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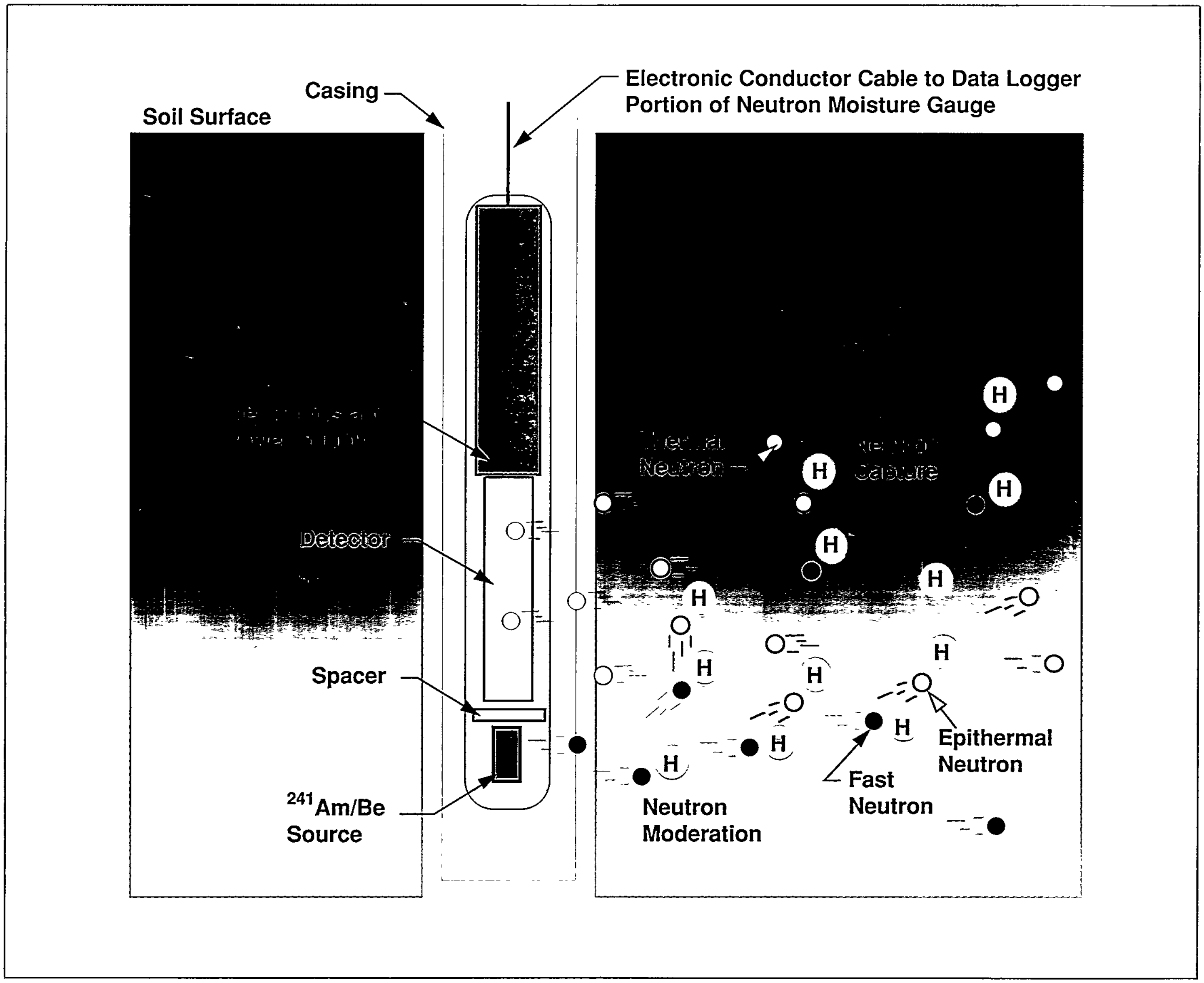
Calibration of Neutron Moisture Gauges and Their Ability to Spatially Determine Soil Water Content in Environmental Studies



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Cover illustration: *Neutron moisture gauges have been used since the 1950s to measure* in situ *soil water content. First, alpha particles impinge on beryllium within the sealed* ^{241}*Am/Be source (red box) resulting in fast neutrons (black spheres) being artificially introduced into the soil water system outside of the access tube casing. Then naturally occurring elements within the soil matrix slow these neutrons and form epithermal neutrons (yellow spheres) through neutron moderation. Finally, the neutrons are thermalized and slowed to very low energies (white spheres) at which they can be captured. A small fraction of these thermalized neutrons migrate toward the moisture gauge detector and are counted.*

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Calibration of Neutron Moisture Gauges and Their Ability to Spatially Determine Soil Water Content in Environmental Studies

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CALIBRATION OF NEUTRON MOISTURE GAUGES AND THEIR ABILITY TO SPATIALLY DETERMINE SOIL WATER CONTENT IN ENVIRONMENTAL STUDIES

by

J. W. Nyhan, J. L. Martinez, and G. J. Langhorst

ABSTRACT

Several neutron moisture gauges were calibrated, and their ability to spatially determine soil water content was evaluated. In 1982, the midpoint of sensitivity of each neutron probe to the detection of hydrogen was determined, as well as the radius of investigation of each probe in crushed Bandelier Tuff with varying water contents. After determining the response of one of the moisture gauges to changes in soil water at the soil-air interface, a neutron transport model was successfully calibrated to predict spatial variations in soil water content. The model was then used to predict various shapes and volumes of crushed Bandelier Tuff interrogated by the neutron moisture gauge. From 1991 through 1994, six neutron moisture gauges were calibrated for soil water determinations in a local topsoil and crushed Bandelier Tuff, as well as for a sample of fine sand and soils from a field experiment at Hill Air Force Base. Statistical analysis of the calibration results is presented and summarized, and a final summary of practical implications for future neutron moisture gauge studies at Los Alamos is included.

I. INTRODUCTION

Waste management practices at a burial site invariably involve a knowledge of the hydrologic cycle. Since repeated destructive sampling of the burial site environs is undesirable, the use of the neutron moisture gauge represents an attractive method for *in situ* measurement of volumetric soil water content and its change in time and space. Thus, estimation of runoff, evapotranspiration, deep drainage, and change in the soil water storage is usually the objective of the measurement program based on the neutron moisture gauge.

In all of these studies, a knowledge of the volume measured by neutron moisture gauges is of importance for several reasons. In field measurements at the burial site, the volume of soil actually measured should be estimated to evaluate the optimal measurement intervals, to accurately estimate small changes in water content at a given sampling depth, and to compare moisture gauge soil water determinations with other measurement techniques. In the laboratory, calibration and hydrologic studies involving the neutron moisture gauge must be performed in containers of proper dimensions.

Although little information exists on the volume of soil interrogated by current neutron moisture gauges, a few estimates were made using modeling and laboratory experimental techniques (Fig. 1). The simplified approach usually taken in these studies is to assume that all the thermalized neutrons counted by the moisture-gauge detector come from a sphere with a radius of investigation (Rj), which is influenced by changes in soil water content. Thus, the most commonly quoted source International Atomic Energy Agency (I.A.E.A., 1970) showed Rjs ranging from 100 cm at 0% volumetric water content to 30 cm at 50% water content with no neutron absorbers present and from 49 cm to 25 cm with absorbers present.

However, both of these curves (lines with square symbols in Fig. 1) are based on modeling exercises where the degree of assumed accuracy in moisture gauge measurements is unusually high, resulting in relatively large values for Soil water. The rest of the data presented in Fig. 1 show generally smaller Soil water and an inverse relationship between soil water content and Rj, which seems to vary in magnitude between soils with varying amounts of naturally occurring neutron absorbers.

This report discusses experiments performed in 1982 at the Los Alamos National Laboratory designed to investigate the volume of crushed Bandelier Tuff interrogated by three commonly used neutron moisture gauges. The behavior of the probes near a crushed tuff-air interface was evaluated in homogenous mixtures of crushed tuff varying

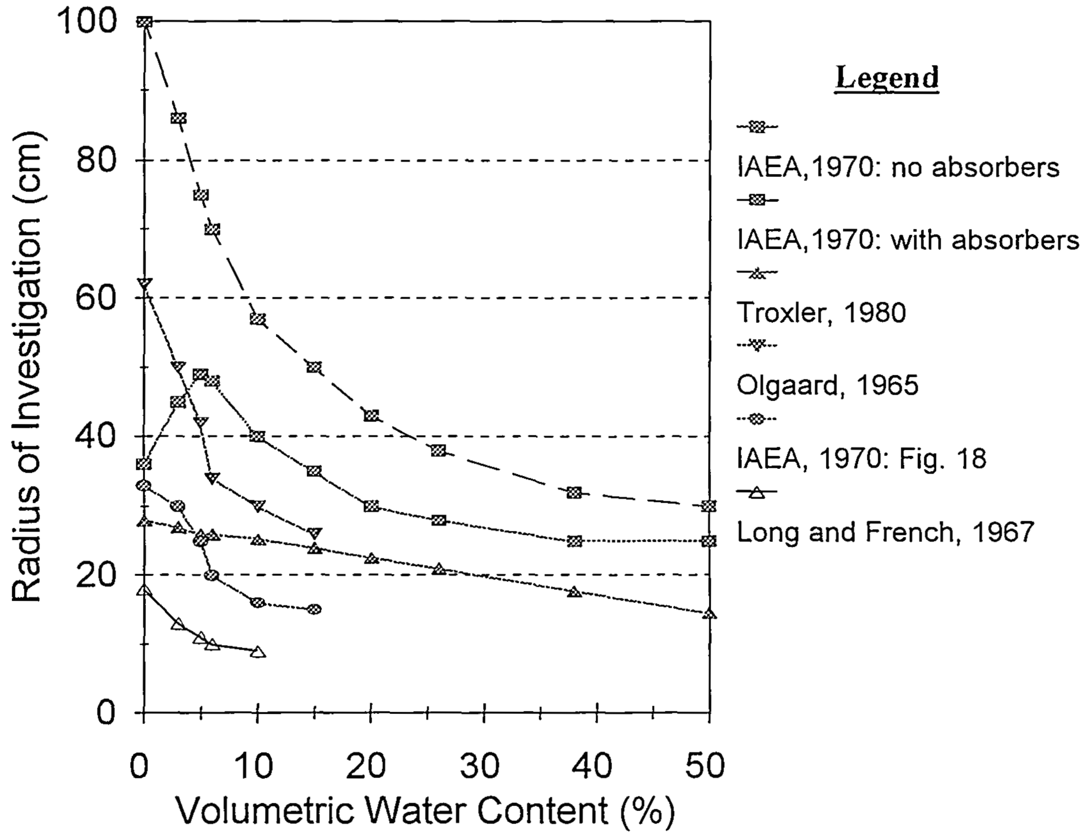


Fig. 1. Previous studies of Rj determinations and model predictions for neutron moisture gauges.

in water content. This data was then used to calibrate a neutron transport model, which was then used to evaluate different shapes and volumes of soil interrogated by the moisture gauges. Because neutron moisture gauge calibrations at the Laboratory have only been performed in crushed Bandelier Tuff between 1991 and 1994, we calibrated six neutron moisture gauges in a local topsoil as well as in several other soil samples used in hydrologic field studies being performed by the Laboratory's Environmental Science Group.

II. MATERIALS AND METHODS

During 1982, three neutron moisture gauges were calibrated to measure the water content of crushed Bandelier Tuff. The Campbell Pacific Model 503 DR moisture gauge (Campbell Pacific Nuclear Corp., Pacheco, California; serial number H-33095079) was designed with a 50 mCi ^{241}Am/Be source enclosed with a 32-cm-long probe with a 38 mm diameter (Fig 2). The Troxler Model 3221-A moisture gauge (Troxler Electronic Laboratories, Inc., Research Triangle Park, North Carolina) contained a 10-mCi ^{241}Am/Be neutron source enclosed within a 27-cm-long probe with a diameter of 38 mm (Fig. 3). The third moisture gauge, commonly used for deep geologic exploration (Fig. 4), was a Gearhart-Owen Model 3500 moisture gauge (Gearhart-Owen Industries, Inc., Fort Worth, Texas). This gauge contains a 250-mCi ^{241}Am/Be neutron source enclosed within a large probe (147 cm long by 27 mm o.d.).

In 1982, we determined the location along the length of each of the three neutron moisture-gauge probes giving the maximum detector response to thermalized neutrons. This location, the midpoint of sensitivity, was determined by sliding a high-density polyethyene annulus (2.5 cm thick, 20 cm o.d., 5 cm i.d.) along the probe and collecting three sample counts at 2.5-cm intervals. The probe portion of each neutron moisture gauge was then x-rayed to determine the exact location of the detector and the ^{241}Am/Be source to match the midpoint of sensitivity. A full-scale photograph was made of each x-ray negative, and precise measurements of both portions of the probe were collected from this photograph.

In 1982, each moisture gauge was calibrated by packing 208-l drums with crushed Bandelier Tuff at a known bulk density over a range of known water contents and determining the corresponding response of the instrument. The crushed tuff was first kiln-dried at 225°C for 48 hours, and then tuff was weighed in 35-kg quantities (Fig. 5). A known amount of water was added to the tuff with a garden sprayer (Fig. 6) while the tuff was being mixed in a cement mixer (Fig. 7). Then the tuff was packed to a known bulk density in 6- to 15-cm lifts in each calibration drum (Fig. 8). Four calibration drums were prepared using this technique with volumetric water contents of 0.12, 4.3,

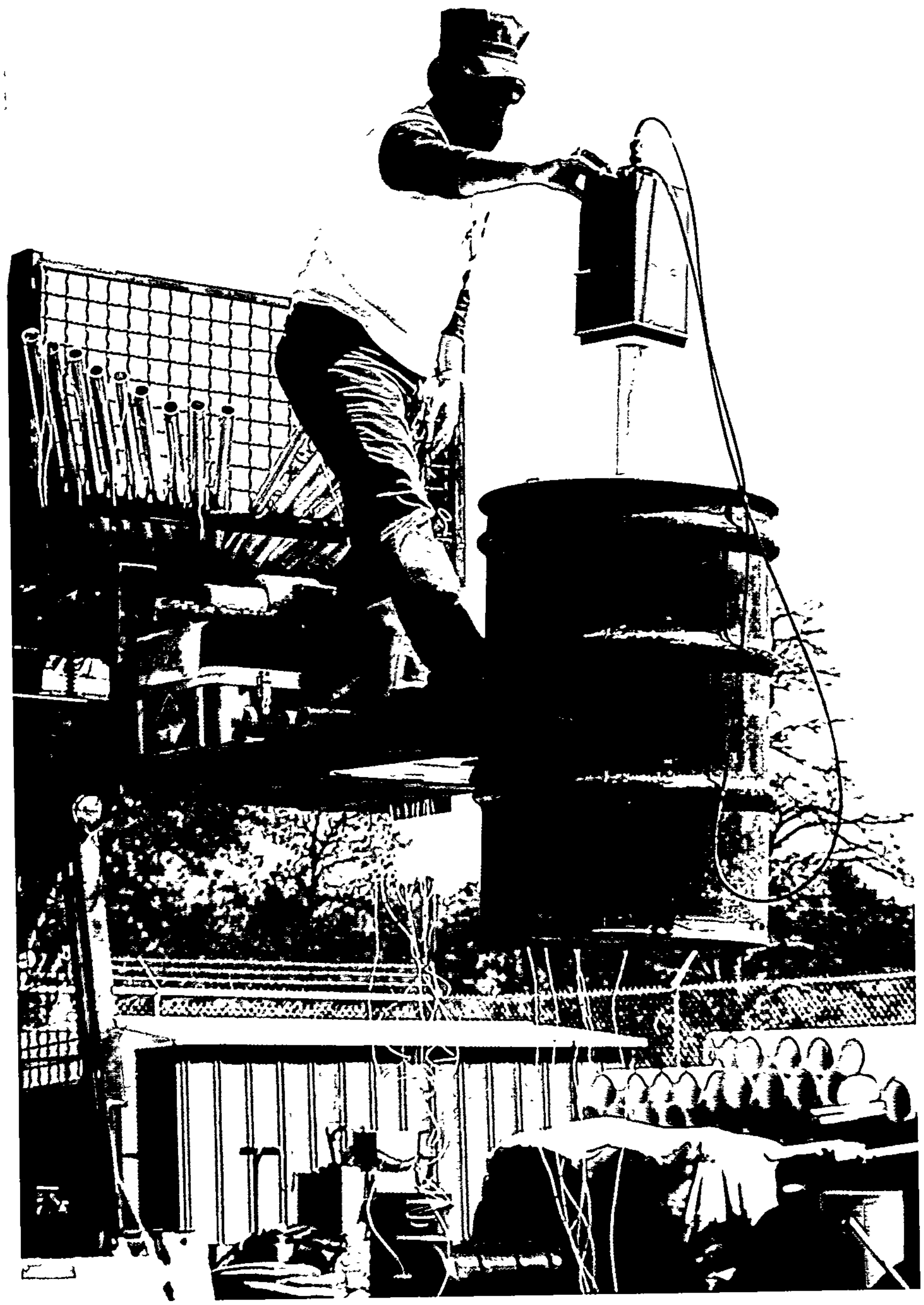


Fig. 2. A typical red-orange Campbell Pacific neutron moisture gauge being used by Barry Drennon to collect Rj data for crushed tuff at the top and bottom of a calibration drum.

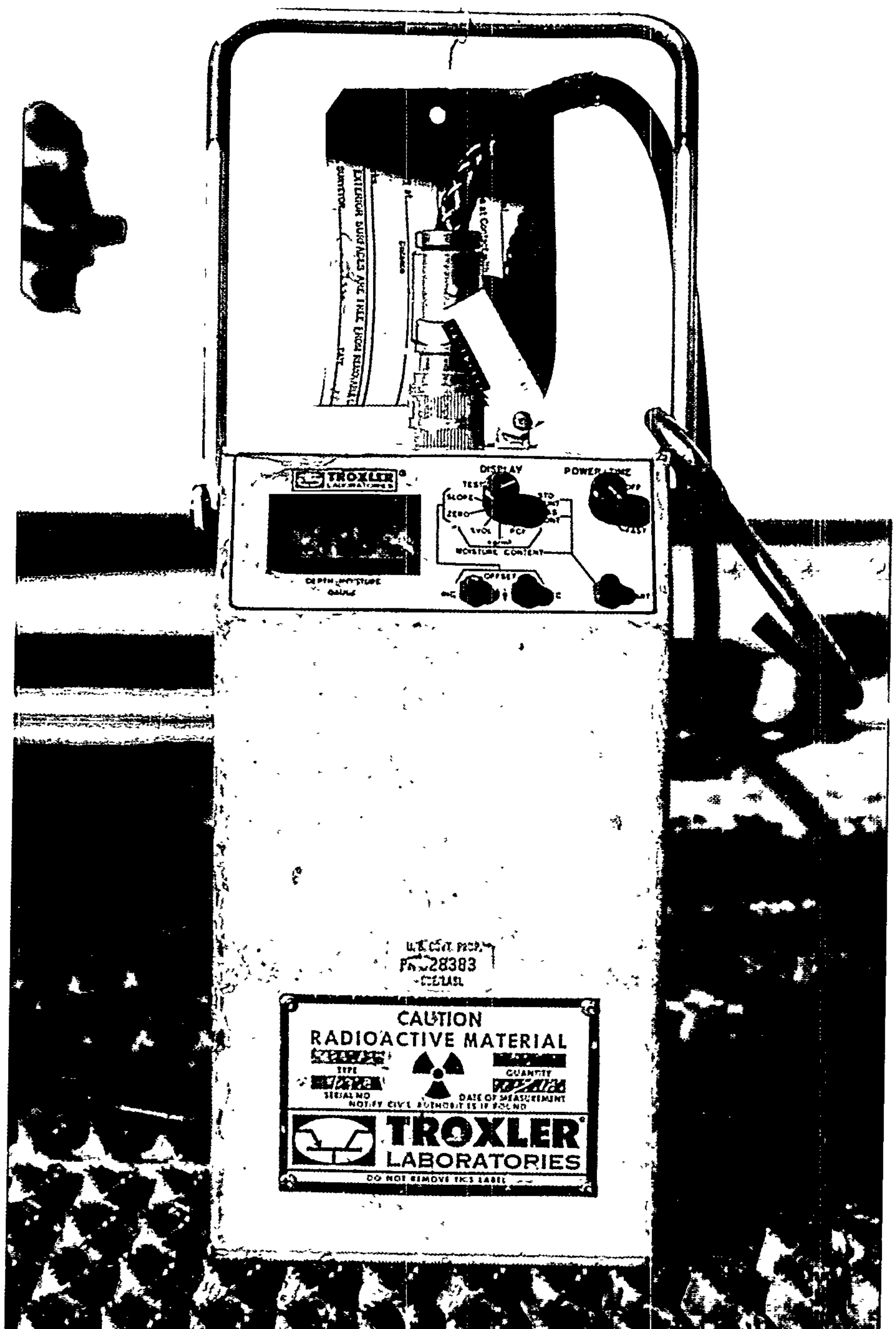


Fig. 3. A typical yellow Troxler neutron moisture gauge used in the 1982 calibration studies.

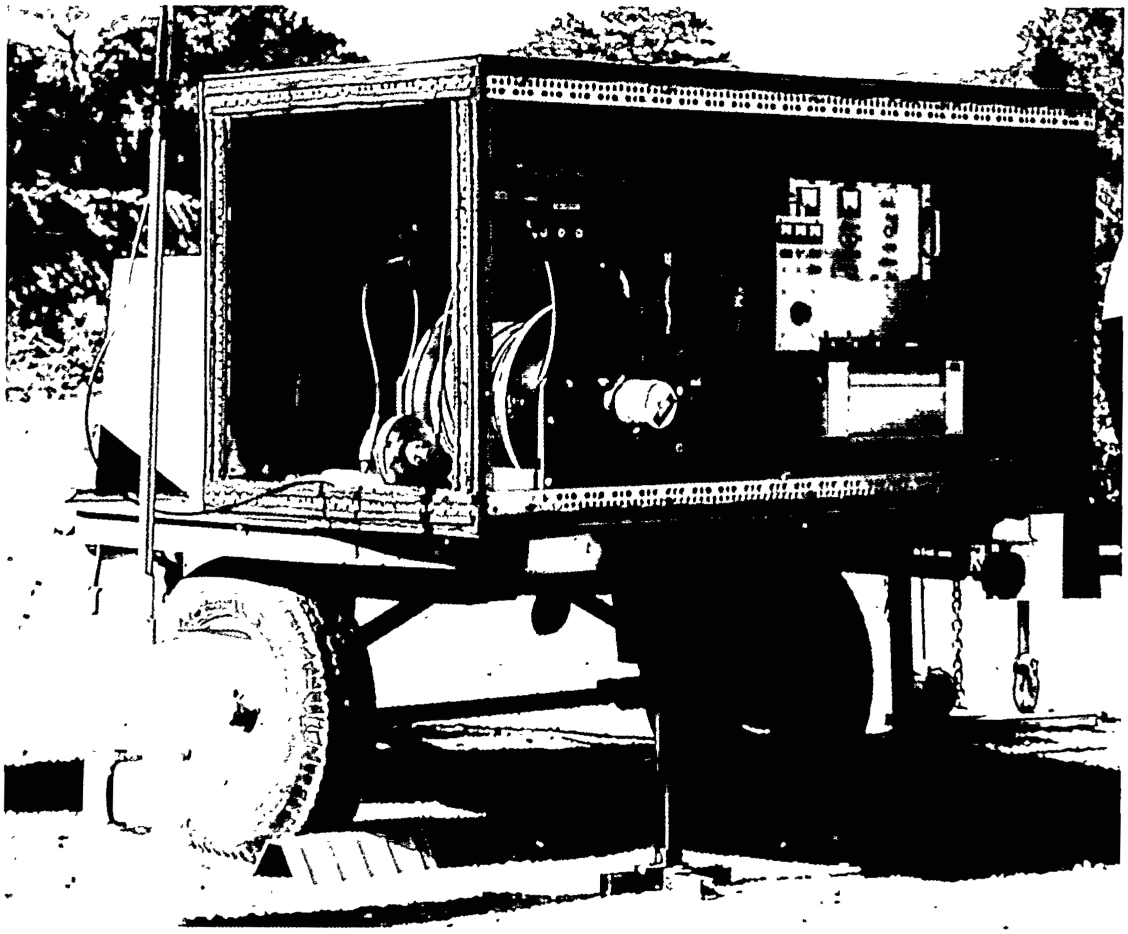


Fig. 4. The Gearhart-Owen neutron moisture gauge (white cylinder, left) consists of a polyethylene shield surrounding the probe. The trailer houses the generator and electronic instrumentation.

8.6, and 15% as determined from the bulk density and the gravimetric water content of samples collected in each 15-cm lift in each drum. To represent saturated conditions in the tuff, a fifth drum was prepared by slowly adding water to the bottom of the tuff-packed drum to result in saturated tuff at the top of the drum. Using only the water contents (Y) and three moisture gauge readings (X) from each 2.5-cm increment of the two 15-cm lifts in the center of each drum, the senior author determined a calibration curve for each moisture gauge using a linear regression model.

Fig. 5. Determination of weight of dry crushed tuff to be added to a 15-cm lift in the 1982 calibration study.

In 1982, Rj was determined as a function for each moisture gauge by taking three moisture gauge readings at each 2.5-cm increment in each of the five calibration drums. Because these measurements were performed with the calibration drums suspended 2.5 m from the ground surface, we determined an Rj for the tuff-air interfaces at the top and bottom of each calibration drum. The moisture gauge readings at each 2.5-cm increment were first converted to estimates of volumetric water content using the calibration curve data. The volumetric water content was then expressed as a function of the distance between the tuff-air interface and the midpoint

Fig. 6. Measurement of amount of water to be added to a 15-cm lift of crushed tuff in the 1982 calibration study.

Fig. 7. Addition of a fine spray of water to the crushed tuff while it was being mixed in a cement mixer in the 1982 calibration study.

Fig. 8. Packing the crushed tuff (known water content) to a known bulk density in a 15-cm lift in a calibration drum in the 1982 calibration study.

of sensitivity of the moisture gauge, using a fourth-order polynomial regression equation. The second derivative of each polynomial regression equation was determined, and the volumetric water content was estimated for the case where the second derivative was set equal to 0. The final Rj estimation was performed by calculating 90% of the latter volumetric water content and estimating the corresponding distance (Rj) by substituting this water-content value in the original fourth order polynomial regression equation.

A neutron transport code was used in 1982 to investigate moisture gauge behavior using various postulated shapes and volumes of tuff at several water contents. The code used was a General Monte Carlo Code for Neutron and Photon Transport (MCNP)—a general purpose, continuous energy, generalized-geometry, time-dependent, coupled neutron photon Monte Carlo transport code developed at Los Alamos (Los Alamos Radiation Transport Group, 1981). All fast neutron reactions were accounted for by using the published ^{241}Am/Be neutron spectral information (Lorch, 1973) and estimates of the chemical composition of the tuff (Christenson and Thomas, 1962). Thermal neutrons are described by this code by both the free gas and $S(\alpha,\beta)$ models.

