44

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AIR GAP PROCEDURE FOR THE MEASUREMENT OF SURFACE DENSITY BY GAMMA RAY BACKSCATTER TECHNIQUE

by

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including discussion by:
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and an author's closure.

EXPLANATION:

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AIR GAP PROCEDURE FOR THE MEASUREMENT OF SURFACE DENSITY BY GAMMA RAY BACKSCATTER TECHNIQUE

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There has been increasing interest in the application of nuclear moisture-density surface gages for the control of compaction in highway construction. Although the backscatter test procedure conventionally used with this nuclear density equipment is rapid and non-destructive, it has been shown by Ralston et al (1) and Weber (2) that the accuracy of these gages is questionable under certain conditions.

It has been recognized by Kühn (3) and Preiss (4) that the measurement of density by the gamma ray backscatter technique is complicated by differences in the absorption characteristics of the materials being tested. The problem is particularly troublesome when the radio-active source is weak and Geiger-Müller tubes are used to detect many energy levels of backscatter radiation. Safety and portability of equipment dictates the use of weak sources and sensitive detectors. In some areas, such as South Carolina where soil composition is significantly variable, a correction for errors caused by differences in chemical composition should be provided in order to realize the full benefits of this rapid, non-destructive test for highway compaction control.

One method of compensating for the effect of soil type is to calibrate the gage with sand-cone, water balloon or other reasonably accurate equipment each time a different type of soil is encountered. This method is time consuming and also somewhat unreliable and impractical when soils are variable within a given area. Unfortunately, soils in South Carolina are quite varied and attempts to apply this approach to these soils from the Coastal Plain, Sand Hills, and Piedmont were not completely successful.

A field calibration curve for several soil regions within the state of South Carolina is shown in Figure 1. This study was made as part of a research program* sponsored by the South Carolina Highway Department and Bureau of Public Roads. In order to obtain the most accurate control density possible, field densities were measured by making a plaster cast of the test hole which was then submerged in a siphon can to determine its volume. Nuclear readings were converted to count ratio by dividing by standard count and then plotted versus control density. With the exception of one soil region, significant correlation between nuclear readings and soil density could not be obtained. The coefficients of correlation for these calibration curves were 0.92 for Piedmont soils, 0.31 for Sand Hills-Slate soils, and 0.62 for Coastal Plains soils. The overall correlation coefficient for the data shown in Figure 2, from all of these soil regions, was 0.82. The attempt to calculate nuclear field densities from regional calibration curves was, therefore, abandoned and the decision was made to use the manufacturer's calibration curve for all soils. Field densities as determined by the nuclear method using the manufacturer's calibration curve were then compared, by regions, with the control density (plaster cast method); and the standard error for the nuclear densities was ±3.8 pcf in Piedmont soils, ±6.2 pcf in Sand Hills-Slate soils, and ±3.1 pcf in the Coastal Plains soils.

Because of these calibration difficulties, particularly in the case of the Sand Hills-Slate soils, it seemed appropriate to explore some other solution to the problem. The air gap or maximum count ratio method suggested by Kühn (3) seemed to hold greatest promise in overcoming the difficulty of calibration for different materials. The following

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*"Rapid Means of Determining Density and Moisture Content of Soils and Granular Materials," sponsored by the South Carolina Highway Department in cooperation with the U. S. Department of Commerce, Bureau of Public Roads.

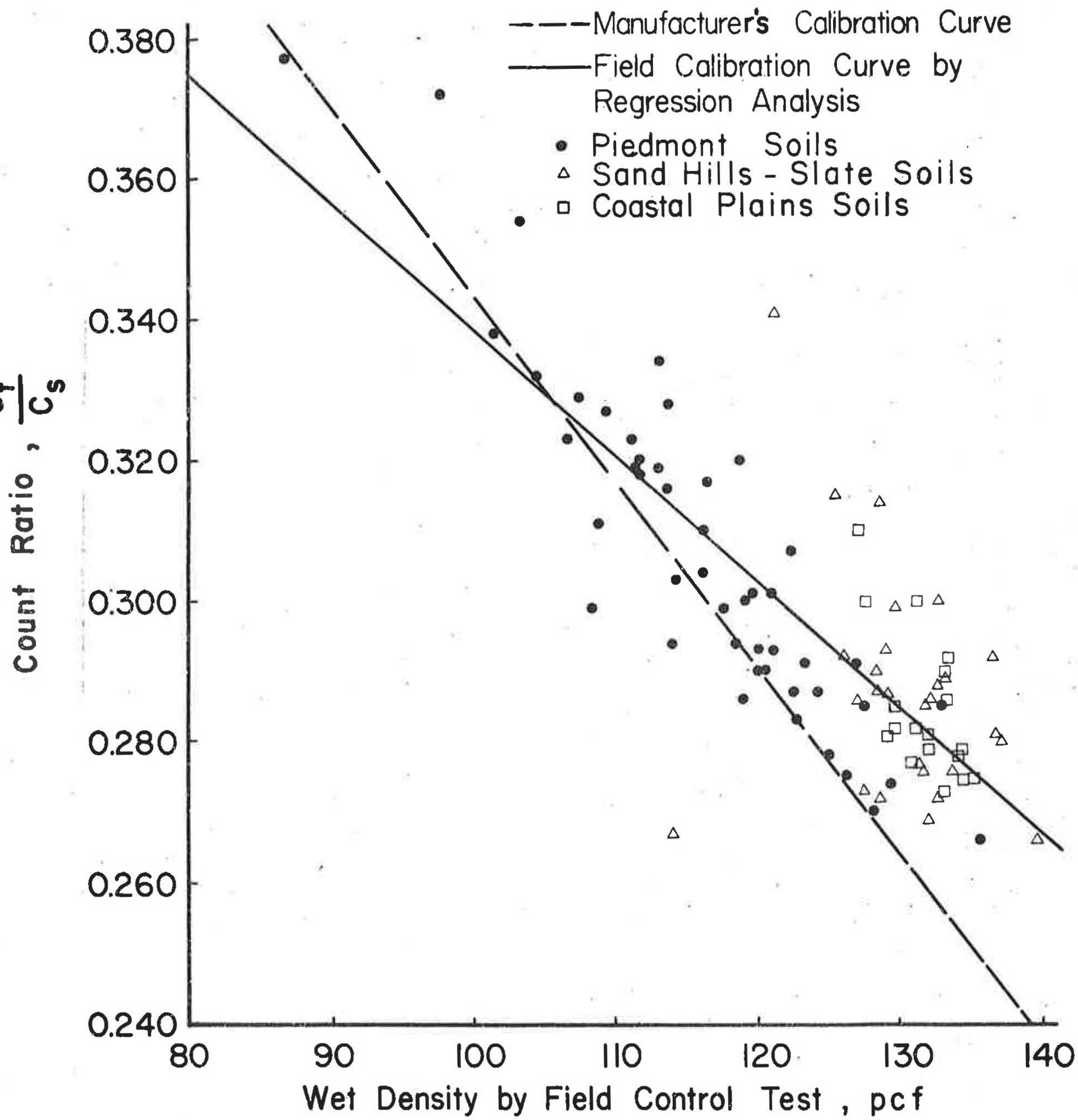

Figure 1 **Field Calibration Curve of Nuclear Density Gage in All Soil Regions of South Carolina**

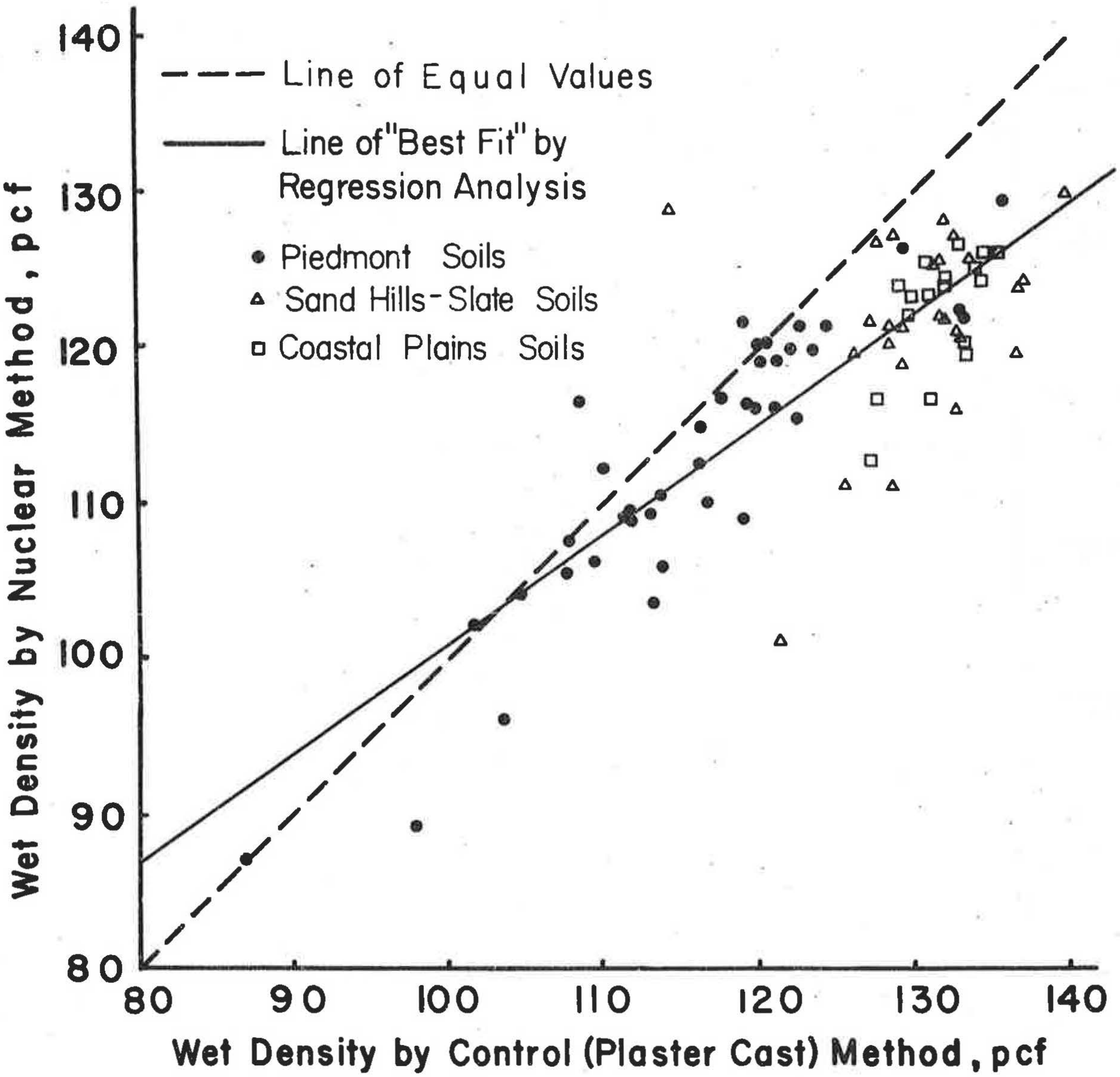

Figure 2 **Correlation Between Control (Plaster Cast) Method and Standard Count Ratio Method using Manufacturer's Curve for Wet Density Determination in South Carolina Soils**

presentation is concerned with the application of the air gap method to a stock Nuclear-Chicago, Model P22A, surface density gage and scaler.

DETERMINATION OF OPTIMUM AIR GAP

A series of counts were made on various samples of typical material used in construction to determine the air gap required to yield the maximum count for each of these materials. The counts were first taken with the gage flush with the surface and then additional counts were taken at air gap increments of 1/4 inch until it was certain that the maximum possible count had been reached. Figure 3 shows a plot of the count rate versus air gap for the different materials tested. From the resulting curves, it was decided that an air gap of 1-5/8 inches was the best compromise to be used in the calibration measurements to follow.

The cradle, illustrated in Figure 4, was designed to support the gage at the required 1-5/8 inch air gap. It is constructed of 3/4" x 3/4" x 1/8" steel angle welded in a rectangular shape (6" x 12" inside dimensions) to fit the density gage. The angles are supported on three legs of 1/4" diameter steel with 2" diameter steel pads.

