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RESEARCH REPORT NO. 341

# CALIBRATION AND USE OF A GAMMA PROBE FOR SOIL DENSITY MEASUREMENTS

by

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December 9, 1960

## ABSTRACT

A gamma-ray probe was obtained and tested for the measurement of soil density in situ. A 1.625-inch steel tube is recommended for use as the access tube but a 2-inch aluminum tube can be employed. The calibration should be based on the field moisture content of the soil. Appropriate corrections for moisture content are made and the bulk density of the soil calculated. A direct calibration of gamma activity density data with the bulk density of soil, dry basis, is not recommended. The gamma probe is capable of reproducing soil density values to ± 0.01 absolute bulk density units. Apparent variations in the gamma activity-soil density relationships with changes in the soil texture preclude the use of a general calibration curve. Based on the experimental findings the prospective user of the gamma probe should prepare a calibration curve applicable to the particular soil to be tested.

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A gamma-ray probe, Nuclear-Chicago Model P-20, was obtained in 1959 for soil density measurements. The manufacturer provides with the Model P-20 density probe a calibration chart which purports to convert activity density readings to wet density values. This calibration curve is based on readings obtained with the Model P-20 density probe placed in standard steel access tubes located in standard materials of infinite volume and known density.

Lacking specific information to the contrary, the user of the Model P-20 density probe is led to believe the calibration curve provided applies equally well to any soil. Both from a theoretical and a practical viewpoint this position is questionable. Workers using the neutron probe for soil moisture measurements are aware of the necessity of individual checks on the calibration curves provided with that instrument. A similar check on the soil density probe appeared in order.

Access tubes have been used in previous work at the Sedimentation Laboratory in connection with soil moisture studies utilizing the neutron method. These access tubes were aluminum of 2-inch outer diameter, whereas the Model P-20 was calibrated in a 1.625 outer diameter steel tube.

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Preliminary calibration tests indicated the use of the 2-inch aluminum tubes as access tubes for soil density determinations with the P-20 density probe was feasible. Originally, attempts were made to obtain a calibration curve which would convert activity readings directly to dry soil density values. Results in 1959 were inconclusive. Therefore, in 1960 work was initiated to study the factors influencing the calibration of the P-20 density probe.

## Materials and Methods

Equipment: A Nuclear-Chicago Model P-20 density probe was used in conjunction with a Nuclear-Chicago Model 2800 portable scaler to determine soil density by gamma-ray attenuation.[1/] The apparatus is shown in Figure 1. Access tubes were installed with the illustrated equipment, Figure 2, by the method described by Kozachyn and McHenry.[2/]

Bulk density measurements were made using a steel ring for collecting the undisturbed core sample and gravimetric determinations of soil mass and moisture. The rings were approximately 390 ml. in volume.

Soil moisture was determined from gravimetric samples taken with a standard Veihmeyer soil sampling tube and with a neutron probe using the same access tube as for soil density measurements. The neutron probe and accessories are shown in Figure 3.

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[1/] The mention of a specific product or of a manufacturer is in no way a recommendation of that product or manufacturer.

[2/] ARS Research Report No. 326, March 1960.

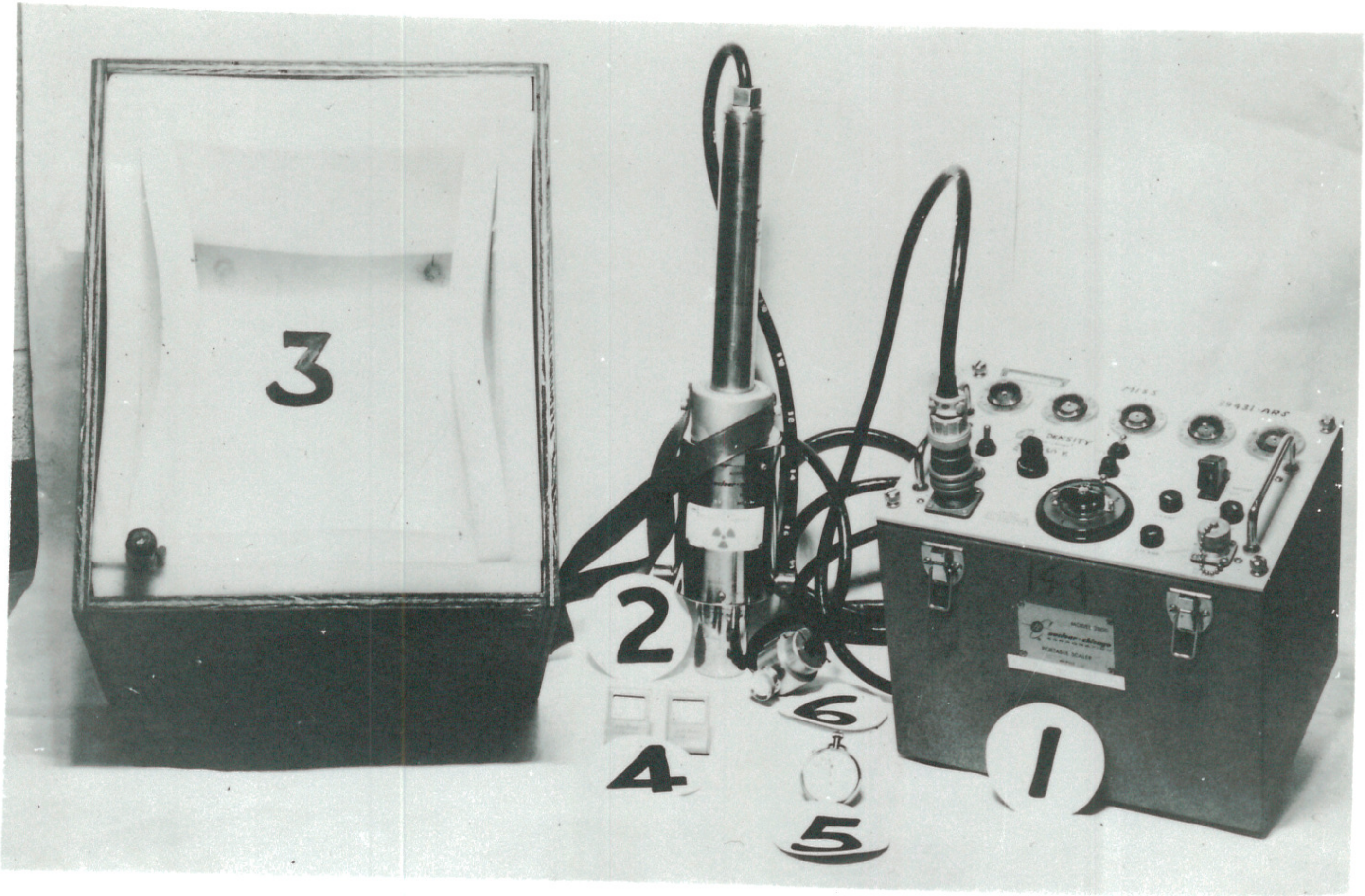

Figure 1. Gamma density probe, portable scaler, and accessories for measuring soil density: 1- portable scaler, 2- density probe in carrying shield, 3- carrying case with foam rubber padding, 4- radiation exposure film badges, 5- stopwatch, and 6- connecting cable and depth control clamp.