In the 1991-1994 calibration studies, six neutron moisture gauges manufactured by the Campbell Pacific Nuclear Corporation, were used, as described in Table 1. One of the objectives of this study involved the evaluation of the effect of access-tube diameter on the calibation results, because we had field experiments with both 5.1-cm and 6.4-cm diameter-access tubes (Table 2). The second major objective was to obtain calibration data for soils other than crushed Bandelier Tuff (Table 3). The same calibration techniques were used as in 1982 with the exception that only two soil water contents were used for each soil material (kiln-dried soil and saturated soil). The other major difference between the two calibration studies was that SAS Software was used for data analysis in the 1994 calibration study (SAS Institute Inc., 1990).

Table 1. Description of Campbell Pacific neutron moisture probes used in 1991-1994.

Model Number	Serial Number	Outside Diameter of Probe (cm)	Source Type
503DR	H-33095079	3.8	^{241}Am/Be
503DR	H-32024274	3.8	^{241}Am/Be
503DR	H-32074519	3.8	^{241}Am/Be
503DR	H-38098459	3.8	^{241}Am/Be
503DR	H-38098460	3.8	^{241}Am/Be
501DR	H-74015254	4.7	^{137}Cs/^{241}Am/Be

Table 2. Soil Moisture Access Tube Data for 1991 Field Study Sites of the Environmental Science Group.

Study Site Location	Access-Tube Diameter (cm)	Numbers of Access Tubes
MDA-B (TA-21)	5.1	47
Pinyon-Juniper Transect (TA-51)	5.1	21
White Rock Site	5.1	2
Integrated Test Plots (TA-51)	5.1	30
Hill Air Force Base (Ogden, UT)	6.4	36
Cover System Plots (TA-51)	6.4	24
Erosion Plots (TA-51)	5.1	24

III. RESULTS AND DISCUSSION

A. Radius-of-Investigation Determinations Performed For Crushed Tuff in 1982

We were interested in the spatial response of the neutron moisture gauges to hydrogen; therefore, we first determined the exact location of the detector and ^{241}Am/Be source for each neutron moisture gauge, because all of the manufacturers could not provide us with this information (Figs. 9-11). The midpoint of sensitivity for each moisture gauge was then estimated by sliding a plastic disk (hydrogen source) along the length of each probe and determining the sample count rate at each position. The

Table 3. Description of soils used in 1991-1994 moisture gauge calibration and access-tube diameter used in calibration drums.

Field Study	Soil Description	Access-Tube Diameter (cm)
Integrated Test Plots and Protective Barrier Landfill Cover Demo (TA-51)	Hackroy clay loam backfill	5.1
Protective Barrier Landfill Cover Demo and Barrier Demo (TA-51)	Fine sand (0.05-0.425 mm, made in classifying/ blending tank system)	5.1
MDA-B (TA-21), Integrated Test Plots (TA-51)	Crushed Bandelier Tuff	5.1
Cover System Plots (TA-51)	Crushed Bandelier Tuff	6.4
Hill Air Force Base Cover Demo (Layton, UT)	Layton loamy fine sand backfill	6.4
Hill Air Force Base Cover Demo, EPA Plot hydraulic barrier material (Layton, UT)	Sodium-saturated bentonite/ Powell Gray subsoil mixture (1:10 [w:w] mixture)	6.4

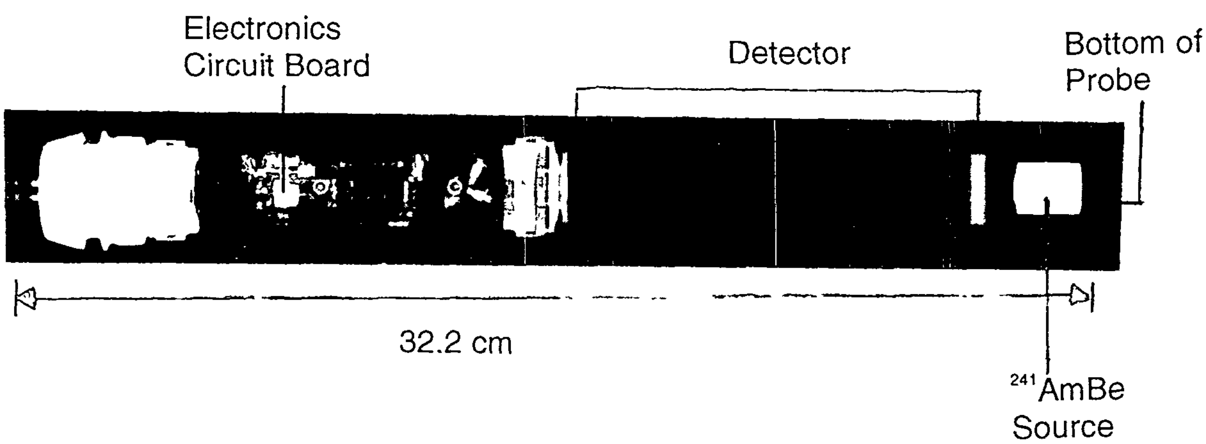


Fig. 9. X-ray of probe in Campbell Pacific moisture gauge (42% reduction of full-size image) showing locations of detector and ^{241}Am/Be source.

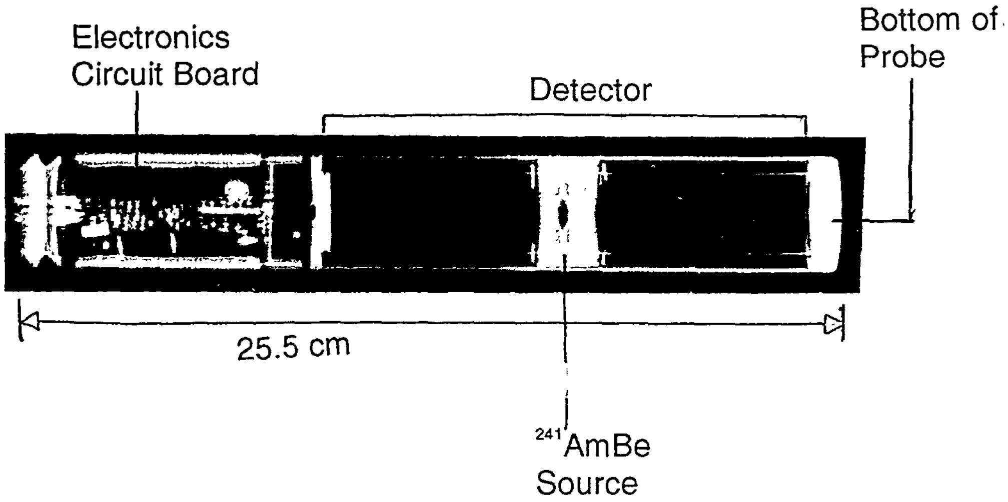


Fig. 10. X-ray of probe in Troxler moisture gauge (42% reduction of full size image) showing locations of detector and ^{241}Am/Be source.

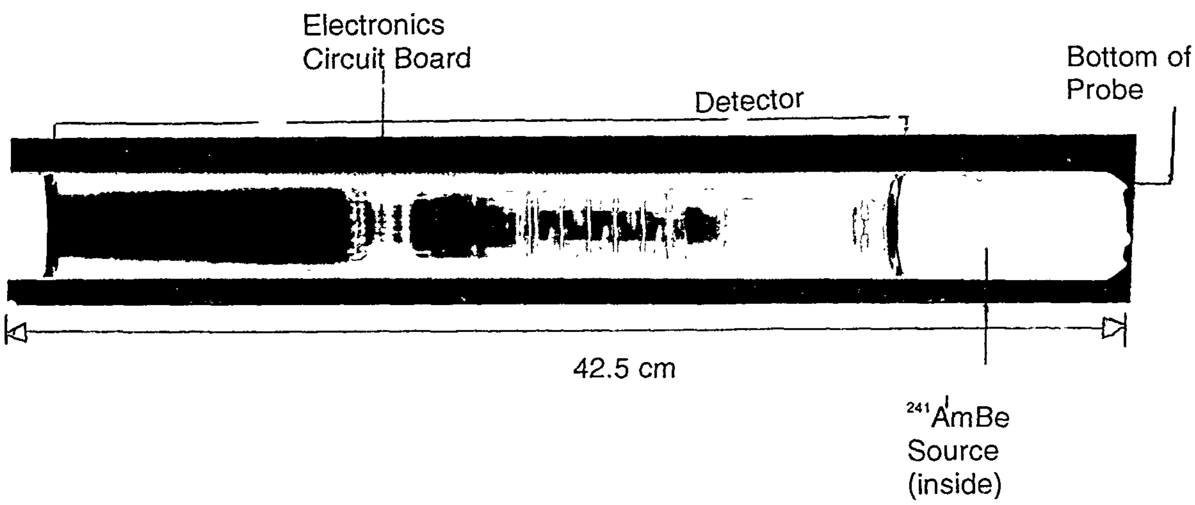


Fig. 11. X-ray of the terminal 42.5 cm of the 147-cm-long probe of the Gearhart-Owen moisutre gauge (42% reduction of full size image) showing locations of detector and ^{241}Am/Be source.

results of this experiment are presented in Figs. 12, 13, and 14 where the average count rate of the plastic disk is expressed as a function of distance from the bottom of each probe. These results are important not only in that they show where the midpoint

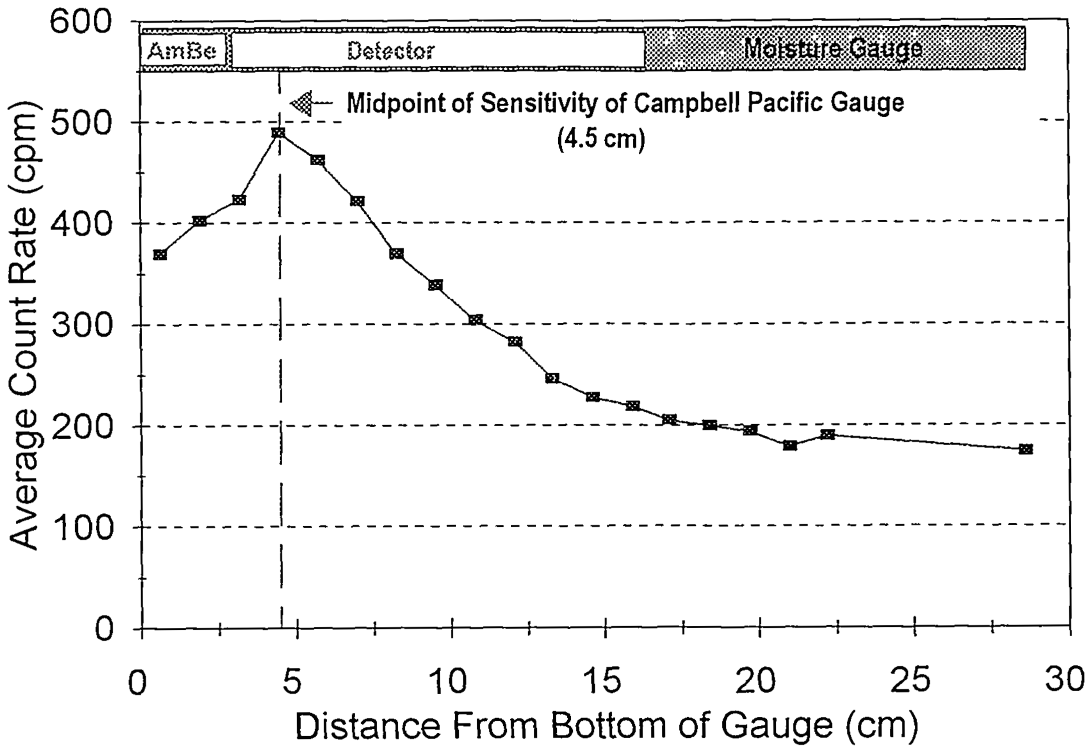


Fig. 12. Midpoint of sensitivity determination for the Campbell Pacific moisture gauge. The relationship of the midpoint of sensitivity to the gauge's $^{241}Am/Be$ source and detector locations is also shown.

of sensitivity of each probe is relative to the source and detector locations, but also because of the symmetry of the curves near the midpoint. Both the Campbell-Pacific and the Gearhart-Owen gauges have their $^{241}Am/Be$ sources located close to the bottom of the probe with the thermalized neutron detector located further up the probe. Both of these gauges showed midpoints of sensitivities that correlated with the bottom of the detector (Fig. 12). In contrast, the Troxler gauge, with its source located in the center of the detector area, exhibited a midpoint of sensitivity that correlated very well with the center of the detector. Notice also that the Troxler and Gearhart-Owen probes exhibited count rates that decreased to background counting rates, proceeding in both

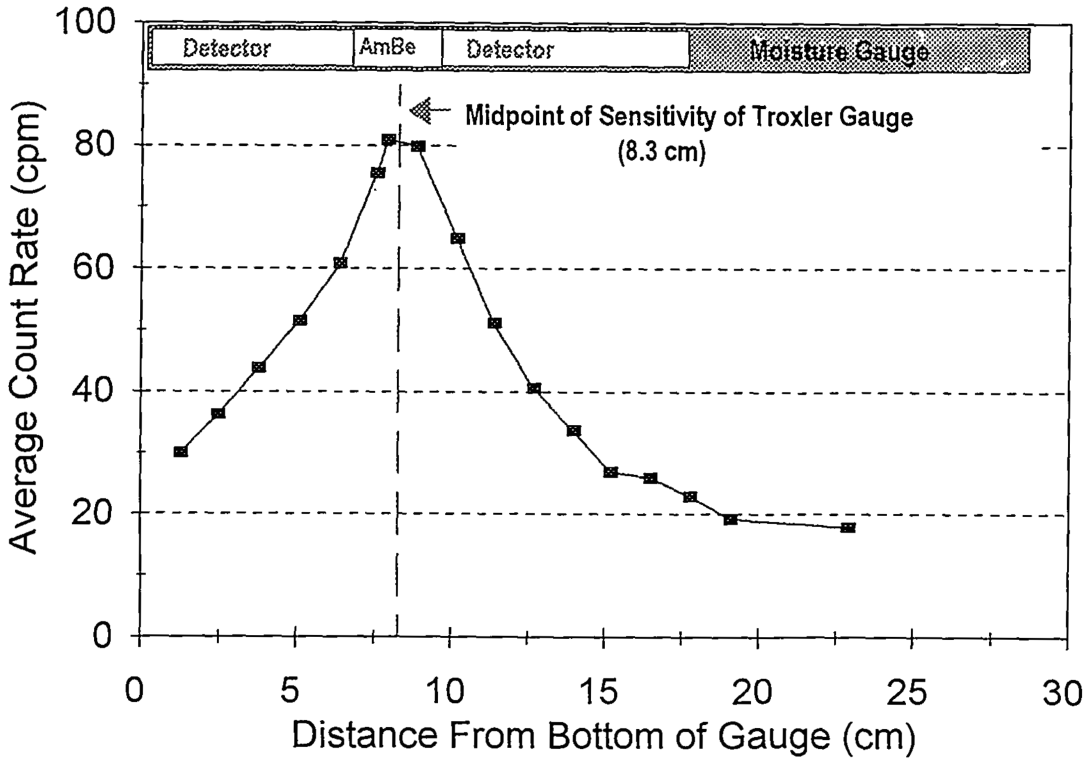


Fig. 13. Midpoint of sensitivity determination for the Troxler moisture gauge. The relationship of the midpoint of sensitivity to the gauge's ^{241}Am/Be source and detector locations is also shown.

directions away from the midpoint of sensitivity along the length of the probe. However, the Campbell Pacific gauge did not exhibit this pattern: background counting rates were reached about 11 cm above the midpoint of sensitivity, but above-background counting rates were still observed with the plastic disk at the bottom of the probe. This observation is important In biasing a probe's response below the midpoint of sensitivity in the field, when layers of varying hydrogen concentrations exist along an access tube.

All three neutron moisture gauges were calibrated using the drums packed with crushed tuff at known bulk densities and soil water contents. After measuring the sample-standard count ratio (X) and calculating volumetric water content (Y) from the

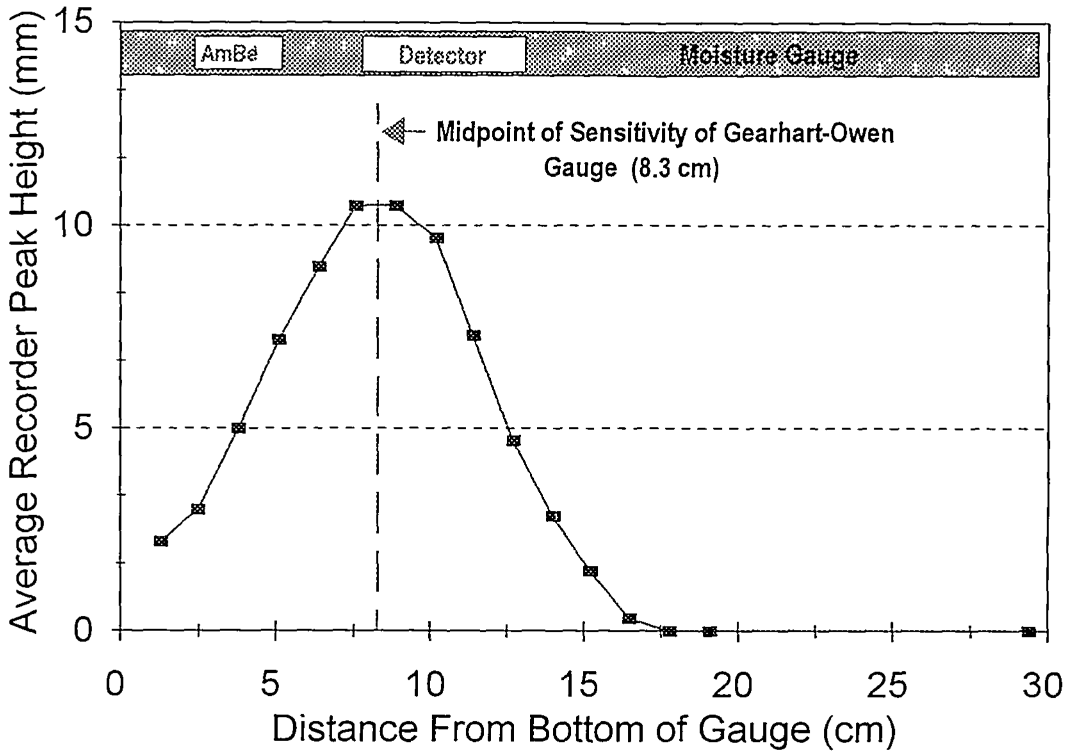


Fig. 14. Midpoint of sensitivity determination for the Gearhart-Owen moisture gauge. The relationship of the midpoint of sensitivity to the gauge's ^{241}Am/Be source and detector locations is also shown.

gravimetric water content and bulk density, a final calibration curve was determined for the Campbell Pacific (Y = 1.14 + 20.2 X, R^2 = 0.99) and the Troxler (Y = 1.40 + 61.5 X, R^2 = 0.99) probes (n = 10). The Gearhart-Owen probe was designed to read out an estimated volumetric water content based on the hydrogen concentrations in a series of plastic cylinders supplied with the instrument. Thus, we used the latter value as the independent variable for this probe's calibration curve (Y = 0.55 + 0.78 X, R^2 = 0. 99).

Using these calibration curves, we then estimated the volumetric water content in each drum as a function of the distance from the soil-air interface to the midpoint of each probe's sensitive area. This was performed for the soil-air interfaces located at both the top and the bottom of each drum (Figs. 15, 16, 17). All three moisture gauges generally showed reduced estimates of volumetric water content upon approaching a soil-air interface. This occurred because increasingly larger amounts of air (with a low water content) were included in the volume of thermalized neutrons sampled by each probe as the interface was approached. The only exception to this pattern occurred in the calibration drum filled with kiln-dried tuff (drum 1), where the moisture gauges detected similar concentrations of hydrogen in the tuff and in the air outside of the drum (Figs. 15, 16, 17).

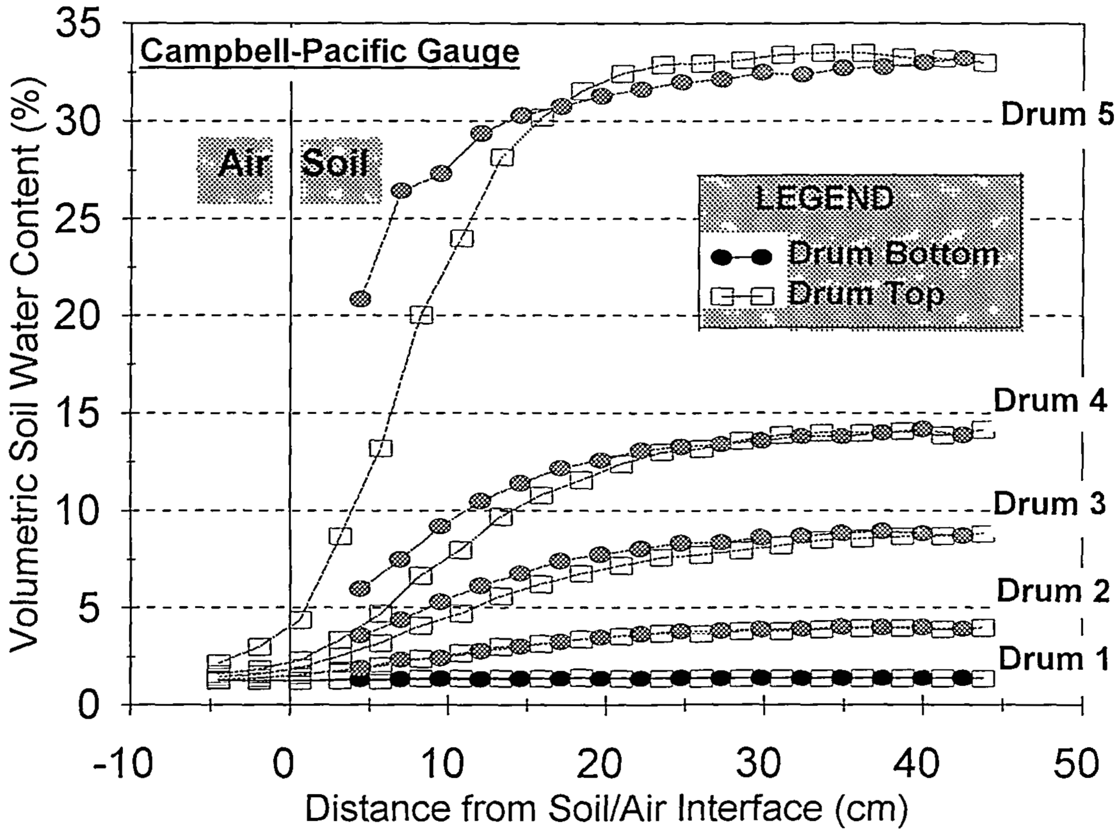


Fig. 15. Estimates of soil water content as a function of distance from the soil-air interface to the midpoint of the probe-sensitive area using the Campbell Pacific moisture gauge. Calibration drums 1, 2, 3, 4, and 5 contained crushed tuff at average volumetric water contents of 0.12, 4.3, 8.6, 14.9 and 33%, respectively.

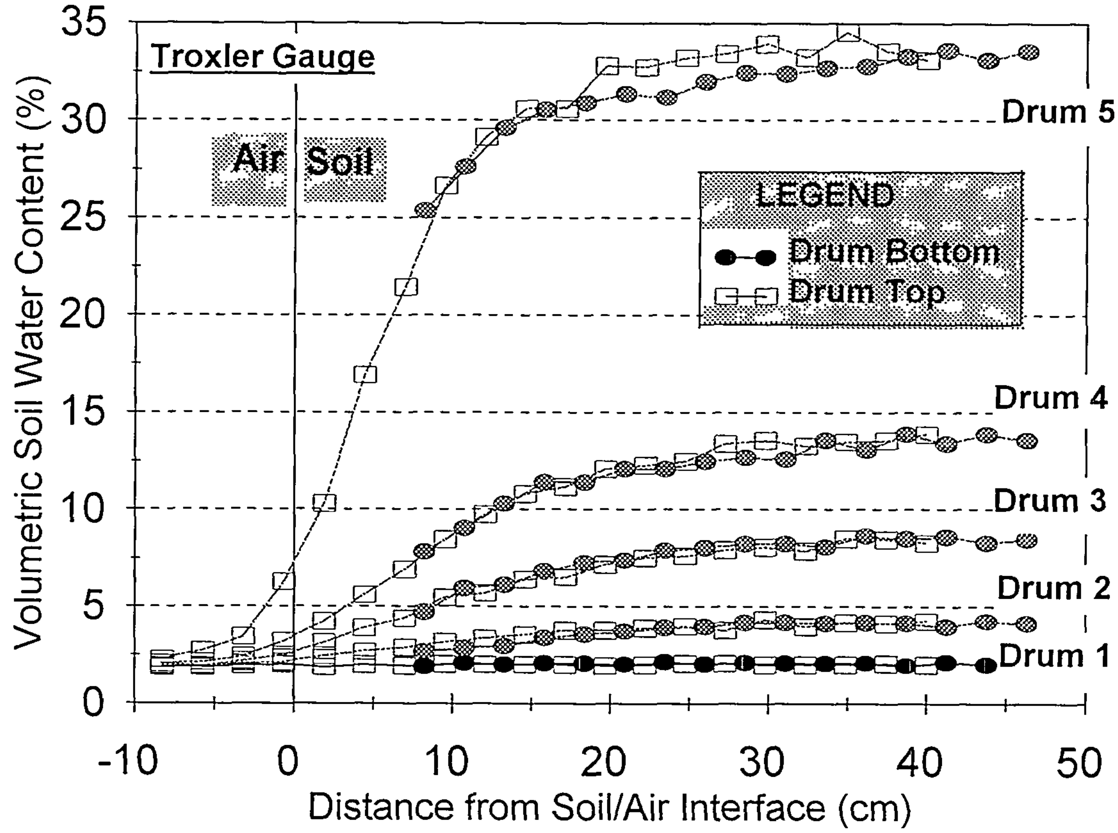


Fig. 16. Estimates of soil water content as a function of distance from the soil-air interface to the midpoint of the probe-sensitive area using the Troxler moisture gauge. Calibration drums 1, 2, 3, 4, and 5 contained crushed tuff at average volumetric water contents of 0.12, 4.3, 8.6, 14.9, and 33%, respectively.

