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A Basic Study of the Nuclear Determination of Moisture and Density

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16. ABSTRACT

A laboratory program was undertaken to study the factors affecting the results obtained using nuclear gages to determine soil moisture and density. Both backscatter and transmission type nuclear soil density gages were studied.

The testing program consisted of conducting readings on laboratory compacted soil samples with the nuclear readings being taken across the compaction plane. Six different soil types were used in this study ranging from sands, sands and gravel, shales, sandstone, to clay. Tests indicate that the compacted soil samples had a soil density variation with a standard deviation of about two pounds per cubic foot.

The density calibration curves obtained by nuclear methods indicate a standard deviation of 4 1/2 pounds per cubic foot for the backscatter and 2 1/2 pounds per cubic foot for the transmission type gages. By collimation of the source the standard deviation of the backscatter type gage calibration was reduced to 2 1/2 pounds per cubic foot. No affect of soil type upon the calibration curves was noted in this study.

The effect of surface roughness was studied by use of regularly spaced grooves on the soil surface. The readings obtained with backscatter type gages were very sensitive to surface roughness while the transmission type gages were only slightly affected by surface roughness. Errors in density of six to eight pounds per cubic foot occurred due to surface roughness when backscatter type gages are used to determine soil density.

The volume of the soil affecting the nuclear readings was determined to be about 0.05 cubic foot for both the backscatter and transmission type gages.

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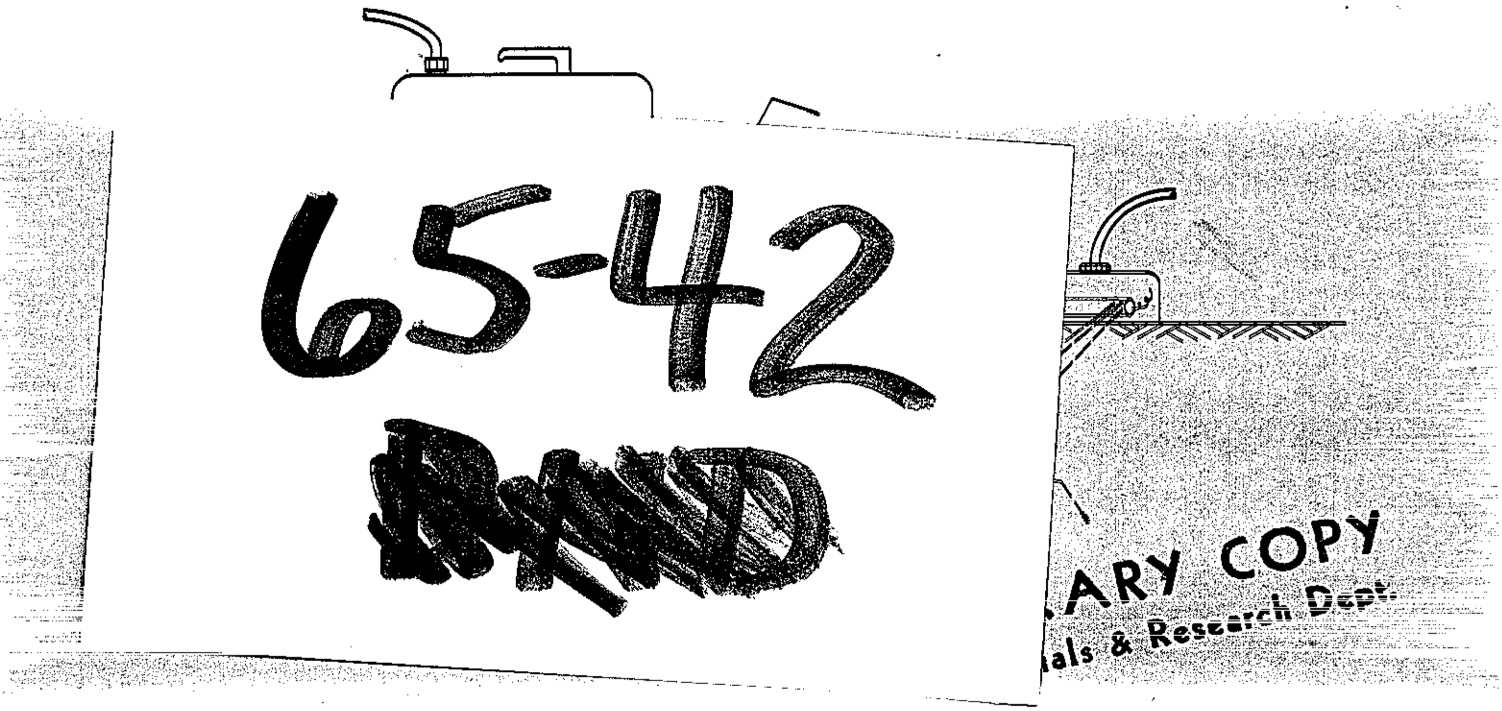
A BASIC STUDY of the NUCLEAR DETERMINATION of MOISTURE and DENSITY



MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 225928

Prepared in Cooperation with The U.S. Department of Commerce, Bureau of Public Roads November, 1965

State of California
Department of Public Works
Division of Highways
Materials and Research Department

November 1965

Lab Auth 225928

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Sir:

Submitted for your consideration is:

A BASIC STUDY

of the

NUCLEAR DETERMINATION

of

MOISTURE AND DENSITY

	Foundation Section
Study made by	Travis Smith
Under direction of	W. G. Weber, Jr.
Work supervised by	R. E. Smith
Report prepared by	W. G. Weber, Jr.

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

cc: LR Gillis
AC Estep
JF Jorgensen

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PREFACE

There is a need in soil construction for improved methods of determining moistures and densities of compacted soils in the field. The rate of present day earth construction makes it difficult to do a satisfactory job of testing by conventional methods to effectively control the field operations, and promote efficient progress. This need has prompted the interest in the nuclear methods of testing soil moisture and density.

Past experience by the California Division of Highways in research with the conventional backscatter density gage was not overly encouraging. The correlation of the nuclear testing with the sand displacement density test was poor on many projects. This correlation was improved materially by establishing separate calibration curves for the different materials. However, this places a considerable restriction on the test method. These results are available in a report by the Division of Highways, Laboratory and Field Investigation of Nuclear Surface Gages, by William G. Weber, Jr., January, 1964.

It was believed that the performance of the nuclear gages could be better evaluated by a greater understanding of the nuclear test itself, and how the various field conditions may affect it. To achieve this objective it was decided by the California Division of Highways and the Department of Water Resources to perform a comprehensive basic research program to learn more about the factors upon which successful nuclear soil testing depends.

ACKNOWLEDGMENTS

The following study was performed as a cooperative effort between the California Division of Highways, Materials and Research Department, Foundation Section; and the California Department of Water Resources, Technical Services Office, Laboratories Branch. Financing for the Division of Highways portion of the program was provided by the Bureau of Public Roads 1½ percent research funds. The Department of Water Resources participated under the authorization of the Special Engineering Analysis and Criteria Development Program, of the Staff Engineering Branch of the Division of Design and Construction.

The following firms each supplied a nuclear soil gage without charge for use in the research program. The Numec gage, Model 8200 by:

Nuclear Materials and Equipment Corporation
Apollo, Pennsylvania

The Hidrodensimeter gage, Model HDM/2 was provided by:

Viatec (PTY) Limited, a Division of
Instrument Manufacturing Corporation
of South Africa, Limited
Plumstead, Cape, South Africa

The Troxler gage, density Model SC-109 and moisture Model 104-117, was owned and provided for the project by the California Department of Water Resources.

Acknowledgment is made to Bobby L. Lister of the Highways Materials and Research Department, and Frank C. Champion of the Water Resources Laboratory, for their participation in the laboratory phase of the program. Appreciation is extended to Robert T. Milhous, Department of Water Resources for his assistance in the analysis of data and the writing of the report.

ABSTRACT

A laboratory program was undertaken to study the factors affecting the results obtained using nuclear gages to determine soil moisture and density. Both backscatter and transmission type nuclear soil density gages were studied.

The testing program consisted of conducting readings on laboratory compacted soil samples with the nuclear readings being taken across the compaction plane. Six different soil types were used in this study ranging from sands, sands and gravel, shales, sandstone, to clay. Tests indicate that the compacted soil samples had a soil density variation with a standard deviation of about two pounds per cubic foot.

The density calibration curves obtained by nuclear methods indicate a standard deviation of 4½ pounds per cubic foot for the backscatter, and 2½ pounds per cubic foot for the transmission type gages. By collimation of the source the standard deviation of the backscatter type gage calibration was reduced to 2½ pounds per cubic foot. No affect of soil type upon the calibration curves was noted in this study.

The effect of surface roughness was studied by use of regularly spaced grooves on the soil surface. The readings obtained with backscatter type gages were very sensitive to surface roughness while the transmission type gages were only slightly affected by surface roughness. Errors in density of six to eight pounds per cubic foot occurred due to surface roughness when backscatter type gages are used to determine soil density.

The volume of the soil affecting the nuclear readings was determined to be about 0.05 cubic foot for both the backscatter and transmission type gages.

The transmission type gages had a greater ability to detect changes in soil density than the backscatter type gages. They also were less affected by surface roughness, and density variation from point to point within the soil mass. This would indicate that the transmission gages are more desirable for determining soil density than the backscatter type gages. However, there is some question as to the practicability of making the necessary hole in the soil for the transmission gage.

The moisture readings were much less affected by the various items, such as surface roughness, than the density readings were. The standard deviation of the moisture readings was about one and one-half pounds of water per cubic foot.

INTRODUCTION

Beginning in the early 1950's considerable work has been done to establish methods and equipment for using radioisotopes to measure the moisture content and density of soils in the field.

The California Department of Water Resources and the California Division of Highways have been working independently on the evaluation of nuclear moisture-density instruments. The Division of Highways has made an extensive investigation both in the laboratory and in the field of the characteristics and methods of using the nuclear instruments. The Department of Water Resources has made a general investigation into the possibility of using the nuclear instruments on works being constructed by the department.

Because work was being done by both the Division of Highways and the Department of Water Resources, it was felt that a better evaluation could be made of the nuclear instruments by a combined effort than if work was done independently; this would also eliminate considerable duplication of effort.

Consequently, a cooperative reaseach project has been carried out. The Division of Highways portion of the program was authorized as a result of a request submitted on December 31, 1963, and approved on April 7, 1964, the work was done under U. S. Bureau of Public Roads No. HPR 1(1) in Part 2 as Item 77, Division of Highways Research and Development Account No. 900.51 (226.00) and Laboratory No. R-24592/300229. The Department of Water Resources portion was authorized as part of the Special Engineering Analysis and Criteria Development Program, of the Staff Engineering Branch of the Division of Design and Construction.

The following paragraphs are a short discussion of the principles that are basic to using the nuclear moisture-density instruments:

Principles of Density Measurement

The ability of material to absorb or scatter gamma radiation is a function of the density of the material. Gamma photons are absorbed by the material in three principal ways: (1) photoelectric effect, (2) Compton effect and (3) formation of positron-electron pairs. Diagrams of the three types of gamma photon absorption are given in Figure 1. Photoelectric effect is most significant for gamma photons of low energy, and for absorbers of high atomic weight. Compton effect plays a major role when the gamma photons have a medium radiation energy, and when the absorber has a low atomic weight. Pair production is most important for photons of high energy, especially when the absorber is of high atomic weight. Sources of gamma photons used in soil density measurement instruments emit photons of lower energy than is required for pair production, and as a soil is not a material of high density, the most important factor in the absorption or scattering of gamma photons in the determination of soil density is the Compton effect.

In pair production and photoelectric effect, the initial gamma photon loses all of its energy and ceases to exist, but in the Compton effect the photon loses only part of its energy to the recoil electron.

The number of gamma photons passing through soil are measured by using a Geiger-Mueller tube or a scintillation crystal. The Geiger-Mueller tube measures gamma photons of all energies striking it and capable of penetrating the tube. The scintillation crystal can be used to count photons of all energies, or those having energies above a given energy level.

Instruments for measuring soil density are of two types, the "backscatter" gage which uses only photons that have been scattered by Compton effect; and the "transmission" gage which uses both photons that have been scattered by the Compton effect, and photons that have been transmitted without energy loss. With both type of gages, low photon counts indicate a high density and high photon counts a low density.

A schematic diagram for each technique is given in Figure 2.

Principle of Moisture Measurement

The basis of measuring soil moisture is that when a high energy neutron collides with a nucleus very much heavier than the neutron, little energy is lost by the neutron. When the collision is with a nucleus of similar mass the neutron loses considerable energy and becomes a slow neutron. The hydrogen nucleus has approximately the same mass as the neutron, and is the most effective element in slowing fast neutrons. Almost all of the hydrogen found in soil is in the soil moisture, and the number of neutrons slowed down by passage through soil is a function of the moisture content. By using a fast neutron source to emit neutrons into a soil mass and then using a slow neutron detector tube to measure the slow neutrons returned from the soil, the amount of water in the soil mass can be determined. A schematic diagram of the moisture measurement technique is given in Figure 3.

Depth Probe

The schematic diagrams given in Figures 2 and 3 are for instruments used at the soil surface; another nuclear technique is to use a depth probe which is dropped into a hole drilled in the ground, and is used to measure the soil density and/or moisture of the soil strata. A schematic diagram of a depth probe is presented in Figure 4.

Project Objectives

Considerable difference of opinion has been expressed in the literature on the reliability of the nuclear instrument, on whether or not one calibration curve can be used for all soil, on the effect of surface roughness, and on the backscatter vs transmission techniques of nuclear density measurement. Consequently a project was established with the following objectives:

(A) To evaluate the laboratory accuracy of nuclear moisture and density test methods.

(B) To compare the backscatter and transmission techniques of nuclear density determination.

(C) To evaluate the effect of detecting different minimum energy levels by the use of a scintillation crystal instrument, and how this affects the density determination.

Studies Performed

(A) A study of the characteristic shape of the spectrum curve, and the effect on the spectrum curve of surface roughness and/or air gap between the instrument and the soil surface.

(B) A study to establish calibration curves for the various instruments, and to determine if one calibration curve is satisfactory for all soils.

(C) A study to determine the depth and volume of soil tested by the nuclear methods.

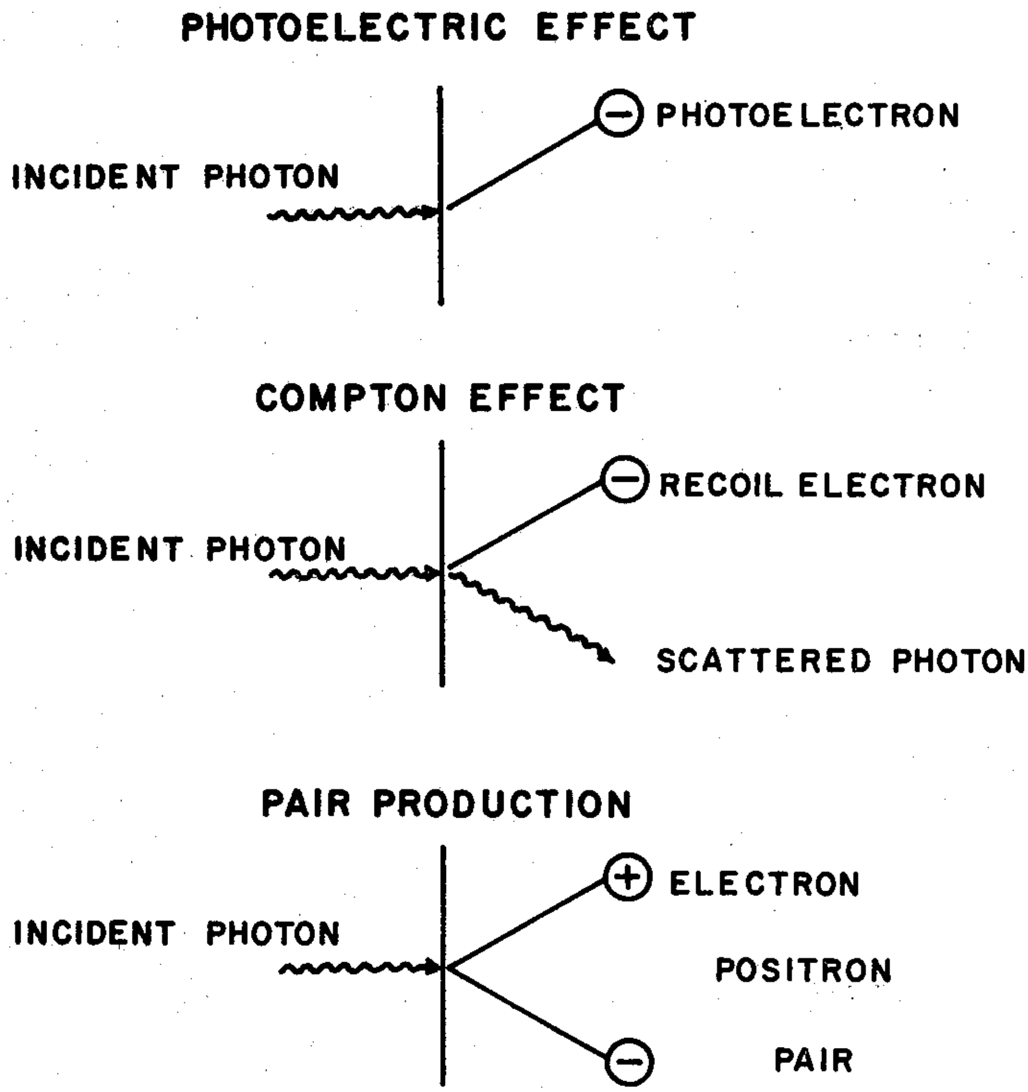
(D) A study of the effect of surface irregularities and roughness on the nuclear moisture and density tests.

(E) A study to determine if a deliberate air gap will eliminate or reduce the effect of irregular (rough) surfaces, and how this air gap affects the calibration curves.

(F) A study to determine if there is an optimum energy discrimination level for the detector in performing density measurements.

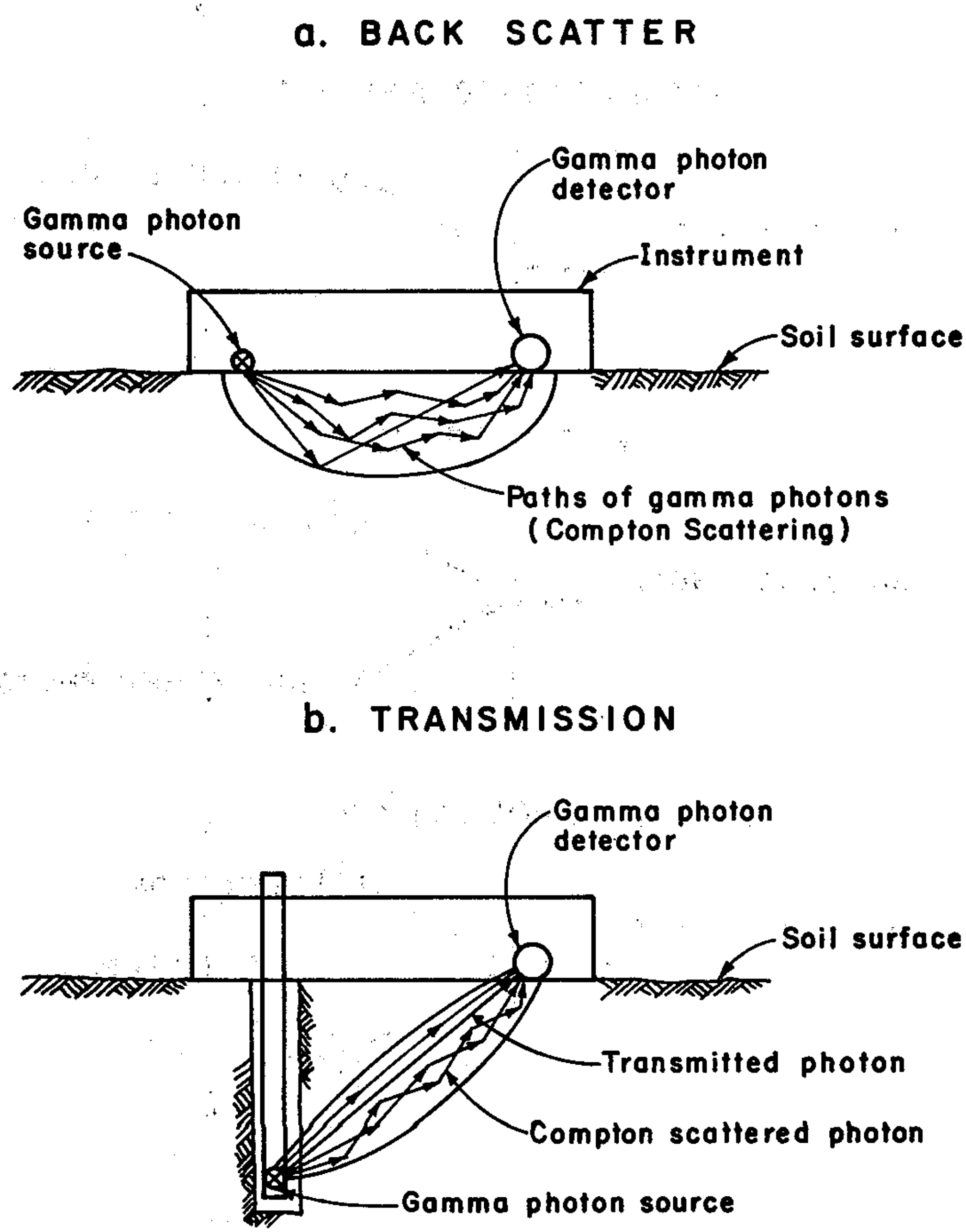
(G) A study to determine the effect of raising the source to a higher position within a backscatter instrument. This action restricts the emission path of the gamma rays due to the shielding within the instrument. This restriction is termed "collimation."

(H) Various sub-studies to evaluate the possible effect on the laboratory tests of procedures used in the study. For example, to determine if the orientation of the sample compaction planes has an effect on the instrument readings.



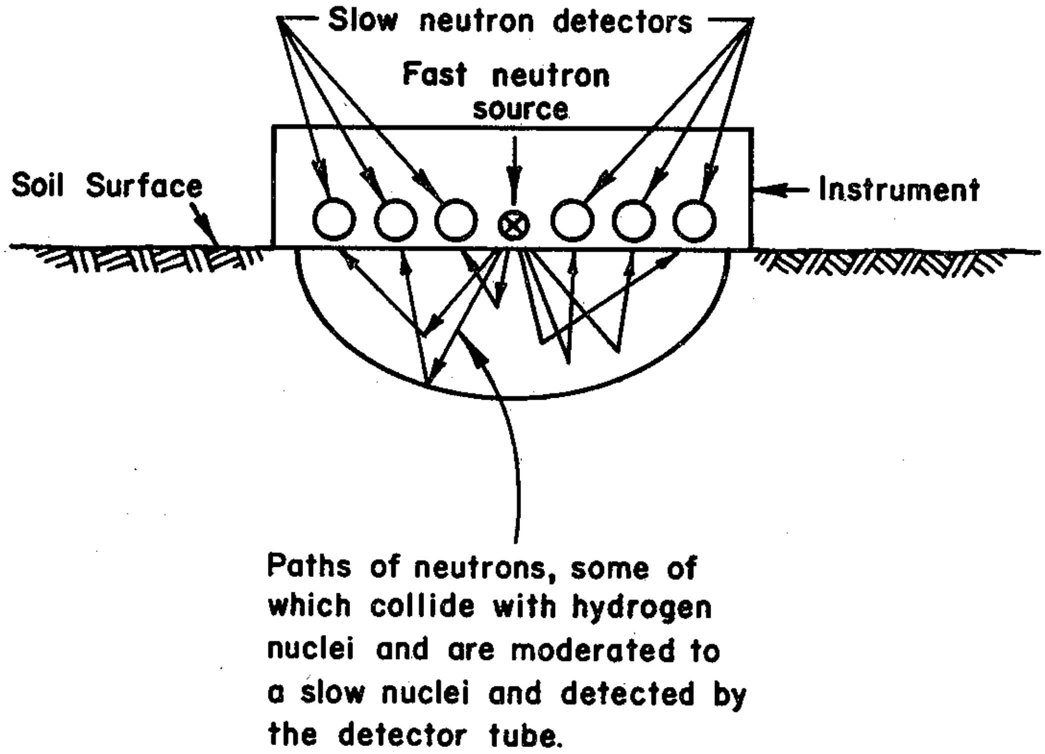
THREE TYPES OF GAMMA PHOTON ABSORPTION

FIGURE I



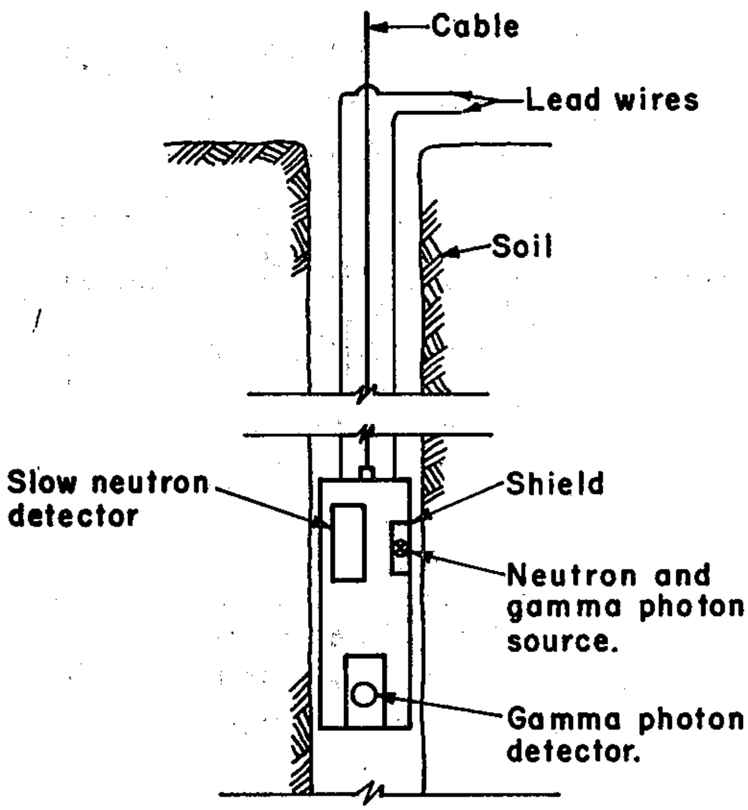
DENSITY MEASUREMENT

FIGURE 2



MOISTURE MEASUREMENT

FIGURE 3



SUBSURFACE MOISTURE AND DENSITY MEASUREMENT

FIGURE 4

CONCLUSIONS

The accuracy of the gages is based upon the readings obtained under laboratory conditions where many factors were under close control, and it is felt represent the ultimate potential of the individual gages. The transmission test had a standard deviation of about 2½ pounds per cubic foot which it is felt approaches the accuracy to which the soil samples were prepared. The use of discrimination of the detector slightly increased the accuracy of the transmission test. The conventional backscatter type test had a standard deviation of about 4½ pounds per cubic foot which indicates a poor potential to indicate the density of the soil. The standard deviation of the backscatter test was reduced to 2½ pounds per cubic foot when the source was collimated.

The transmission test was less sensitive to surface roughness of the soil mass and variation in density from point to point within the soil mass than the conventional backscatter test. The transmission type test appears superior to the conventional backscatter test in this study. The collimation of the source in the backscatter type gage results in a gage comparable to the transmission gage.

The use of discrimination of the detector in the conventional backscatter gage did not improve the results obtained. It appears that the energy level of the photons being received are at a low level where discrimination is not practical. The use of discrimination of the detector in the transmission gage slightly improved the accuracy of the test results. Due to the increased equipment and time required in the field, it is not felt that the cost in time or money is justified in the field use of a gage utilizing discrimination.

The moisture tests indicated a standard deviation of 1½ pounds of water per cubic foot. This is adequate accuracy for field use of these gages. The moisture gages showed less sensitivity to surface roughness than the density gages.

RECOMMENDATIONS

The work performed in this study indicates that collimation of the source improved the operation of the backscatter type gage. The collimation was obtained in this study by recessing the source in its shield, which was very inefficient. An investigation in Austria used a collimated source at 45 degree angle with the ground surface. Mr. K. Preiss reported a study at the 44th Annual HRB meeting where both a collimated source and detector were used. As in this study, only partial evaluation of the effect of collimation was conducted in each study. However, elimination of some of the problems were reported in each study. It is recommended that an evaluation of the effect of collimation of both the source and detector be made.

Moisture determinations in this study were all made by the backscatter method. With the apparent superior performance of the transmission type density gage it would be desired to also make the moisture determination by the transmission method. This would enable the determination of both the moisture and density in the field without changing the gage as is now necessary. It is recommended that the feasibility of determining the moisture by direct transmission be investigated.

It is recommended that transmission type gages be used in the field so as to evaluate its practicability. There is some feeling that the placing of a hole in embankment soils may be difficult. This problem can only be evaluated from field experience. The transmission gage would not require the discriminator type detector.

GENERAL PROCEDURE

A brief general description of the testing procedure used is given below, and is followed by the detailed procedures in Appendix A.

A soil sample to be tested was prepared by compacting soil into a 12 by 18 by 18 inch mold. The mold was placed with the 12 by 18 inch side up for compaction. It was then turned so that the 18 by 18 inch side was up for testing. The sequence is illustrated by Photos 1 thru 5. The resulting specimen, Photo 6, shows clearly the compaction planes. Readings on this surface were taken across and parallel to these compaction planes to minimize their effect and to more nearly measure the average density of the specimen. A typical backscatter measurement is shown in Photo 7.

Holes were drilled in various specimens to accommodate the probe of the transmission gage which must be extended into the transmission position are presented in Photos 8 and 9. This particular picture shows the rod with the source on one end (seen protruding through the top of the gage) extended some ten inches into the test hole.

An air gap was formed by using the methods shown in Photos 10 and 11. The adjustable frame was used in the first tests of air gap, then an arbitrary setting was selected and the sticks shown in the second figure were used as spacers throughout the balance of the project.

The effect of surface roughness was studied by making 1/16 and 1/8 inch grooves spaced 1/2 inch center to center. Nuclear measurements were made on these roughened surfaces and then compared to readings previously taken on the smooth surface. Photo 12 shows the tool used to make the grooves and the following Photos 13 and 14 show the grooves one way only and the diamond pattern produced by making a second set of striations perpendicular to the first. On one box, Photo 14, the one way 1/8 inch grooves were filled with fines from the soil used.

Photo 16 is a display of some of the varied equipment used in the project.

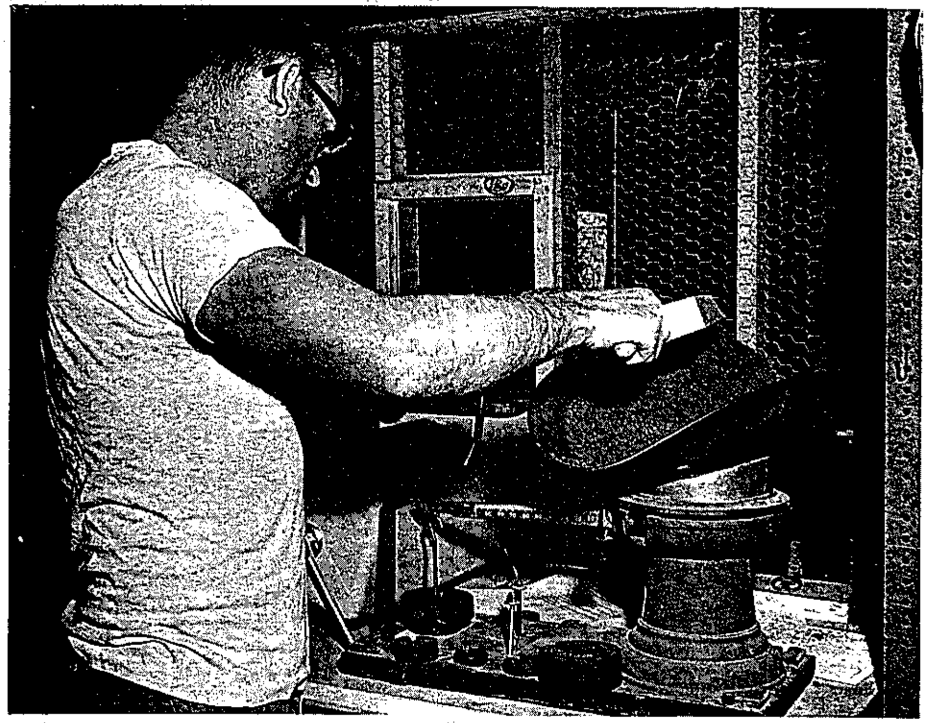


PHOTO 1, Weighing Soil for Each Layer to Obtain Uniform Thickness and Density.

PHOTO 2, Placing Soil in Mold.

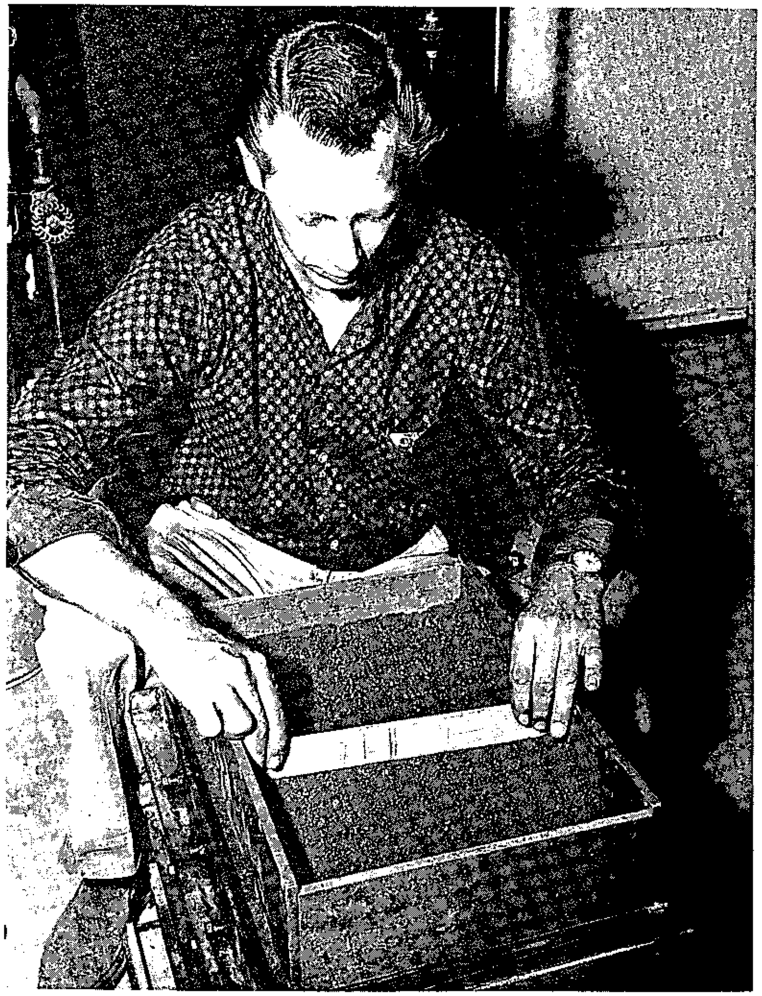


PHOTO 3. Leveling Soil Prior to Compaction.

PHOTO 4, Compacting Soil.

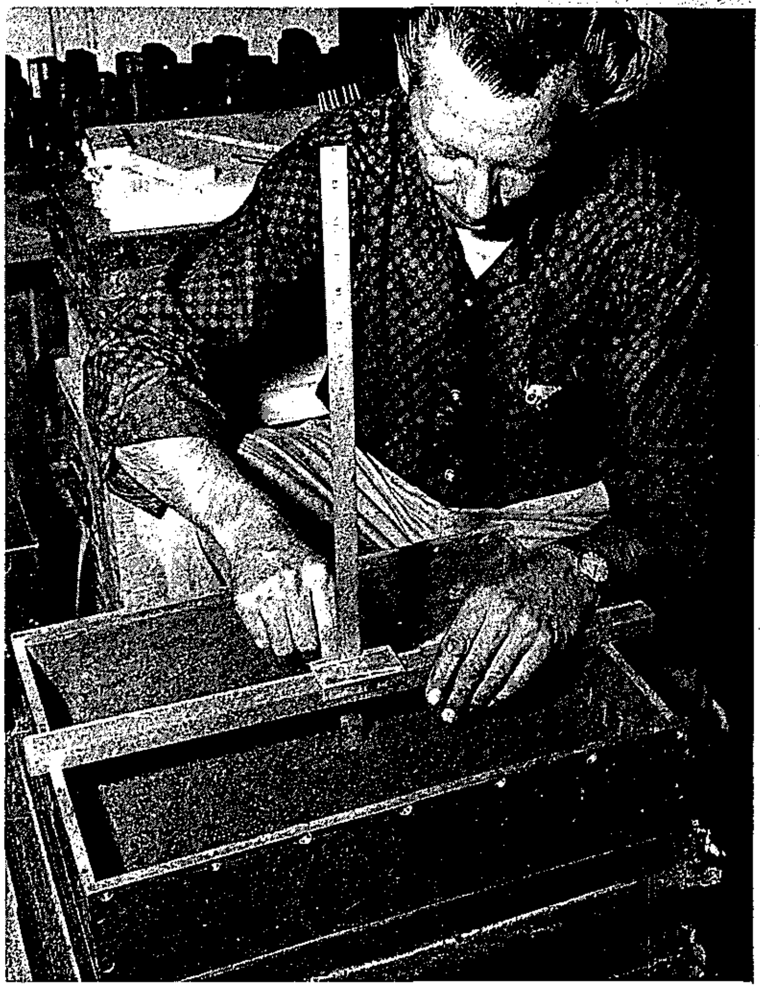


PHOTO 5, Measuring Thickness of Layer.

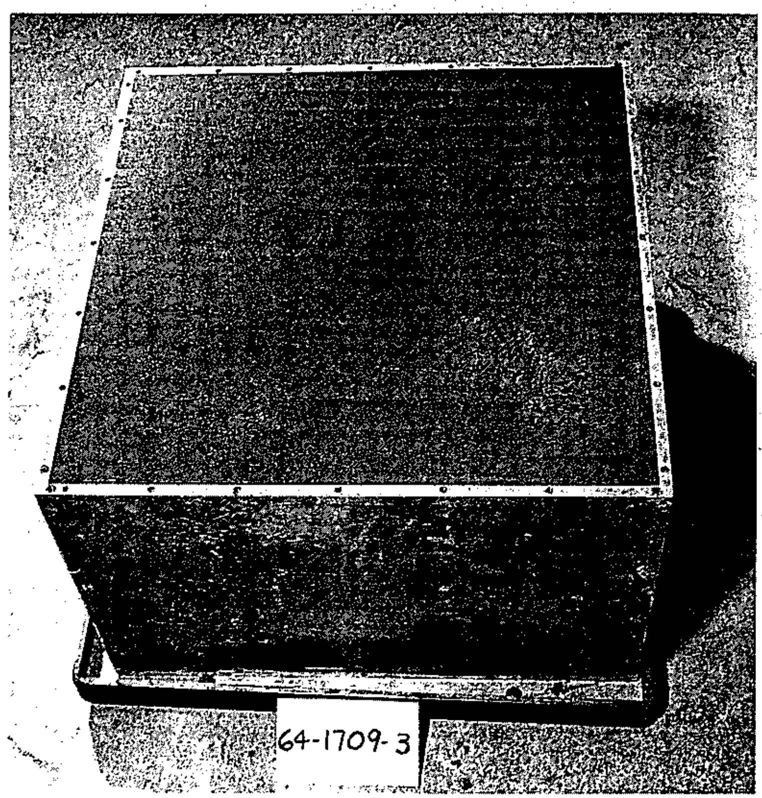


PHOTO 6, Compaction Planes, Mold Turned and Side Removed.

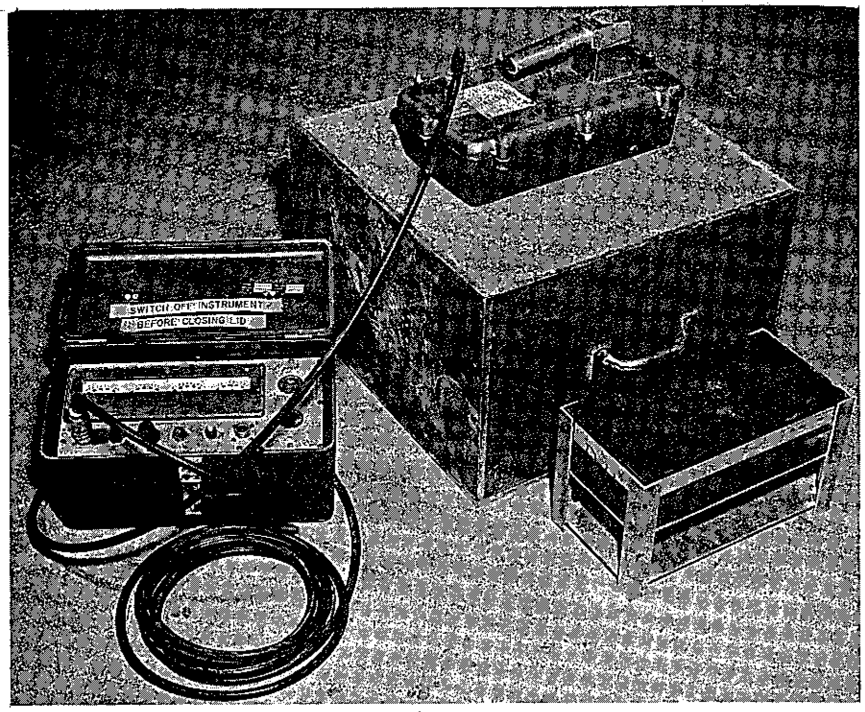


PHOTO 7, Backscatter Measurement.

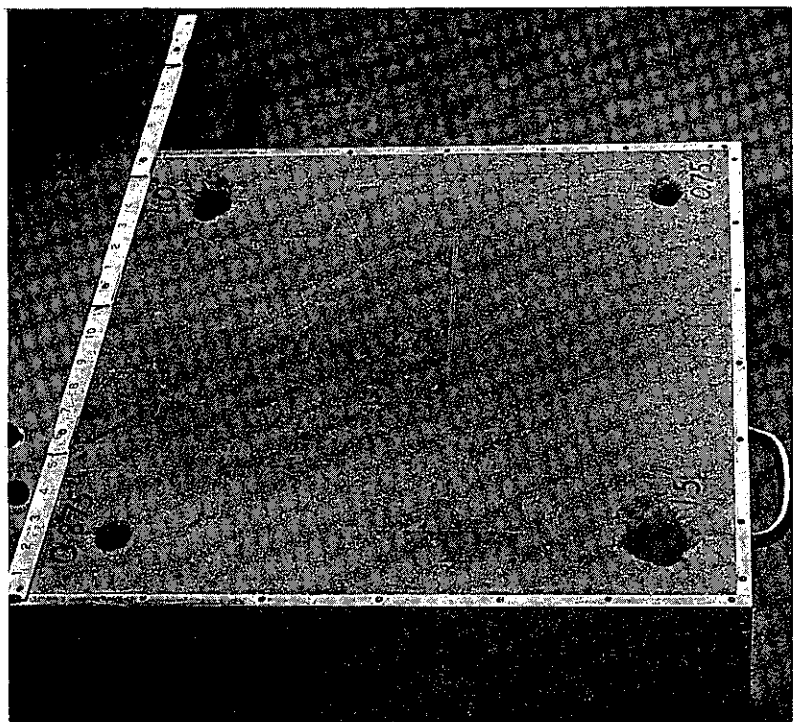


PHOTO 8, Holes for Transmission Measurement.

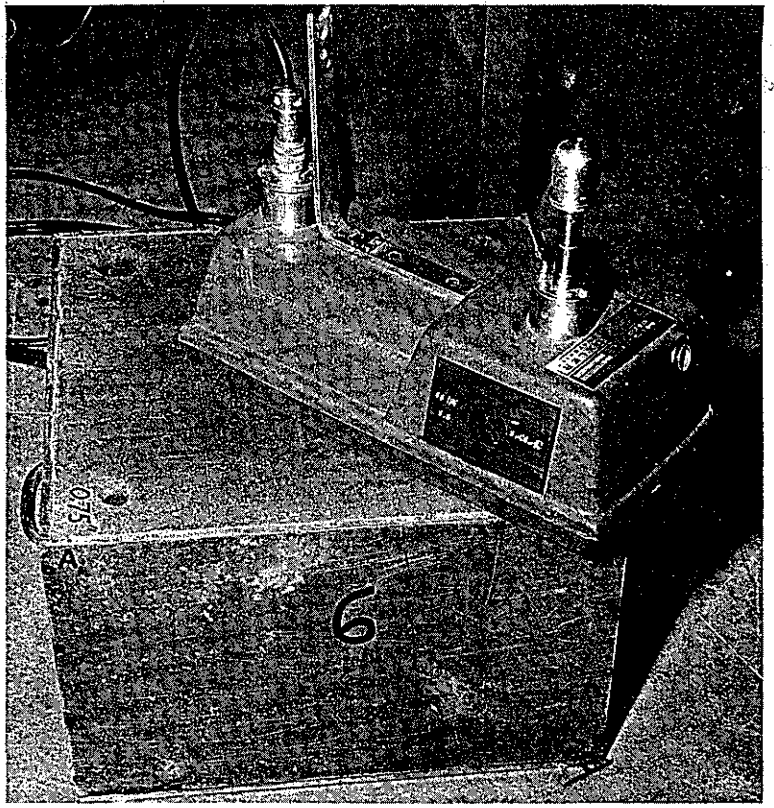


PHOTO 9, Transmission Measurement, Source Approximately 10 inches in Soil.

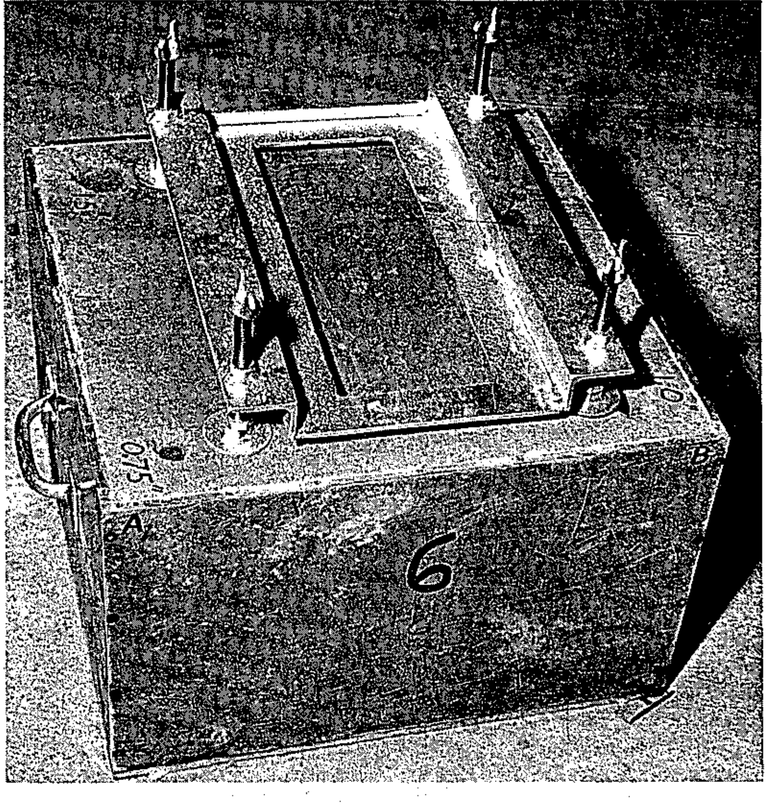


PHOTO 10, Adjustable Frame for Air Gap.

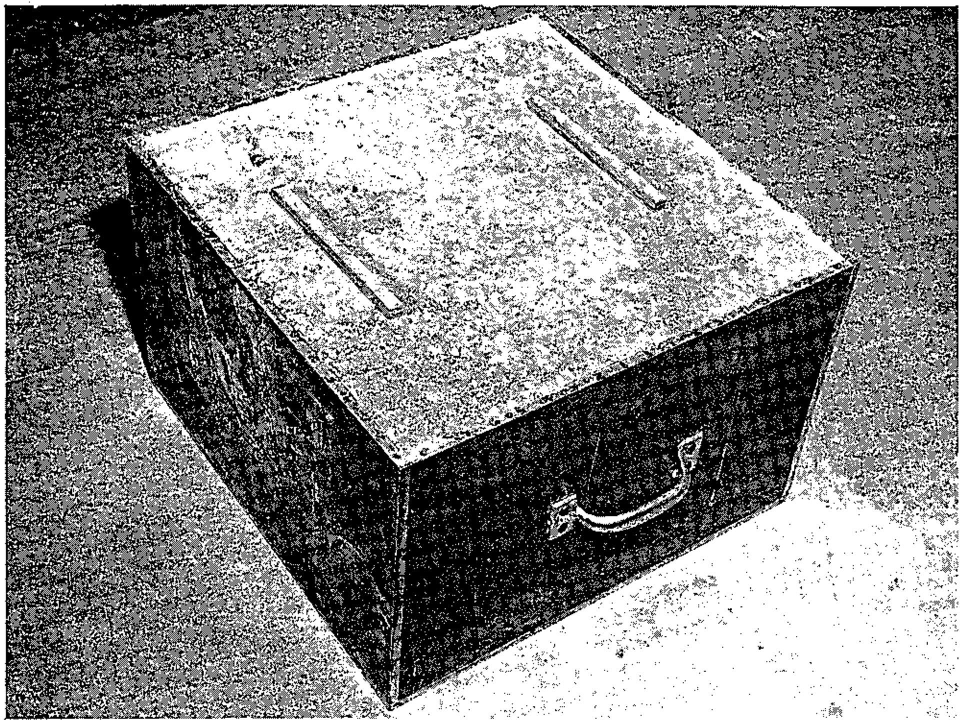


PHOTO 11, Sticks Used for Air Gap.

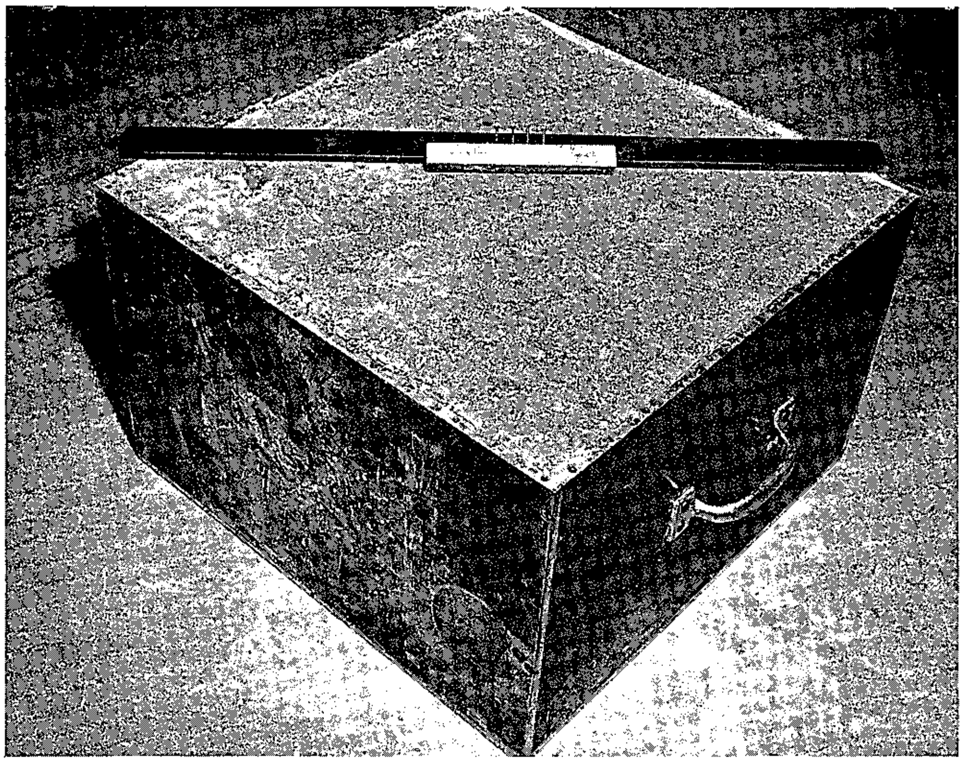


PHOTO 12, Tool Used to Make Grooves for Surface Roughness Study.