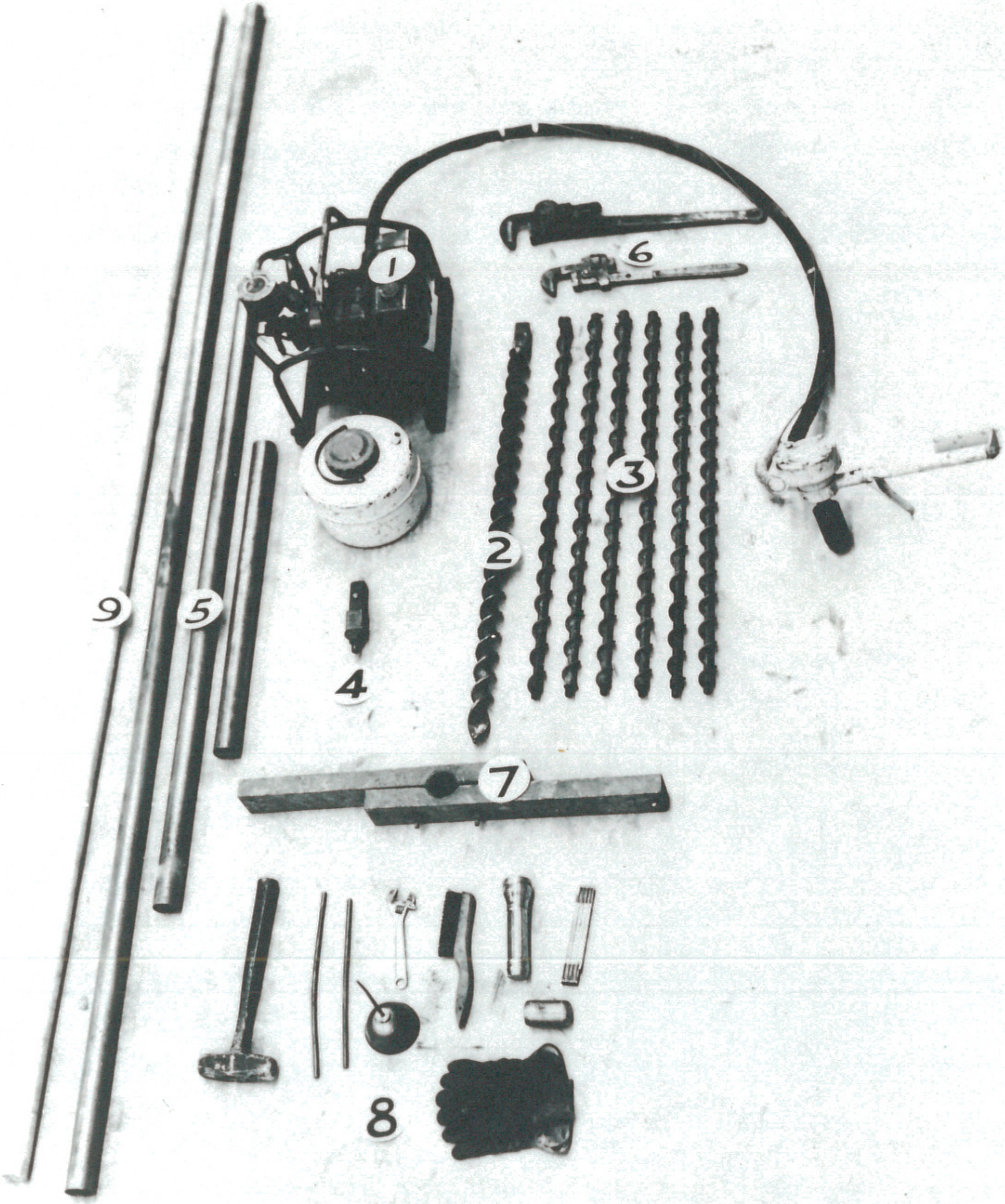

Figure 2. Equipment used in the installation of access tubes for soil density measurement by the gamma ray attenuation method: 1- portable power soil auger, 2- flight auger, 3- full-flight extensions, 4- adapter for power soil auger, 5- steel tubing, 6- pipe wrenches, 7- oak puller, 8- miscellaneous, and 9- aluminum access tube.

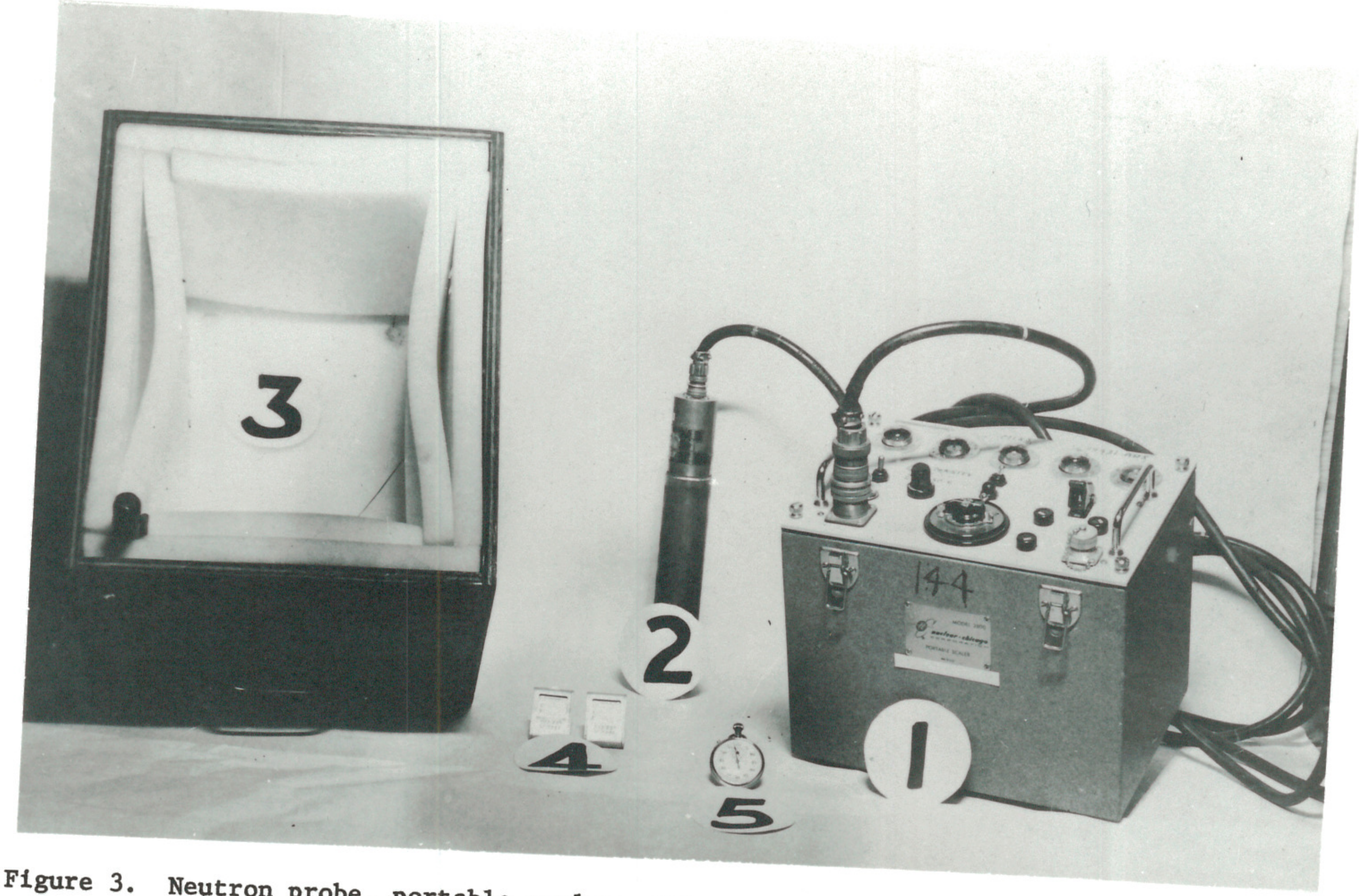

Figure 3. Neutron probe, portable scaler, and accessories for measuring soil moisture: 1- portable scaler, 2- slow neutron detector probe, 3- carrying case with foam rubber lining, 4- radiation exposure film badge, and 5- stopwatch.