The Campbell Pacific neutron moisture gauge did not detect changes in soil water (unlike the other two probes) upon approaching the air-soil interfaces at the top and bottom of the calibration drums (Fig. 15). In every drum, the Campbell Pacific probe detected the soil-air interface at the bottom of the drum closer to the interface than at the top of the drum. The observed distribution of counts around the midpoint of sensitivity of this probe (Fig. 12) would support an explanation for this observation because the Campbell Pacific gauge is detecting thermalized neutrons coming from the bottom of the probe, unlike the other two moisture gauges. Using the data presented in Figures 13 through 15, we found that a fourth order polynomial regression equation

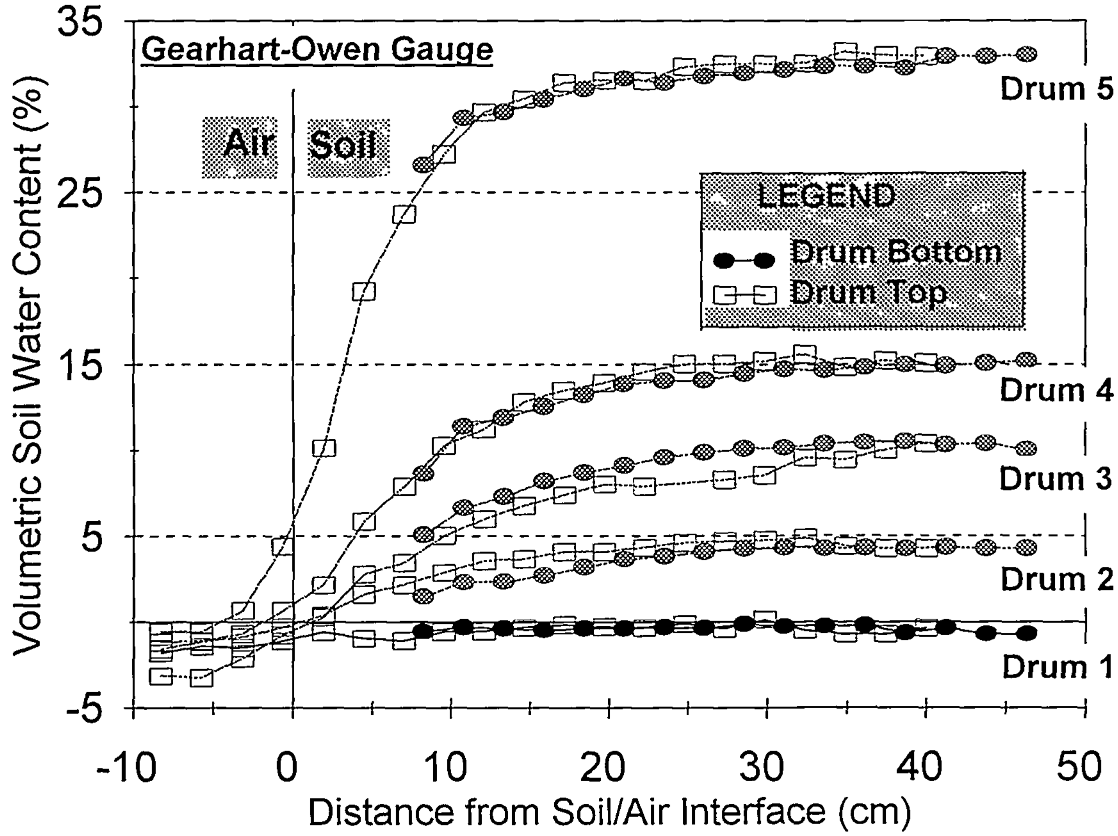


Fig. 17. Estimates of soil water content as a function of distance from the soil-air interface to the midpoint of the probe-sensitive area using the Gearhart-Owen moisture gauge. Calibration drums 1, 2, 3, 4, and 5 contained crushed tuff at average volumetric water contents of 0.12, 4.3, 8.6, 14.9, and 33%, respectively.

approximated the relationship between volumetric water content and distance to the soil-air interface very precisely (R^2 = 0.98 to 0.99, n = 10 to 15) for the interface at the top and the bottom of each drum. The Rj determinations were calculated from these regression equations for all three moisture gauges. Because the Troxler and the Gearhart-Owen gauges both demonstrated similar relationships between water content and distance to the soil-air interface at both the top and bottom of the drum (Figs. 14 and 15), the average Rj is presented in Fig. 16 for these probes as a function of soil water content. This was not the case for the Campbell Pacific moisture gauge

(Fig. 14), so individual determinations at the drum top and bottom (dashed lines) are shown (Fig. 16).

Although the calibration drum with the 0.075% volumetric water content did not contain enough hydrogen to calculate an Rj for any moisture gauge, the other four drums yielded reliable Rj estimates as function of water content (Fig. 18). The Troxler gauge, for example, demonstrated Soil water of 18, 23, 21, and 14 cm for corresponding volumetric water contents of 4.6, 9.5, 12.7, and 32.5%, respectively. The largest Rj (27 cm) was observed at the soil-air interface at the top of the drum containing tuff at a volumetric water content of 9.5%. The general relationship of Rj to water content reflected relatively low Rjs at low-water content, followed by a peak Rj

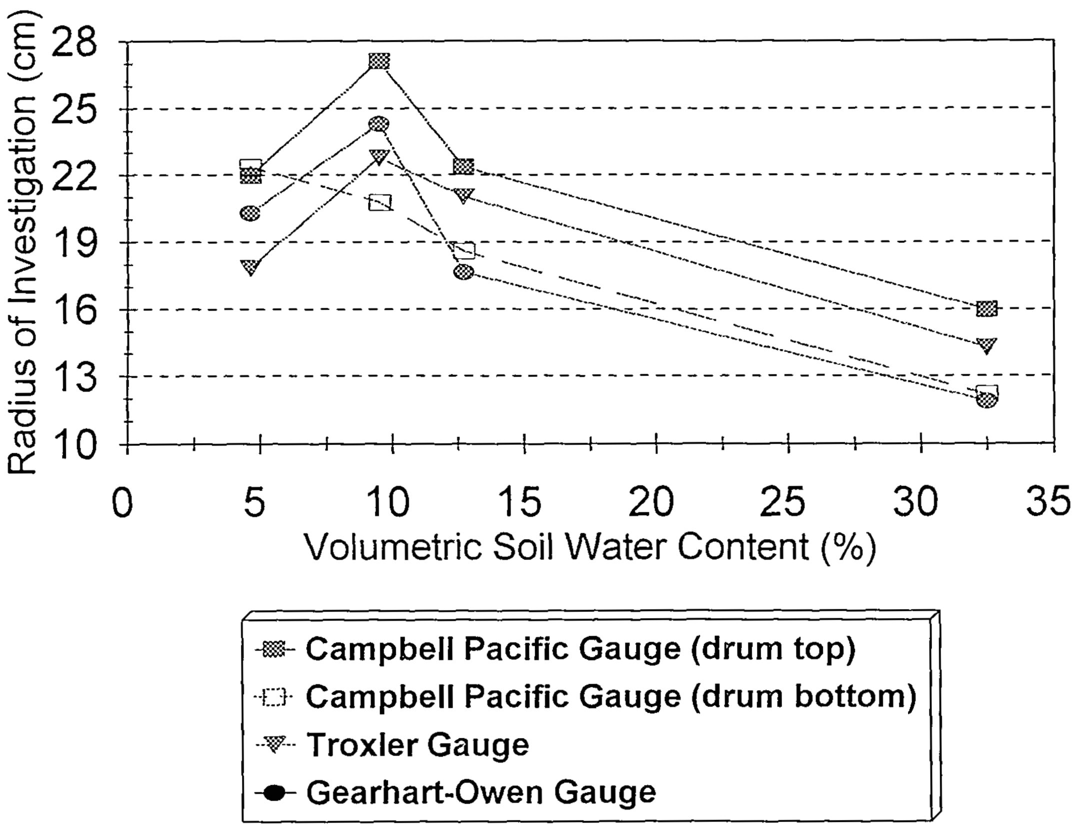


Fig. 18. Rj determinations as a function of crushed-tuff water content for the three moisture gauges used in the study.

value at intermediate-water content, and then an inverse relationship between these two variables at higher tuff-water contents. This pattern in the data compares quite well with the I.A.E.A. Rj curve with absorbers (Fig. 1), however, Rj values are half as large as the I.A.E.A. modeling estimates.

B. MCNP Modeling Results for Crushed Tuff

After analyzing the calibration drum data describing the behavior of the neutron moisture gauges near the soil surface, we used these data to calibrate an MCNP model to further investigate volumes of tuff interrogated by the Campbell Pacific probe. The MCNP model was calibrated for our specific configurations of access tube, calibration drum, and Campbell Pacific moisture gauge, with its midpoint of sensitivity, source, and detector located in a known position relative to the tuff-air interface. The other specific information required was the approximate atom densities of Si, Al, Fe, O, C, and H in the tuff, and the fast neutron spectra data for an ^{241}Am/Be source.

Using the above information, MCNP simulations (Campbell Pacific moisture gauge) were performed in seven different positions relative to the soil-air interface of our calibration drums (Fig. 19). The average and standard deviation of the three measurements of water content agreed quite well with the model predictions of volumetric water content for each calibration drum. In fact, because a part of MCNP computer output included an estimate of variation of predicted water content, we observed no statistically significant differences between computer predicted and measured water content. We later found that the variation in our MCNP model estimates, which were routinely made with 4-m simulations on a CRAY computer, could be reduced with 10-m computer simulation times, resulting in even better agreement between measured and model-predicted water contents.

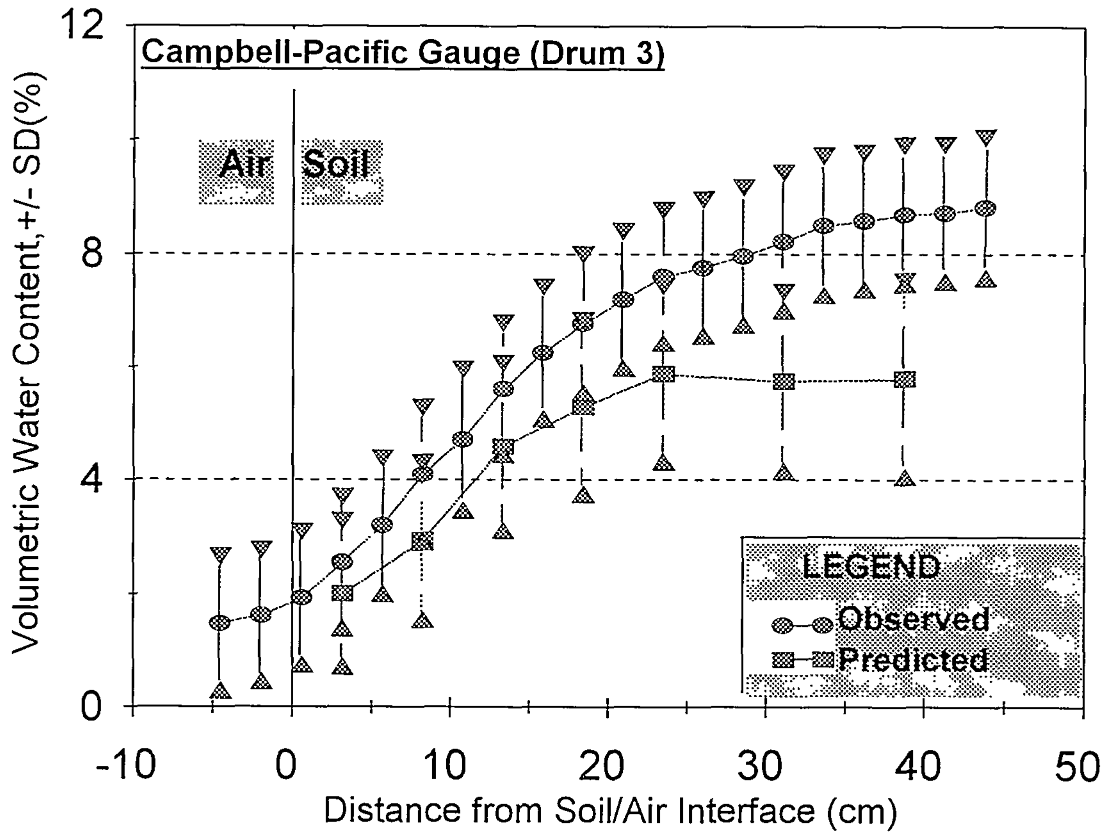


Fig. 19. Observed measurements and MCNP model predictions of volumetric crushed-tuff water content near the soil-air interface of calibration drum 3 containing tuff at an average volumetric water content of 8.6%.

Because these encouraging MCNP modeling results implied that the model was predicting thermalized neutron transport successfully in three-dimensional space, we decided to use MCNP to further evaluate the volumes of soil water contributing thermalized neutrons to the moisture gauge detector. More specifically, this was done by performing MCNP simulations where the probe was placed in the center of the drum and the calibration drum was divided into 1) a series of concentric right circular cylinders as tall as the calibration drum ("rings") and 2) a stack of 4-cm tall right circular cylinders. This allowed us to estimate the number of counts observed at the detector originating from cells of tuff located varying distances along the X and Z axes, as well as along the Y axis for calibration drums with varying soil water contents. The number of counts coming from each cell was normalized with respect to the volume of the cell, and then expressed as percentage of the total counts observed at the detector.

The MCNP modeling results for the case with the calibration drum divided into a series of concentric rings are presented in Fig. 20. These modeling results show how the neutron moisture gauge's response along the X and Z axes is influenced by the water content of the surrounding tuff. Approximately 90% of the counts arriving at the probe detector came from moist tuff at distances of 25, 23, 20, and 14 cm with corresponding volumetric water contents of 4.3, 8.6, 15, 33%, respectively. These

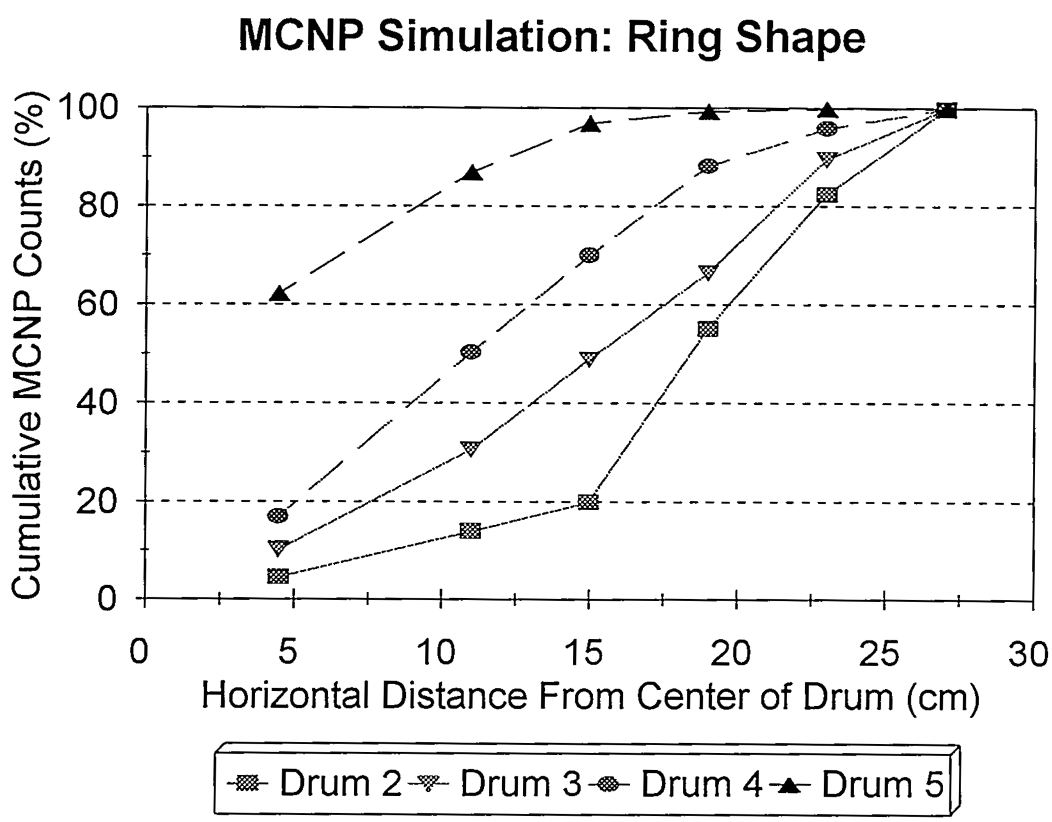


Fig. 20. MCNP modeling results for simulations of crushed tuff in calibration drums with MCNP cells consisting of concentric rings. Calibration drums 2, 3, 4, and 5 contained crushed tuff at average volumetric water contents of 4.3, 8.6, 14.9, and 33%, respectively.

distances in the X-Z plane corresponded quite well with the Rj field data collected at the tuff-air interface (Fig. 16).

In the next modeling simulations, the moisture gauge's response along the Y axis was investigated by dividing the drum into a stack of 17 4-cm-thick tuff layers and again placing the probe in the center of the calibration drum (Fig. 21). The MCNP results predict that the moisture gauge detects thermalized neutrons similarly from soil volumes above and below the midpoint of sensitivity of the probe. Thus, 90% of the counts arriving at the probe detector came from moist tuff at distances of 27, 21, 19 and 11 cm with corresponding water contents of 4.3, 8.6, 15, and 33%, respectively.

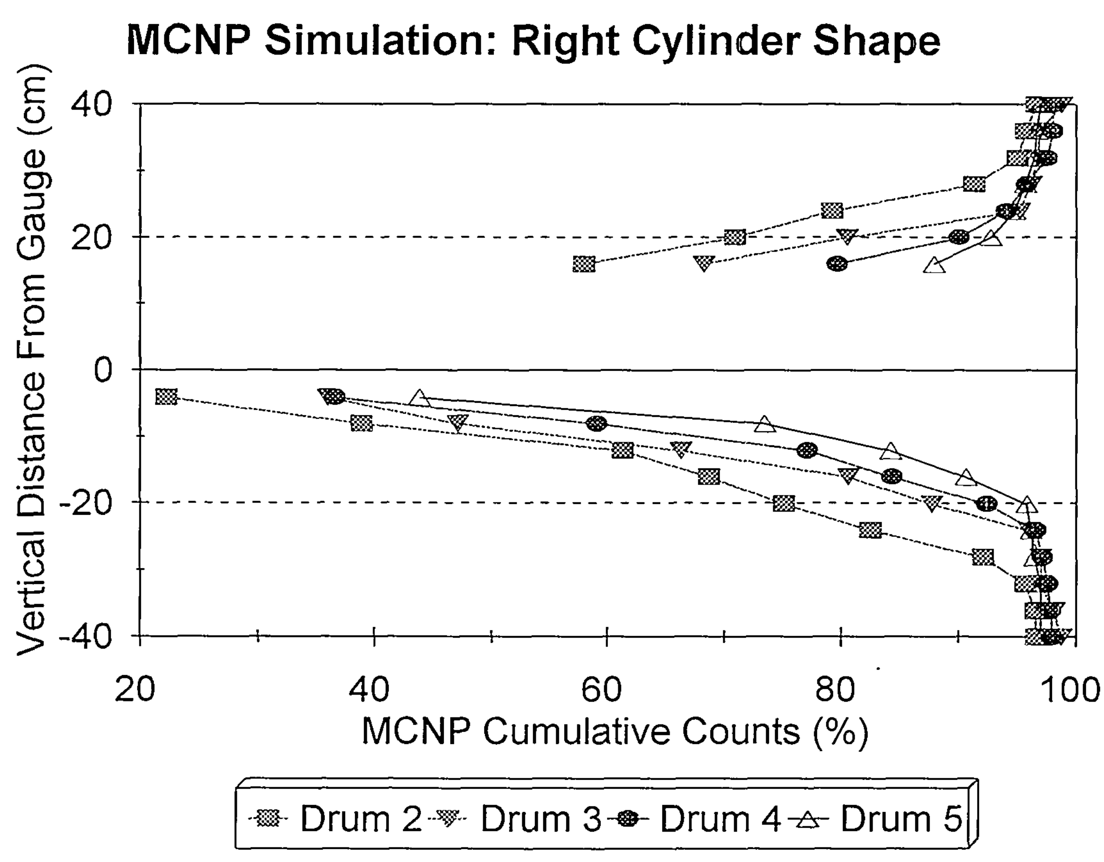


Fig. 21. MCNP modeling results for simulations of crushed tuff in calibration drums with MCNP cells consisting of a stack of many right cylindrical segments. Calibration drums 2, 3, 4, and 5 contained crushed tuff at average volumetric water contents of 4.3, 8.6, 14.9, and 33%, respectively.

Our overall modeling impressions of the shape of the volume interrogated by the Campbell Pacific moisture gauge thus seemed to vary with the water content of the tuff (Figs. 18 and 19). However, because we considered the ^{241}Am/Be source to be emitting fast neutrons isosymetrically into the tuff in the calibration drums, the principles of the radiation physics involved imply that the modeling should also be designed isosymetrically about the midpoint of sensitivity of the neutron probe. Thus, a concentric series of five different shapes were modeled for three of our calibration drums. The shapes used were 1) spheres, 2) right cylindrical rings as tall as the calibration drums, 3) a spheroid shape with the X and Z axes 30% larger than the Y axis, 4) a spheroid shape with the X and Z axes 20% larger than the Y axis, and 5) a spheroid shape with the values of the X and Z axes equal to the Y axis value divided by 1.3.

Five to six concentric MCNP model cells of each shape were designed around the midpoint of sensitivity of the probe and the total detector counts originating from thermalized neutrons coming from each cell were determined and divided by the cell volume. The detector cpm/cc for each cell was then plotted as function-of-distance from the center of the calibration drum to the cell's midpoint along the X axis.

The MCNP modeling results are presented for the calibration drums at 8.6% (Fig. 22), 15% (Fig. 23), and 33% (Fig. 24) volumetric water contents. The basic assumption of this approach is that maximum cell cpm/cc will be observed relatively close to the center of the drum if the correct shape is approximated in the modeling simulation. Thus, from Fig. 19, it appears that very few thermalized neutrons are detected by the neutron probe from near the top and bottom of the calibration drum. When the ring shapes as tall as the drum were modeled, we observed low cpm/cc in each cell relative to the other shapes investigated (Figs. 20, 21, 22).

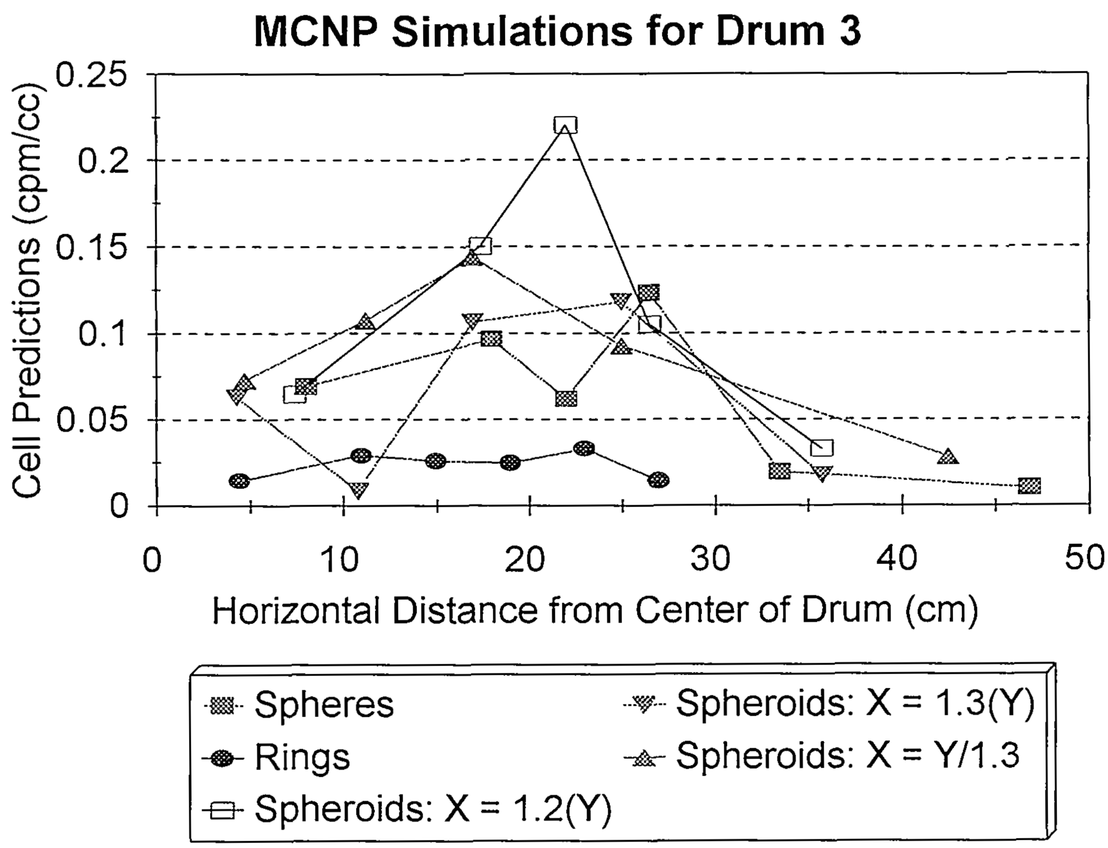


Fig. 22. MCNP shape simulations for calibration drum 3 containing crushed tuff at an average volumetric water content of 8.6%.

Using this criteria, we estimated that at volumetric water contents of 8.6% and 15%, the most appropriate shapes seemed to be spheroids with X and Z axes having values 1.2 and 1.3 times larger than the Y axis values, respectively. In contrast, the calibration drum with a volumetric water content of 33% exhibited an optimized sampling shape that was more elongated along the Y axis, i.e., a spheroid with the X and Z axis values equal to the Y axis value divided by 1.3. This latter case represented the only case where a spherical shape could also be considered optimal (Figs. 20, 21, 22).

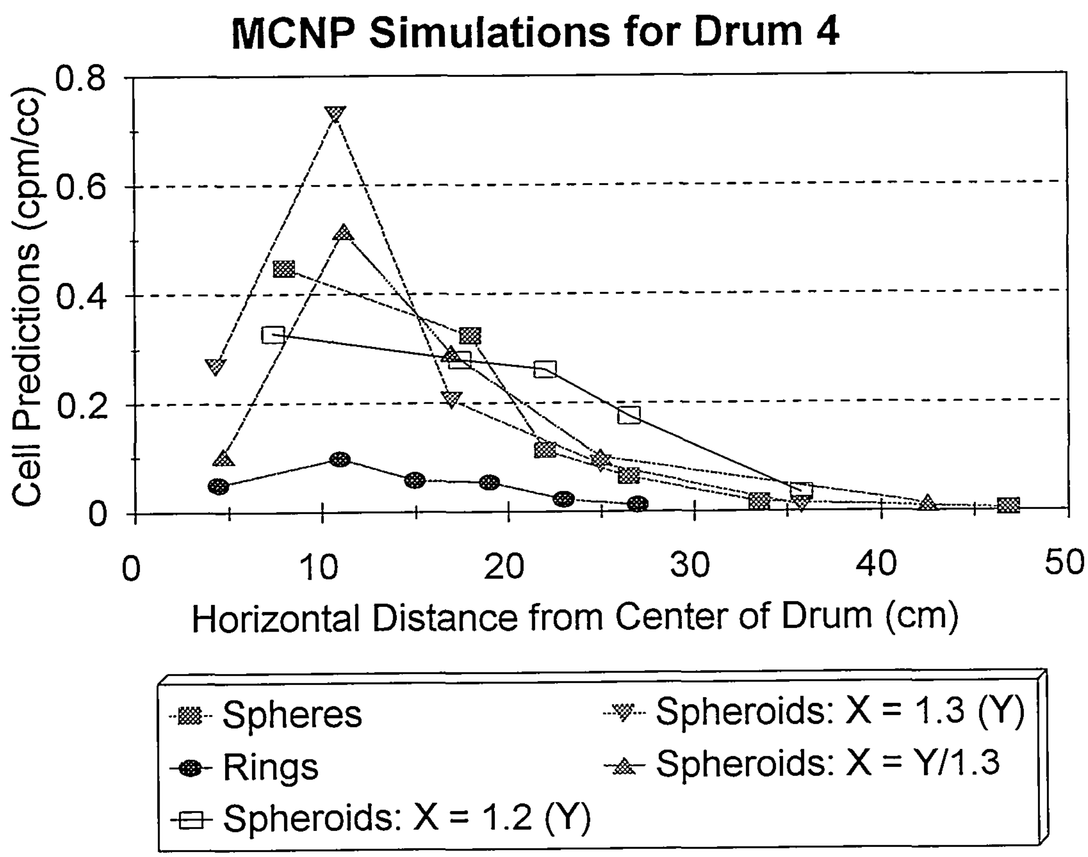


Fig. 23. MCNP shape simulations for calibration drum 4 containing crushed tuff at an average volumetric water content of 14.9%.