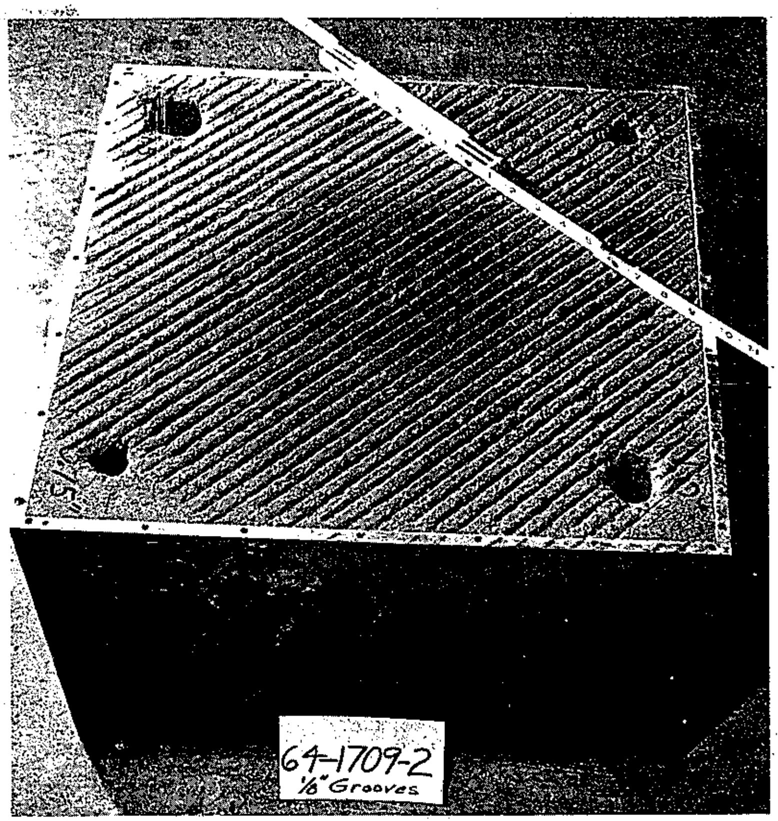


PHOTO 13, Illustration of Grooves for Roughness Study.

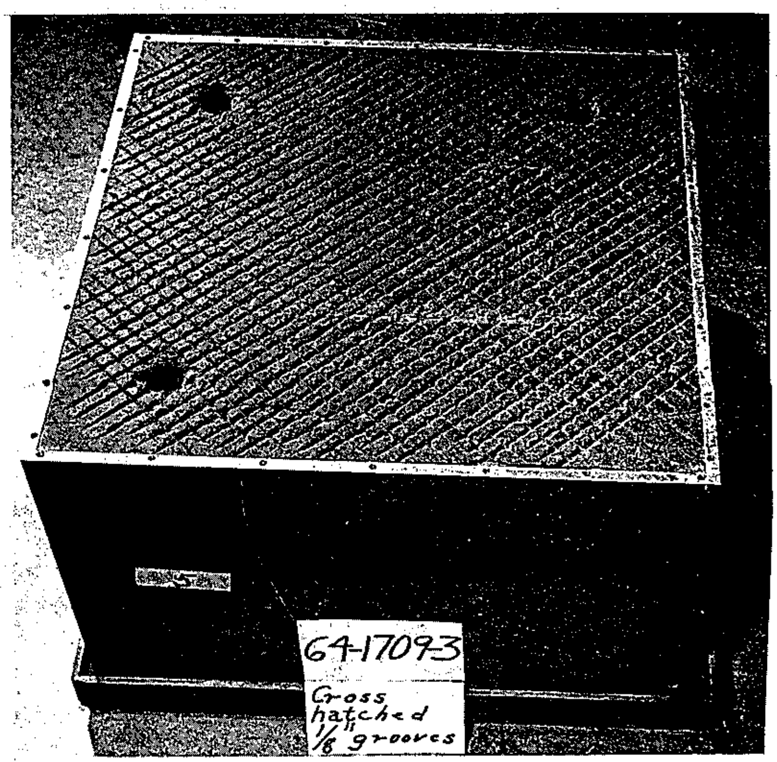


PHOTO 14, Illustration of Cross-Hatched Grooves for Roughness Study.

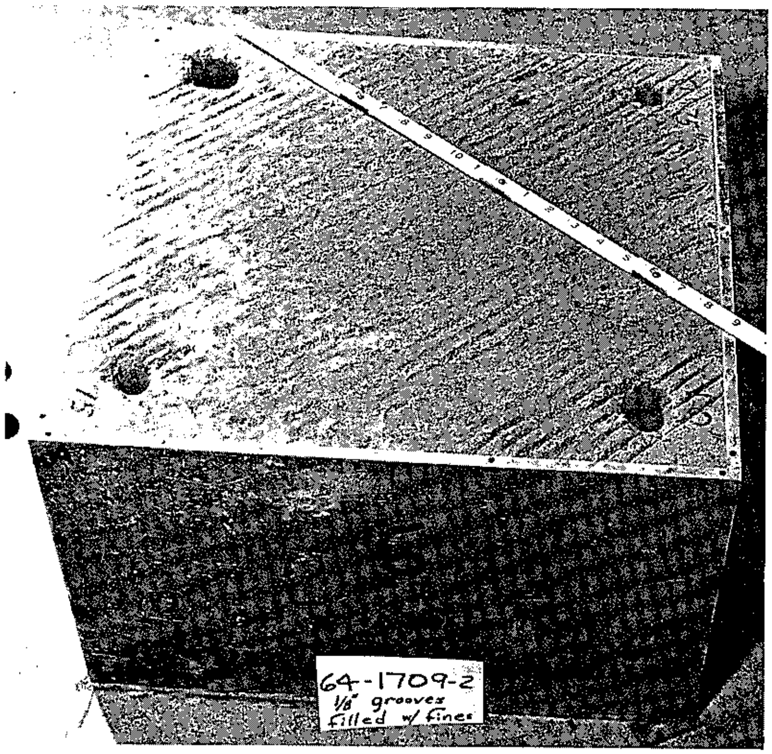


PHOTO 15, Grooves Filled With Fines.

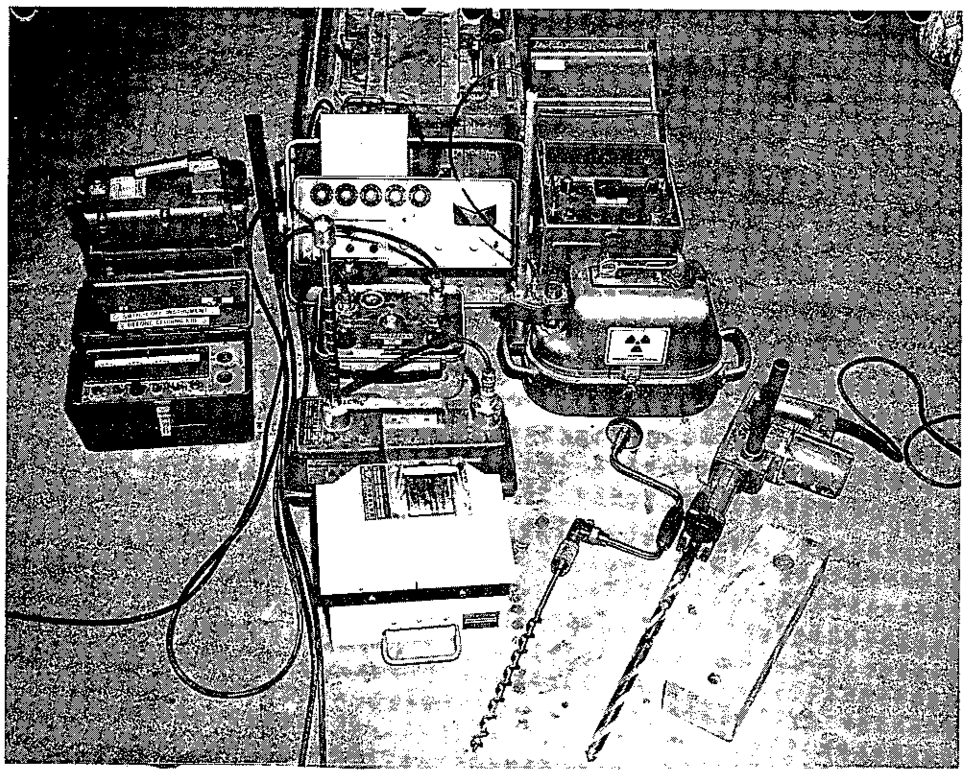


PHOTO 16, Variety of Equipment Used on Project.

SOILS USED IN THE STUDY

Various soils were used to determine calibration points and one was used primarily in the studies to determine the factors that influence the instrument readings. The materials are described below in the order in which they were used:

Sample 64-1709	South Sacramento Soil. This soil was used to determine the factors that influence instrument readings and was obtained from the Division of Highways South Sacramento Freeway Project. It is a sandy silty clay of low plasticity.
Sample 64-2487	Folsom Soil. Soil Sample 2487 is from a Division of Highways project near Folsom in Sacramento County and is a clayey, sand-rock mixture. The rock is mostly weathered and fragmented.
Sample 64-2484	San Luis Soil. From a relocation project near the San Luis Reservoir. The soil is a gravelly sand-clay.
Sample 64-3694	Monterey Sand. A uniform medium sand from the Monterey area.
Sample 64-3681	Volcanic tuff. A volcanic tuff from the Benicia area.
Sample 64-3472	West Sacramento Sand. From the American River near Sacramento and is a medium fine sand.

The samples containing rock were scalped on the 1½ inch or one inch sieve. The fractions between the 1½ inch or 1 inch sieve and the No. 4 sieve were increased so as to keep the coarse fraction of the sample tested the same as the original field sample. The scalping permitted more uniform compaction control in the laboratory sample.

Classification and other test data on the soils are given in Tables 1 through 6.

TABLE 1

CLASSIFICATION TESTS
Sample No. 64-1709 - South Sacramento Soil
Sampled from various locations
on South Sacramento Freeway

GRAIN SIZE ANALYSIS

Sieve Size	Gradation Field	Gradation "As Used"	Sieve Size	Gradation Field	Gradation "As Used"
3"			No. 8	99	99
2½"			16	97	97
1½"			30	94	94
1			50	92	92
3/4			100	81	81
1/2			200	64	64
3/8			5 micron	20	20
No. 4	100	100	1 micron	10	10

Atterberg Limits	
PL	17
LL	22
PI	5

Sand Equivalent
10

Specific Gravity	
+ No. 4 Material	
- No. 4 Material	2.72

Combined differential thermal analysis and X-ray Diffraction (Material passing No. 200 only)

Quartz	10-15%	Kaoline	5%
Feldspar	5-10%	Organic	2-3%
Vermiculite	5%	Magnetite	1%
Muscovite	5%		
Chlorite	5%		

Compaction Results

Highways Impact γd	Highways Impact w,%	Standard AASHO γd	Standard AASHO w,%
122.1	10.0	104.6	7.3
125.2	12.1	109.6	8.7
119.9	14.3	113.1	10.6
113.6	16.4	115.1	14.5
117.6	8.0	115.6	12.9
		113.7	16.5

TABLE 2

CLASSIFICATION TESTS
Sample No. 64-2487 - Folsom Soil
Sampled from various locations east of
Latrobe Road Intersection on Road III - Sac - I

GRAIN SIZE ANALYSIS					
	Gradation			Gradation	
Sieve Size	Field	"As Used"	Sieve Size	Field	"As Used"
3"	99		No. 8	40	40
2½"	97		16	35	35
1½"	86		30	30	30
1"	75	100	50	26	26
3/4	69	88.4	100	22	22
1/2	61	33.1	200	18	18
3/8	56	63.4	5 micron	8	8
No. 4	48	48.1	1 micron	3	3

Atterberg Limits	
PL	19
LL	29
PI	10

Sand Equivalent
20

Specific Gravity	
+ No. 4 Material	2.58
- No. 4 Material	2.77

Combined differential thermal analysis and X-ray diffraction (Material passing No. 200 only)			
Quartz	10%	Montmorillonite	5-10%
Feldspar	10%	Kaolin	10%
Vermiculite	30%	Amphibole	5%

Compaction Results			
Highways Impact		Standard AASHO	
γd	w,%	γd	w,%
131.6	12.2	121.0	14.1
131.0	12.3	122.2	14.9
135.6	10.7	116.3	16.5
136.1	10.1	118.3	11.2
136.5	10.0		
136.1	9.5		
135.5	8.3		
135.5	7.8		
137.5	8.6		

TABLE 3

CLASSIFICATION TESTS
Sample No. 64-2484
San Luis Soil
Sampled from San Luis Reservoir Relocation Project

GRAIN SIZE ANALYSIS					
Sieve Size	Gradation		Sieve Size	Gradation	
	Field	"As Used"		Field	"As Used"
3"	100		No. 8	49	49
2½"	100		16	42	42
1½"	96	100	30	37	37
1"	89	100	50	32	32
3/4	83	91.5	100	27	27
1/2	76	82.0	200	23	23
3/8	71	75.0	5 micron	11	11
No. 4	60	60.0	1 micron	6	6

Atterberg Limits	
PL	17
LL	32
PI	15

Sand Equivalent
17

Specific Gravity	
+ No. 4 Material	2.77
- No. 4 Material	2.62

Combined differential thermal analysis and X-ray diffraction (Material passing No. 200 only)		
Quartz	15%	
Vermiculite	30%	Several unknown x-ray peaks and
Kaoline	10%	unknown endothermic peak at 650°C
Mica	5%	

Compaction Results			
Highway Impact		Standard AASHO	
γd	w,%	γd	w,%
141.4	5.0	126.1	8.3
144.1	6.9	126.5	12.1
143.8	5.3	120.4	14.5
144.0	7.5	126.7	10.1
141.5	8.4	126.8	12.8
135.3	10.5		
143.2	7.0		

TABLE 4

CLASSIFICATION TESTS
Sample No. 64-3694

Monterey Sand

GRAIN SIZE ANALYSIS

Sieve Size	Gradation Field	Gradation "As Used"	Sieve Size	Gradation Field	Gradation "As Used"
3"			No. 8		
2½"			16	100	100
1½"			30	90	90
1"			50	25	25
3/4			100	2	2
1/2			200	1	1
3/8			5 micron	0	0
No. 4			1 micron	0	0

Atterberg Limits	
PL	
LL	
PI	N.P.

Sand Equivalent
100

Specific Gravity	
+ No. 4 Material	
- No. 4 Material	

Visual Classification

Quartz, Feldspar, Granitic with traces of ultrabasics, chert, shale, sandstone and mica.

Compaction Results

Highways Impact γd	Highways Impact w,%	Standard AASHO γd	Standard AASHO w,%
106.7	3.4	101.1	7.9
107.1	5.9	101.5	9.8
107.4	8.6	101.5	14.3
107.3	11.7	102.4	15.6
108.3	12.8	103.5	16.4
107.8	13.6		

TABLE 5

CLASSIFICATION TESTS
Sample No. 64-3681

Benicia Volcanic Tuff

GRAIN SIZE ANALYSIS					
Sieve Size	Gradation		Sieve Size	Gradation	
	Field	"As Used"		Field	"As Used"
3"	100		No. 8	63	63
2"	98		16	55	55
1½"	96	100	30	48	48
1	92	95	50	42	42
3/4	89	91	100	36	36
1/2	85	86	200	31	31
3/8	80	80	5 micron	10	10
No. 4	70	70	1 micron	5	5

Atterberg Limits	
PL	48
LL	53
PI	5

Sand Equivalent
22

Specific Gravity	
+ No. 4 Material	
- No. 4 Material	

Combined differential thermal analysis and x-ray diffraction on all -#4 material	
Tuff and volcanic (basalt) - very highly altered and weathered	
Nontronite	10-15%
Feldspar	5%
Quartz	10%
Volcanic glass (Palgonaite)	25%

Compaction Results			
Highways Impact		Standard AASHO	
γd	w,%	γd	w,%
80.2	26.1	71.1	24.4
77.7	29.2	72.5	27.6
79.5	23.2	74.3	28.7
75.7	33.9	74.3	29.0
71.1	38.6	73.6	30.0

TABLE 6

CLASSIFICATION TESTS
Sample No. 64-3172
West Sacramento Soil
Sampled along the American River

GRAIN SIZE ANALYSIS

Sieve Size	Gradation Field	Gradation "As Used"	Sieve Size	Gradation Field	Gradation "As Used"
3"			No. 8		
2½"			16	100	100
1½"			30	94	94
1			50	45	45
3/4			100	5	5
1/2			200	1	1
3/8			5 micron		
No. 4			1 micron		

Atterberg Limits	
PL	
LL	
PI	N.P.

Sand Equivalent

Specific Gravity	
+ No. 4 Material	
- No. 4 Material	

Visual Classification			
Quartz	35%	Slate or Thyllite	7%
Granitic	20%	Schist	3%
Volcanic	20%	Ultrabasic	3%
Mica	12%	Meta-sandstone	1%

Compaction Results

Highways Impact γd	Highways Impact w,%	Standard AASHO γd	Standard AASHO w,%
102.4	5.5		
104.1	19.8		
104.4	12.8		
104.8	17.5		
105.0	18.0		
103.0	2.8		
105.3	15.4		

DISCUSSION OF TEST DATA

CALIBRATION DATA

The deviation of the nuclear readings from the soil densities is a measure of the accuracy of the various nuclear systems. The densities of the compacted soil samples were assumed to be absolute values, however, it is known that deviations exist due to variation in compaction, measurement, and surface condition. All possible care was taken to minimize these variations, and it is felt that these variations would not result in a nuclear reading in error in excess of one to two pounds per cubic foot. Using this data, calibration curves were obtained for the various nuclear systems.

Nuclear calibrations were obtained on six different soils. The densities of the soil samples ranged from 77 to 148 pounds per cubic foot wet density, and the moistures from 3.0 to 27.5 pounds per cubic foot. The resulting calibration data are presented in Table 7. All the density values are in terms of wet density, and the moisture as pounds of water per cubic foot of soil.

These calibration points of density versus the instrument reading in count ratio are plotted on the calibration graphs, Figures 5 thru 21. The backscatter calibration curves are plotted on both arithmetic and semi-logrithmic graphs. The transmission calibration curves are plotted on semi-logrithmic graphs only. Solution of the theoretical equations representing the calibration curves indicate that; using the backscatter gages the calibration curves will approach a linear relationship in a portion of the density range and may tend to approach a straight line in a semi-log plot; using the transmission gages the calibration curves will have a logrithmic relationship. The moisture calibration curves are plotted on arithmetic graphs, as the theory indicates a linear relationship exists.

A linear regression analysis was made on the density data by computer, using a modified BIMD-29 multiple-regression program originally written by the University of California School of Medicine at Los Angeles. A summary of the data obtained from this analysis is shown on Tables 8 and 9. The equations of the linear regression line are in terms of wet density and are of the form: γ wet = Ao + A R and γ wet = Ao + A (ln R) where γ wet = wet density, R = count ratio, ln = natural logarithm of the number.

The linear regression line is shown on the plots as a solid line and is always a straight line. The best visual fit of line is shown as a shown as a dashed line which may be a curve. The standard deviation as computed for the linear regression line is presented in Table 8 and 9.

The density calibration curves show that as the density of the soil increases the counts or count ratio decrease. This effect occurs with both the backscatter and transmission type of tests. This results in a negative slope of the calibration curves. The moisture calibration curves show that as the moisture content of the soil increases the count ratio increases. This results in a calibration curve with a positive slope.

The data from this analysis shows that the linear arithmetic plot gives slightly better results for the back-scatter test with the Troxler and Numec instruments. The Hidrodensimeter in the backscatter position is an appreciably better fit when plotted on a semi logrithmic graph. The reason for this discrepancy is not known. The linear portion for all of the backscatter tests is in the range of 100 to 150 lbs. per cu. ft. To use the conventional backscatter instrument or soils of density below 90 lbs. per cu. ft. would require special calibration, based upon the single low density point available.

The use of discrimination of the detector in the non-collimated backscatter test resulted in decreased correlation of the data. The standard deviation in every test condition increased as the discrimination level increased. The data indicates that the use of discrimination of the detector is not desirable in regard to the backscatter type test.

Collimation of the source had a varying effect upon the standard deviation depending upon the discrimination level of the detector. At 0 KEV. discrimination level the standard deviation of the data obtained with the collimated source was reduced to one-half of value obtained when the non collimated source was used. When the 350 and 500 KEV level discrimination was used the standard deviation of the data with the collimated source was two to three times the value obtained when the non-collimated source was used. The collimation of the source benefitted the low discrimination levels resulting in a standard deviation of 2½ pounds per cubic foot, which approached the estimated standard deviation to which the soil samples were prepared.

Considering only the standard deviation of the test data for the calibration curves for backscatter gages, it appears that the present nuclear gages using non collimated sources can be expected to indicate densities in the range of 4½ to 7½ pounds per cubic foot. The use of collimation of the source will reduce the standard deviation to about 2½ pounds per cubic foot.

Collimation of the source thus increases the accuracy of the backscatter gages while the use of discrimination of the detector reduces the accuracy of the backscatter type of density test.

Previous work had indicated that a different calibration curve would be required for different soil types with back-scatter gages. This was found both in laboratory and field studies. Preliminary test performed at the Materials and Research Department indicated that this apparent shift in calibration curve was due to variation in density within the compaction layers. To avoid this possible difficulty the nuclear readings were performed on the side of the sample so that the readings were through several compaction layers. The data did not indicate that any of the soils tested consistently deviated from the one calibration for all of the soils tested.

Table 9 indicates that as the depth of measurement increases the standard deviation of the data decreased with the Troxler transmission gage. This was as expected due to the increased volume of soil being measured. With the Hidrodensimeter the standard deviation of the data was about the same for all depths. The geometry of the two systems are reversed, that is, the Troxler has the source underground and the Hidrodensimeter has the pickup underground, and it is not known if this or other differences effect the accuracy of the data. At a depth of 8 to 10 inches the standard deviation is 2½ to 3 pounds per cubic foot for both gages.

A study of the families of curves for the Troxler instrument at the 0, 300, 500 KEV discriminator settings shows that the 300-KEV test has a markedly greater linear range than the other tests; about 75 to 150 lbs. per cu. ft. The same test with a 0-KEV discriminator setting is linear for approximately the 100 to 145 lb. per cu. ft. range, or about the same as the backscatter tests. This is based upon one point below 100 pounds per cubic foot and further data may modify this statement.

The use of discrimination in the transmission test appears to decrease the standard deviation. It is questionable if there is a significant difference between the standard deviation for the 300 and 550 KEV discrimination level. Consideraing that the counts were greatly reduced at the 550 KEV discrimination level, it would appear that the two discrimination levels have about the same accuracy. In the use of discrimination it appears that the 300 to 400 KEV level would be desirable and that the size of the source be increased so as to keep the count level high.

In general, the transmission type of test had a lower standard deviation than the backscatter type of test using a non collimated source. By collimating the source in the backscatter test the standard deviation is about equal to transmission type of test.

A regression analysis was not performed on the moisture data. The curves were fit to the data by visual methods, and the standard deviation computed. These are tabulated on Table 10. The moisture calibration curves are in terms of pounds of water per cubic foot of soil, not percent of dry weight.

A summary of the results as indicated by the lowest standard deviation for each instrument and type of test is as follows:

Backscatter, Standard	
Troxler, 0-KEV	4.45 lb per cu ft, soil
Hidrodensimeter	7.70 " " " " "
Numec	4.72 " " " " "
Backscatter, Collimated	
Troxler, 0-KEV	2.39 " " " " "
Transmission	
Troxler, 0-KEV	2.52 " " " " "
Troxler, 300-KEV	1.91 " " " " "
Hidrodensimeter	3.13 " " " " "
Moisture	
Troxler	1.4 " " " " water
Hidrodensimeter	1.7 " " " " "
Numec	1.5 " " " " "

Another approach to the evaluation of the calibration curves is to compare the slope of the calibration curves. That is the change in count ratio that a change in density of one pound will produce. This is a measure of the ability of the gage to detect a change in density. This data is shown in Table No. 11.

The slope of the calibration curve for the Troxler backscatter test is about three times that for the Hidrodensimeter and Numec gages. The only major difference in the three gages is the use of a photo multiplier pickup tube in the Troxler gage instead of the Muller-Geiger tube used in the other gages. This also may be the reason that the standard deviation of the calibration curve for the Troxler gage was lower than the other gages.

The use of discrimination in the non collimated backscatter test reduced the slope of the calibration curve from 0.036 to 0.015 which is still a greater slope than the other gages used in this study. However, the standard deviation of the data was greatly increased with discrimination which would make the desirability of using discrimination questionable.

The use of discrimination with the collimated backscatter gage results in a zero slope to the calibration curve. This would indicate that discrimination of the detector at the 300 KEV level and above was not measuring the gamma photons that were the result of Compton rebound from the soil. Discrimination at a lower level may respond to the density of the medium being tested. Other investigators have indicated that discrimination in the 100 to 200 KEV level responded to changes in density. However, this information was not available when this test program was initiated and we apparently set the discrimination level too high in the collimated backscatter type gage.

The use of a collimated source, at the zero KEV discrimination level, reduced the slope of the calibration curve from 0.036 for the non collimated source to 0.018. This is a reduction in response to a change in density of one-half. As this response to a change in density of the soil is only one item in the complete evaluation of a system, this reduction may be tolerated.

In the transmission test, at zero discrimination for the Troxler and for the Hidrodensimeter gages, the slope of the calibration curve was essentially constant with depth of measurement. The slope with the Troxler gage was about 0.050 and with the Hidrodensimeter was about 0.006, or a reduction of one-tenth the slope. There were three factors different between the two gages: (1) source underground with the Troxler and pickup underground with the Hidrodensimeter, (2) a photo multiplier detector with the Troxler and Muller-Geiger detector with the Hidrodensimeter, and (3) the Troxler used a Cs 137 source and the Hidrodensimeter used a Ra 226 source. The work of other investigators have indicated that the type of source had minor effect in transmission gages, the Troxler Co. supplies gages with either Cs 137 or Ra 226 sources. This would indicate that either the geometry or the detection system is responsible for this difference in slope. The work in this study did not indicate which condition affected the slope but theoretical considerations have indicated that it probably is the detection system. This would have to be determined by experimental data to substantiate the theory.

When discrimination of the detector was used in the transmission test the slope of the calibration curve decreased with increasing depth. This decrease in slope was from 0.064 at a 4-inch depth to 0.020 at a 10-inch depth and a 300 KEV discrimination level. The reduction in the ability of the gage to detect changes in the density when discrimination is used could be a significant item in the selection of a transmission gage, and would have to be considered along with other items.

TABLE 7

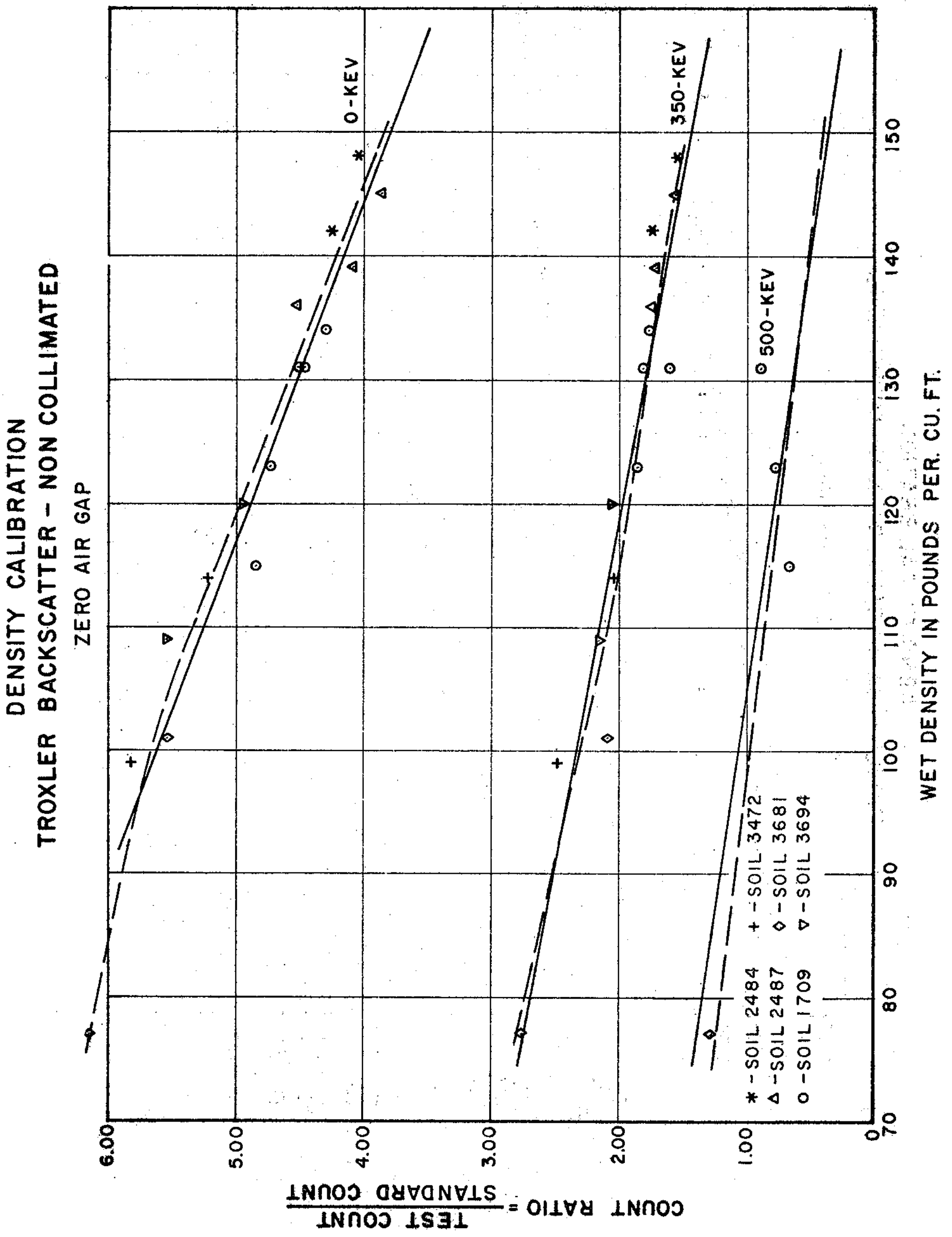
Calibration Points in Count Ratio
Backscatter, Transmission, and Moisture
Zero Air Gap

Test	Instrument	Probe Position (inches)	KEV	1709 - 2	1709 - 3	1709 - 5	1709 - 4	1709 - 6	1709 - 7	2487 - 3	2487 - 1	2487 - 2	2484 - 1	2484 - 2	3694 - 1	3694 - 2	3472 - 1	3472 - 2	2681 - 1	3681 - 2
Soil Density△				115	123	128	131	131	134	136	139	145	142	148	109	120	99	114	77	101
Soil H_2O◇				10	13.5	15	13.5	14.5	13.2	9.5	8.0	10.0	6.0	10.0	3.0	14.0	5.0	20.0	10.5	27.5
Backscatter	Troxler	0	0	4.86	4.73	-	4.51	4.47	4.30	4.52	4.09	3.87	4.25	4.03	5.56	4.95	5.82	5.22	6.16	5.55
		0	350	-	1.86	-	1.81	1.60	1.78	1.73	1.70	1.56	1.72	1.55	2.14	2.06	2.49	2.03	2.75	2.10
		0	500	0.66	0.78	-	0.89	-	-	-	-	-	-	-	-	-	-	-	1.28	-
		-3/4"	0	1.43	1.28	-	1.17	1.14	1.11	1.09	1.02	0.94	1.05	0.98	1.63	1.38	1.76	1.48	2.20	1.75
		-3/4"	350	0.26	0.24	-	0.25	0.22	0.25	0.23	0.24	0.22	0.23	0.22	0.23	0.23	0.25	0.22	0.25	0.24
		-3/4"	500	0.16	0.14	-	0.15	-	-	-	-	-	-	-	-	-	-	-	0.14	-
	Hidro-densimeter	0	-	-	1.59	-	1.56	-	1.44	1.48	-	1.36	1.50	1.43	1.72	1.64	1.75	1.73	1.83	1.74
	Numec	-	-	-	1.17	-	1.28*	1.14	1.08	1.08	0.99	0.96	1.04	0.95	1.43	1.32	1.50	1.36	1.69	1.48
Transmission	Troxler	4	0	5.33	5.00	4.62	-	-	-	4.01	3.98	3.74	4.06	3.73	6.12	5.32	6.23	5.42	6.50	6.09
		6		4.29	3.84	3.51	-	-	-	2.94	2.80	2.55	2.89	2.58	5.19	4.08	5.50	4.43	6.40	5.26
		8		3.04	2.58	2.38	-	-	-	1.83	1.73	1.50	1.75	1.58	3.92	2.84	4.34	3.25	5.58	4.04
		10		2.08	1.63	1.48	-	-	-	1.18	1.07	0.88	1.03	0.91	2.76	1.87	3.16	2.21	4.77	2.94
		4	300	3.84	3.36	3.19	-	2.89	2.71	2.57	2.53	2.34	2.71	2.11	5.27	3.66	5.68	3.96	8.60	5.15
		6		2.50	2.05	1.92	-	1.68	1.57	1.59	1.42	1.31	1.54	1.19	3.39	2.16	3.76	2.52	5.80	3.38
		8		1.50	1.13	1.09	-	0.86	0.82	0.78	0.73	0.65	0.75	0.69	1.99	1.20	2.32	1.48	3.94	2.06
		10		0.84	0.62	0.58	-	0.49	0.44	0.44	0.41	0.34	0.39	0.32	1.20	0.69	1.40	0.86	2.80	1.25
		4	550	2.32	1.96	1.87	-	1.64	1.50	1.37	1.42	1.34	1.49	1.14	3.36	2.13	3.89	2.45	6.85	3.25
		6		1.33	1.08	0.97	-	0.86	0.76	0.78	0.70	0.65	0.75	0.56	1.89	1.09	2.23	1.35	3.80	1.90
		8		0.71	0.52	0.50	-	0.42	0.36	0.33	0.32	0.30	0.33	0.27	0.98	0.56	1.22	0.76	2.33	1.04
		10		0.36	0.27	0.26	-	0.26	0.19	0.18	0.17	0.14	0.17	0.13	0.52	0.30	0.67	0.38	1.52	0.59
	Hidro-densimeter	4	-	-	0.32	0.33	-	0.30	0.29	0.29	0.26	0.25	0.29	0.26	0.46	0.36	0.52	0.42	0.69	0.48
		6		-	0.37	0.38	-	0.31	0.32	0.30	0.30	0.27	0.31	0.28	0.56	0.40	0.62	0.48	0.83	0.58
		8		-	0.32	0.32	-	0.28	0.28	0.25	0.24	0.22	0.25	0.23	0.49	0.35	0.54	0.41	0.75	0.50
		10		-	0.23	0.24	-	0.20	0.19	0.19	0.17	0.15	0.17	0.16	0.38	0.26	0.42	0.32	0.61	0.39
Moisture	Troxler	-	-	.690	.750	-	.770	.770	.730	.720	.689	.722	.660	.705	.493	.749	.525	.800	.655	.847
	Hidro-densimeter	-	-	-	3.20	3.25	3.33	3.30*	2.84*	2.33	2.08**	2.55**	1.66	2.50	0.25	2.69	0.52	3.82	1.86	6.20
	Numec	-	-	-	1.11	-	1.39	1.42	1.12	1.06	0.89	1.08	0.80	1.04	0.17	1.28	0.29	1.78	0.82	2.55

*Possible error due to standard
**Based on assumed standard count of 660

△ (Density) Wet density in lbs. per cu. ft.
◇ (H_2O) Soil water content in lbs. per cu. ft.

FIGURE 5



DENSITY CALIBRATION
TROXLER BACKSCATTER - NON COLLIMATED
ZERO AIR GAP
0-KEV
350-KEV
500-KEV
* -SOIL 2484
Δ -SOIL 2487
o -SOIL 1709
+ -SOIL 3472
◇ -SOIL 3681
▽ -SOIL 3694
COUNT RATIO = TEST COUNT / STANDARD COUNT
6.00
5.00
4.00
3.00
2.00
1.00
0
70
80
90
100
110
120
130
140
150
WET DENSITY IN POUNDS PER. CU. FT.

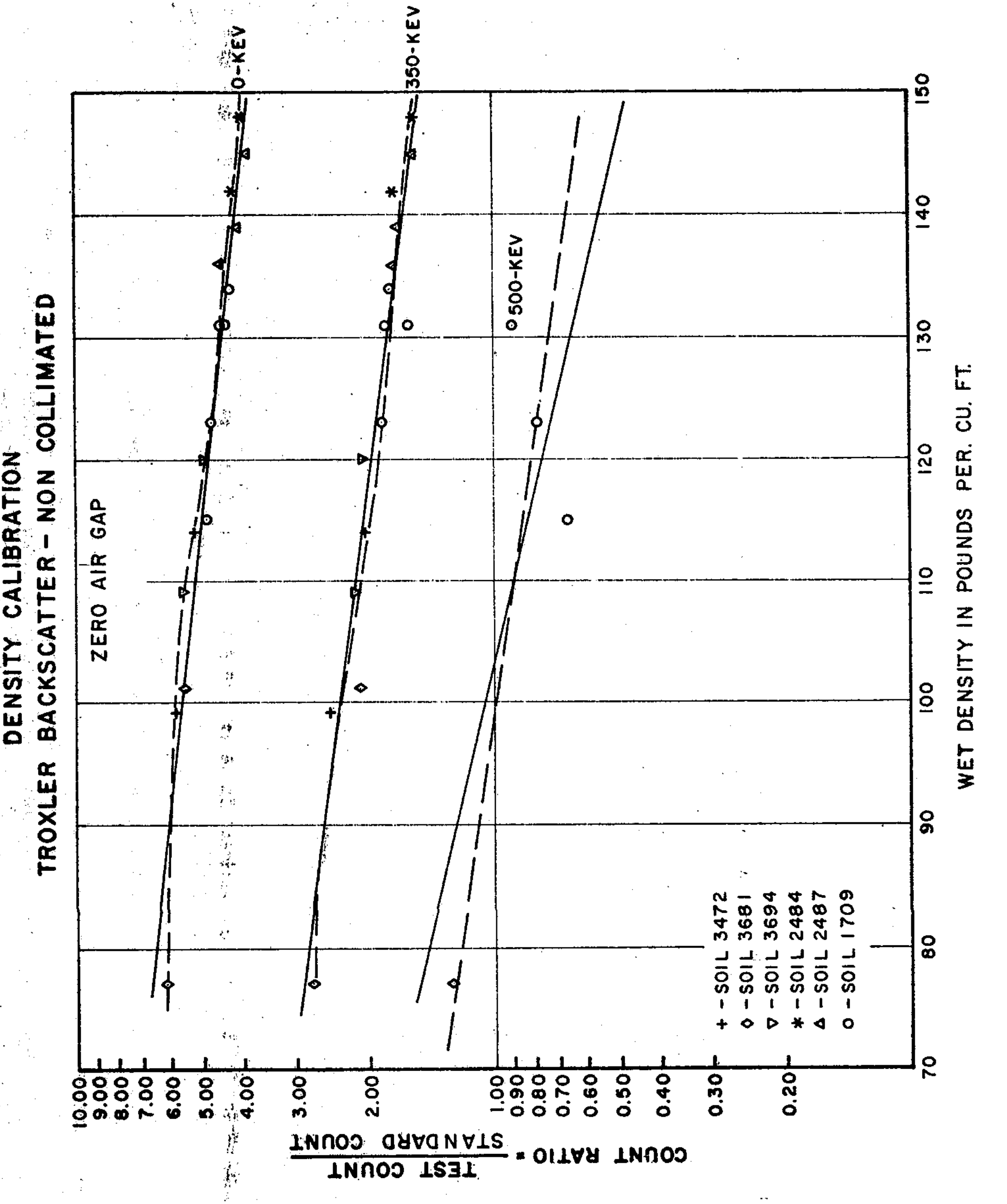

DENSITY CALIBRATION
TROXLER BACKSCATTER - NON COLLIMATED
ZERO AIR GAP
0-KEV
350-KEV
500-KEV
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
✱ - SOIL 2484
△ - SOIL 2487
○ - SOIL 1709
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

FIGURE 6

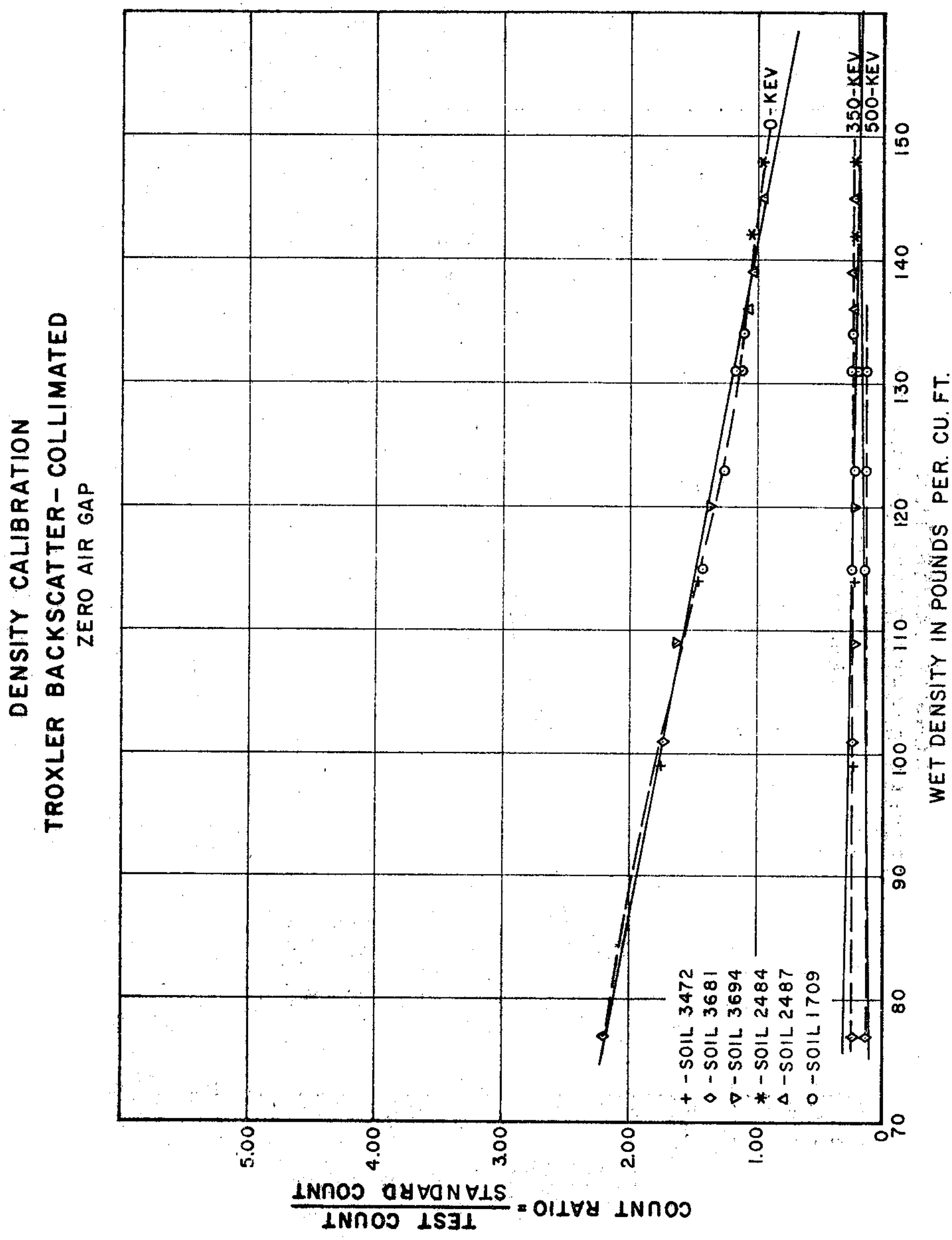

DENSITY CALIBRATION
TROXLER BACKSCATTER- COLLIMATED
ZERO AIR GAP
0-KEV
350-KEV
500-KEV
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
✱ - SOIL 2484
△ - SOIL 2487
○ - SOIL 1709
0
1.00
2.00
3.00
4.00
5.00
COUNT RATIO = TEST COUNT / STANDARD COUNT
70
80
90
100
110
120
130
140
150
WET DENSITY IN POUNDS PER. CU. FT.

FIGURE 7

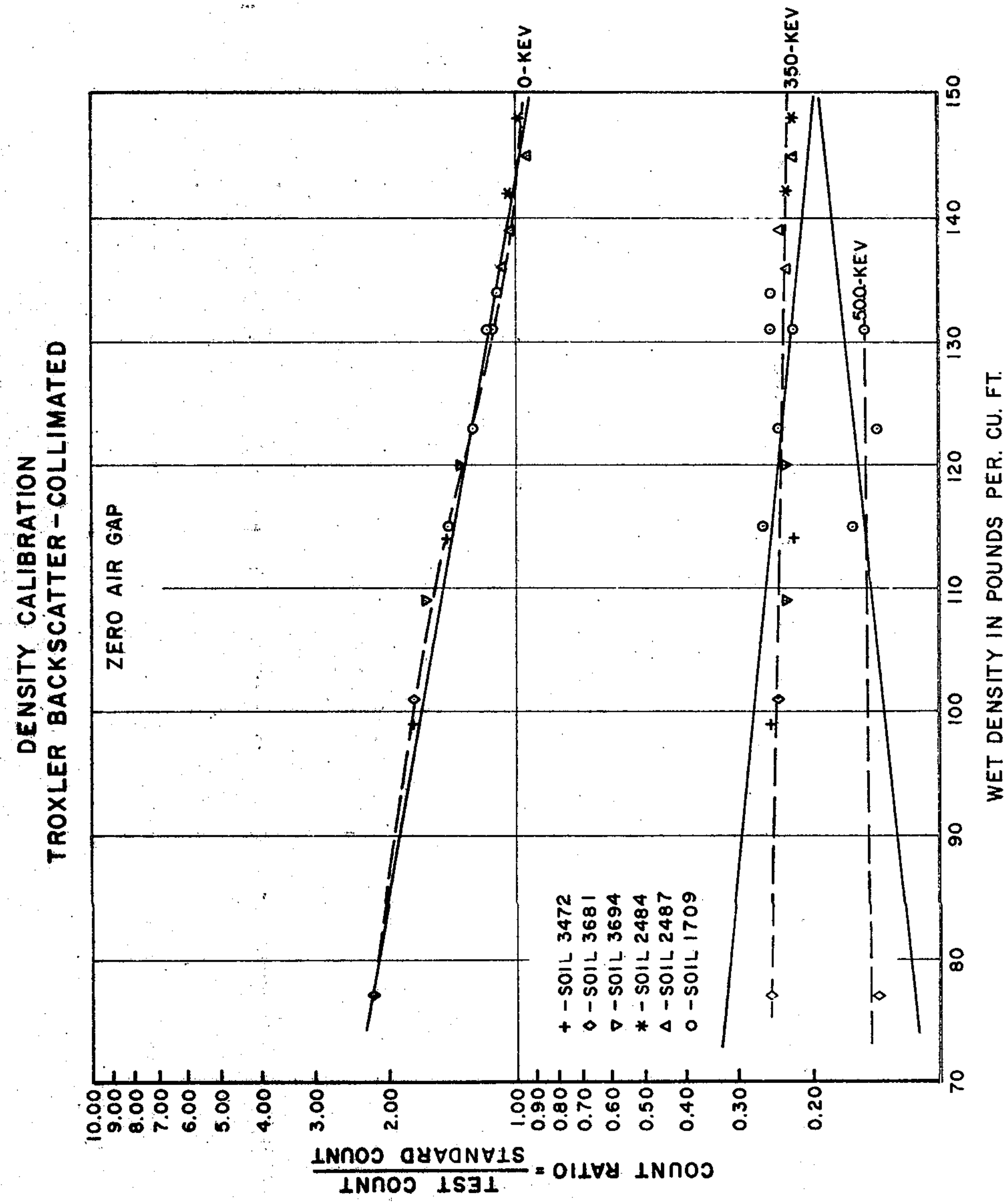

DENSITY CALIBRATION
TROXLER BACKSCATTER - COLLIMATED
ZERO AIR GAP
0-KEV
350-KEV
500-KEV
+ – SOIL 3472
◇ – SOIL 3681
▽ – SOIL 3694
✱ – SOIL 2484
△ – SOIL 2487
○ – SOIL 1709
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150

FIGURE 8

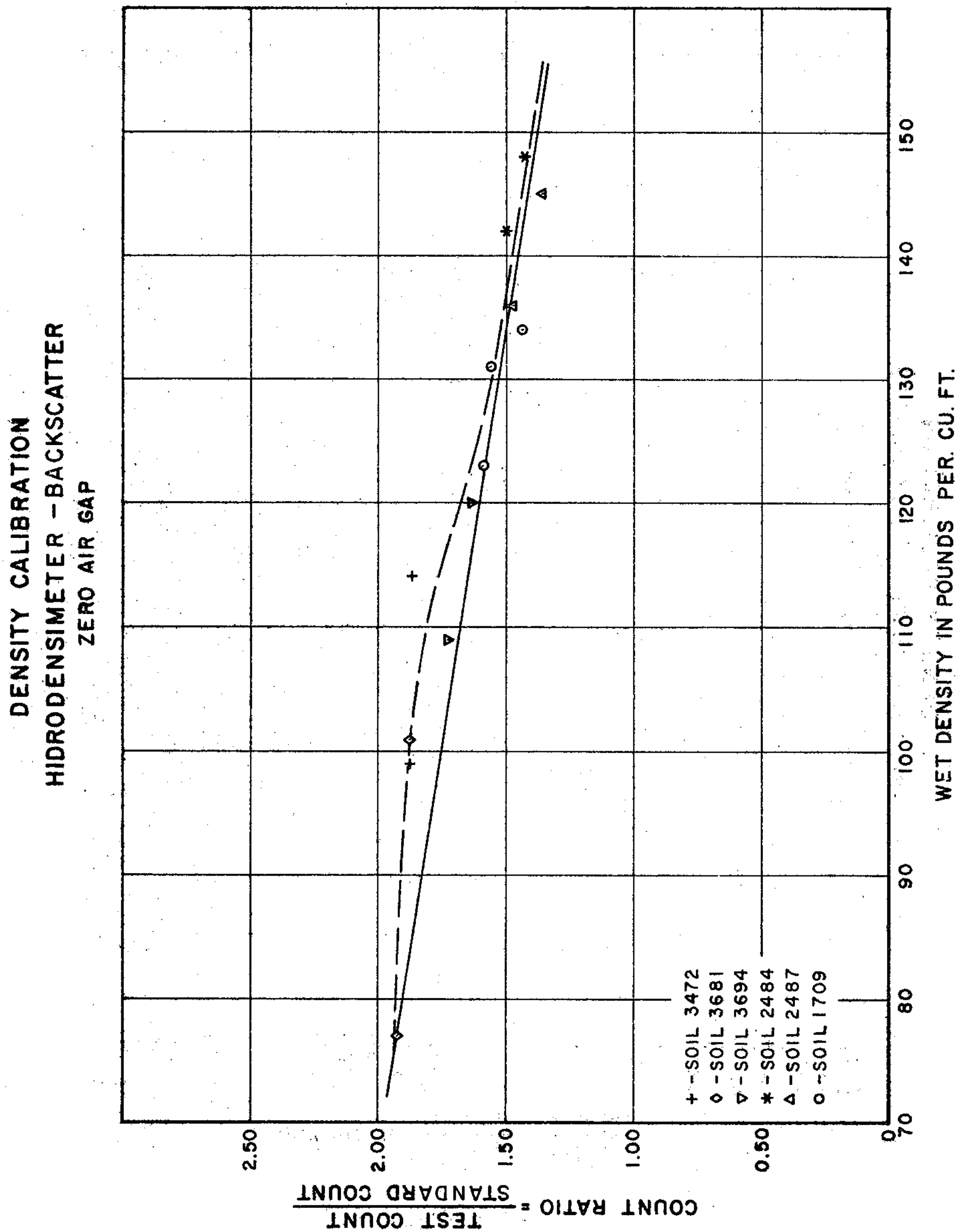

DENSITY CALIBRATION
HIDRODENSIMETER - BACKSCATTER
ZERO AIR GAP
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
0.50
1.00
1.50
2.00
2.50
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
✱ - SOIL 2484
△ - SOIL 2487
⊙ - SOIL 1709

