Density Blocks and The Two Transportation District Blocks.

Part II. Procedure For Determination Of Direct Transmission and Backscatter Density Calibration Tables.

Part III. Procedure For Determination Of Moisture Calibration Tables.

## PART I. PROCEDURE FOR CORRELATING THE SIX TRANSPORTATION LABORATORY BLOCKS AND THE TWO TRANSPORTATION DISTRICT BLOCKS

### A. Apparatus

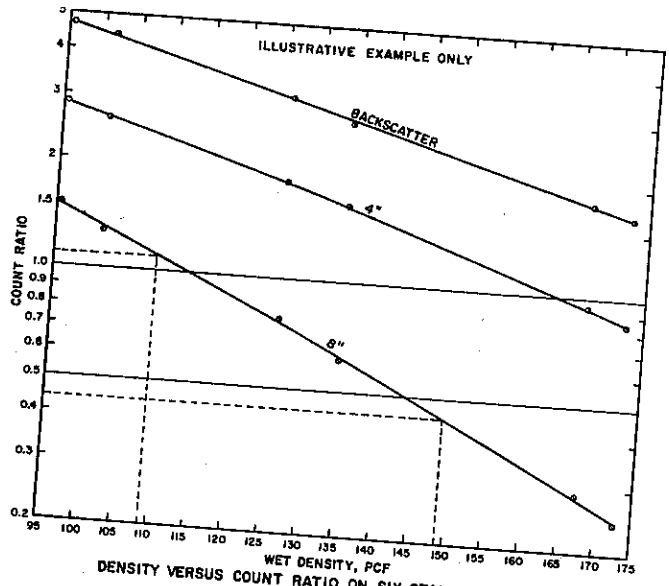
1. All nuclear gages with their standardizing devices in each Transportation District.
2. The six CTLMSDB or the two Transportation blocks maintained in each Transportation District.

### B. Standardization Of Gage For Density

1. Set the standardizing devices five feet from any object and twenty-five feet from any gage. Place the gage on the standardizing device in the safe position for the source in the rod gage and take ten density counts. For the detector in the rod type of gage, see the manufacturer's manual for the correct position for taking standard counts. The ten measurements taken are part of the warmup procedure and are entered in a gage log book but are not used in the subsequent parts of this procedure. After the warmup, take five or more one minute counts for density. Record the data on Form DH-TL-204A (Figure 1) and in the gage log book. The average of the five measurements is the *standard count* for the gage.

### C. Calibration Procedure For Density

1. Set the detector or source rod at the desired depth and position the gage on one of the two Transportation District reference standard blocks with the rod in the hole provided for this purpose. All blocks must be spaced at least twenty-five feet apart unless there is proper shielding between the blocks. Each block should show the exact position of the gage by lines marked on the block.
2. Adjust the gage so that the rod is firmly against the side of the hole nearest to the source (detector tube).
3. Take four or more one minute counts at backscatter, 2, 3, 4, 5, 6, 7 and 8 inch direct transmission modes. Repeat the measurements on the second Transportation District block. Record all data on Form DH-TL-204 A (Figure I).
4. Repeat the steps in C-1, C-2 and C-3 on the six CTLMSDB and record all data on Form DH-TL-204 B (Figure II). Every gage in a Transportation District should be included in this correlation procedure.
5. The calibration data from a gage on the 6 CTLMSDB (Figure II) are plotted as gage count ratios versus known densities of the CTLMSDB. The *count ratio* is the average block count divided by the standard count. The ex-




DENSITY VERSUS COUNT RATIO ON SIX STANDARD BLOCKS

FIGURE III

NOTE: See Section 121 of the Materials Manual For Administrative Instructions regarding use of nuclear gages.



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ample on Figure III shows a plot of only the 8 inch reading.

The calibration of the same gage on the two district blocks (Figure I) are plotted so that the count ratio of the gage falls on the average CTLMSDB calibration curve for a particular mode of test (Figure III). The corresponding density for the particular count ratio is then determined by reading the density on the abscissa.

The count ratio for district block No. 6 is 1.091 for the 8-inch direct transmission mode. Draw a line from 1.091 perpendicular to the ordinate until it intersects the average line for the 6-block calibration. Draw a line from the intersection parallel to the ordinate and read a density of 109.0 cf on the abscissa. Following the same procedure, the density for a count ratio of 0.439 is 149.0 pcf.

6. Repeat the above procedure for the count ratios on the two district blocks for all test modes.
7. A tabulation is made of all individual densities for all gages in each district and an average value is calculated for each test mode and each district block (Table I).
8. The assigned values for the district block will be the average value calculated in Step 7 plus 0.5 pounds.
9. Steps C-5 through C-8 can be performed on a computer.
10. No adjustment to the assigned values of the Transportation District blocks shall be made if the annual calibration is within ± 0.5 pcf of the previous year's calibration.

## PART II. PROCEDURE FOR DETERMINATION OF DIRECT TRANSMISSION AND BACKSCATTER DENSITY CALIBRATION TABLES

### A. Apparatus

1. Nuclear gage and its standardizing device.
2. The six CTLMSDB or the two Transportation District Blocks.

### B. Standardization Of Gage For Density

1. Follow the procedure specified in B of Part I.
2. The *count ratio* (average block count divided by the standard count) related to block density is used for preparing a calibration table.