Procedure: At each selected location soil samples were taken at 6-inch increments with a Veihmeyer soil sampling tube and the soil moisture was determined gravimetrically. The hole was then enlarged sufficiently with a power auger so a steel access tube, 1.625-inch o.d., could be inserted. Care was taken to obtain a snug fit of the tube. Soil density measurements were made at 6-inch intervals with the P-20 density probe. The steel tube was then removed and the hole was enlarged so a 2-inch aluminum access tube could be installed. Soil moisture measurements were made with the neutron probe and soil density measurements were again made with the P-20 density probe. Soil density and moisture readings were taken generally to six feet.

A pit was dug alongside the aluminum access tube. Undisturbed core samples were taken with steel rings. These rings were two inches in height. The core of soil was taken so the center of the sample corresponded to the depth of center of the sphere of the measured soil density or soil moisture. These latter measurements were taken at 6-inch increments so the core samples represented the center of the sphere of soil whose density and moisture content were determined by the above described nuclear methods. The soil cores were taken to the laboratory where the soil moisture content was determined gravimetrically and the bulk density each of the wet and dry soil cores calculated.

## Experimental Results

A calibration curve was prepared in 1959 for a Grenada silt loam soil. This particular soil series is the normal soil found on the ridgetops in the loess-capped hills of north-central Mississippi. The readings for the calibration curve were obtained using a 2-inch aluminum access tube. The calibration curve prepared is shown in Figure 4, and is designated as curve A. This curve was for the bulk density of the soil, i. e., the dry density of the sample. Curve B was calculated on a field moisture basis. Calibration curve A was used to calculate soil densities from data collected in 1959 with the P-20 density probe. Subsequently, additional data indicated these results were not sufficiently representative. Two questions remained unanswered. First, what effect did the use of the 2-inch aluminum access tube have on the accuracy of the soil density measurements as compared to the use of the 1.625-inch steel access tube? Second, could the use of a calibration curve giving activity densities of the attenuated gamma rays in terms of dry density of the soil be justified?

Additional work was undertaken, therefore, in 1960. Six sites were selected representing five differing soil types found on the North Mississippi Branch Experiment Station, Holly Springs. The soils used and their laboratory designations are given in Table 1. At each site comparisons of steel and aluminum access tubes for soil density determinations were made and calibration curves for both the wet and dry soil were calculated.

The relationship between bulk densities (wet) of the soils and the observed activity density readings of the P-20 density probe are shown in Figure 5, together with a curve of the regression equation which was used as the calibration curve. For comparison purposes the calibration curve provided by the manufacturer is included. These data were obtained with

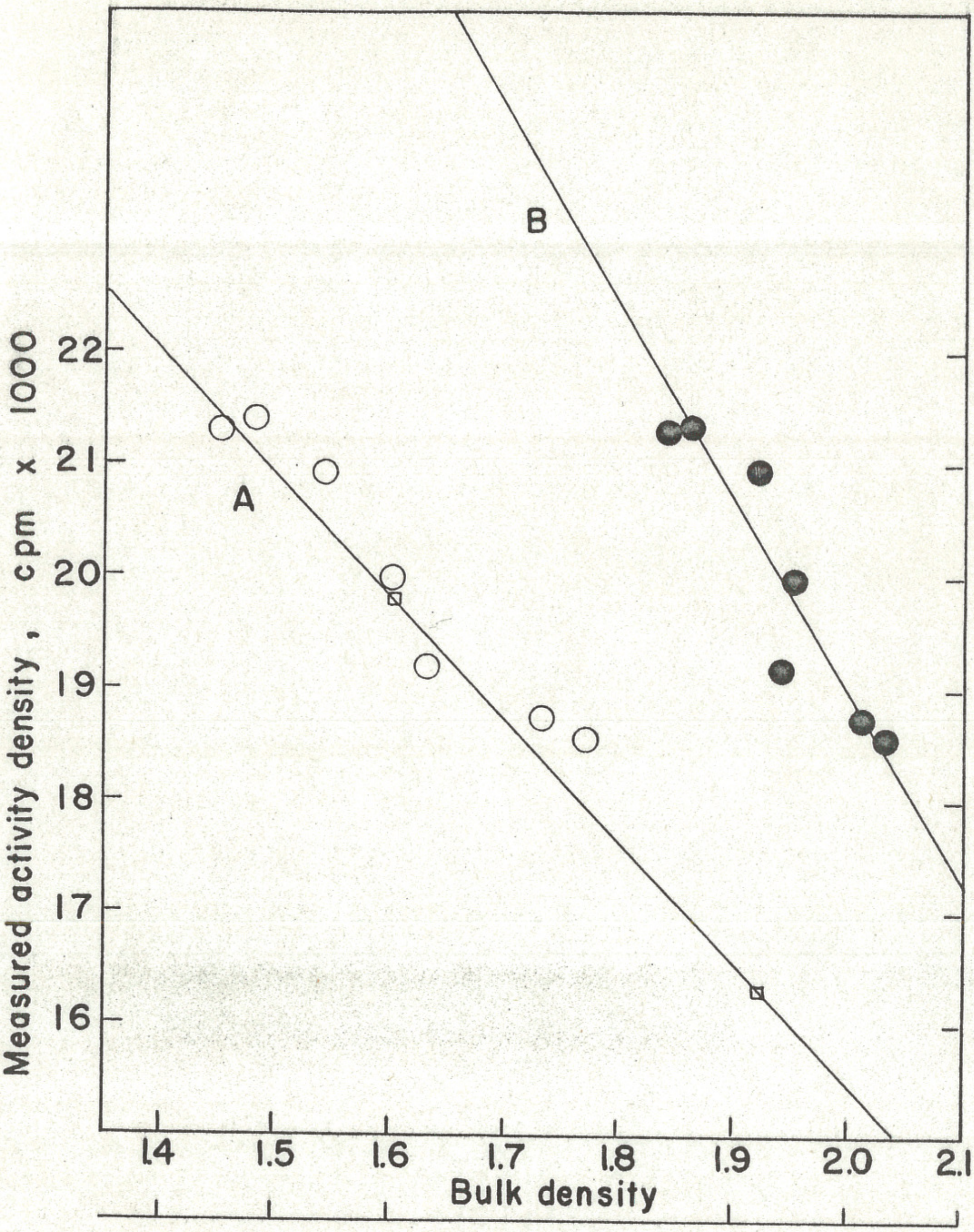

Figure 4. The measured activity density of attenuated gamma rays plotted as a function of soil density, Grenada silt loam, North Mississippi Branch Experiment Station, 1959. Curve A is the calculated dry soil density; Curve B is the calculated curve for the field moisture density