FIGURE 9

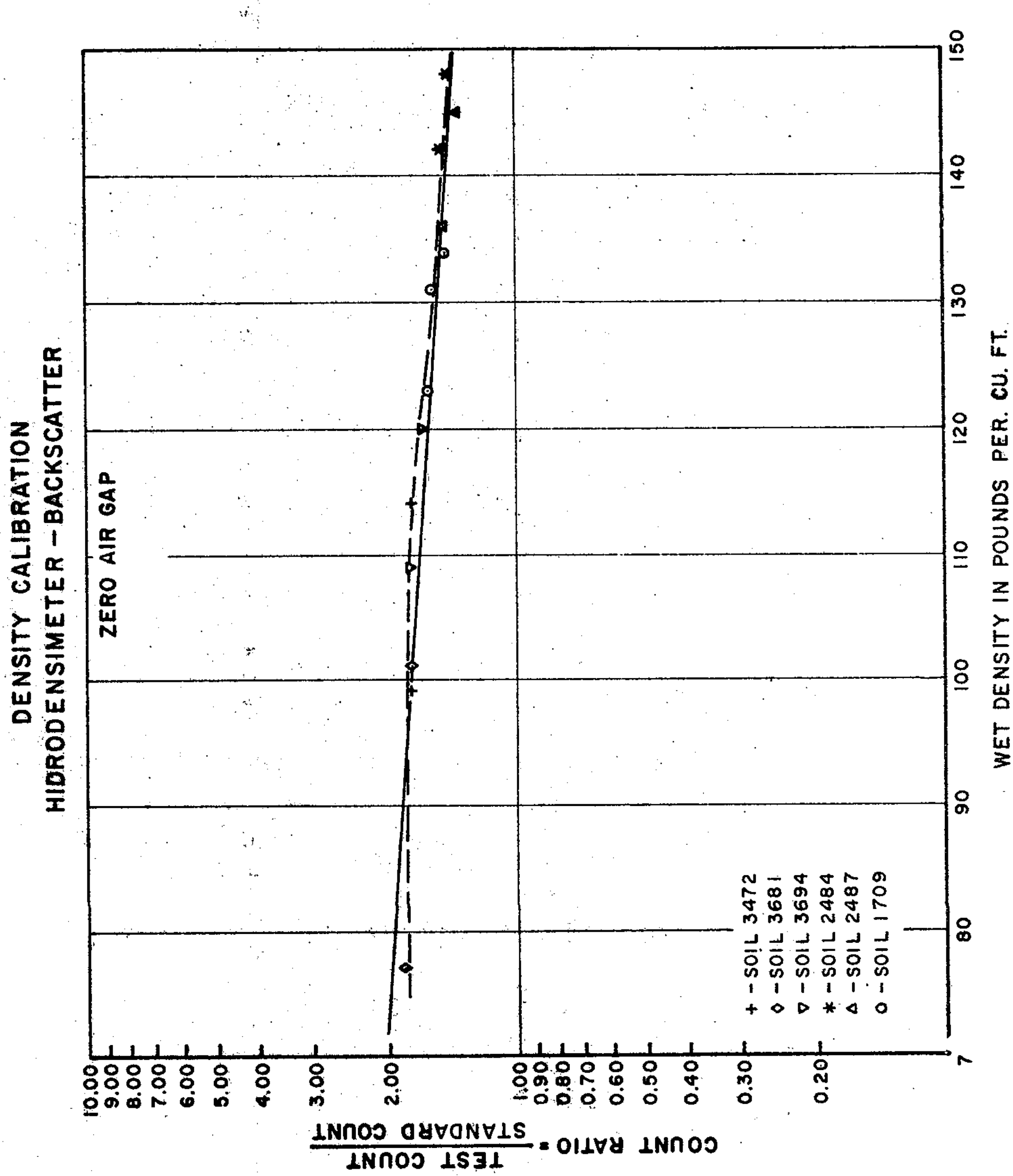

DENSITY CALIBRATION
HIDRODENSIMETER — BACKSCATTER
ZERO AIR GAP
+ — SOIL 3472
◇ — SOIL 3681
▽ — SOIL 3694
✱ — SOIL 2484
△ — SOIL 2487
○ — SOIL 1709
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

FIGURE 10

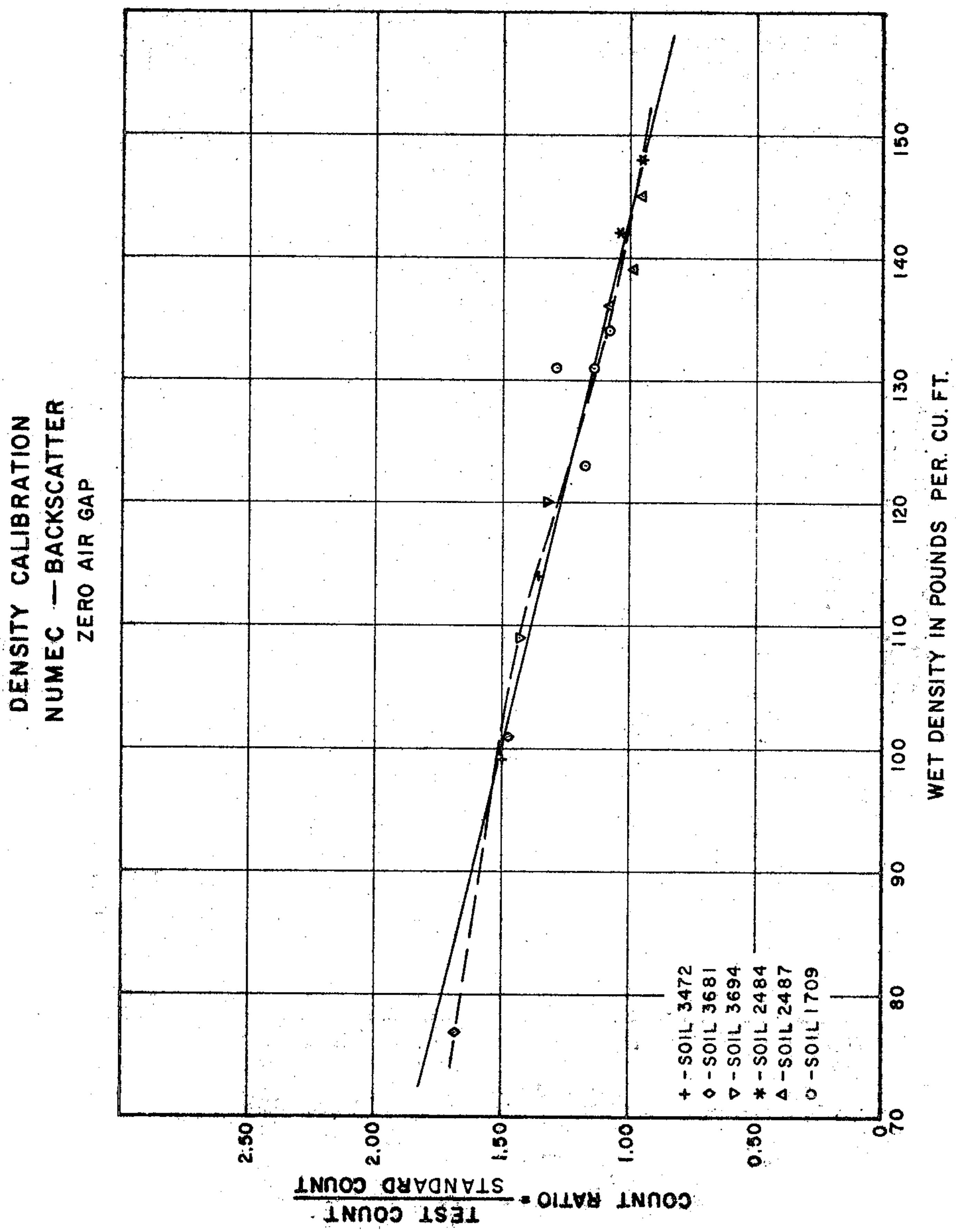

DENSITY CALIBRATION
NUMEC — BACKSCATTER
ZERO AIR GAP
WET DENSITY IN POUNDS PER CU. FT.
COUNT RATIO = TEST COUNT / STANDARD COUNT
70
80
90
100
110
120
130
140
150
0.50
1.00
1.50
2.00
2.50
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
✱ - SOIL 2484
△ - SOIL 2487
○ - SOIL 1709

FIGURE 11

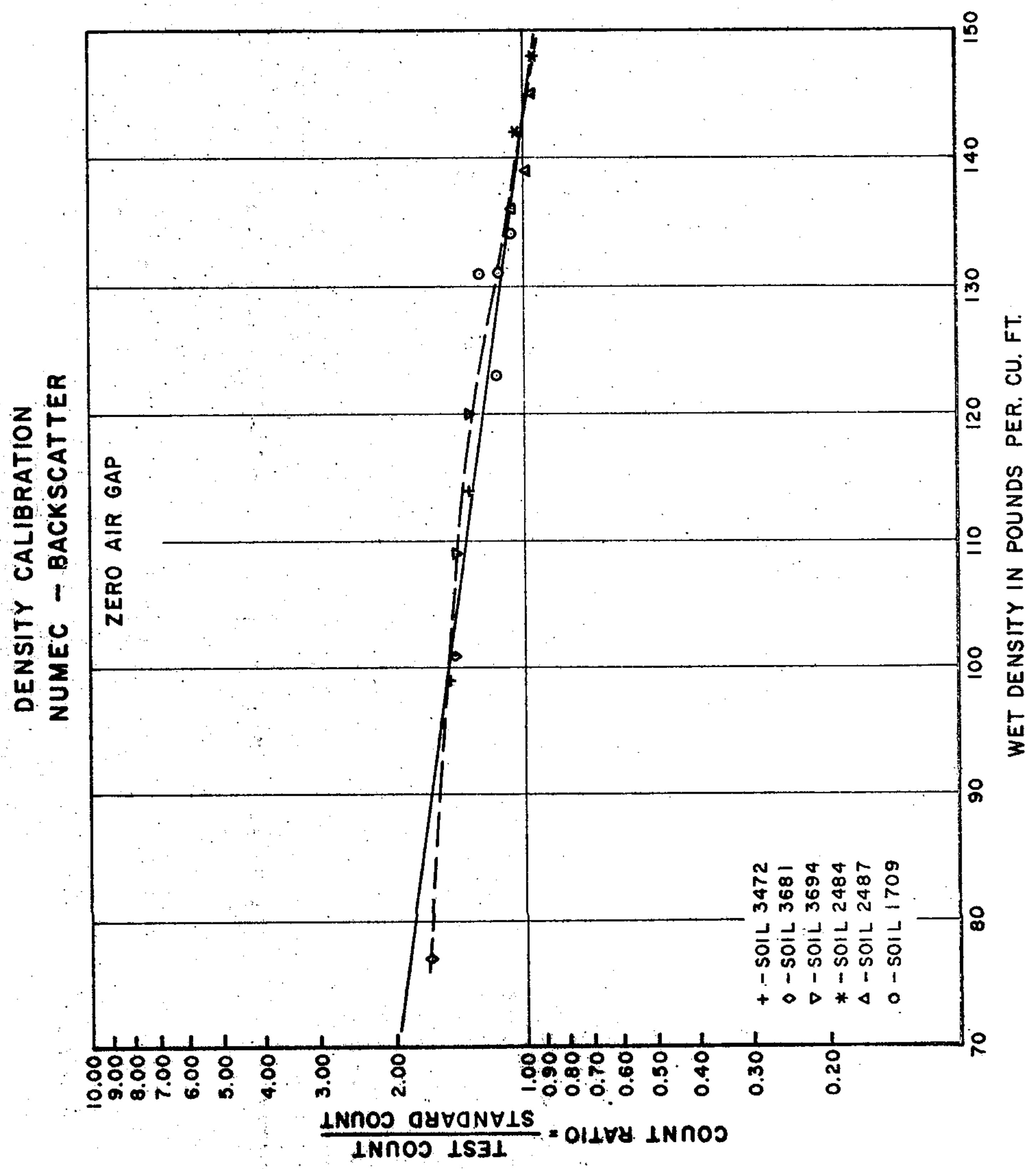

DENSITY CALIBRATION
NUMEC — BACKSCATTER
ZERO AIR GAP
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
* - SOIL 2484
△ - SOIL 2487
○ - SOIL 1709
WET DENSITY IN POUNDS PER. CU. FT.
COUNT RATIO = TEST COUNT / STANDARD COUNT
70
80
90
100
110
120
130
140
150
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

FIGURE 12

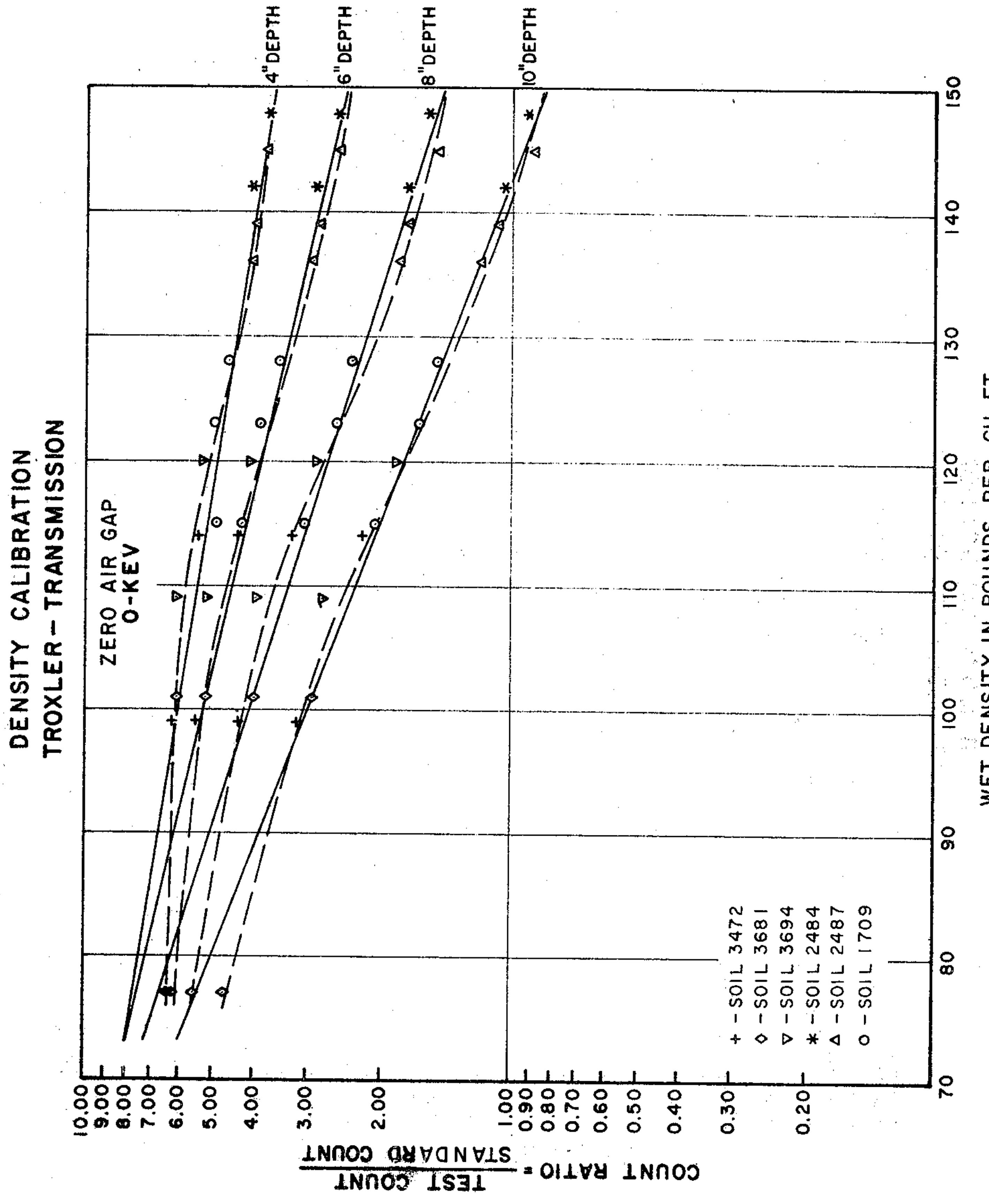
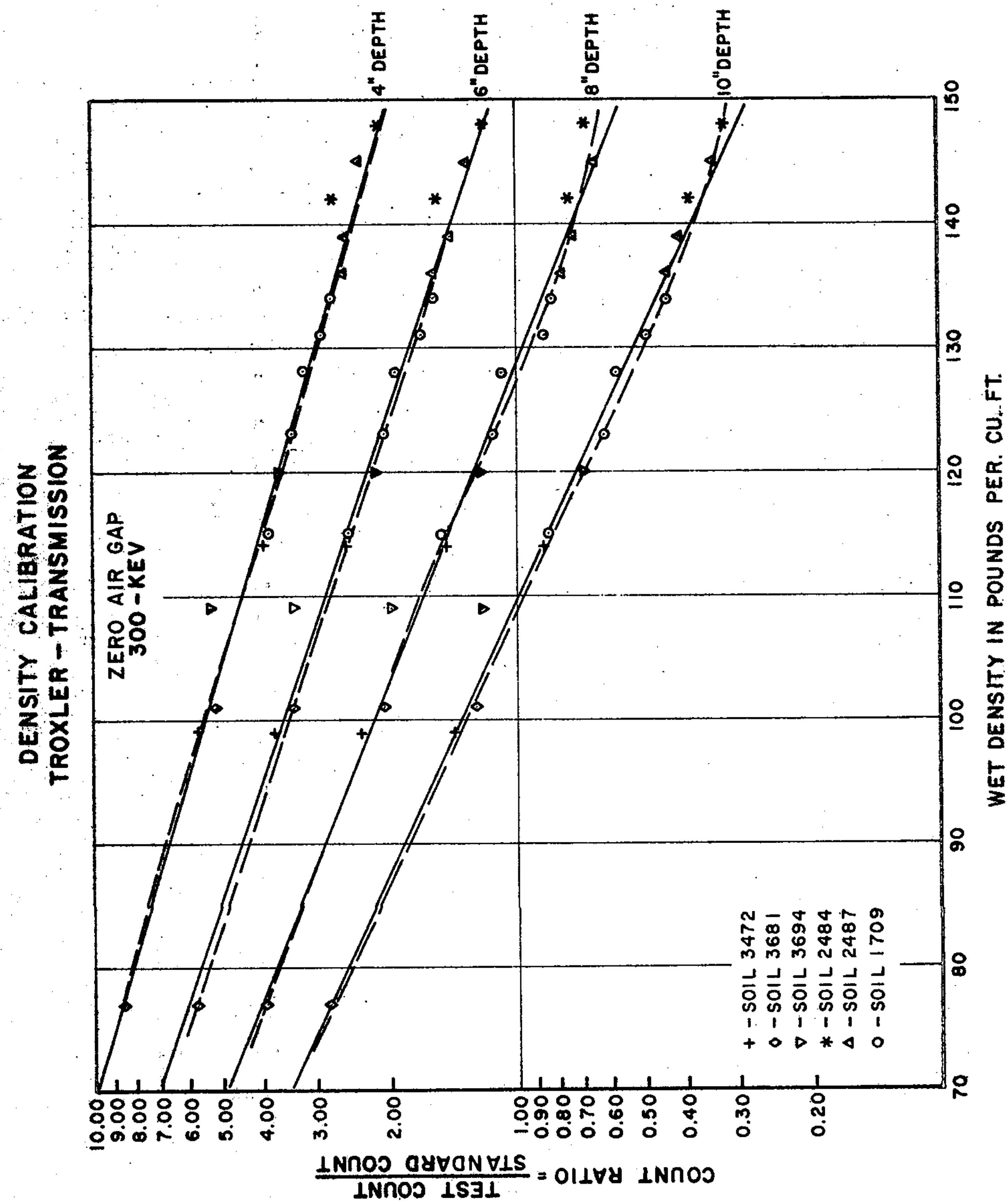

DENSITY CALIBRATION
TROXLER – TRANSMISSION
ZERO AIR GAP
O-KEV
4" DEPTH
6" DEPTH
8" DEPTH
10" DEPTH
+ – SOIL 3472
◇ – SOIL 3681
▽ – SOIL 3694
✱ – SOIL 2484
△ – SOIL 2487
○ – SOIL 1709
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

FIGURE 13



DENSITY CALIBRATION
TROXLER – TRANSMISSION
ZERO AIR GAP
300-KEV
4" DEPTH
6" DEPTH
8" DEPTH
10" DEPTH
+ – SOIL 3472
◇ – SOIL 3681
▽ – SOIL 3694
✱ – SOIL 2484
△ – SOIL 2487
⊙ – SOIL 1709
WET DENSITY IN POUNDS PER. CU. FT.
COUNT RATIO = TEST COUNT / STANDARD COUNT
70
80
90
100
110
120
130
140
150
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

FIGURE 14

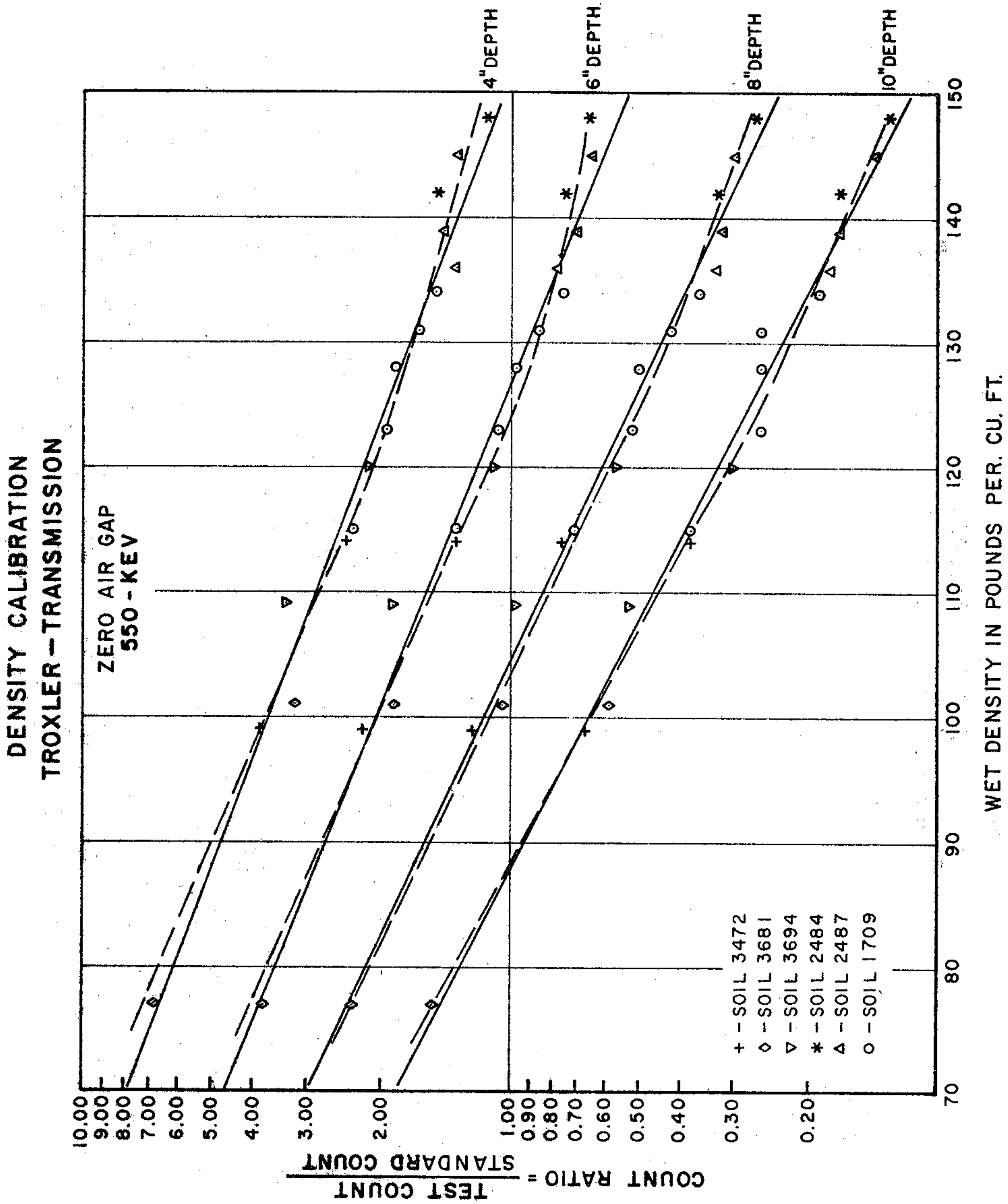

DENSITY CALIBRATION
TROXLER — TRANSMISSION
ZERO AIR GAP
550 - KEV
4" DEPTH
6" DEPTH
8" DEPTH
10" DEPTH
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
* - SOIL 2484
Δ - SOIL 2487
○ - SOIL 1709
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

FIGURE 15

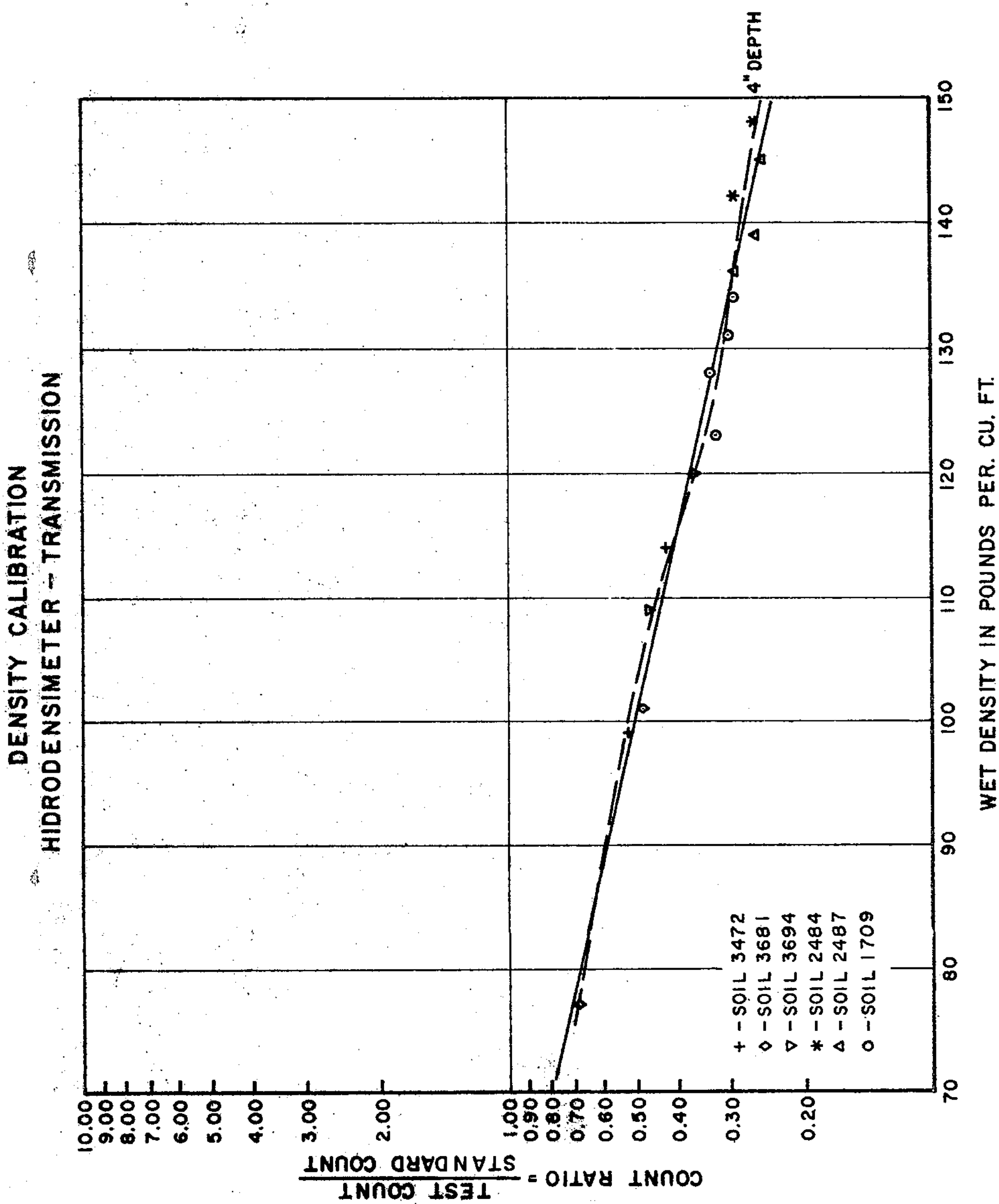

DENSITY CALIBRATION
HIDRODENSIMETER - TRANSMISSION
4" DEPTH
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
✱ - SOIL 2484
△ - SOIL 2487
o - SOIL 1709
70
80
90
100
110
120
130
140
150
WET DENSITY IN POUNDS PER. CU. FT.
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
COUNT RATIO = TEST COUNT / STANDARD COUNT

FIGURE 16

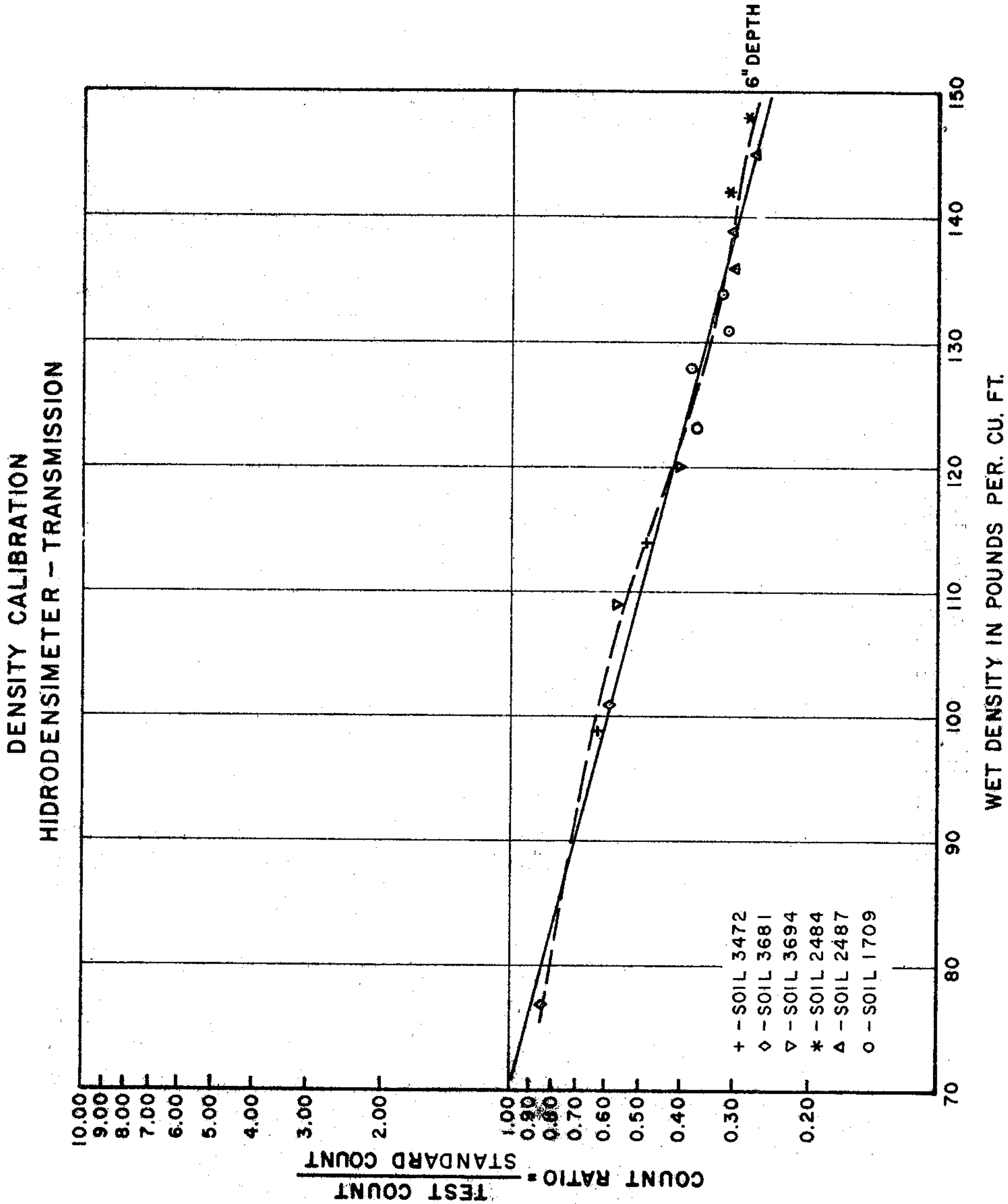

DENSITY CALIBRATION
HIDRODENSIMETER – TRANSMISSION
6" DEPTH
+ – SOIL 3472
◇ – SOIL 3681
▽ – SOIL 3694
✱ – SOIL 2484
△ – SOIL 2487
○ – SOIL 1709
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
70
80
90
100
110
120
130
140
150
WET DENSITY IN POUNDS PER. CU. FT.

FIGURE 17

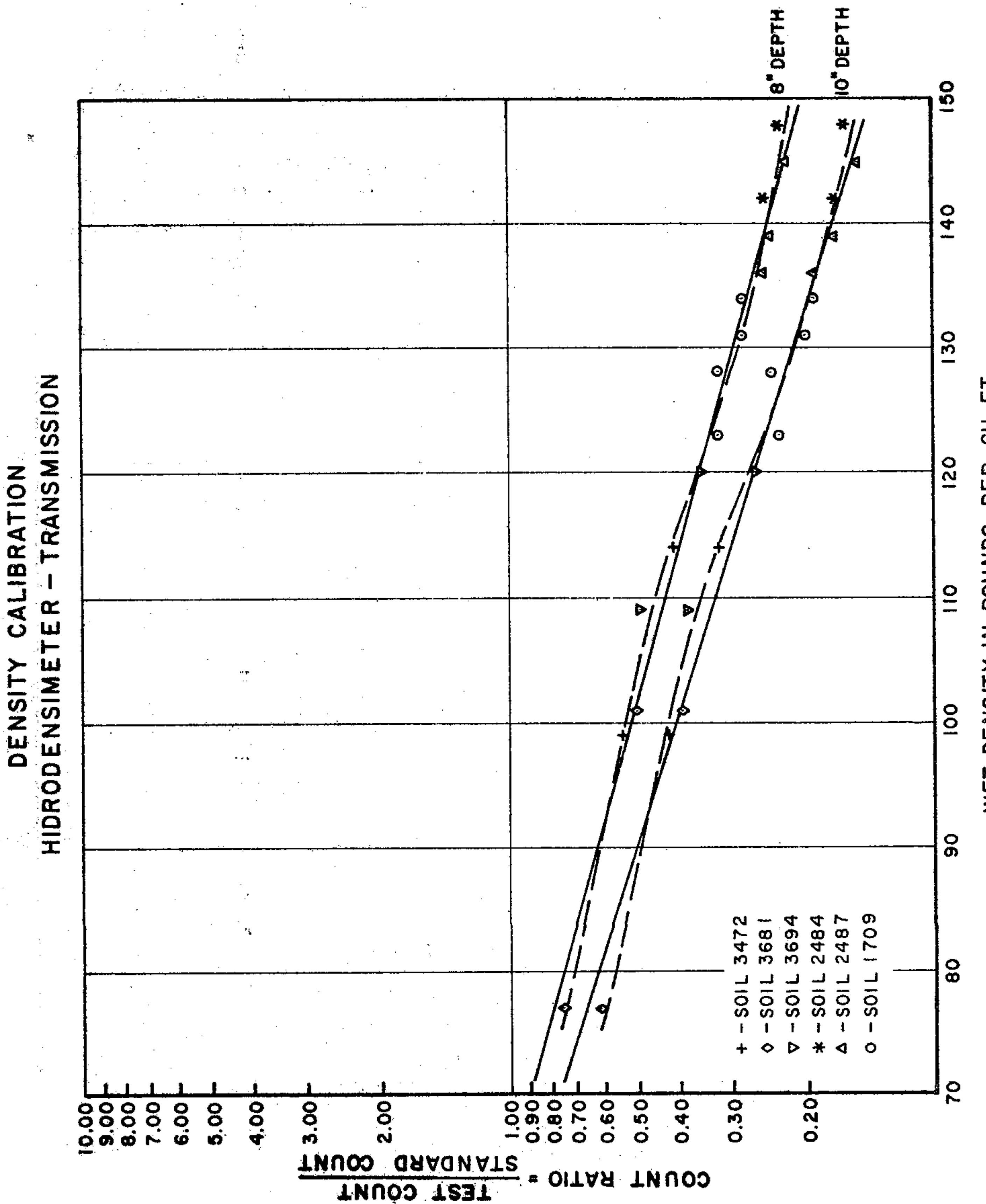

DENSITY CALIBRATION
HIDRODENSIMETER – TRANSMISSION
WET DENSITY IN POUNDS PER. CU. FT.
70
80
90
100
110
120
130
140
150
COUNT RATIO = TEST COUNT / STANDARD COUNT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
8" DEPTH
10" DEPTH
+ – SOIL 3472
◇ – SOIL 3681
▽ – SOIL 3694
✱ – SOIL 2484
△ – SOIL 2487
○ – SOIL 1709

FIGURE 18

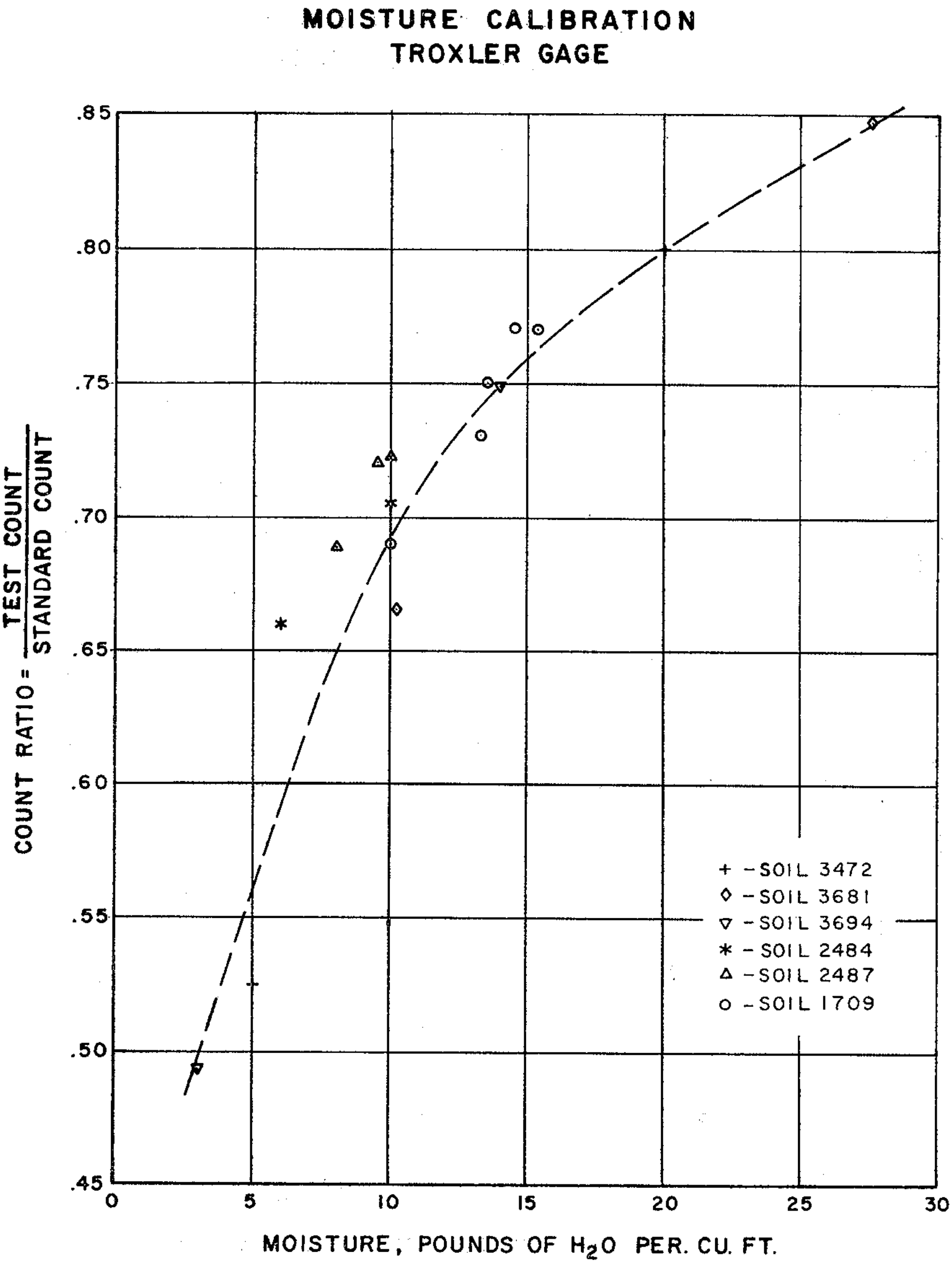

MOISTURE CALIBRATION
TROXLER GAGE
COUNT RATIO = TEST COUNT / STANDARD COUNT
.85
.80
.75
.70
.65
.60
.55
.50
.45
0
5
10
15
20
25
30
MOISTURE, POUNDS OF H_2O PER. CU. FT.
+ -SOIL 3472
◇ -SOIL 3681
▽ -SOIL 3694
✱ -SOIL 2484
△ -SOIL 2487
○ -SOIL 1709

FIGURE 19

MOISTURE CALIBRATION
HIDRODENSIMETER GAGE

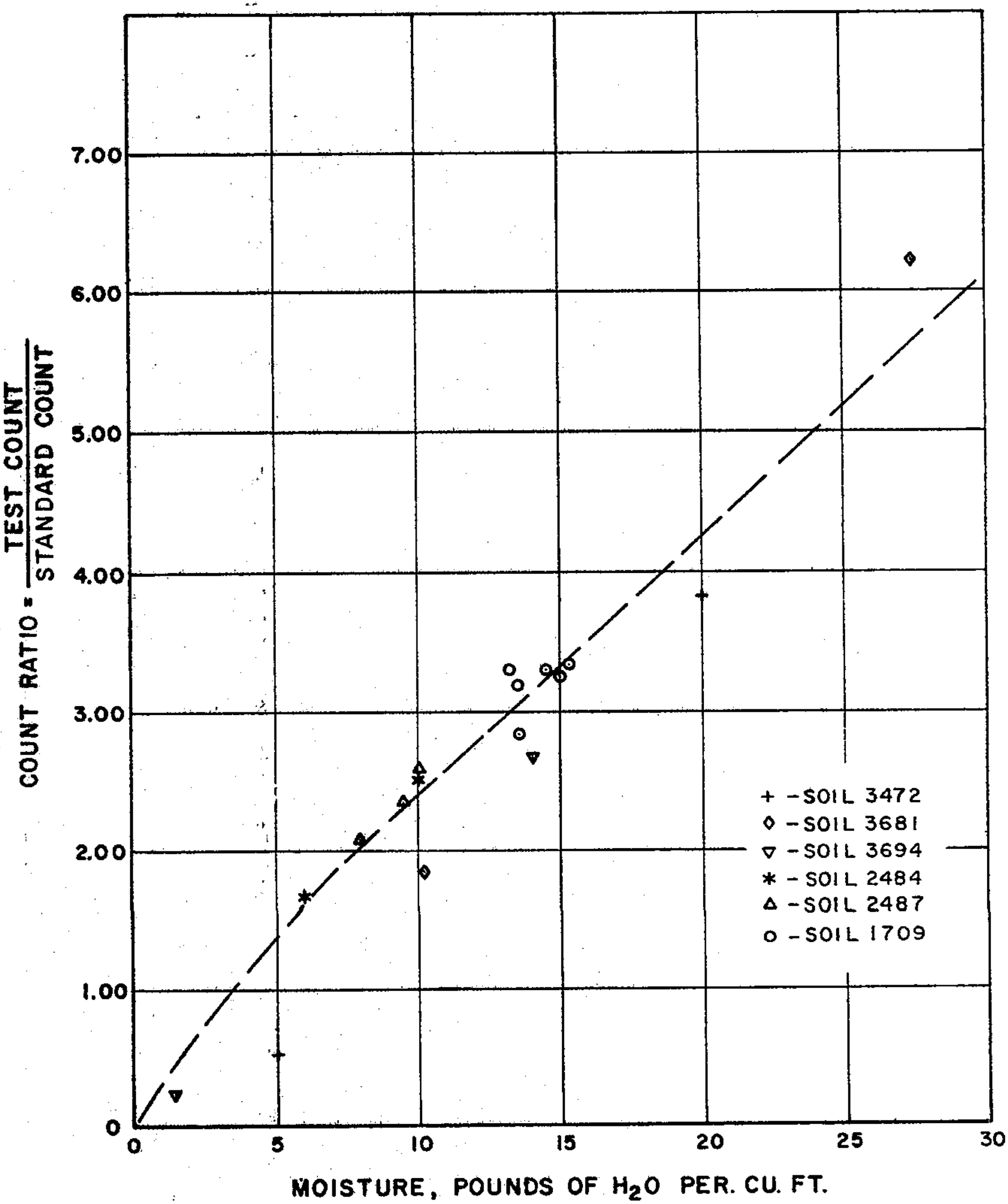


FIGURE 20

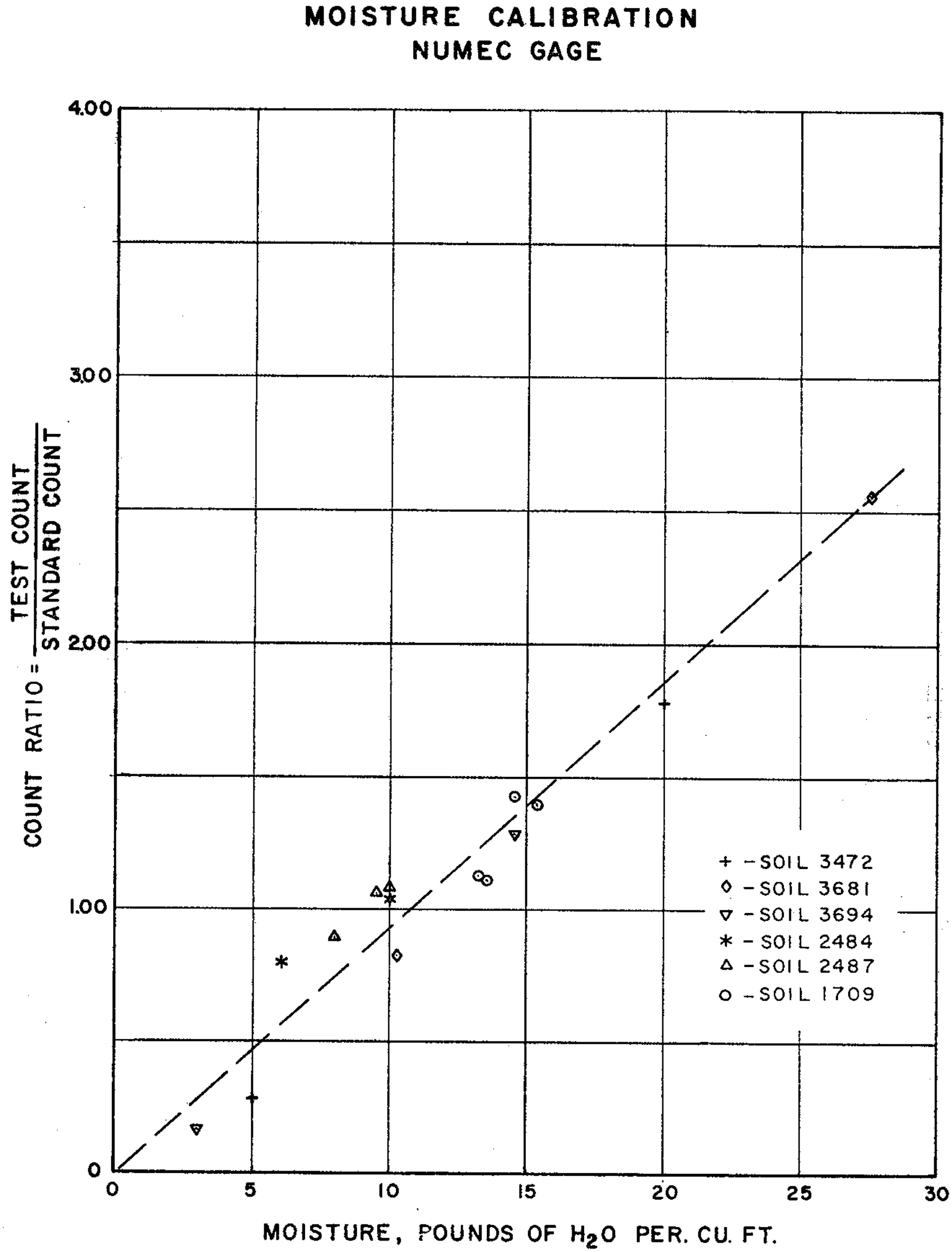

MOISTURE CALIBRATION
NUMEC GAGE
4.00
3.00
2.00
1.00
0
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
5
10
15
20
25
30
MOISTURE, POUNDS OF H_2O PER. CU. FT.
+ - SOIL 3472
◇ - SOIL 3681
▽ - SOIL 3694
* - SOIL 2484
△ - SOIL 2487
○ - SOIL 1709

FIGURE 21

TABLE 8

Tabulation of Regression Analysis Data for Calibration Curves (Wet Density vs. Count Ratio "R")

Backscatter

Instrument	KEV	Source Position	A_o	A_1	Standard Deviation	Sample Size	Corr. Coeff.	Est. Std. Error (1)
* Troxler	0	0	256.0	--27.7	4.46	16	0.975	4.5
	350	0	230.6	- 55.8	5.94	15	0.993	7.2
	500	0	176.2	- 71.7	17.34	4	0.806	-
	0	-3/4"	196.1	- 54.8	2.39	16	0.993	1.9
	350	-3/4"	274.6	-641.1	18.33	16	0.412	-
	500	-3/4"	- 30.6	963.6	27.02	4	0.386	-
Hidrodensimeter			333.7	-132.9	13.8	13	0.945	6.4
Numec			229.3	- 86.2	4.72	15	0.974	4.1
** Troxler	0	0	333.8	-135.3	4.97	16	0.961	4.8
	350	0	196.7	-114.5	5.89	15	0.959	7.5
	500	0	103.0	- 63.5	19.44	4	0.748	-
	0	-3/4"	143.2	- 78.3	2.46	16	0.993	2.0
	350	-3/4"	96.3	-151.9	18.34	16	0.411	-
	500	-3/4"	393.0	146.9	26.91	4	0.394	-
Hidrodensimeter			218.4	-208.7	7.70	13	0.936	7.5
Numec			143.8	-106.5	5.75	15	0.961	4.1

* $\gamma Wet = A_o + A_1 R$

** $\gamma Wet = A_o + A_1 \ln R$

(1) Estimated standard error of estimate from calibration curve drawn to best visual fit.

TABLE 9

Tabulation of Regression Analysis Data for Calibration Curves (Wet Density vs. Count Ratio "R")

Transmission

Instrument	KEV	Depth of Measurement	A_o	A_1	Standard Deviation	Sample Size	Corr. Coeff.	Est. Std. Error (1)
** Troxler	0	4	274.8	- 96.5	6.33	14	0.954	1.9
	0	6	209.6	-65.6	4.30	14	0.979	2.4
	0	8	167.8	- 47.8	3.70	14	0.985	2.3
	0	10	142.9	- 38.7	2.52	14	0.993	1.5
	300	4	185.6	- 50.2	3.01	16	0.989	2.9
	300	6	155.7	- 43.6	2.65	16	0.991	2.5
	300	8	129.0	- 36.8	2.74	16	0.991	2.2
	300	10	109.8	- 31.9	1.91	16	0.995	1.8
	550	4	152.1	- 39.9	3.28	16	0.987	3.0
	550	6	126.6	- 36.9	2.42	16	0.993	2.6
	550	8	104.6	- 31.6	2.34	16	0.993	1.8
	550	10	87.6	- 29.0	2.25	16	0.994	2.5
Hidrodensimer		4	54.5	- 65.6	3.13	15	0.985	3.8
		6	70.1	- 57.3	3.71	15	0.984	3.6
		8	64.9	- 53.7	2.49	15	0.989	2.4
		10	57.7	- 47.0	3.02	15	0.989	2.7

* $\gamma Wet = A_o + A_1 R$
** $\gamma Wet = A_o + A_1 \ln R$

(1) Estimated standard error of estimate from calibration curve drawn to best visual fit.