   Any subsequent standard count must be within ± 3 standard deviations of the value used to prepare the calibration table. If it is not, the Radiation Administrative Officer will establish a new standard count and prepare a new calibration table or have the gage checked and/or repaired.

   NOTE: A standard deviation is defined in this method as $\sigma = \sqrt{n}$; where $\sigma$ = standard deviation, and n = number of counts indicated on the gage. Table 2 gives an estimate of $3\sigma$ for various counts.

### C. Calibration Procedure For Density Using the Two Transportation District Blocks

1. Follow the procedure specified in C-1 through C-3 of Part I.
2. Calculate the average of the four counts for each test mode for each block and determine count ratio by dividing the average block count by the standard count (Figure 1).
3. Transmit the count ratios and the assigned values for the two district blocks to the Office of Computer Systems of the California Department of Transportation (Figure IV). Table 3 shows the printout for 8-inch direct transmission mode based on data from the two Transportation District blocks (Figure I).
4. A computer calculated calibration table of count ratios and corresponding densities for each test mode can also be developed using the data from the six CTLMSDB at the Transportation Laboratory in Sacramento, California.

## PART III. DETERMINATION OF MOISTURE CALIBRATION TABLES

### A. Apparatus

1. Nuclear gage and standardizing device.
2. The two moisture standards located at the Transportation Laboratory in Sacramento or the two moisture standards in each Transportation District of the California Department of Transportation.

### B. Calibration Procedure

1. Following the procedure in B-1 of Part I except take moisture readings instead of density readings. Record the data on Form DH-TL-204A (Figure I). The warmup and P.M. standard counts for moisture can be recorded in the space provided for the density standard counts. These counts are not necessary if the density counts were already made during the same day.
2. Place the gage on the moisture standard and take four or more one minute counts.
3. Repeat the test on the second standard.
4. Record the data on Form DH-TL-204A (Figure I), calculate the average and determine count ratio by dividing the average count on the moisture calibration standard by the standard count for moisture.
5. Transmit the count ratios and the assigned values for the moisture standards to the Office of Computer Systems of the California Department of Transportation (Figure IV). Table 4 shows the printout for moisture based on the data shown on Figure I. This table may not give moisture contents comparable to oven drying (Test Method No. Calif. 226). If this correlation is needed, the table must be verified by performing nuclear gage field moisture tests and related to oven dry moistures and field densities.

### C. Field Moisture Calibration Procedure

1. Follow Section A and B-1 through B-4 of this Part III.



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# CALIBRATION FOR NUCLEAR GAGE

DISTRICT 06 DATE 5-10-73 TESTS BY P.M. GAGE No. 715

STANDARD COUNTS DENSITY

| | WARMUP | AM | PM |
|---|---|---|---|
| 1 | 41900 | 42040 | 41880 |
| 2 | 42180 | 41690 | 42070 |
| 3 | 41910 | 41960 | 41760 |
| 4 | 41800 | 42080 | 42040 |
| 5 | 42240 | 41660 | 42030 |
| 6 | 41790 | | |
| 7 | 42040 | | |
| 8 | 41850 | | |
| 9 | 42090 | | |
| 10 | 41610 | | |
| Σ | 419410 | 209430 | 209780 |
| X̄ | 41941 | 41886 | 41956 |

STD. COUNTS MOISTURE

| | |
|---|---|
| 1 | 5560 |
| 2 | 5460 |
| 3 | 5550 |
| 4 | 5620 |
| 5 | 5610 |
| Σ | 27800 |
| X̄ | 5560 |

MOIST. CALIB. STANDARD NO.

| | 0.0 | 18.8 |
|---|---|---|
| 1 | 410 | 4220 |
| 2 | 450 | 4330 |
| 3 | 430 | 4380 |
| 4 | 480 | 4350 |
| 5 | | |
| 6 | | |
| Σ | 1770 | 17280 |
| X̄ | 443 | 4320 |
| CR | 0.080 | 0.777 |

Note: 1. PM Standard Count taken to check gage stability.
2. CR = Average test count ÷ Average AM Standard Count.

Remarks

| | | BS | 2" | 3" | 4" | 5" | 6" | 7" | 8" |
|---|---|---|---|---|---|---|---|---|---|
| BLK 6 | 1 | 15030 | 102160 | 102770 | 95970 | 83910 | 69650 | 57180 | 45320 |
| | 2 | 14950 | 101600 | 102600 | 95760 | 84230 | 69100 | 56480 | 46080 |
| | 3 | 14980 | 101910 | 102690 | 96030 | 84210 | 69560 | 57060 | 45590 |
| | 4 | 15140 | 101780 | 102650 | 95310 | 84160 | 69510 | 57030 | 45740 |
| | 5 | | | | | | | | |
| | 6 | | | | | | | | |
| | Σ | 60100 | 407450 | 410710 | 383070 | 336510 | 277820 | 227750 | 182730 |
| | X̄ | 15025 | 101863 | 102678 | 95768 | 84128 | 69455 | 56938 | 45683 |
| | CR | 0.359 | 2.432 | 2.451 | 2.286 | 2.008 | 1.658 | 1.359 | 1.091 |
| BLK 19 | 1 | 8810 | 60280 | 58880 | 51670 | 42440 | 33730 | 25410 | 18500 |
| | 2 | 8820 | 60230 | 58700 | 51540 | 42510 | 33310 | 25350 | 18320 |
| | 3 | 8820 | 60270 | 58730 | 51240 | 42790 | 33390 | 25270 | 18430 |
| | 4 | 8690 | 60480 | 58730 | 51720 | 42590 | 33270 | 25340 | 18290 |
| | 5 | | | | | | | | |
| | 6 | | | | | | | | |
| | Σ | 35140 | 241260 | 235040 | 206170 | 170330 | 133700 | 101370 | 73540 |
| | X̄ | 8785 | 60315 | 58760 | 51543 | 42583 | 33425 | 25343 | 18385 |
| | CR | 0.210 | 1.440 | 1.403 | 1.231 | 1.017 | 0.798 | 0.605 | 0.439 |