CALIBRATION PROCEDURE

It was first necessary to obtain a number of standards with densities ranging from about 60 to 170 pcf to cover the maximum range of field densities expected in highway work. To be certain that the calibration will be independent of soil type, it is also necessary to use standards of about the same density but of different chemical composition so as to reveal any descrepancies resulting from the chemical effect. The standards must also be of known and uniform density. Standards meeting these requirements were chosen and are summarized in Table 1.

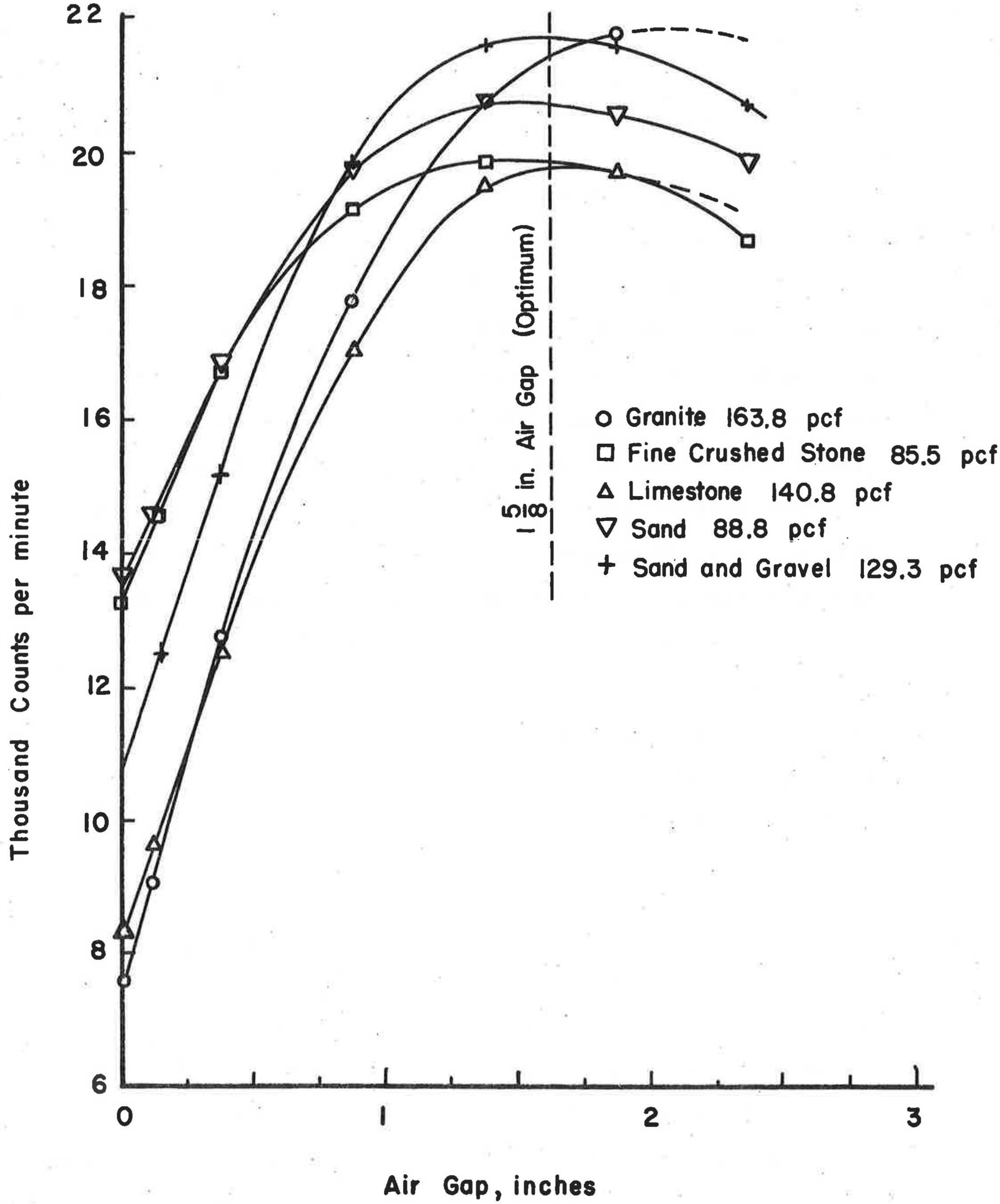

Figure 3 - Count Rate versus Air Gap

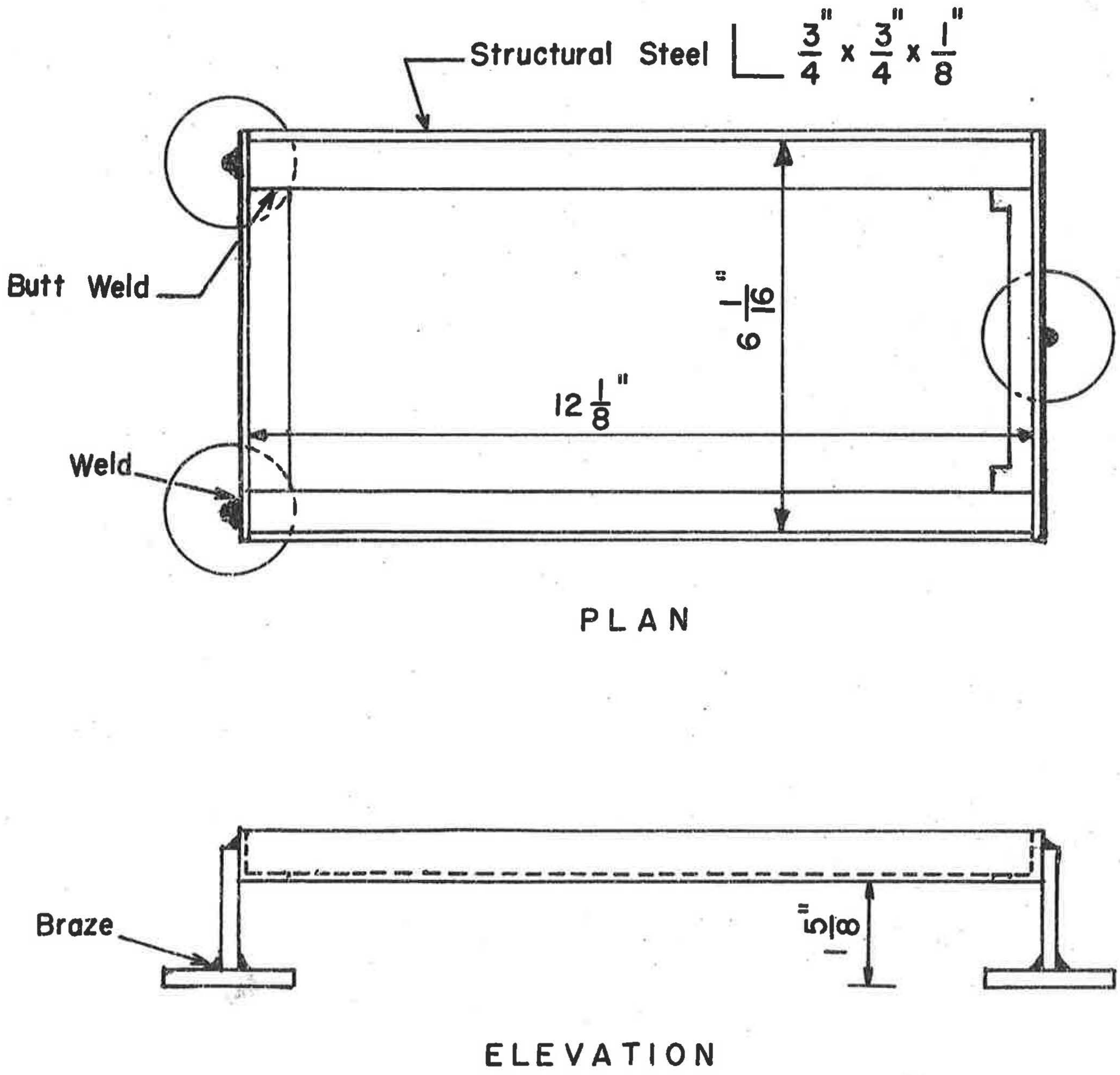

Figure 4 - Gauge Support Cradle for Air Gap

TABLE 1. Summary of Density Standards

Material	Density, pcf
Sand and Vermiculite	58.1
Aluminum (1/8" sheets spaced @ 3/8"	58.8
Water (in 14" x 14" x 8" aluminum box)	62.2
Water (in 18" x 18" x 18" plexiglass tank)	62.2
Aluminum (1/8" sheets spaced @ 1/4")	84.1
Graphite	96.5
Carbon Tetrachloride	98.8
Saturated quartz sand	113.5
Aluminum (1/8" sheets spaced @ 3/16")	117.4
Aluminum (1/8" sheets spaced @ 5/32")	136.8
Indiana Limestone	140.8
Limestone from IE Building	141.8
Granite	163.8
Aluminum (solid)	168.2

Four minute counts were taken on each of the above standards while the gage was flush with the surface of the material and again with the gage supported on the cradle to provide the 1-5/8 inch air gap. Standard counts were also taken at frequent intervals to provide a means of comparing the standard count ratio method with the air gap methods for determining density.

COUNT RATIO RELATIONSHIPS

A number of count ratio relationships based on standard count, flush count, air gap count, and the attenuation or difference between air gap count and flush count was explored in order to find mathematical expressions for density which would be free of chemical effect and give greatest accuracy over the range of densities studied. Calibration curves were prepared for the standard count ratio method as well as for two other relationships involving flush count and air gap count.

Figure 5 shows the calibration curve derived from the flush count divided by the standard count as suggested by the manufacturer of the equipment. The following straight line equation was determined from a computer regression analysis of the calibration data:

$$\text{Density} = 233.4 - 383.0 \frac{C_f}{C_s} \text{ pcf} \qquad \text{. . . . . (1)}$$

where,

C_f = Flush Count

C_s = Standard Count

The manufacturer's calibration curve is also plotted on Figure 5 and appears to fit the calibration points about as well as the calibration curve obtained from the regression analysis. However, in order to obtain