TABLE NO. 10

Tabulation of Standard Deviations
From Moisture Calibration Curves

(Moisture Content in Pounds Per Cubic Foot vs Count Ratio "R")

Instrument	Estimated Standard Deviation	Sample Size
Troxler	1.4	16
Hidrodensimeter	1.7	17
Numec	1.5	15

TABLE NO. 11

SLOPE OF CALIBRATION CURVES
(From 100 to 150 pounds per cubic foot)

Backscatter

Gage	KEV	Source Position	Slope
Troxler	0	0	0.036
	350	0	0.018
	500	0	0.015
	0	-3/4	0.018
	350	-3/4	0.001
	500	-3/4	0.000
Hidrodensimeter			0.009
Numec			0.012

Transmission

Gage	KEV	Depth	Slope
Troxler	0	4	0.048
	0	6	0.054
	0	8	0.052
	0	10	0.044
	300	4	0.064
	300	6	0.050
	300	8	0.031
	300	10	0.020
	550	4	0.056
	550	6	0.030
	550	8	0.018
	550	10	0.010
Hidrodensimeter		4	0.005
		6	0.007
		8	0.006
		10	0.006

The calibration curves using air gap method are given in Figures 22 thru 26. The air gap ratio method uses the reading at optimum air gap divided by the surface reading at optimum air gap divided by the surface reading as an index of the density.

The slope of the calibration curves is positive, that is, the ratio increases with an increase in density. The use of discrimination did not alter the slope of the calibration curves with the Troxler gage. During the testing program it was apparent that the air gap method did not overcome some of the deficiencies in the backscatter type measurements. Therefore, the obtaining of data for the air gap calibration curves was discontinued.

A review of the data presented in the surface roughness section indicates that the air gap readings are constant insofar as density is concerned, particularly Figure 42. The actual density determination is therefore done with the surface reading. This explains the "reverse slope" of the air gap ratio calibration curves. As the surface count decreases with an increase in density, the denominator in the air gap ratio becomes smaller, and the resulting ratio increases with an increase in density.

In a practical sense it means that the density determination by the air gap ratio method can only be as good as the surface reading, consequently, any uncertainty in the reading with air gap increases the probability of error in an estimate of density using this method.

The conclusion is that the use of a deliberate air gap, either by itself or in conjunction with a surface reading, is not an aid in reducing the effect of an irregular surface. The original reason for utilizing the air gap method was to eliminate the chemical composition effect of the soil being measured, and the air gap method appears to accomplish this purpose. This does not mean that a test cannot be developed using an air gap, but all things equal; the test with air gap will be affected more by surface roughness than will the same test without.

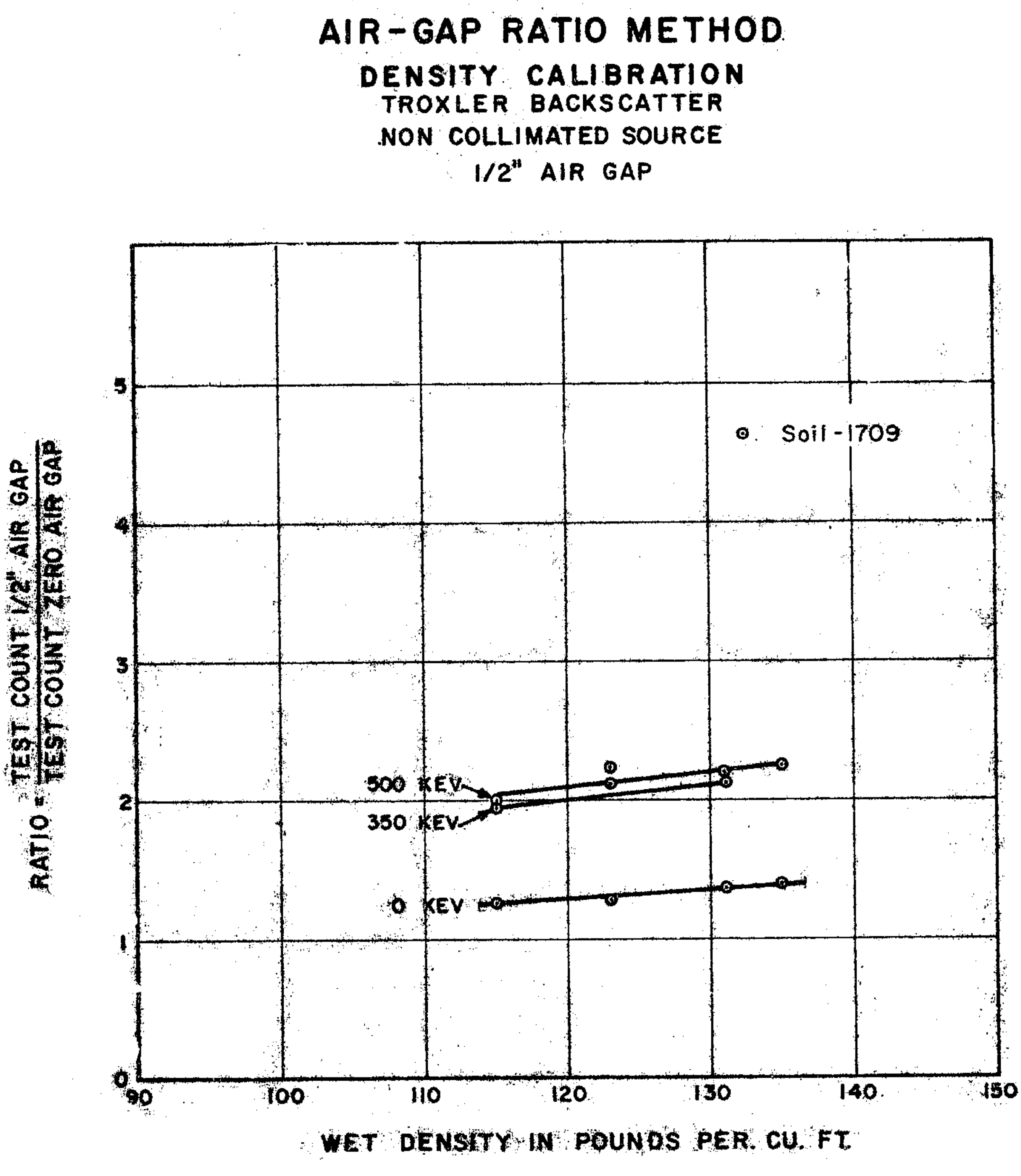

AIR-GAP RATIO METHOD
DENSITY CALIBRATION
TROXLER BACKSCATTER
NON COLLIMATED SOURCE
1/2" AIR GAP
Soil-1709
500 KEV
350 KEV
0 KEV
RATIO = TEST COUNT 1/2" AIR GAP / TEST COUNT ZERO AIR GAP
WET DENSITY IN POUNDS PER. CU. FT.
0
1
2
3
4
5
90
100
110
120
130
140
150

FIGURE 22

AIR-GAP RATIO METHOD

DENSITY CALIBRATION

TROXLER BACKSCATTER
COLLIMATED SOURCE
1/2" AIR GAP

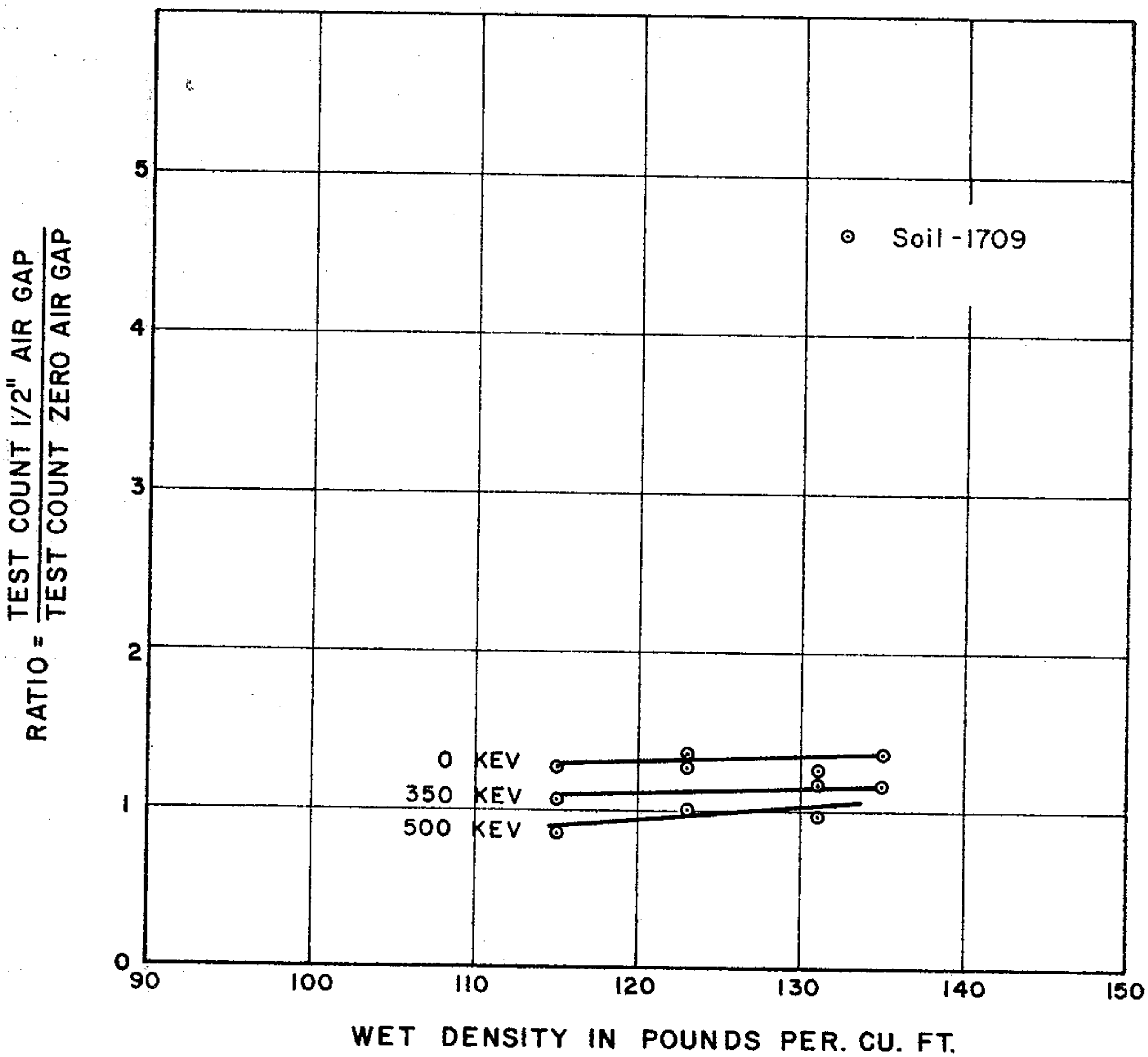


FIGURE 23

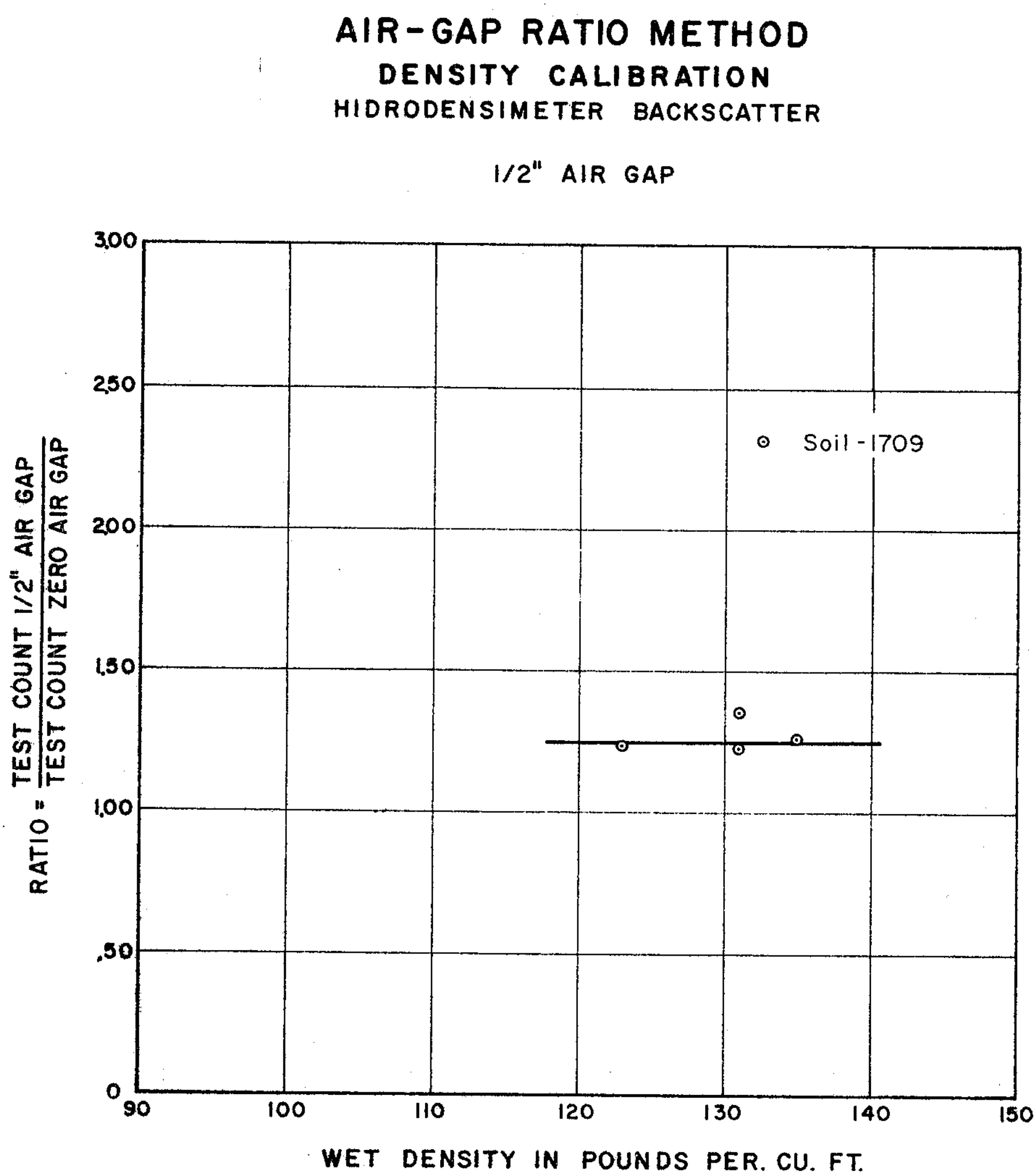

AIR-GAP RATIO METHOD
DENSITY CALIBRATION
HIDRODENSIMETER BACKSCATTER
1/2" AIR GAP
Soil - 1709
3.00
2.50
2.00
1.50
1.00
.50
0
90
100
110
120
130
140
150
RATIO = TEST COUNT 1/2" AIR GAP / TEST COUNT ZERO AIR GAP
WET DENSITY IN POUNDS PER. CU. FT.

FIGURE 24

AIR-GAP RATIO METHOD
DENSITY CALIBRATION
NUMEC BACKSCATTER

1/2" AIR GAP

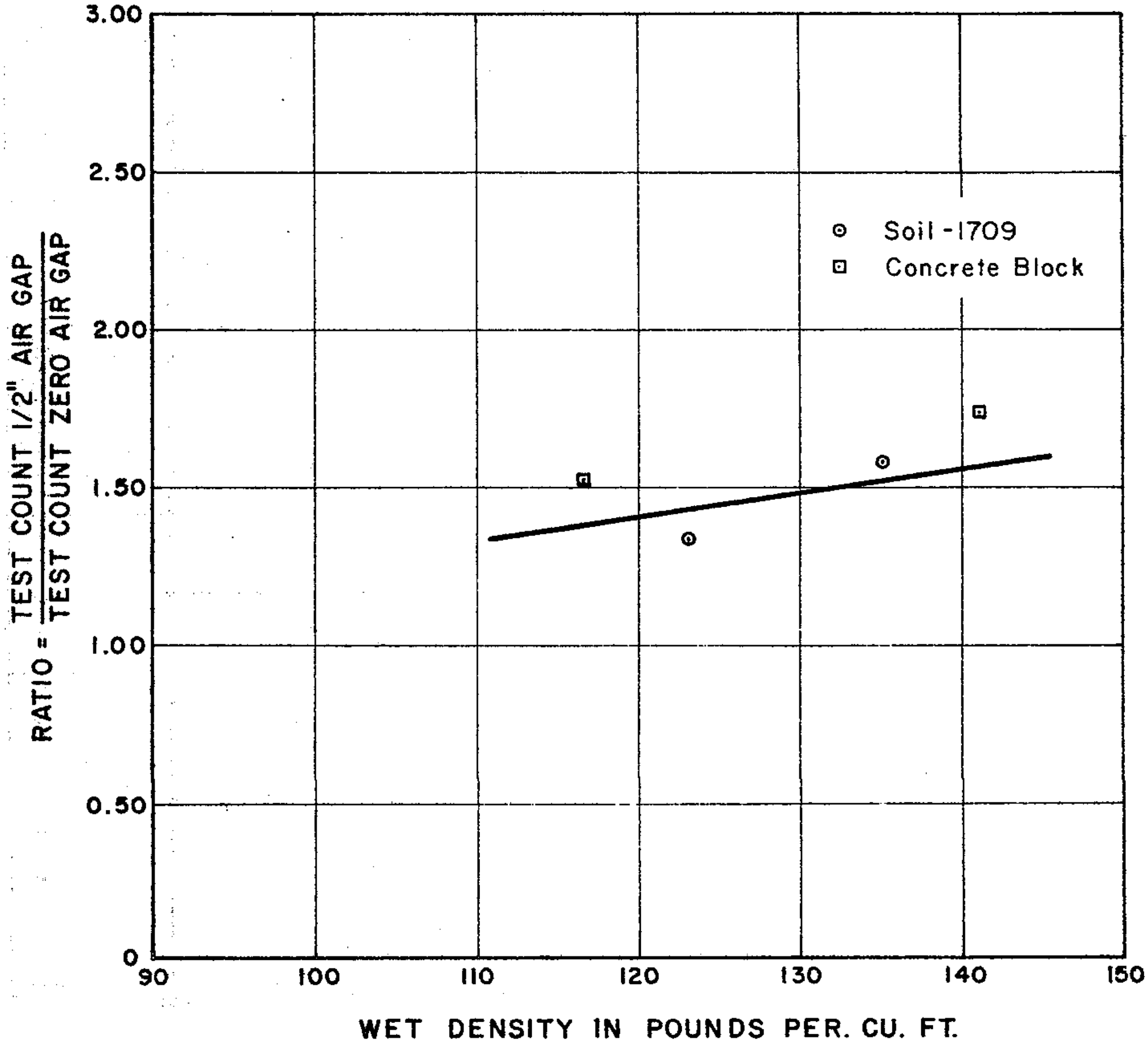


FIGURE 25

SURFACE ROUGHNESS STUDIES

A portion of this project was to determine the effect of surface roughness on nuclear moisture and density measurements, and how this affect can be alleviated. For this purpose various degrees and amounts of surface roughness were formed on the fine grained South Sacramento soil at three densities, 115, 123, and 134 pounds per cubic foot.

The roughness studies required an artificial roughness that could be duplicated and extended both in degree and amount. The procedure was to lay out a diagonal pattern of grooves 1/2 inch on center. These diagonal grooves were varied in depth, and later a diamond or cross hatched grid was produced by adding a second set of similarly spaced grooves perpendicular to the first set.

It was necessary to know the possible effect of varying the position of the source in relation to the grooves. See Table 11a. The difference in count ratios obtained with various source positions indicate density variations of less than 1.5 lb. pe cu. ft. could be expected. This effect of source position was therefore considered negligible. Random positioning of the source insofar as the grooves are concerned was then permitted for the roughness studies.

The question arose as to whether the source end or the pick-up end of the probe was the more sensitive to surface roughness. Consequently one-half of the surface of the 134 lbs. per cu. ft. soil was roughened with the 1/8" grooves in the cross hatched pattern. The gage was placed with the edge of the roughened surface about half way between the source and pick-up. The gage was then turned so that alternately both the source and the pick-up were over the roughened surface. (Photo 17). Those readings obtained may be found in Table 12.

Although the data is inconclusive, it may be tentatively surmised that for the non-collimated backscatter test, the source over a partially rough surface will give a slightly higher reading than if the position is reversed. The collimated test does not appear to be sensitive to partial roughness as tested.

TABLE 11 A

Compton Backscatter
Check on Source Position in
Relation to Specimen Grooves

Troxler Probe **Specimen 64-1709-2**

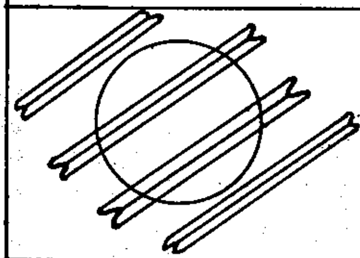
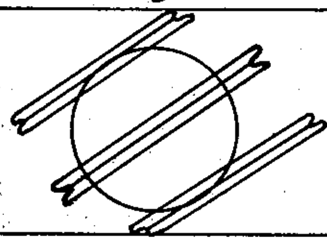
Source Position In Relation To Grooves	Probe Position	Count Ratio-Standard Position		
		0 KEV	350 KEV	500 KEV
	-3/4"	1.466	0.283	0.152
	0	4.953	1.966	0.809
	-3/4"	1.456	0.280	0.150
	0	4.996	1.991	0.834
Random	-3/4"	1.460	0.284	0.152
	0	4.950	1.970	0.809

TABLE 12

Orientation of Instruments with Respect
to a Partially Rough Surface
Backscatter, Zero Air Gap
South Sacramento Soil, 134 lbs. per cu. ft.

			Count Ratio			
				1/2 of Surface 1/8" Cross Hatch		All of Surface 1"/8 Cross Hatch
Instrument	KEV	Probe Position	Smooth	Source Over Rough	Detector Over Rough	
Troxler	0	-3/4"	1.11	1.11	1.12	1.10
	350	-3/4"	0.25	0.22	0.23	0.23
	0	0	4.30	4.45	4.33	4.32
	350	0	1.78	1.79	1.62	1.88
Hidro-densimeter		0	1.44	1.02	1.03	1.48
Numec		-	1.08	1.10	1.07	1.10

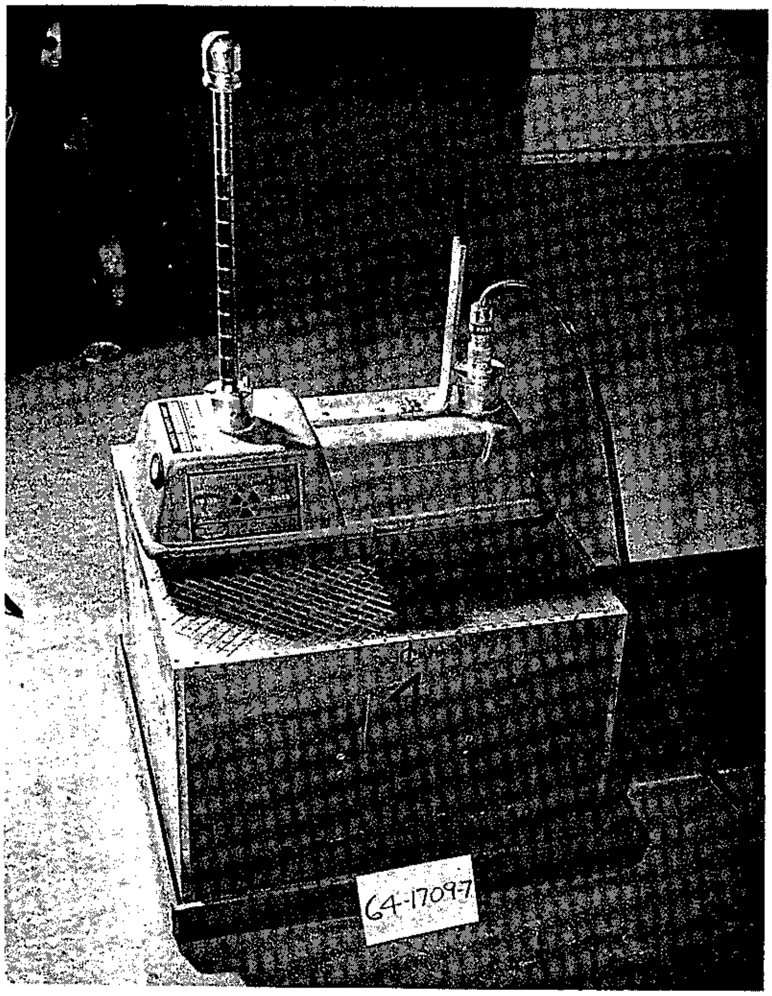


PHOTO 17, Illustration of Partial Roughness Study.

The effect of varying the discriminator setting of backscatter gages without an air gap, upon surface roughness is shown in Figures 26, 27, and 28. The noncollimated source type gages showed a constant change in count ratio due to surface roughness for the three densities of soils tested at all discriminator settings. This indicates that the effect of surface roughness is approximately equal at all discriminator settings. An interesting item also shown on these plots is that all degrees of surface roughness had about the same effect upon the nuclear readings. This would indicate that with the noncollimated backscatter type gage a slightly rough surface will result in almost as large an error in the nuclear reading as with a very rough surface.

The collimated source data showed only a slight effect upon the nuclear readings occurred with the rough surfaces compared to the smooth surface. This occurred at all discriminator settings. This data indicates that the collimated test is appreciably less sensitive to surface roughness than the noncollimated type.

TROXLER BACKSCATTER
SURFACE ROUGHNESS STUDY
SOUTH SACRAMENTO SOIL 115 LBS. PER CU. FT.

0 AIR GAP

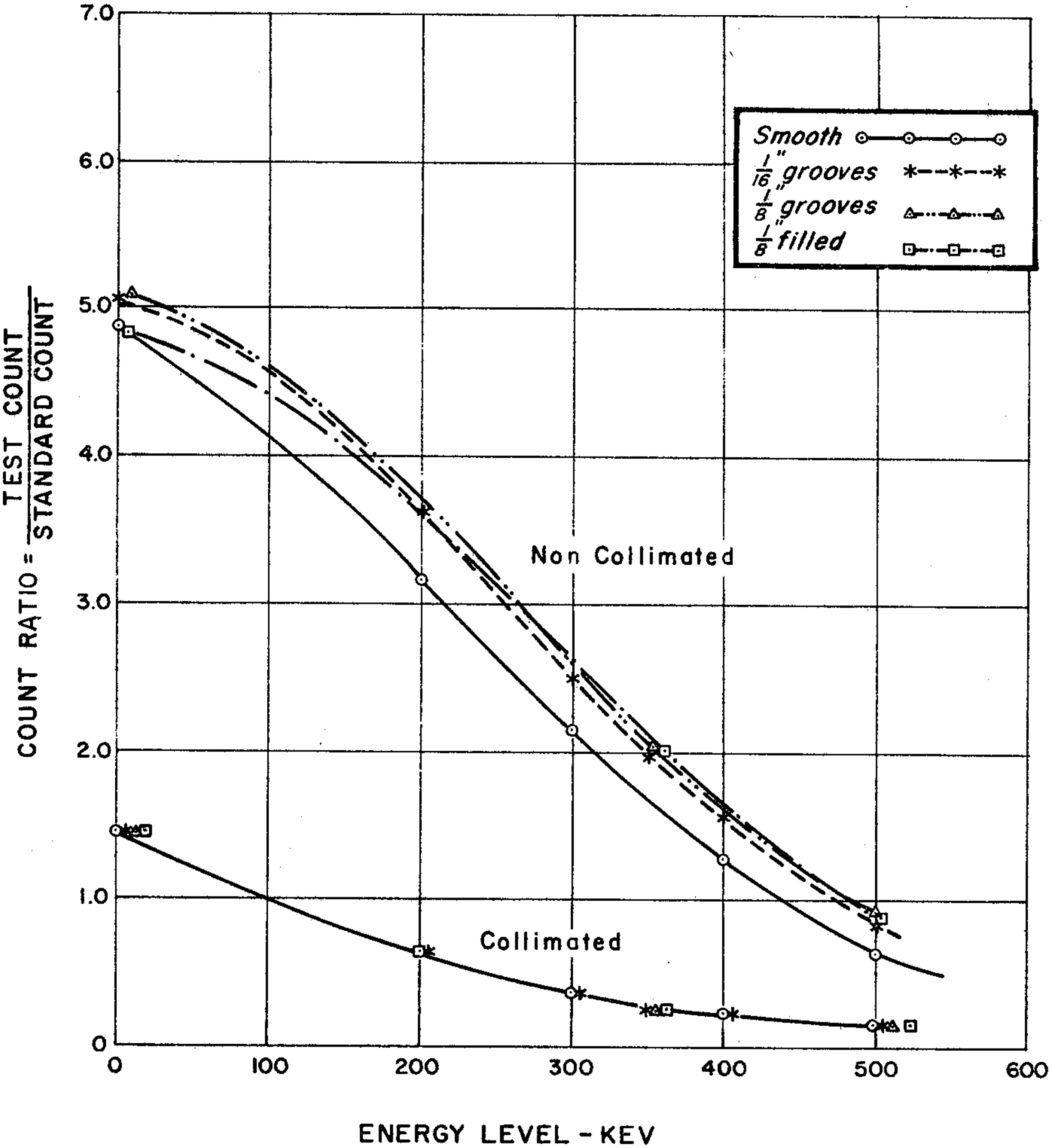


FIGURE 26

TROXLER BACKSCATTER
SURFACE ROUGHNESS STUDY
SOUTH SACRAMENTO SOIL 123 LBS. PER CU. FT.

O AIR GAP

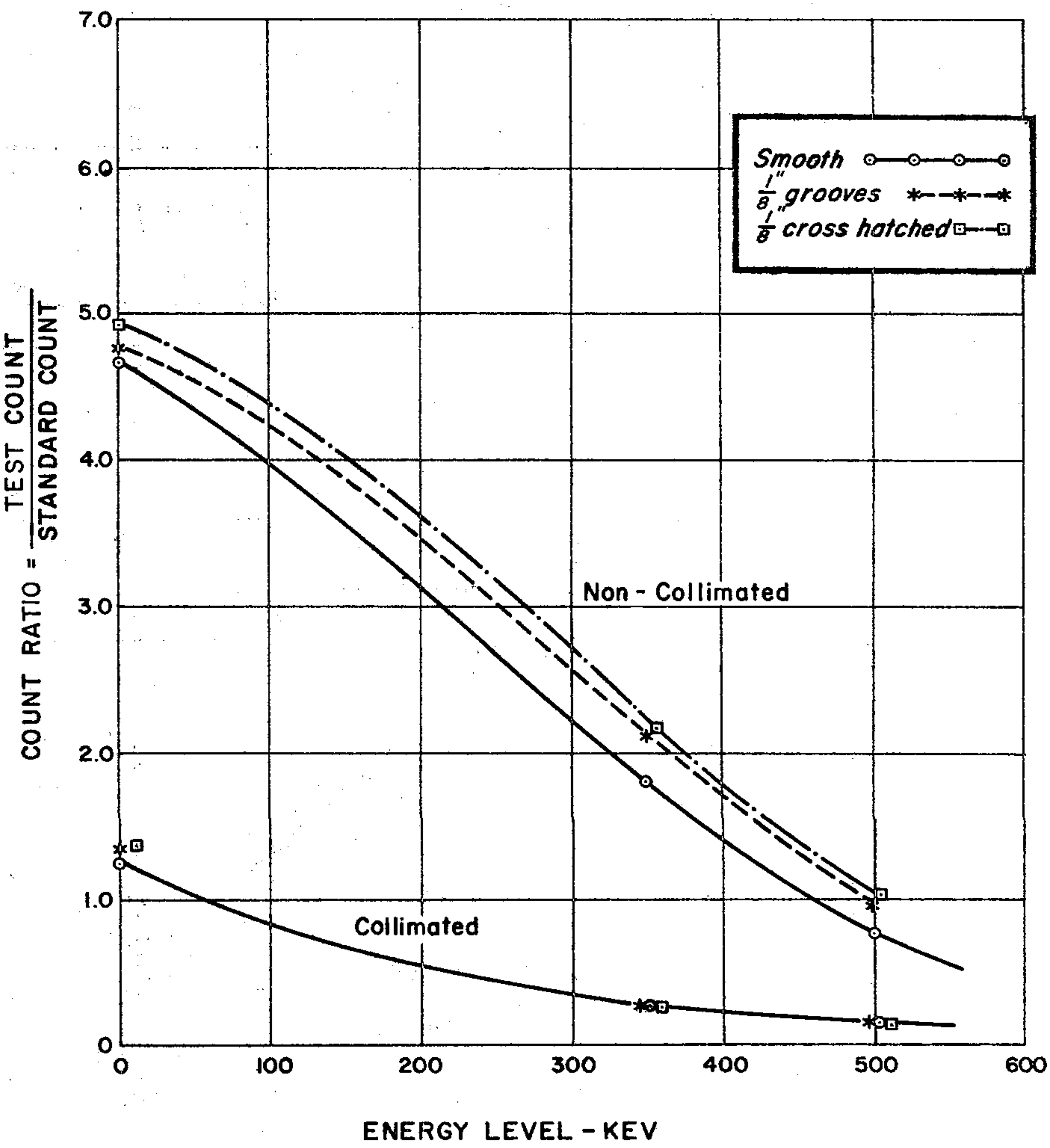


FIGURE 27

TROXLER BACKSCATTER
SURFACE ROUGHNESS STUDY
SOUTH SACRAMENTO SOIL 134 LBS. PER CU. FT.

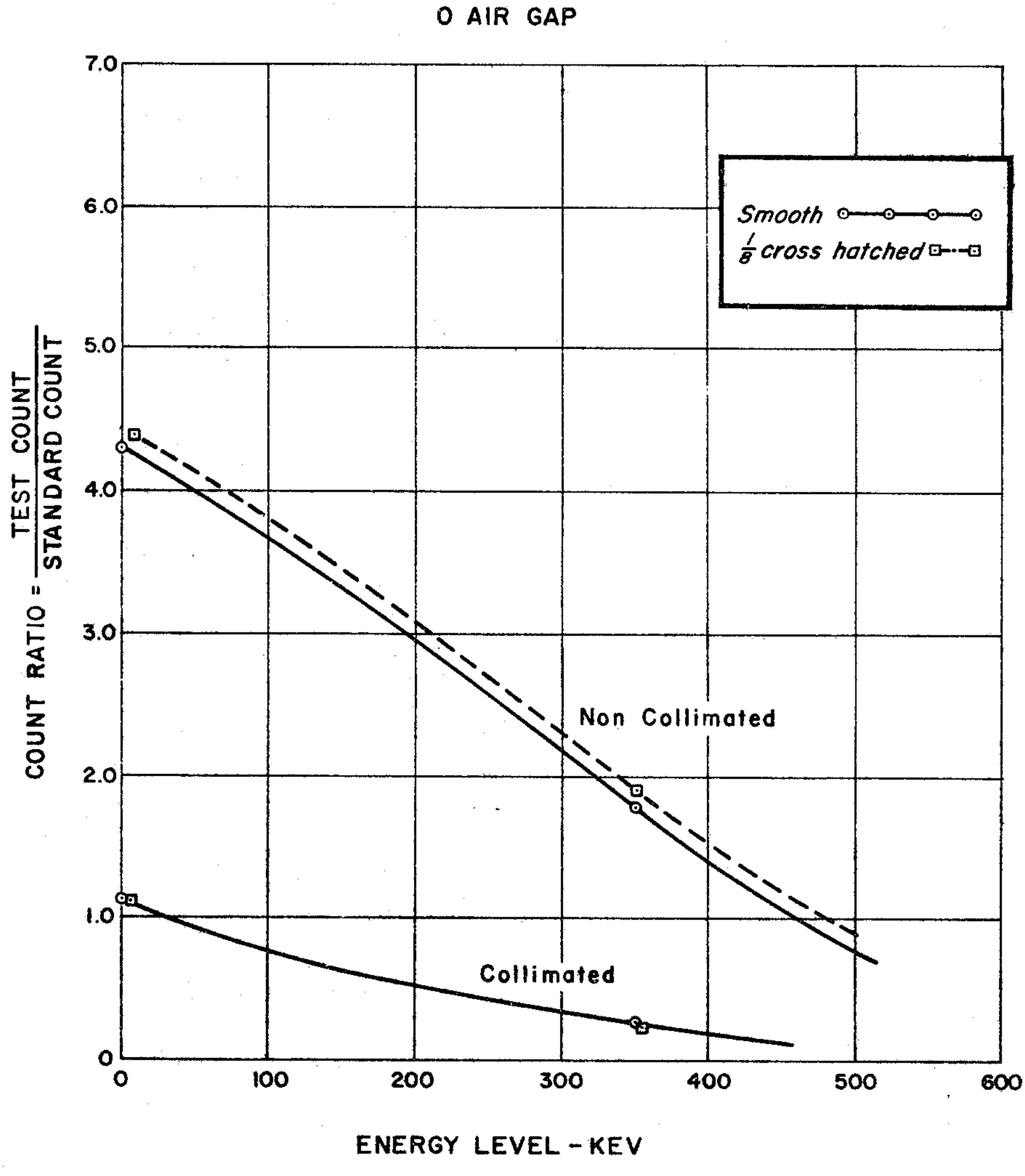


FIGURE 28

The effect of varying the discriminator setting, of backscatter type gages with a $\frac{1}{2}$-inch air gap, upon surface roughness is shown in Figures 29, 30 and 31. Instead of the rough surface causing an offset in the curves to one side of the smooth curve as occurred with the zero air gap data, the offset of the air gap curves was to both sides of the smooth curve. The reason for this is unknown.

The spread of the curves at all discriminator settings due to the different surface roughnesses is as great as that of the readings without air gap. The air gap reading is affected as much or more by roughness as is a reading flush on the surface of the sample.

The most important feature of the graphs is that the backscatter noncollimated readings with air gap do not respond to a desnity change between samples. The 0 KEV readings for the noncollimated test without air gap range from approximately a count ratio of 4.9 to 4.3 as the density increases, Figures 26, 27, and 28. The same test with air gap has approximately a 6.0 count ratio at all three densities, Figures 29, 30, and 31.

TROXLER BACKSCATTER
SURFACE ROUGHNESS STUDY
SOUTH SACRAMENTO SOIL 115 LBS. PER CU. FT.

1/2" AIR GAP

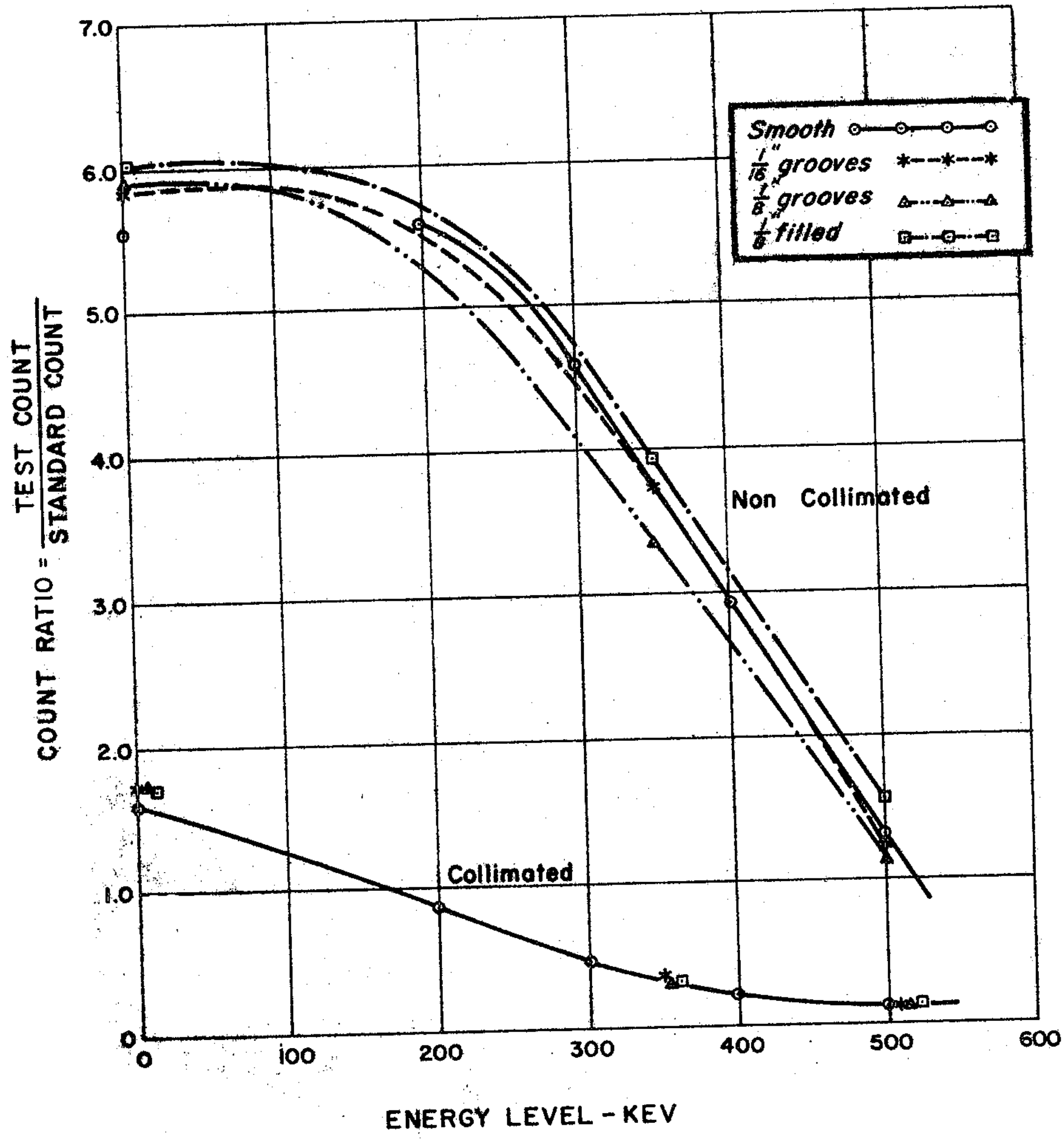


FIGURE 29

TROXLER BACKSCATTER
SURFACE ROUGHNESS STUDY
SOUTH SACRAMENTO SOIL 123LBS. PER CU. FT.

1/2" AIR GAP

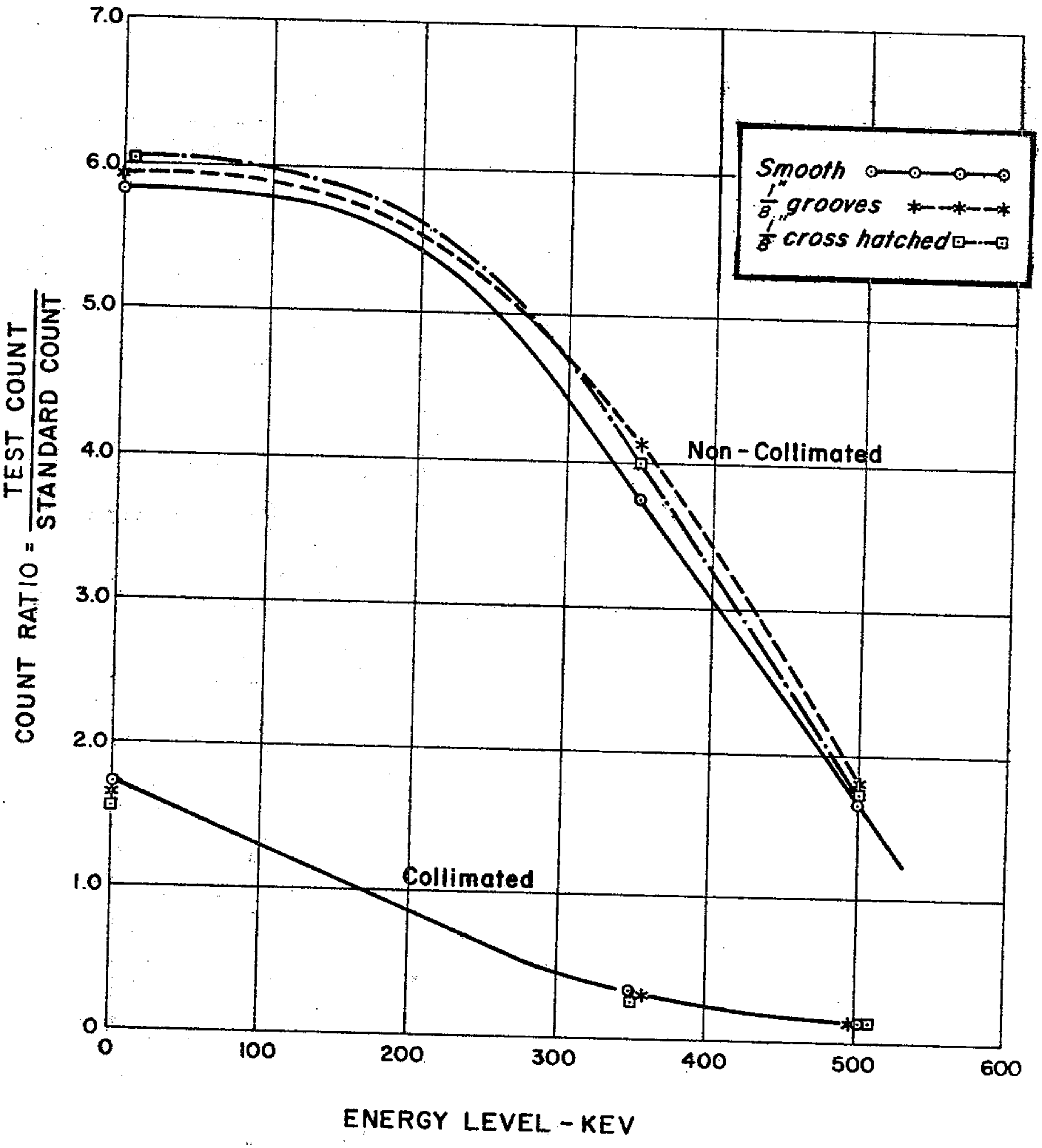


FIGURE 30

TROXLER BACKSCATTER
SURFACE ROUGHNESS STUDY
SOUTH SACRAMENTO SOIL 134 LBS. PER CU. FT.

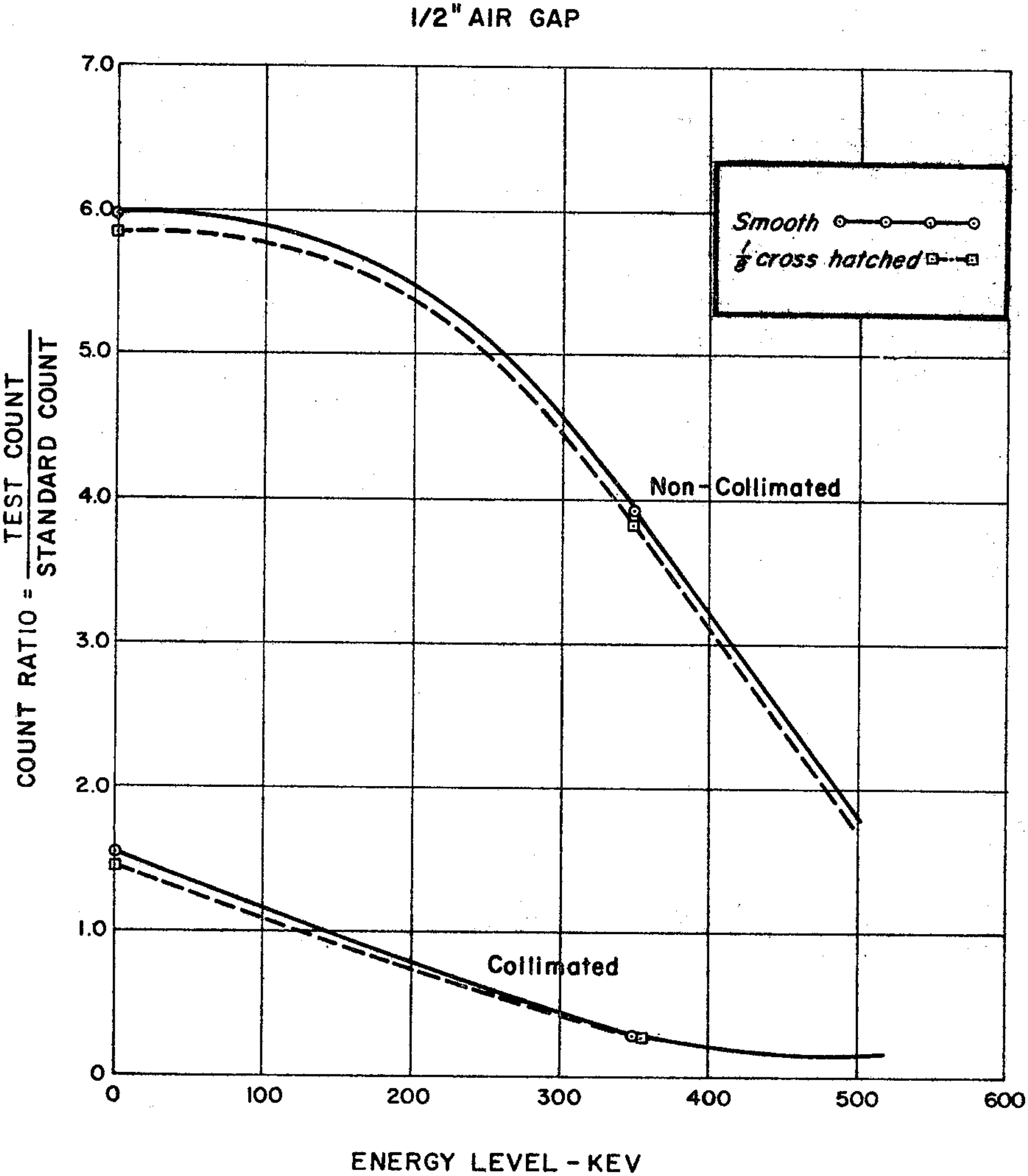


FIGURE 31

The transmission roughness data is plotted with intervals on the abscissa for the 4, 6, 8, and 10 inch probe depths, each at several roughnesses. At each depth of probe the values for a given air gap are connected across the different roughness values. Each graph represents a different discriminator setting. The first set, Figures 32, 33, 34, are for the 115 pound soil. The second set, Figures 35, 36, 37, are for the 123 pound soil and the third, Figures 38, 39, are for the 134 pound per cubic foot soil.

The important feature of these is that the effect of the surface roughnesses and air gap is significantly diminished with each increase in probe depth.

The plots of the different transmission discriminator settings for each density show that the effect of roughness and air gap is about the same for all discriminator settings. The conclusion is that discrimination does not reduce the affect of surface roughness in the transmission density test.

The effect of going from a smooth surface to that of increased roughness is small at the deeper depths of reading. The variation in indicated density at the 8 inch depth for the test roughnesses alone is approximately 1.0 lb. per cu. ft.

The relative effect of the test air gap is greater than that of surface roughness to test depths of 10 inches. The 1/8 inch air gap will cause a variation in indicated density at the 8 inch depth of approximately 2.0 lbs. per cu. ft. The conclusion is that the transmission instrument must be flush with the surface of the soil for best results.

The recommended practical depth of hole for the transmission test would be 10 to 12 inches, based on achieving a maximum reduction in surface effects on the density determinations.

Surface roughness and air gap both affect the transmission test relatively more on soil of low density than on soil of high density.