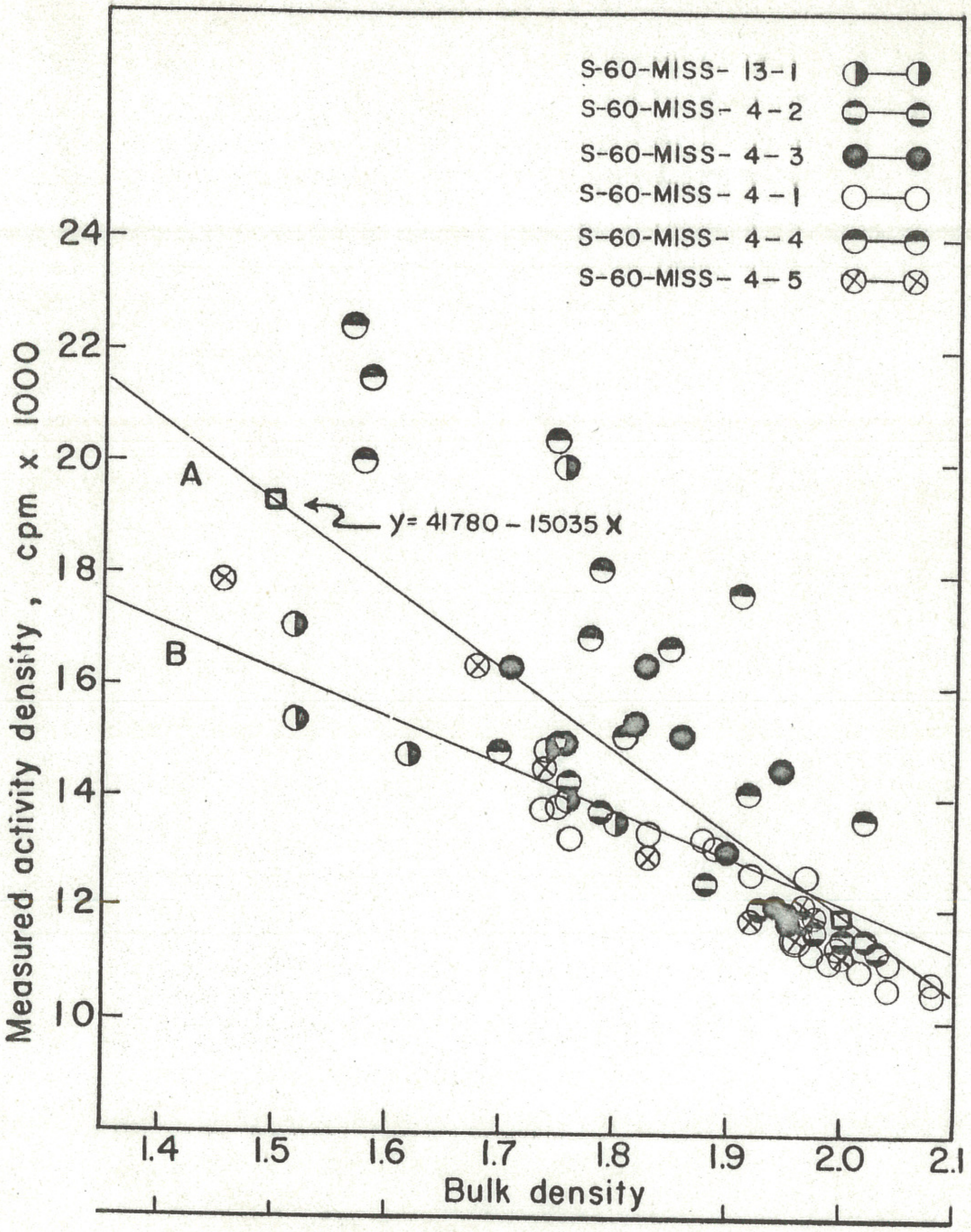

Figure 5. The measured activity density of attenuated gamma rays plotted as a function of soil density using 1.625-inch steel access tubes. The regression equation for all 1960 data is plotted as Curve A; the calibration curve supplied by the manufacturer as Curve B.

the 1.625-inch steel access tube equivalent to that recommended by Nuclear-Chicago.

A considerable scatter of points was observed. However, much of this scatter appeared to be due to the Ruston data. In Figure 6, therefore, a plot of the density data is given exclusive of the Ruston soil. In Figure 7 the Ruston data is presented.

All the soils involved, with the exception of the Ruston, are of loessial origin. The Ruston has developed on Coastal Plains sands. The regression curve for the data from the loessial soils (Figure 6) is similar to the Nuclear-Chicago calibration curve. The regression line serves, in all cases, as the calibration curve. The slope of the regression line for the Ruston soil is considerably different. At the present time no explanation is advanced to account for this difference other than the difference in texture and origin of the Ruston soil.

Table 1. Soil Types and Laboratory Designations of the Experimental Sampling Sites.

| Location | Soil Type | Laboratory Number |
|---|---|---|
| Sedimentation Laboratory, Grounds, Oxford, Miss. | Alluvium of unknown series | S-60-Miss-13-1 |
| North Mississippi Branch Experiment Station, Holly Springs, Mississippi | Grenada silt loam | S-60-Miss-4-1 |
| | Grenada silt loam | S-60-Miss-4-2 |
| | Atwood loam | S-60-Miss-4-3 |
| | Ruston sandy loam | S-60-Miss-4-4 |
| | Loring silt loam | S-60-Miss-4-5 |