DH-TL-204A (Rev. 8-73)

FIGURE I



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# CALIBRATION FOR NUCLEAR GAGE

DISTRICT 06 DATE 5-10-73 TESTS BY PM STANDARD COUNT 41886 GAGE No. 715

| | | BS | 2" | 3" | 4" | 5" | 6" | 7" | 8" |
|---|---|---|---|---|---|---|---|---|---|
| S-1 | 1 | 19710 | 12292 0 | 12455 0 | 11991 0 | 10647 0 | 9202 0 | 7708 0 | 6256 0 |
| | 2 | 19840 | 12336 0 | 12507 0 | 11921 0 | 10642 0 | 9222 0 | 7723 0 | 6256 0 |
| | 3 | 19660 | 12293 0 | 12557 0 | 11929 0 | 10664 0 | 9180 0 | 7687 0 | 6302 0 |
| 95.7 | 4 | 19550 | 12292 0 | 12533 0 | 11934 0 | 10666 0 | 9188 0 | 7733 0 | 6326 0 |
| | Σ | 78760 | 49213 0 | 50052 0 | 47783 0 | 42619 0 | 36792 0 | 30851 0 | 25140 0 |
| 1.53 | X̄ | 19690 | 12303 3 | 12513 0 | 11945 8 | 10654 8 | 9198 0 | 7712 8 | 6285 0 |
| | CR | 0.470 | 2.937 | 2.987 | 2.852 | 2.544 | 2.196 | 1.841 | 1.501 |
| S-2 | 1 | 13120 | 87100 | 85180 | 77740 | 65910 | 54180 | 41940 | 32340 |
| | 2 | 12970 | 87180 | 85220 | 77800 | 65870 | 53930 | 42400 | 32140 |
| | 3 | 13130 | 86840 | 85440 | 77710 | 66560 | 53840 | 42390 | 32070 |
| 126.0 | 4 | 13190 | 87410 | 85450 | 77820 | 66300 | 54010 | 42500 | 32390 |
| | Σ | 52410 | 34853 0 | 34129 0 | 31107 0 | 26464 0 | 21596 0 | 16223 0 | 12894 0 |
| 2.02 | X̄ | 13103 | 87133 | 85323 | 77768 | 66160 | 53990 | 42308 | 32235 |
| | CR | 0.313 | 2.080 | 2.037 | 1.857 | 1.580 | 1.289 | 1.010 | 0.770 |
| S-3 | 1 | 7600 | 48380 | 45620 | 39070 | 31430 | 23580 | 17000 | 11970 |
| | 2 | 7490 | 48560 | 45740 | 39350 | 31220 | 23500 | 16750 | 11930 |
| | 3 | 7520 | 48930 | 45780 | 39560 | 31040 | 23460 | 17250 | 12060 |
| 167.3 | 4 | 7340 | 48390 | 45190 | 39580 | 31150 | 23580 | 16940 | 11830 |
| | Σ | 29950 | 19426 0 | 18233 0 | 15756 0 | 12484 0 | 9412 0 | 6794 0 | 4779 0 |
| 2.68 | X̄ | 7488 | 48565 | 45583 | 39390 | 31210 | 23530 | 16985 | 11948 |
| | CR | 0.179 | 1.159 | 1.088 | 0.940 | 0.745 | 0.562 | 0.406 | 0.285 |
| C-1 | 1 | 18330 | 11980 0 | 11796 0 | 10858 0 | 95200 | 80310 | 66440 | 52900 |
| | 2 | 18380 | 12014 0 | 11793 0 | 10833 0 | 94860 | 80760 | 66620 | 53310 |
| | 3 | 18560 | 11921 0 | 11792 0 | 10900 0 | 95410 | 80550 | 66670 | 53270 |
| 101.5 | 4 | 18400 | 11994 0 | 11856 0 | 10863 0 | 94830 | 80260 | 66050 | 52770 |
| | Σ | 73670 | 47909 0 | 47237 0 | 43454 0 | 38030 0 | 32188 0 | 26578 0 | 21250 |
| 1.63 | X̄ | 18418 | 11972 2 | 11809 3 | 10863 5 | 95075 | 80470 | 66445 | 53063 |
| | CR | 0.440 | 2.859 | 2.819 | 2.594 | 2.270 | 1.921 | 1.586 | 1.267 |
| C-2 | 1 | 11390 | 77590 | 75010 | 67860 | 55370 | 43830 | 33810 | 25610 |
| | 2 | 11360 | 77520 | 74960 | 67810 | 55560 | 44160 | 34020 | 25700 |
| | 3 | 11500 | 77850 | 75240 | 67710 | 55660 | 44350 | 33920 | 25700 |
| 134.4 | 4 | 11480 | 77460 | 74960 | 68020 | 56040 | 44290 | 34210 | 25420 |
| | Σ | 45730 | 31042 0 | 30017 0 | 27140 0 | 22263 0 | 17663 0 | 13596 0 | 10243 0 |
| 2.15 | X̄ | 11433 | 77605 | 75043 | 67850 | 55658 | 44158 | 34990 | 25608 |
| | CR | 0.273 | 1.853 | 1.792 | 1.620 | 1.329 | 1.055 | 0.811 | 0.611 |
| C-3 | 1 | 7000 | 44810 | 41530 | 35510 | 27750 | 21000 | 15160 | 10320 |
| | 2 | 7030 | 44920 | 41690 | 35620 | 28250 | 20880 | 14830 | 10270 |
| | 3 | 6910 | 44790 | 41910 | 35130 | 27810 | 20840 | 14930 | 10160 |
| 173.0 | 4 | 6890 | 44770 | 41540 | 35440 | 27950 | 20720 | 15110 | 10180 |
| | Σ | 27830 | 17929 0 | 16667 0 | 14170 0 | 11176 0 | 8344 0 | 6003 0 | 4093 0 |
| 2.77 | X̄ | 6958 | 44823 | 41668 | 35425 | 27940 | 20860 | 15008 | 10233 |
| | CR | 0.166 | 1.070 | 0.995 | 0.846 | 0.667 | 0.498 | 0.358 | 0.244 |