C. Calibration of Moisture Gauges in 1994 for Crushed Tuff and Soils Used in Hydrologic Studies

The detailed results of the Campbell Pacific moisture gauge calibrations performed from 1991-1994 are presented in Appendix A. The results of the linear regression analysis of these data are presented in Figures 25 through 44 for each neutron moisture gauge and for each soil studied. The data are then summarized graphically in Figures 45 through 48 by moisture gauge, as well as in a final summary table listing the regression parameters used to calculate volumetric water content (Table 4).

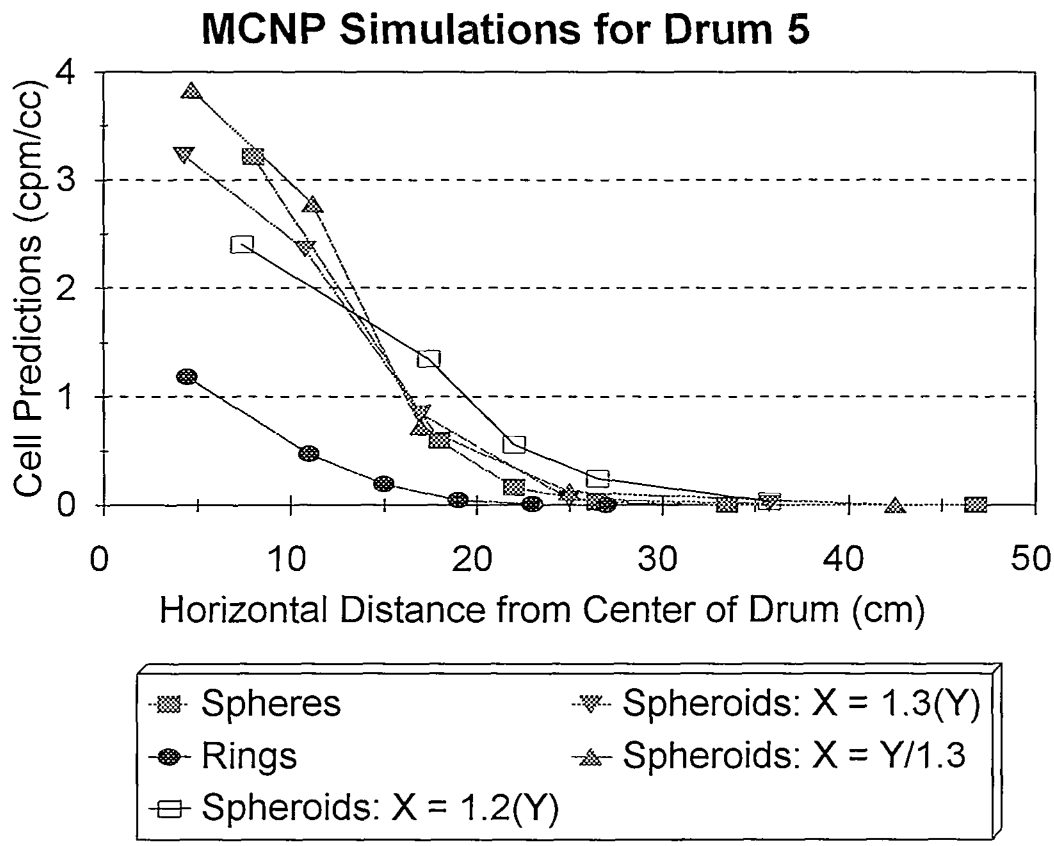
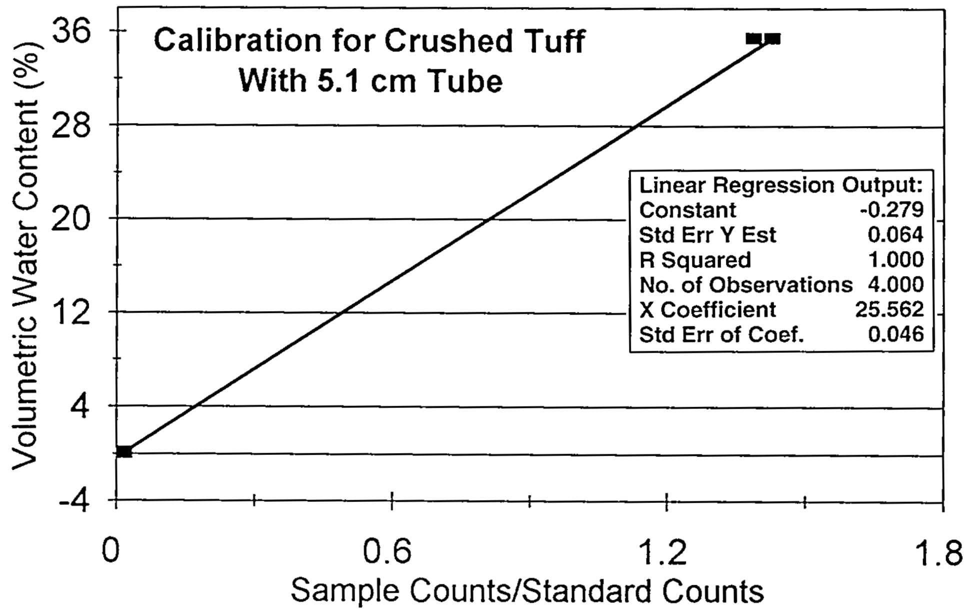


Fig. 24. MCNP shape simulations for calibration drum 5 containing crushed tuff at an average volumetric water content of 33%.

The calibration data presented in Figures 45 through 48 generally show that volumetric water content increased with sample standard counts, as was expected. Crushed tuff at saturation had the highest sample/standard counts for every moisture gauge tested relative to the other saturated soils. The crushed tuff with the 5.1-cm-diam access tubes usually had more sample counts at saturation than when the larger 6.4-cm-diam tubes were used; this was also expected since the moisture gauge in the larger access tube is measuring the air inside of the access tube within its Rj, resulting in smaller sample counts than when the probe is situated very close to the access tube sidewall. However, this effect could not be differentiated by two of the moisture gauges (Serial numbers 4519 and 5254). The Hackroy clay loam sample always exhibited substantially fewer sample counts at saturation than the saturated crushed tuff, the parent material of this soil type (Nyhan et al., 1978). Fewer sample counts were expected since porous materials with relatively higher clay content usually exhibit this trend (CSIRO, 1981). The Layton loamy fine sand always exhibited the smallest sample counts at saturation compared with all of the other soils at saturation. The low count is probably due to the occurrence of strong absorbers of thermal neutrons in this soil such as boron, chlorine, iron, and gadolinium (CSIRO, 1981).



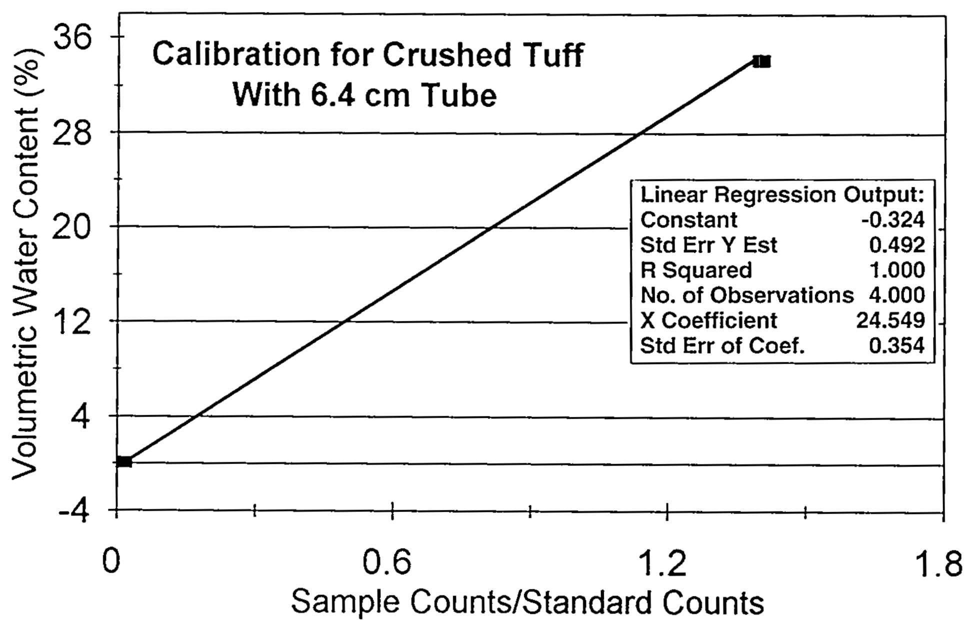
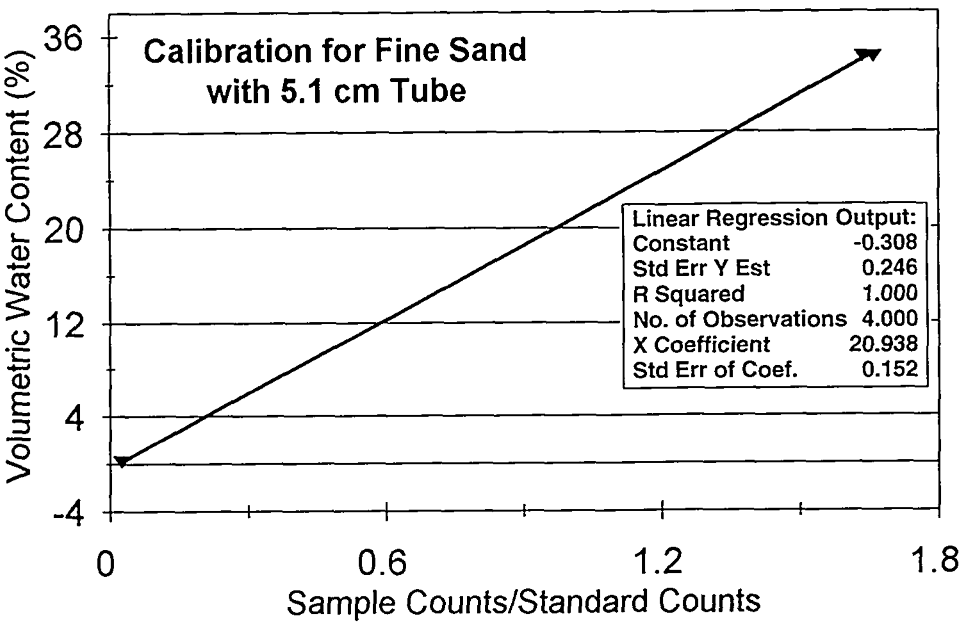


Fig. 25. Statistical analysis results for crushed tuff samples for neutron moisture gauge with serial number 4274.



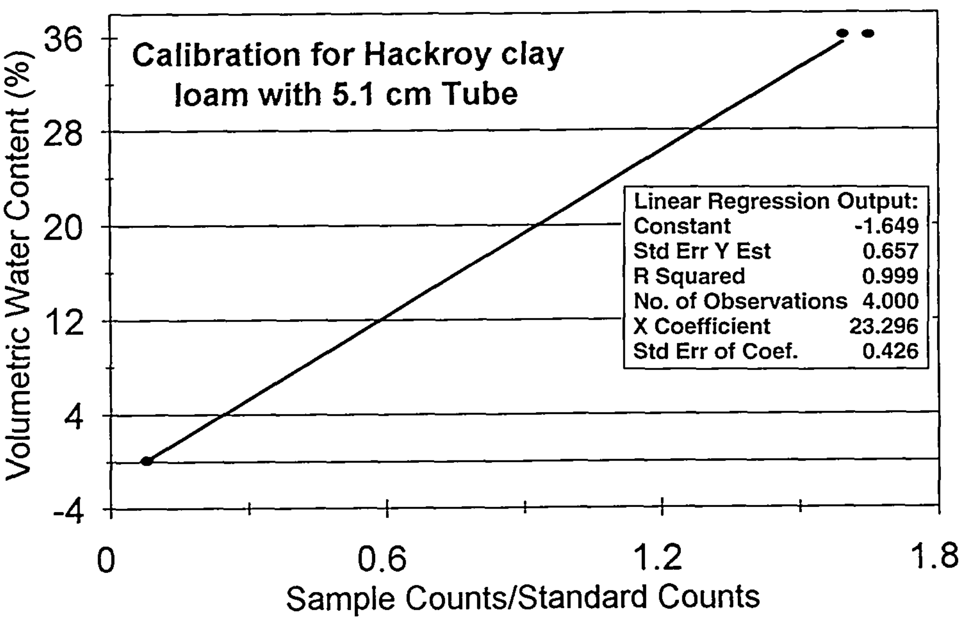


Fig. 26. Statistical analysis results for fine sand and Hackroy clay loam samples for neutron moisture gauge with serial number 4274.

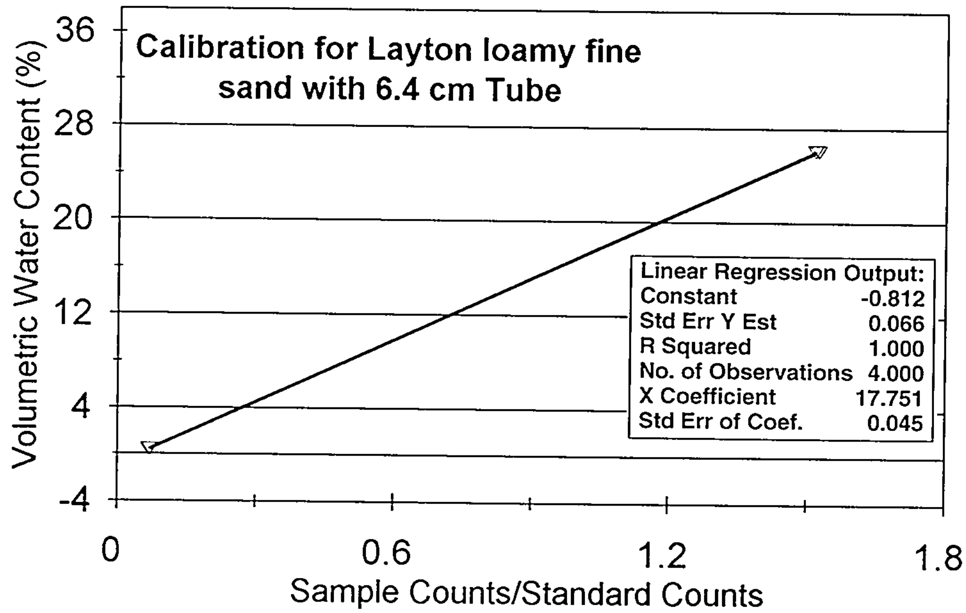
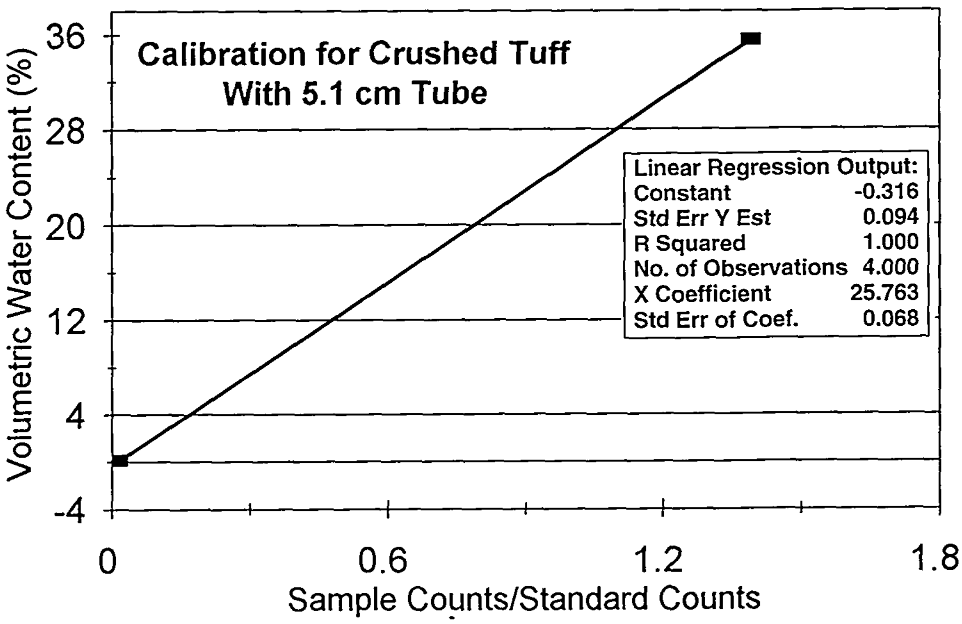


Fig. 27. Statistical analysis results for Layton loamy fine sand sample for neutron moisture gauge with serial number 4274.



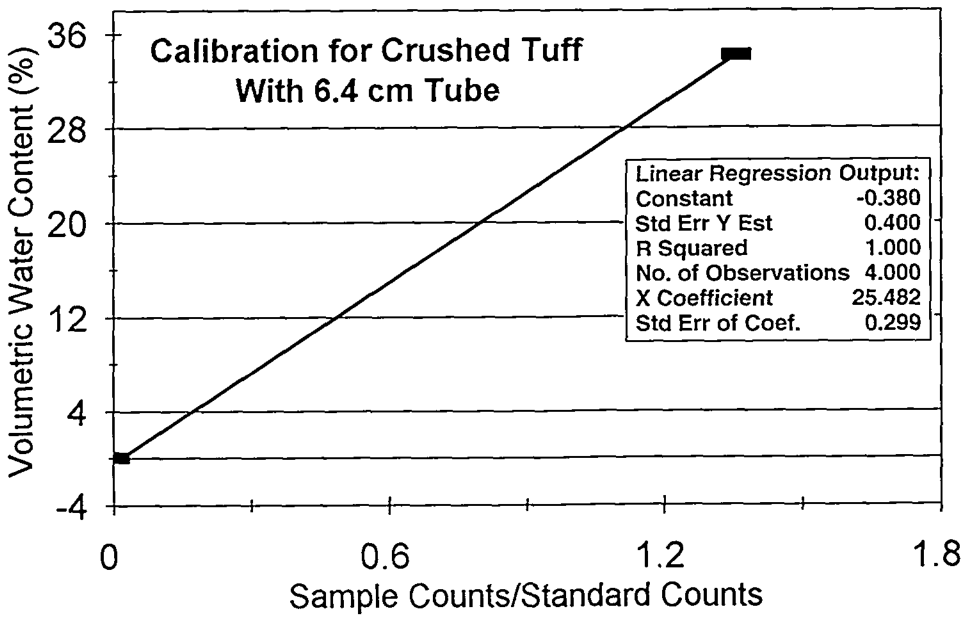
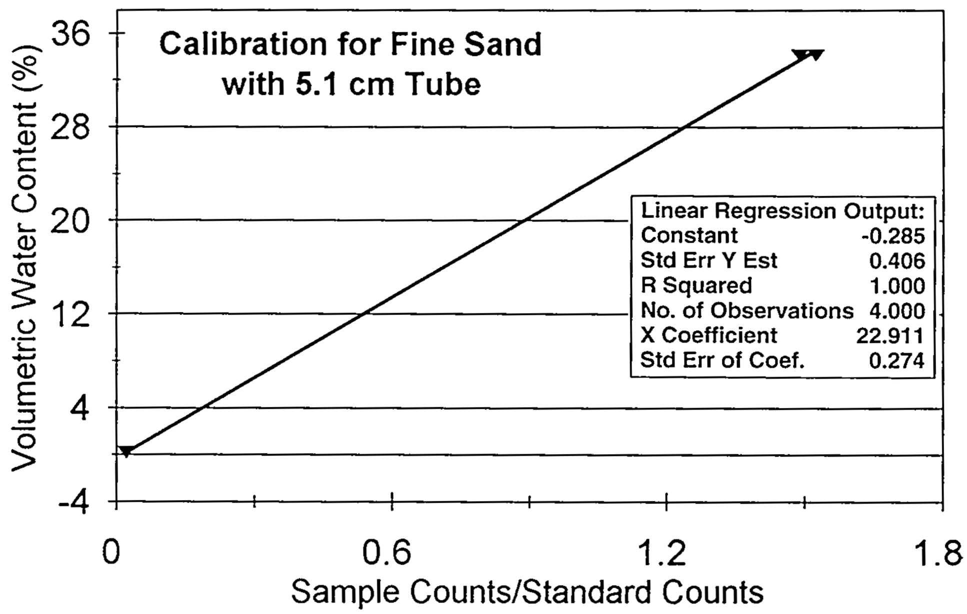


Fig. 28. Statistical analysis results for crushed tuff samples for neutron moisture gauge with serial number 4519.



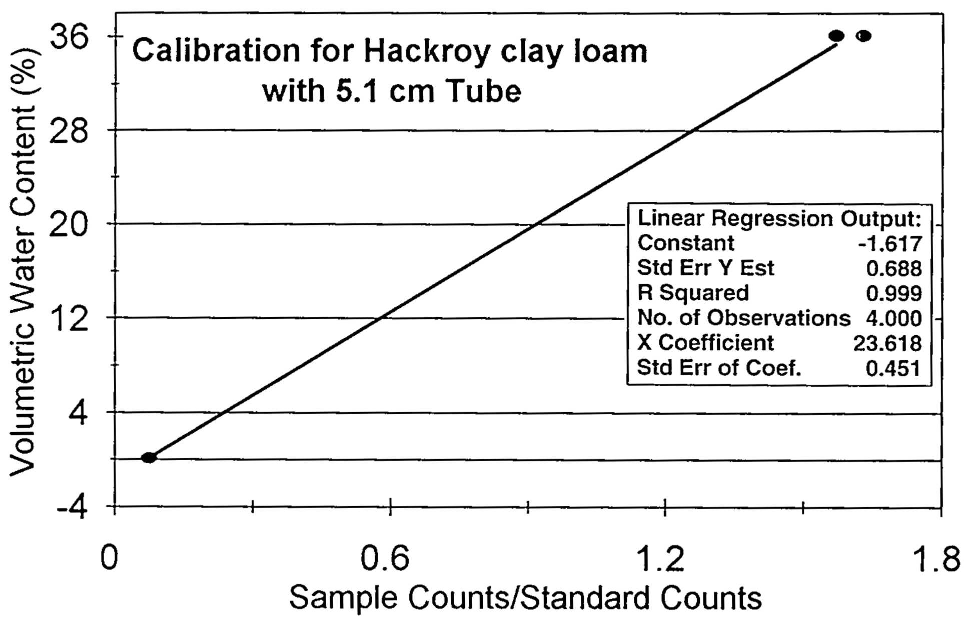


Fig. 29. Statistical analysis results for fine sand and Hackroy clay loam samples for neutron moisture gauge with serial number 4519.

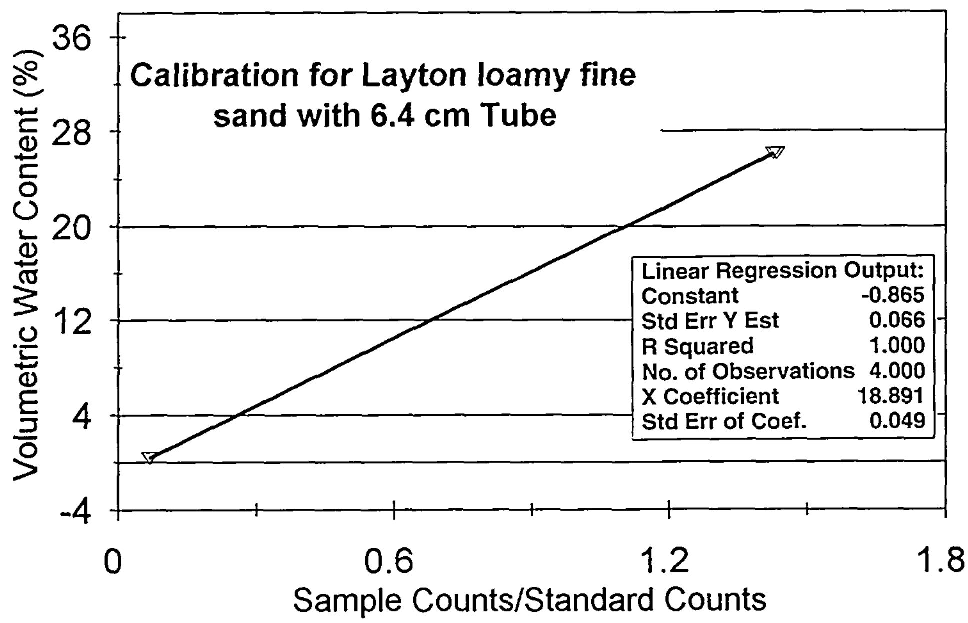
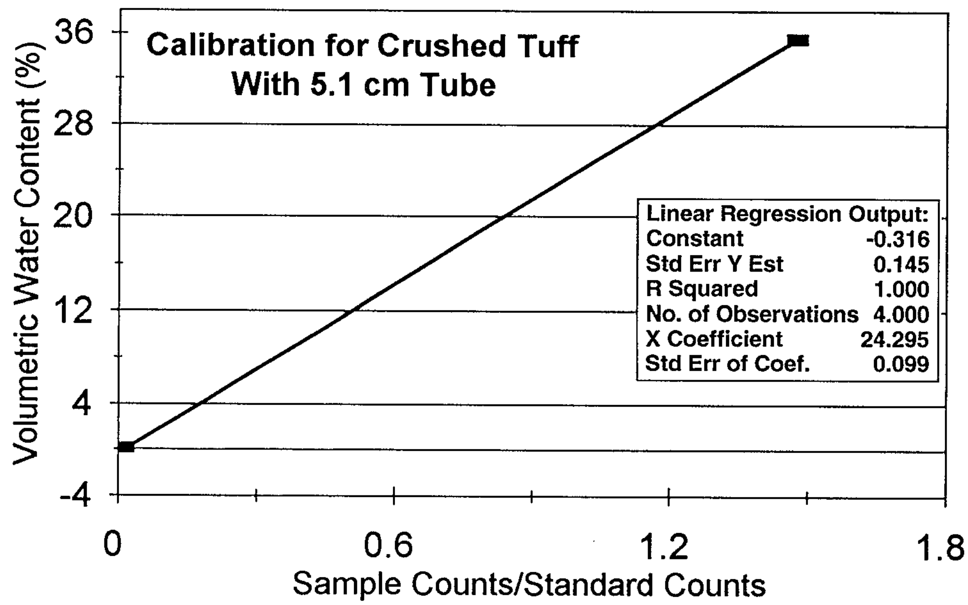


Fig. 30. Statistical analysis results for Layton loamy fine sand sample for neutron moisture gauge with serial number 4519.