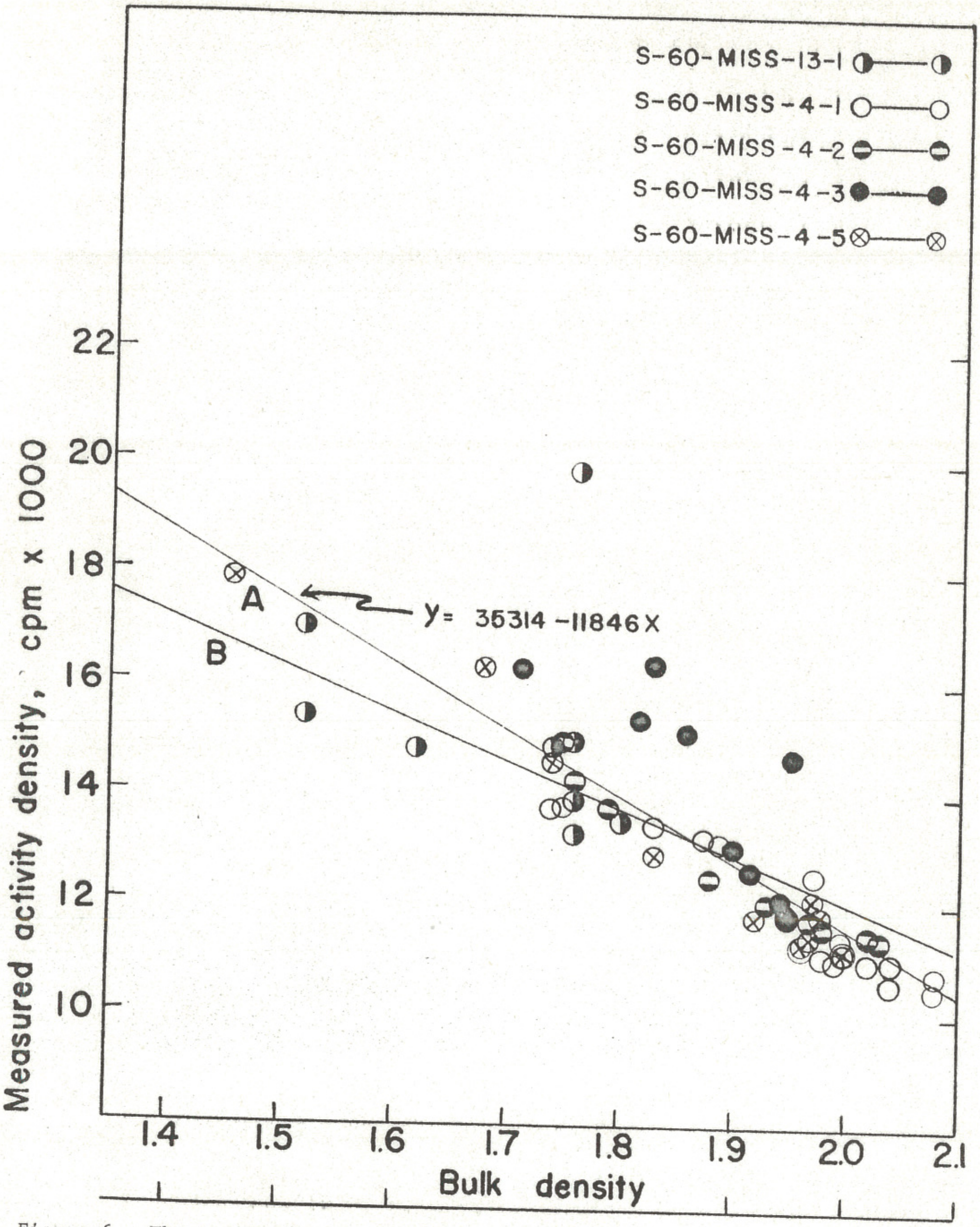

Figure 6. The measured activity density of attenuated gamma rays plotted as a function of soil density using 1.625-inch steel access tubes. The regression equation for the data from the soils of aeolian origin is plotted as Curve A and the calibration curve supplied by the manufacturer as Curve B.

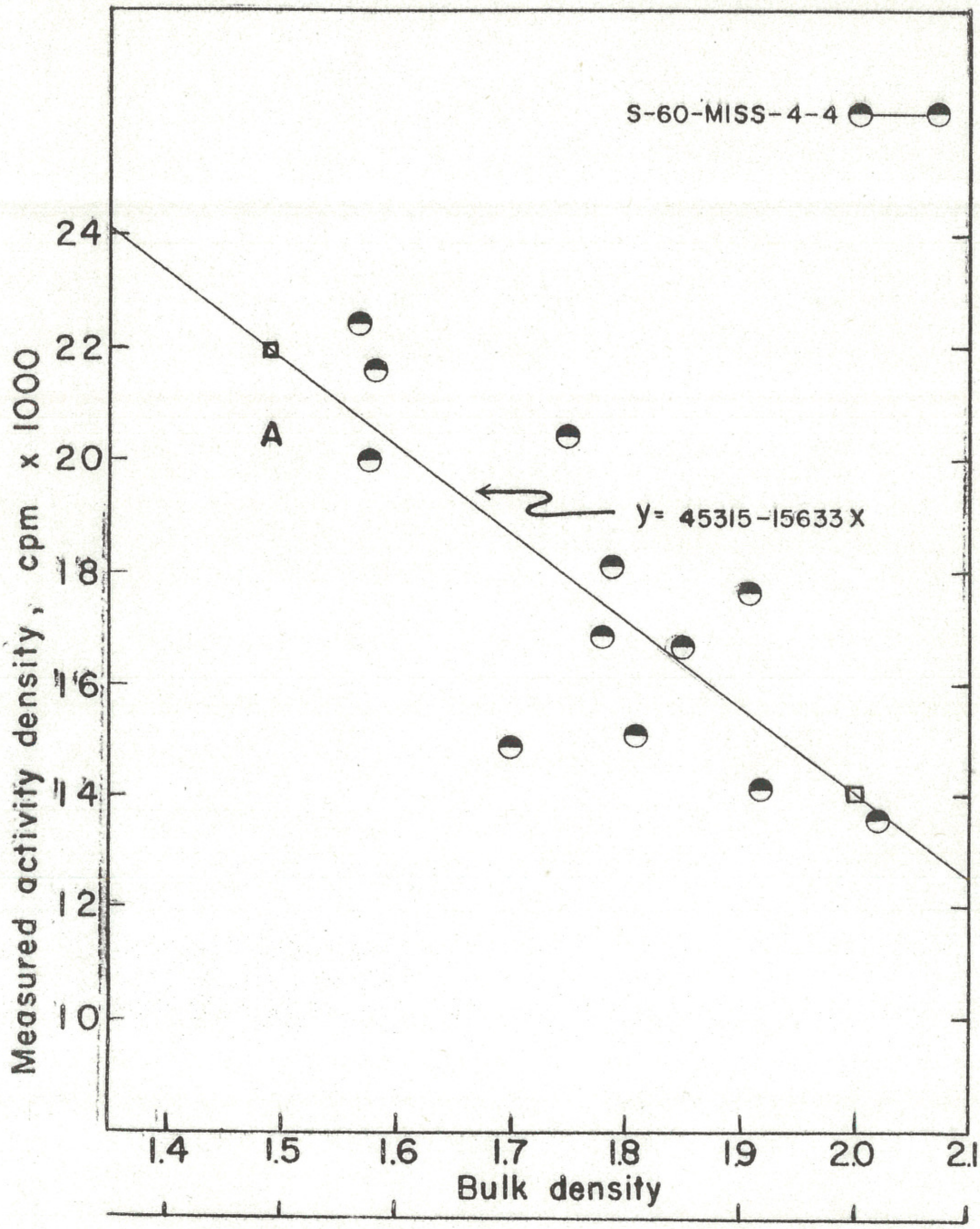

Figure 7. The measured activity density of attenuated gamma rays plotted as a function of soil density using a 1.625-inch steel access tube. The data and regression equation, Curve A, are for the Ruston sandy loam.

Although the slopes of the regression curves in Figures 5 and 6 are similar to that of the Nuclear-Chicago calibration curve, it is recommended that the research worker employing the Model P-20 density probe prepare a calibration curve applicable to the particular soil to be examined. The data presented are limited but considerable variation in the relationship between gamma-ray attenuation and soil density has been shown. With this variation in soils in the same geographical area caution is indicated in adopting a calibration curve not checked with local soil types.

As indicated above in this report in 1959 2-inch aluminum access tubes had been employed for density measurements. In these tubes the probes did not occupy the full volume of the tube. The observed activity readings were considerably higher due to the air space involved. Theoretically, the results obtained in these larger tubes should be the same relatively as with the smaller steel tubes. A smaller soil volume is "seen" by the density probe and hence there would be less attenuation of the gamma rays. However, changes in soil density should be as readily observed in the aluminum tube as in the steel tube. Whether the probe was suspended in the center of the larger tube or to one side was immaterial as the ratio of air space to measured soil volume was constant.

A plot of the recorded activity densities and measured (wet) bulk densities obtained with the 2-inch aluminum access tubes are shown in Figure 8. The regression curve is shown together with the similar calibration curve used for the 1959 data based on a Grenada soil type. The scatter of points was decreased somewhat by excluding the Ruston data.