DH-TL-204B (Rev. 8-73)

FIGURE II



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TABLE 1

CORRELATION OF DISTRICT TO TRANSPORTATION LABORATORY DENSITY BLOCKS

DISTRICT 06 DATE 6-1-73 BY M H

| GAGE NUMBER | BACKSCATTER | | 2" | | 3" | | 4" | |
|---|---|---|---|---|---|---|---|---|
| | L | H | L | H | L | H | L | H |
| 715 | 115.5 | 155.5 | 112.5 | 152.2 | 110.9 | 151.0 | 110.0 | 150.0 |
| C25 | 114.9 | 154.3 | 112.3 | 152.1 | 111.2 | 151.7 | 110.5 | 151.5 |
| 713 | 116.8 | 156.5 | 112.2 | 151.2 | 110.6 | 150.3 | 111.0 | 150.8 |
| C39 | 114.3 | 156.8 | 112.8 | 153.0 | 111.0 | 151.3 | 110.5 | 151.3 |
| C42 | 116.0 | 156.0 | 113.0 | 153.8 | 111.7 | 151.8 | 113.3 | 152.0 |
| 726 | 116.0 | 156.0 | 113.5 | 153.8 | 112.0 | 151.5 | 111.2 | 152.0 |
| C44 | 114.5 | 153.3 | 112.0 | 153.1 | 111.5 | 150.9 | 112.0 | 151.3 |
| 735 | 113.8 | 154.8 | 113.3 | 153.2 | 111.2 | 151.3 | 111.8 | 151.2 |
| | | | | | | | | |
| $\Sigma$ | 921.8 | 1244.2 | 901.6 | 1222.4 | 890.1 | 1209.8 | 890.3 | 1210.1 |
| $\bar{X}$ | 115.2 | 155.5 | 112.7 | 152.8 | 111.3 | 151.2 | 111.3 | 151.3 |
| | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Assigned Value | 115.7 | 156.0 | 113.2 | 153.3 | 111.8 | 151.7 | 111.8 | 151.8 |
| | | | | | | | | |
| | | | | | | | | |



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TABLE 1 (Continued)

CORRELATION OF DISTRICT TO TRANSPORTATION LABORATORY DENSITY BLOCKS

DISTRICT 06 DATE 6-1-73 BY MH

| GAGE NUMBER | 5" | | 6" | | 7" | | 8" | |
|---|---|---|---|---|---|---|---|---|
| | L | H | L | H | L | H | L | H |
| 715 | 110.0 | 150.4 | 110.5 | 150.0 | 110.5 | 149.2 | 110.0 | 149.0 |
| C25 | 110.0 | 151.0 | 110.7 | 150.3 | 112.0 | 150.0 | 111.8 | 149.3 |
| 713 | 110.0 | 149.5 | 111.0 | 149.0 | 111.2 | 148.3 | 111.0 | 148.4 |
| C39 | 110.0 | 151.0 | 110.0 | 150.0 | 111.2 | 149.8 | 110.0 | 149.0 |
| C42 | 111.0 | 150.8 | 111.3 | 150.8 | 112.0 | 150.2 | 111.6 | 149.5 |
| 726 | 111.0 | 151.2 | 111.9 | 150.6 | 112.0 | 149.9 | 112.1 | 149.5 |
| C44 | 110.9 | 150.3 | 110.5 | 149.8 | 112.0 | 149.7 | 109.9 | 150.2 |
| 735 | 110.8 | 151.5 | 110.8 | 150.2 | 111.0 | 149.8 | 111.0 | 149.2 |
| | | | | | | | | |
| $\Sigma$ | 883.5 | 1205.7 | 886.7 | 1200.7 | 891.9 | 1196.9 | 887.4 | 1194.1 |
| $\bar{X}$ | 110.4 | 150.7 | 110.8 | 150.1 | 111.5 | 149.6 | 110.9 | 149.3 |
| | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Assigned Value | 110.9 | 151.2 | 111.3 | 150.6 | 112.0 | 150.1 | 111.4 | 149.8 |
| | | | | | | | | |
| | | | | | | | | |