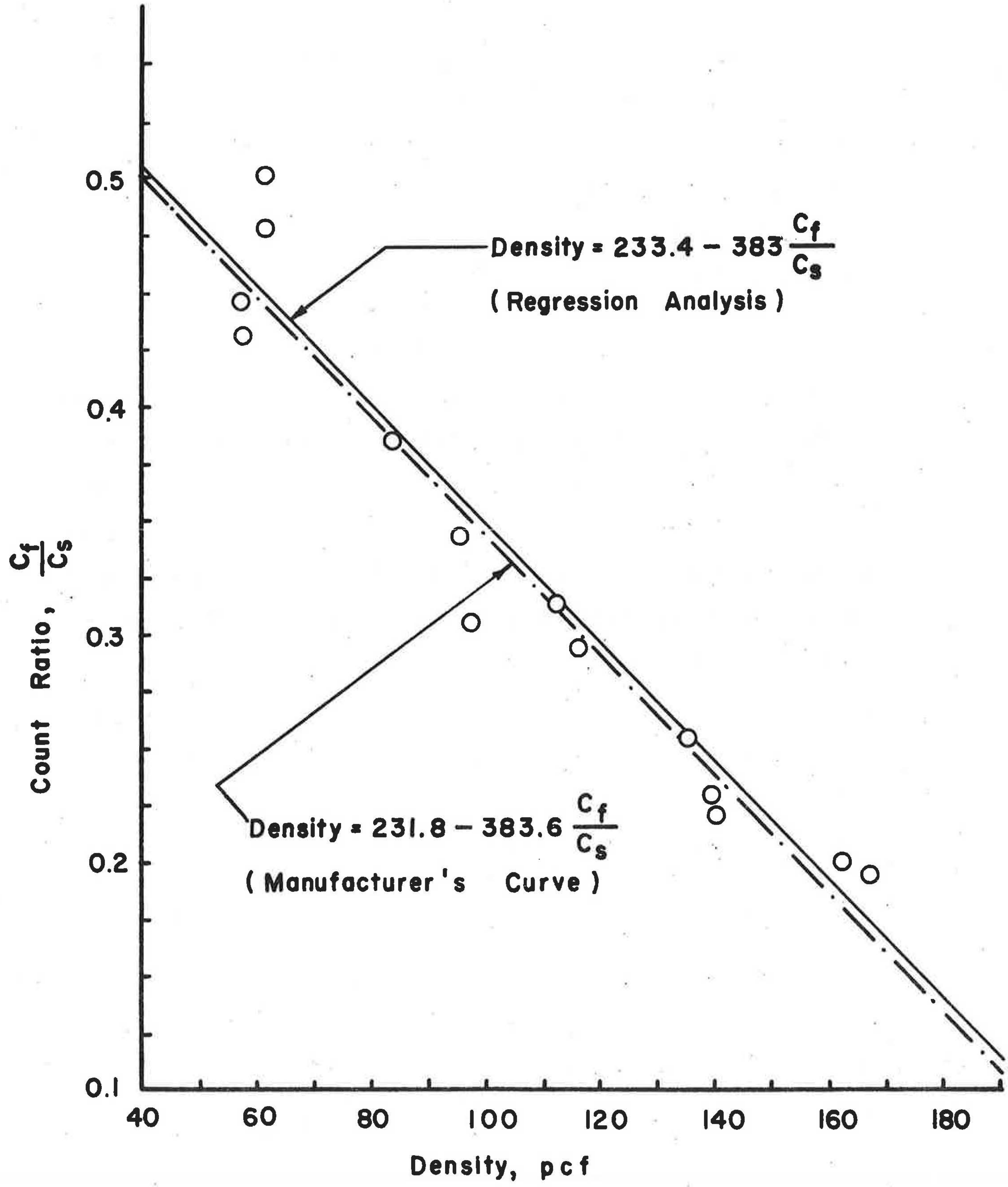

Figure 5 - Calibration Curve for Standard Count Ratio

the most favorable comparisons with the air gap methods of calibration, the above calibration curve based on regression analysis was used in the comparisons.

Figure 6 shows the calibration curve derived from the ratio, gap count divided by flush count, as proposed by Kühn (3). This is a straight line relationship when plotted on semi-log graph paper and is given by the equation:

$$\text{Density} = 265.7 \text{ Log } \frac{C_g}{C_f} + 42.4 \text{ pcf} \quad \ldots\ldots\ldots\ldots(2)$$

where,

C_f = Flush Count

C_g = Gap Count (1-5/8" standoff)

The calibration curve shown in Figure 7 was derived to yield a straight line plot on an arithmetic rather than a semi-log plot. This relationship is based on the ratio of attenuation divided by the sum of the flush count and 20 per cent of the standard count, and is given by the equation:

$$\text{Density} = 128.0 \frac{C_g - C_f}{C_f + 0.2C_s} + 47.0 \text{ pcf} \quad \ldots\ldots\ldots(3)$$

Both of the calibration curves based on the air gap procedure show much less susceptibility to chemical effect than the conventional calibration method shown in Figure 5. Admittedly, the standards were selected from unconventional materials so as to exagerate the effect of composition differences. However, the air gap procedure was confronted with the same composition differences and showed minimum effects. Table 2 summarizes the densities as determined from the three calibration curves and compares these values with the actual density of the standards.

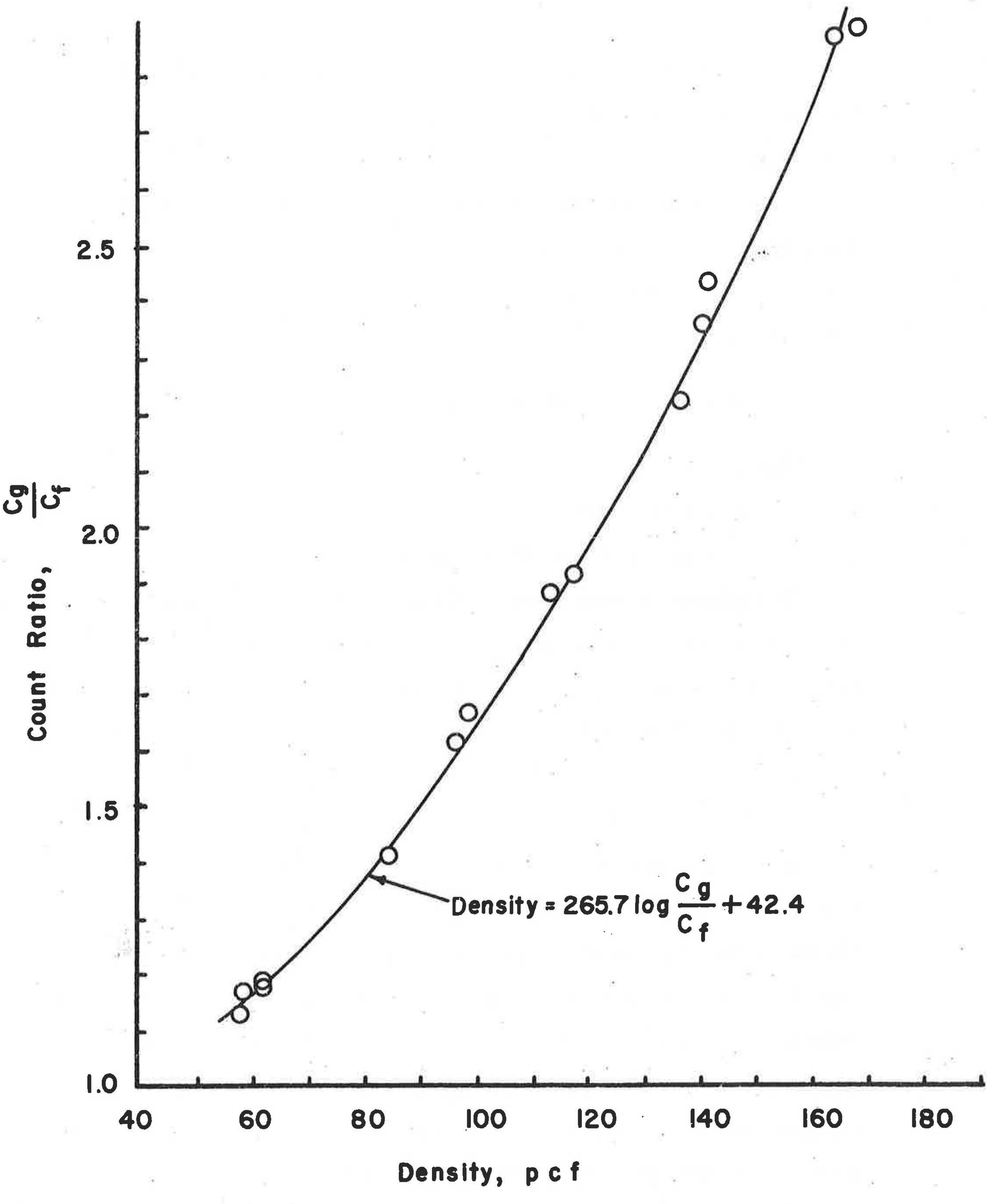

Figure 6 - Calibration Curve for Maximum Count Ratio

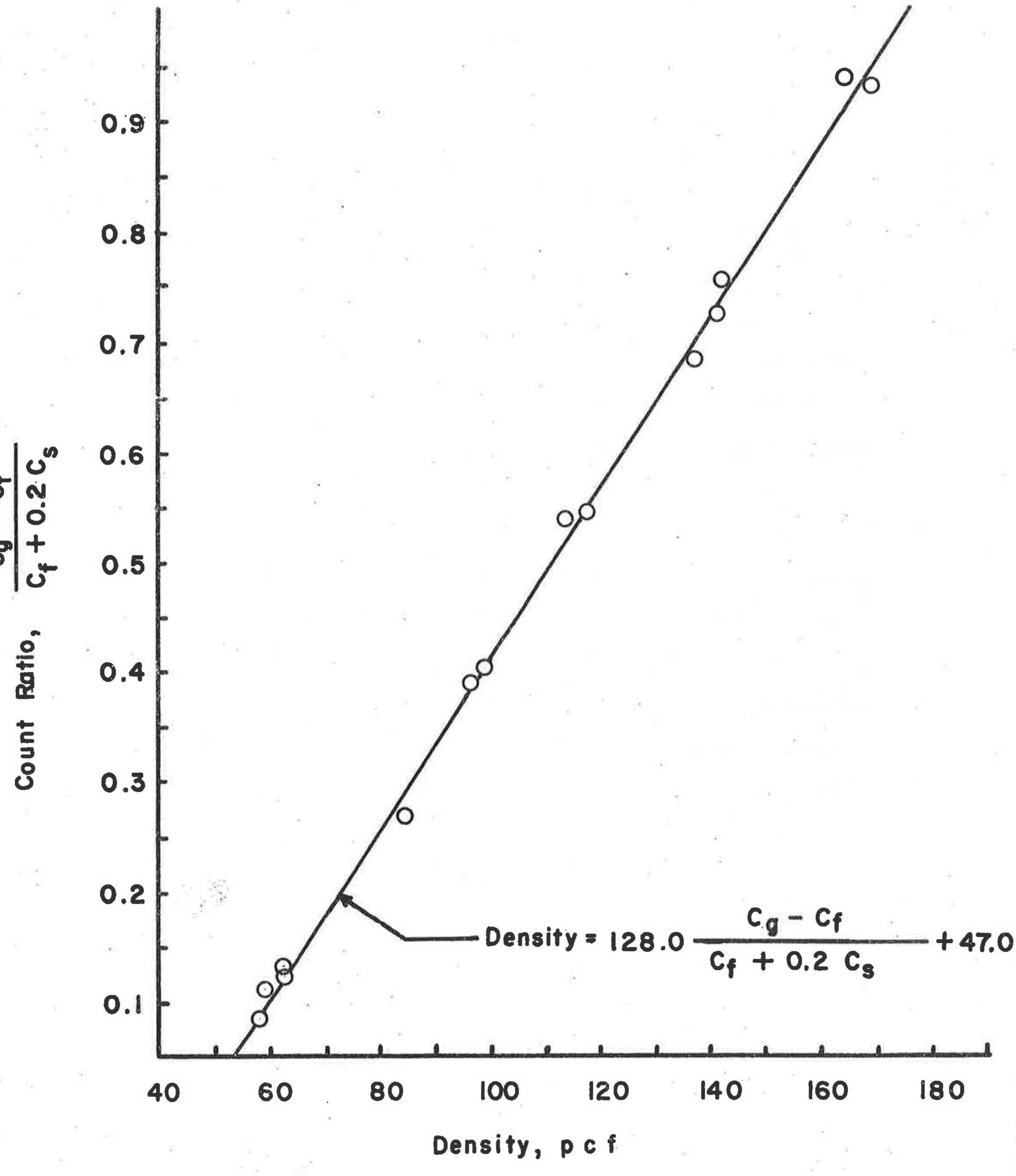

Figure 7 - Calibration Curve for Attenuation Count Ratio

TABLE 2. Summary of Densities Calculated from Calibration Curves.

Density Standard	Control Density, pcf	Density Calculated by: SCR Method[1] Density	SCR Method[1] Error	MCR Method[2] Density	MCR Method[2] Error	ACR Method[3] Density	ACR Method[3] Error
Sand & Vermiculite	58.1	62.6	+4.5	56.2	-2.0	58.1	0
Aluminum	58.8	67.9	+9.1	59.9	+1.1	61.1	+2.4
Water (Box)	62.2	50.2	-12.0	61.1	-1.1	62.9	+0.7
Water (Tank)	62.2	40.1	-22.1	61.7	-0.5	63.9	+1.7
Aluminum	84.1	86.1	+2.1	82.9	-1.2	81.6	-2.5
Graphite	96.5	101.7	+5.2	97.6	+1.1	96.9	+0.4
CCl_4	98.8	116.6	+17.8	100.4	+1.6	98.7	-0.1
Sat. quartz sand	113.5	113.1	-0.4	115.2	+1.7	115.9	+2.4
Aluminum	117.4	120.9	+3.5	117.3	-0.1	116.6	-0.8
Aluminum	136.8	135.8	-1.0	134.3	-2.5	134.4	-2.4
Indiana Limestone	140.8	145.3	+4.5	141.6	+0.8	140.2	-0.6
Limestone (IE)	141.8	148.4	+6.6	145.2	+3.4	144.1	+2.3
Granite	163.8	156.1	-7.7	164.3	+0.5	167.4	+3.6
Aluminum	168.2	158.8	-9.4	164.8	-3.4	166.4	-1.8

(1) standard count ratio, calibration equation
(2) maximum count ratio, calibration equation
(3) attenuation count ratio, calibration equation

The standard error of calculated density versus actual density for the 14 standards was ±10.0 pcf for the conventional standard count ratio method while the standard errors for the air gap methods were both ±1.9 pcf.