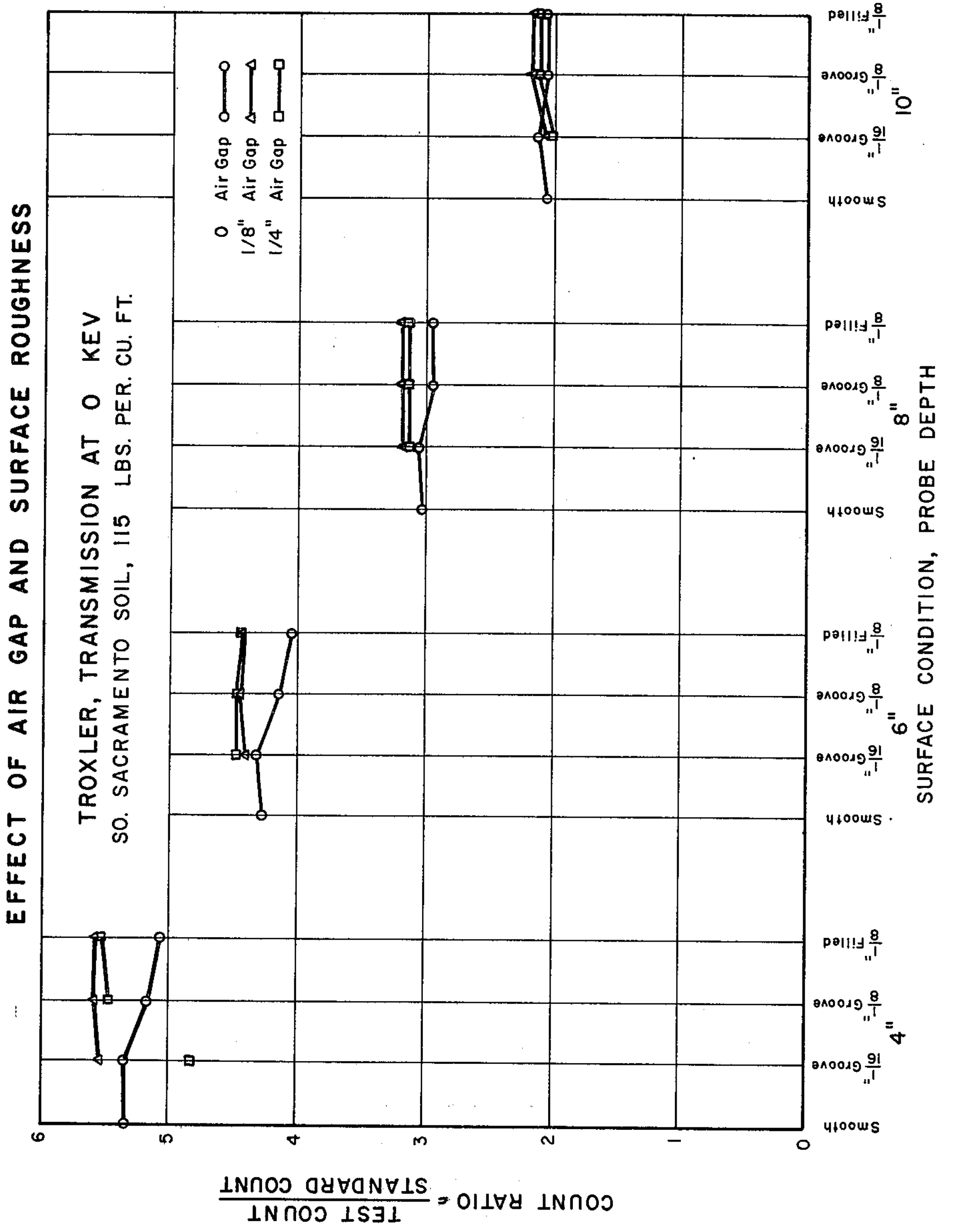

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT O KEV
SO. SACRAMENTO SOIL, 115 LBS. PER. CU. FT.
0 Air Gap
1/8" Air Gap
1/4" Air Gap
Smooth
1/16" Groove
1/8" Groove
1/8" Filled
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH
0
1
2
3
4
5
6
COUNT RATIO = TEST COUNT / STANDARD COUNT

FIGURE 32

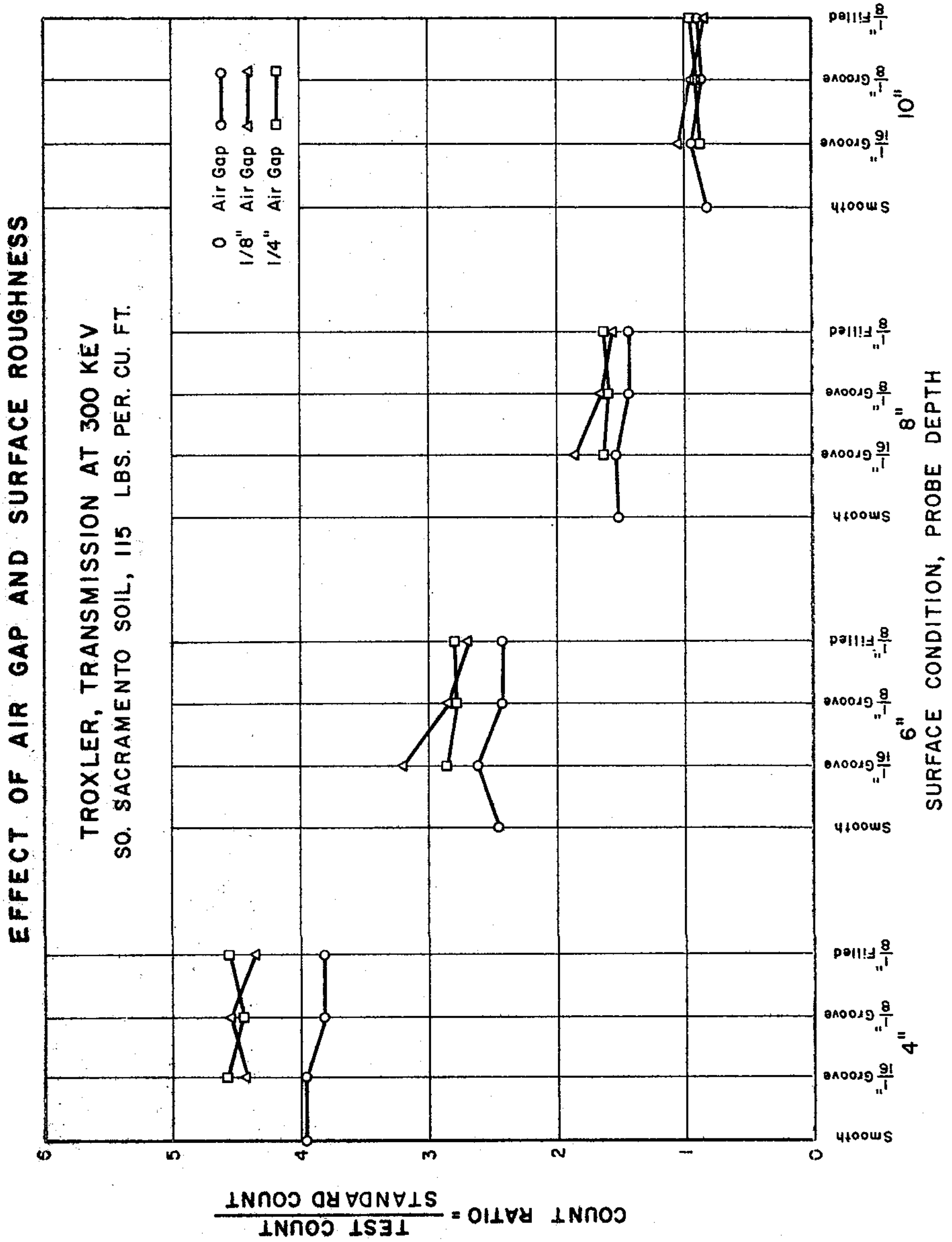

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 300 KEV
SO. SACRAMENTO SOIL, 115 LBS. PER. CU. FT.
0 Air Gap
1/8" Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/16" Groove
1/8" Groove
1/8" Filled
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 33

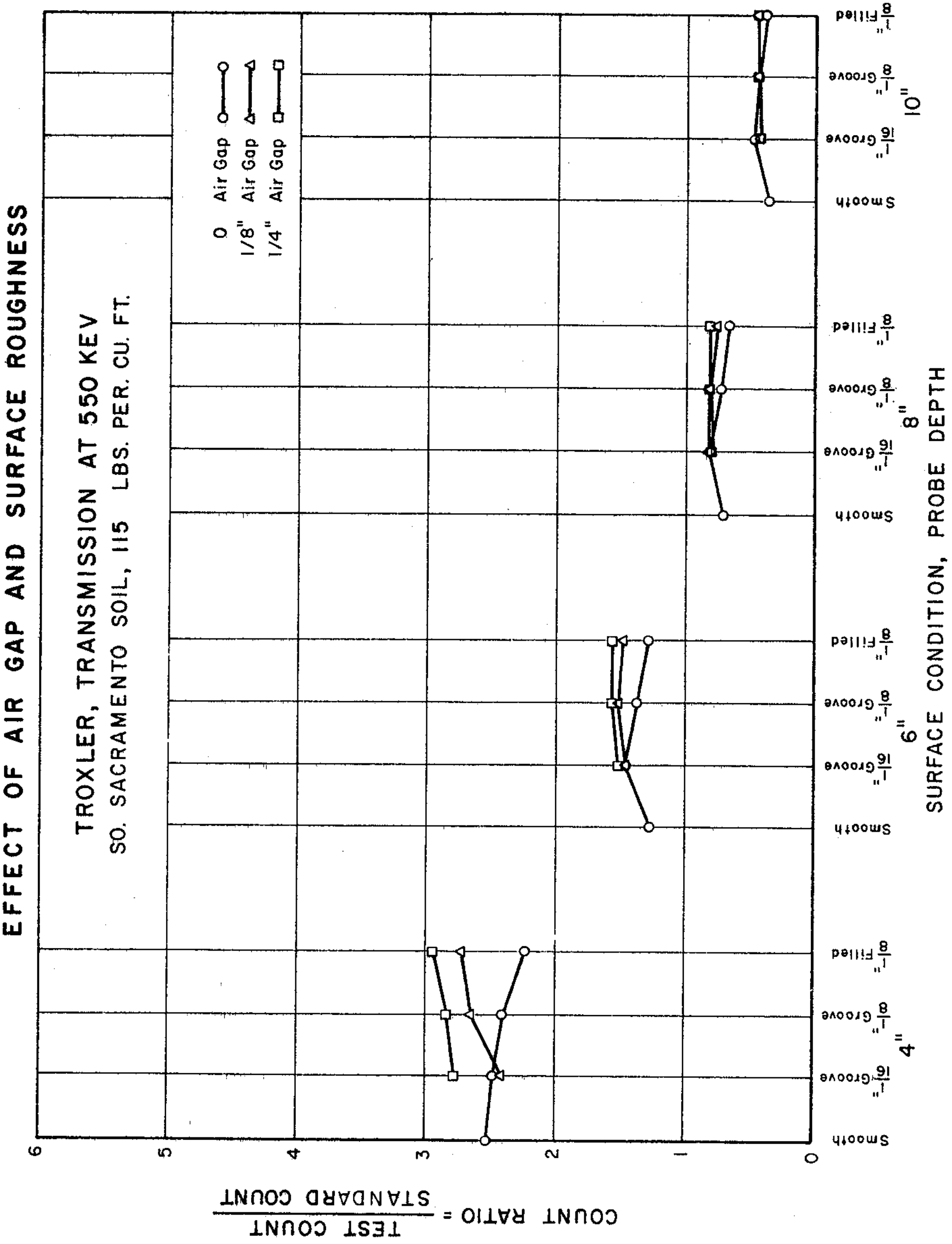

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 550 KEV
SO. SACRAMENTO SOIL, 115 LBS. PER. CU. FT.
0 Air Gap
1/8" Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/16" Groove
1/8" Groove
1/8" Filled
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 34

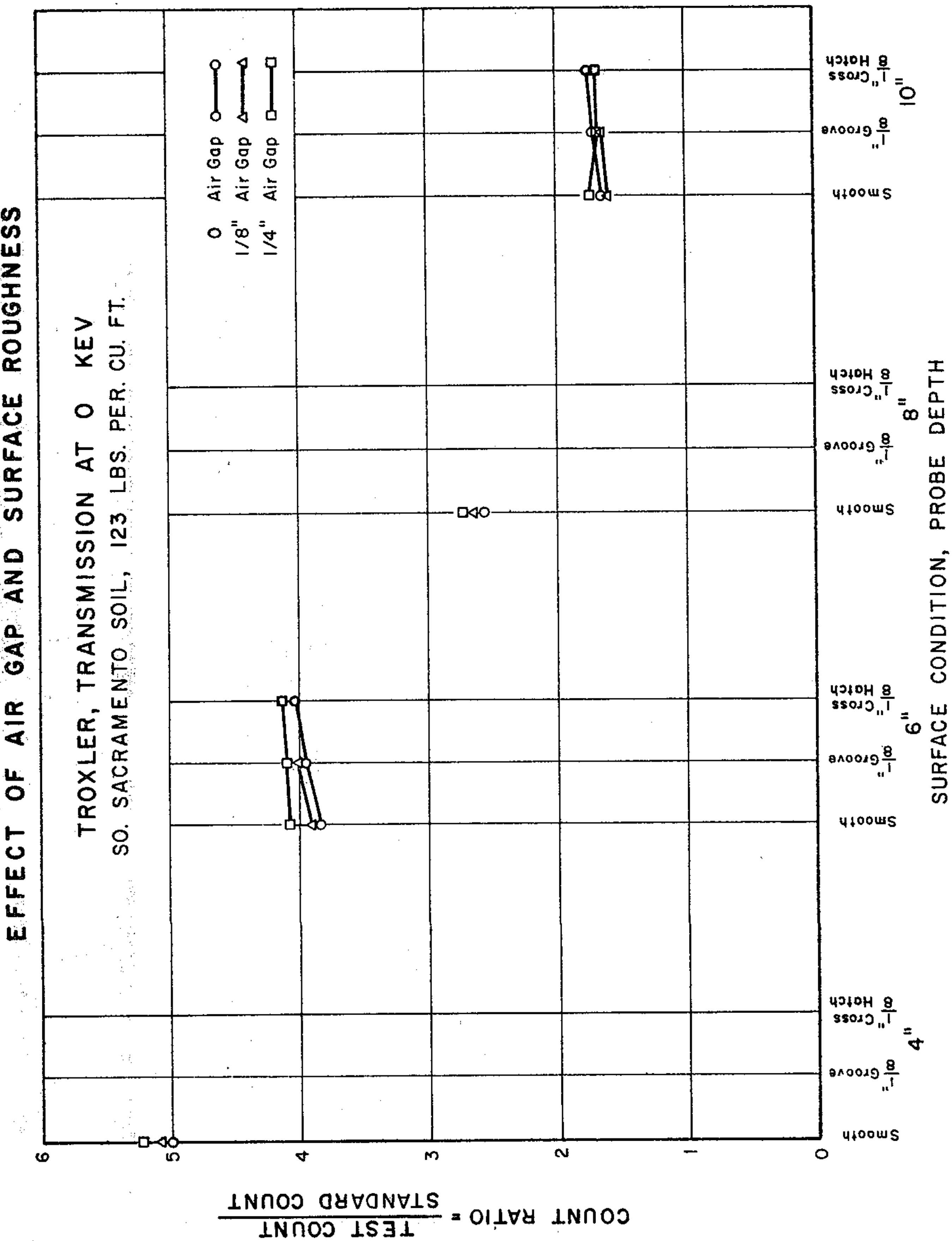
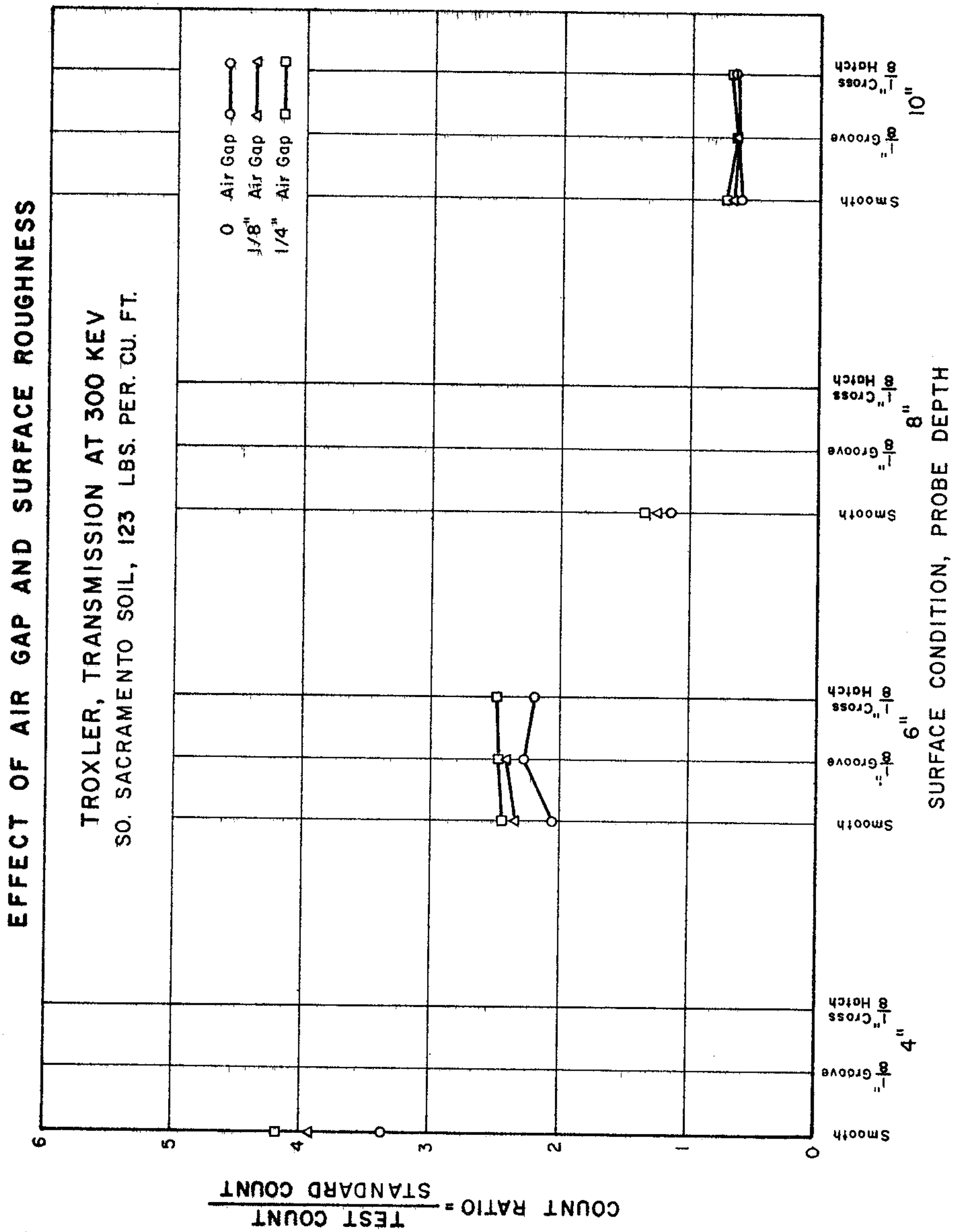

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 0 KEV
SO. SACRAMENTO SOIL, 123 LBS. PER. CU. FT.
0 Air Gap
1/8" Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/8" Groove
1/8" Cross Hatch
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 35



EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 300 KEV
SO. SACRAMENTO SOIL, 123 LBS. PER. CU. FT.
0 Air Gap
1/8" Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/8" Groove
1/8" Cross Hatch
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 36

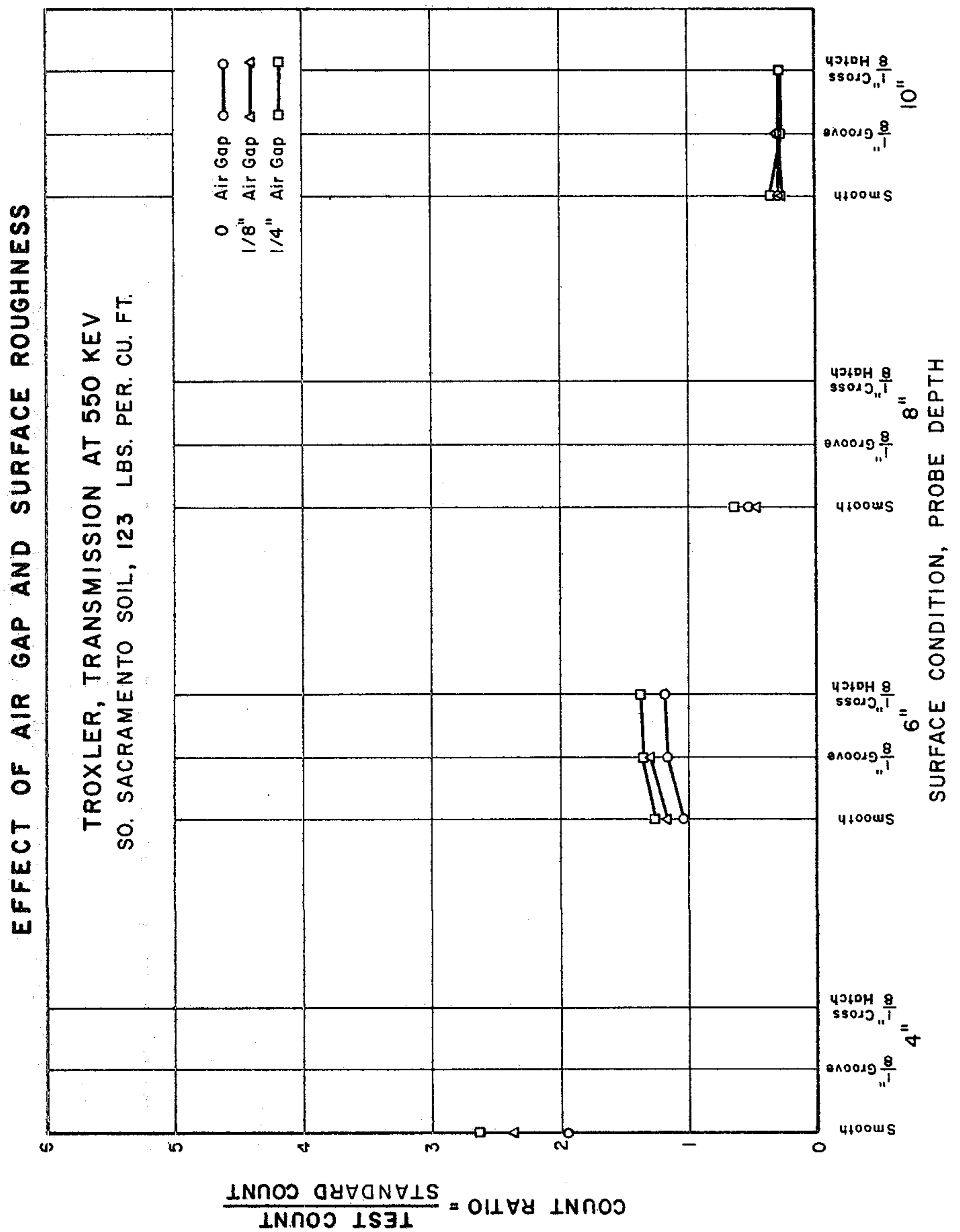

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 550 KEV
SO. SACRAMENTO SOIL, 123 LBS. PER. CU. FT.
0 Air Gap
1/8" Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/8" Groove
1/8" Cross Hatch
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 37

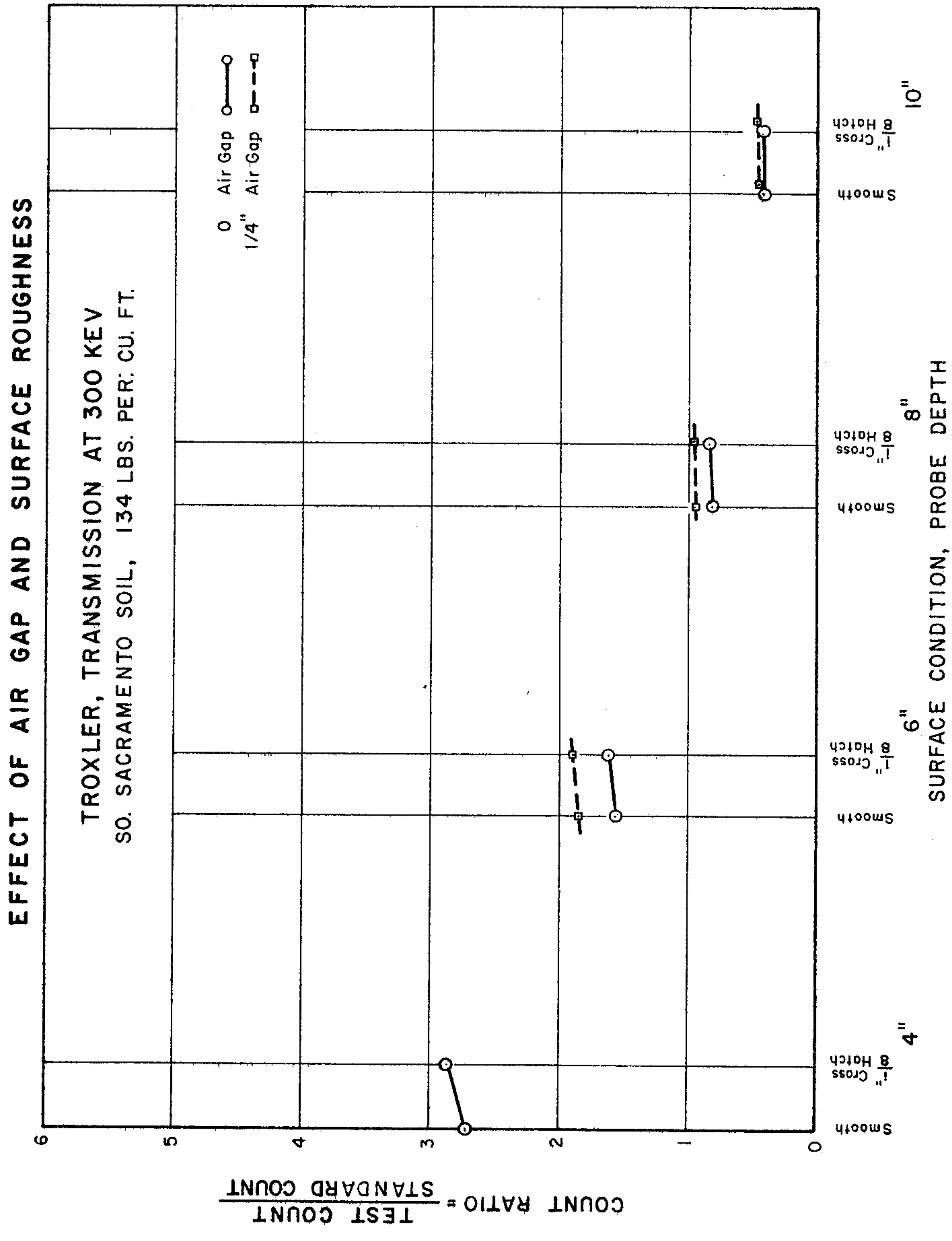

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 300 KEV
SO. SACRAMENTO SOIL, 134 LBS. PER. CU. FT.
0 Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/8" Cross Hatch
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 38

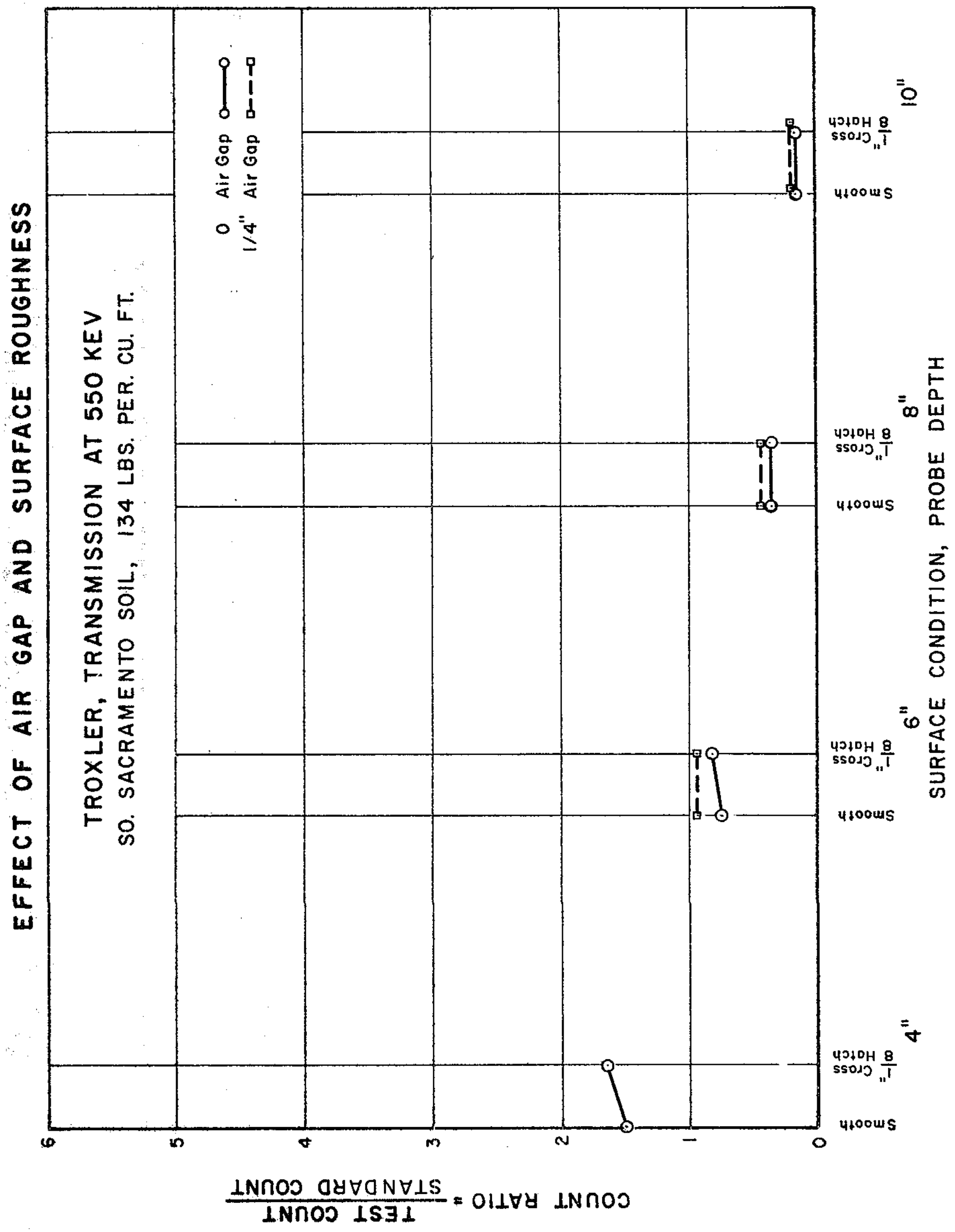

EFFECT OF AIR GAP AND SURFACE ROUGHNESS
TROXLER, TRANSMISSION AT 550 KEV
SO. SACRAMENTO SOIL, 134 LBS. PER. CU. FT.
0 Air Gap
1/4" Air Gap
COUNT RATIO = TEST COUNT / STANDARD COUNT
0
1
2
3
4
5
6
Smooth
1/8" Cross Hatch
4"
6"
8"
10"
SURFACE CONDITION, PROBE DEPTH

FIGURE 39

The following Tables 13 and 14 present a brief summary of the effect of surface roughness on density measurements by two gages of different manufacture. The Numec gage takes backscatter readings only while the Hidrodensimeter can be used as a transmission type instrument as well as backscatter.

The effect of roughness on the moisture count ratios by these gages is also included in the tables.

It is estimated that a roughness comparable to the 1/8 inch cross hatched surface can cause approximately a 3 to 6 lb. per cu. ft. error in a density estimate for the Hidrodensimeter backscatter test. No estimate of probable error is made for the Numec instrument as the data is erratic. The probable error caused by the roughness on the Hidrodensimeter transmission test is in the order of 4 lbs. per cu. ft. An error of approximately 3/4 lb. per cu. ft. for the moisture tests of the gages is caused by this roughness.

TABLE 13

Surface Roughness Study
So. Sacramento Soil, 123 lbs. per cu. ft.

Test	Instrument	Probe Position	Count Ratio: Smooth	Count Ratio: 1/8" Grooves	Count Ratio: 1/8" Cross Hatch
Back-scatter	Hidrodensimeter	0	1.58	1.59	1.64
	Numec	-	-	1.29	1.22
Transmission	Hidrodensimeter	4" 6" 8" 10"	0.32 0.37 0.32 0.24	0.34 0.41 0.34 0.26	- 0.41 - 0.26
Moisture	Hidrodensimeter	-	3.20	2.80	2.75
	Numec	-	1.10	1.25(?)	1.08

TABLE 14

Surface Roughness Study
So. Sacramento Soil, 134 lbs. per cu. ft.

Test	Instrument	Probe Position	Count Ratio: Smooth	Count Ratio: 1/8" Cross Hatch
Back-scatter	Hidrodensimeter	0	1.44	1.48
	Numec	-	1.08	1.10
Transmission	Hidrodensimeter	4" 6" 8" 10"	0.288 0.322 0.277 0.194	0.290 0.320 0.264 0.190
Moisture	Hidrodensimeter	-	2.27	2.12
	Numec	-	1.12	1.04

The foregoing studies of roughness present the basic factors affecting the nuclear readings. However, the effect of surface roughness on calibration curves, which are based on data from smooth surface readings, will determine the importance of this factor in field use. The roughness data is presented in the form of standard count ratio vs soil density, with the respective values for both smooth and rough surfaces plotted. The material for the zero air gap curves are presented in Figures 40 and 41, and that for the ½-inch air gap tests in Figures 42 and 43.

Of interest in the zero air gap graphs is that there is no response to changes in density at discriminator settings of 350-KEV and above. It is cautioned, however, the the relative slope of these curves is not an absolute indication of sensitivity.

The collimated test without air gap at 0-KEV is less sensitive to roughness than the noncollimated, as is evident from a comparison of Figures 41 and 42. It is estimated that a roughness equivalent to the laboratory "cross hatched" grooves can cause an error of approximately seven pounds for the non-collimated test in the 120-130 lb. per cu. ft. density range. It is estimated that this same roughness would cause approximately a 3-pound error for the collimated test in this same density range.

It is noted that the noncollimated ½-inch air gap test curves vary with roughness, but do not respond to changes in density when using standard count ratio (test count/standard count). These readings are essentially constant at various densities, Figure 42.

However, the collimated ½-inch air gap curve at 0-KEV does have a definite response to a change in density, Figure 43, when the standard count ratio is used. It may be concluded that the collimated test is not affected as much by the ½-inch air gap itself as is the noncollimated test. The air gap does accentuate the effect of roughness for the collimated source at 0-KEV discrimination level, Figures 41 and 43.

The effect of surface roughness on the count ratio decreased as the density increased with a zero air gap. See Figure No. 40 and 41. If the affect of surface roughness was due to the low density of the air directly below the gage the reverse of the above would occur. Also the rough surface tends to increase the indicated density whereas if the low density of the air was the cause, a low density would have been indicated. It appears that the affect of surface roughness on the count ratio is caused by the surface condition or texture and not the low density of the air.

SURFACE ROUGHNESS–DENSITY STUDY
TROXLER BACKSCATTER
NON – COLLIMATED
ZERO AIR GAP

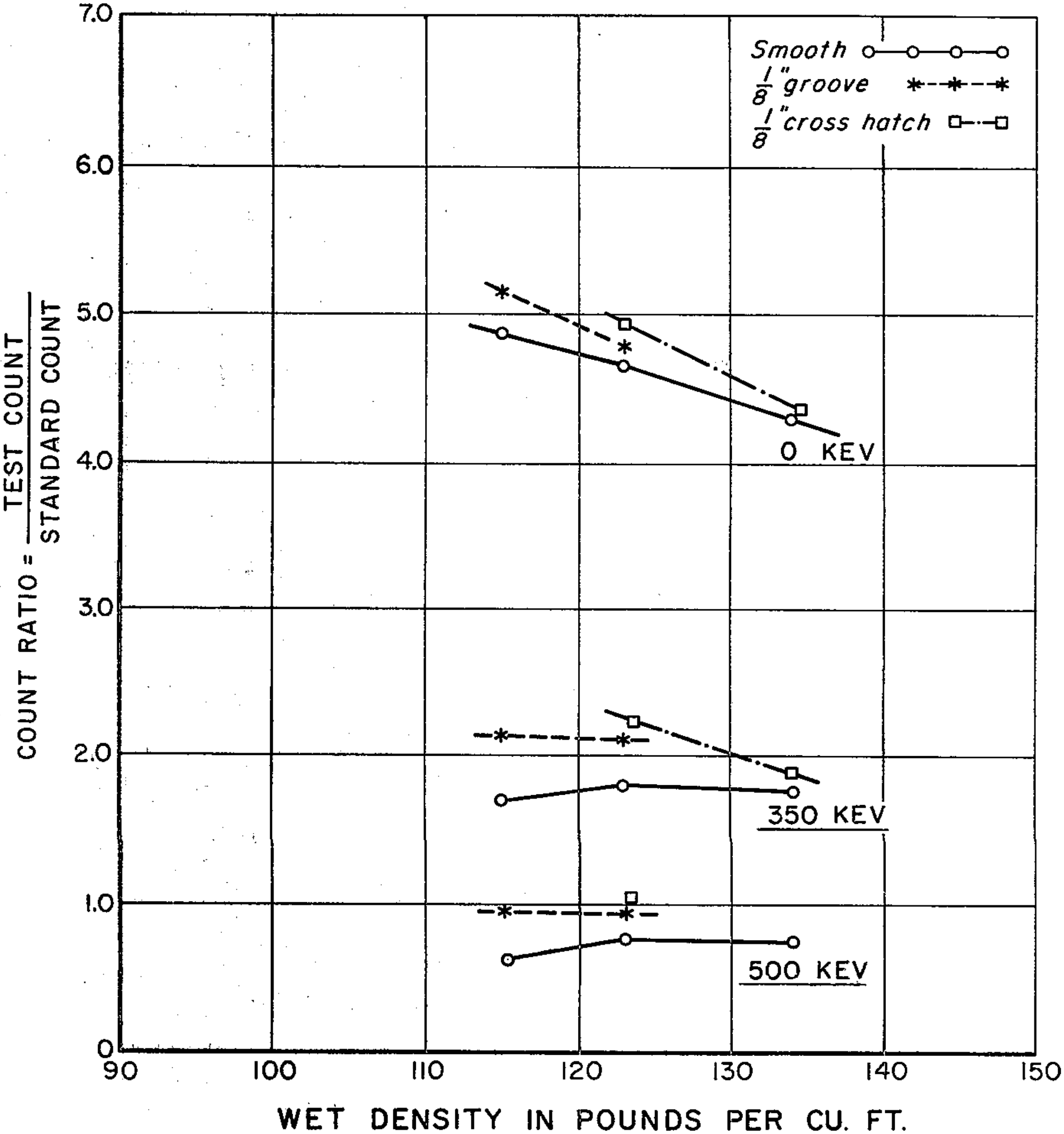


FIGURE 40

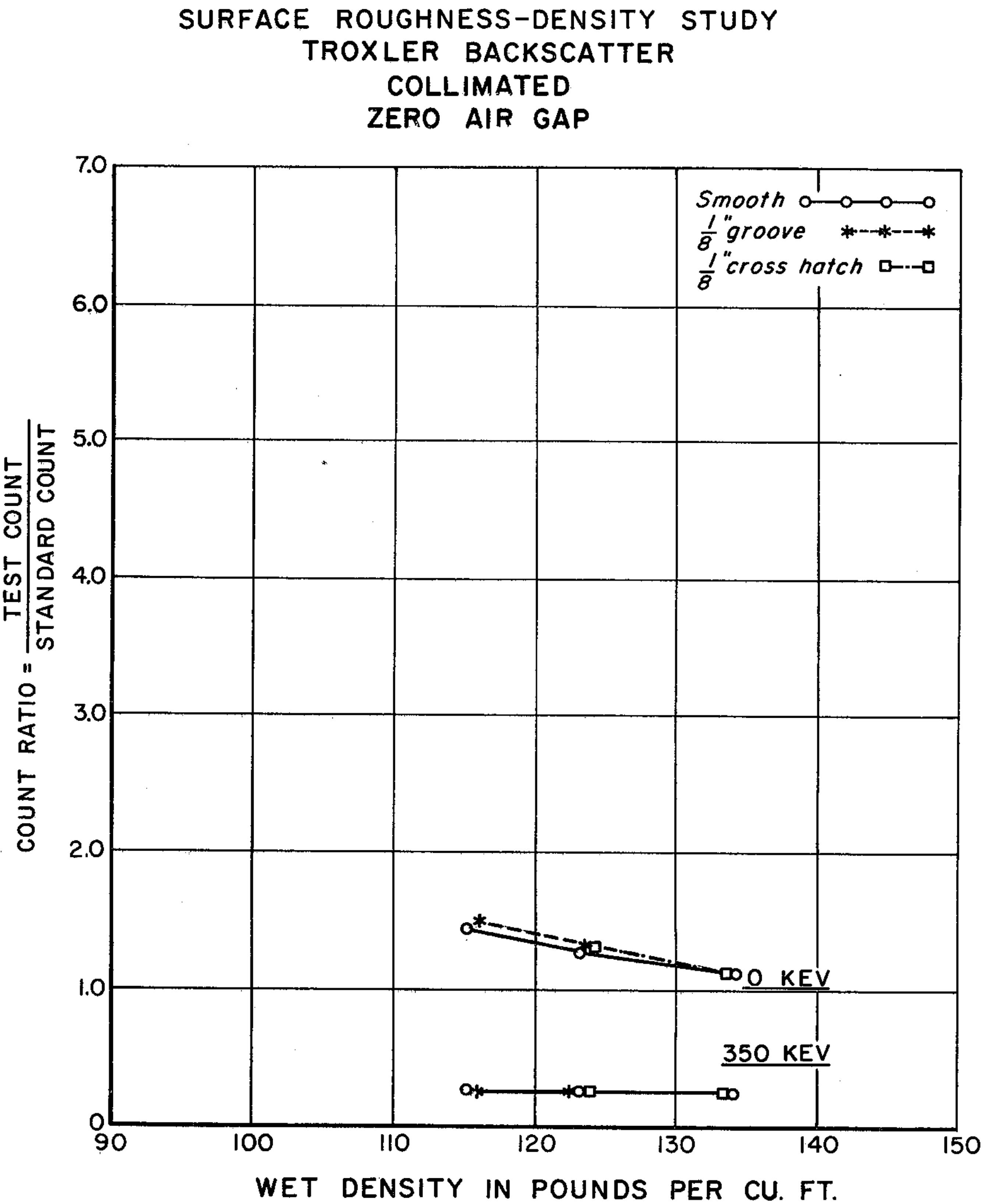

SURFACE ROUGHNESS-DENSITY STUDY
TROXLER BACKSCATTER
COLLIMATED
ZERO AIR GAP
Smooth
1/8" groove
1/8" cross hatch
COUNT RATIO = TEST COUNT / STANDARD COUNT
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
90
100
110
120
130
140
150
0 KEV
350 KEV
WET DENSITY IN POUNDS PER CU. FT.

FIGURE 41

SURFACE ROUGHNESS-DENSITY STUDY
TROXLER BACKSCATTER
NON — COLLIMATED
1/2" AIR GAP

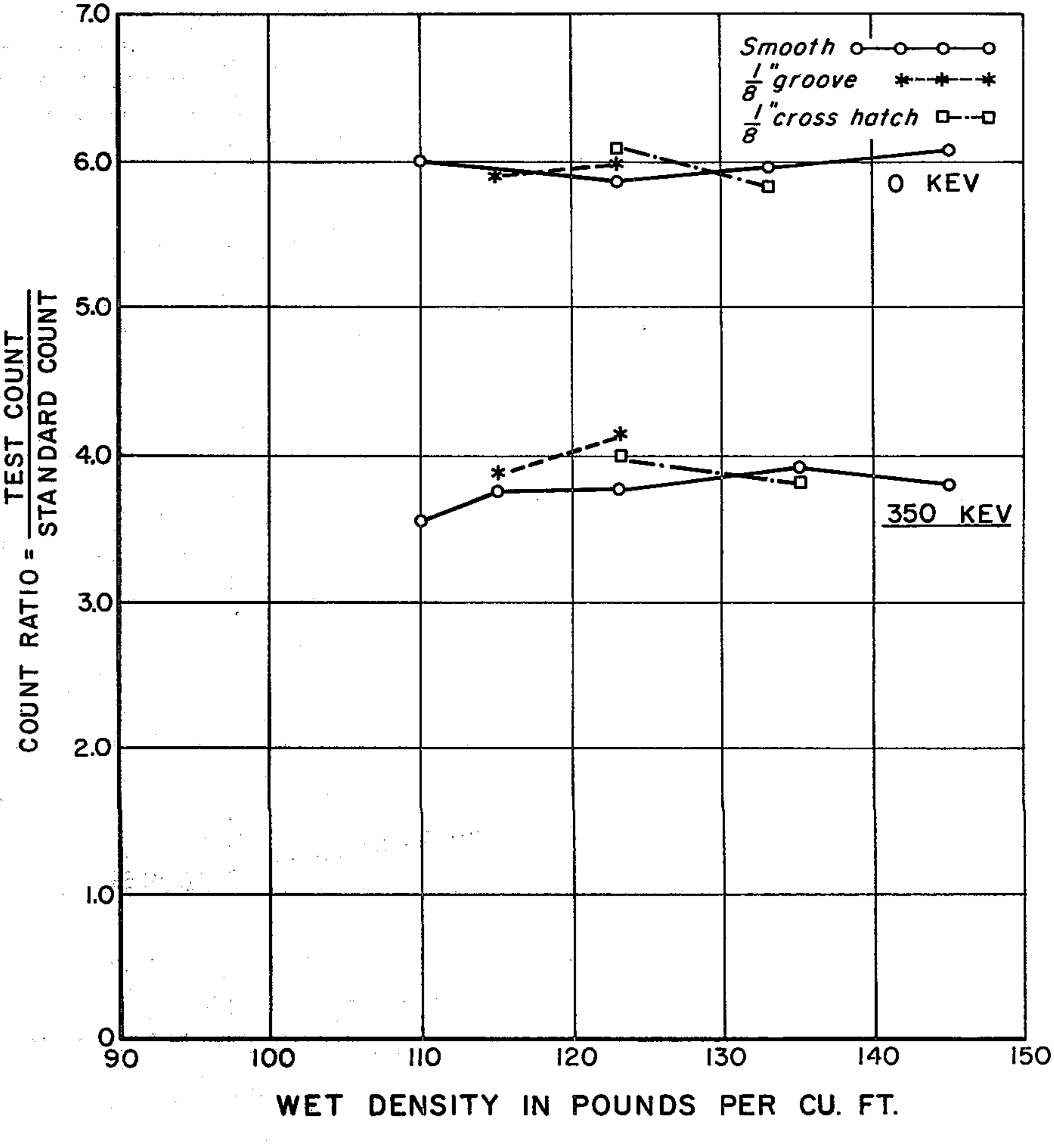


FIGURE 42

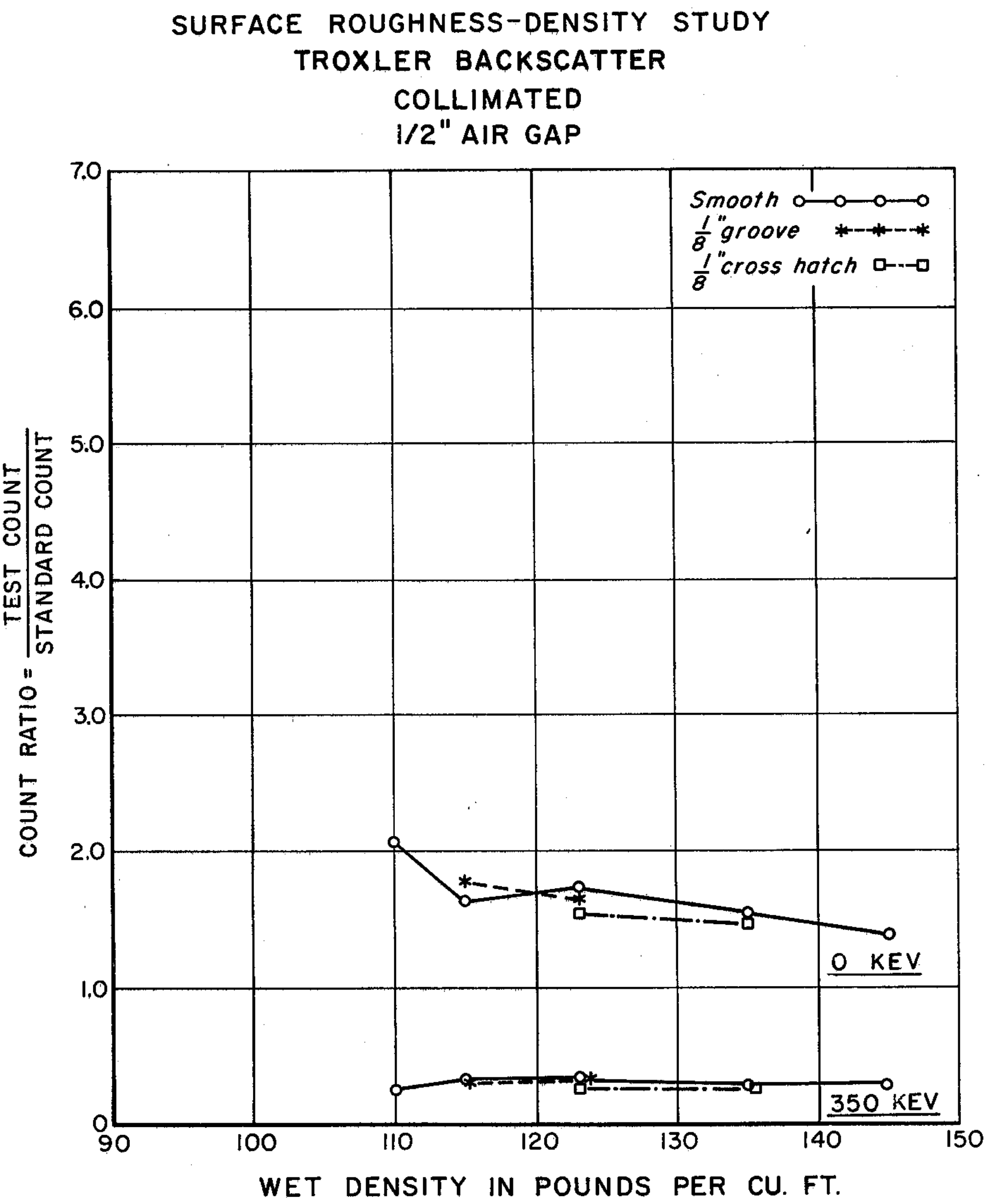

SURFACE ROUGHNESS-DENSITY STUDY
TROXLER BACKSCATTER
COLLIMATED
1/2" AIR GAP
Smooth
1/8" groove
1/8" cross hatch
0 KEV
350 KEV
COUNT RATIO = TEST COUNT / STANDARD COUNT
WET DENSITY IN POUNDS PER CU. FT.
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
90
100
110
120
130
140
150

FIGURE 43

Figures 44, 45, 46 present in graphical form the relationship of the various roughnesses and air gaps to the basic calibration test points for the transmission test which are based on smooth surface readings. The principal interest is the diminishing of the surface effects at the deeper depths of measurement.

It is estimated that a roughness similar to the laboratory "cross hatched" grooves can cause an error of approximately two to three pounds on a 0-KEV transmission test at probe depths of eight inches and deeper when testing soils in the 120 - 130-lb. per cu. ft. range.

Figures 44, 45, 46 are plotted on arithmetic paper for this illustration, though normally calibration data for the transmission test is usually presented as a semilogarithmic graph.

The effect of the ¼-inch air gaps is minor, about two pounds per cubic foot in the ten inch depth of measurement. This small effect observed in both surface roughness and air gap is due to the small volume of soil these represent compared to the total volume of soil affecting the reading.