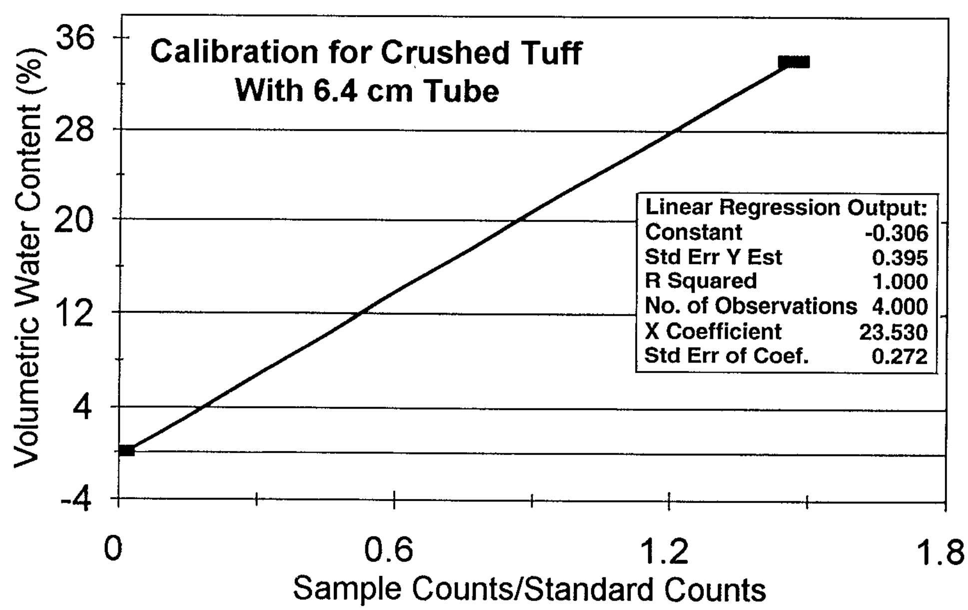
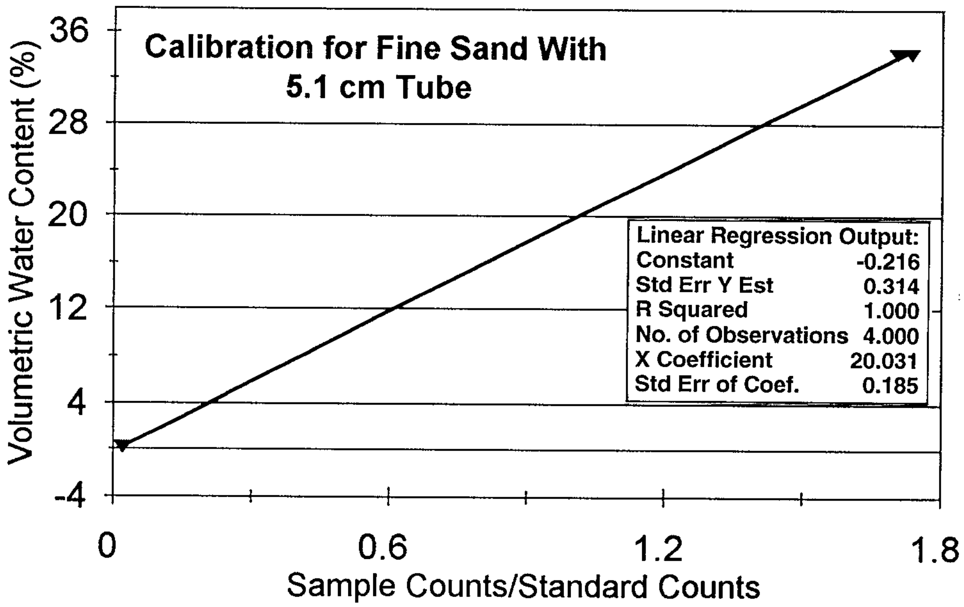


Fig. 31. Statistical analysis results for crushed tuff samples for neutron moisture gauge with serial number 5079.



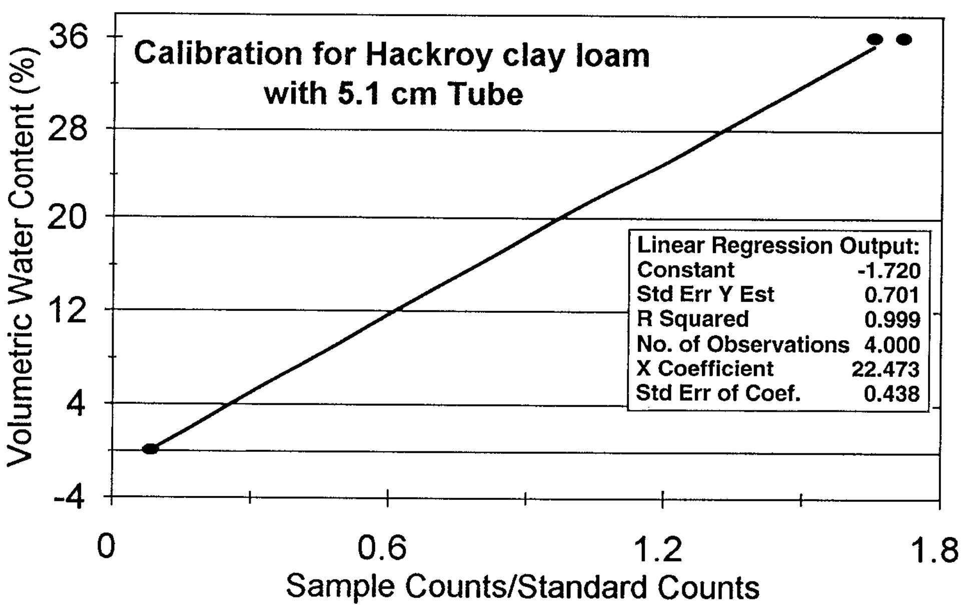


Fig. 32. Statistical analysis results for fine sand and Hackroy clay loam samples for neutron moisture gauge with serial number 5079.

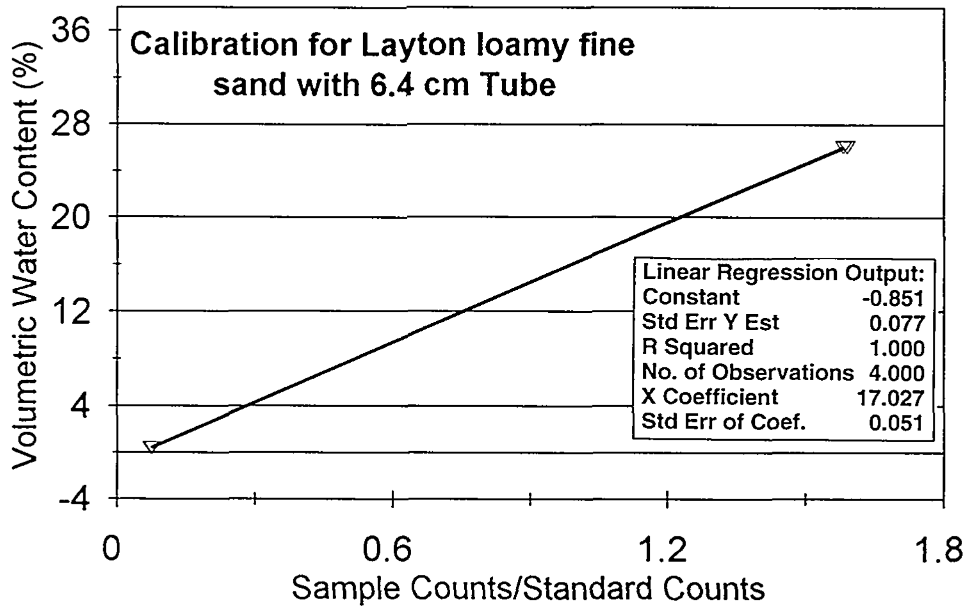
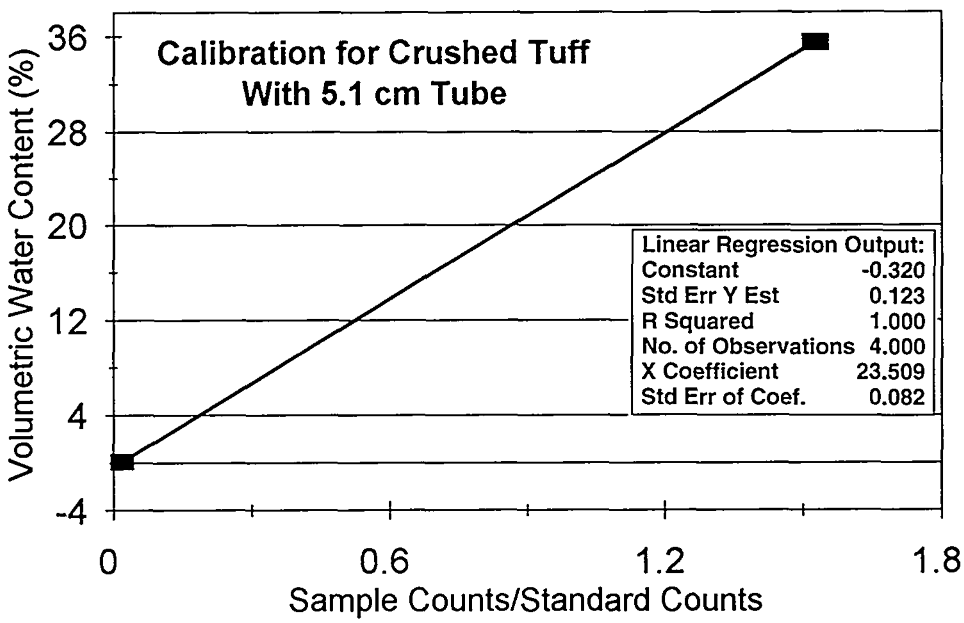


Fig. 33. Statistical analysis results for Layton loamy fine sample for neutron moisture gauge with serial number 5079.



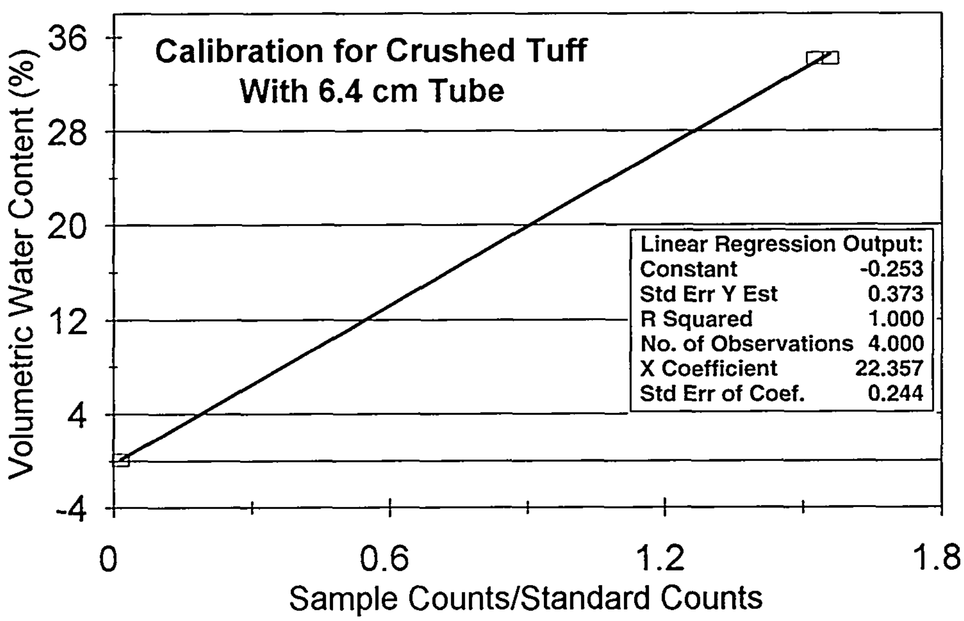
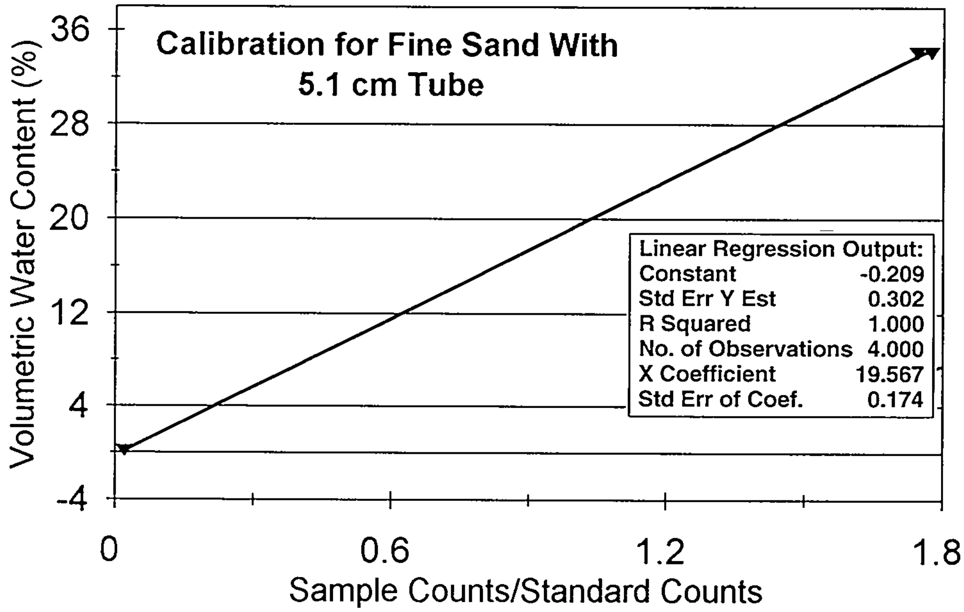


Fig. 34. Statistical analysis results for crushed tuff samples for neutron moisture gauge with serial number 7832.



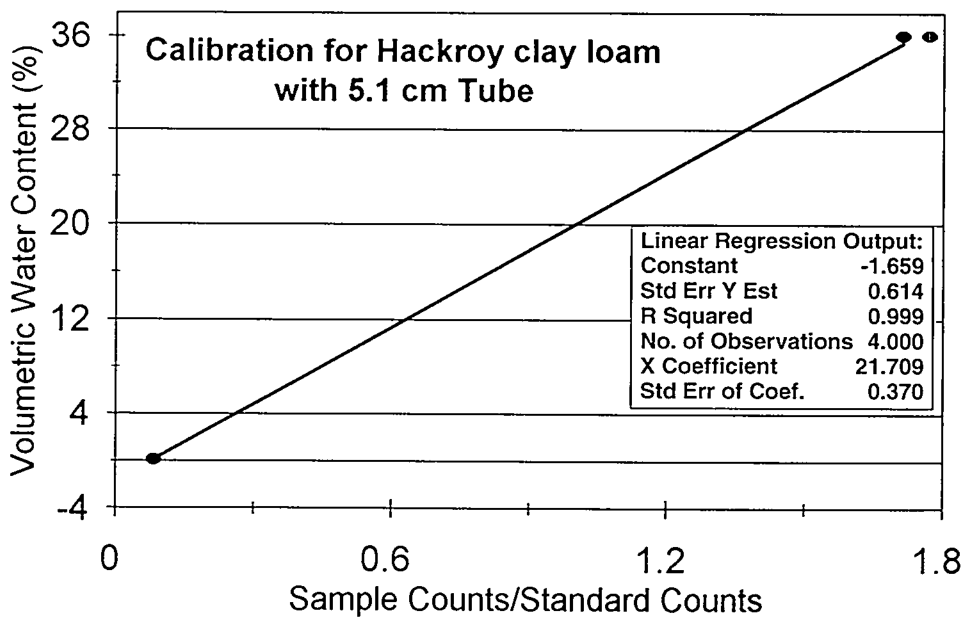


Fig. 35. Statistical analysis results for fine sand and Hackroy clay loam samples for neutron moisture gauge with serial number 7832.

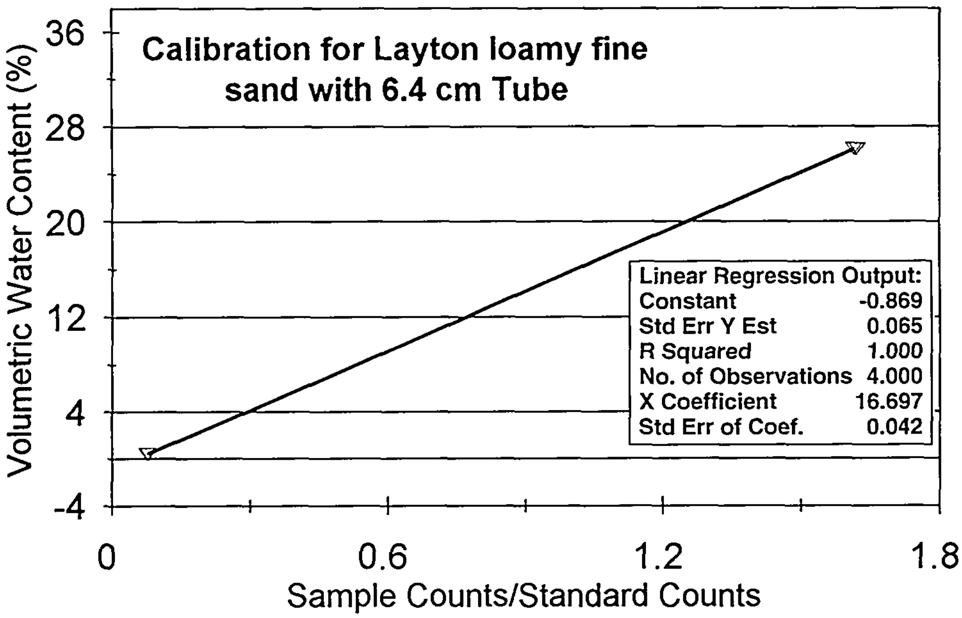
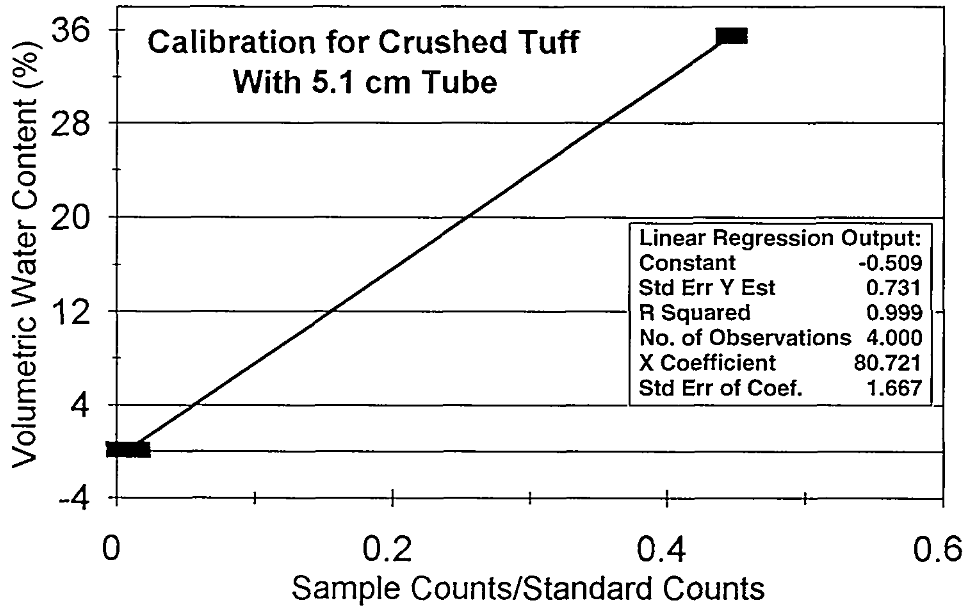


Fig. 36. Statistical analysis results for Layton loamy fine sand samples for neutron moisture gauge with serial number 7832.



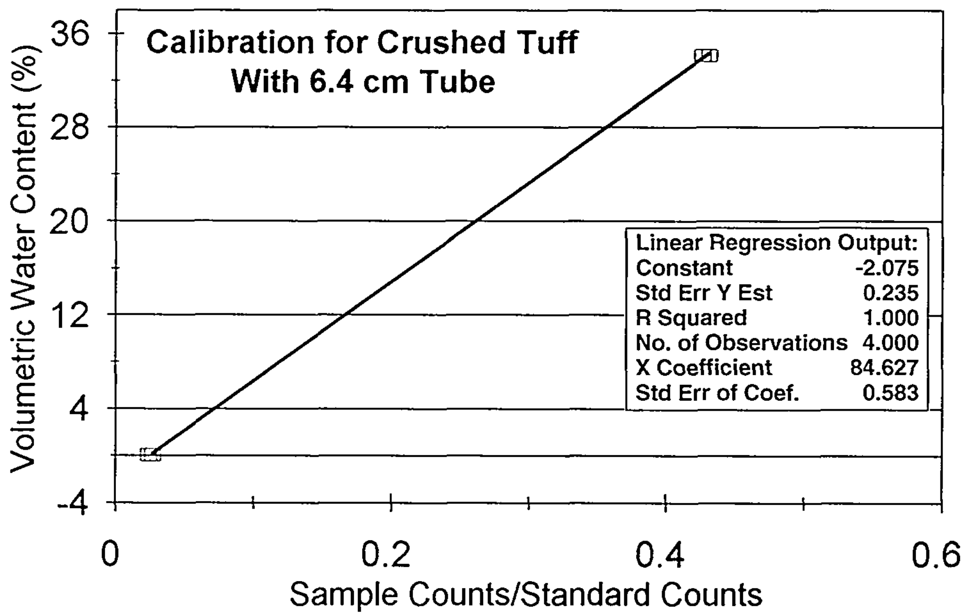
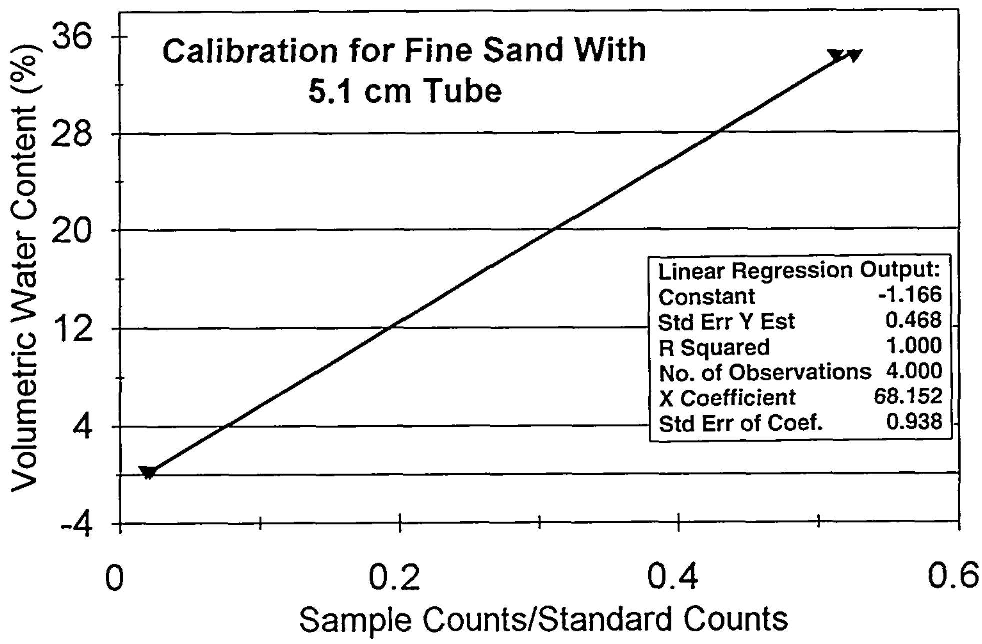


Fig. 37. Statistical analysis results for crushed tuff samples for neutron moisture gauge with serial number 5254.



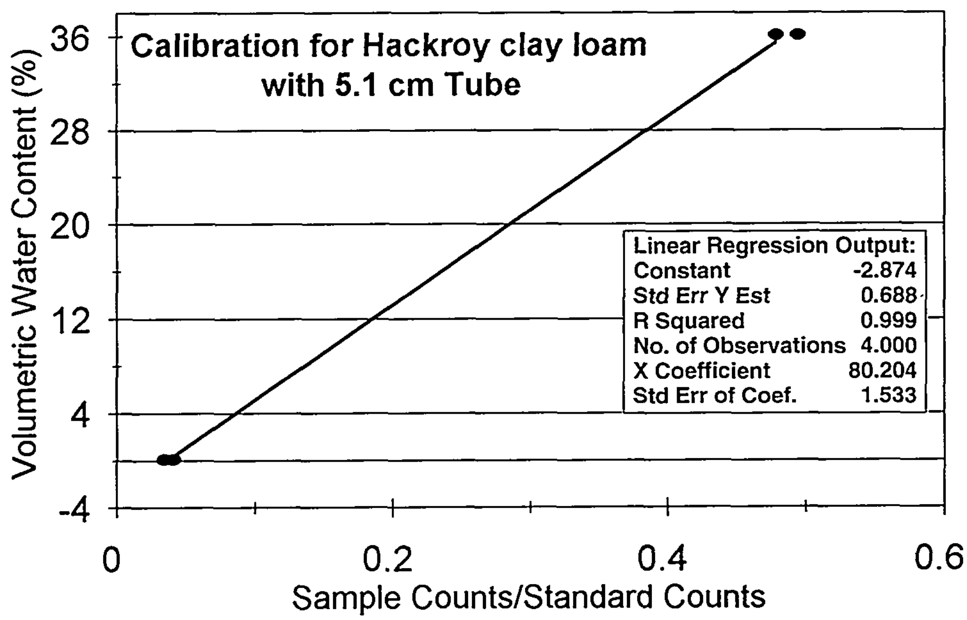
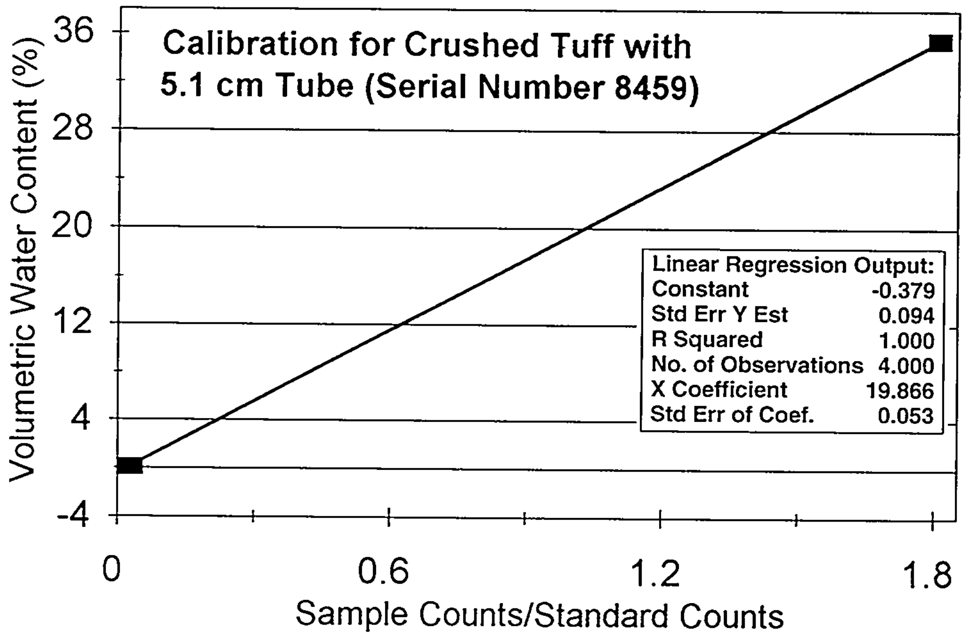


Fig. 38. Statistical analysis results for fine sand and Hackroy clay loam samples for neutron moisture gauge with serial number 5254.