SOIL DENSITY MEASUREMENTS

Weber (2) has described entensive laboratory and field tests which were conducted to obtain nuclear calibration curves for various soils in California and to determine the accuracy of these calibration curves. He found that using one calibration curve will result in 95 per cent of the nuclear readings being within about ±7 pcf of true density. The use of separate calibration curves, however, resulted in a substantial decrease in this error to about ±3.5 pcf. Studies similar to Weber's were conducted at Clemson University using a variety of South Carolina soils. These soils were compacted in aluminum boxes and density measurements obtained from nuclear readings were compared to densities measured by weighing these boxes which were of known volume.

The compaction molds were 14 inches square and one cubic foot in volume. The depth of the soil sample was over 8 inches which, according to Ralston (1) and Carey (5),is sufficient to provide an infinite volume for the nuclear gage within the range of densities tested. Several techniques to produce a uniformly compacted soil sample were investigated. The procedure selected consisted of preparing four samples for each of the soil types summarized in Table 3 as follows: dry, loose; dry, dense; wet, loose; and wet, dense. A moisture content close to optimum was selected for the wet samples. The loose samples were prepared by placing 10 pounds of soil at a time in the box and leveling each of these layers omitting any tamping. The dense samples were produced by tamping

TABLE 3. Description of Test Soils

Soil Designation	Description	Region
A	Micaceous Silt	Piedmont
B	Red Clay	Piedmont
C	Red Sandy Clay	Piedmont
D	Sandy Clay	Sand Hills-Slate
E	Sandy Clay	Sand Hills-Slate
F	Sandy Clay	Sand Hills-Slate
G	Pink Clay (Kaolin)	Sand Hills-Slate
H	Olive Silty Clay	Sand Hills-Slate
I	Sand	Coastal Plain
J	Sand	Sand Hills-Slate
K	Sand	Sand Hills-Slate
L	Sand	Sand Hills-Slate

each of these thin layers with a round steel tamper dropped by hand. A total of 48 soil samples were made with a density range from 77 pcf to 124.5 pcf. In order to keep the effects of surface roughness and non-uniformity at a minimum, the soil samples were inverted after compaction was completed and the bottom of the sample box was removed. Air gap and flush readings were then taken with the nuclear gage on the exposed bottom surface of the sample. (See Table 4.)

Figure 8 illustrates the correlation between the control or box density and the nuclear density as determined by the standard count ratio method recommended by the manufacturer using calibration equation (1). The standard error of estimate was ±4.2 pcf; however, the mean of these nuclear densities was 0.9 pcf lower than the mean of the control densities indicating either a bias in calibration or a consistant error in determining the control density. From these results, about 95 per cent of the nuclear readings have an accuracy within ±8.4 pcf which is similar to Weber's findings when only one calibration curve is used for all soils.

Figure 9 presents the comparison between control densities and nuclear densities as determined by the maximum count ratio method originally proposed by Kühn (3) using calibration equation (2). The precision of the nuclear measurements is substantially improved by employing the air gap readings. The standard error of estimate is only ±2.1 pcf with a mean error of -0.8 pcf. Expected accuracy for 95 per cent of these measurements is then about ±4.2 pcf using calibration equation (2).

A comparison of nuclear densities computed by the attenuation count ratio method and control density using calibration equation (3) is shown in Figure 10. Density determinations using this relationship were again consistantly lower than the control values with a mean error of -1.0 pcf

TABLE 4. Summary of Nuclear Density Measurements on Soil

Soil	Control Density, pcf	Density Calculated by:					
		SCR Method		MCR Method		ACR Method	
		Density	Error	Density	Error	Density	Error
A	90.0	93.2	+3.2	89.4	-0.6	88.7	-1.3
	93.5	97.1	+3.6	94.5	+1.0	93.9	+0.4
	104.0	103.6	-0.4	101.6	-2.4	100.8	-3.2
	118.5	124.6	+6.1	124.0	+5.5	124.0	+5.5
B	101.5	104.3	+2.8	101.2	-0.3	100.5	-1.0
	98.0	100.5	+2.5	97.7	-0.3	96.9	-1.1
	89.0	88.6	-0.4	88.4	-0.6	88.0	-1.0
	105.0	103.9	-1.1	104.0	-1.0	103.6	-1.4
C	97.5	103.6	+6.1	97.8	+0.3	96.7	-0.8
	95.5	100.1	+4.6	95.0	-0.5	94.0	-1.5
	100.0	103.6	+3.6	98.2	-1.8	97.1	-2.9
	106.0	112.4	+6.4	106.9	+0.9	105.5	-0.5
D	110.0	107.8	-2.2	109.5	-0.5	109.8	-0.2
	107.5	105.9	-1.6	107.6	+0.1	107.6	+0.1
	113.0	107.8	-5.2	109.9	-3.1	110.4	-2.6
	124.5	118.9	-5.6	123.4	-1.1	125.0	+0.5
E	110.0	112.0	+2.0	113.1	+3.1	113.4	+3.4
	107.5	104.7	-2.8	106.4	-1.1	106.4	-1.1
	105.5	103.2	-2.3	104.8	-0.7	104.9	-0.6
	115.5	114.7	-0.8	116.3	+0.8	116.7	+1.1
F	107.5	107.8	+0.3	106.7	-0.8	106.4	-1.1
	98.5	100.9	+2.4	100.6	+2.1	100.3	+1.8
	89.0	87.1	-1.9	87.6	-1.4	87.5	-1.5
	117.0	115.1	-2.9	115.5	-1.5	115.8	-1.2
G	90.5	87.1	-3.4	88.1	-2.4	87.7	-2.8
	100.5	97.4	-3.1	100.1	-0.4	100.0	-0.5
	95.5	90.9	-4.6	93.0	-2.5	92.8	-2.7
	110.5	101.6	-8.9	104.3	-6.2	104.5	-6.0
H	84.5	92.1	+7.6	84.4	-0.1	83.4	-1.1
	98.0	100.5	+2.5	96.1	-1.9	94.9	-3.1
	109.5	113.1	+3.6	110.0	+0.6	109.3	-0.2
	90.5	93.2	+2.7	89.3	-1.2	88.7	-1.8
I	85.0	79.1	-5.9	80.7	-4.3	81.0	-4.0
	97.5	92.8	-4.7	95.3	-2.2	95.2	-2.3
	77.0	74.1	-2.9	75.3	-1.7	75.6	-1.4
	100.0	95.1	-4.9	96.6	-3.4	96.2	-3.8
J	88.2	81.0	-7.2	84.9	-3.3	84.9	-3.2
	106.2	99.7	-6.5	103.3	-2.9	103.6	-2.6
	94.5	89.8	-4.7	94.0	-0.5	94.2	-0.3
	113.5	107.0	-6.5	110.8	-2.7	111.6	-1.9
K	94.0	92.7	-1.3	94.3	+0.3	94.0	0
	109.5	107.1	-2.4	109.3	-0.2	109.3	-0.2
	76.5	79.4	+2.9	79.4	+2.9	79.1	+2.6
	113.5	110.4	-3.1	112.9	-0.6	113.7	+0.2
L	108.0	107.0	-1.0	108.2	+0.2	107.7	-0.3
	97.5	95.5	-2.0	96.6	-0.9	96.3	-1.2
	84.0	84.0	0	85.2	+1.2	85.0	+1.0
	114.0	107.8	-6.2	111.1	-2.9	111.9	-2.1

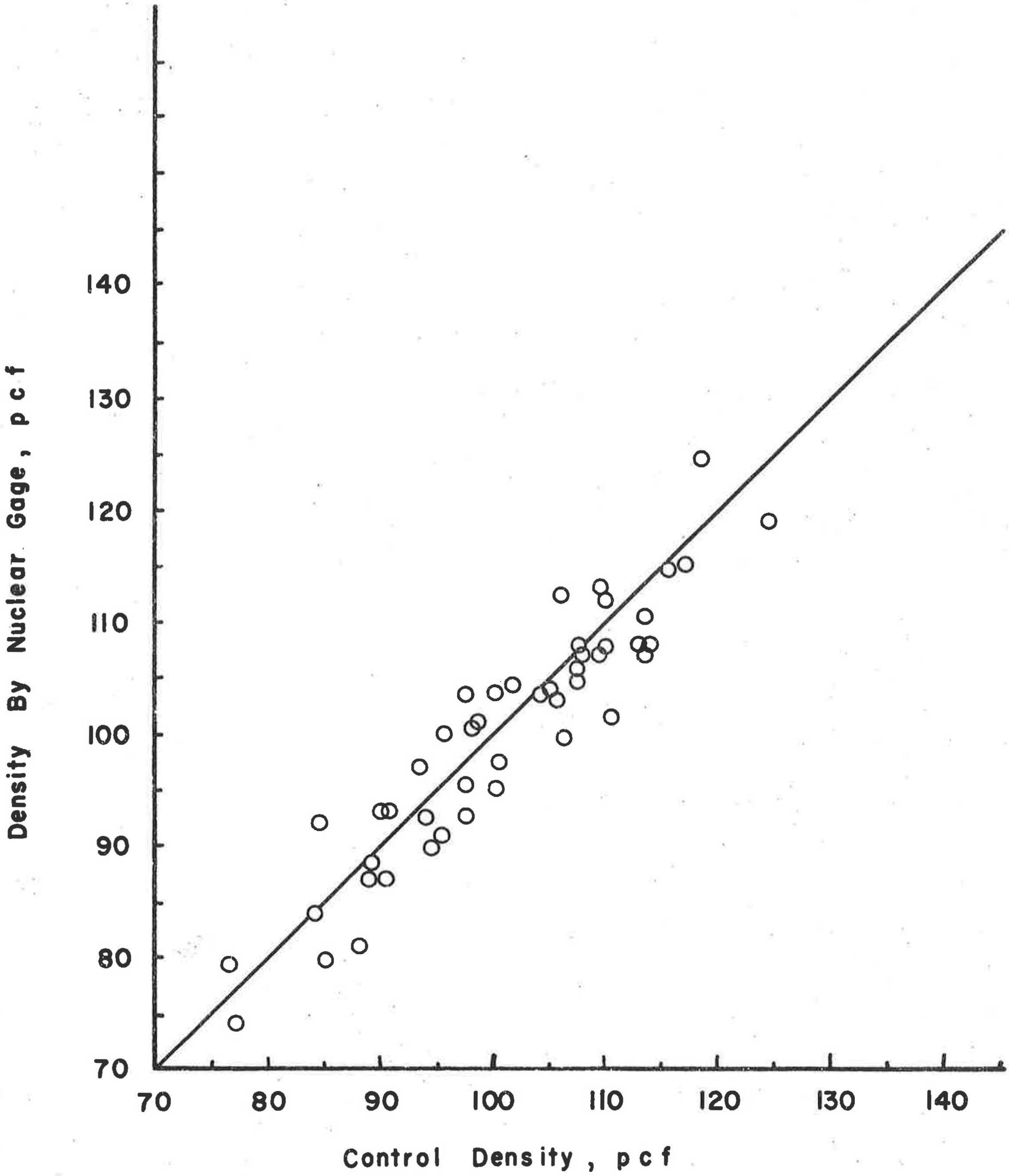

Figure 8 - Correlation Between Control Density and Nuclear Density Using Standard Count Ratio Method