SURFACE ROUGHNESS DENSITY STUDY
TROXLER TRANSMISSION
O - KEV

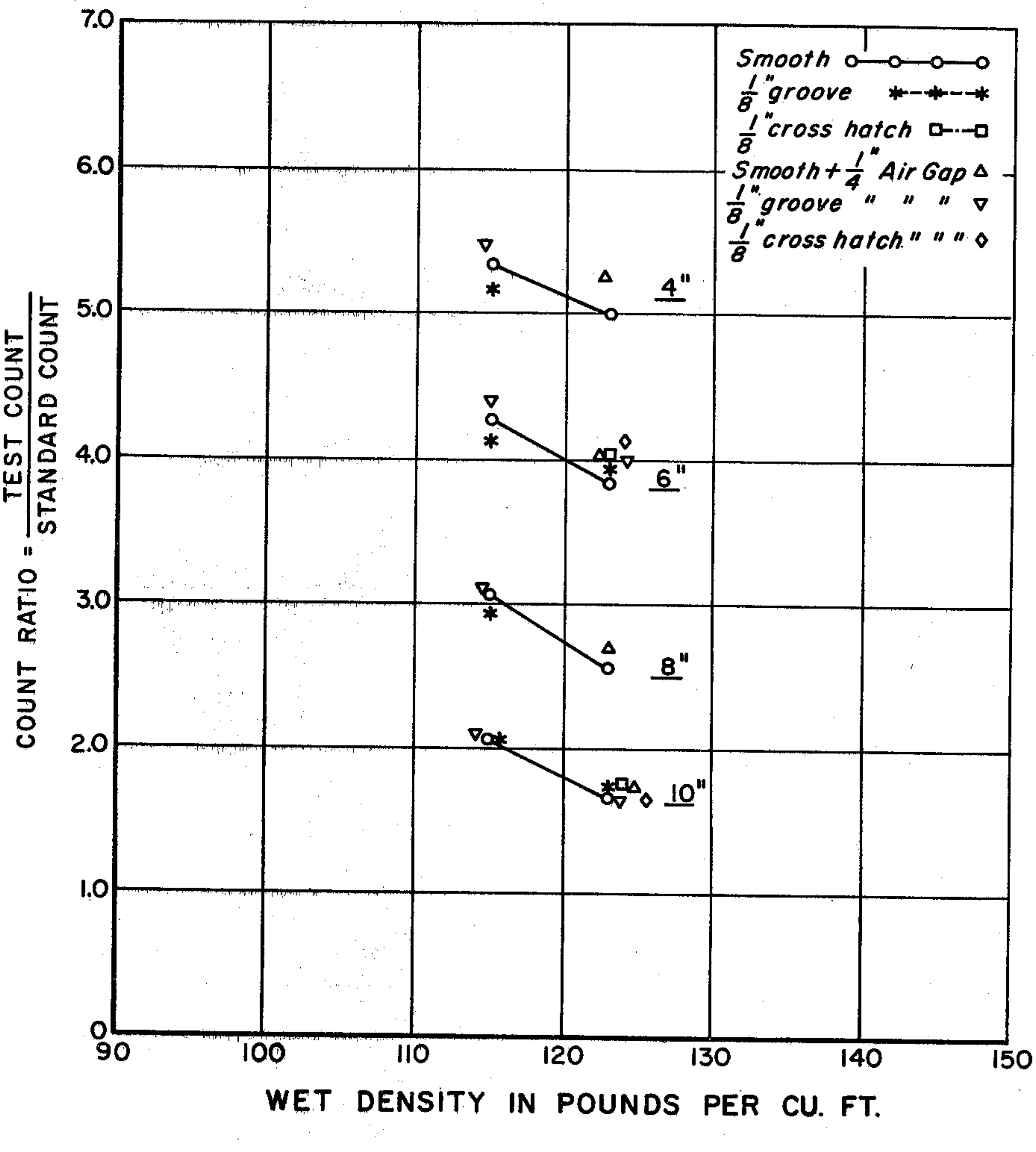


FIGURE 44

SURFACE ROUGHNESS DENSITY STUDY
TROXLER TRANSMISSION
300-KEV

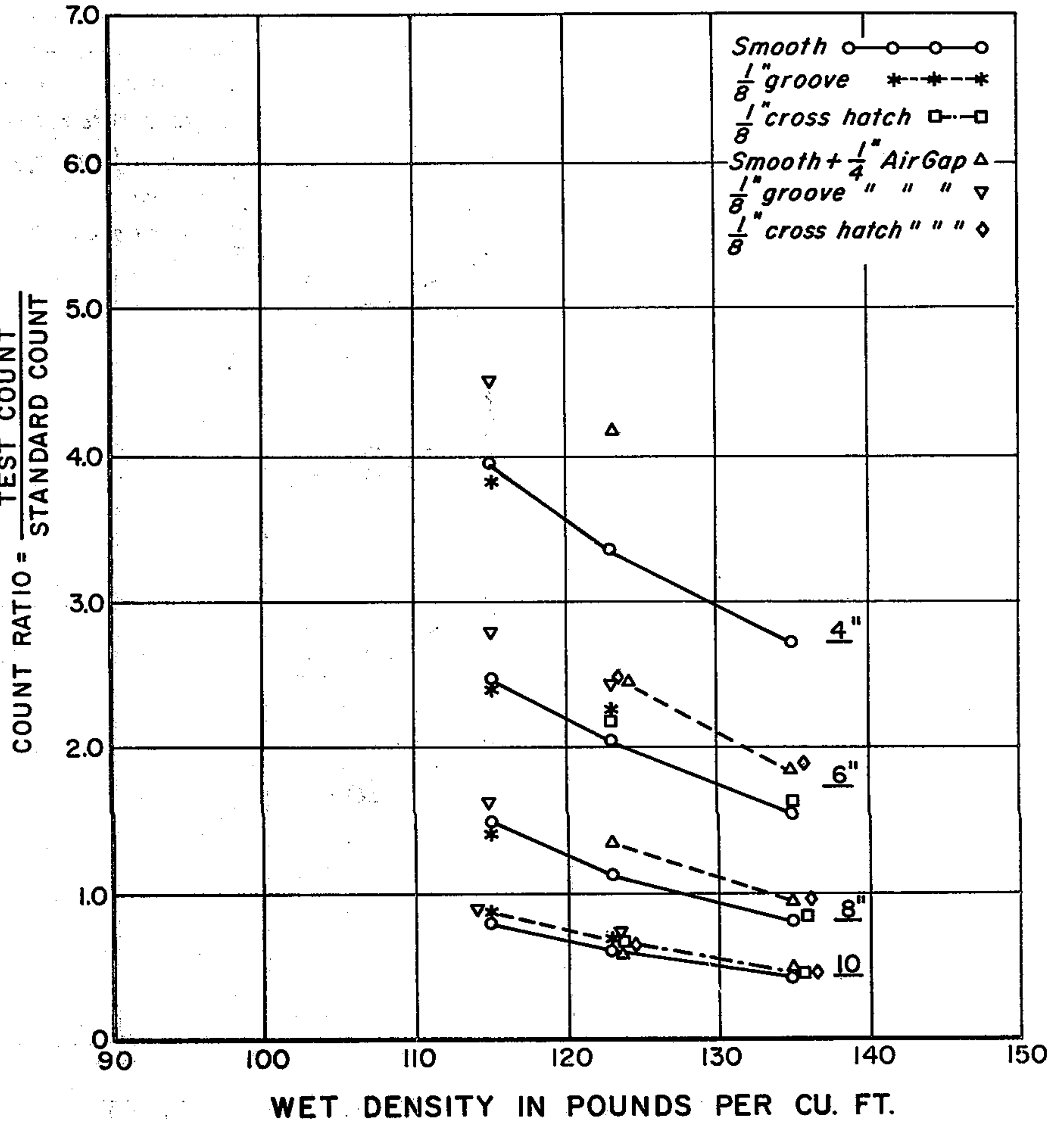


FIGURE 45

SURFACE ROUGHNESS-DENSITY STUDY
TROXLER TRANSMISSION
550-KEV

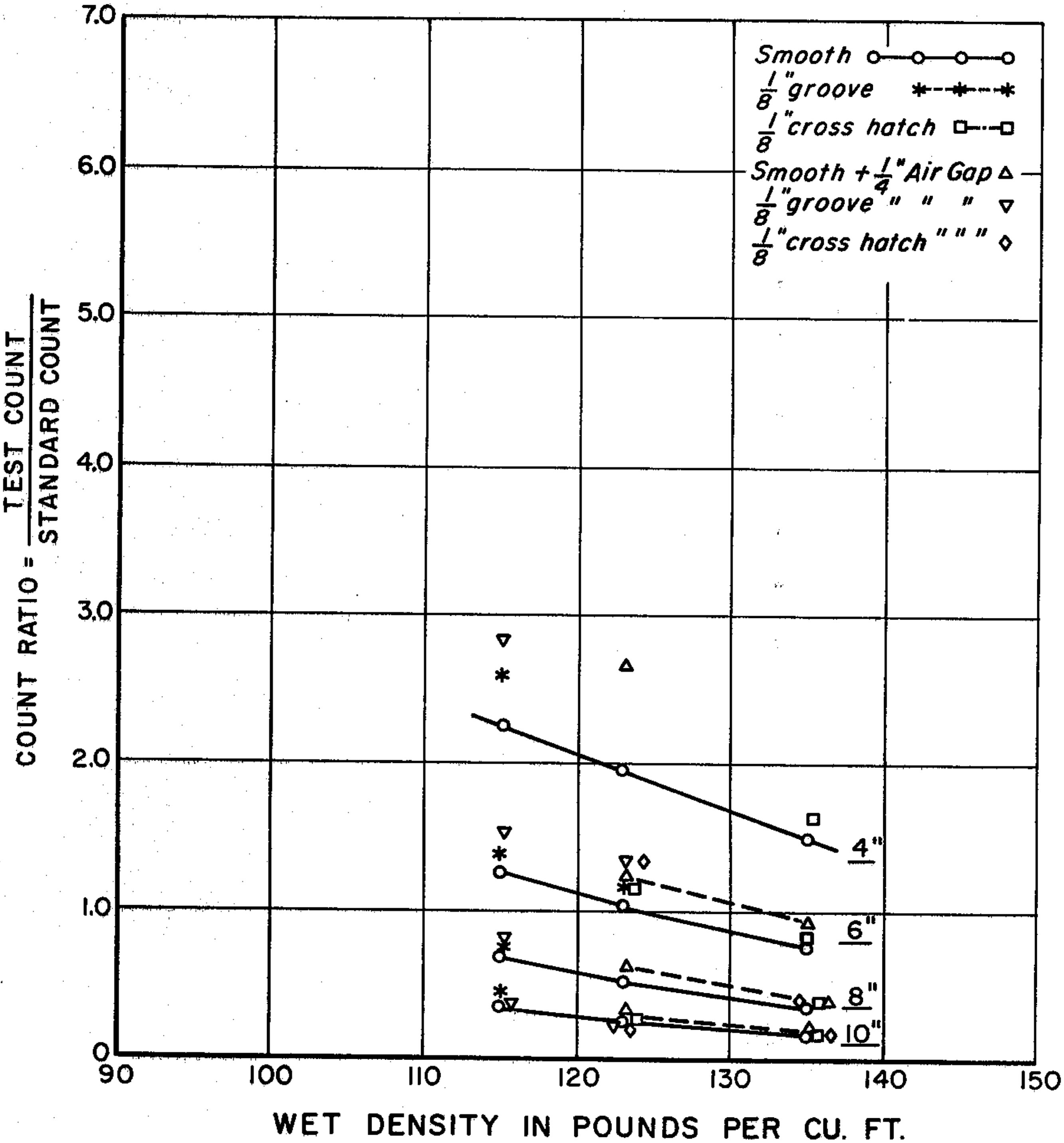


FIGURE 46

VOLUME OF SOIL AFFECTING READINGS

A portion of this study was the determination of the volume of soil affecting the reading by the various types of test methods.

The testing procedure used in studying the backscatter type gages is described in Appendix A. Photo 18 shows the Troxler instrument resting on a 6-inch thickness of soil, and Photo 19 illustrates the removal of a layer of soil.

The criteria for the estimates of the dimensions used in calculating volume of soil affecting readings are as follows:

Longitudinal. Assumed to be the distance between the probe and detector tube.

Lateral. The distance from the instrument centerline to the edge of sample when the air boundary caused approximately a five percent change in the reading as the gage was moved accross the sample.

Depth. Assumed to be that point at which there was a distinct break in the curve plotted in count or count ratio vs depth.

The basic data is presented in Tables 15 and 16, and the graphs of count or count ratio in Figures 47 thru 55.

The data for lateral movement for the air gap tests is not presented. The test with air gap was found to be affected by the edge air boundary in an erratic manner. This is due to simple leakage into the air through the air gap when approaching the edge, rather than reading a greater side dimension.

The results of the study indicate that the maximum volume being measured with the backscatter type density gages is in the order of 0.05 cubic foot. The Numec, Hidrodensimeter, and Troxler operated at 0-KEV discrimination level have depths of measurement between two and three inches without an air gap. The higher discrimination levels studied with the Troxler instrument have a depth of influence of about two inches. The depth of the soil affecting the readings with an air gap was in the range of two to three inches, about the same as without an air gap.

The depth of influence indicated by this study is less than the four to six inches indicated by some previous studies. The previous studies used either wood or air beneath the soil, where aluminum and steel was used in this investigation. The results of a depth of influence study performed in this manner is dependent on two things: the density of the material being tested, and the difference in densities of the materials at the boundary. Previous test data has indicated that if the material tested is of low density, the indicated depth of measurement will be deeper than if the material is of high density. Also, if the difference in density between the material tested and the boundary material is slight, the indicated depth of measurement will be greater than if the difference between the two is great. The Troxler and Numec gages used Cs^{137} sources with gamma radiation of 0.66 MEV and the Hidrodensimeter a Ra^{226} source with a spectrum of gamma radiation up to about 2 MEV energy level. There was no apparent difference in the depth of readings using these two different energy levels of gamma radiation.

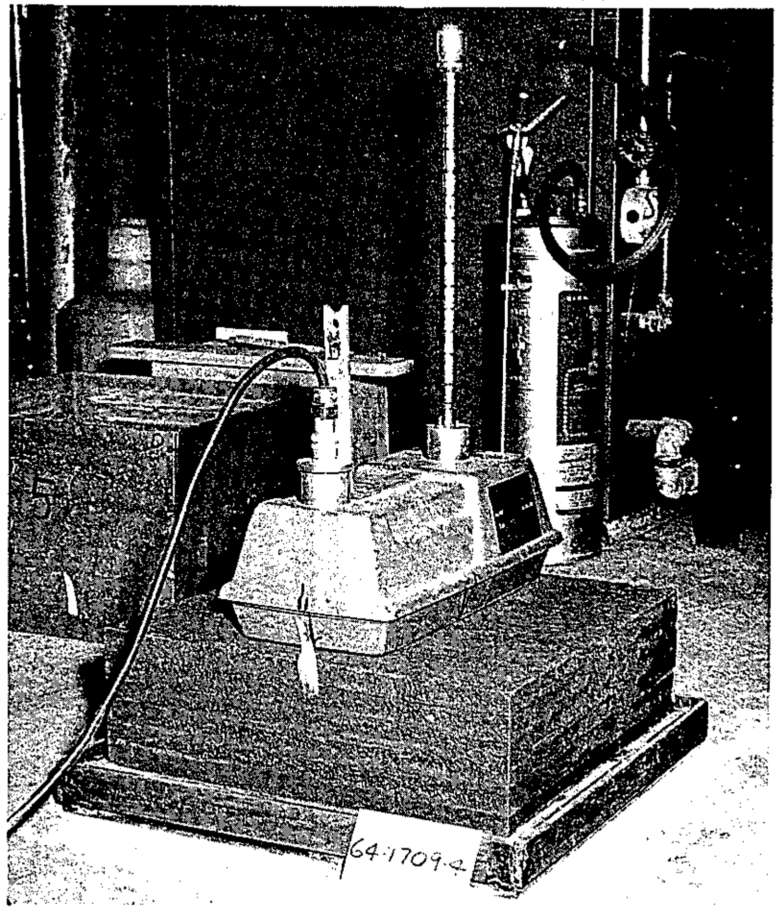


PHOTO 18, Troxler Instrument on 6 inch Thickness of Soil, Depth of Inflence Study.

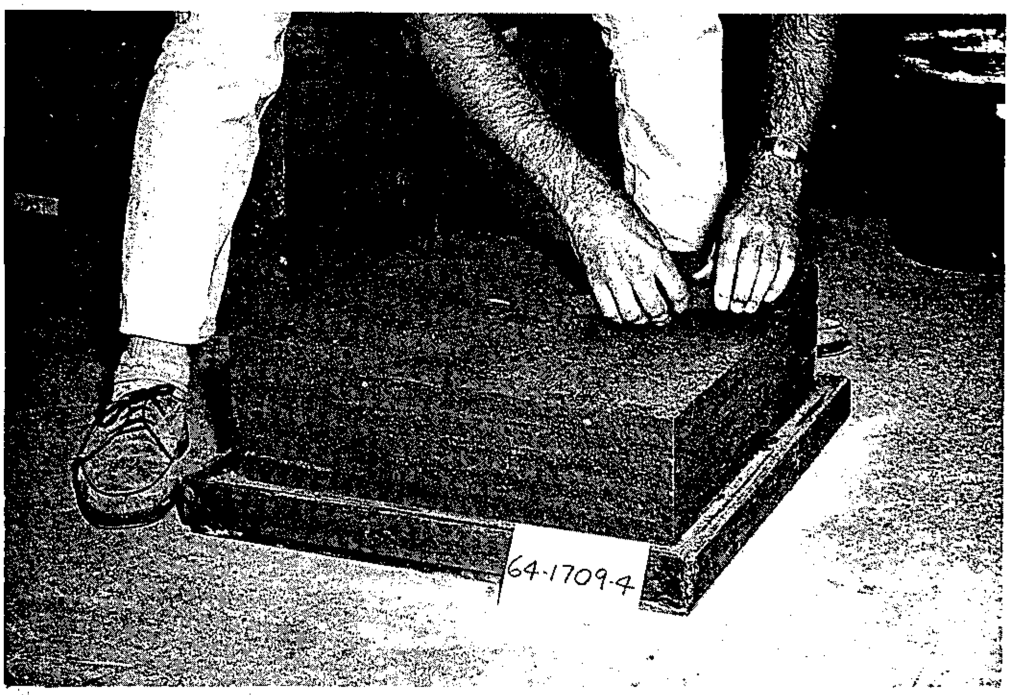


PHOTO 19, Removal of Soil Layer, Depth of Influence Study.

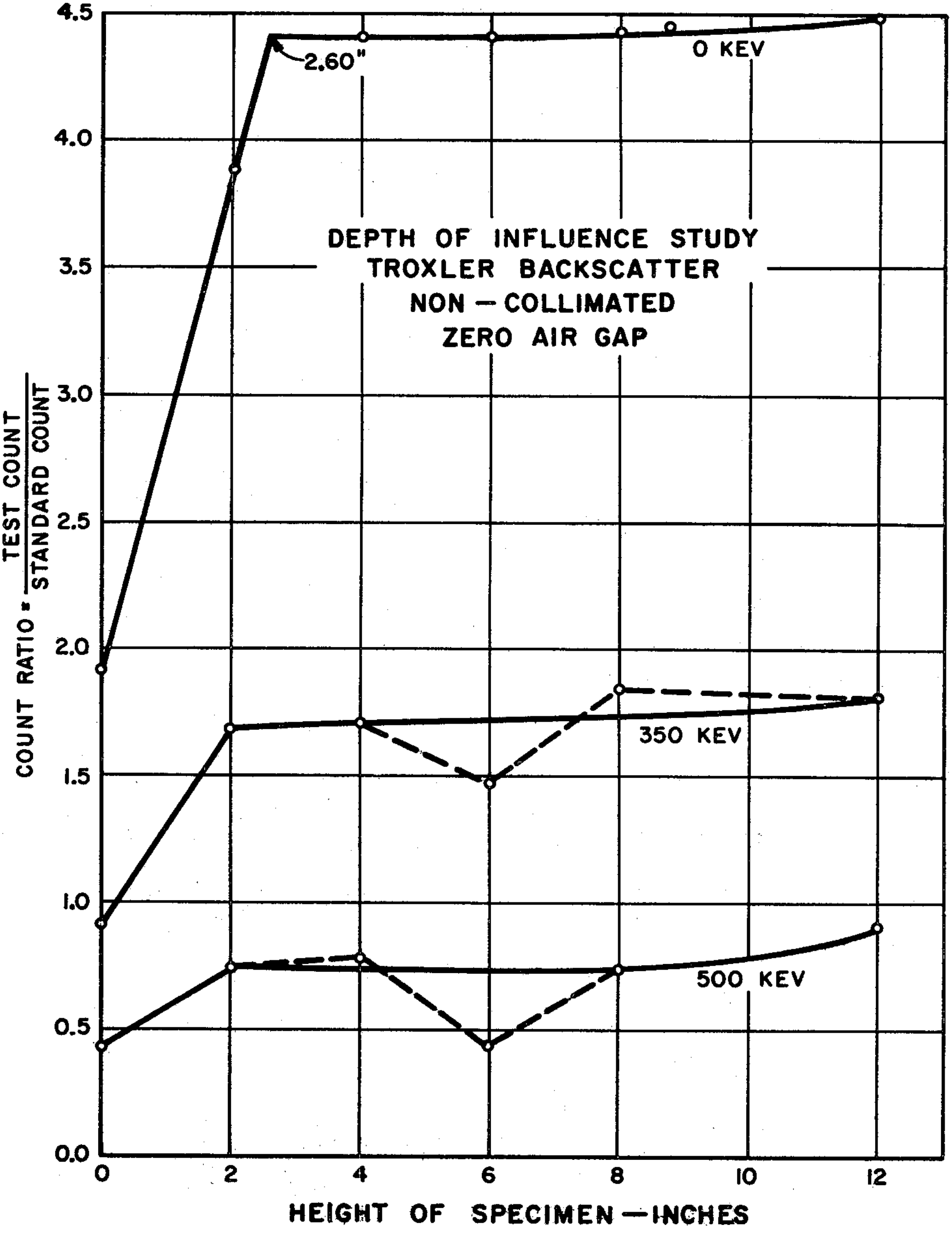

4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
COUNT RATIO = TEST COUNT / STANDARD COUNT
2.60"
0 KEV
DEPTH OF INFLUENCE STUDY
TROXLER BACKSCATTER
NON — COLLIMATED
ZERO AIR GAP
350 KEV
500 KEV
0
2
4
6
8
10
12
HEIGHT OF SPECIMEN — INCHES

FIGURE 47

DEPTH OF INFLUENCE STUDY
TROXLER BACKSCATTER
COLLIMATED
ZERO AIR GAP

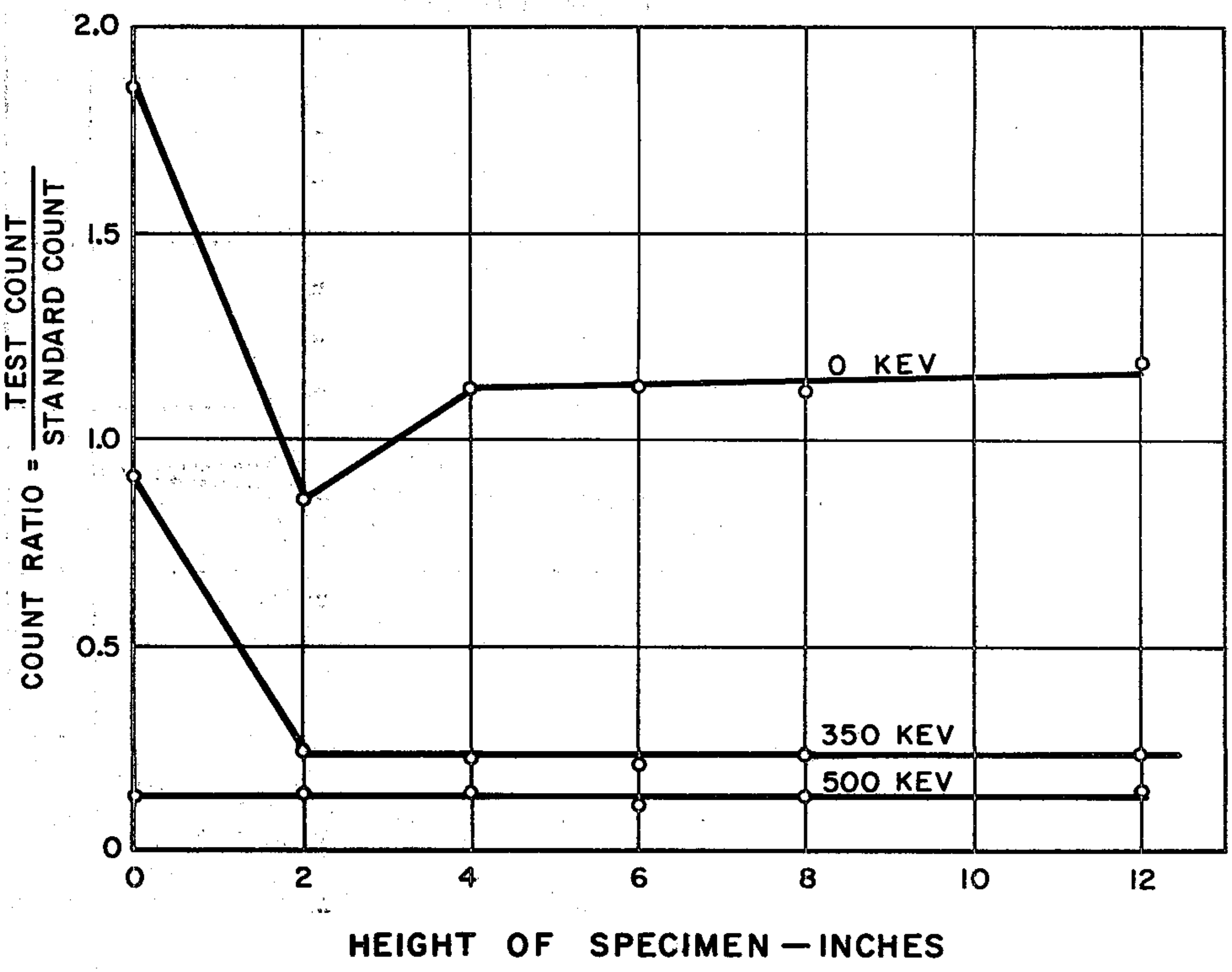


FIGURE 48

DEPTH OF INFLUENCE STUDY
TROXLER BACKSCATTER
NON – COLLIMATED
1/2" AIR GAP

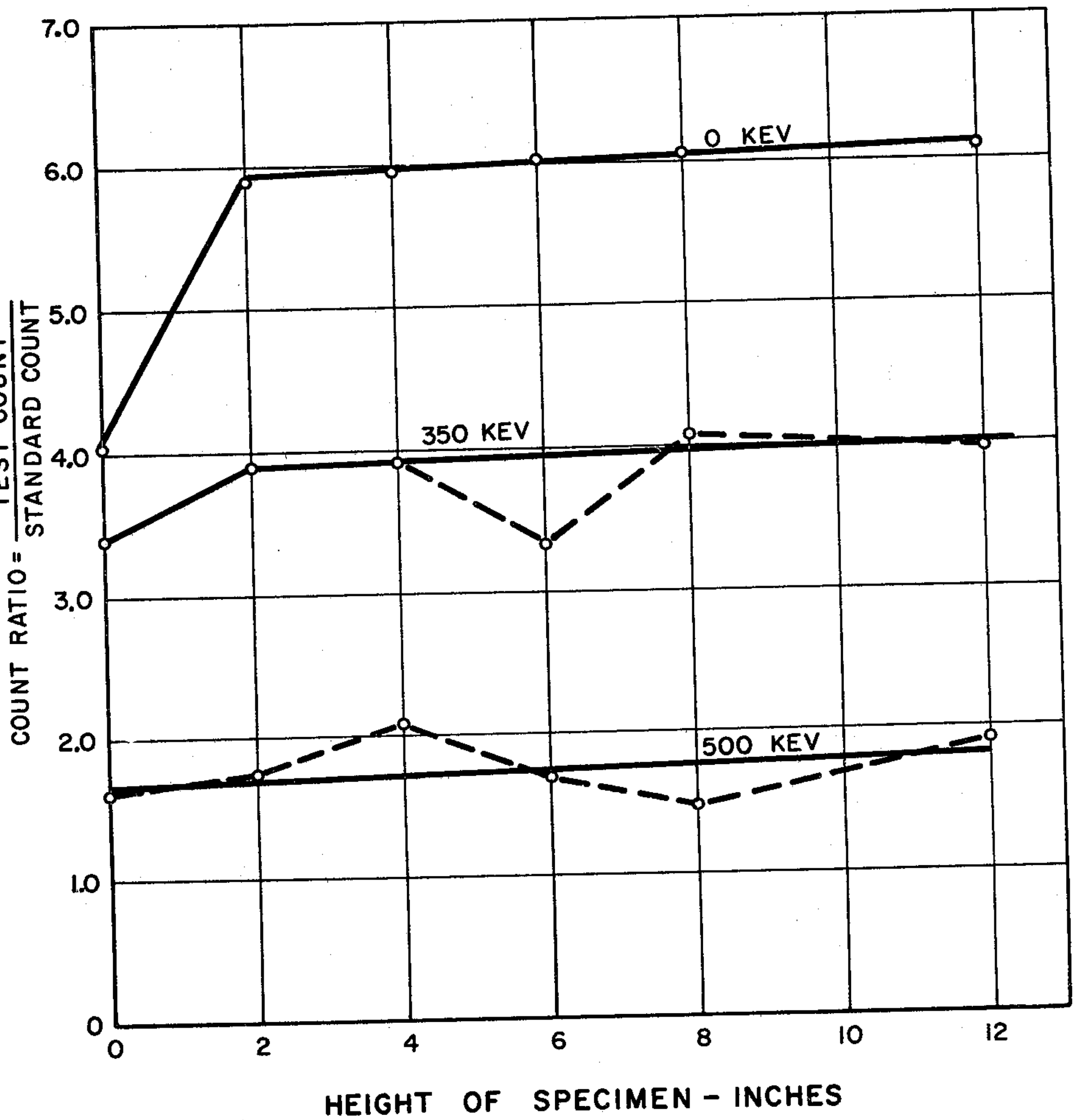
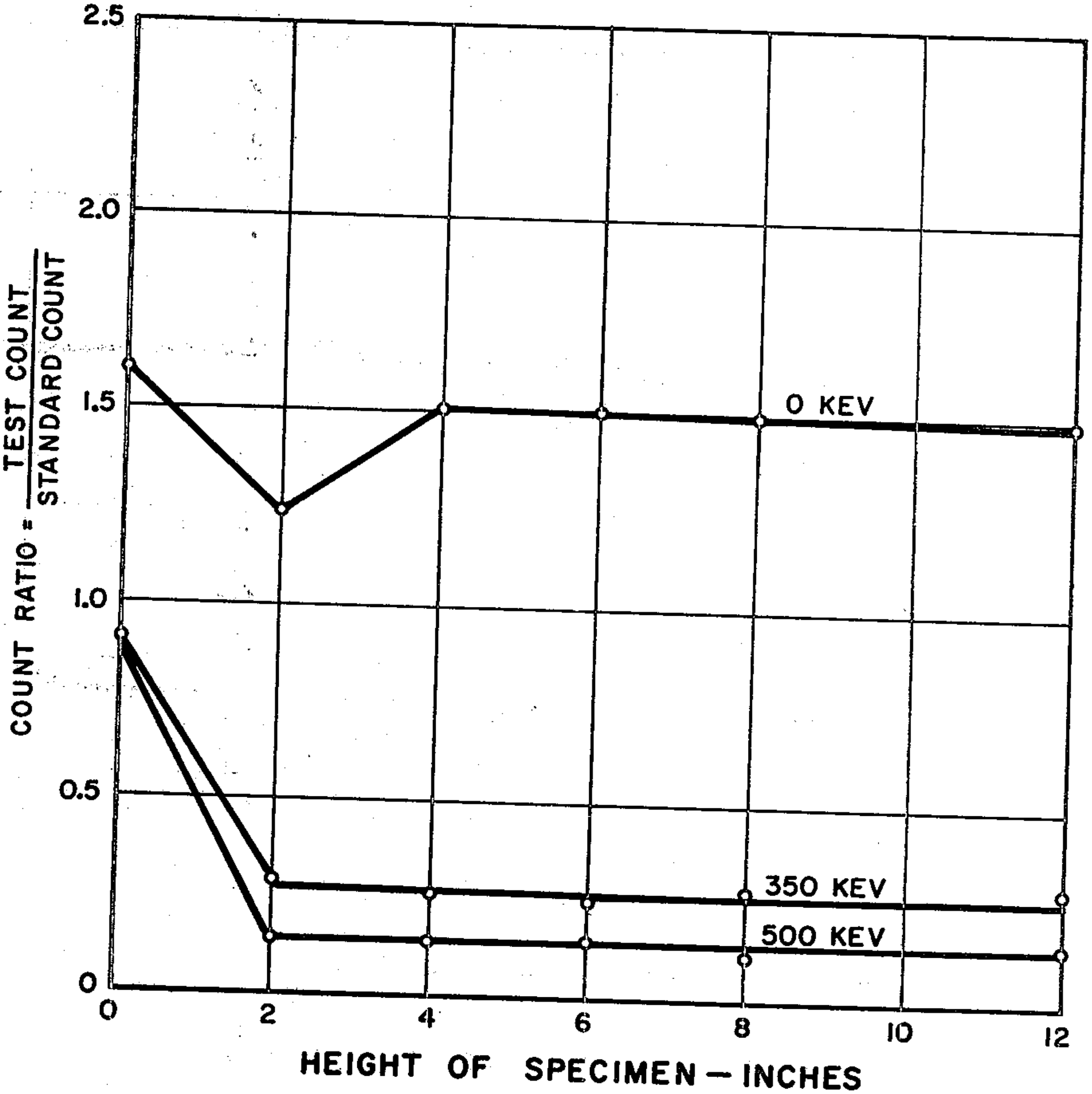


FIGURE 49

DEPTH OF INFLUENCE STUDY, DENSITY
TROXLER BACKSCATTER
COLLIMATED
1/2" AIR GAP



DEPTH OF INFLUENCE STUDY
HIDRODENSIMETER BACKSCATTER

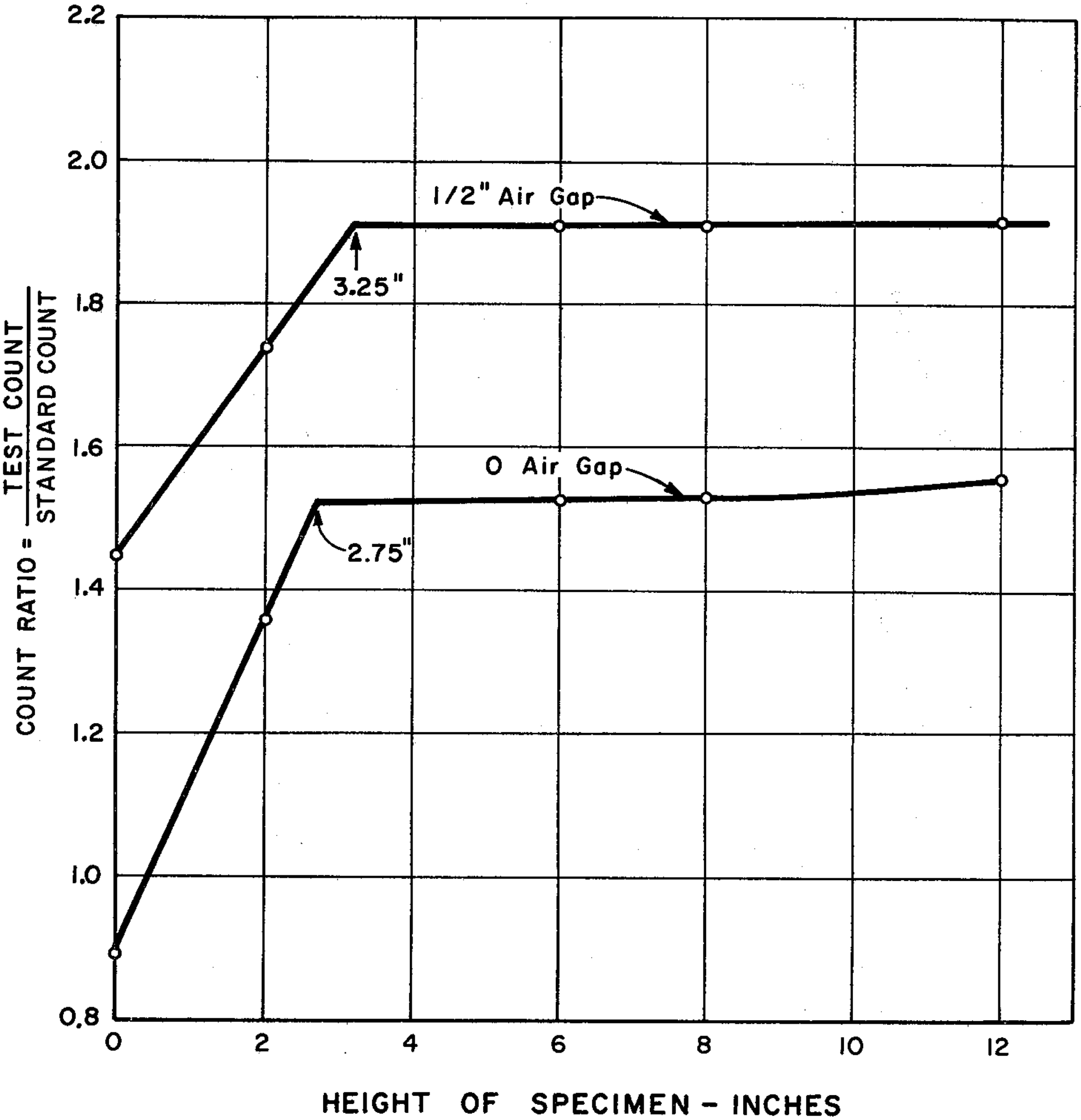


FIGURE 51

DEPTH OF INFLUENCE STUDY
NUMEC BACKSCATTER

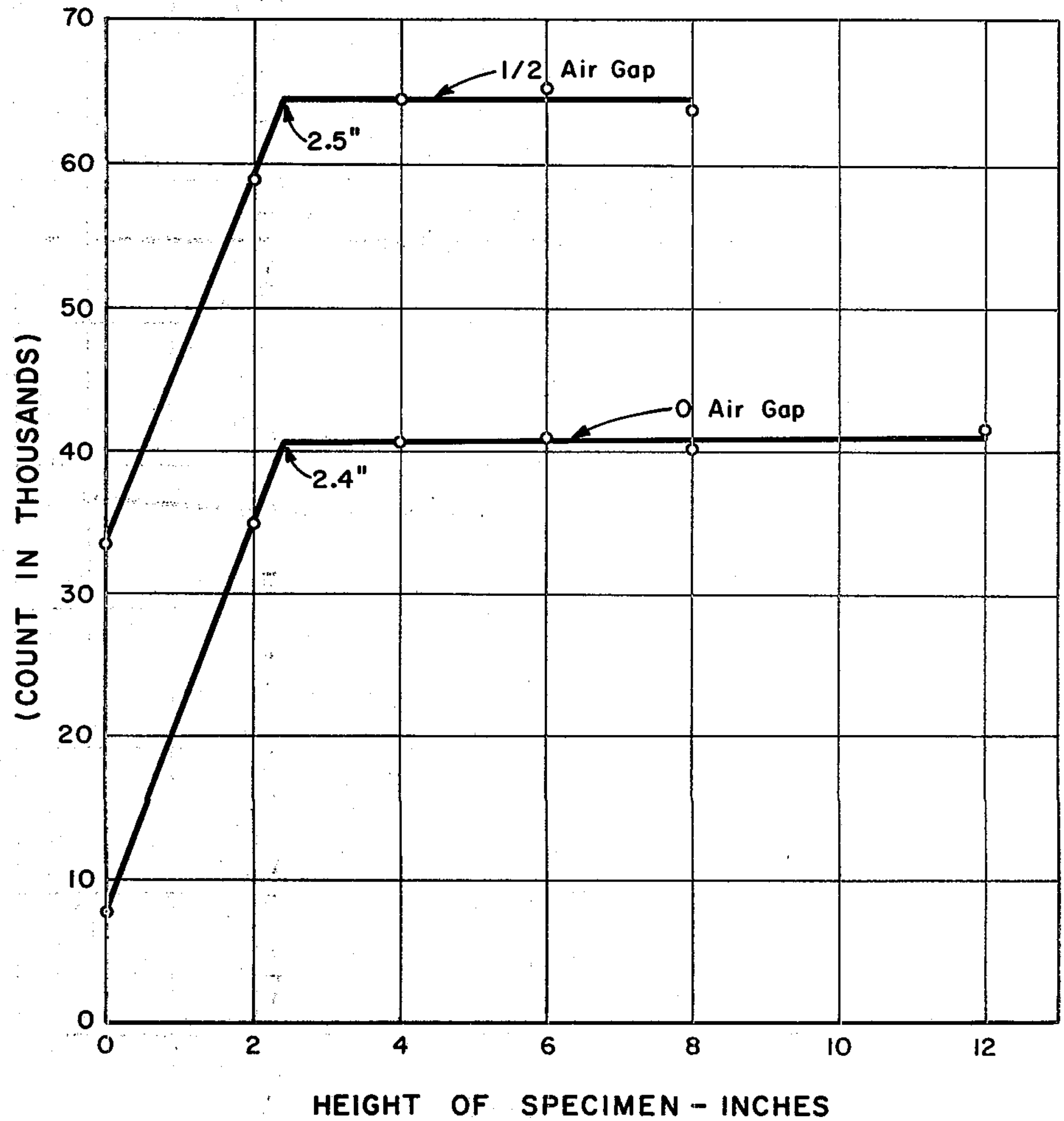


FIGURE 52

DEPTH OF INFLUENCENCE STUDY, MOISTURE
TROXLER

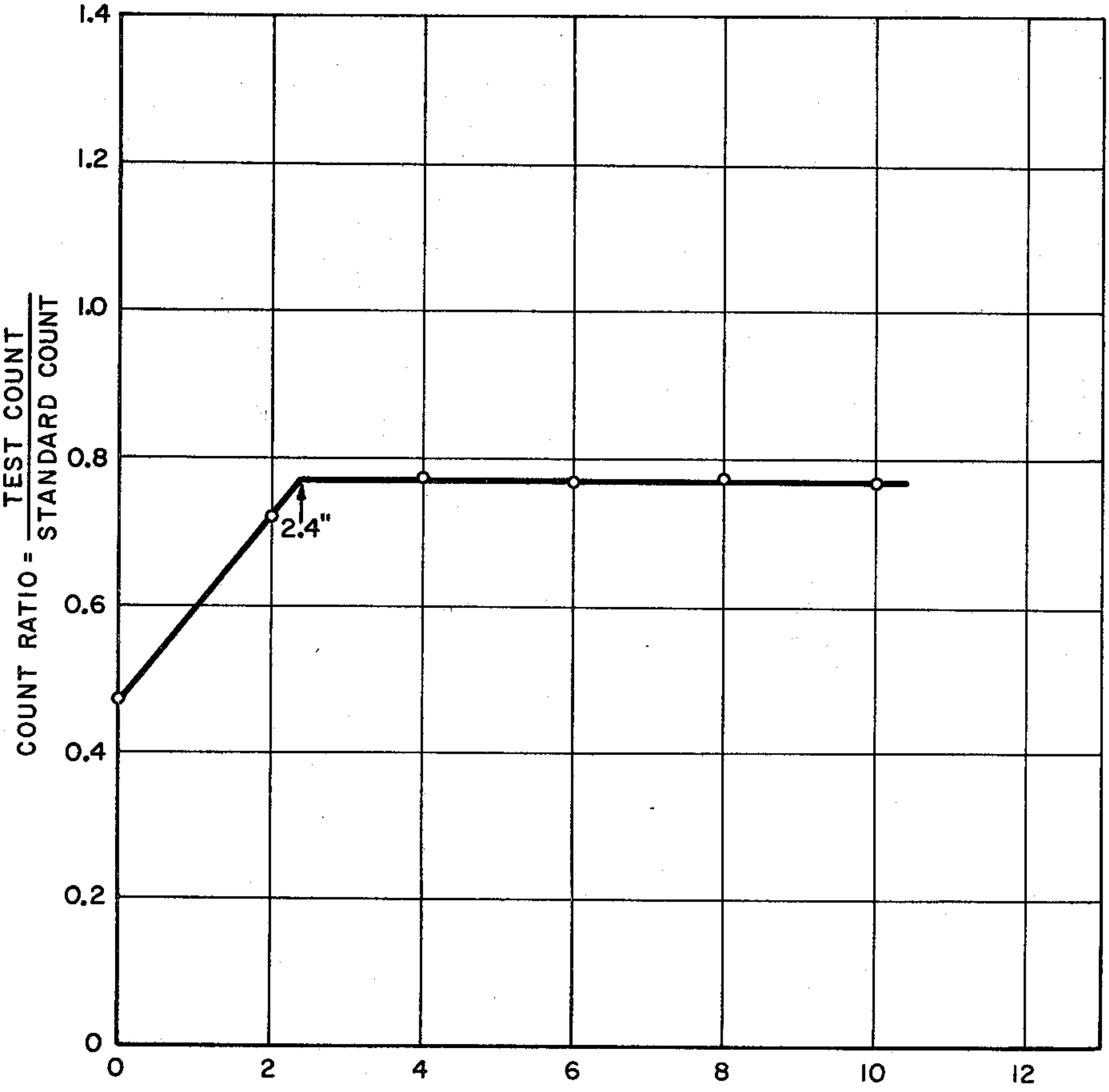


FIGURE 53

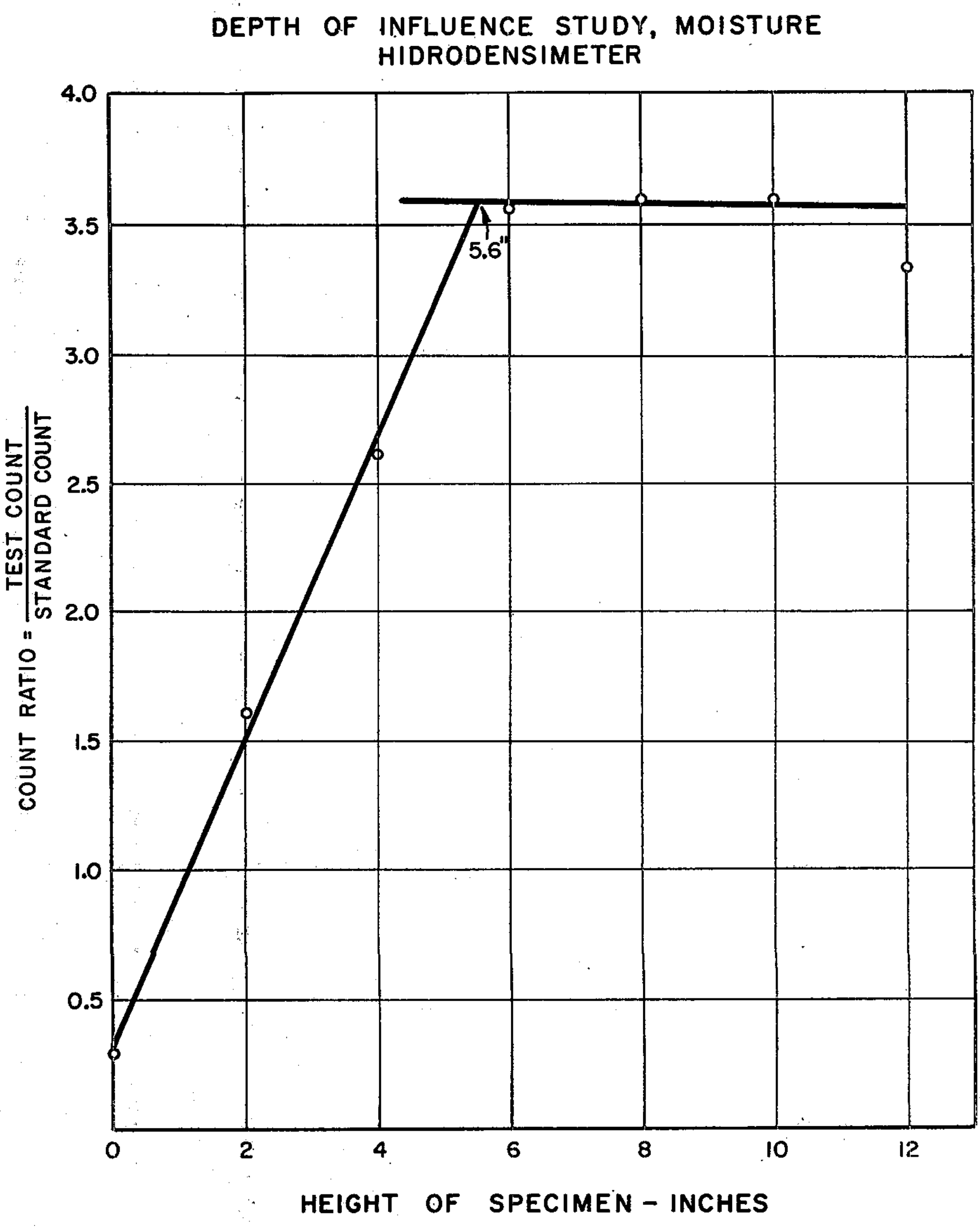

DEPTH OF INFLUENCE STUDY, MOISTURE
HIDRODENSIMETER
COUNT RATIO = TEST COUNT / STANDARD COUNT
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
5.6"
0
2
4
6
8
10
12
HEIGHT OF SPECIMEN - INCHES

FIGURE 54

DEPTH OF INFLUENCE STUDY, MOISTURE
NUMEC

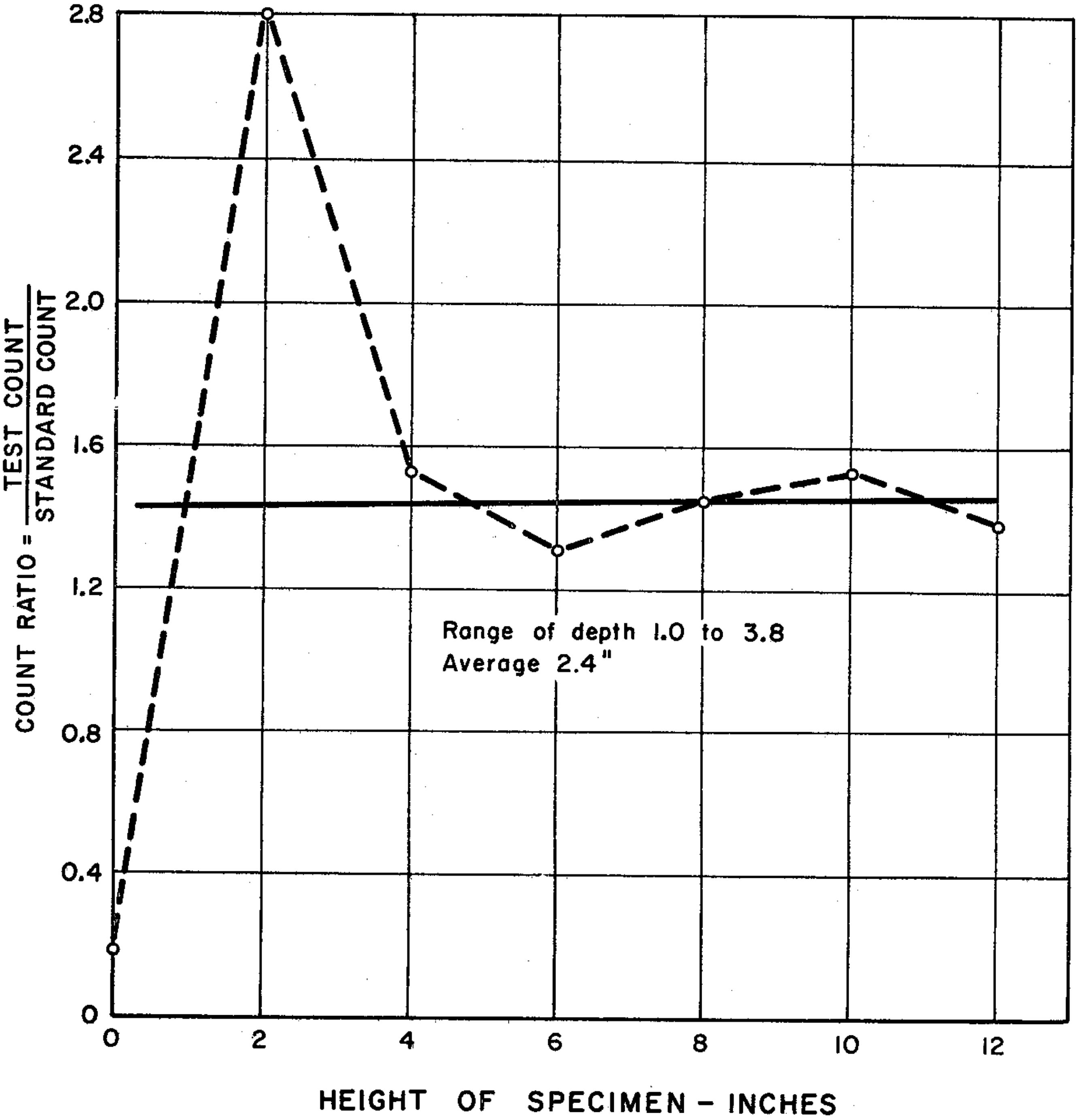


FIGURE 55

TABLE 15

Depth of Influence Study
Backscatter and Moisture
(Count, Count Ratio)

Test	Instrument	KEV	Air Gap	Probe Position	Count Ratio: Height of Sample in Inches 12.0	10.1	8.1	6.1	4.0	1.9	0.0
Backscatter	Troxler	0	0	-3/4"	1.19		1.12	1.13	1.13	0.86	1.86
		0	0	0	4.50		4.43	4.42	4.42	3.89	1.91
		0	½"	-3/4"	1.51		1.51	1.53	1.52	1.24	1.60
		0	½"	0	6.10		6.02	6.00	5.95	5.73	4.27
		350	0	-3/4"	0.25		0.25	0.21	0.23	0.25	0.91
		350	0	0	1.82		1.85	1.47	1.71	1.69	0.90
		350	½"	-3/4"	0.29		0.28	0.24	0.26	0.29	0.91
		350	½"	0	3.93		4.07	3.32	3.80	3.74	3.42
		500	0	-3/4"	0.15		0.13	0.11	0.15	0.15	0.13
		500	0	0	0.90		0.74	0.43	0.78	0.74	0.45
		500	½"	-3/4"	0.15		0.10	0.15	0.14	0.15	0.89
		500	½"	0	1.95		1.46	1.70	2.07	1.75	1.61
	Hidro-densimeter	-	0	0	1.56		1.53	1.53	-	1.36	0.89
		-	½"	0	1.92		1.90	1.91	-	1.73	1.45
	Numec	-	0	-	41,610		40,300	40,970	40,690	34,880	7,960
		-	½"	-	-		1.85	1.78	1.71	1.59	0.91
Moisture	Troxler					0.77	0.77	0.77	0.78	0.72	0.47
	Hidro-densimeter				3.33	3.61	3.60	3.57	2.63	1.62	0.30
	Numec				1.39	1.53	1.46	1.32	1.54	2.80	0.19

TABLE 16

Width of Influence Study
Backscatter and Moisture

Test	Instrument	KEV	Air Gap	Probe Position	Percent of ℄ Readings							
					Inches from Edge of Soil							
					8	7	6	5	4	3	2	1
Backscatter	Troxler	0	0	-3/4"	100	100	100	99	100	99		112
		0	0	0	100	100	100	100	99	98	95	93
		0	1/2"	-3/4"	100	100	100	100	99	98	98	
		0	1/2"	0	100	100	100	99	99	97	94	
		350	0	-3/4"			100			99		
		350	0	0			99			101		
		350	1/2"	-3/4"		98	100	95		98		
		350	1/2"	0		102	99	95		94		
		500	0	-3/4"			112		98	97		
		500	0	0			98		95	102		
		500	1/2"	-3/4"			97		100	96		
		500	1/2"	0			98		95	96		
	Hidrodensimeter	-	0	0		100	100	99	99	98	96	
		-	1/2"	0		100	100	99	98	95	92	
	Numec	-	0	-				101	99	98	91	
Moist.	Hidrodensimeter						95	89	84	70		
	Numec							91	91	74	59	

The study of the volume of soil measured by the transmission tests was conducted with a soil sample compacted to a wet density of 128 lbs. per cu. ft. The first set of measurements were made using only the 7/8" transmission hole. Holes were then drilled in the arrangements shown in Figure 56 as successive sets of measurements were made. The results of these are graphically shown by Figures 58 and 59. These graphs indicate at which point the readings for a particular test were affected by the proximity of the rows of holes. The assumptions made in determining the volumes are presented in Figure 57. The dimension "D" is estimated from the data shown in the prior figure. A calculated volume of soil measured by each test according to this criteria is shown by Table 17.