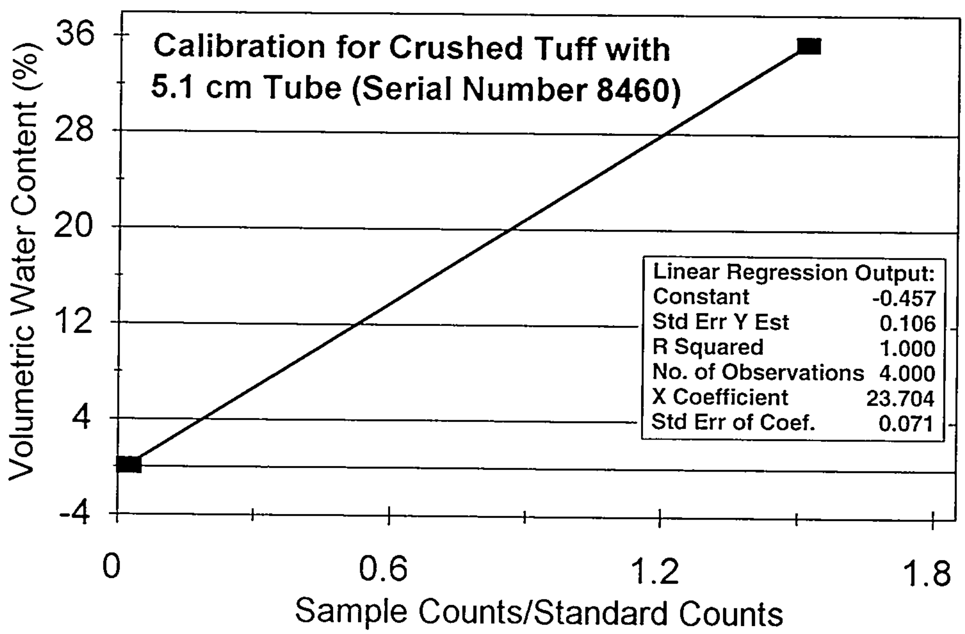
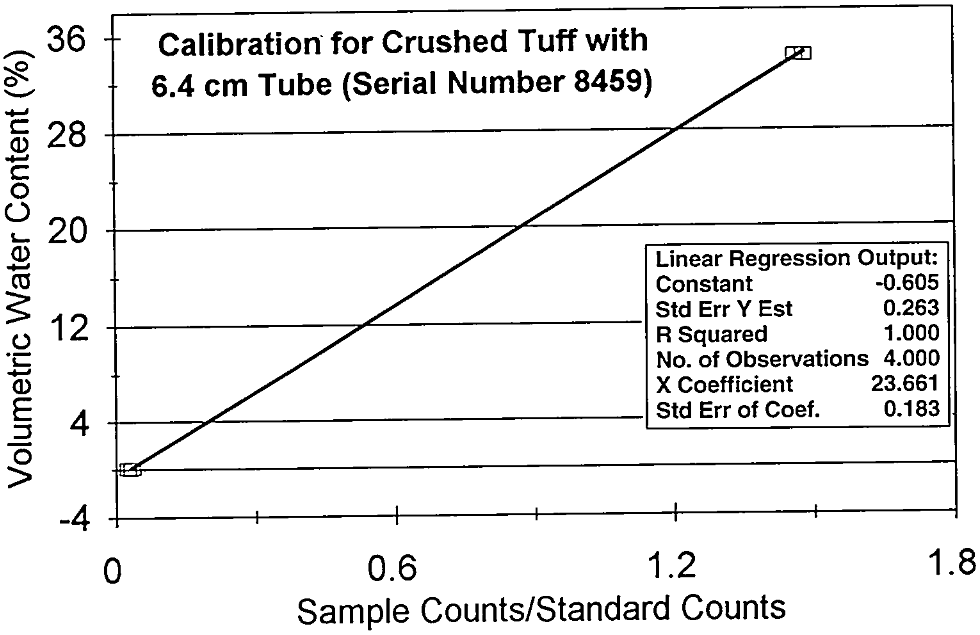


Fig. 39. Statistical analysis results for Layton loamy fine sand samples for neutron moisture gauges with serial numbers 8459 and 8460.



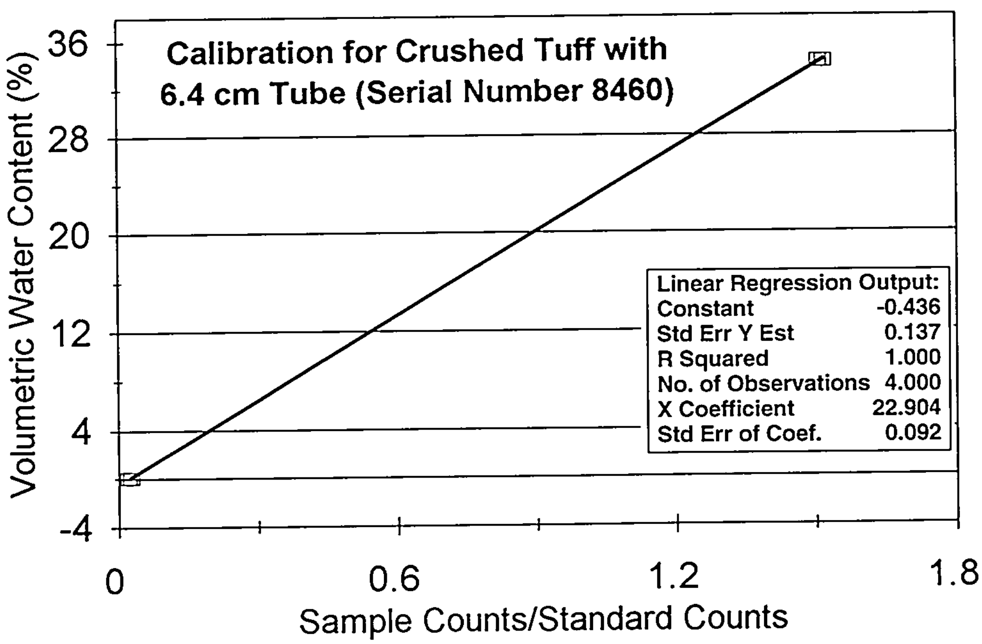
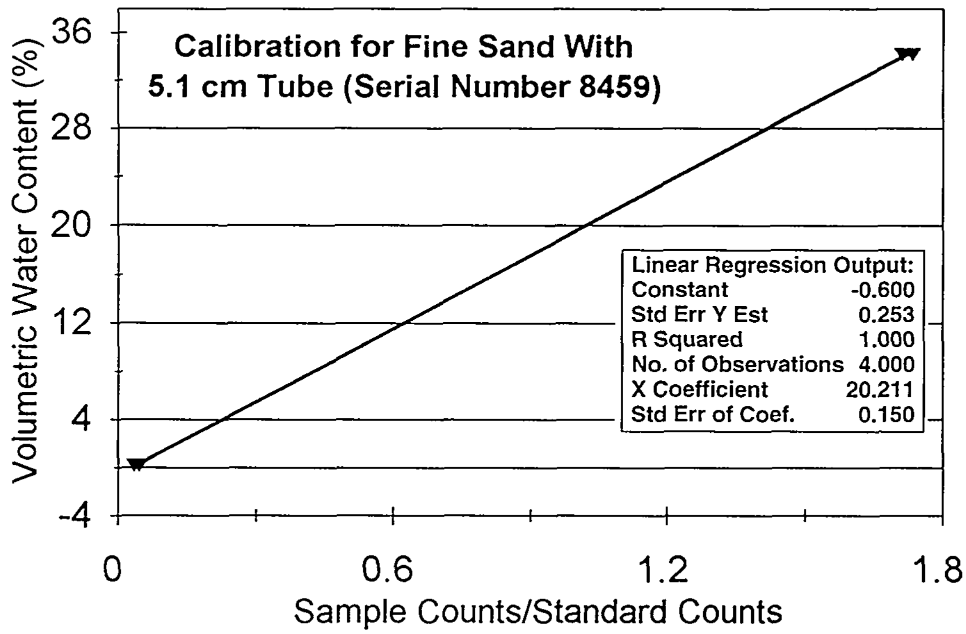


Fig. 40. Statistical analysis results for crushed tuff samples for neutron moisture gauges with serial numbers 8459 and 8460.



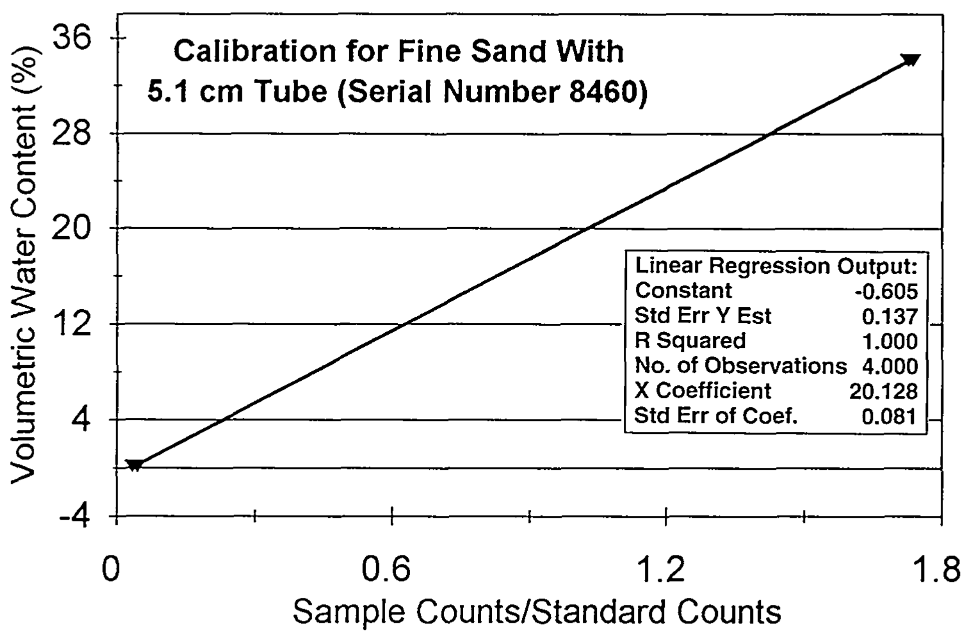
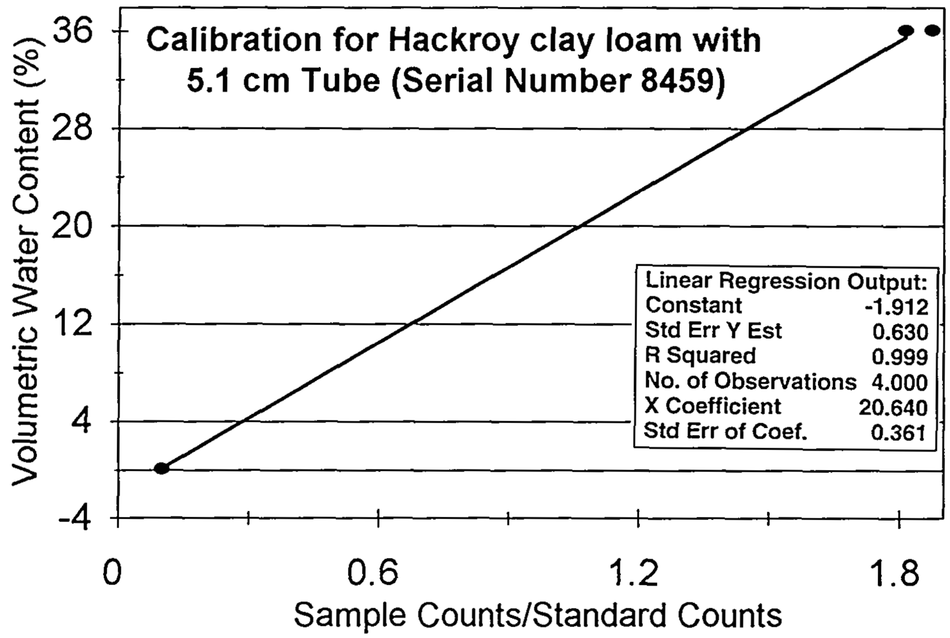


Fig. 41. Statistical analysis results for fine sand samples for neutron moisture gauges with serial numbers 8459 and 8460.



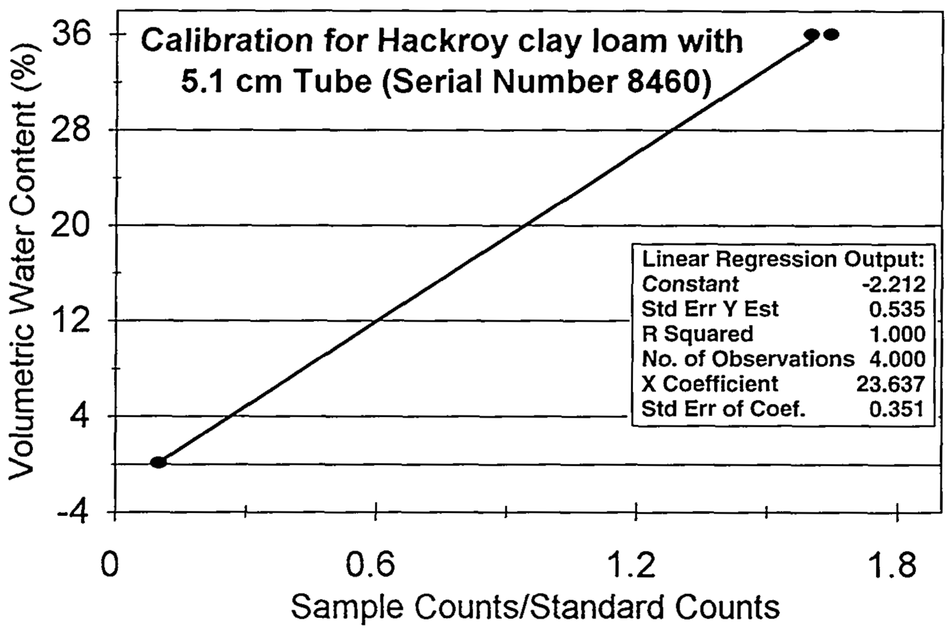
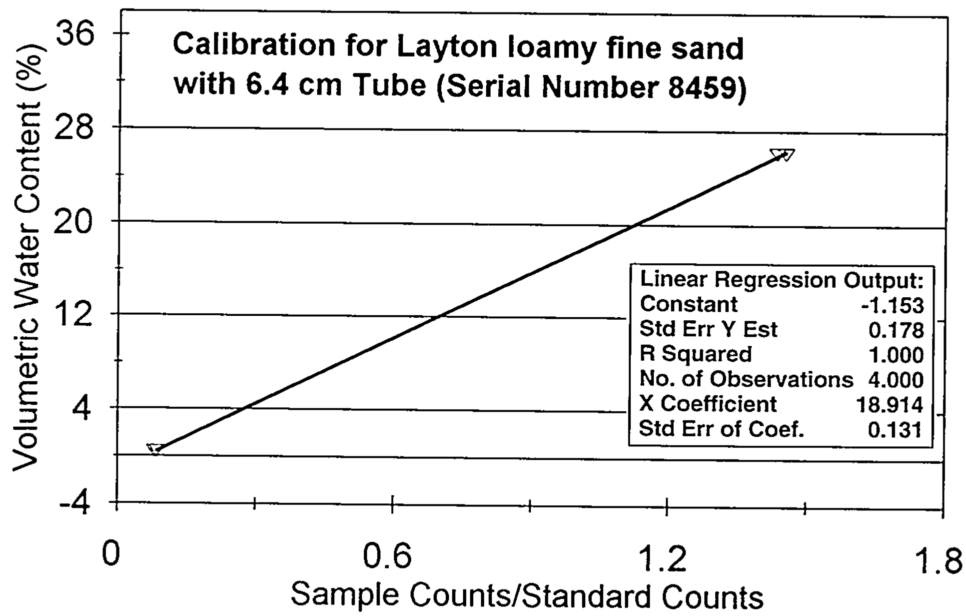


Fig. 42. Summary of regression predictions for all soil samples for neutron moisture gauge with serial number 5254.



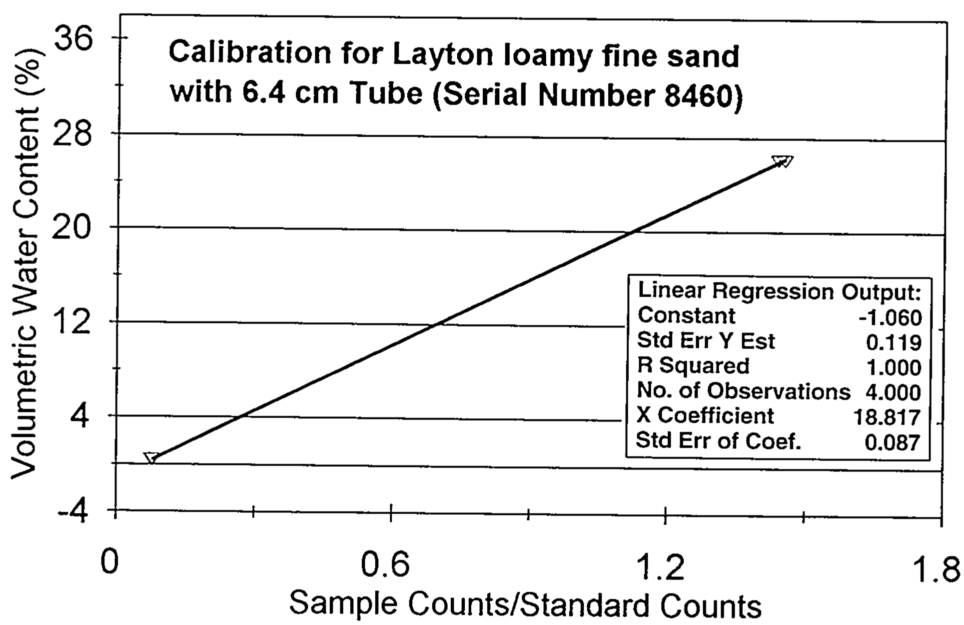
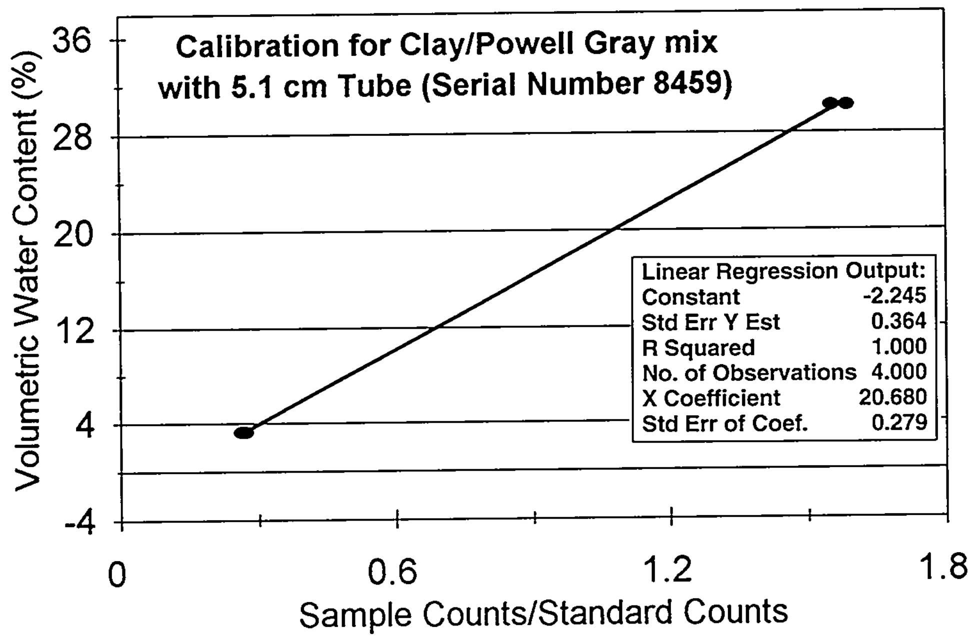


Fig. 43. Statistical analysis results for Layton loamy fine sand samples for neutron moisture gauges with serial numbers 8459 and 8460.



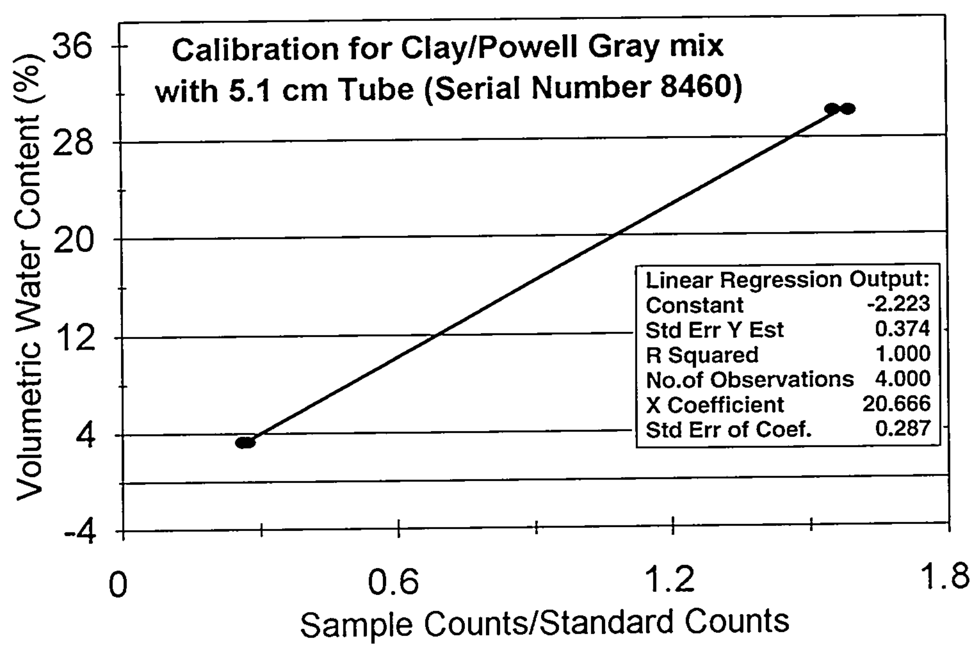
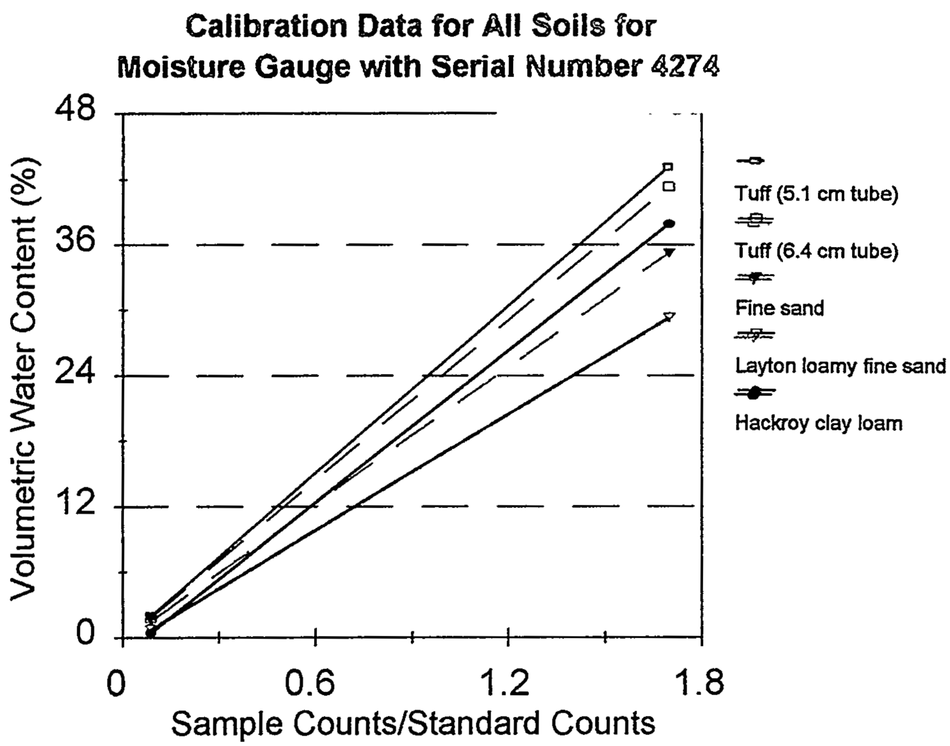


Fig. 44. Statistical analysis results for Bentonite/Powell Gray mixture samples for neutron moisture gauges with serial numbers 8459 and 8460.



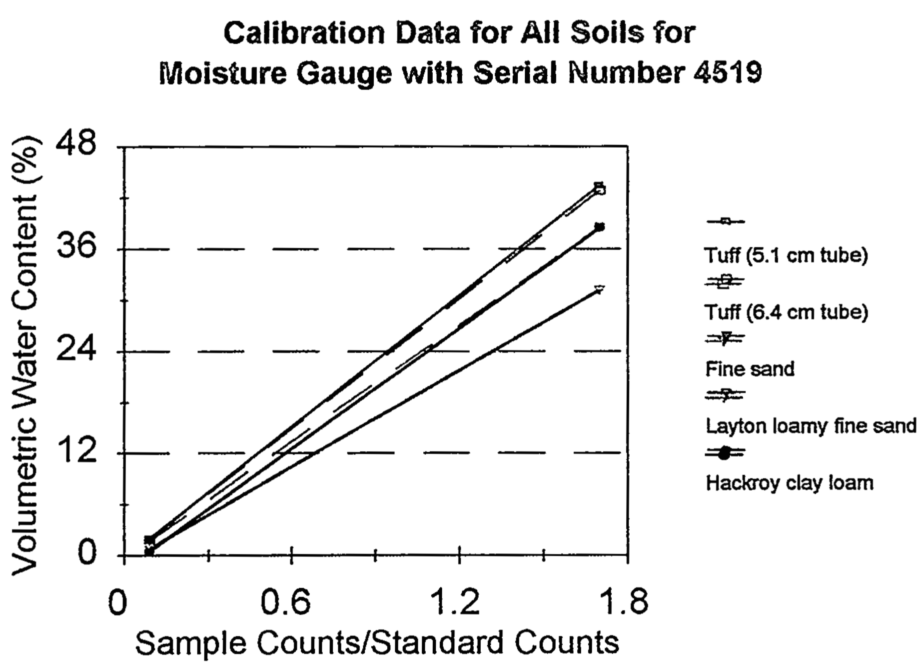
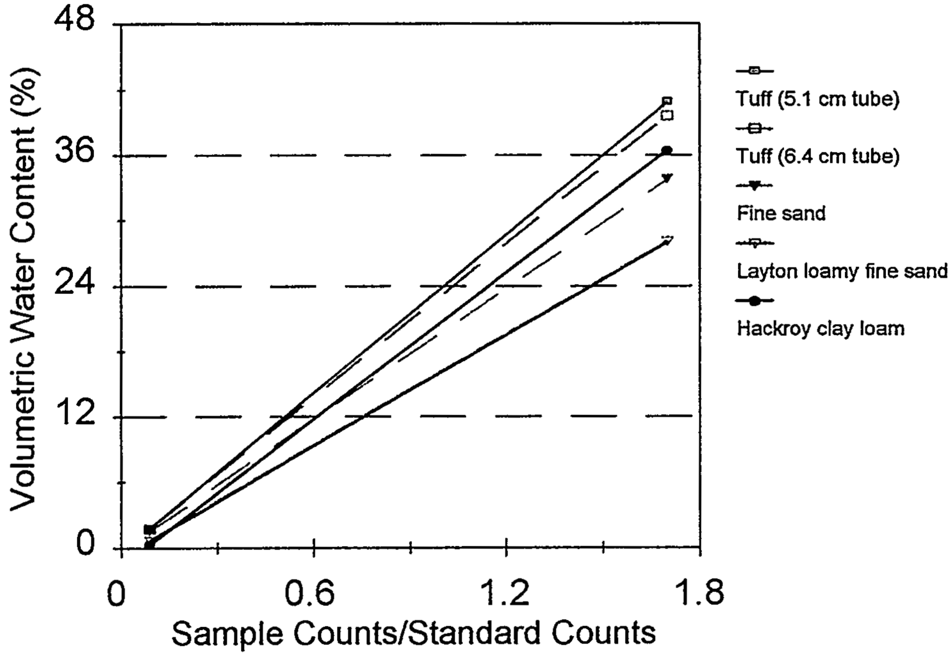


Fig. 45. Summary of regression predictions for all soil samples for neutron moisture gauges with serial numbers 4274 and 4519.