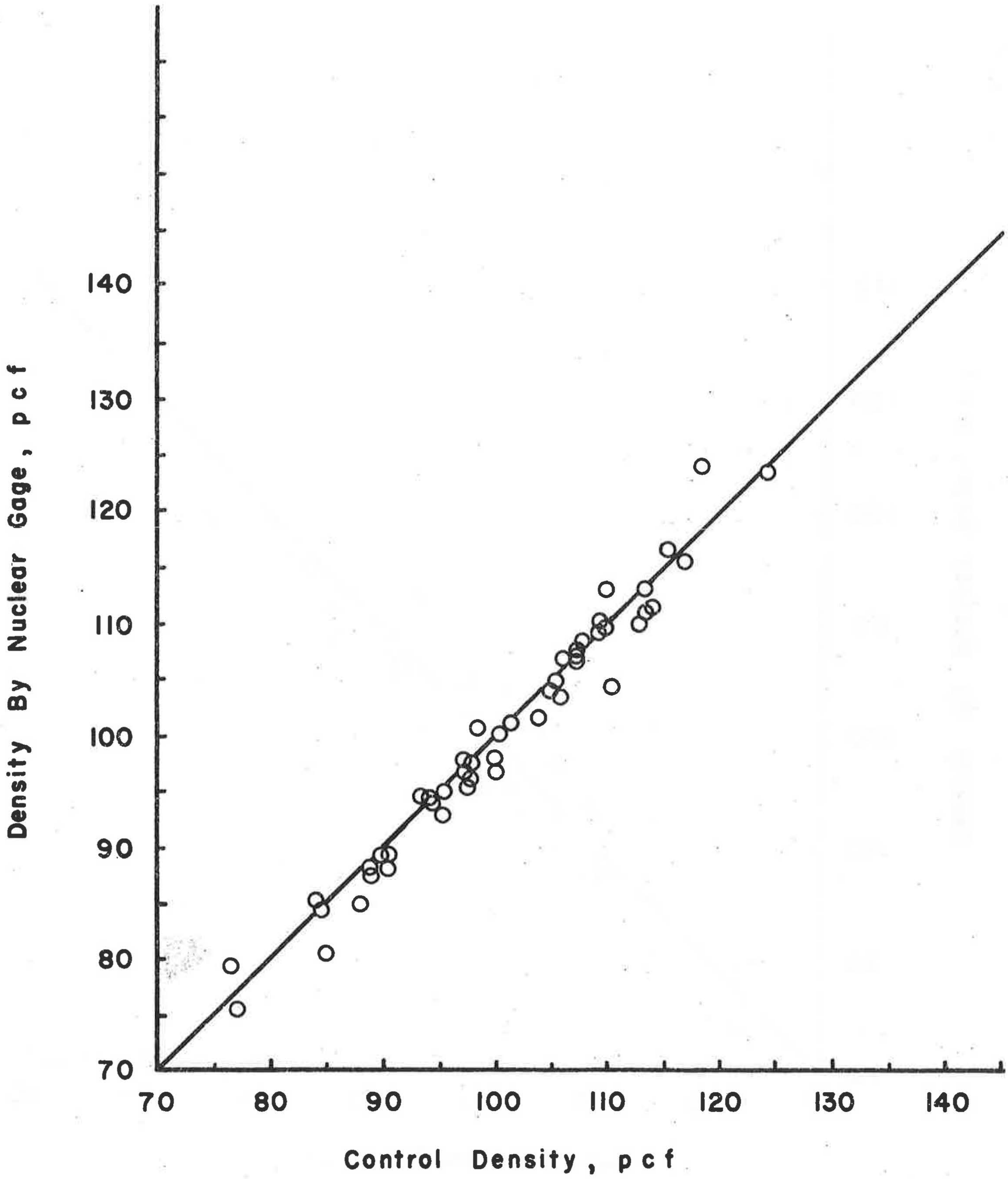

Figure 9- Correlation Between Control Density and Nuclear Density Using Maximum Count Ratio Method

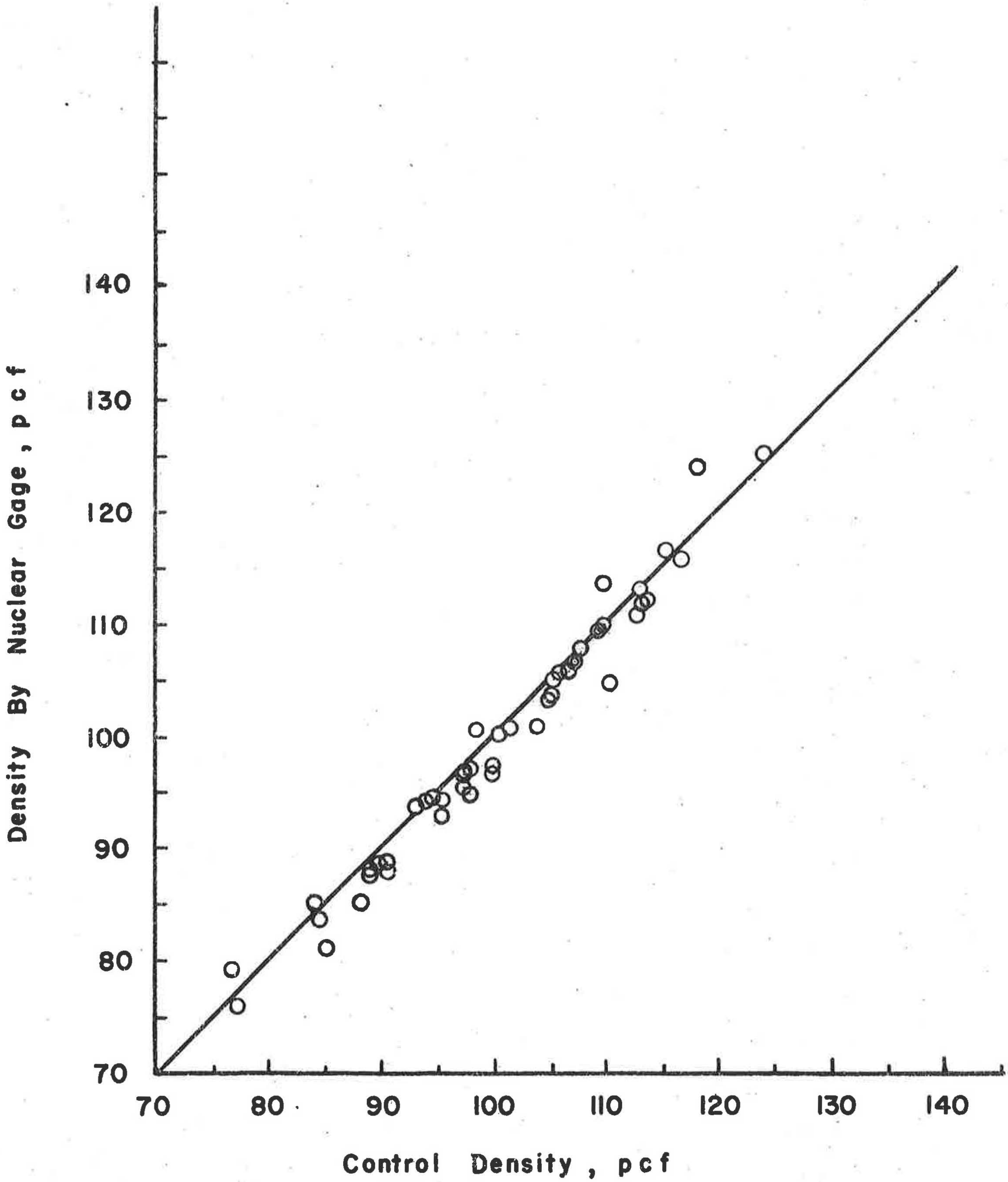

Figure 10 - Correlation Between Control Density and Nuclear Density Using Attenuation Count Ratio Method

and the standard error of estimate was ±2.2 pcf.

DISCUSSION

No rigorous theoretical reason can be given why the air gap method produces a rather smooth curve when plotted versus density. This procedure, however, does seem to either cancel or subtract out the chemical effect. Furthermore, the compositional sensitivity of gap count rate and flush count rate are closely related. Thus, by normalizing the count readings, the chemical effect can be minimized, and the gap count rate, in effect, furnishes an individual calibration for each material tested. Even though the precise theory responsible for the improved accuracy of the air gap method is obscure, the following discussion is presented in an effort to explain, in a general way, why the air gap procedure is beneficial.

A number of the density standards used in the study were made up of 16" x 16" x 1/8" aluminum sheets stacked horizontally and separated by small spacers at each corner of the sheets. By varying the thickness of the spacers the mean density of the aluminum standards was varied between about 40 and 170 pcf. Thus, standards were provided which were made up of identical chemical composition but which had different densities. From these standards, it was found that the relative intensity of radiation reaching the detector of the gage was nearly constant within the range of 90 and 160 pcf for the air gap readings, whereas the flush count rate diminished with increasing density. Figure 11, showing the plot of air gap count rate and flush count rate versus density, illustrates this phenomenon. In the case of the air gap reading, the radiation is backscattered and reflected by the material, as shown in Figure 12-a. The penetration of the radiation is relatively shallow (depending on density) so that the