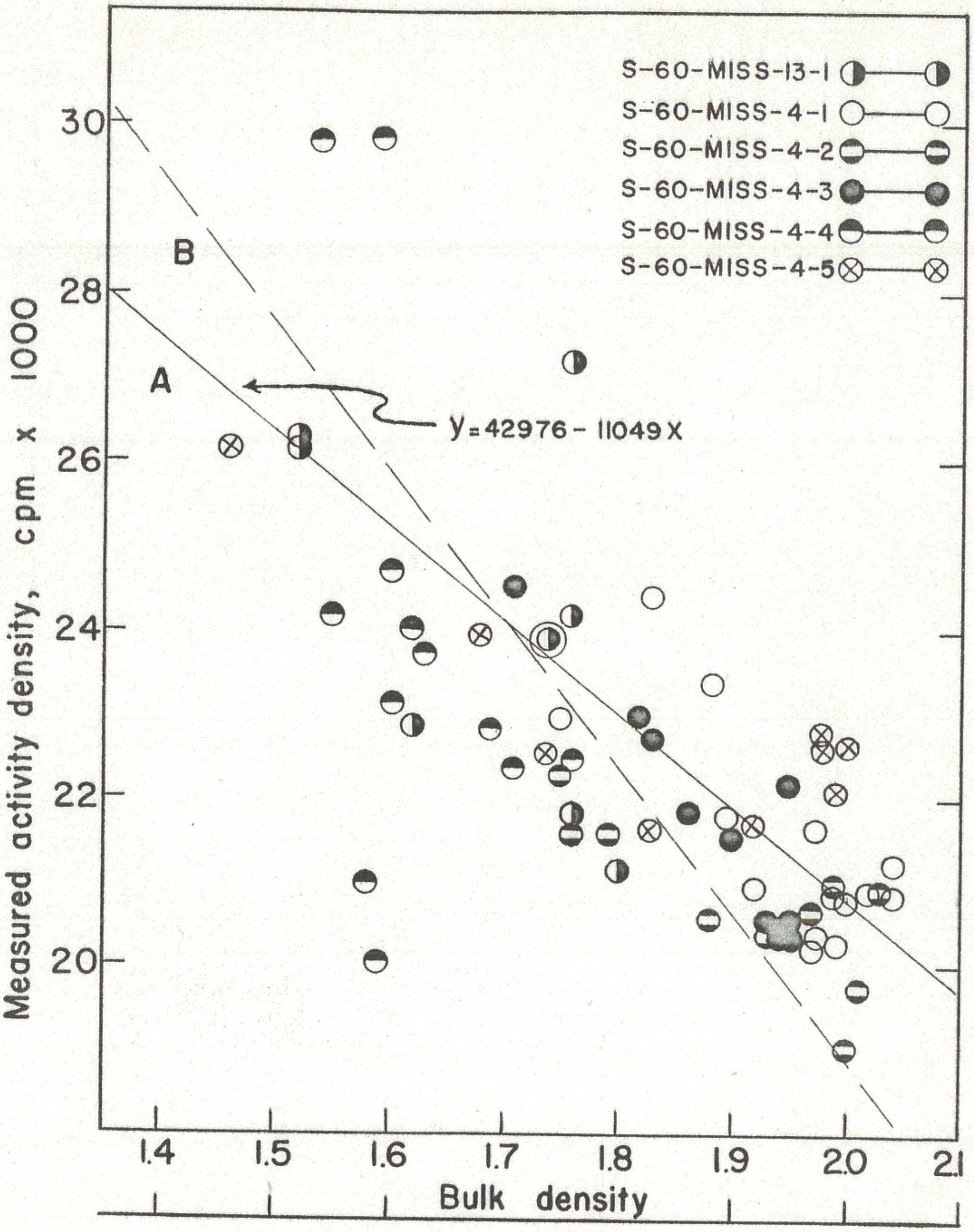

Figure 8. The measured activity density of attenuated gamma rays plotted as a function of soil density using 2-inch aluminum access tubes. The regression equation for the 1960 data is plotted as Curve A and the 1959 calibration curve as B.

The resulting plot and regression curve are shown in Figure 9. Despite the greater spread of points in Figure 9 as compared to Figure 6, the use of the 2-inch aluminum access tube was found feasible based on statistical considerations. In Table II a statistical summary is given of the significance of the regression lines. The t-values for the steel tube are greater but the aluminum tube data still is statistically highly reliable.

The use of the 1.625-inch steel access tubes for soil density measurements is preferred but the use of the 2-inch aluminum tube is permissible. The research worker may, therefore, utilize a number of materials of varying size as access tubes for soil density measurements. A calibration curve would be required for each material, each size of access tube, and for each major change in soil type.

Table II. Calculated Regression Equations and Their Significance as Measured by t-Tests for Attenuation of Gamma Rays as a Function of the Bulk Density (Field Moisture) of North Mississippi Soils.

| | Steel Access Tube | Aluminum Access Tube |
|---|---|---|
| All Soils | Y = 41780 - 15035 X<br>(t = 10.4**) | Y = 42976 - 11049 X<br>(t = 9.85**) |
| All Soils Except Ruston | Y = 35314 - 11846 X<br>(t = 12.9**) | Y = 41624 - 10476 X =<br>(t = 10.0**) |
| Ruston | Y = 45315 - 15633 X<br>(t = 4.0**) | Y = 42516 - 10467 X =<br>(t = 1.88 n.s.) |