Calibration Data For All Soils For Moisture Gauge With Serial Number 5079



Calibration Data for All Soils for Moisture Gauge with Serial Number 7832

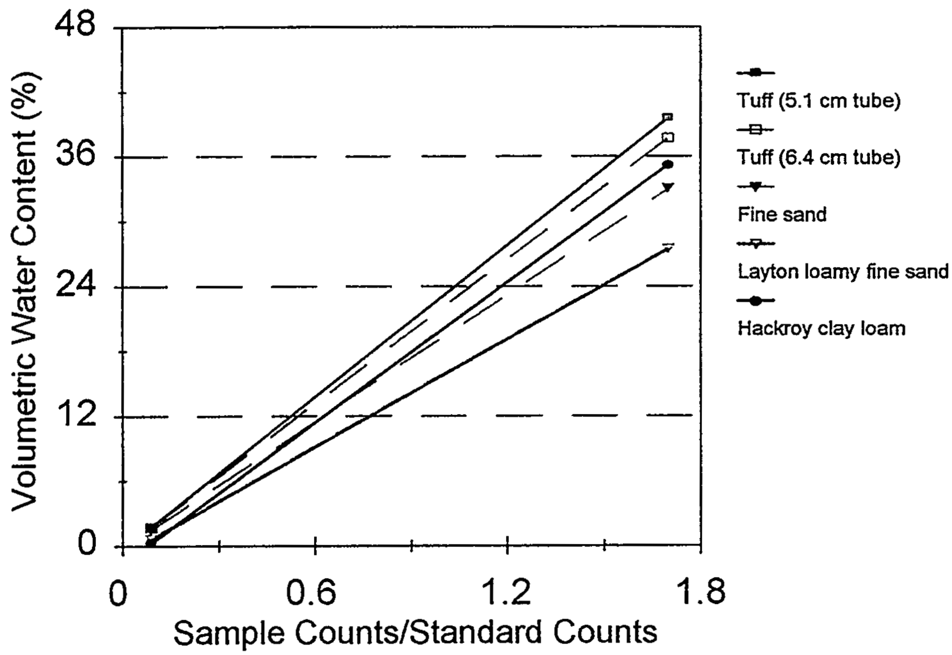


Fig. 46. Summary of regression predictions for all soil samples for neutron moisture gauges with serial numbers 5079 and 7832.

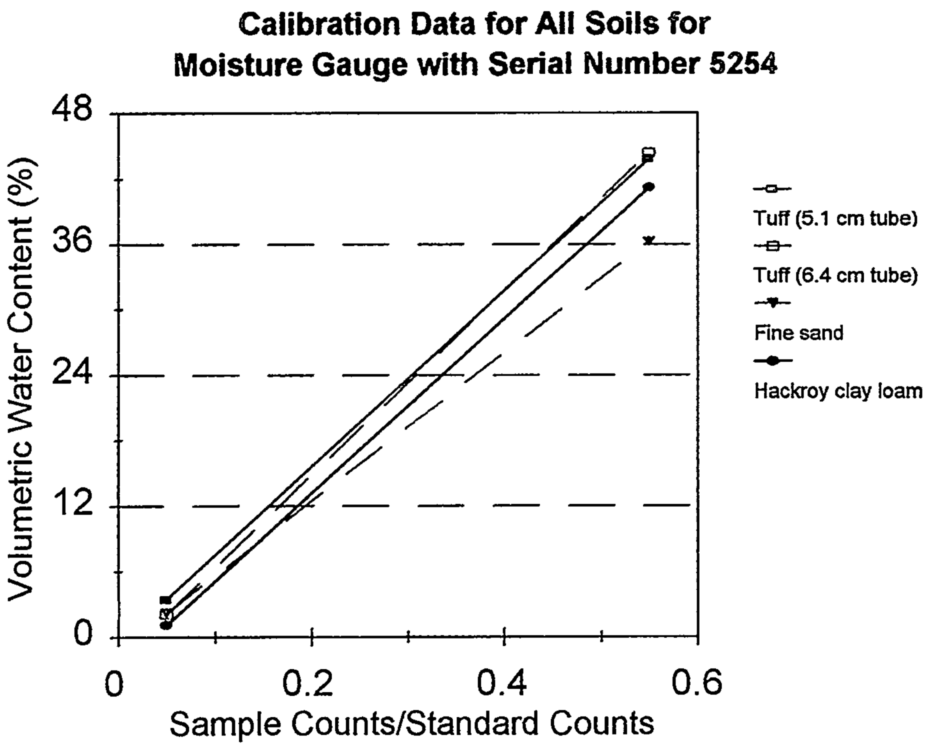
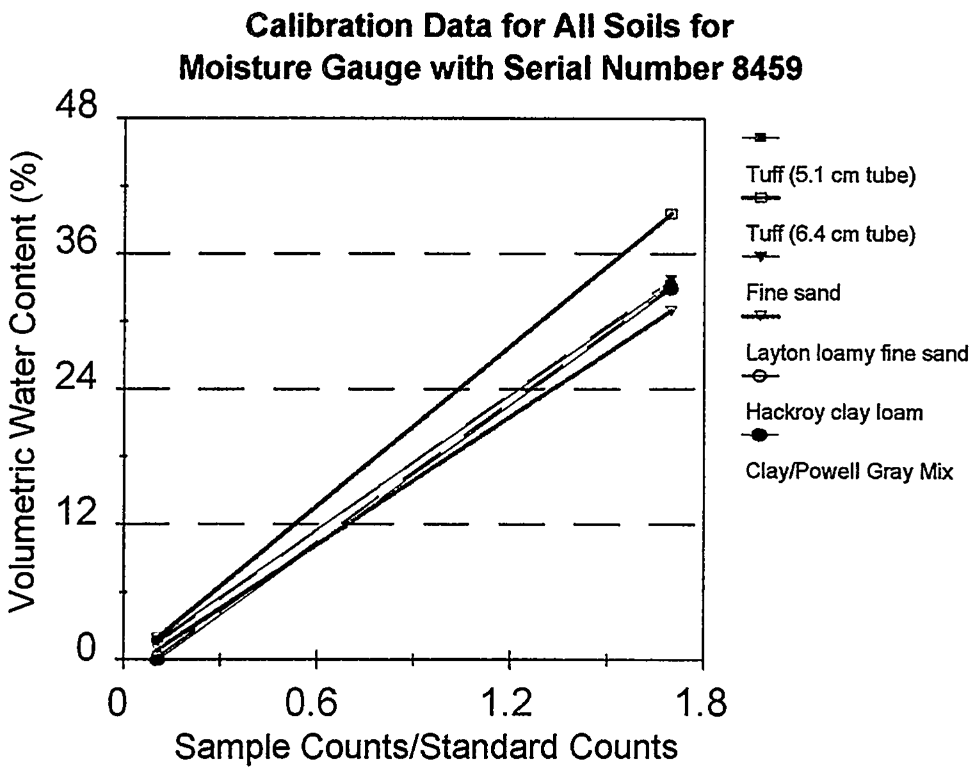


Fig. 47. Summary of regression predictions for all soil samples for neutron moisture gauge with serial number 5254.



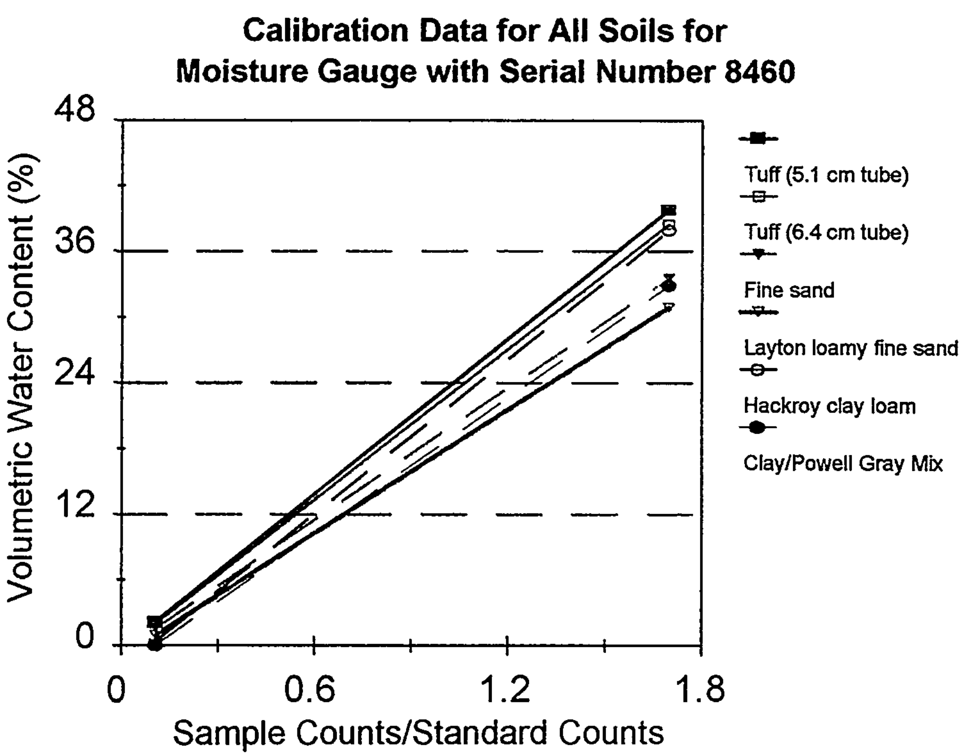


Fig. 48. Summary of regression predictions for all soil samples for neutron moisture gauges with serial numbers 8459 and 8460.

Table 4. Summary of regression results for 1994 neutron probe calibrations on all study soils and moisture gauges (% volumetric water content units)

Soil sample	Access Tube Diam. (cm)	Drum depths (cm) Dry Drum	Wet Drum	Slope[1] A	Y-intercept[1] B
Moisture Gauge Serial Number 4274					
Standard Factory Sand	5.1			21.950	-0.410
Crushed tuff	5.1	20-33,35-48	18-41,43-66	25.562	-0.279
Hackroy clay loam	5.1	33-46,48-61	20-43,46-69	23.296	-1.649
Crushed tuff	6.4	20-33,35-48	18-41,43-66	24.549	-0.324
Fine sand	5.1	20-33,35-48	18-41,43-66	20.938	-0.308
Layton loamy fine sand	6.4	33-46,48-61	33-46,48-61	17.751	-0.812
Moisture Gauge Serial Number 4519					
Standard Factory Sand	5.1			20.070	-0.380
Crushed tuff	5.1	20-33,35-48	18-41,43-66	25.763	-0.316
Hackroy clay loam	5.1	33-46,48-61	20-43,46-69	23.618	-1.617
Crushed tuff	6.4	20-33,35-48	18-41,43-66	25.482	-0.380
Fine sand	5.1	20-33,35-48	18-41,43-66	22.911	-0.285
Layton loamy fine sand	6.4	33-46,48-61	33-46,48-61	18.891	-0.865
Moisture Gauge Serial Number 5079					
Standard Factory Sand	5.1			20.390	-0.470
Crushed tuff	5.1	20-33,35-48	18-41,43-66	24.295	-0.316
Hackroy clay loam	5.1	33-46,48-61	20-43,46-69	22.473	-1.720
Crushed tuff	6.4	20-33,35-48	18-41,43-66	23.530	-0.306
Fine sand	5.1	20-33,35-48	18-41,43-66	20.031	-0.216
Layton loamy fine sand	6.4	33-46,48-61	33-46,48-61	17.027	-0.851
Moisture Gauge Serial Number 7832					
Standard Factory Sand	5.1			18.280	-0.480
Crushed tuff	5.1	20-33,35-48	18-41,43-66	23.509	-0.320
Hackroy clay loam	5.1	33-46,48-61	20-43,46-69	21.709	-1.659
Crushed tuff	6.4	20-33,35-48	18-41,43-66	22.357	-0.253
Fine sand	5.1	20-33,35-48	18-41,43-66	19.567	-0.209
Layton loamy fine sand	6.4	33-46,48-61	33-46,48-61	16.697	-0.869
Moisture Gauge Serial Number 5254					
Standard Factory Sand	5.1			55.940	-1.590
Crushed tuff	5.1	23-38,41-56	23-38,41-56	80.721	-0.509
Hackroy clay loam	5.1	23-38,41-56	23-38,41-56	80.204	-2.874
Crushed tuff	6.4	23-38,41-56	23-38,41-56	84.627	-2.075
Fine sand	5.1	23-38,41-56	23-38,41-56	68.152	-1.166

Table 4. Summary of regression results for 1994 neutron probe calibrations on all study soils and moisture gauges (% volumetric water content units) (Cont.)

Soil sample	Access Tube Diam (cm)	Drum depths (cm) Dry Drum	Wet Drum	Slope[1] A	Y-intercept[1] B
Moisture Gauge Serial Number 8459					
Standard Factory Sand	5.1			17.350	-0.880
Crushed tuff	5.1	33-46,48-61	33-46,48-61	19.866	-0.379
Hackroy clay loam	5.1	33-46,48-61	33-46,48-61	20.640	-1.912
Crushed tuff	6.4	33-46,48-61	33-46,48-61	23.661	-0.605
Fine sand	5.1	33-46,48-61	33-46,48-61	20.211	-0.600
Layton loamy fine sand	6.4	33-46,48-61	33-46,48-61	18.914	-1.153
Bentonite/Powell Gray mixture	6.4	38-46,48-56	38-46,48-56	20.680	-2.245
Moisture Gauge Serial Number 8460					
Standard Factory Sand	5.1			17.120	-0.880
Crushed tuff	5.1	33-46,48-61	33-46,48-61	23.704	-0.457
Hackroy clay loam	5.1	33-46,48-61	33-46,48-61	23.637	-2.212
Crushed tuff	6.4	33-46,48-61	33-46,48-61	22.904	-0.436
Fine sand	5.1	33-46,48-61	33-46,48-61	20.128	-0.605
Layton loamy fine sand	6.4	33-46,48-61	33-46,48-61	18.817	-1.060
Bentonite/Powell Gray mixture	6.4	38-46,48-56	38-46,48-56	20.666	-2.223

[1]Regression parameters determined for calibration drums at known volumetric water contents: for crushed tuff with 5.1-cm-diam access tube (dry drum: 33-46 cm depth [0.15%] and 48-61 cm depth [0.13%], wet drum: [35.55%]); for Hackroy clay loam (dry drum: 33-46 cm depth [0.14%] and 48-61 cm depth [0.15%], wet drum: [36.14%]; for crushed tuff with 6.4-cm-diam access tube (dry drum: 33-46 cm depth [0.11%] and 48-61 cm depth [0.10%], wet drum: [34.2%]; for fine sand (dry drum: 33-46 cm depth [0.19%] and 48-61 depth [0.20%], wet drum: [34.2%]; for Layton loamy fine sand (dry drum: 33-46 cm depth [0.42%] and 48-61 cm depth [0.42%], wet drum: [26.15%]); and for the Bentonite/Powell Gray mixture (dry drum: 38-46 cm depth [3.28%] and 48-56 cm depth [3.28%], wet drum: [30.23%]).

IV. SUMMARY AND IMPLICATIONS

One of the most important implications of this report is that it stresses formality of operations for the environmental research currently being performed by members of the Laboratory's Environmental Science Group for a number of different sponsors. It is a documentation of how we are performing the measurement of volumetric water content under field conditions using neutron moisture gauges.

The field measurements of the Rj of each neutron probe near the soil surface will contribute greatly to the small amount of field data gathered to date. Since, obviously, neutron moisture probe readings taken near the soil surface underestimate soil water content, we now have quantitative data to evaluate this effect. This information will be used to estimate *in situ* water balance parameters such as evapotranspiration rates from earth covers used in shallow land burial of wastes at Los Alamos. The other major significance of this study involves the new information relating to the neutron probe calibration data collected for a local Los Alamos soil type, instead of having only a calibration curve for crushed tuff, as has been the case to date at the Laboratory.

After the midpoint of sensitivity of each of three currently used neutron moisture gauges to the detection of hydrogen was determined, the behavior of the neutron probes near an soil-air interface was determined. The Rj was determined in the field for each gauge as a function of varying soil water content, and this spatial response of the gauges to varying volumes of soil water was successfully modeled using a neutron transport model. After validating the model, the spatial resolution of soil water was investigated for one of the moisture gauges. These modeling results indicated that both the shape and the volume of soil interrogated by the neutron moisture gauge vary as a function of soil water content. The MCNP neutron transport model used in this study can be used as a very powerful tool in exploring the behavior of the neutron moisture gauge in the soil environment. Future plans for MCNP model investigations should involve investigating the basic design of the neutron moisture gauge, studying the behavior of the gauges near wet-dry soil interfaces, and determining the influence of thermalized neutron absorbers on moisture gauge performance.

There are two other very important practical benefits that can be derived from this calibration study. Electrical service to locations where neutron moisture gauges are stored is discontinued routinely during a typical year. When this happens, it is common to discharge the battery power to the data logger portion of the neutron moisture gauge, resulting in a loss of all the stored calibration data (Table 4) in the data logger. A copy of the correct calibration data for each neutron moisture gauge is now kept with each neutron probe in case this information needs to be re-entered in the data logger. This practice minimizes the chance of the following types of errors being made (all of which have been observed by the senior author):

(1) the technician can enter the calibration data incorrectly into the correct neutron moisture gauge

(2) the technician can enter the calibration data correctly into the wrong neutron moisture gauge

(3) the neutron moisture gauge manufacturer provided the technician with the correct factory standard sand calibration factors, but used incorrect units

The second major benefit derived from the documentation of the neutron moisture gauge calibration is related to what happens if the entire neutron moisture gauge has to undergo repair. Each neutron moisture gauge has its own specific factory-determined calibration curve in a standard sand (Table 4, Fig. 49). If, for example, the electronics circuit board within the probe (Fig. 9) needs to be repaired, there is a good chance that the gain of the detector (Fig. 9) will be changed by the manufacturer, resulting in a new factory standard sand calibration curve. If this happens, the neutron moisture gauge must be recalibrated for all of the soils, resulting in months of unnecessary work and loss of time and money. If the customer is aware of the importance of the factory standard sand calibration results, the customer can simply request that the neutron moisture gauge be returned from any repair work performed on the probe with the same calibration results reported previously (Table 4, Fig. 49).

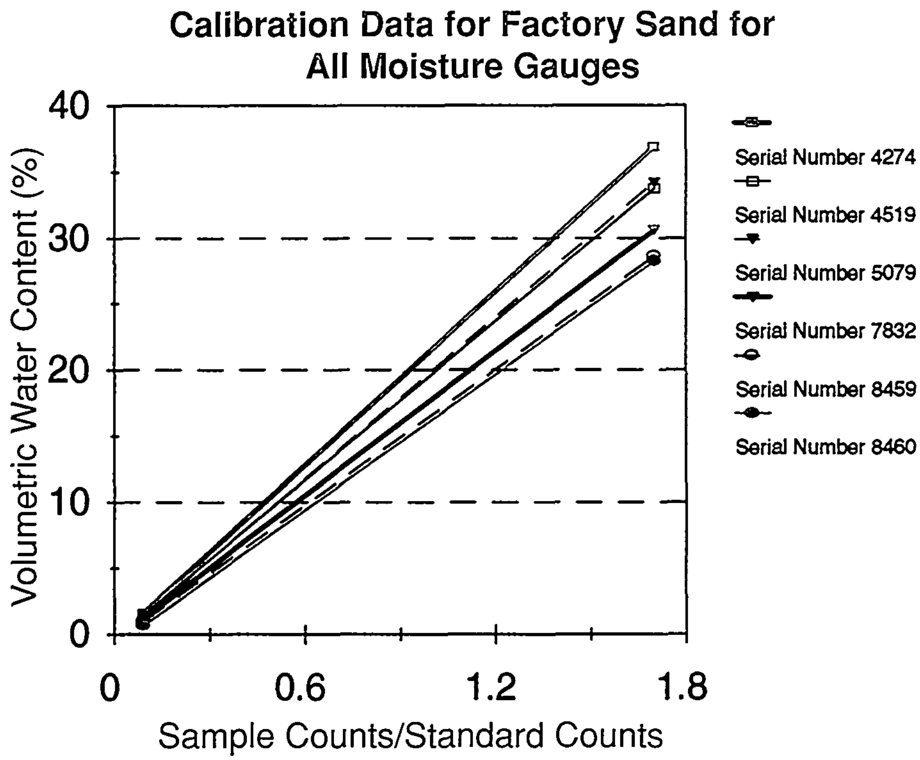


Fig. 49. Summary of regression predictions for the standard factory sand samples for all neutron moisture gauges.

Finally, three practical implications of this neutron moisture gauge calibration study should be taken into account by the user:

(1) The measurement of soil water content with depth in a soil profile should take into account the following:

(a) a precise measurement of the distance between the soil surface and the midpoint of sensitivity of the neutron moisture gauge (Fig. 12) and not the distance between the soil surface and the bottom of the probe

(b) the type of soil at each depth in the soil profile, because calibration curves vary with soil type (Figs. 25-44)

(c) the diameter of the aluminum access tube (Figs. 25-44)

(2) Because we do not have a calibration curve for each of the 61 soils listed in the local soil survey (Nyhan et al., 1978), we suggest

(a) using the crushed tuff calibration curves (Table 4) for samples of local soils within the following textural classes: sands, loamy sands, sandy loams, sandy clay loams, loams, silt loams, and silts,

(b) using the Hackroy clay loam calibration curves (Table 4) for samples of local soils within the following textural classes: clay loams, silty clay loams, silty clays, sandy clays, and clays,

(c) using the crushed-tuff calibration curves for *in-situ* tuff, but only for the upper geologic unit of Bandelier Tuff on the local mesas (Unit 3, usually found within the top 5 m of the geologic profile). Some of the other geologic local materials (deeper units of Bandelier Tuff, El Cajete Pumice, Tsankawi Pumice, Cerro Rubio Quartz Latites, Basaltic Rocks of Chino Mesa, and Tschicoma Formation deposits) discussed in the soil survey manual should have significantly different calibration curves than our sample of the upper tuff unit.

(3) When it is time to either calibrate a new neutron moisture gauge or recalibrate the gauges used in this study, for consistency, use the data presented in Table 4 and the techniques described in this report. A calibration curve for a particular neutron moisture gauge should remain valid for several years and should vary with time within narrow limits of experimental error (CSIRO, 1981), independant of the effect of the decay of americium in the gauge's source; we recommend a recalibration effort every two years since little long-term documentation exists in this area of science. Our most pertinent experience has shown that it was important to follow the manufacturer's procedures for checking for drift in count rate caused by electronic instability: two of our group of neutron moisture gauges exhibited severe drops in standard count rates after about 10 years of service due to electronic hardware failures.

REFERENCES

Christenson, C. W. and R. G. Thomas. "Movement of plutonium through Los Alamos," in "Ground Disposal of Radioactive Wastes," J. M. Morgan, Jr., D. K. Jamison, and J. D. Stevenson Eds., report TID-7628, NTIS, (1962) pp. 248-281.

Commonwealth Scientific and Industrial Research Organization, "Soil water assessment by the neutron method," E.L. Greacen, Ed., ISBN 0 643 00414 9, East Melbourne, Victoria, Australia (1981).

International Atomic Energy Agency, "Neutron moisture gauges: a guidebook on theory and practice," I.A.E.A. techincal report series No. 112, Vienna, Australia (1970).

Long, I. F. and B. K. French, "Measurement of Soil Moisture in the Field by Neutron Moderation," *Jour. Soil Sci.* **18**: 147-158 (1967).

Lorch, E. A. "Neutron Spectra of ^{241}Am/B, ^{241}Am/Be, ^{241}Am/F, ^{242}Cm/Be, ^{238}Pu/^{13}C and ^{252}Cf Isotopic Neutron Sources," *International J. Applied Radiation and Isotopes* **24**: 484-591 (1973).

Los Alamos Radiation Transport Group, "MCNP a General Monte Carlo Code for Neutron and Photon transport," Los Alamos National Laboratory report LA-7396-M (1981).

Nyhan, J.W., L. W. Hacker, T. E. Calhoun, and D. L. Young, "Soil Survey of Los Alamos County, New Mexico," Los Alamos Scientific Laboratory report LA-6779-MS (1978).

Olgaard, P. L. "On the theory of the neutronic method for measuring the water content in soil," Danish Atomic Energy Commission, Riso, Report No. 97 383-397 (1965).

SAS Institute, Inc. *SAS Language: Reference, Version 6, First Edition.* Cary, NC (1990).

Troxler Electronic Laboratories, Inc., *Instruction Manual for Depth Moisture Gauge*, Research Triangle Park, NC (1980).