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TABLE 2

**STANDARD DEVIATION FOR VARIOUS GAGE COUNTS**

| N | 3σ | N | 3σ | N | 3σ | N | 3σ | N | 3σ |
|---|---|---|---|---|---|---|---|---|---|
| ≤10,100 | 300 | | | | | | | | |
| 10100–10302 | 303 | 19740–20022 | 423 | 32580–32942 | 543 | 48620–49062 | 663 | 67860–68382 | 783 |
| 10302–10506 | 306 | 20022–20306 | 426 | 32942–33306 | 546 | 49062–49506 | 666 | 68382–68906 | 786 |
| 10506–10712 | 309 | 20306–20592 | 429 | 33306–33672 | 549 | 49506–49952 | 669 | 68906–69432 | 789 |
| 10712–10920 | 312 | 20592–20880 | 432 | 33672–34040 | 552 | 49952–50400 | 672 | 69432–69960 | 792 |
| 10920–11130 | 315 | 20880–21170 | 435 | 34040–34410 | 555 | 50400–50850 | 675 | 69960–70490 | 795 |
| 11130–11342 | 318 | 21170–21462 | 438 | 34410–34782 | 558 | 50850–51302 | 678 | 70490–71022 | 798 |
| 11342–11556 | 321 | 21462–21756 | 441 | 34782–35156 | 561 | 51302–51756 | 681 | 71022–71556 | 801 |
| 11556–11772 | 324 | 21756–22052 | 444 | 35156–35532 | 564 | 51756–52212 | 684 | 71556–72092 | 804 |
| 11772–11990 | 327 | 22052–22350 | 447 | 35532–35910 | 567 | 52212–52670 | 687 | 72092–72630 | 807 |
| 11990–12210 | 330 | 22350–22650 | 450 | 35910–36290 | 570 | 52670–53130 | 690 | 72630–73170 | 810 |
| 12210–12432 | 333 | 22650–22952 | 453 | 36290–36672 | 573 | 53130–53592 | 693 | 73170–73712 | 813 |
| 12432–12656 | 336 | 22952–23256 | 456 | 36672–37056 | 576 | 53592–54056 | 696 | 73712–74256 | 816 |
| 12656–12882 | 339 | 23256–23562 | 459 | 37056–37442 | 579 | 54056–54522 | 699 | 74256–74802 | 819 |
| 12882–13110 | 342 | 23562–23870 | 462 | 37442–37830 | 582 | 54522–54990 | 702 | 74802–75350 | 822 |
| 13110–13340 | 345 | 23870–24180 | 465 | 37830–38220 | 585 | 54990–55460 | 705 | 75350–75900 | 825 |
| 13340–13572 | 348 | 24180–24492 | 468 | 38220–38612 | 588 | 55460–55932 | 708 | 75900–76452 | 828 |
| 13572–13806 | 351 | 24492–24806 | 471 | 38612–39006 | 591 | 55932–56406 | 711 | 76452–77006 | 831 |
| 13806–14042 | 354 | 24806–25122 | 474 | 39006–39402 | 594 | 56406–56882 | 714 | 77006–77562 | 834 |
| 14042–14280 | 357 | 25122–25440 | 477 | 39402–39800 | 597 | 56882–57360 | 717 | 77562–78120 | 837 |
| 14280–14520 | 360 | 25440–25760 | 480 | 39800–40200 | 600 | 57360–57840 | 720 | 78120–78680 | 840 |
| 14520–14762 | 363 | 25760–26082 | 483 | 40200–40602 | 603 | 57840–58322 | 723 | 78680–79242 | 843 |
| 14762–15006 | 366 | 26082–26406 | 486 | 40602–41006 | 606 | 58322–58806 | 726 | 79242–79806 | 846 |
| 15006–15252 | 369 | 26406–26732 | 489 | 41006–41412 | 609 | 58806–59292 | 729 | 79806–80372 | 849 |
| 15252–15500 | 372 | 26732–27060 | 492 | 41412–41820 | 612 | 59292–59780 | 732 | 80372–80940 | 852 |
| 15500–15750 | 375 | 27060–27390 | 495 | 41820–42230 | 615 | 59780–60270 | 735 | 80940–81510 | 855 |
| 15750–16002 | 378 | 27390–27722 | 498 | 42230–42642 | 618 | 60270–60762 | 738 | 81510–82082 | 858 |
| 16002–16256 | 381 | 27722–28056 | 501 | 42642–43056 | 621 | 60762–61256 | 741 | 82082–82656 | 861 |
| 16256–16512 | 384 | 28056–28392 | 504 | 43056–43472 | 624 | 61256–61752 | 744 | 82656–83232 | 864 |
| 16512–16770 | 387 | 28392–28730 | 507 | 43472–43890 | 627 | 61752–62250 | 747 | 83232–83810 | 867 |
| 16770–17030 | 390 | 28730–29070 | 510 | 43890–44310 | 630 | 62250–62750 | 750 | 83810–84390 | 870 |
| 17030–17292 | 393 | 29070–29412 | 513 | 44310–44732 | 633 | 62750–63252 | 753 | 84390–84972 | 873 |
| 17292–17556 | 396 | 29412–29756 | 516 | 44732–45156 | 636 | 63252–63756 | 756 | 84972–85556 | 876 |
| 17556–17822 | 399 | 29756–30102 | 519 | 45156–45582 | 639 | 63756–64262 | 759 | 85556–86142 | 879 |
| 17822–18090 | 402 | 30102–30450 | 522 | 45582–46010 | 642 | 64262–64770 | 762 | 86142–86730 | 882 |
| 18090–18360 | 405 | 30450–30800 | 525 | 46010–46440 | 645 | 64770–65280 | 765 | 86730–87320 | 885 |
| 18360–18632 | 408 | 30800–31152 | 528 | 46440–46872 | 648 | 65280–65792 | 768 | 87320–87912 | 888 |
| 18632–18906 | 411 | 31152–31506 | 531 | 46872–47306 | 651 | 65792–66306 | 771 | 87912–88506 | 891 |
| 18906–19182 | 414 | 31506–31862 | 534 | 47306–47742 | 654 | 66306–66822 | 774 | 88506–89102 | 894 |
| 19182–19460 | 417 | 31862–32220 | 537 | 47742–48180 | 657 | 66822–67340 | 777 | 89102–89700 | 897 |
| 19460–19740 | 420 | 32220–32580 | 540 | 48180–48620 | 660 | 67340–67860 | 780 | 89700–90300 | 900 |