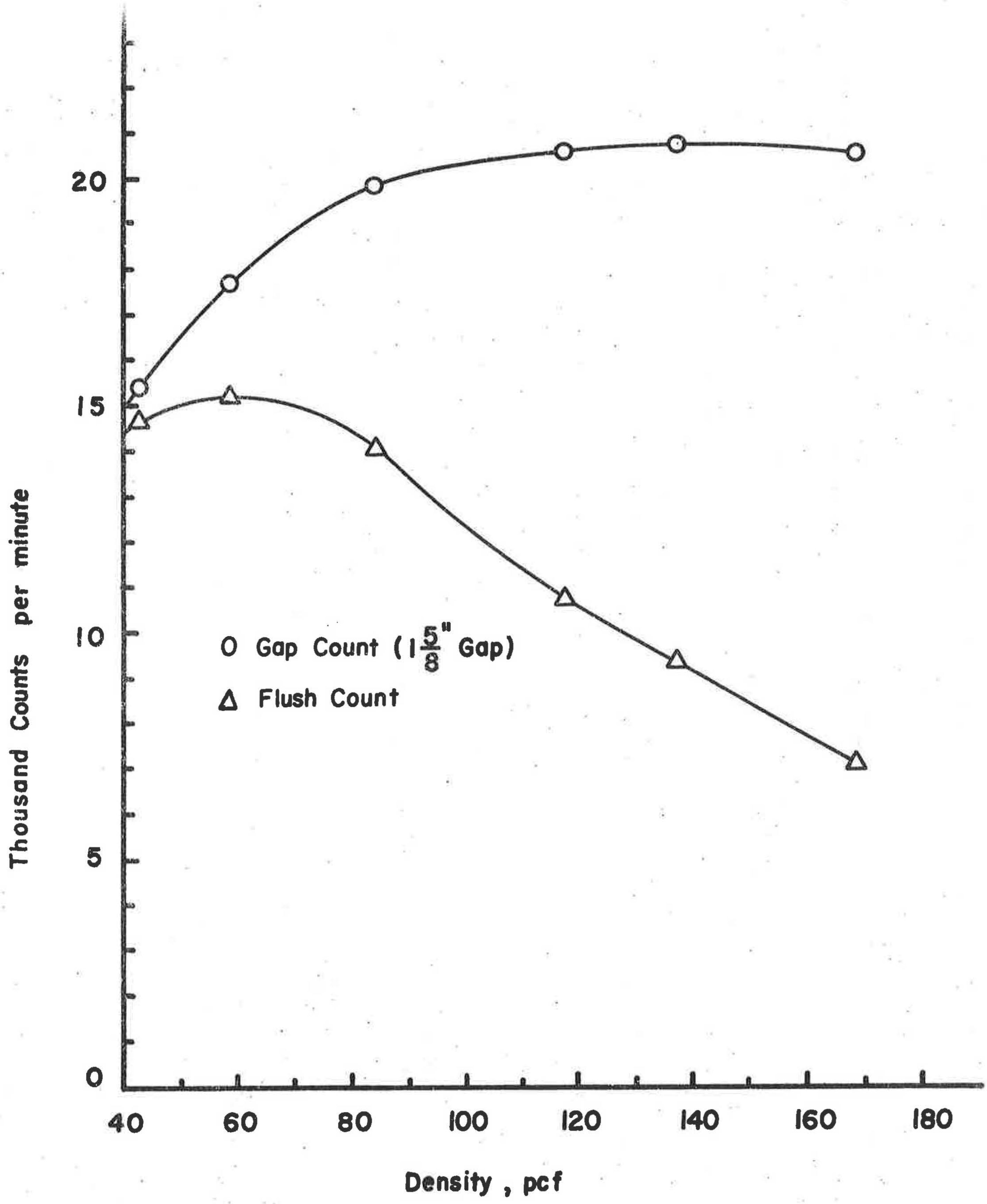

Figure 11 – Count Rate versus Density for Aluminum

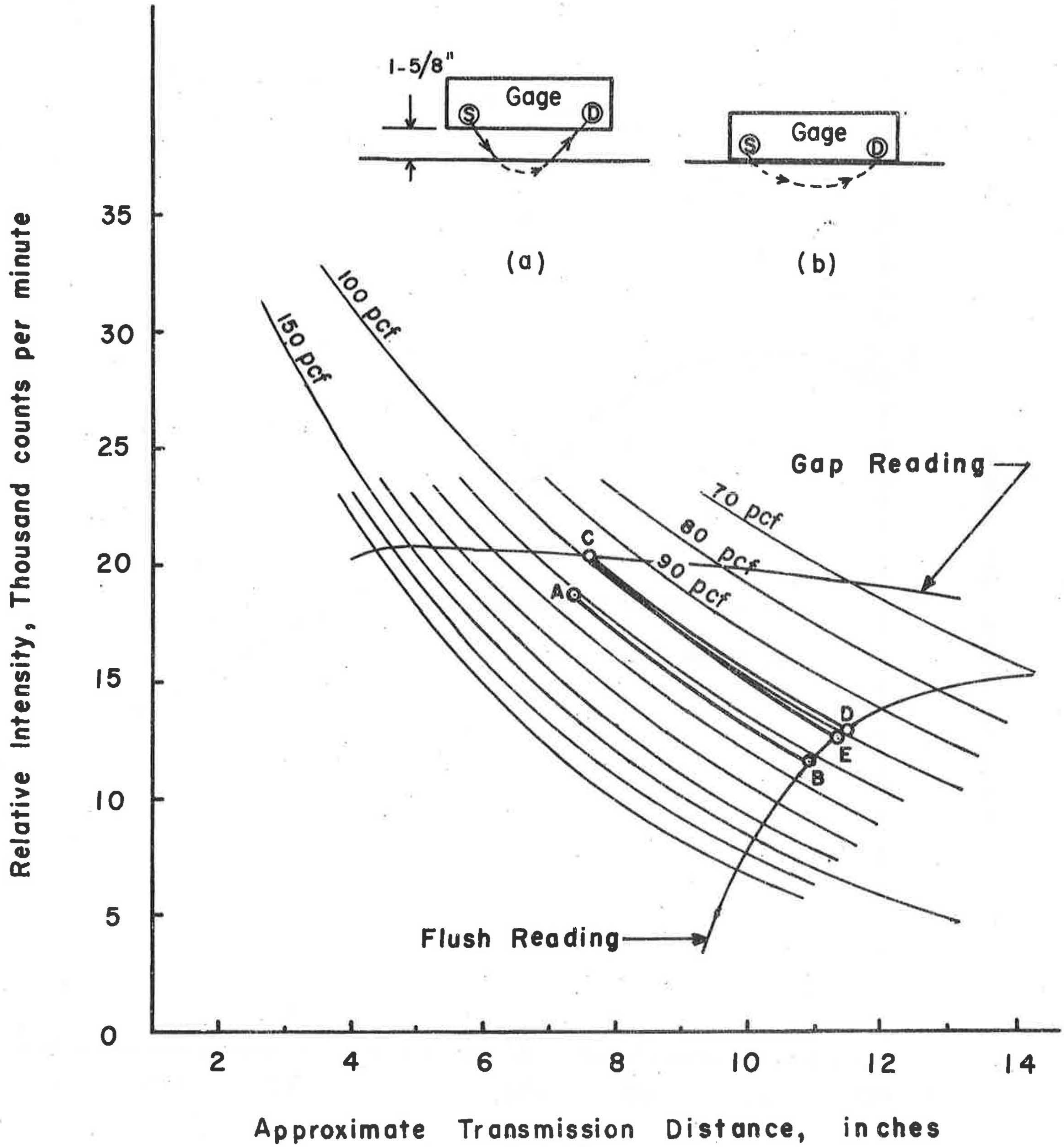

Figure 12 - Count Rate versus Transmission Distance for Aluminum

absorption of energy is small. Thus, absorption of radiation is minimized as it passes through the material a relatively short distance. However, in the case of the flush readings, illustrated in Figure 12-b, the path of the photons lies entirely within the material which is a much more resistant path than the air-material-air path taken by the photons in the air gap position. For the air gap position, it is presumed that the average depth of penetration will vary inversely with the density of a given material. Since the absorption of the photon energy is less for lower density material, the deeper penetration and increased distance of transmission does not cause any significant additional reduction in intensity of radiation reaching the detector. Thus, the air gap count rate is relatively insensitive to density within the normal range of densities encountered in highway construction. The air gap count rate does, however, differ for different materials as their backscatter and absorption characteristics vary from material to material.

The family of curves shown in Figure 12 illustrates exponential decay for relative intensity with increasing transmission distance. The upper, nearly horizontal, line cutting across the family of curves is the locus of points for air gap count rate for aluminum while the diagonal, curved line cutting across these curves in the lower right hand area of the diagram is the locus of points representing the flush count rate taken on the aluminum samples. Transmission distance includes air space between the aluminum sheets when they are separated by spacers. The scale of the graph denoting transmission distance approximates that required to accomodate the geometry of the density gage.

To ullustrate the chemical effect, the gap count rate, flush count rate and the decay curve, AB, for CCl_4 (98.8 pcf) are plotted on Figure 12. This curve can be visually compared with the decay curve, CD, for aluminum at the same 98.8 pcf density. Because of differences in the absorption and/or backscatter cross-section of the two materials, the gap count rate and flush count rate are lower for CCl_4 than for aluminum of the same density. If the lower gap and flush count rates for CCl_4 are both multiplied by the constant, 1.091, the product will yield an adjusted gap count rate equal to the gap count rate for aluminum and the flush count rate for CCl_4 will also be increased proportionally so as to approach the flush count rate for aluminum. With appropriate adjustments in abscissa scale, the adjusted or normalized, gap and flush count rates for CCl_4 can then be plotted on Figure 12 at points C and E respectively and line CE becomes the adjusted decay curve for CCl_4. The density for CCl_4 determined from the adjusted flush count rate (point E) will then be 101.8 pcf or 3 pcf higher than aluminum when using a standard count ratio calibration curve calibrated on aluminum. Although this result is not exactly correct, the difference in density obtained by this method is only about 1/4 as great as the difference obtained when using the original, unnormalized flush count rate represented by point B.

The above example shows how the normalized flush count rate can be used with the standard count ratio method to yield a more accurate density result. Since the normalizing process cited above, in effect, makes the gap count rates the same for the two materials, it is equally valid to employ a count rate relationship which utilizes only the ratio of the gap count rate divided by the flush count rate. This ratio, which was suggested by Kühn (3), is known as the maximum count ratio and was utilized in calibration equation (2). The attenuation count ratio method, equation (3), is also similar in principle to the maximum count ratio method. However, the introduction of the term $0.2C_s$ tends to make the density versus ACR relationship a straight line and, at the same time, provides additional compensation for chemical effect.

Not all error was eliminated by the use of the air gap method since errors inherent in determining the control density, surface roughness and non uniformity of the soil and density standards were present for both the standard count and air gap methods of nuclear density measurement. However, nuclear density measurements on both density standards and typical soils experienced a significant reduction in errors when the air gap method was employed.

Therefore, it is recommended that the air gap method be applied to the Nuclear Chicago Model P22A gage whenever soils or construction materials of adverse chemical composition are encountered. In order to minimize the limited chemical effect which may not be eliminated by the use of the air gap method, the gage should be calibrated, if possible, on density standards which have nuclear response characteristics similar to the material to be tested. This can easily be checked by comparing the gap count rates taken on the various materials involved. These density standards should be very uniform, of known density, and cover the range of densities to be expected in the field. The calibration on the standards meeting the above requirements should then be used to determine the constants for equation (2) or equation (3).

CONCLUSIONS

1) Air gap calibration procedures were successfully applied to a

Nuclear Chicago, Model P22A, Surface Density Gage.

2) The acuuracy of the nuclear gage was improved from a standard error of estimate of ±10 pcf for the standard count ratio method to ±1.9 pcf for the air gap method when calibrating on a series of density standards with widely varying chemical composition.

3) The standard error of estimate between gravimetric soil densities and nuclear gage measurements was reduced from ±4.2 pcf for the standard count ratio method to ±2.1 by the use of the air gap method.

ACKNOWLEDGMENTS

The authors wish to acknowledge the aid of graduate research assistants D. Lavoie, R. Owens, and H. Tyner and student assistant, O. Kadaster, for performing many of the tests to obtain the data presented in this paper. Special recognition is given to Mr. John F. Wentzel who suggested to the authors that the air gap method might be applied to any backscatter density gage of conventional design.

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Discussion by C. S. Hughes and M. C. Anday

On Paper by

Joseph P. Rostron, Arnold E. Schwartz, and Farrell B. Brown
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Assistant Professor of Civil Engineering, and Assistant
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Entitled

AIR GAP PROCEDURE FOR THE MEASUREMENT OF SURFACE DENSITY BY GAMMA RAY BACKSCATTER TECHNIQUE

We would like to congratulate the authors on the valuable contribution they have made to the field of nuclear density testing.

We have recently conducted tests at the Virginia Highway Research Council which compared backscatter, direct transmission, and these two procedures used as a base for an air gap ratio.

As seen in Figure 1, the optimum air gap for the particular gauge used (the optimum air gap varies from gauge to gauge) is between 2.25 inches for tufa at a density of 110 pcf and 2.75 inches for granite at a density of 163 pcf. However, since most subgrade soils have wet densities below 130 pcf, it was felt that the 2.25 inch air gap, which was the optimum on the lighter blocks, should be used.

The air gap ratio (air gap reading/surface reading) occurring at 2.25 inches air gap was then plotted against the wet density of the blocks to obtain the calibration curve shown in Figure 2. In this figure the standard error, which is an indication of how well the curve fits the data, is 3.4 pcf. This is evidently better than the standard errors of 11.0 and 5.7 pcf respectively for the backscatter and the direct transmission curves obtained on the same four blocks. These curves are shown in Figures 3 and 4. The increased accuracy of the air gap technique is evidently due to minimization of chemical effects, since the blocks tested were the same in each case. Also, since direct transmission gave a smaller standard error than backscatter (5.7 to 11.0 pcf), it appeared worthwhile to extend the air gap technique one step further — instead of using a surface reading as the base for the air gap ratio, a direct transmission reading at a 6 inch depth was used. This produced the curve shown in Figure 5, which has a standard error of only 0.9 pcf.

The high degree of accuracy obtained with the air gap technique dictated that it should be field tested. At this time very few field results have been obtained, but some trends are in evidence. One is that in our Piedmont soils there is so much variation in chemical composition within a given area that an air gap must be run at every test. This is contrary to Kuhn's recommendation* that the air gap can be used to

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*S. H. Kuhn, Effects of Type of Material on Nuclear Density Measurements, Highway Research Record Number 66, 1965.