** Significant, 1% level

n.s. not significant at 5% level

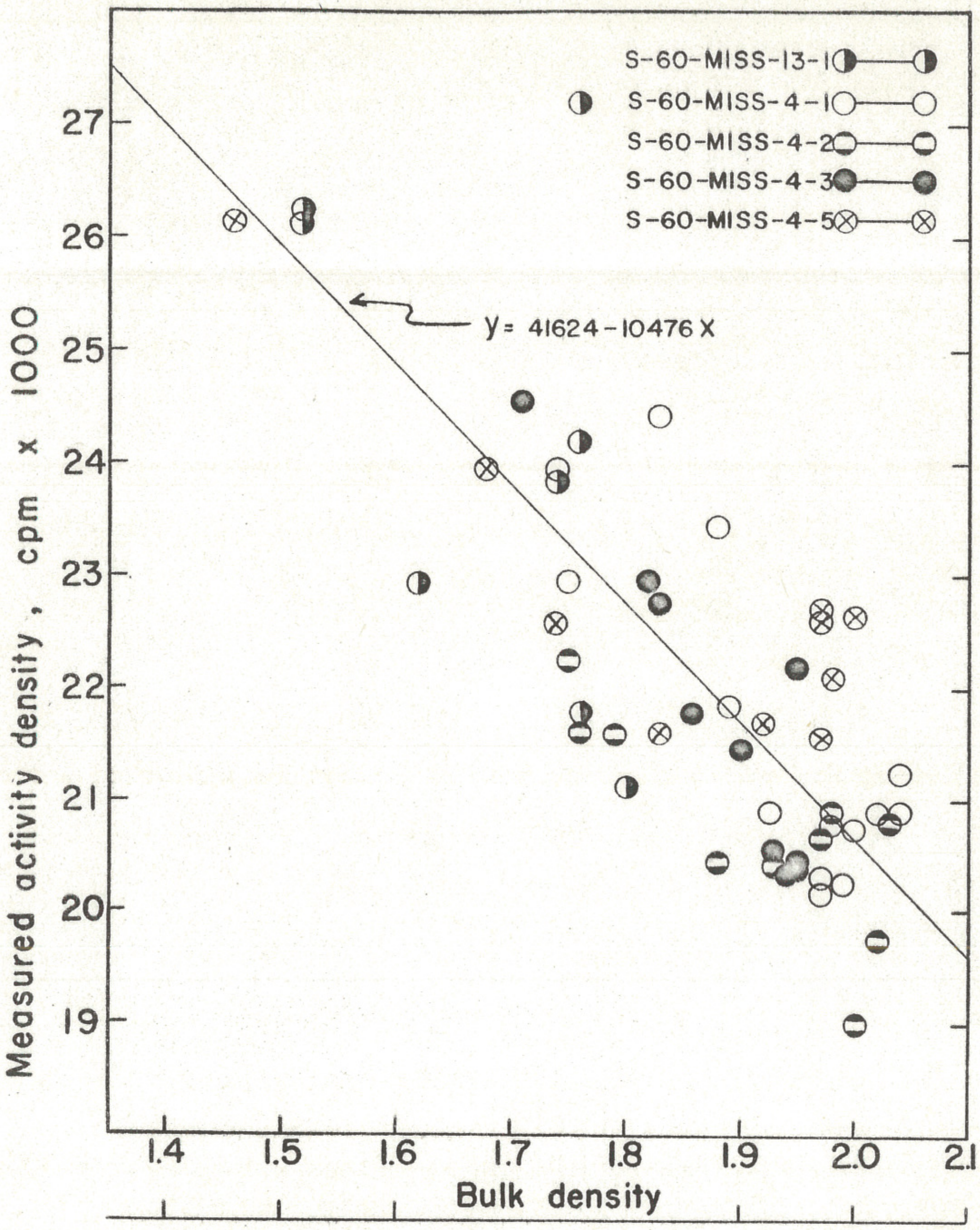

Figure 9. The measured activity density of attenuated gamma rays plotted as a function of soil density using a 2-inch aluminum access tube. The data plotted and the regression line are for soils of aeolian origin.

An attempt was made in 1959 to construct a calibration curve which would relate attenuated gamma-ray readings directly to the bulk density of dry soil (Figure 4). Similar calculations were made from the 1960 field data and the results are summarized in Figures 10 and 11. The scatter of the points is wider than with wet density data (Figures 6 and 8). However, the t-test values calculated for all soils from the plotted data--Figures 10 and 11--are 6.6 and 10.4 respectively. These values are both significant at the 1% level. Statistically speaking, a highly significant regression curve can be constructed and used as a calibration curve. This curve would convert scaler readings of the attenuated gamma-rays directly to soil bulk density readings. No moisture corrections would be required. However, this data was based upon the relationship existing at the observation time of the total density to scaler readings. The same soils at differing moisture contents might well show differing relationships.

The use of a calibration curve to directly relate observed scaler readings of gamma-ray activity to dry bulk density of soil is not recommended because of the unknown contribution of varying moisture content of the soil. A calibration curve valid for a soil under one set of moisture conditions is not necessarily valid at other moisture levels.

Measurements of radioactivity are subject to a random variation. These variations are due to the random nature of radioactive disintegration but can be characterized statistically. It is possible to obtain almost any degree of reliability by varying the counting time. For instance, a one minute count, N, of 10,000 is subject to an error, $\sqrt{N/t}$, of 1%; a

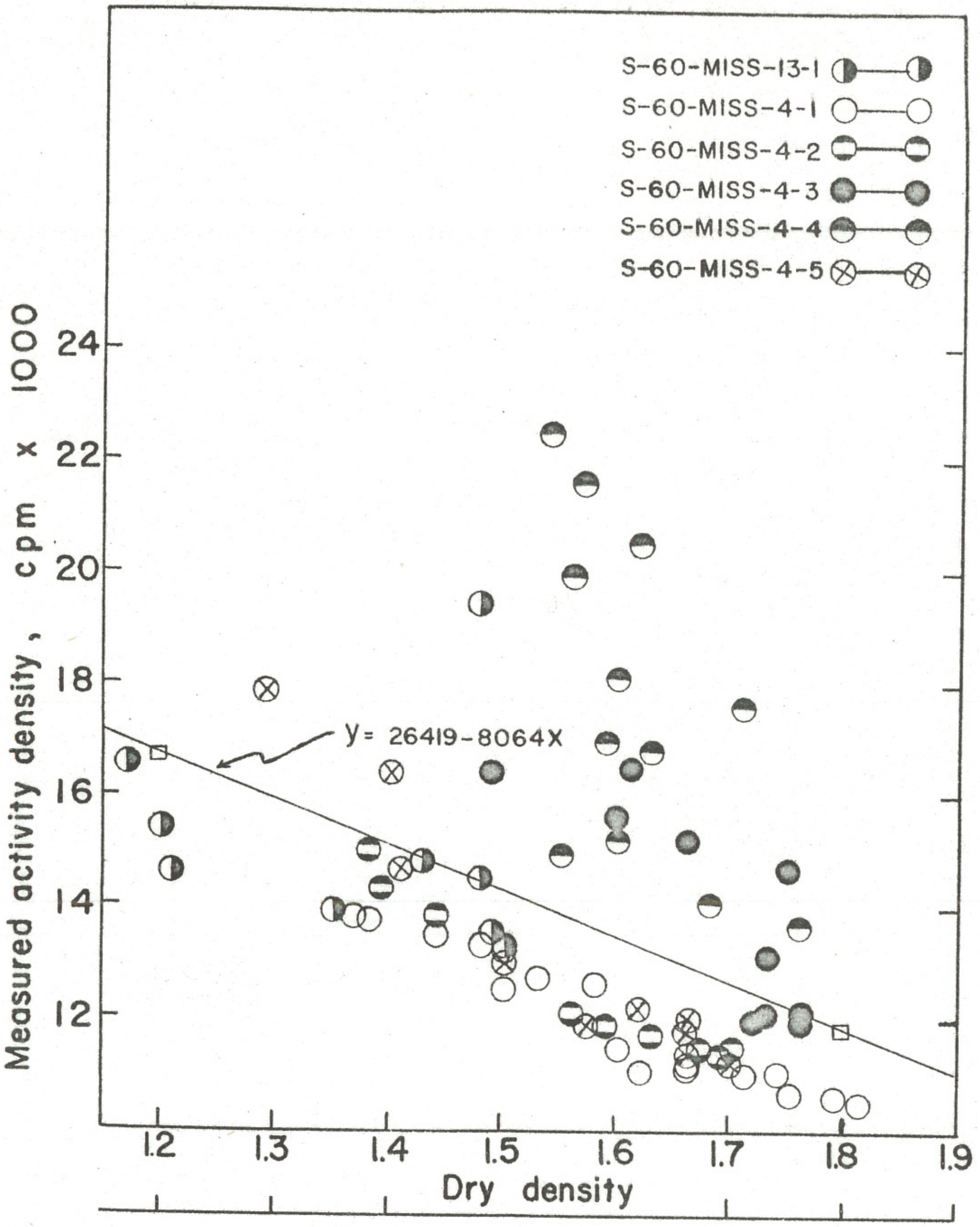

Figure 10. The measured activity density of attenuated gamma rays plotted as a function of the calculated dry densities of soil using a 1.625 inch steel access tube. The data plotted are for all soils tested in 1960.