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# NUCLEAR GAGE CALIBRATION DATA INPUT FORM

| LINE TYPE | DIST | DATE | SUBMITTER | GAGE | COMMENT | LINE |
|---|---|---|---|---|---|---|
| I | 06 | MAY 10 1973 | P.MONAHAN | 715 | | |

| LINE TYPE | TEST CODE | STANDARD COUNT | BLOCK 1 DENSITY | BLOCK 1 COUNT RATIO | BLOCK 2 DENSITY | BLOCK 2 COUNT RATIO | COMMENT | LINE |
|---|---|---|---|---|---|---|---|---|
| D | 8 | 41886 | 111.4 | 1.091 | 149.8 | 0.439 | | |
| D | M | 5560 | 0.0 | 0.080 | 18.8 | 0.777 | | |

| LINE TYPE | DIST | DATE | SUBMITTER | GAGE | COMMENT | LINE |
|---|---|---|---|---|---|---|
| | | | | | | |

| LINE TYPE | TEST CODE | STANDARD COUNT | BLOCK 1 DENSITY | BLOCK 1 COUNT RATIO | BLOCK 2 DENSITY | BLOCK 2 COUNT RATIO | COMMENT | LINE |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |

TEST CODES: 2, 3, 4, 5, 6, 7, 8 = PROBE DEPTHS, DIRECT TRANSMISSION
B = BACKSCATTER M = MOISTURE

DEPARTMENT

ROOM

HCS 130 (REV 6/72)

IN CASE OF QUESTION CONTACT:

NAME

PHONE

DATE

VERIFY

PAGE OF

FIGURE IV



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# TABLE 3

COUNT RATIO VS DENSITY FOR NUCLEAR GAGE NO. 715

DIST. 6 10 MAY 73 STD. CT 41886 8 IN D/T BY P. MONAHAN

BASED ON: DENSITY PCF 111.4 149.8

G/CC 1.784 2.399 PCF=(G/CC)X(62.43)