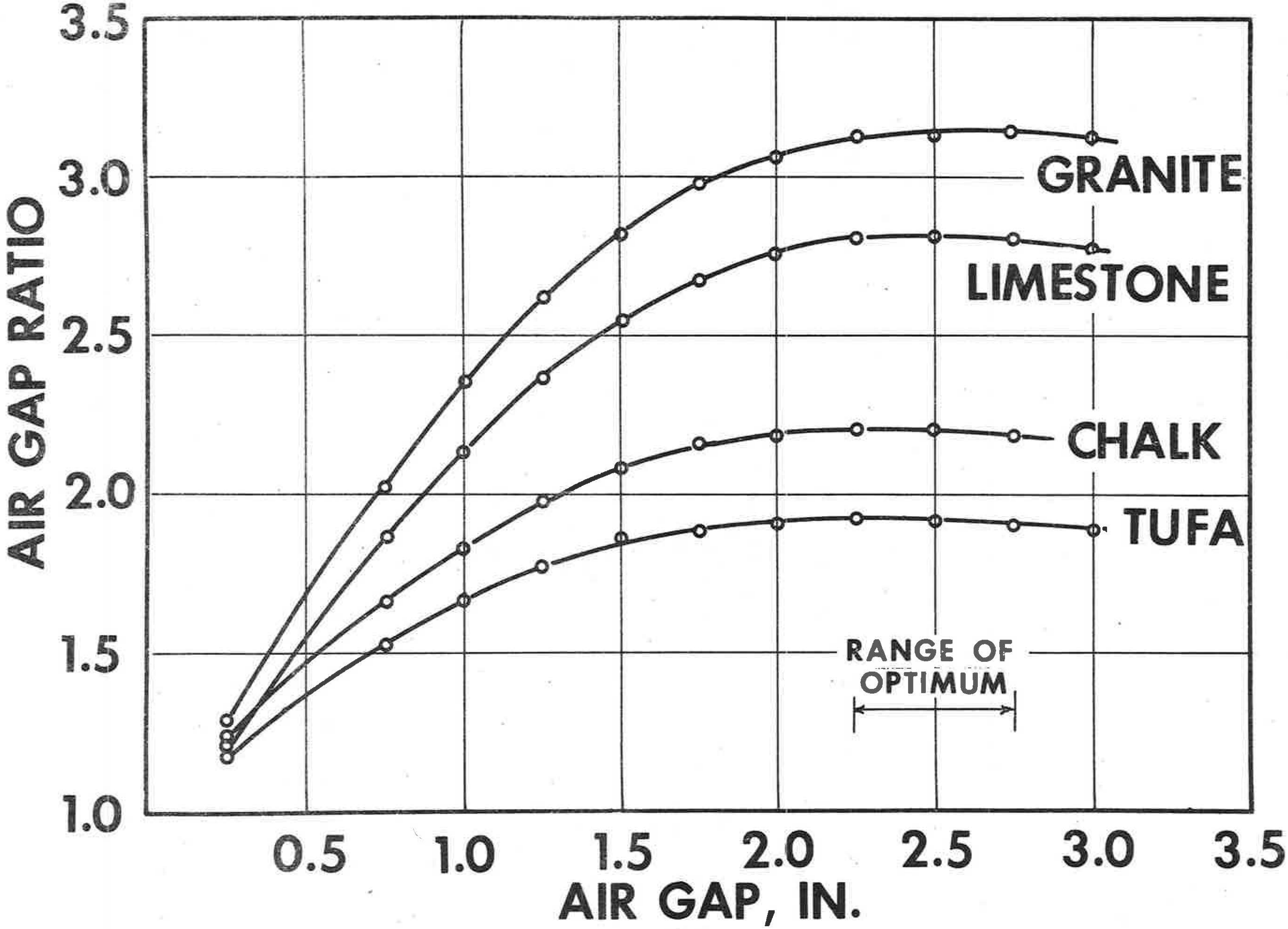

Figure 1. Determination of optimum air gap.

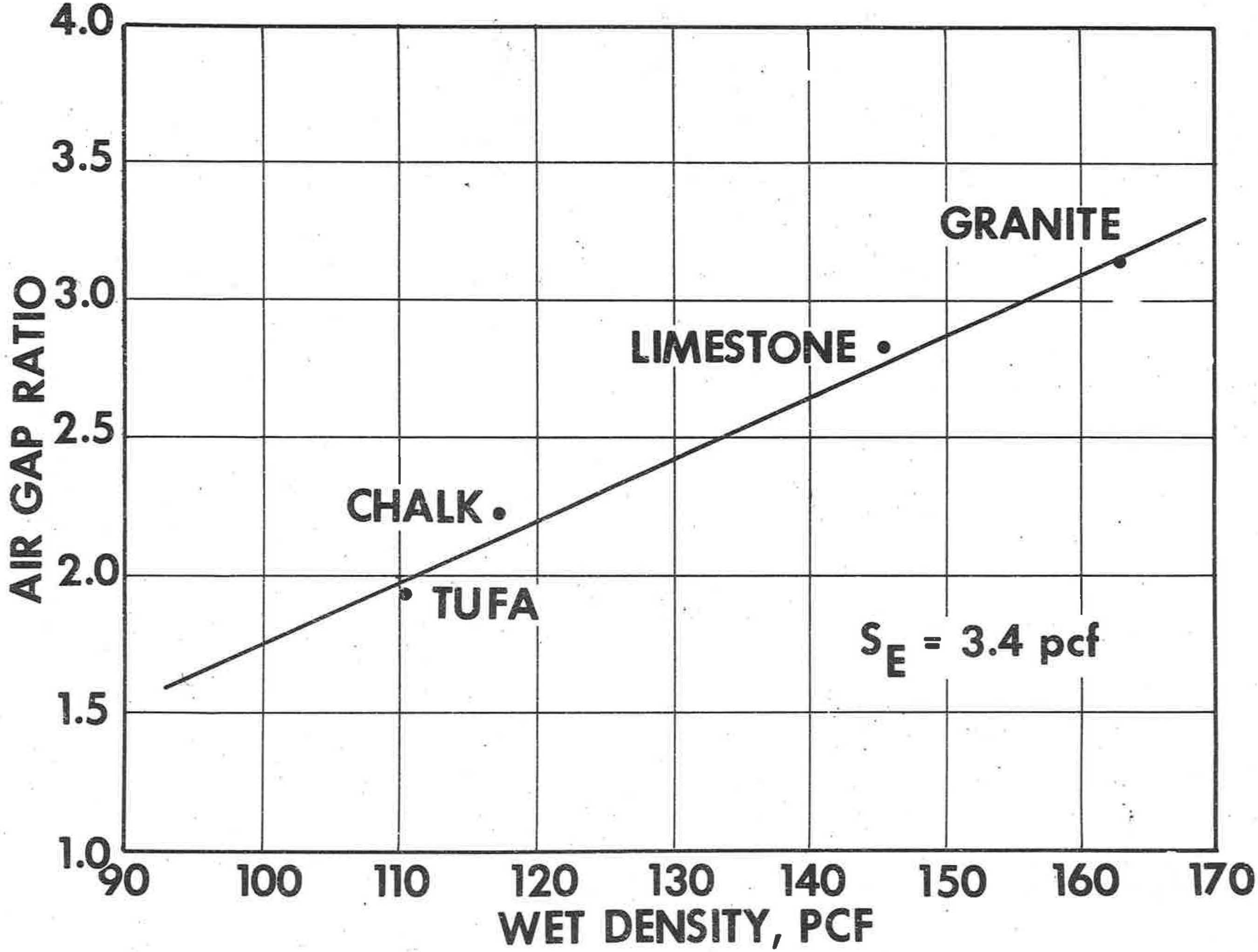

Figure 2. Air gap ratio vs wet density (backscatter).

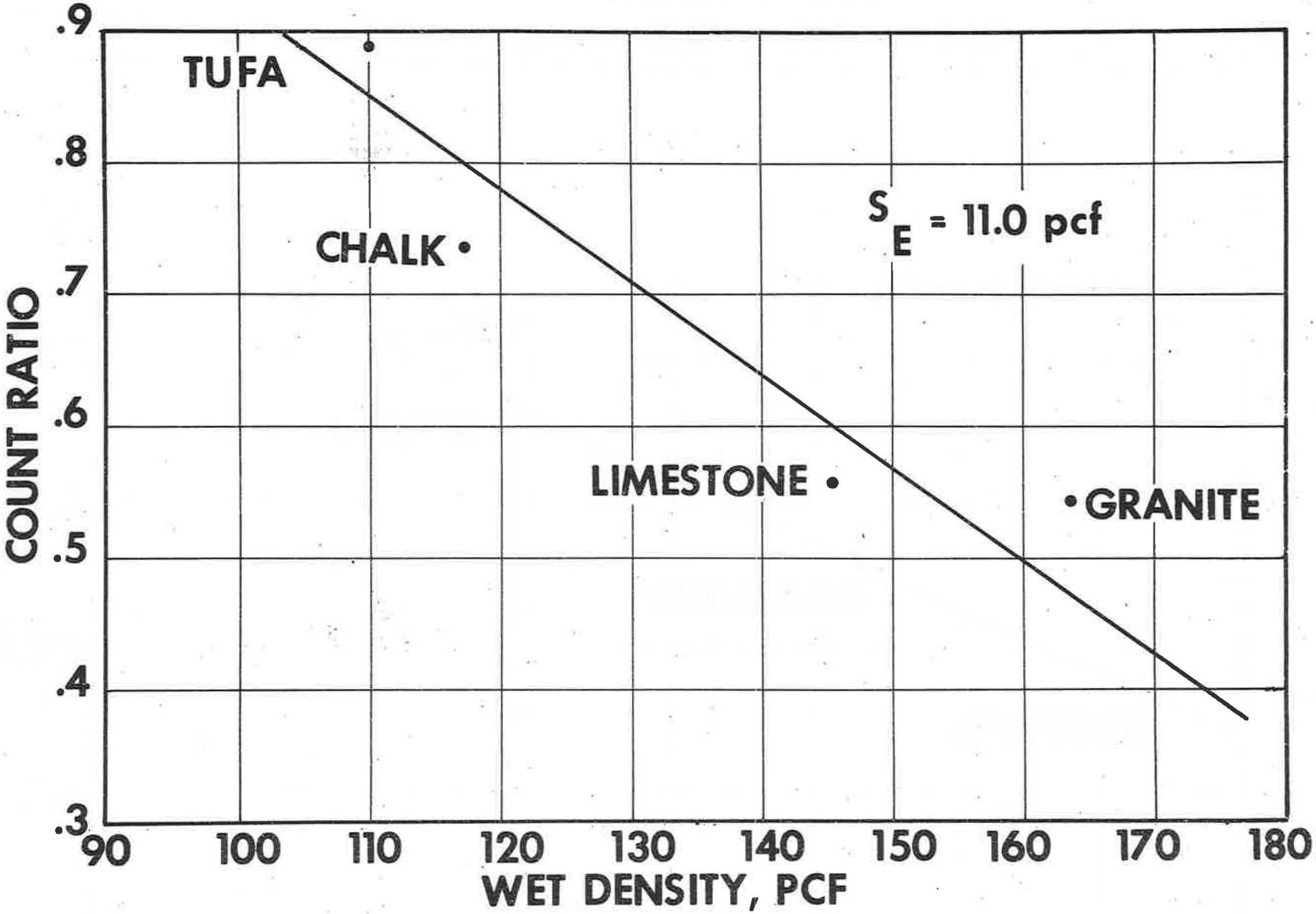

Figure 3. Count ratio vs wet density (backscatter).