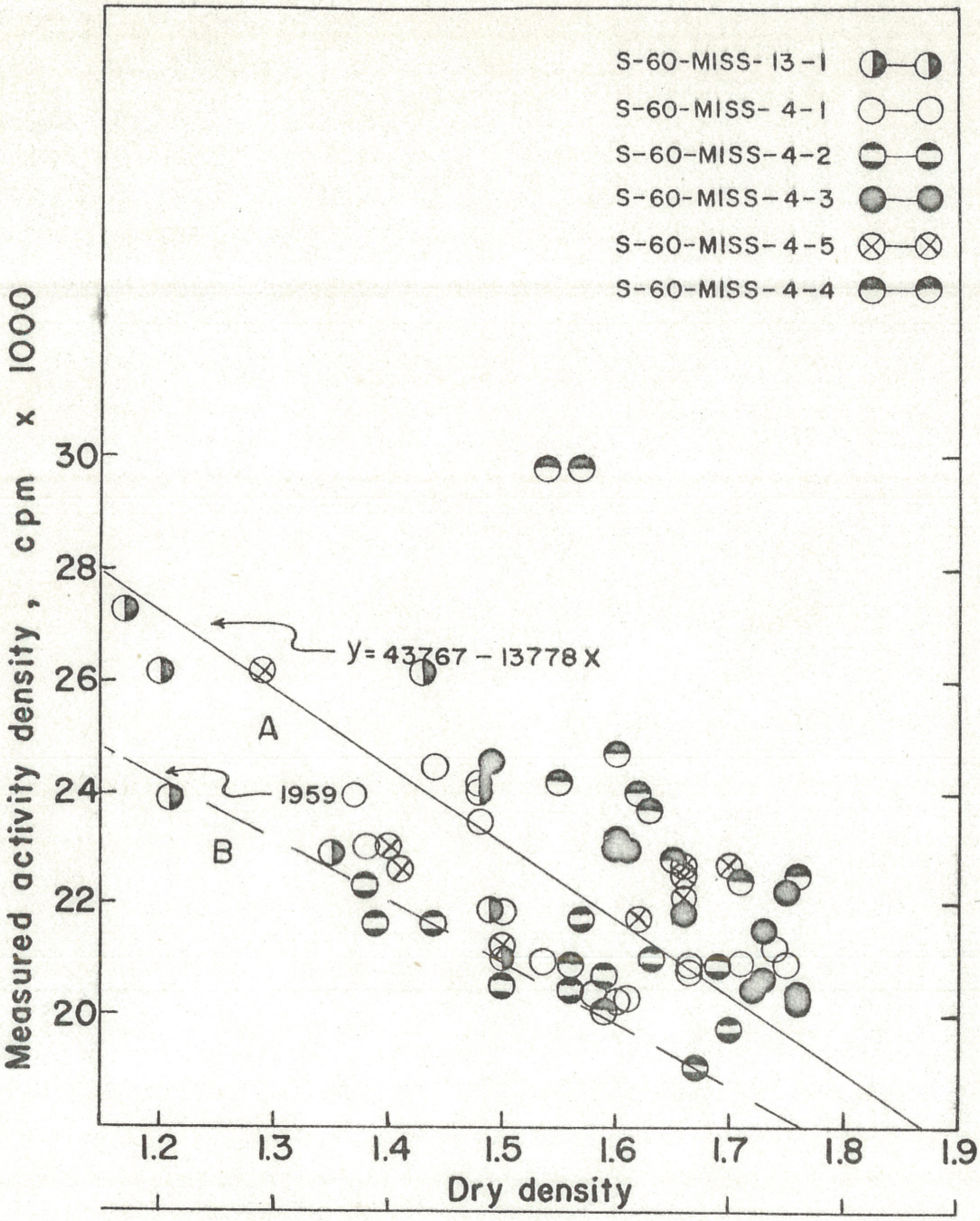

Figure 11. The measured activity density of attenuated gamma rays plotted as a function of the calculated dry densities of soil using a 2-inch aluminum tube. Curve A is the regression line for all 1960 data; Curve B is the 1959 calibration curve.

count of 40,000 is subject to an error of 1/2%. If the time is raised to 10 minutes, the same activity levels are subject to errors of 0.1% and 0.05% respectively. The activity of the source provided with the Nuclear-Chicago P-20 density probe is sufficiently great that readings of 10,000 to 20,000 cpm (counts per minute) are obtained. The precision of the method is adequate; for most purposes a minute reading will suffice. If not greater precision is possible by simply increasing the total observed count.

The reliability of the Model P-20 density probe was checked in one test. Soil density values were obtained for the same access tube in May and in June, 1959, and again in August, 1960. The results are shown in Table III. The bulk densities are computed from the calibration curve shown in Figure 8. Moisture corrections were made on the basis of routine moisture determinations made with the neutron probe. Moisture contents were measured within 24 hours of the time the density measurements were made.

Some variation in density is noted; the 1960 readings appear to be somewhat greater. For a 20,000 cpm reading the statistical error due to random radioactive disintegration is $\pm \sqrt{20,000/1}$, or ± 141 cpm. In terms of bulk density this error is in the order of ± 0.01 units. In many cases in Table 3 the variation with data is less than this statistical counting error.

Table III. Bulk Density Measurements, Grenada Silt Loam, North Mississippi Branch Experiment Station, Holly Springs.

| DEPTH | May 25, 1959 | | June 24, 1959 | | August 30,1960 | |
|---|---|---|---|---|---|---|
| (Inches) | R | Bulk Density | R | Bulk Density | R | Bulk Density |
| 6 | 23,867 | 1.47 | 23,178 | 1.54 | 23,865 | 1.54 |
| 12 | 23,248 | 1.49 | 23,292 | 1.48 | 23,466 | 1.58 |
| 18 | 22,321 | 1.56 | 22,447 | 1.54 | 23,283 | 1.57 |
| 24 | 23,107 | 1.47 | 22,557 | 1.52 | 23,045 | 1.57 |
| 30 | 22,917 | 1.49 | 22,968 | 1.48 | 23,104 | 1.56 |
| 36 | 23,731 | 1.42 | 23,077 | 1.48 | 23,644 | 1.50 |
| 42 | 21,638 | 1.62 | 22,368 | 1.54 | 21,603 | 1.68 |
| 48 | 19,922 | 1.79 | 19,829 | 1.78 | 19,220 | 1.91 |
| 54 | 19,567 | 1.82 | 19,427 | 1.82 | 19,312 | 1.90 |
| 60 | 19,843 | 1.79 | 19,792 | 1.79 | 20,156 | 1.82 |
| 66 | 20,351 | 1.73 | 19,702 | 1.78 | 20,382 | 1.79 |
| 72 | 20,447 | 1.71 | 19,511 | 1.79 | 21,162 | 1.71 |
| 78 | 20,441 | 1.69 | 20,284 | 1.71 | 22,145 | 1.61 |
| 84 | 20,128 | 1.71 | 20,284 | 1.70 | 20,352 | 1.78 |
| 90 | 19,540 | 1.76 | 19,771 | 1.75 | 19,463 | 1.84 |
| 96 | 20,127 | 1.71 | 19,521 | 1.77 | 20,102 | 1.75 |
| 102 | 20,209 | 1.69 | 20,401 | 1.68 | 20,395 | 1.71 |
| 108 | 19,787 | 1.73 | 19,841 | 1.73 | 19,788 | 1.71 |