The volume of soil affecting the transmission test tended to increase with the increased depth that the source was in the soil with the Troxler gage. Also the volume of soil affecting the nuclear readings decreased when higher discrimination levels were used for the detector. The range of volumes of soil was 0.02 to 0.10 cubic foot.

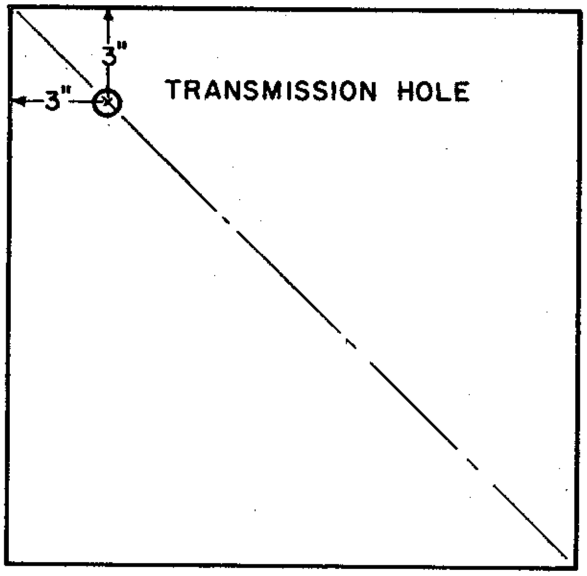
The data in Figure No. 58 indicates that the diameter of influence was proportional to the energy level of discrimination at the detector. That is the higher the energy level of discrimination the smaller the zone of influence. This is due to the restriction of the angle of the compton rebound photons being detected as the discrimination level is increased.

The Hidrodensimeter had the pickup tube placed in the soil and the source on the ground surface, which is the reverse of of the Troxler gage. The diameter of the sphere of influence of the Troxler was about 7 inches and the Hidrodensimeter was about 4 inches in diameter. The source used in the Troxler was Cs^{137} and in the Hidrodensimeter Ra^{226}. It is not known whether the geometry or the energy level of the gamma photons is responsible for this difference in the diameter of influence of these two gages.

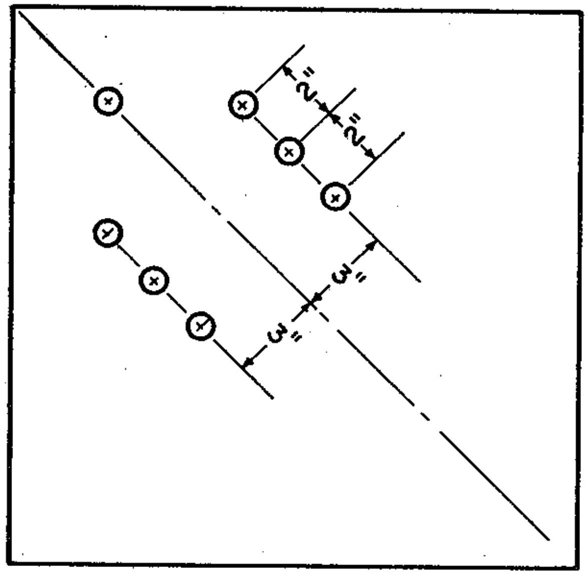
TRANSMISSION VOLUME STUDY

Arrangement of holes used in making the determinations of the volumes measured by the transmission technique.

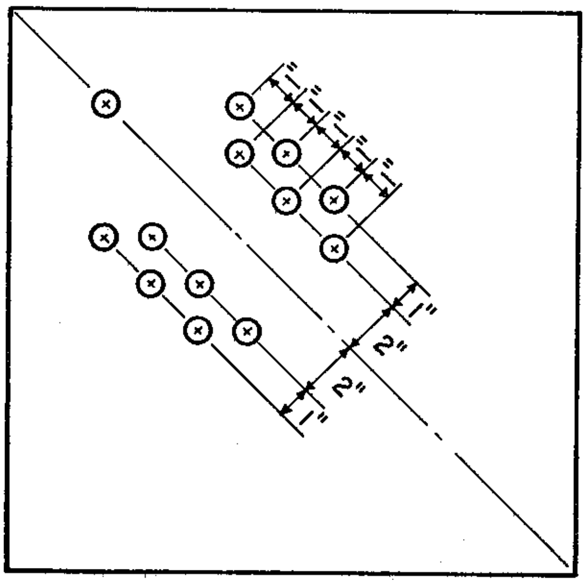
NOTE: Mold is 18"x 18" x 12", 18" x 18" Side shown. All holes are 7/8" in diameter.



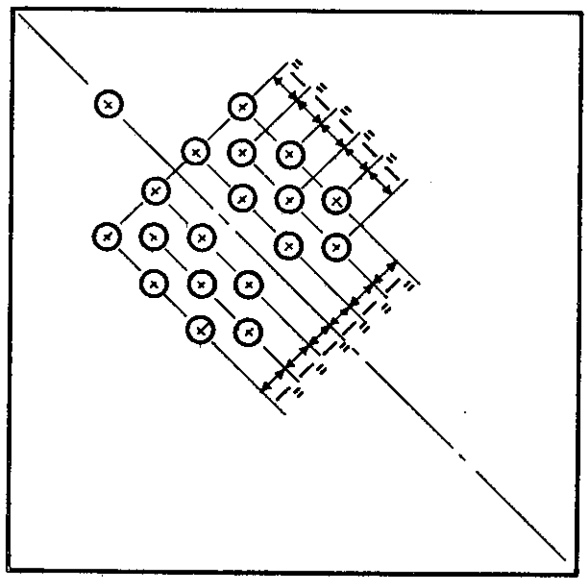
A



B



C



D

FIGURE 56

TRANSMISSION VOLUME STUDY

ASSUMED SHAPE FOR CALCULATION OF TRANSMISSION VOLUMES

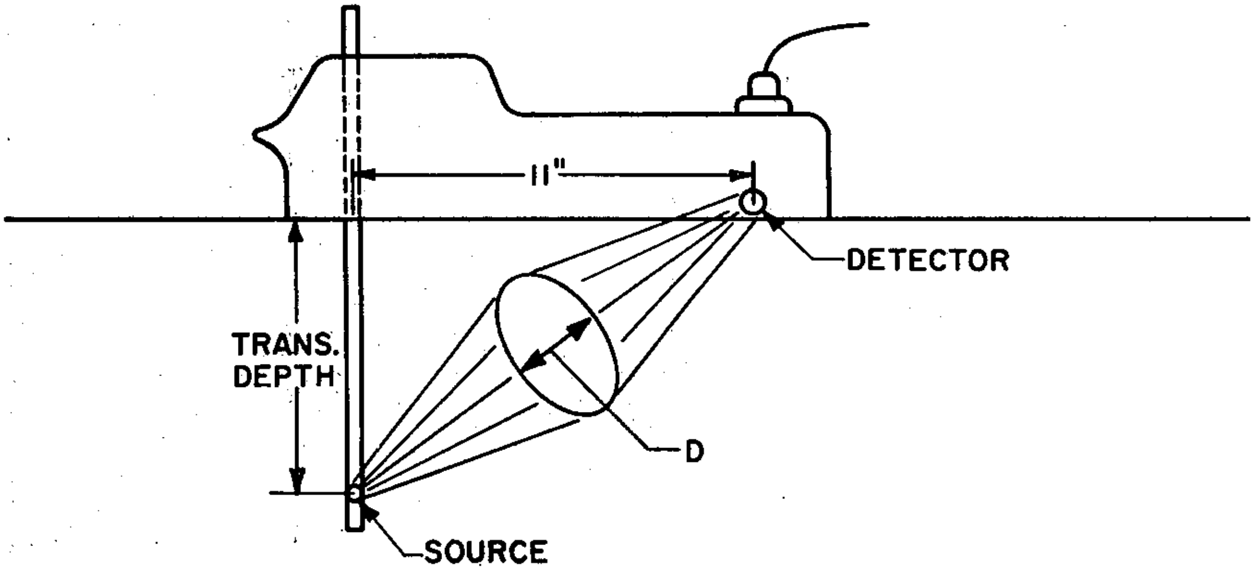


FIGURE A — TROXLER

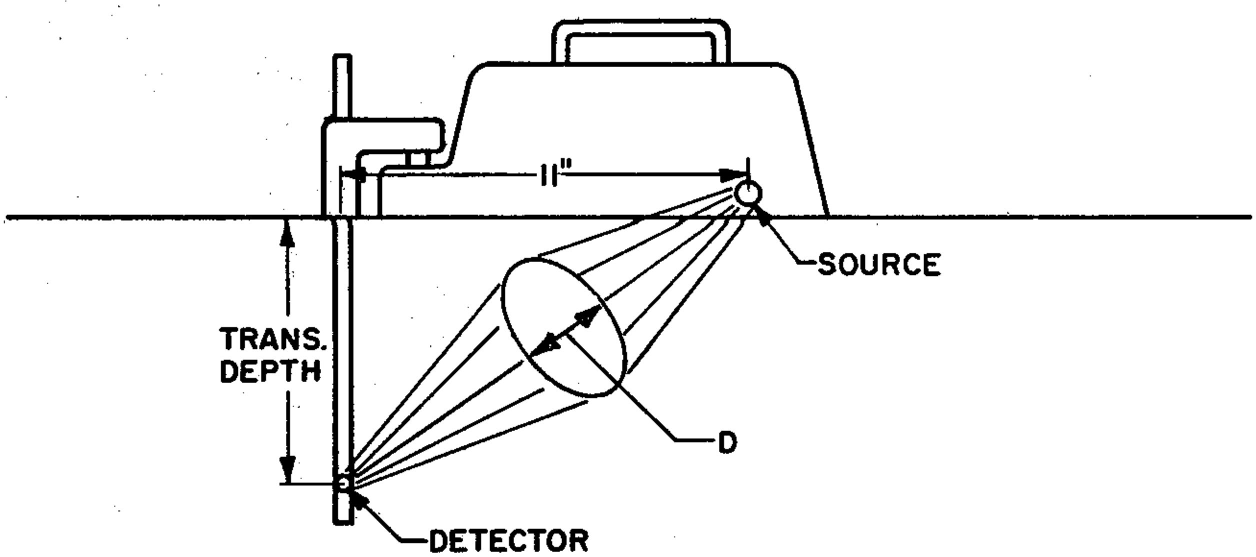


FIGURE B — HIDRODENSIMETER

FIGURE 57

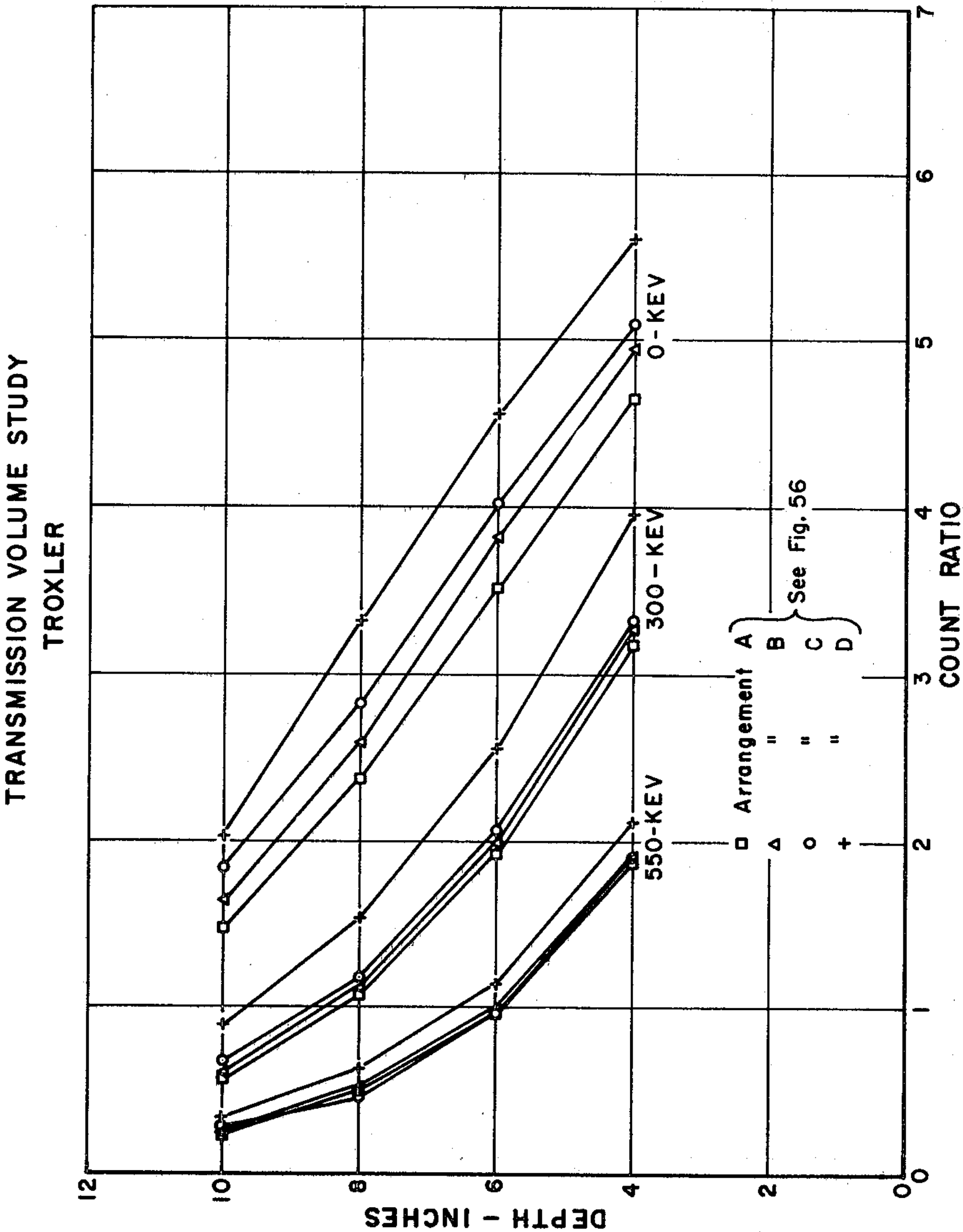

TRANSMISSION VOLUME STUDY
TROXLER
DEPTH - INCHES
COUNT RATIO
0-KEV
300-KEV
550-KEV
□ Arrangement A
△ " B
○ " C
+ " D
See Fig. 56
0
1
2
3
4
5
6
7
2
4
6
8
10
12

FIGURE 58

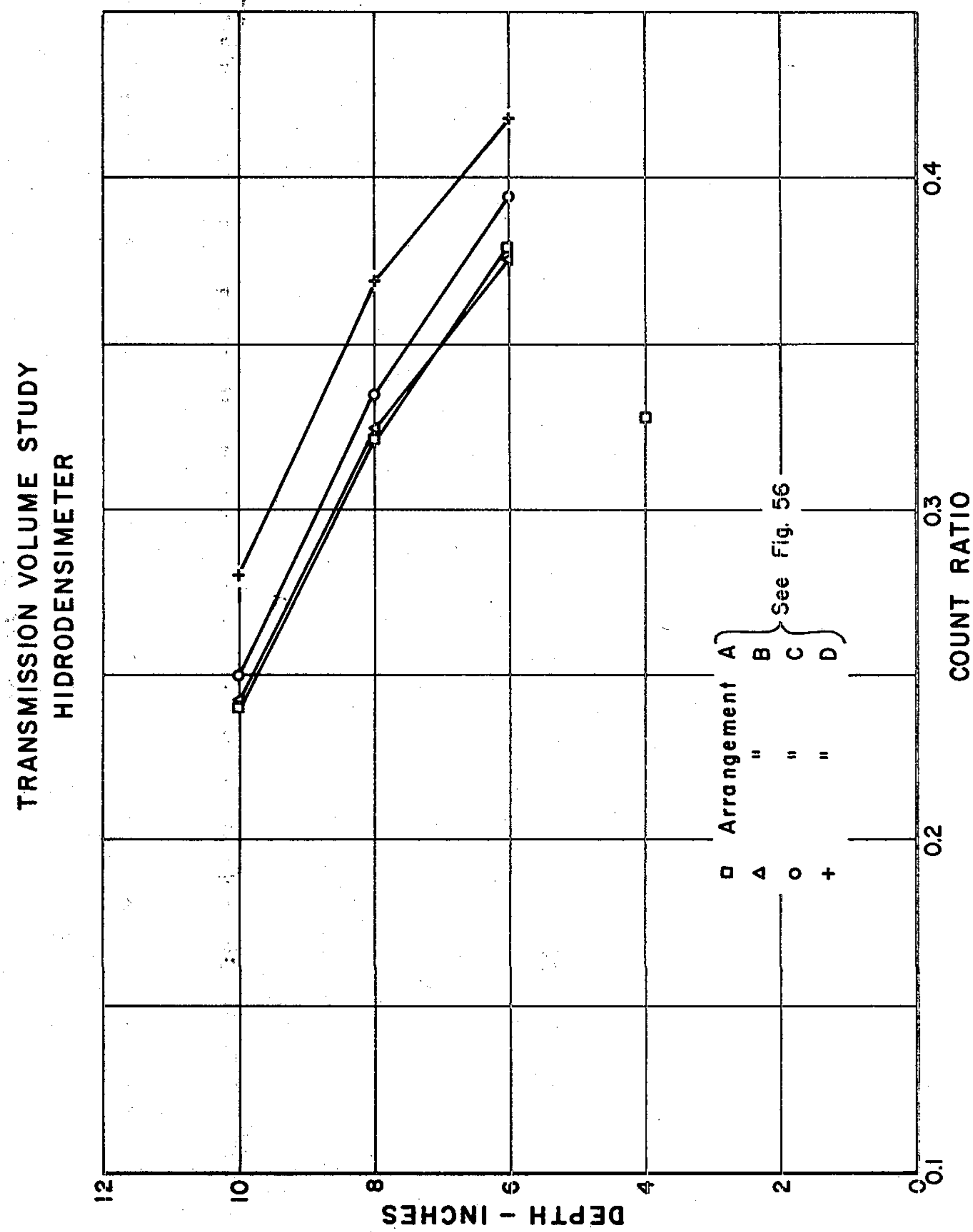

TRANSMISSION VOLUME STUDY
HIDRODENSIMETER
DEPTH - INCHES
12
10
8
6
4
2
0
COUNT RATIO
0.1
0.2
0.3
0.4
□ Arrangement A
Δ " B
o " C
+ " D
See Fig. 56

FIGURE 59

TABLE 17

TRANSMISSION VOLUME STUDY

SUMMARY TABLE

Depth of Transmission (inches)	Diameter of Cone (inches)	Length of Cone (inches)	Volume of Cone (ft.^{3})
TROXLER 0 KEV			
4	7.2	11.7	0.08
6	7.2	12.5	0.09
8	7.2	13.6	0.09
10	7.2	14.9	0.10
TROXLER 300 KEV			
4	5.4	11.7	0.04
6	5.4	12.5	0.05
8	5.4	13.6	0.05
10	5.4	14.9	0.06
TROXLER 550 KEV			
4	3.4	11.7	0.02
6	3.4	12.5	0.02
8	3.4	13.6	0.02
10	3.4	14.9	0.02
HIDRODENSIMETER			
4		11.7	0.02
6		12.5	0.02
8		13.6	0.02
10		14.9	0.02

DISCRIMINATION AND SPECTRA

The photons or gamma rays received by the detector tubes have a wide range of energies. The Troxler instrument used in this study is constructed so that it may be set to detect only photons having energies equal to or greater than that selected. This practice has been termed discrimination. Thus, a discriminator setting of 300-KEV means that only photons having energies greater than 300 kilo electron vols will be detected by the instrument.

This particular instrument can also be set to detect gamma rays within a particular range of energies. Studies may be then made of the spectrum received by the detector for a given test condition. The range of energies selected for this work was 2.5 percent of the maximum energy setting, which was 1000 KEV in all of the studies.

The significance of the spectra is that the greater the area between the curves the greater the ability of the nuclear system to detect changes in density. Also the energy levels of the gamma rays that are detected which are responding to a change in density can be studied. Thus, the response of a nuclear system to a change in density and the need for discrimination of the detected gamma rays can be evaluated.

Backscatter and transmission spectrum measurements were obtained for rough and smooth surfaces at two densities on the South Sacramento soil. Spectrum measurements were also made at one density each for the Folsom soil and the volcanic tuff. These graphs are plotted on semi-logarithmic scale and presented in Figures 60 thru 64.

The spectrum curve for the noncollimated backscatter test without air gap, normal backscatter type gage, Figure 60 shows that the curves for the different densities tend to be somewhat parallel. This means that the relative response to density is equal at all energy levels for the normal backscatter test. The use of discrimination of the detector would not improve the sensitivity of this type of test.

There is a distinct curve (Figure 60) generated for the 77 lbs. per cu. ft. material, the volcanic tuff; but the curves for the 115 and 135 lbs. per cu. ft. soils are very close together. This indicates that the test is slightly responsive to a variation in soil density for this range of densities. Also, the effect of surface roughness upon the nuclear readings is as much as the effect of density.

The two curves for the Folsom and South Sacramento soils at 136 and 135 pounds per cubic foot indicate that there is some minor difference in the energy levels of the gammas being received by the detector. This could either be due to changes in soil type or surface condition. However, the limited data is not conclusive.

The collimated backscatter test without air gap, Figure 61, shows a clear difference between the curves of 77, 115, and 135 lbs. per cu. ft. density up to about the 400 KEV energy level. The relative effect of the surface roughness upon the nuclear readings is minor. The convergence of the curves (Figure 61) above the 400 KEV energy level may be largely due to leakage radiation from within the gage and not from reflected rays from the soil. The use of discrimination should increase the sensitivity of this type of test.

The curves for the Folsom and South Sacramento soils at 136 and 135 pounds per cubic foot are almost identical. This would indicate that there is no effect of soil type

The noncollimated backscatter test with the 3/4-inch air gap, Figure 62, shows a varied response to density and roughness. The effect of the 1/16-inch roughness is as great as that of the higher density for this test condition.

The collimated backscatter test with the 3/4-inch air gap Figure No. 63 exhibits a constant distance between the curves of different density, and the roughnened surface has an effect upon the nuclear readings.

The data indicates that the use of an air gap increases the effect of surface roughness rather than improving the readings, but collimating the source helps overcome both the effect of roughness, and the combined effect of surface roughness and air gap.

The transmission spectrum with the source at the 6 inch depth, Figure 64, shows an increase in response to density variation as the selected energy increases. This indicates that the higher energy level gamma rays are more sensitive in indicating the change in density than the lower energy gamma rays. However, all energies of gamma rays indicate a response to a change in density. The gamma rays below about 400 KEV are primarily the result of compton rebound, but do not indicate the affect of surface roughness that the backscatter gage does. The affect of surface roughness is minor in the transmission test. This means that discrimination may possibly be useful with the transmission technique to increase the sensitivity to a variation in density.

The difference between the curves of the different densities for the transmission gage is greater than that of the backscatter test, and the relative effect of surface roughness is less. The indication is that the transmission type test has a greater capacity to respond to density than the backscatter test.

The curves for the Folsom and South Sacramento soils are identical, which would indicate no affect of soil type in the transmission type test.

COMPTON BACKSCATTER SPECTRUM
SO. SACRAMENTO SOIL, VOLCANIC TUFF, FOLSOM SOIL
COMPARING SURFACE CONDITION AND DENSITY OF SOIL
SOURCE NON COLLIMATED

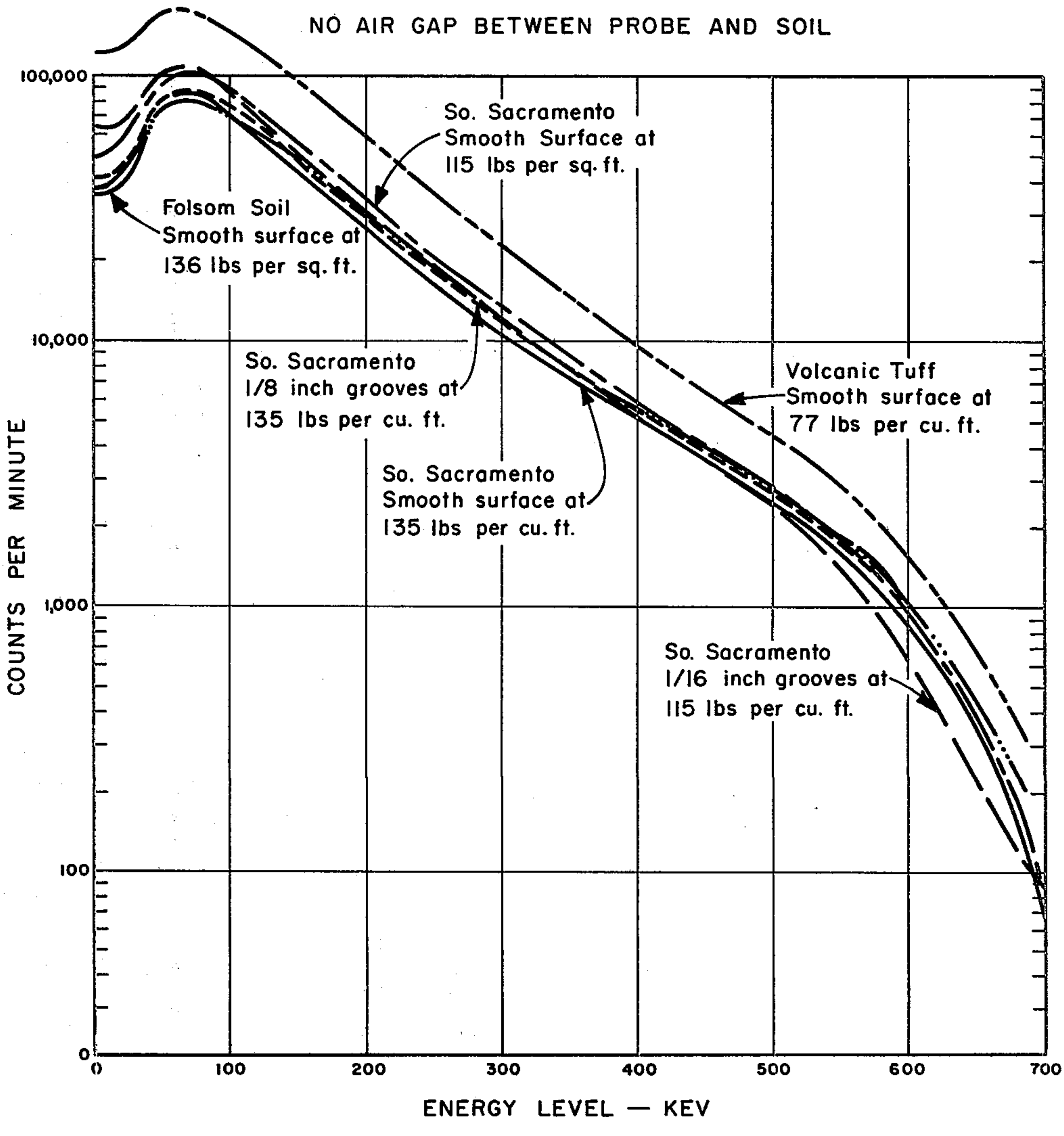


FIGURE 60

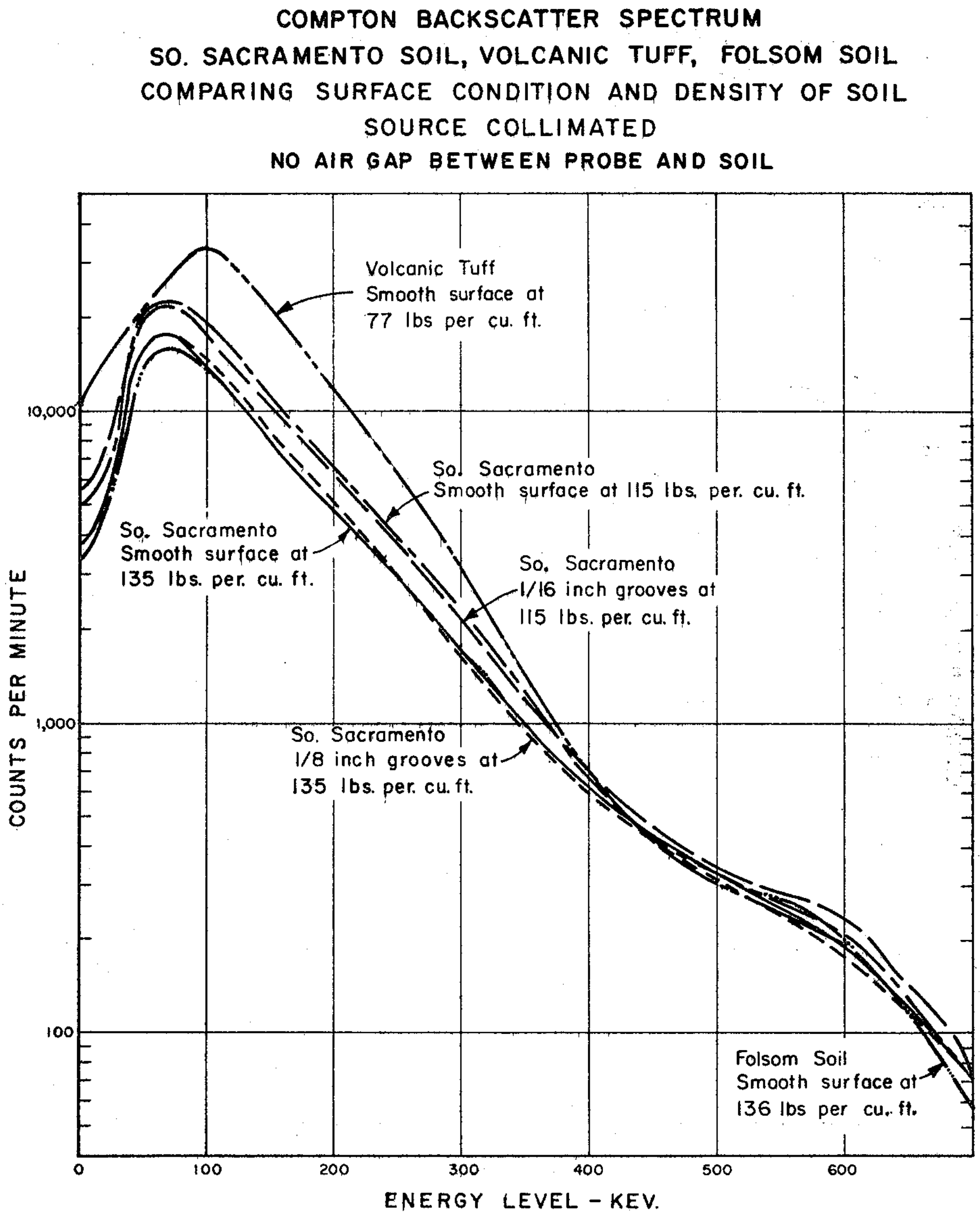

COMPTON BACKSCATTER SPECTRUM
SO. SACRAMENTO SOIL, VOLCANIC TUFF, FOLSOM SOIL
COMPARING SURFACE CONDITION AND DENSITY OF SOIL
SOURCE COLLIMATED
NO AIR GAP BETWEEN PROBE AND SOIL
Volcanic Tuff Smooth surface at 77 lbs per cu. ft.
So. Sacramento Smooth surface at 115 lbs. per. cu. ft.
So. Sacramento Smooth surface at 135 lbs. per. cu. ft.
So. Sacramento 1/16 inch grooves at 115 lbs. per. cu. ft.
So. Sacramento 1/8 inch grooves at 135 lbs. per. cu. ft.
Folsom Soil Smooth surface at 136 lbs per cu. ft.
COUNTS PER MINUTE
10,000
1,000
100
0
100
200
300
400
500
600
ENERGY LEVEL - KEV.

FIGURE 61

COMPTON BACKSCATTER SPECTRUM, SO. SACRAMENTO SOIL
COMPARING SURFACE CONDITION AND DENSITY OF SOIL
SOURCE NON COLLIMATED

3/4 INCH AIR GAP

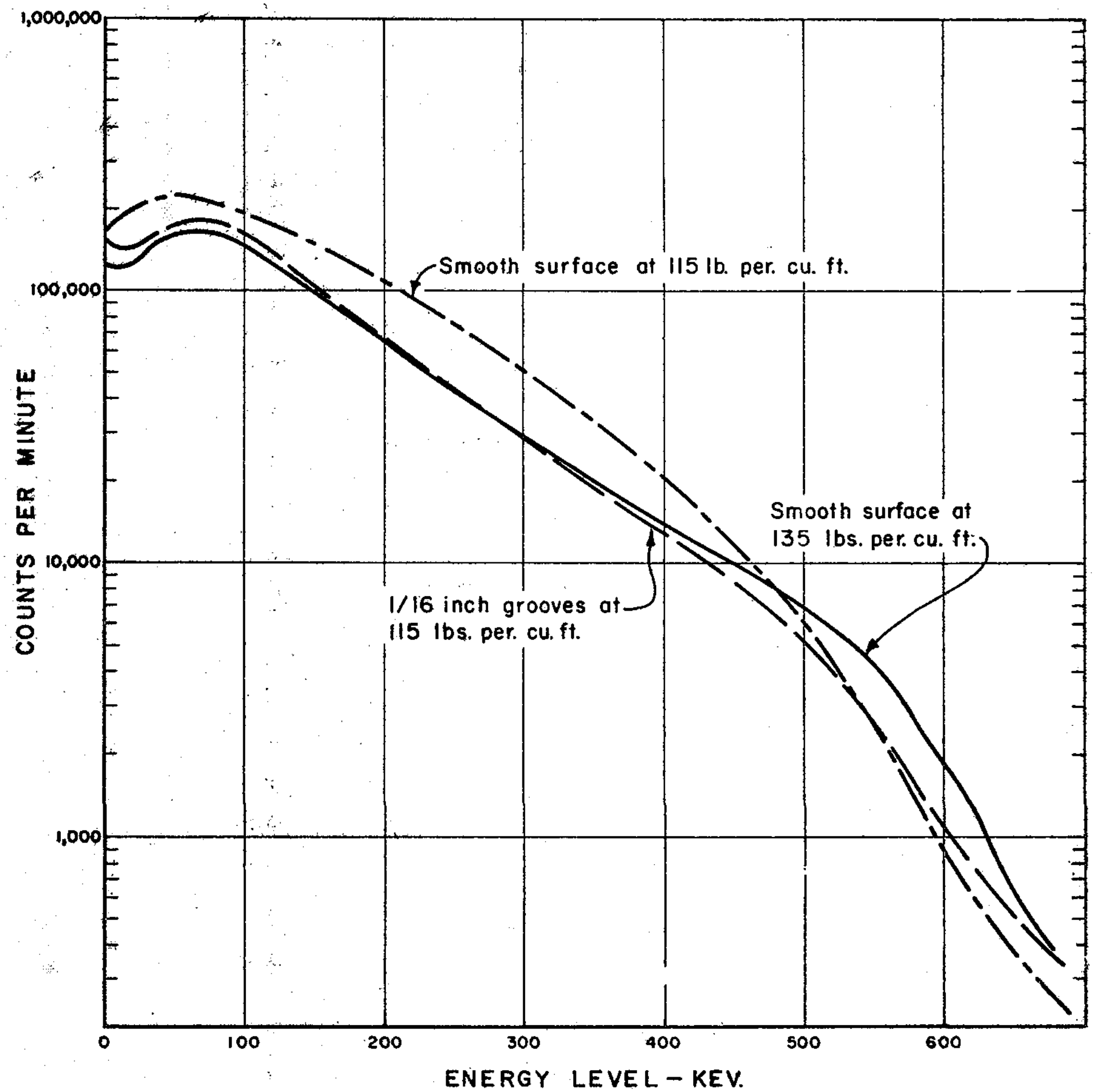


FIGURE 62

COMPTON BACKSCATTER SPECTRUM, SO. SACRAMENTO SOIL
COMPARING SURFACE CONDITION AND DENSITY OF SOIL
SOURCE COLLIMATED
3/4 INCH AIR GAP

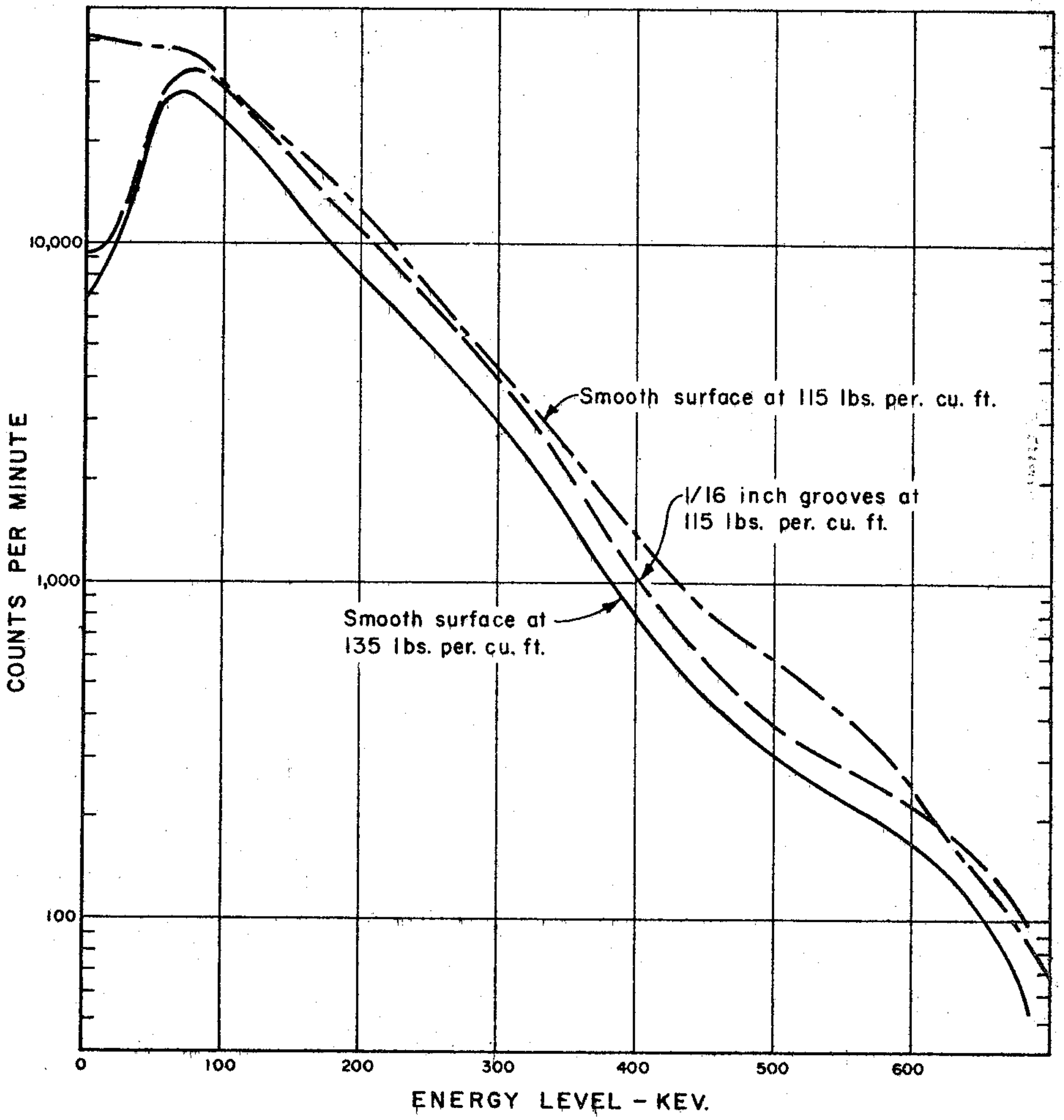


FIGURE 63

TRANSMISSION SPECTRUM
SO. SACRAMENTO SOIL, VOLCANIC TUFF, FOLSOM SOIL
COMPARING SURFACE CONDITION AND DENSITY OF SOIL
6" PROBE DEPTH

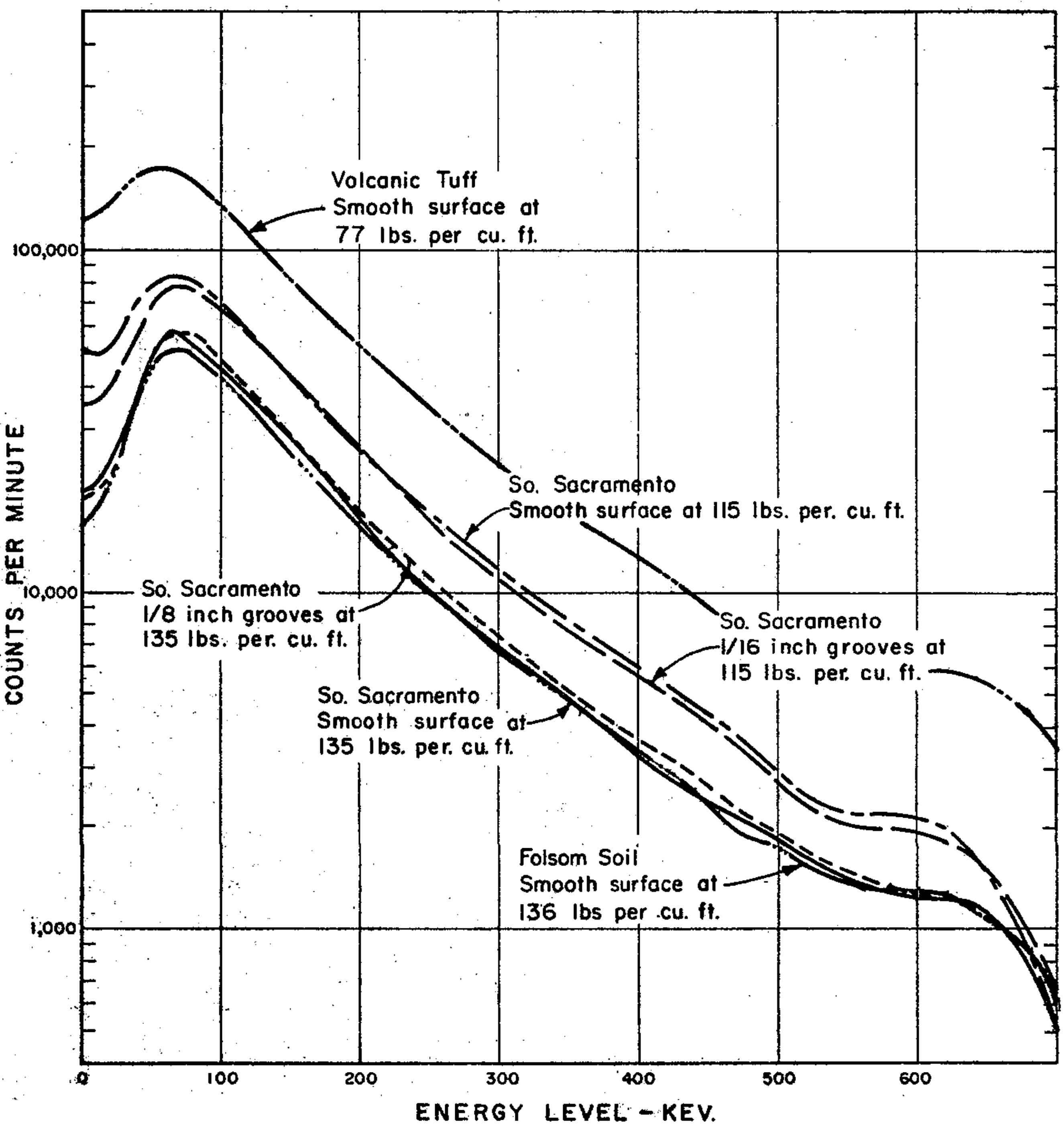


FIGURE 64

MOLD SIZE, EFFECT OF COMPACTION PLANES ON DENSITY READINGS

Early in the test program an effort was made to check the 12" x 12" x 18" mold to be sure it provided an effective infinite volume for the nuclear probes. This was done by placing concrete blocks against the mold sides to see if the count changed due to the presence of the high density material. No noticeable effect on the count was observed, and it was concluded that the mold was sufficiently large.

This effort included placing paraffin blocks against the mold to check for infinite volume with respect to moisture determination. It was found to be satisfactory.

To evaluate the effects of taking measurements across the compaction layers the soil specimen (123 lbs. per cu. ft.) was turned so that readings could be taken on the sides and bottom. It was hoped this would minimize the effect of unavoidable differences in density within compaction layers.

Figure 65 shows the numbering scheme that was used to identify the various sides of the soil sample during the experiment.

The results are reported in terms of count ratio in Table 18. By using the calibration curves determined in this study the differences in densities represented by the count ratio change have been estimated to be six to seven lbs. per cu. ft. for the backscatter gages and about three lbs. per cu. ft. for the transmission gages. The range for the moisture gages is approximately 2 lbs. per cu. ft.

Previous work had indicated that the backscatter type gages required different calibration curves for different soil types. Limited work had indicated that this was due to the density gradient within each compacted layer. The concept used in this study of measuring across the compaction planes was to minimize this effect, and the data obtained substantiates the previous work. It is now apparent that the backscatter gages are extremely sensitive to a density gradient within the soil directly below the gage. This effect of density gradient is much less in the transmission type test. For calibration work in the laboratory or in the field care must be taken to avoid density gradients within the soil mass being tested when using backscatter type gages.

TABLE 18

Effect of Mold Compaction Planes
Backscatter, Transmission, Moisture
So. Sacramento Soil, 123 lbs. per cu. ft.

Test	Instrument	KEV	Air Gap	Probe Position	Count Ratio Number of Side 1	3	5*	6
Backscatter	Troxler	0 0 350 350	0 0 0 0	-3/4" 0 -3/4" 0	1.27 4.67 0.24 1.80	1.30 4.87 0.25 1.94	1.32 4.84 0.24 1.94	1.23 4.66 0.24 1.90
	Hidrodensimeter		0	0	1.58	1.56	1.56	1.53
	Numec		0	-	1.18	1.17	1.22	1.14
Transmission	Troxler	0 0 550 550	0 0 0 0	6" 10" 6" 10"	3.83 1.68 1.03 0.07	- - - -	3.90 1.58 1.09 0.24	- - - -
	Hidrodensimeter		0 0	6" 10"	0.37 0.24	- -	0.39 0.24	0.38 0.24
Moisture	Troxler		0		0.74			
	Hidrodensimeter		0		3.20	2.66	2.66	2.84
	Numec		0		1.10	1.09	1.16	1.11

*This surface slightly rough

MOLD NUMBERING SCHEME

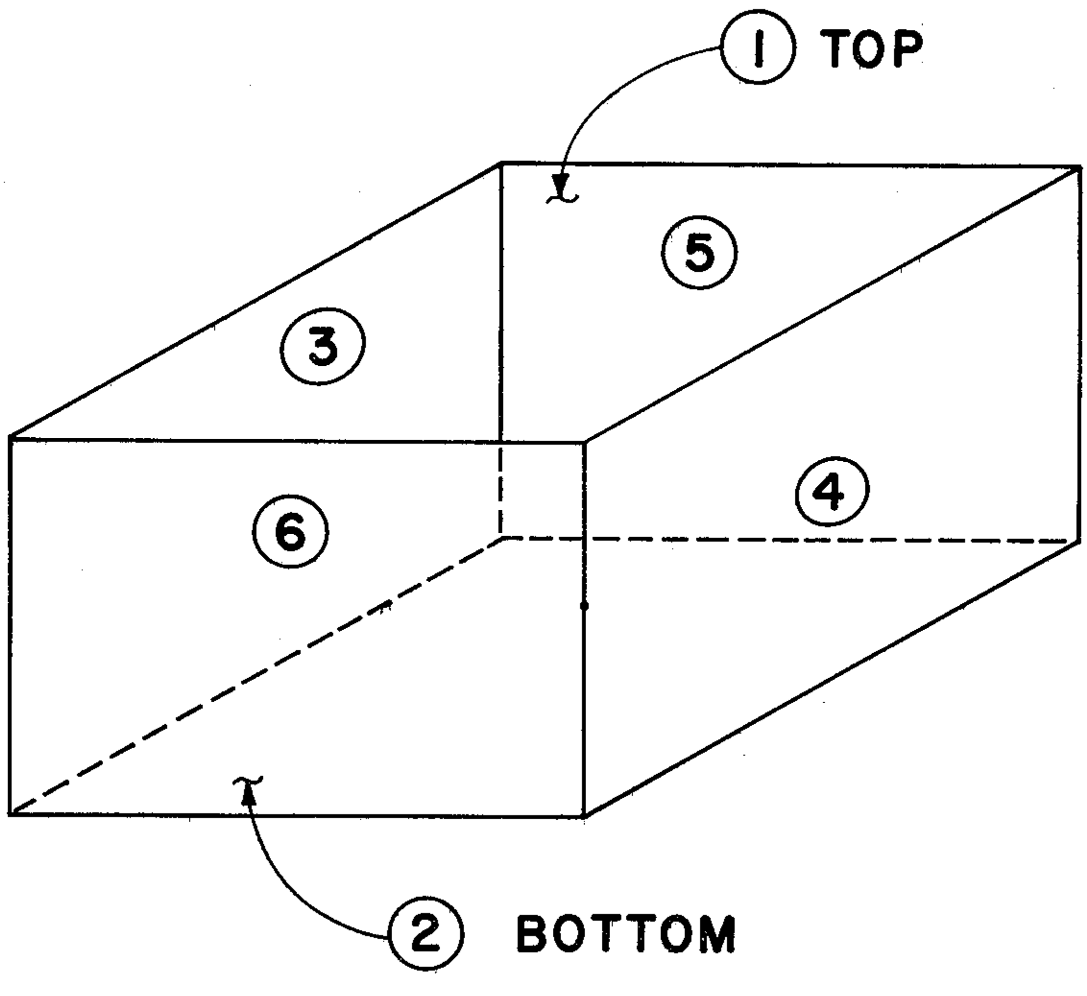


FIGURE 65

Most of the samples were compacted with the mold placed on its side, and then turning the specimen 90° so that readings could be taken across the compaction planes. There was some question as to the effect of mold friction at the sides of the mold on the density readings by possibly forming a thin layer of less dense soil next to the plate, which would then be the top or reading surface for the experiment. It was felt that the earlier compaction planes study did not fully answer the question as perhaps a less dense layer might exist right at the surface of the soil adjacent to the mold.