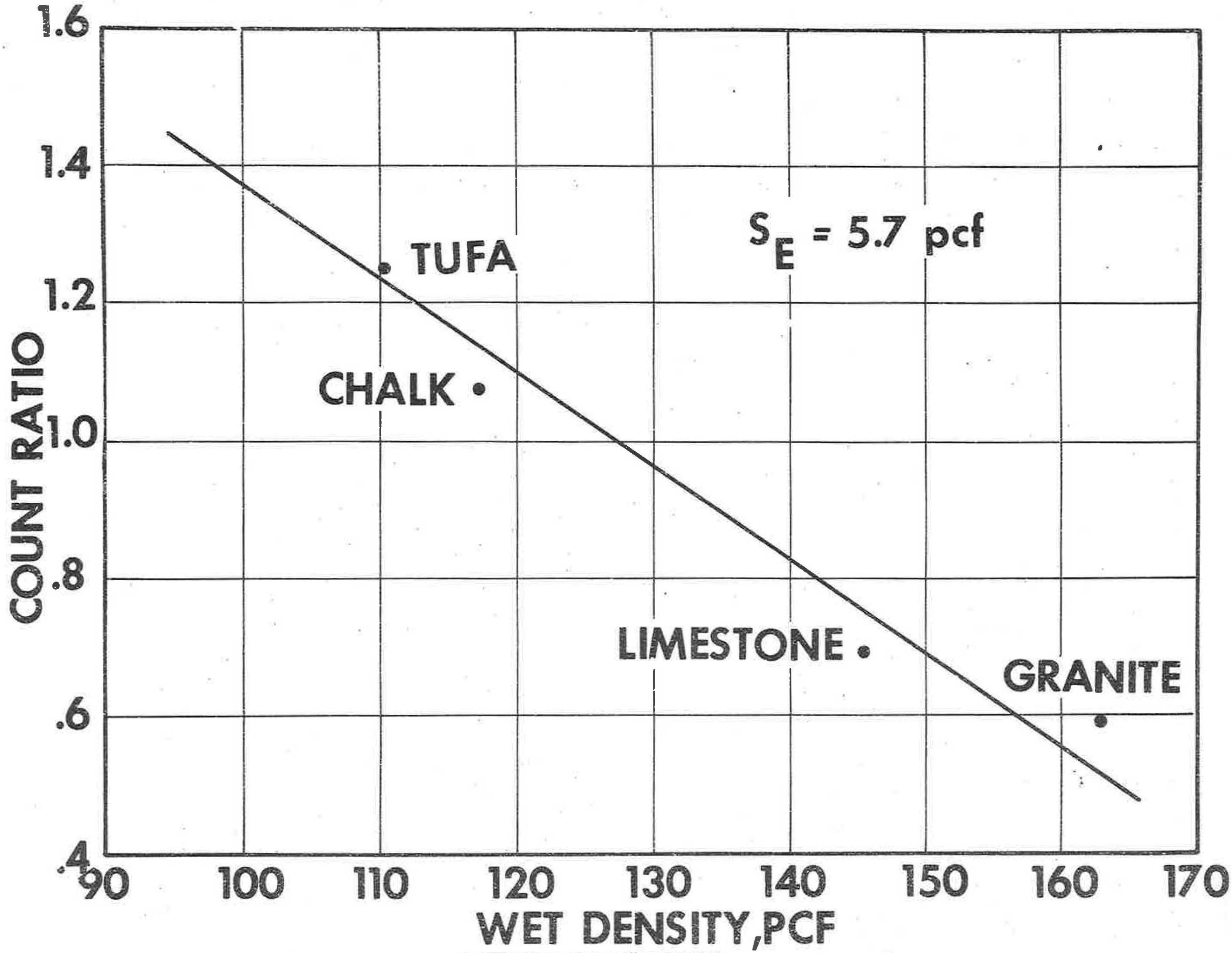

Figure 4. Count ratio vs wet density (direct transmission).

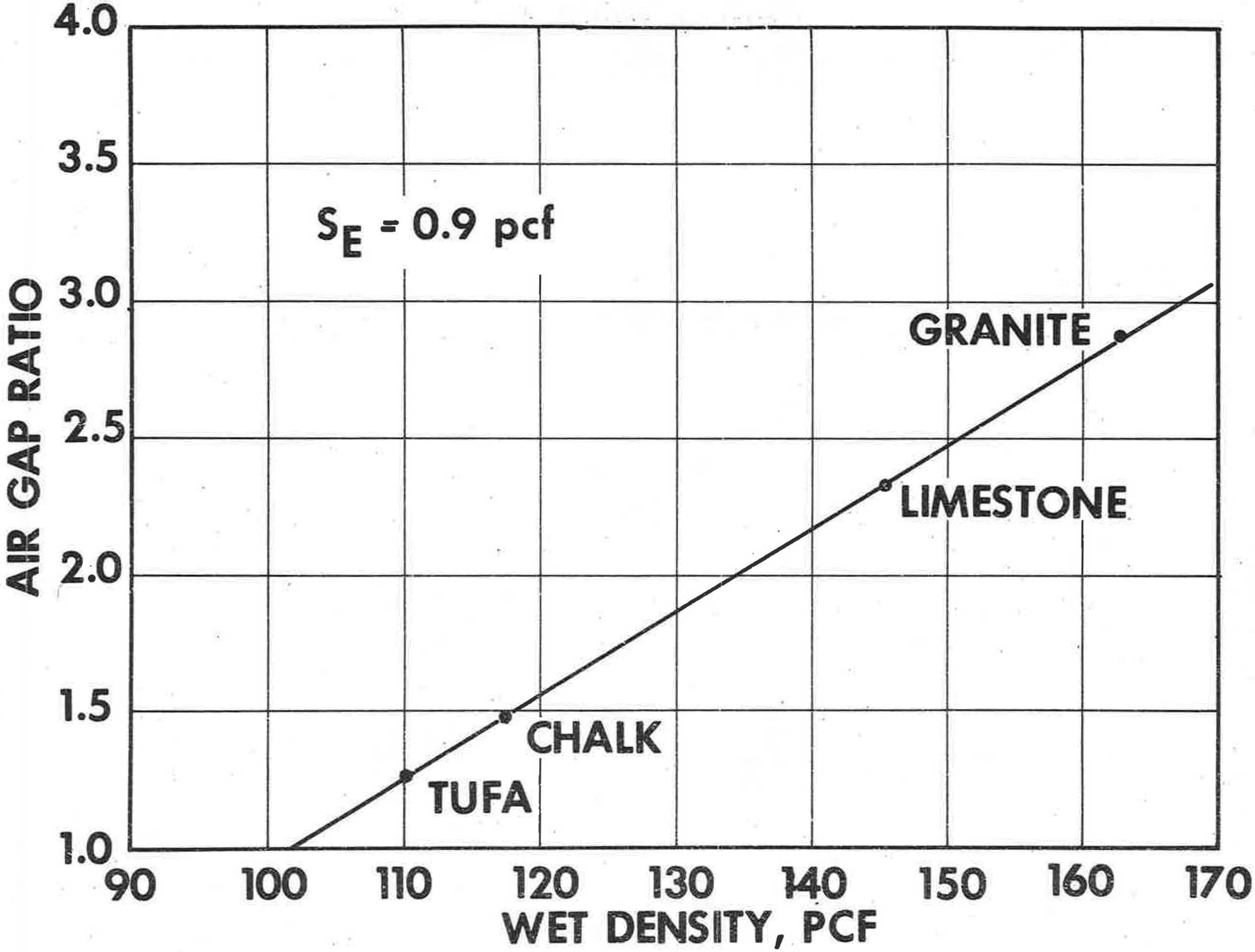

Figure 5. Air gap ratio vs wet density (direct transmission).

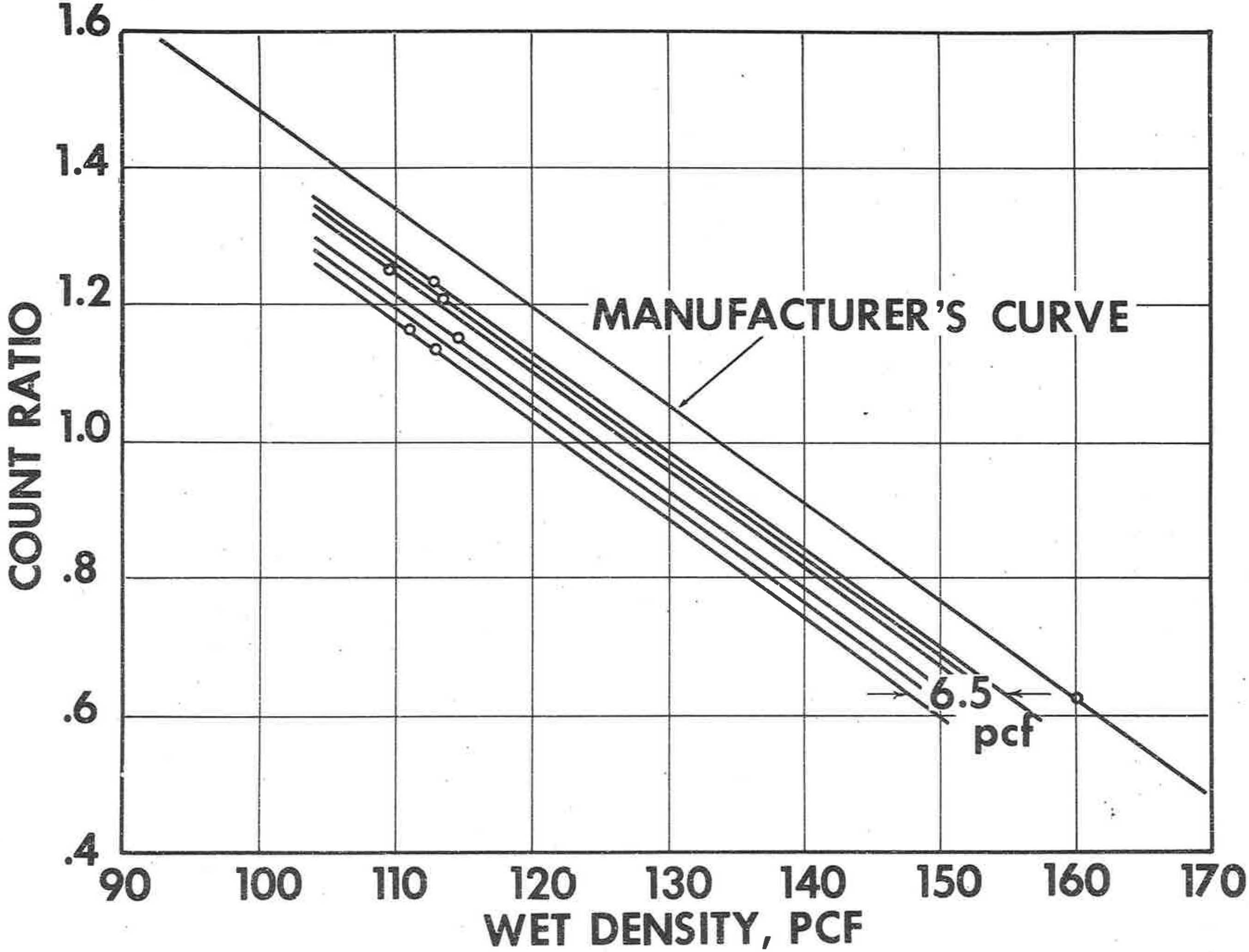

Figure 6. Indication of chemical effect.

Discussion by C. S. Hughes & M. C. Anday

establish a field calibration for backscatter measurements. Kuhn advocates the establishment of a field calibration curve by plotting the density given by the air gap technique against the normal count ratio for the surface (or in this case 6" depth) reading. Through this point a curve with the same slope as the manufacturer's is drawn to produce a field calibration curve for that soil. This was done on seven tests (Figure 6) and a spread of about 6.5 pcf, which is caused mainly by chemical effect, is indicated. It would seem worth the extra time of one or two minutes to obtain an air gap reading on soils to minimize the chemical effect, the magnitude of which is unknown.

CLOSURE

The work performed by Messrs. Hughes and Anday supports the contention that the air gap method can be successfully applied to a variety of backscatter-type nuclear gages, and the authors appreciate their discussion presenting this data. Even though Hughes and Anday used a straight line calibration relationship rather than the semi-log plot developed for the maximum count ratio method, the improvement of calibration accuracy using the MCR method over the SCR method was quite significant. It should be pointed out, however, that although Hughes and Anday obtained good correlation using a linear calibration curve for their four points, the authors found that a semi-log plot provided better correlation for the numerous points and wide range of densities which were used in their study.

The application of the air gap method to the direct transmission system is a significant contribution to nuclear density techniques. The results of their work using this technique were excellent and the authors commend Hughes and Anday for discovering this unique application of the air gap method.

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* As of December 31, 1965.