COUNT RATIO 1.091 .439

| CR | TO | CR | G/CC | CR | TO | CR | G/CC | CR | TO | CR | G/CC |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.869 | - | 1.895 | 1.40 | 1.060 | - | 1.074 | 1.80 | .592 | - | .601 | 2.20 |
| 1.843 | - | 1.868 | 1.41 | 1.045 | - | 1.059 | 1.81 | .583 | - | .591 | 2.21 |
| 1.817 | - | 1.842 | 1.42 | 1.030 | - | 1.044 | 1.82 | .574 | - | .582 | 2.22 |
| 1.792 | - | 1.816 | 1.43 | 1.015 | - | 1.029 | 1.83 | .566 | - | .573 | 2.23 |
| 1.766 | - | 1.791 | 1.44 | 1.001 | - | 1.014 | 1.84 | .557 | - | .565 | 2.24 |
| 1.741 | - | 1.765 | 1.45 | .987 | - | 1.000 | 1.85 | .548 | - | .556 | 2.25 |
| 1.717 | - | 1.740 | 1.46 | .973 | - | .986 | 1.86 | .540 | - | .547 | 2.26 |
| 1.693 | - | 1.716 | 1.47 | .959 | - | .972 | 1.87 | .532 | - | .539 | 2.27 |
| 1.669 | - | 1.692 | 1.48 | .946 | - | .958 | 1.88 | .524 | - | .531 | 2.28 |
| 1.645 | - | 1.668 | 1.49 | .932 | - | .945 | 1.89 | .516 | - | .523 | 2.29 |
| 1.622 | - | 1.644 | 1.50 | .919 | - | .931 | 1.90 | .508 | - | .515 | 2.30 |
| 1.599 | - | 1.621 | 1.51 | .906 | - | .918 | 1.91 | .500 | - | .507 | 2.31 |
| 1.577 | - | 1.598 | 1.52 | .894 | - | .905 | 1.92 | .492 | - | .499 | 2.32 |
| 1.554 | - | 1.576 | 1.53 | .881 | - | .893 | 1.93 | .485 | - | .491 | 2.33 |
| 1.533 | - | 1.553 | 1.54 | .869 | - | .880 | 1.94 | .477 | - | .484 | 2.34 |
| 1.511 | - | 1.532 | 1.55 | .856 | - | .868 | 1.95 | .470 | - | .476 | 2.35 |
| 1.490 | - | 1.510 | 1.56 | .844 | - | .855 | 1.96 | .463 | - | .469 | 2.36 |
| 1.469 | - | 1.489 | 1.57 | .832 | - | .843 | 1.97 | .456 | - | .462 | 2.37 |
| 1.448 | - | 1.468 | 1.58 | .821 | - | .831 | 1.98 | .449 | - | .455 | 2.38 |
| 1.428 | - | 1.447 | 1.59 | .809 | - | .820 | 1.99 | .442 | - | .448 | 2.39 |
| 1.407 | - | 1.427 | 1.60 | .798 | - | .808 | 2.00 | .435 | - | .441 | 2.40 |
| 1.388 | - | 1.406 | 1.61 | .786 | - | .797 | 2.01 | .429 | - | .434 | 2.41 |
| 1.368 | - | 1.387 | 1.62 | .775 | - | .785 | 2.02 | .422 | - | .428 | 2.42 |
| 1.349 | - | 1.367 | 1.63 | .764 | - | .774 | 2.03 | .416 | - | .421 | 2.43 |
| 1.330 | - | 1.348 | 1.64 | .754 | - | .763 | 2.04 | .409 | - | .415 | 2.44 |
| 1.311 | - | 1.329 | 1.65 | .743 | - | .753 | 2.05 | .403 | - | .408 | 2.45 |
| 1.293 | - | 1.310 | 1.66 | .733 | - | .742 | 2.06 | .397 | - | .402 | 2.46 |
| 1.274 | - | 1.292 | 1.67 | .722 | - | .732 | 2.07 | .391 | - | .396 | 2.47 |
| 1.256 | - | 1.273 | 1.68 | .712 | - | .721 | 2.08 | .385 | - | .390 | 2.48 |
| 1.239 | - | 1.255 | 1.69 | .702 | - | .712 | 2.09 | .379 | - | .384 | 2.49 |
| 1.221 | - | 1.238 | 1.70 | .691 | - | .701 | 2.10 | .373 | - | .378 | 2.50 |
| 1.204 | - | 1.220 | 1.71 | .680 | - | .690 | 2.11 | .367 | - | .372 | 2.51 |
| 1.187 | - | 1.203 | 1.72 | .670 | - | .679 | 2.12 | .362 | - | .366 | 2.52 |
| 1.170 | - | 1.186 | 1.73 | .660 | - | .669 | 2.13 | .356 | - | .361 | 2.53 |
| 1.154 | - | 1.169 | 1.74 | .650 | - | .659 | 2.14 | .351 | - | .355 | 2.54 |
| 1.137 | - | 1.153 | 1.75 | .640 | - | .649 | 2.15 | .345 | - | .350 | 2.55 |
| 1.121 | - | 1.136 | 1.76 | .630 | - | .639 | 2.16 | .340 | - | .344 | 2.56 |
| 1.106 | - | 1.120 | 1.77 | .620 | - | .629 | 2.17 | .335 | - | .339 | 2.57 |
| 1.090 | - | 1.105 | 1.78 | .611 | - | .619 | 2.18 | .330 | - | .334 | 2.58 |
| 1.075 | - | 1.089 | 1.79 | .602 | - | .610 | 2.19 | .325 | - | .329 | 2.59 |



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# TABLE 4

COUNT RATIO VS MOISTURE FOR NUCLEAR GAGE NO. 715

DIST. 6 10 MAY 73 STD. CT 5560 BY P.MONAHAN

| BASED ON: | | | |
|---|---|---|---|
| MOISTURE | PCF | .0 | 18.8 |
| | G/CC | .000 | .301 |
| COUNT RATIO | | .080 | .777 |

PCF=(G/CC)X(62.43)

| CR TO CR | G/CC | CR TO CR | G/CC | CR TO CR | G/CC |
|---|---|---|---|---|---|
| .069 - .092 | .00 | .532 - .554 | .20 | .995 - 1.017 | .40 |
| .093 - .115 | .01 | .555 - .578 | .21 | 1.018 - 1.041 | .41 |
| .116 - .138 | .02 | .579 - .601 | .22 | 1.042 - 1.064 | .42 |
| .139 - .161 | .03 | .602 - .624 | .23 | 1.065 - 1.087 | .43 |
| .162 - .184 | .04 | .625 - .647 | .24 | 1.088 - 1.110 | .44 |
| .185 - .207 | .05 | .648 - .670 | .25 | 1.111 - 1.133 | .45 |
| .208 - .230 | .06 | .671 - .693 | .26 | 1.134 - 1.156 | .46 |
| .231 - .254 | .07 | .694 - .717 | .27 | 1.157 - 1.179 | .47 |
| .255 - .277 | .08 | .718 - .740 | .28 | 1.180 - 1.203 | .48 |
| .278 - .300 | .09 | .741 - .763 | .29 | 1.204 - 1.226 | .49 |
| .301 - .323 | .10 | .764 - .786 | .30 | 1.227 - 1.249 | .50 |
| .324 - .346 | .11 | .787 - .809 | .31 | 1.250 - 1.272 | .51 |
| .347 - .369 | .12 | .810 - .832 | .32 | 1.273 - 1.295 | .52 |
| .370 - .392 | .13 | .833 - .855 | .33 | 1.296 - 1.318 | .53 |
| .393 - .416 | .14 | .856 - .879 | .34 | 1.319 - 1.341 | .54 |
| .417 - .439 | .15 | .880 - .902 | .35 | 1.342 - 1.365 | .55 |
| .440 - .462 | .16 | .903 - .925 | .36 | 1.366 - 1.388 | .56 |
| .463 - .485 | .17 | .926 - .948 | .37 | 1.389 - 1.411 | .57 |
| .486 - .508 | .18 | .949 - .971 | .38 | 1.412 - 1.434 | .58 |
| .509 - .531 | .19 | .972 - .994 | .39 | 1.435 - 1.457 | .59 |