In this study readings were taken at the testing surface, and then the soil carefully trimmed 1/2" to 1" and another set of readings taken.

The results are presented in Table 19. The results are random indicating both a less dense and more dense soil, depending on which set of results are used. The density measurements are within 2 to 5 pcf and the moisture measurement within approximately 1 pcf of the initial readings. The test results indicate that a minor or no error was introduced by mold friction causing a less dense layer at the soil surface.

TABLE 19

Effect of Mold "Skin Friction" on Surface Density*
Backscatter-Transmission-Moisture
So. Sacramento Soil, 134 lbs. per cu. ft.

Test	Instrument	KEV	Air Gap	Probe Position	Count Ratio Surface #1	Count Ratio Surface* #2	Ratio #1/#2
Backscatter	Troxler	0	0	-3/4"	1.11	-	-
		0	0	0	4.30	-	-
		350	0	-3/4"	0.25	0.23	1.09
		350	0	0	1.78	1.75	1.02
	Hidrodensimeter	-	0	-	1.44	1.46	0.98
	Numec	-	0	-	1.08	1.10	0.98
Transmission	Troxler	300	0	4"	2.71	2.76	0.98
		300	0	6"	1.57	1.58	0.99
		300	0	8"	0.82	0.84	0.98
		300	1/4	6"	1.85	1.82	1.02
		300	1/4	8"	0.95	0.95	1.00
		550	0	4"	1.50	1.53	0.98
		550	0	6"	0.76	0.76	1.00
		550	0	8"	0.36	0.36	1.00
		550	1/4	6"	0.94	0.88	1.07
		550	1/4	8"	0.42	0.40	1.05
	Hidrodensimeter	-	0	4"	0.288	0.290	0.99
		-	0	6"	0.322	0.336	0.96
		-	0	8"	0.277	0.267	1.04
		-	0	10"	0.194	0.197	0.98
		-	1/4	6"	0.405	0.390	1.04
		-	1/4	8"	0.314	0.305	1.03
		-	1/4	10"	0.226	0.216	1.04
Moisture	Troxler	-	-	-	0.73	0.72	1.01
	Hidrodensimeter	-	-	-	2.27	2.09	1.09
	Numec	-	-	-	1.12	1.00	1.12

*Surface #2 is Surface #1 with ½" to 1" soil removed. This surface (surfaces) was at the side of the mold during compaction and rotated to take readings.

AIR GAP STUDY

Previous work with nuclear density determination by the backscatter method had indicated an apparent need to calibrate the instrument for different soils. This was assumed to be caused by chemical differences in the soil, or soil texture.

Kuhn* proposed that the introduction of a deliberate air gap might overcome this problem. His recommended procedure is to first determine the magnitude of air gap at which the ratio between a measurement with air gap and a measurement flush on the surface was the largest. This is termed "optimum air gap." The "optimum air gap ratio" using the selected air gap is then computed for different densities to establish calibration curves.

A specific study of the optimum air gap for backscatter readings on a smooth surface was performed on the 115-pound per cubic foot soil (specimen 1709) at various air gaps from 0 to 1 inch. The results are shown on Figures 66 and 67. The optimum air gap selected for most subsequent work was 1/2 inch, although the air gap used for the spectra-air gap measurements was 3/4 inch.

The "optimum air gap" was found to vary from 3/4 inch at low discriminator settings to about 1/4 inch at a 500 KEV discriminator setting, for the noncollimated source. The curves for the various discriminator settings tended to form the characteristic peaks with ratios of about 2 at the peak.

With the collimated source there were no peaks to the curves. They tended to form straight lines to an air gap of 3/4 inch and then show a rapid increase in ratio. At a discriminator setting of 400 KEV the count ratio was about unity and at 500 KEV was below unity. This would indicate that photons of 400 KEV and above are not being reflected from the soil mass with an air gap and collimated source.

The various studies in this report have indicated that the counts with an air gap and noncollimated source tend to be a constant independent of the density of the soil mass. The surface texture has marked effect upon the nuclear counts. The nuclear reading on the soil surface, zero air gap, is the item which is affected by the soil density. The net result of these various factors is an increased sensitivity to surface texture with the air gap method using a noncollimated source.

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*Kuhn, S. H. "The Effects of Type of Material on Nuclear Density Measurements." Presented at the 43d Annual Meeting of the Highway Research Board.

As the air gap curves, Figure 67, did not peak for the collimated source the 1/2 inch air gap used in the noncollimated study was also used in the collimated study. From the surface roughness study, there was minor effect of surface roughness upon the nuclear readings with the air gap. Also the nuclear counts were affected by the density of the soil mass when an air gap and collimated source were used. The data would indicate that a gage designed with a collimated source and an air gap may be a practical backscatter type gage. The limited data in Figure 67 would indicate that discrimination at 100 to 200 KEV of the detector may improve the operation of the gage.

TROXLER BACKSCATTER

AIR GAP STUDY-SMOOTH SURFACE
SO. SACRAMENTO SOIL 115 lbs per cu. ft.
SOURCE NON-COLLIMATED

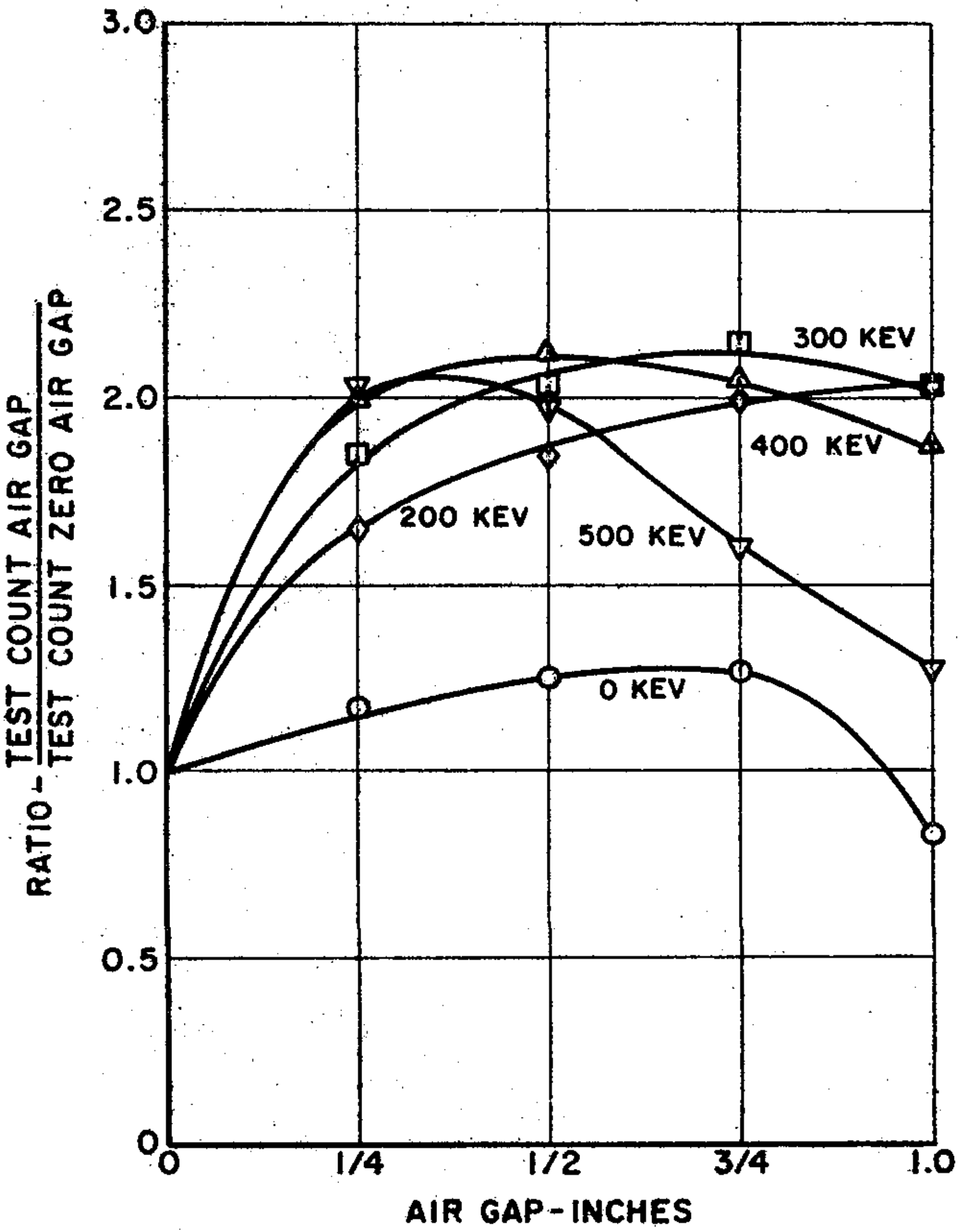


FIGURE 66

TROXLER BACKSCATTER

AIR GAP STUDY-SMOOTH SURFACE
SO. SACRAMENTO SOIL 115 lbs per cu. ft.
SOURCE COLLIMATED 3/4"

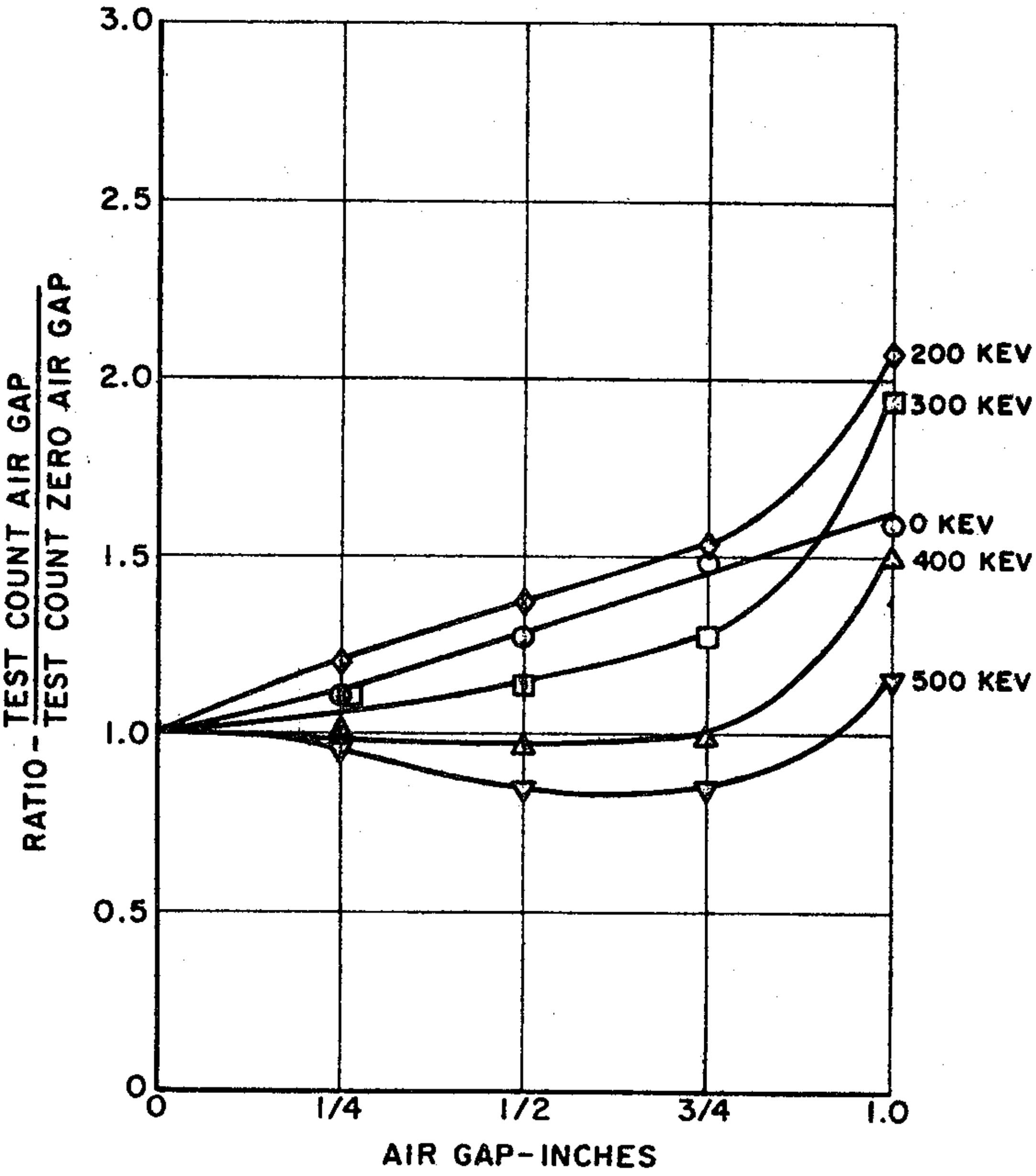


FIGURE 67

EFFECT OF HOLE ON THE TRANSMISSION READINGS

The holes made in the original fine grained material were placed with an ordinary carpenters brace and bit for the transmission type test. This is illustrated in Photo 20.

The object of this study was to determine the importance of hole size, and the position of source or detector in the hole. Table 20 indicates that a large difference in readings could be obtained by various combinations of hole size and position. However, it was determined that by consistently placing the rod snugly against the inside of the hole, (closest to the detector or source) the effect of hole size was made a minimum. The difference in the densities indicated by the measurements in the various sized holes was about two pounds per cu. ft. provided the rod was snug against the inside of the hole. This procedure was adopted as standard, together with the 7/8 inch hole size for the rest of the program.

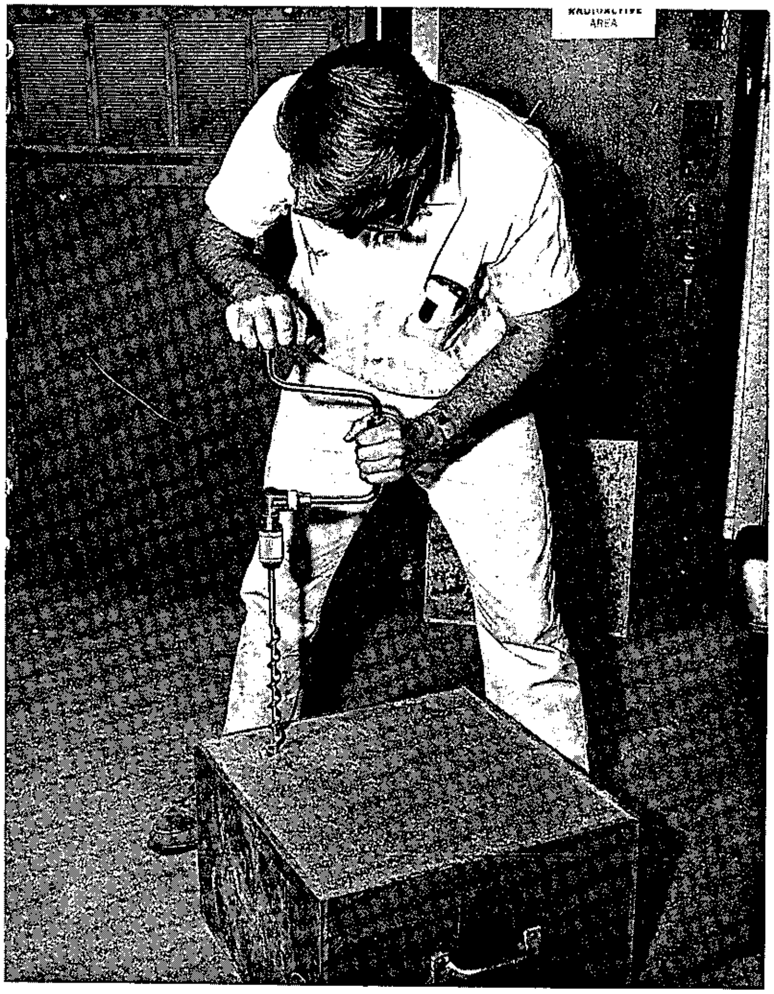


PHOTO 20, Use of Brace and Bit for Drilling Transmission Holes.

TABLE 20

Study of Troxler Transmission
Hole Size and Probe Position
South Sacramento Soil, 115 lbs. per cu. ft.
(smooth surface)

Depth Source (inches)	Hole Size (inches)	Count Ratio - Standard Reference Count									
		0 Kev		300 Kev		500 Kev		550 Kev		600 Kev	
		Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside	Inside	Outside
4	3/4*	5.332	-	3.956	-	2.543	-	2.252	-	1.823	-
	7/8	5.366	5.373	3.782	4.164	2.590	2.856	2.381	2.523	2.283	2.279
	1	5.242	5.326	4.090	4.508	2.631	3.053	2.431	2.564	2.144	2.404
	1½	5.399	5.613	3.903	4.550	2.531	3.362	2.322	3.110	1.751	2.861
6	3/4*	4.288	-	2.481	-	1.579	-	1.281	-	1.104	-
	7/8	4.286	4.379	2.513	2.750	1.574	1.741	1.383	1.497	1.241	1.268
	1	4.306	4.295	2.541	2.721	1.644	1.601	1.411	1.449	1.251	1.124
	1½	4.284	4.813	2.566	3.071	1.537	2.132	1.518	1.937	1.140	1.728
8	3/4*	3.055	-	1.513	-	0.823	-	0.704	-	0.594	-
	7/8	3.031	3.190	1.497	1.620	0.854	0.916	0.717	0.777	0.604	0.670
	1	3.013	3.309	1.520	1.508	0.854	0.804	0.727	0.655	0.619	0.783
	1½	3.017	3.472	1.514	1.852	0.829	1.246	0.712	1.084	0.566	0.936
10	3/4*	2.076	-	0.809	-	0.427	-	0.361	-	0.311	-
	7/8	2.084	2.153	0.865	0.916	0.479	0.498	0.396	0.426	0.344	0.361
	1**	2.053	-	0.839	-	0.450	-	0.386	-	0.330	-
	1½	2.029	1.651	0.874	1.106	0.465	0.594	0.384	0.479	0.326	0.432

*Probe is a tight fit in 3/4" hole, therefore, count ratios are recorded as inside hole position.
**Probe cannot be shifted from inside to outside in 10" hole. Readings are recorded as inside measurements, even though such may not actually be true.

Transmission holes may be placed considerably out of plumb in the field. A study was made of the effect of having a hole with a 4½° inclination with the soil surface. With a 3/4" hole, this angle was sufficient to cause a considerable air gap at the rear of the instrument when the rod is extended into the soil.

Table 21 indicates that the inclined hole caused a significant variation in the readings. The error in densities indicated by the count ratios determined in the inclined hole is approximately 15 lbs. per cu. ft. It was concluded that transmission holes must be essentially perpendicular to the bottom of the gage. The probe must enter the hole freely and be "snugged" in the hole toward the rear of the instrument without disturbing the surface seating of the gage. However, limited field experience indicates that drilling a satisfactorily perpendicular hole is not a great problem; and that the angle of the test hole (4½°) was much greater than that resulting from placing a hole with normal care.

TABLE 21

Troxler Transmission
Inclination of 3/4" Hole
South Sacramento Soil, 115 lbs. per cu. ft.
(smooth surface)

KEV	Depth of Source (inches)	Count Ratio		
		Vertical 3/4" Hole	3/4" hole at 4.5 deg. inclination	Ratio: Inclined Vertical
0	4	5.00	5.93	1.18
	6	3.83	4.82	1.26
	8	2.58	3.41	1.32
	10	1.68	2.18	1.30
300	4	3.36	5.25	1.56
	6	2.05	3.17	1.55
	8	1.13	1.74	1.54
	10	0.62	0.92	1.48
550	4	1.96	3.64	1.86
	6	1.03	1.86	1.81
	8	0.52	0.88	1.69
	10	0.27	0.42	1.55

NOTE: Inclination of hole caused air gap of 1-3/16" maximum **at back** of instrument.

METHOD OF PREPARING THE HOLE FOR THE TRANSMISSION TYPE TEST

The original technique for placing transmission holes was by employing a hammer driven pin. Therefore, a brief study was made comparing the readings of a pin driven hole of approximately 1 inch in diameter with a 7/8 inch drilled hole using the carpenters bit. These readings were essentially the same for the soil studied. It was observed that the driven pin caused a slight hump at the surface around the hole. If pronounced, this would have to be smoothed to reduce the resulting air gap. The pin used is illustrated in Photo 21 and the hump around the hole in Photo 22.

The pin is not expected to work well in a rocky or very hard soil. It would, however, be satisfactory for much of the work in fine grained soil.

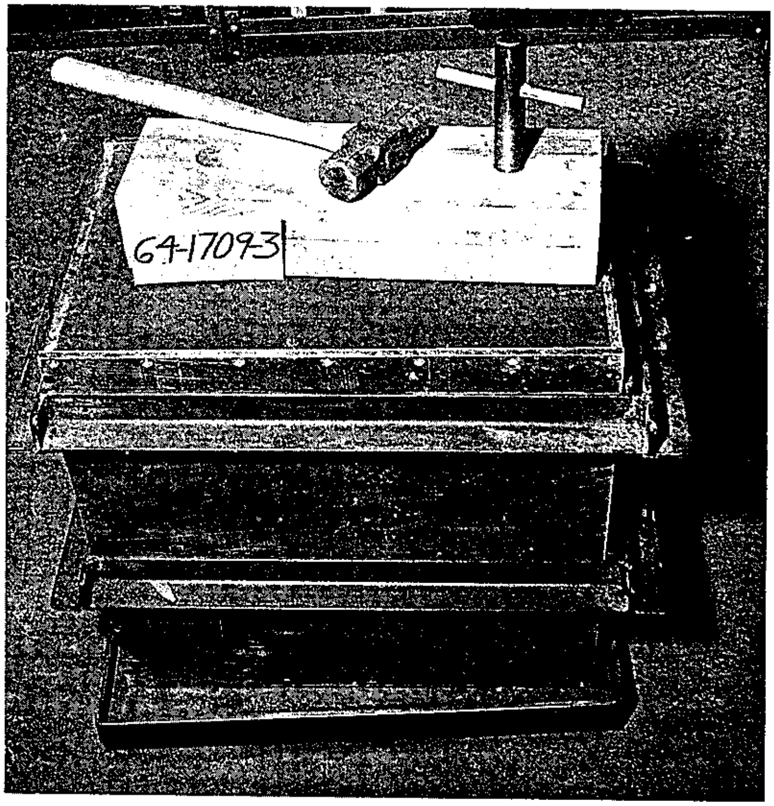


PHOTO 21, Equipment for Pin Driven Holes.

PHOTO 22, Illustration of Hump Caused by Pin Driving.

One of the principal objections to the transmission technique has been the supposed practical difficulty of placing the hole in hard or rocky soil. The possibility of using one of the newer masonry drills which drive a carbide bit with a combined rotary and percussion action was studied. This is illustrated in Photo 23. In the laboratory this method easily and quickly drilled a clean and undisturbed hole in several rocky soils studied. Photos 24 and 25 were taken when one of the specimens was torn down. It shows that it is possible to place a hole through rock fragments of various sizes without disturbing the supporting matrix.

This masonry drill was tried on a construction project and appeared to be satisfactory.

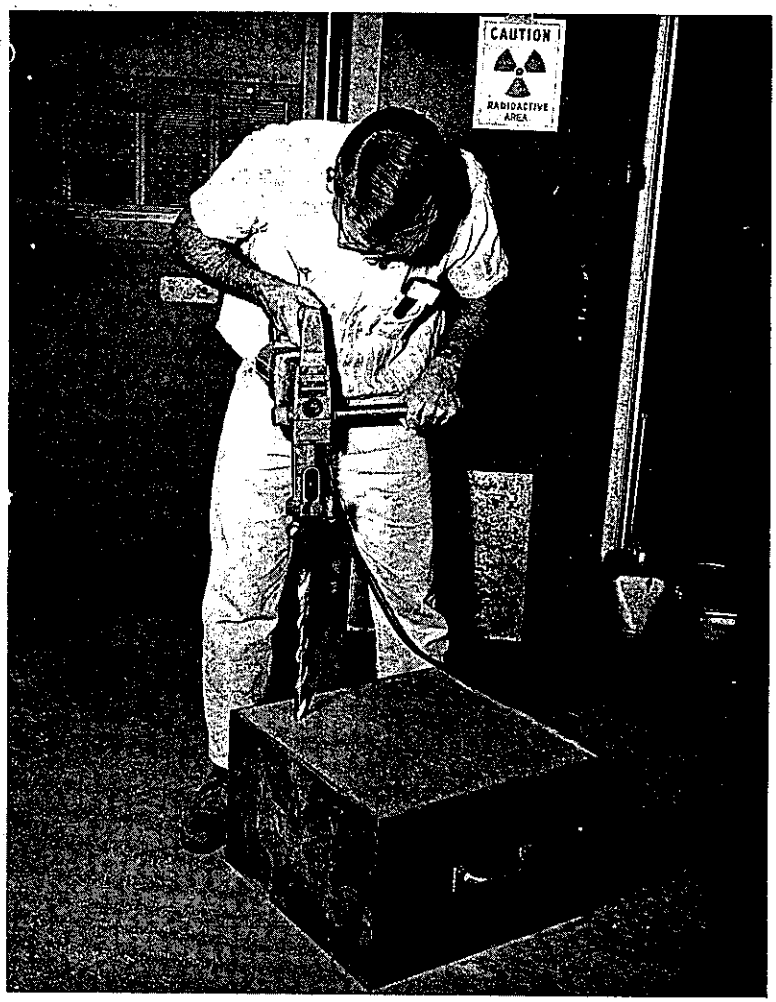


PHOTO 23, Use of Rotary-Impact Drill for Transmission Holes.

PHOTO 24, Illustration of Undisturbed Rock and Matrix After Drilling With Rotary Impact Drill.

PHOTO 25, Illustration of Undisturbed Rock and Matrix after Drilling With Rotary Impact Drill.

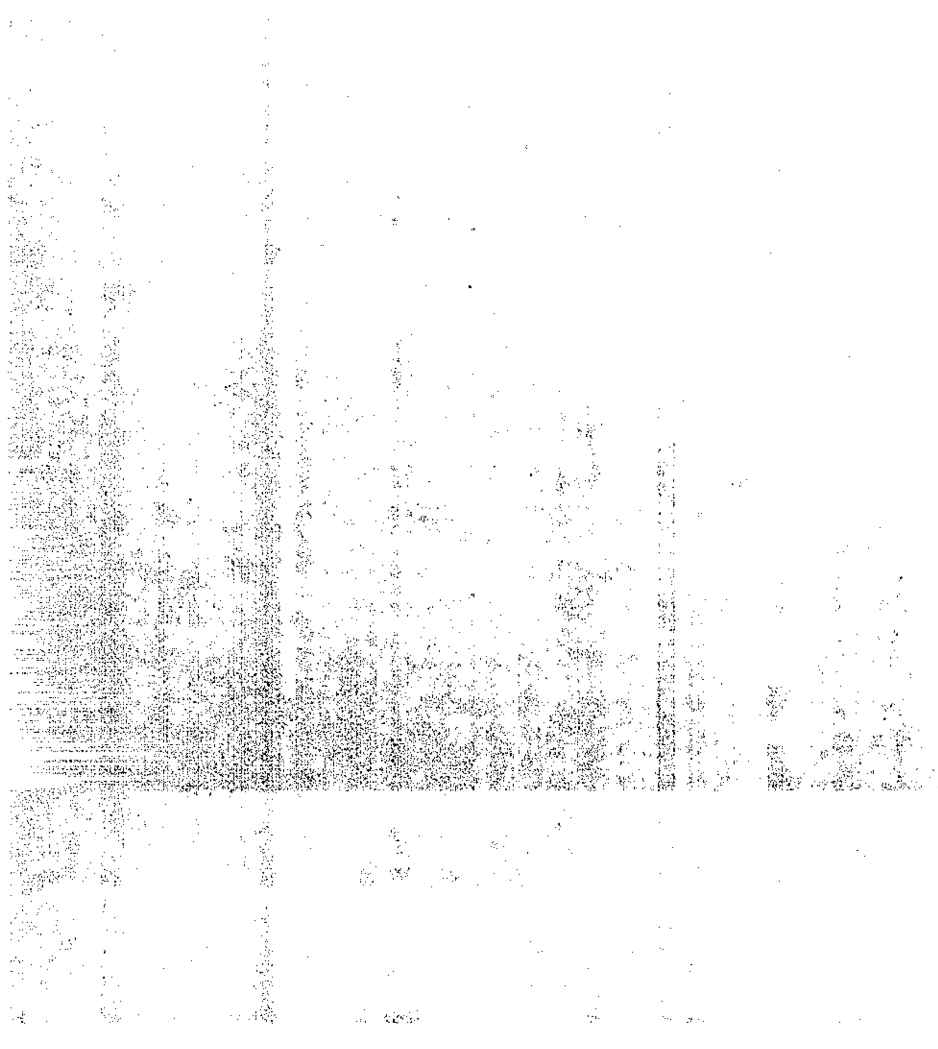
EFFECT OF MOISTURE UPON THE DENSITY READING

In theory the Hydrogen atom is not "seen" the same by a gamma ray as the heavier elements. This has resulted in considerable discussion as to the effect that moisture has upon the density determination. To obtain data upon this moisture effect, two sands were tested specially. They were compacted in the mold in the damp condition and tests performed upon them. They were then saturated with water and again tested.

Examination of the calibration curves indicate that the damp and saturated conditions had about the same deviation. This indicates that the moisture content of the soil will have no effect upon the density determination. See the calibration curves, Figure No 5 to 18, soils 3472 and 3694.

APPENDIX A

TESTING PROCEDURE



COMPACTION PROCEDURE

A soil sample was compacted by impact methods in ½-inch, 1-inch or 2-inch layers into an aluminum mold constructed of 3/8-inch panels bolted together with Allen-head bolts. Any or all of the panels could be removed independently of the other panels. The inside dimensions of the mold were 18-inch by 18-inch by 12-inch. Prior to the compaction of the samples, the mold was calibrated by a water volume weight measurement.

The samples were compacted by impact methods using a 10 or 15-pound hammer falling through a height of 18 or 27 inches. The hammer is illustrated in Photo 26. The "foot" is 4¾ by 4¾ inch square. The 10-pound hammer falling through 18 inches was converted into a 15-pound hammer falling through 27 inches by the addition of a 5-pound weight to the hammer and by raising the stop on the rod from 18 inches to 27 inches.

In order to keep the mold from deforming during compaction of the sample, angle iron braces were bolted around the mold as shown in Photo 26.

The soil for each sample was wet to the desired moisture condition and allowed to hydrate before compaction.

The compaction was done in such a manner that the blows were evenly distributed over the entire surface of each layer. The pattern for the first two coverages is illustrated in Photo 26. The remaining coverages were done in a regular pattern so that the area was covered uniformly. The surface formed by the compaction of a layer was scarified before the next layer was placed, Photo 27.

A coverage on a sample compacted with the 18-inch by 18-inch side up consisted of 25 blows, and a coverage for compacting with the 18-inch by 12-inch side up consisted of 15 blows. The number of coverages varied depending on the required density. Generally the number of coverages varied from 6 to 8, with the fewer coverages in the bottom two or three layers to compensate for the densification of lower lifts due to transmitted compactive effort with succeeding lifts.

The first two boxes of soil (64-1709) were compacted with the mold on the concrete floor, the remainder on a 1-inch thick steel base plate which was bolted to the concrete floor.

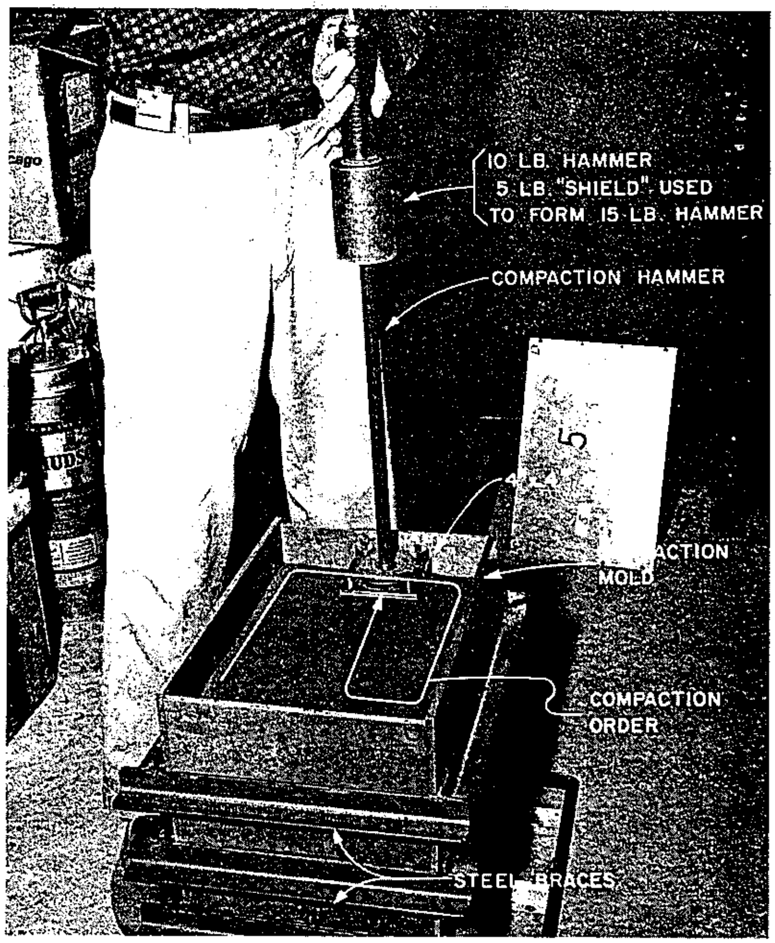


PHOTO 26, Compaction Equipment and Procedure.

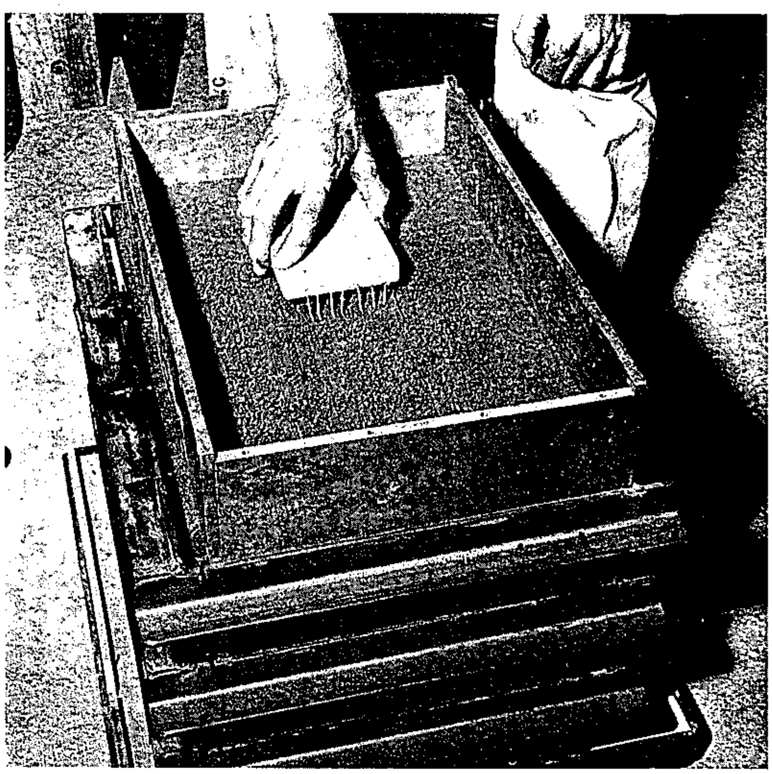


PHOTO 27, Scarifying Prior to Placement of Next Layer.

CHRONOLOGICAL TESTING PROCEDURE

The chronological procedure of testing is described by soil type. The purpose of each specimen is given, as well as the manner of preparation. The testing performed on each specimen is briefly described.

South Sacramento Soil (64-1709)

The following is a discussion of the measurements and procedures used on the specimens compacted from soil (64-1709).

Box 1 - Box 1 was compacted in 1-inch layers with an energy of 12,600 ft. lbs./cu. ft. The purpose of this box was to determine the uniformity of the density of the compacted soil. This trial box was not used for any nuclear measurements.

Box 2 - Box 2 was compacted with the 12-inch by 18-inch side up, in 1-inch layers with a nominal energy of 12,600 ft. lbs./cu. ft. The purpose of this box was for the basic studies of energy level discrimination, air gap, and the beginning of the roughness studies.

Measurements were made on the smooth surface left by rotating the box so that an 18-inch by 18-inch side was up and removing the top panel. The backscatter measurements thus were made on a surface perpendicular to the compaction planes, and the transmission hole was drilled parallel to the compaction planes with a carpenter's brace and bit.

Measurements were made with the Troxler in backscatter position with minimum energies of 0, 100, 200, 300, 350, 400 and 500 kilo electron volts (KEV) being counted by the detector. Readings were obtained with the Troxler gage in the transmission position with the discriminator set at 0, 300, 550 KEV energy levels. Measurements were made with the Troxler at various energy levels on the following surface conditions:

1. smooth surface
2. 1/16-inch grooves, one way
3. 1/8-inch grooves, one way
4. 1/8-inch grooves filled with fines from the soil used

The basic air gap study was performed on this box. Measurements were made with 1/4, 1/2, 3/4 and 1-inch air gaps with the backscatter method. Transmission measurements were made with 1/8 and 1/4-inch air gaps.

Measurements were made with the Troxler to determine the spectrum received by the detector tubes. The window opening was 2.5 percent of the maximum energy setting. The base line was varied from 0 to 750 kilo electron volts.

Measurements were also made with the Troxler moisture gage.

Box 3 - Box 3 was compacted in 1-inch lifts with a total energy of 12,600 ft. lbs./cu. ft. The purpose of this box was to continue the roughness study with other investigations mentioned for Box 2. The minimum energy levels were 0, 350, and 500 KEV for backscatter and 0, 350, and 550 KEV for transmission with the Troxler density gage.

The surface conditions used were as follows:

1. smooth surface
2. 1/8-inch grooved surface
3. 1/8-inch diamond grooved surface

The effect of an inclined transmission hole upon the readings was investigated by drilling a hole at an angle of 4.5° from the vertical and then making transmission measurements.

The effect of driving a 1-inch pin instead of using an auger to make the transmission hole was also investigated.

Most of the measurements were made on a side perpendicular to the compaction planes but measurements were also made on other sides of the box to determine if the orientation of the box had any effect on the count ratio obtained.

Box 4 - Box 4 was compacted with an energy of 12,000 ft. lbs./cu. ft. in 1-inch layers with saran wrap between each layer. The purpose of Box 4 was to determine the volume measured by the instruments using the backscatter technique. This box was not turned after compaction. Thus, the instruments were parallel to the compaction planes. A smooth surface was obtained for the readings by trimming the top of the specimens. The panels on the side of the mold were removed before any measurements were made.

The operating procedure used was as follows:

1. Move the detector end of the instruments toward the sample edge until a change in count was noted.

2. Move the source end toward the sample edge until a change in count was noted.

3. Move the instrument sideways until a change in count was noted.

4. Strip the layers taking readings with the probe at the center of each layer. Measurements were made at the top and at heights of 10, 8, 6, 4, 2-inches. The total sample height was 12 inches. The measurements for the bare aluminum plate which rested on the steel compaction plate had previously been determined.

Box 5 - The box was compacted in 1-inch layers with an energy of 12,000 ft. lbs./cu. ft. and rotated after compaction. The purpose of this box was to determine the volume measured in transmission. Transmission measurements only were made on Box 5. The measurements were made on a side perpendicular to the compaction planes, thus, the transmission hole was drilled parallel to the compaction planes.

The first step was to drill the transmission hole as shown in Figure 47A and then make measurements; next, holes were drilled with a carpenter's auger and bit as shown in Figure 47B and measurements made. This procedure was followed for the additional holes required for the arrangements shown in Figures 47C and 47D.

Box 6 - Box 6 was compacted in 1/2-inch layers with a compaction effort of 25,200 ft. lbs./cu. ft. The purpose of this box was to provide a high density for a calibration point. All the measurements were made on a smooth surface after the box had been rotated so that the instrument was located on a plane perpendicular to the compaction planes.

Box 7 - Box 7 was compacted with an energy of 56,700 ft. lbs./cu. ft. in 1/2-inch lifts. The purpose of this box was to provide a very dense soil for calibration and the extended roughness study. Measurements were made with the following surface conditions:

1. Smooth surface with the backscatter and transmission gage.

2. Backscatter only with one-half of the surface covered with 1/8-inch diamond grooves. The source was located over the grooves for one set of measurements, then over the smooth portion for another set.

3. Transmission and backscatter measurements on a surface that was completely covered with 1/8-inch diamond grooves.

4. The top 1/2 to 1-inch was removed and transmission and backscatter measurements made on the resulting smooth surface.

The plane on which measurements were made was normal to the compaction planes.

Folsom Soil (64-2487)

The measurements made on the boxes compacted from the Folsom soil (64-2487) are described below. The purpose of these boxes was to provide calibration points from a different soil, and for a side study of readings parallel and perpendicular to the compaction planes in the case of Box 2.

Box 1 - The sample was compacted in 2-inch layers with an energy of 14,200 ft. lbs./cu. ft. Measurements were made by the backscatter and transmission techniques on smooth surfaces with the instruments flush on the surface; all the measurements were made on a side perpendicular to the compaction planes. The transmission hole was formed in this box by using the rotary impact drill shown in Photo 22. All of the transmission holes drilled in the rocky soils were made with the drill after the method was proven to be practicable. Two transmission holes were drilled in this box on adjacent sides and transmission measurements made in each hole.

Box 2 - This box was compacted in 2-inch layers with an energy of 14,200 ft. lbs./cu. ft. Measurements were made on two sides of the box by both the backscatter and transmission methods with and without an air gap under the instruments. Measurements were made on a smooth surface only.

Box 3 - This box was compacted in 2-inch layers with an energy of 6,300 ft. lbs./cu. ft. Backscatter and transmission measurements were made on a smooth surface perpendicular to the compaction planes with no air gap.

San Luis Soil (64-2484)

The measurements made on soil (64-2484) are given in the following paragraphs. The boxes were compacted in 2-inch lifts with the 18-inch by 12-inch side up, then rotated for the nuclear readings.

Box 1 - Box 1 was compacted with an effort of 14,200 ft. lbs./cu. ft. The purpose of this box was to provide calibration points. Backscatter and transmission measurements were made on a smooth surface.

Box 2 - Was compacted with an effort of 14,200 ft. lbs./cu. ft. Transmission and backscatter measurements were made on a smooth surface for the purpose of establishing calibration points.

Monterey Sand (64-3694)

The measurements made on the Monterey Sand (64-3694) are given below. The box was compacted in 2-inch layers with an energy of 14,000 ft. lbs./cu. ft. and was compacted with the 18-inch by 18-inch side up and not turned. Therefore, the readings were made with the instruments on a side parallel to the compaction planes. The purpose of this box was to provide calibration points on a different soil, and to study the effect of a density change due to the addition of water without a change in dry density. Thus, only one box was compacted from the Monterey Sand. Perforated plastic tubing was placed in the bottom of the mold prior to compaction of the soil. The specimen was placed at a low moisture content and nuclear measurements made. Then, the specimen was saturated by introducing water through the perforated tube. Record was made of the water added through the plastic tubing and another set of nuclear measurements taken.

The forming of the 7/8-inch transmission hole was no problem in the moist sand. The hole had a tendency to close at the bottom after saturation, and some difficulty was encountered in taking the transmission readings at 10-inch depth. The sand was removed from the box after the nuclear measurements were made, and it was observed to have a fairly uniform water content except for approximately the bottom one inch of the box where an excess of moisture was noted.

Volcanic Tuff (64-3681)

The purpose of the sample of volcanic tuff (64-3681) was to provide calibration points on a very light soil at two densities. The first box was compacted in 2-inch layers with an energy of 4,500 ft. lbs./cu. ft. The second box was compacted at a considerably higher moisture content than the first. Both backscatter and transmission measurements were made on each specimen. All readings were made with the instrument on a side perpendicular to the compaction planes.

West Sacramento Sand (64-3472)

The West Sacramento sand (sample 64-3472) was prepared for the purpose of obtaining calibration points from another sand, and to study the effect of a change in density caused by the addition of water without any actual change in dry density. It was compacted in 1-inch layers with an effort of 3,300 ft. lbs./cu. ft. Readings were taken with the gages on a side parallel to the compaction planes.

The sand was compacted and read at a low moisture. The sample was then saturated in a manner similar to that used for the Monterey Sand (64-3694), and a second set of readings were taken.

TABLE 22

Sample Densities
Wet Density in lbs. per cu. ft.

Soil Sample	Box Number	Selected Density	"As Compacted" Density	Measured Density: Minimum Density	Maximum Density	Range Δ γWet
1709	2	115	117	115	116	1
	3	123	124	119	126	7
	4	131	131	-	-	-
	5	128	128	126	132	6
	6	131	133	125	132	7
	7	134	135	132	135	3
2487	1	139	141	137	139	2
	2	145	145	144	146	2
	3	136	135	134	139	5
2484	1	142	141	141	143	2
	2	148	148	148	149	1
3694	1	109	109	-	-	-
	2	120	120	-	-	-
3672	1	99	99	-	-	-
	2	114	114	-	-	-
3681	1	77	77	76	79	3
	2	101	100	99	102	3
			Average Density Range			3.5

TABLE 23

Sample Moistures

Percent of Dry Wt. of Soil

Soil Sample	Box Number	"Selected" Moisture	Measured Moisture (W%)		
			Minimum Moisture	Maximum Moisture	Range Moist.
1709	2	9.5	9.0	9.5	0.5
	3	12.3	12.3	13.5	1.2
	4	13.2	9.6	14.7	5.1
	5	13.3	13.0	13.6	0.6
	6	12.4	12.1	12.6	0.5
	7	10.8	9.7	11.2	1.5
2487	1	6.0	5.5	6.1	0.6
	2	7.2	6.7	7.5	0.8
	3	7.7	7.2	8.2	1.0
2484	1	4.4	4.2	4.9	0.7
	2	7.5	6.9	8.5	1.6
3694	1	2.7	-	-	-
	2	13.2	-	-	-
3472	1	5.3	-	-	-
	2	21.3	-	-	-
3681	1	15.8	15.3	17.7	2.4
	2	37.5	31.2	38.8	7.6
		Average Moisture Range			1.8

SAMPLE DENSITY AND MOISTURE DETERMINATIONS FOR CORRELATION

Correlation moistures and densities as determined by non-nuclear methods for the compacted box samples are presented in Table 22 and 23.

Even though the samples were prepared with care, it is known that the soil density and moisture within each layer vary randomly within each layer. Moreover, the average density of one layer is not exactly the same as the adjacent layers. Consequently the average density and moisture of any particular volume within the mold may be different from the average specimen moisture and density.

Secondly, the results of the different type tests such as sand volume and "chunk" densities vary in themselves and from one to another. Therefore, the procedure in determining the "selected" density and moisture to be used in the correlation study was to evaluate all available density and moisture data from the sample.

Density data included average layer densities, the average mold density; and sand volume densities and "chunk" densities taken on the finished sample after completion of the nuclear testing. Moisture data included specimens taken from the prepared soil prior to compaction, from the soil layers during compaction, and from the finished sample.

The "selected" average density and moisture for the nuclear correlation was determined by comparing the location of the non-nuclear density and moisture tests with the volume of the soil sample being tested by the nuclear instrument. The moisture and densities were then selected which were estimated to best represent the soil being tested by the nuclear instruments.

The "As Compacted" density is the density calculated from the volume of the mold and total soil compacted therein.

The "Measured Density" values in Table 7 refer to measurements made on the samples by the sand volume and "chunk" density methods.

Sand volume and chunk densities were performed on all samples prepared from soil 1709, except specimen 1709-4. Density measurements on soils 2487, 2484, and 3681, were by sand volume only. Neither sand volume or chunk densities were made on soils 3694, 3672, which were sands; or sample 1709-4 which was compacted in layers with the seran wrap for the depth study.

References for these test methods are:

(A) Sand volume displacement.

Test Method No. Calif. 216-F, Part I --
DWR Des. S-13

(B) Chunk Densities - DWR Des. S-8, Part E

(C) Oven-dry moisture determination
Test Method No. Calif. 216-F, Part 1H --
DWR Des. S-9.

APPENDIX B

Definitions

STANDARD COUNT RATIO, DEFINITION

Due to the natural "drift" of much electronic equipment such as the nuclear gages, it is desirable to reduce data to some form whereby it can be studied without considering a time variable. The gages in this study all have a self standard by which the performance at a particular time can be judged. The density and moisture readings were divided by a reading taken on this standard. The result is an index value called the "count ratio." (Defined as: Test count/standard count)

Typical "standard counts" are presented in Table 9. These are average values taken over a period of time for the count recorded when reading the self standard with a particular instrument and test condition.

TABLE 24

TYPICAL STANDARD COUNTS

Instrument	Test	KEV	Counts/Min.
Troxler	Density	0	136,000
"	"	300	37,000
"	"	350	30,000
"	"	500	17,000
"	"	550	14,000
"	Moisture		10,600
Hidrodensimeter	Density		20,200
	Moisture		660
Numec	Density		36,700
	Moisture		4,800

The assumption is that a change or drift at a particular time is proportional for both the reading on the standard and the reading of moisture or density. This may not be strictly true in all cases, but the use of the count ratio results in less error than the uncorrected readings in terms of counts. Much of the data in this report is presented in this form.

It must be cautioned, however, that the count ratio does not reduce all test data to a common denominator. The various conditions tested can only be considered in themselves, and not compared one to another on the basis of either counts or count ratio. The reason for this is that the relative response to an external condition may appear different simply due to a change in the range of counts recorded. In this report the data has been reduced to the change in density or moisture indicated so as to have a common basis of comparison.

COLLIMATION

The term "collimation" as used in this report is employed in the sense that the external radiation from the source is restricted within certain angles by the position of the source within the shielding.

The normal backscatter position is with the source as close to the bottom surface of the gage as the design of the instrument will allow. One instrument used in the test series permitted the raising of the source approximately 3/4 inch above the normal backscatter position. The source is thus raised within the instrument shielding, restricting the radiation to a cone-shaped pattern rather than hemispherical. This restriction does not change the characteristics of the radiation in any way but does permit only photons emitting at a high angle to be scattered through the soil. It was thought that collimation of the source would reduce the effect of the surface roughness.

Collimation as thus described was therefore made a variable throughout this study.