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ILLUSTRATIVE EXAMPLE ONLY

## MOISTURE CALIBRATION CURVE

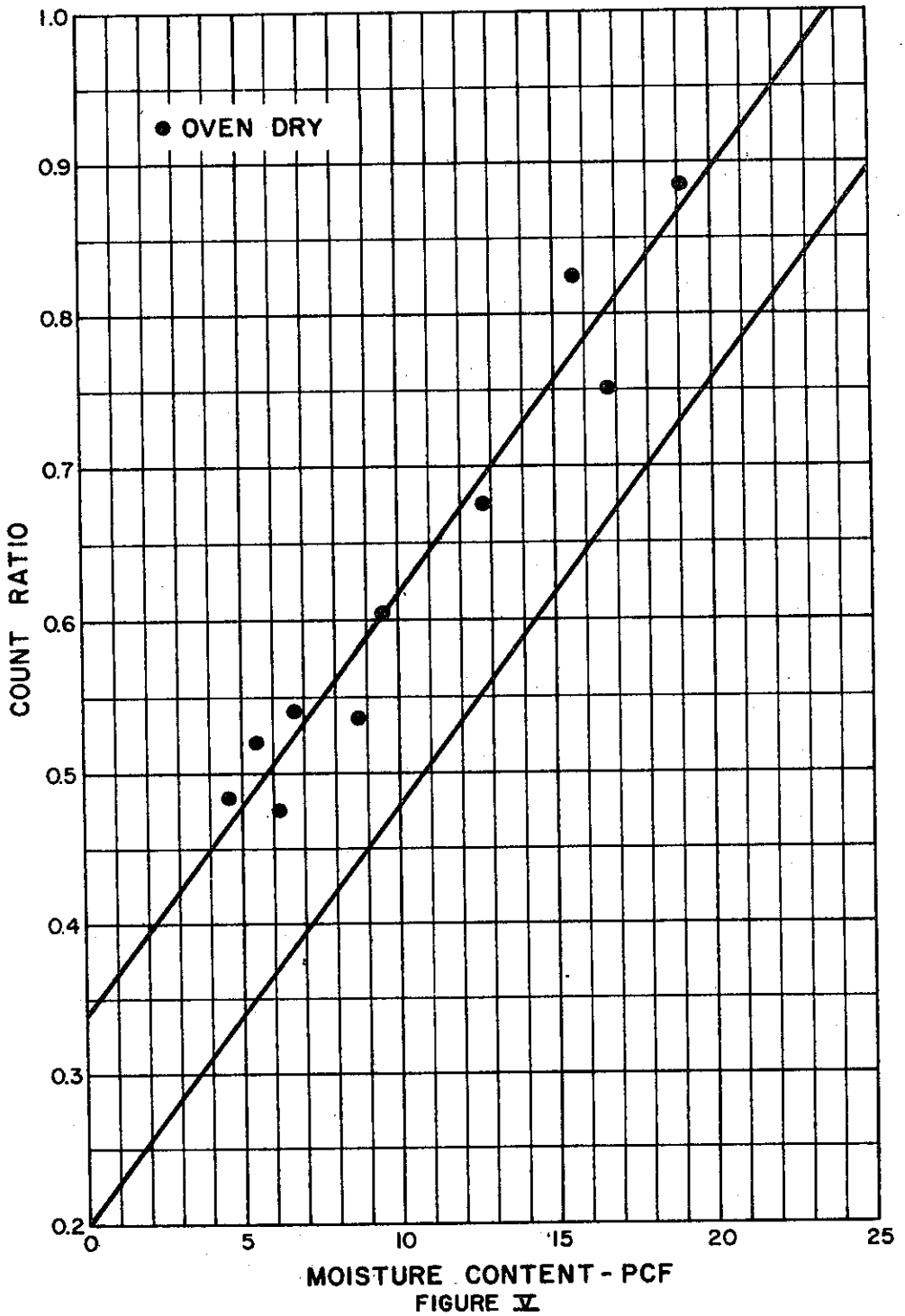


FIGURE V



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2. Plot the data from B-4 and draw a curve (Figure V).
3. Take at least 10 nuclear gage field moisture and density tests (Test Method No. Calif. 231).
4. At these same sites, take representative soils samples and determine oven dry moistures (Test Method No. Calif. 226).
5. Plot the field gage count ratios versus field moistures (Figure V).
6. Draw a best fit curve through the points and parallel to the standard curve determined in C-2 of this Part III.
7. Take a count ratio at 0.3 and 1.0 and the corresponding moistures at these two points. Transmit this data to the Office of Computer Systems for a computer calculated table of moistures and count ratios.

Each gage should be checked for density and moisture calibration at least once a year, or oftener if variations in standard counts exceed the limits of Part II-B or when the gage is repaired.

**REFERENCES**

Test Method Nos. Calif. 226, 231 and Section 121 of the Materials Manual.

End of Text on Calif. 911-C



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