Appendix A. 1994 NEUTRON MOISTURE GAUGE CALIBRATION DATA

Table A-1. Calibration Data for Neutron Probe With Serial Number 4274 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	**Mean**	**Std Dev**	**CV**
2.5	131.7	32.0	24.32
5.1	135.7	11.1	8.15
7.6	158.0	8.0	5.06
10.2	163.7	11.8	7.24
12.7	157.0	7.5	4.81
15.2	171.0	20.1	11.74
17.8	180.3	2.9	1.60
20.3	189.0	10.8	5.72
22.9	191.7	25.8	13.47
25.4	189.0	7.9	4.20
27.9	194.7	6.7	3.42
30.5	199.3	16.9	8.46
33.0	220.0	28.1	12.75
35.6	201.3	8.5	4.22
38.1	209.7	8.7	4.17
40.6	219.7	8.4	3.82
43.2	210.3	6.5	3.09
45.7	218.3	23.2	10.62
48.3	214.7	13.3	6.19
50.8	223.0	16.5	7.38
53.3	236.3	7.2	3.06
55.9	260.7	14.0	5.38
58.4	281.7	7.5	2.66
61.0	292.3	8.6	2.95
63.5	298.3	20.1	6.74
66.0	330.3	18.7	5.67
68.6	365.7	21.4	5.84
71.1	425.7	16.0	3.76
73.7	470.3	22.4	4.76
76.2	501.3	27.7	5.52
Standard Counts	12475		

Crushed Tuff Sample with 5-1 cm diam access tube (saturated sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	8556.3	97.4	1.14
5.1	11653.0	61.5	0.53
7.6	14161.3	20.1	0.14
10.2	15954.3	110.3	0.69
12.7	16863.0	46.0	0.27
15.2	17273.0	101.3	0.59
17.8	17590.0	164.6	0.94
20.3	17533.3	9.0	0.05
22.9	17491.0	109.7	0.63
25.4	17556.3	229.2	1.31
27.9	17419.0	118.4	0.68
30.5	17424.7	81.7	0.47
33.0	17554.0	12.1	0.07
35.6	17339.7	114.1	0.66
38.1	17347.7	199.1	1.15
40.6	17288.7	16.3	0.09
43.2	17309.3	130.1	0.75
45.7	17456.0	141.2	0.81
48.3	17417.0	128.7	0.74
50.8	17416.3	29.0	0.17
53.3	17532.7	183.2	1.04
55.9	17710.0	27.7	0.16
58.4	17697.0	64.1	0.36
61.0	17618.0	62.0	0.35
63.5	17516.7	208.1	1.19
66.0	17448.3	154.9	0.89
68.6	17373.0	79.7	0.46
71.1	166.12.7	107.7	0.65
73.7	15513.0	262.0	1.69
76.2	14101.0	140.3	0.99
Standard Counts	12473		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	247.3	15.9	6.45
5.1	247.3	27.5	10.84
7.6	253.7	10.4	4.21
10.2	226.3	9.8	4.34
12.7	223.7	15.0	6.73
15.2	211.7	8.5	4.02
17.8	214.3	10.1	4.70
20.3	203.0	15.0	7.39
22.9	218.0	10.4	4.79
25.4	231.7	15.3	6.61
27.9	225.3	5.1	2.28
30.5	219.0	27.9	12.73
33.0	226.7	15.9	7.04
35.6	236.0	13.5	5.73
38.1	210.7	5.5	2.61
40.6	213.3	9.3	4.36
43.2	215.7	16.2	7.51
45.7	212.0	17.1	8.05
48.3	228.3	15.5	6.79
50.8	235.7	19.3	8.19
53.3	254.7	25.7	10.11
55.9	252.0	6.0	2.38
58.4	243.3	7.2	2.97
61.0	277.3	4.9	1.78
63.5	316.3	5.7	1.80
66.0	317.7	12.7	3.99
68.6	350.3	24.9	7.12
71.1	408.3	18.6	4.56
73.7	477.7	18.5	3.87
76.2	588.0	13.7	2.34
Standard Counts	12381		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	7207.0	178.5	2.48
5.1	10336.3	110.0	1.06
7.6	13053.7	276.3	2.12
10.2	15068.3	111.3	0.74
12.7	16296.7	139.0	0.85
15.2	17115.3	104.5	0.61
17.8	17459.3	103.8	0.59
20.3	17630.3	51.4	0.29
22.9	17793.0	107.6	0.60
25.4	17816.3	83.7	0.47
27.9	17911.0	61.2	0.34
30.5	17971.3	135.1	0.75
33.0	17743.0	103.7	0.58
35.6	17809.3	186.7	1.05
38.1	17678.0	187.9	1.06
40.6	17580.0	12.1	0.07
43.2	17549.3	320.3	1.83
45.7	17385.0	36.9	0.21
48.3	17525.7	96.7	0.55
50.8	17413.0	178.5	1.02
53.3	17318.7	173.3	1.00
55.9	17243.0	176.7	1.02
58.4	17167.0	68.8	0.40
61.0	17076.7	51.5	0.30
63.5	17028.0	145.0	0.85
66.0	16699.3	71.4	0.43
68.6	16219.3	122.3	0.75
71.1	15319.7	125.5	0.82
73.7	14210.7	159.1	1.12
76.2	12601.7	107.1	0.85
Standard Counts	12439		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	315.3	4.6	1.46
5.1	301.7	24.2	8.02
7.6	287.3	9.5	3.31
10.2	271.7	16.1	5.92
12.7	256.7	11.1	4.31
15.2	281.3	20.6	7.32
17.8	274.7	15.9	5.78
20.3	276.0	13.0	4.71
22.9	303.7	9.5	3.11
25.4	297.7	12.6	4.23
27.9	303.7	30.7	10.13
30.5	311.7	6.7	2.14
33.0	288.7	30.9	10.70
35.6	308.0	16.5	5.36
38.1	305.3	27.2	8.91
40.6	295.7	6.1	2.07
43.2	296.3	22.3	7.52
45.7	289.0	10.1	3.51
48.3	317.7	8.0	2.52
50.8	333.3	8.1	2.42
53.3	343.3	12.5	3.64
55.9	337.3	9.8	2.91
58.4	340.3	26.4	7.76
61.0	323.3	23.5	7.28
63.5	337.7	23.7	7.02
66.0	404.7	10.0	2.48
68.6	421.3	13.5	3.20
71.1	472.0	7.2	1.53
73.7	485.3	30.1	6.20
76.2	588.3	12.7	2.15
Standard Counts	12431		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth	**Sample Counts**		
(cm)	**Mean**	**Std Dev**	**CV**
2.5	7789.3	87.8	1.13
5.1	10179.3	65.0	0.64
7.6	13541.3	212.0	1.57
10.2	16050.0	276.0	1.72
12.7	18189.3	112.0	0.62
15.2	19337.7	182.6	0.94
17.8	20089.0	175.2	0.87
20.3	20371.7	114.2	0.56
22.9	20395.7	194.5	0.95
25.4	20539.7	159.2	0.78
27.9	20441.7	183.6	0.90
30.5	20462.3	168.4	0.82
33.0	20514.0	196.1	0.96
35.6	20669.0	219.6	1.06
38.1	20547.3	83.4	0.41
40.6	20404.3	125.1	0.61
43.2	20462.7	63.5	0.31
45.7	20362.3	168.7	0.83
48.3	20358.3	90.5	0.44
50.8	20130.0	190.1	0.94
53.3	20297.7	322.8	1.59
55.9	20037.7	3.5	0.02
58.4	20010.0	132.6	0.66
61.0	20108.0	144.8	0.72
63.5	20037.7	166.8	0.83
66.0	19734.3	67.6	0.34
68.6	19185.7	169.9	0.89
71.1	18452.0	138.5	0.75
73.7	16972.0	217.1	1.28
76.2	14261.3	49.9	0.35
Standard Counts	12317		

Layton loamy fine sand sample with 6.4 cm diam access tube (dry sample).

Depth	**Sample Counts**		
(cm)	**Mean**	**Std Dev**	**CV**
2.5	209.7	10.1	4.80
5.1	229.7	22.3	9.70
7.6	308.3	28.6	9.27
10.2	400.7	9.6	2.40
12.7	460.7	30.0	6.51
15.2	526.0	21.6	4.11
17.8	552.0	3.6	0.65
20.3	622.7	29.1	4.68
22.9	702.3	14.0	2.00
25.4	754.3	47.6	6.32
27.9	753.0	24.8	3.29
30.5	781.0	34.5	4.42
33.0	815.0	32.1	3.94
35.6	847.0	19.7	2.32
38.1	833.7	45.3	5.44
40.6	866.7	20.8	2.40
43.2	846.7	30.1	3.55
45.7	833.0	24.2	2.91
48.3	869.3	33.6	3.86
50.8	858.7	15.0	1.75
53.3	858.7	33.5	3.90
55.9	900.7	8.7	0.97
58.4	869.3	18.8	2.16
61.0	898.7	39.4	4.39
63.5	888.0	17.4	1.96
66.0	868.3	15.0	1.73
68.6	913.3	27.5	3.01
71.1	959.7	48.1	5.02
73.7	1029.7	17.0	1.65
76.2	1016.3	22.7	2.23
Standard Counts	12363		

Layton loamy fine sand sample with 6.4 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	4099.0	58.9	1.44
5.1	6107.3	81.8	1.34
7.6	8982.3	92.4	1.03
10.2	12038.0	225.0	1.87
12.7	14710.7	178.8	1.22
15.2	16392.3	153.8	0.94
17.8	17385.0	182.2	1.05
20.3	17968.7	121.0	0.67
22.9	18264.3	229.1	1.25
25.4	18493.3	22.5	0.12
27.9	18505.3	156.0	0.84
30.5	18519.7	148.1	0.80
33.0	18444.3	162.7	0.88
35.6	18561.0	133.2	0.72
38.1	18611.0	64.9	0.35
40.6	18603.3	174.3	0.94
43.2	18374.0	96.8	0.53
45.7	18459.3	201.5	1.09
48.3	18591.7	137.5	0.74
50.8	18696.0	90.8	0.49
53.3	18710.3	106.0	0.57
55.9	18548.3	249.4	1.34
58.4	18530.7	150.4	0.81
61.0	18476.0	119.1	0.64
63.5	18445.3	45.3	0.25
66.0	18064.0	232.5	1.29
68.6	17716.3	68.7	0.39
71.1	17330.7	197.3	1.14
73.7	16610.7	104.3	0.63
76.2	15427.0	156.9	1.02
Standard Counts	12213		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	791.0	20.5	2.59
5.1	678.7	25.0	3.68
7.6	642.3	22.3	3.47
10.2	653.3	26.4	4.04
12.7	691.7	9.1	1.31
15.2	689.3	14.2	2.06
17.8	732.7	37.2	5.07
20.3	771.3	44.7	5.80
22.9	822.7	36.7	4.46
25.4	843.3	38.4	4.55
27.9	891.0	7.0	0.79
30.5	913.3	38.0	4.16
33.0	907.3	33.6	3.70
35.6	922.3	35.8	3.89
38.1	933.0	43.2	4.63
40.6	979.3	32.8	3.35
43.2	974.0	6.2	0.64
45.7	963.7	23.8	2.47
48.3	982.0	4.4	0.44
50.8	948.0	15.7	1.66
53.3	1003.7	23.7	2.36
55.9	991.7	18.2	1.83
58.4	926.3	13.7	1.47
61.0	952.0	14.7	1.55
63.5	983.7	35.2	3.57
66.0	949.7	29.4	3.10
68.6	960.0	30.3	3.16
71.1	992.7	41.9	4.22
73.7	1028.7	15.0	1.46
76.2	1020.3	39.6	3.88
Standard Counts	12342		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	8443.0	202.2	2.40
5.1	11349.7	53.3	0.47
7.6	14034.3	250.3	1.78
10.2	16190.3	130.5	0.81
12.7	17361.7	215.0	1.24
15.2	18092.3	44.0	0.24
17.8	18752.7	80.3	0.43
20.3	18972.3	76.4	0.40
22.9	19388.0	42.8	0.22
25.4	19433.7	46.8	0.24
27.9	19460.3	87.8	0.45
30.5	19804.3	136.8	0.69
33.0	19809.3	122.5	0.62
35.6	19877.3	38.7	0.19
38.1	19794.7	143.6	0.73
40.6	19802.7	114.0	0.58
43.2	20060.3	87.2	0.43
45.7	20055.7	45.9	0.23
48.3	20172.0	42.6	0.21
50.8	20144.7	61.1	0.30
53.3	20101.3	56.2	0.28
55.9	20224.3	69.6	0.34
58.4	20482.0	79.8	0.39
61.0	20446.7	50.2	0.25
63.5	20507.7	152.7	0.74
66.0	20575.0	106.4	0.52
68.6	20644.0	22.7	0.11
71.1	20171.7	125.5	0.62
73.7	19773.0	159.0	0.80
76.2	18603.0	69.2	0.37
Standard Counts	12326		

Table A-2. Calibration Data for Neutron Probe With Serial Number 4519 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	126.7	10.6	8.37
5.1	139.7	11.1	7.92
7.6	160.7	9.1	5.65
10.2	172.3	19.1	11.11
12.7	180.7	8.5	4.71
15.2	190.7	5.0	2.64
17.8	203.3	23.4	11.53
20.3	195.0	13.7	7.05
22.9	197.3	15.0	7.61
25.4	222.3	6.7	2.99
27.9	222.0	30.3	13.67
30.5	223.7	24.8	11.11
33.0	217.0	16.7	7.70
35.6	212.7	5.9	2.76
38.1	234.0	16.1	6.88
40.6	233.7	4.0	1.73
43.2	245.3	27.4	11.17
45.7	254.7	0.6	0.23
48.3	244.3	11.1	4.53
50.8	256.0	15.7	6.14
53.3	266.3	14.6	5.47
55.9	255.7	1.2	0.45
58.4	287.7	12.9	4.47
61.0	306.0	6.1	1.99
63.5	315.7	16.0	5.07
66.0	338.3	6.0	1.78
68.6	389.7	15.0	3.86
71.1	441.3	24.2	5.49
73.7	461.3	47.0	10.19
76.2	537.7	17.2	3.20
Standard Counts	12724		

Crushed Tuff sample with 5.1 cm diam access tube (saturated sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	6012.3	111.6	1.86
5.1	8692.3	34.6	0.40
7.6	11548.7	20.2	0.17
10.2	13591.0	148.0	1.09
12.7	14843.3	160.0	1.08
15.2	15475.3	165.1	1.07
17.8	15824.7	129.9	0.82
20.3	15920.3	124.1	0.78
22.9	15834.0	127.5	0.81
25.4	15855.7	159.3	1.00
27.9	15787.0	128.2	0.81
30.5	15762.7	132.9	0.84
33.0	15812.7	20.5	0.13
35.6	15840.0	24.3	0.15
38.1	15613.7	107.0	0.69
40.6	15710.7	93.6	0.60
43.2	15721.0	72.1	0.46
45.7	15686.0	131.9	0.84
48.3	15808.0	133.6	0.85
50.8	15829.0	117.6	0.74
53.3	15857.0	154.5	0.97
55.9	16060.7	187.0	1.16
58.4	15989.0	116.1	0.73
61.0	15973.7	57.2	0.36
63.5	16010.7	55.6	0.35
66.0	15843.3	146.8	0.93
68.6	15613.0	59.4	0.38
71.1	15206.0	58.5	0.38
73.7	14689.3	97.3	0.66
76.2	12820.7	78.6	0.61
Standard Counts	11376		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	312.7	15.3	4.90
5.1	272.0	7.6	2.78
7.6	274.3	37.4	13.64
10.2	258.7	7.4	2.85
12.7	262.0	9.8	3.76
15.2	248.0	31.8	12.82
17.8	231.7	20.7	8.95
20.3	223.3	12.7	5.67
22.9	235.0	10.6	4.50
25.4	234.7	30.1	12.84
27.9	246.3	19.8	8.02
30.5	242.7	17.2	7.11
33.0	230.3	29.5	12.82
35.6	245.7	18.5	7.53
38.1	242.0	11.4	4.69
40.6	253.3	12.3	4.87
43.2	265.7	9.3	3.50
45.7	260.7	24.0	9.22
48.3	270.7	8.4	3.10
50.8	244.0	2.0	0.82
53.3	257.7	28.0	10.86
55.9	271.3	18.8	6.92
58.4	266.0	27.7	10.42
61.0	301.7	17.0	5.65
63.5	322.3	22.8	7.08
66.0	365.0	14.5	3.98
68.6	398.7	15.9	4.00
71.1	453.0	6.6	1.45
73.7	507.3	16.7	3.28
76.2	605.7	14.6	2.41
Standard Counts	12790		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	5999.0	76.7	1.28
5.1	8517.7	89.8	1.05
7.6	11907.0	80.7	0.68
10.2	14315.0	107.7	0.75
12.7	15733.0	72.5	0.46
15.2	16582.0	191.5	1.15
17.8	17185.0	57.9	0.34
20.3	17451.3	212.0	1.21
22.9	17610.7	189.9	1.08
25.4	17758.0	226.6	1.28
27.9	17683.7	215.9	1.22
30.5	17761.0	117.5	0.66
33.0	17567.7	169.4	0.96
35.6	17562.3	72.8	0.41
38.1	17526.7	149.5	0.85
40.6	17425.0	107.1	0.61
43.2	17298.3	138.2	0.80
45.7	17272.7	88.6	0.51
48.3	17349.0	225.0	1.30
50.8	17371.0	80.1	0.46
53.3	17147.3	134.9	0.79
55.9	17142.7	191.3	1.12
58.4	17147.7	93.4	0.54
61.0	17004.0	93.7	0.55
63.5	16941.7	58.5	0.35
66.0	16846.3	138.0	0.82
68.6	16273.0	97.5	0.60
71.1	15658.0	195.6	1.25
73.7	14757.0	43.6	0.30
76.2	12558.0	152.1	1.21
Standard Counts	12789		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	301.3	54.8	18.20
5.1	251.3	22.6	8.99
7.6	268.0	14.8	5.52
10.2	269.0	6.2	2.32
12.7	259.7	23.1	8.90
15.2	266.7	6.7	2.50
17.8	262.0	6.1	2.32
20.3	265.7	38.7	14.56
22.9	237.0	10.1	4.28
25.4	222.7	15.1	6.80
27.9	249.7	5.5	2.21
30.5	250.0	14.1	5.64
33.0	242.3	9.0	3.72
35.6	231.0	14.2	6.14
38.1	253.3	26.1	10.30
40.6	243.0	23.3	9.57
43.2	262.7	0.6	0.22
45.7	248.3	14.0	5.64
48.3	241.7	15.9	6.57
50.8	265.0	28.8	10.87
53.3	265.0	19.7	7.42
55.9	260.7	4.6	1.77
58.4	283.3	27.8	9.81
61.0	329.0	47.0	14.30
63.5	355.7	51.9	14.58
66.0	352.7	33.3	9.44
68.6	379.7	20.6	5.44
71.1	435.0	5.6	1.28
73.7	584.0	155.0	26.54
76.2	552.7	13.8	2.50
Standard Counts	11599		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	5807.7	129.3	2.23
5.1	8164.7	109.3	1.34
7.6	12733.3	273.1	2.14
10.2	15797.7	713.2	4.51
12.7	16495.0	199.8	1.21
15.2	19127.3	46.7	0.24
17.8	19712.3	214.8	1.09
20.3	18546.0	110.7	0.60
22.9	20148.7	112.3	0.56
25.4	20098.0	70.1	0.35
27.9	20058.3	549.5	2.74
30.5	20476.0	133.0	0.65
33.0	18664.0	91.0	0.49
35.6	18678.3	121.5	0.65
38.1	19348.0	998.2	5.16
40.6	18642.0	71.3	0.38
43.2	18379.3	164.9	0.90
45.7	18511.3	79.1	0.43
48.3	20304.3	410.1	2.02
50.8	18604.0	114.5	0.62
53.3	18593.3	127.1	0.68
55.9	18433.3	232.4	1.26
58.4	18289.3	129.3	0.71
61.0	19356.0	1320.8	6.82
63.5	19787.0	78.5	0.40
66.0	19587.7	66.4	0.34
68.6	19168.7	70.9	0.37
71.1	18332.3	139.5	0.76
73.7	16984.0	296.9	1.75
76.2	14205.0	1.0	0.01
Standard Counts	12765		

Layton loamy fine sand sample with 6.4 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	236.3	20.0	8.48
5.1	303.0	4.6	1.51
7.6	374.0	11.3	3.01
10.2	449.0	17.4	3.86
12.7	503.3	35.7	7.10
15.2	548.3	30.1	5.50
17.8	640.3	9.9	1.54
20.3	701.3	8.0	1.14
22.9	707.7	23.5	3.32
25.4	729.7	40.0	5.48
27.9	766.7	24.5	3.20
30.5	796.0	48.1	6.05
33.0	826.7	7.2	0.88
35.6	842.0	17.5	2.08
38.1	875.3	30.3	3.46
40.6	860.0	28.6	3.33
43.2	906.0	50.0	5.52
45.7	843.3	31.7	3.75
48.3	873.7	33.3	3.81
50.8	874.3	17.2	1.97
53.3	844.7	28.0	3.32
55.9	889.7	44.5	5.00
58.4	867.3	14.5	1.67
61.0	896.3	24.4	2.72
63.5	899.7	11.5	1.28
66.0	907.7	41.9	4.61
68.6	943.7	9.3	0.98
71.1	914.3	4.9	0.54
73.7	992.7	2.3	0.23
76.2	1018.7	14.6	1.43
Standard Counts	12735		

Layton loamy fine sand sample with 6.4 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	4135.3	34.3	0.83
5.1	6613.0	89.4	1.35
7.6	9955.0	146.5	1.47
10.2	12890.3	75.1	0.58
12.7	15245.0	53.7	0.35
15.2	16650.7	62.3	0.37
17.8	17505.0	83.7	0.48
20.3	17865.0	8.0	0.04
22.9	18131.3	156.7	0.86
25.4	18236.0	200.3	1.10
27.9	18287.7	128.8	0.70
30.5	18231.0	71.1	0.39
33.0	18283.3	44.9	0.25
35.6	18317.7	63.1	0.34
38.1	18296.0	248.9	1.36
40.6	18215.3	107.1	0.59
43.2	18202.0	112.9	0.62
45.7	18446.0	41.6	0.23
48.3	18299.3	109.4	0.60
50.8	18481.3	32.0	0.17
53.3	18533.0	33.2	0.18
55.9	18481.0	78.5	0.42
58.4	18283.7	73.1	0.40
61.0	18214.3	49.4	0.27
63.5	18172.7	188.6	1.04
66.0	17798.3	134.0	0.75
68.6	17698.0	106.7	0.60
71.1	17225.3	189.0	1.10
73.7	16529.7	171.3	1.04
76.2	15539.0	81.6	0.52
Standard Counts	12823		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	492.7	19.0	3.86
5.1	497.0	3.6	0.73
7.6	500.0	8.7	1.74
10.2	562.3	13.7	2.43
12.7	562.3	15.4	2.73
15.2	633.7	13.9	2.19
17.8	703.3	31.6	4.49
20.3	723.7	9.1	1.25
22.9	721.7	31.0	4.29
25.4	750.0	3.5	0.46
27.9	803.0	28.8	3.59
30.5	831.3	38.7	4.65
33.0	827.7	24.5	2.96
35.6	841.0	51.7	6.15
38.1	836.0	21.7	2.60
40.6	873.0	7.6	0.86
43.2	874.3	14.2	1.62
45.7	880.0	26.5	3.01
48.3	832.0	11.5	1.39
50.8	868.7	33.9	3.91
53.3	901.3	23.0	2.56
55.9	868.0	20.2	2.33
58.4	882.3	9.0	1.02
61.0	907.7	26.5	2.92
63.5	889.7	49.7	5.58
66.0	926.3	95.2	10.28
68.6	893.7	23.2	2.59
71.1	908.0	33.0	3.63
73.7	1220.0	280.7	23.00
76.2	1146.7	120.4	10.50
Standard Counts	11524		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth	**Sample Counts**		
(cm)	**Mean**	**Std Dev**	**CV**
2.5	6626.3	46.5	0.70
5.1	9572.3	108.4	1.13
7.6	12374.0	144.0	1.16
10.2	14505.7	121.3	0.84
12.7	15619.0	292.4	1.87
15.2	16274.7	175.9	1.08
17.8	16759.3	11.7	0.07
20.3	17104.0	33.2	0.19
22.9	17505.3	259.2	1.48
25.4	17735.0	33.5	0.19
27.9	17613.7	73.9	0.42
30.5	18020.3	163.7	0.91
33.0	18010.0	117.2	0.65
35.6	18075.0	70.6	0.39
38.1	18077.0	78.2	0.43
40.6	18280.7	122.9	0.67
43.2	18177.7	297.0	1.63
45.7	18185.7	109.0	0.60
48.3	18132.0	36.1	0.20
50.8	18415.7	46.1	0.25
53.3	18565.7	125.4	0.68
55.9	18512.7	235.2	1.27
58.4	18539.0	21.6	0.12
61.0	18637.7	119.8	0.64
63.5	18686.3	122.4	0.66
66.0	18848.7	131.1	0.70
68.6	18700.0	155.2	0.83
71.1	18595.3	28.7	0.15
73.7	18112.3	185.2	1.02
76.2	17130.0	242.5	1.42
Standard Counts	11383		

Table A-3. Calibration Data for Neutron Probe With Serial Number 5079 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	184.3	2.5	1.37
5.1	201.3	15.4	7.64
7.6	209.3	7.2	3.46
10.2	237.7	12.7	5.34
12.7	243.3	6.7	2.74
15.2	223.7	6.5	2.91
17.8	250.7	20.3	8.10
20.3	266.3	17.2	6.46
22.9	258.3	21.4	8.28
25.4	264.0	6.9	2.62
27.9	276.7	31.0	11.21
30.5	280.3	23.2	8.29
33.0	275.3	10.0	3.64
35.6	282.0	13.2	4.69
38.1	281.3	29.8	10.61
40.6	279.0	7.8	2.80
43.2	273.0	3.6	1.32
45.7	279.3	4.9	1.77
48.3	308.3	21.4	6.93
50.8	314.3	12.3	3.93
53.3	323.3	28.0	8.65
55.9	330.0	10.6	3.21
58.4	336.3	5.8	1.72
61.0	370.7	16.0	4.33
63.5	438.3	18.7	4.27
66.0	432.7	26.5	6.13
68.6	476.0	8.5	1.80
71.1	533.7	13.7	2.56
73.7	609.7	2.1	0.34
76.2	674.0	16.5	2.45
Standard Counts	14749		

Crushed Tuff sample with 5.1 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	10576.7	99.5	0.94
5.1	15225.0	93.3	0.61
7.6	17682.0	77.1	0.44
10.2	19515.7	123.8	0.63
12.7	20947.7	29.1	0.14
15.2	21484.3	87.8	0.41
17.8	21652.7	219.5	1.01
20.3	21791.7	88.7	0.41
22.9	21714.7	138.0	0.64
25.4	21701.7	137.7	0.63
27.9	21651.3	90.4	0.42
30.5	21630.7	86.9	0.40
33.0	21519.3	44.5	0.21
35.6	21651.0	123.0	0.57
38.1	21458.3	160.0	0.75
40.6	21587.0	165.9	0.77
43.2	21394.0	36.4	0.17
45.7	21684.3	94.6	0.44
48.3	21875.7	80.4	0.37
50.8	21949.7	82.7	0.38
53.3	22091.0	259.0	1.17
55.9	21765.7	28.4	0.13
58.4	21954.3	98.3	0.45
61.0	21953.7	167.5	0.76
63.5	21781.7	83.8	0.38
66.0	21647.3	37.8	0.17
68.6	21162.0	41.6	0.20
71.1	20464.7	64.6	0.32
73.7	19208.0	81.5	0.42
76.2	17385.0	243.6	1.40
Standard Counts	14715		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	168.7	9.1	5.38
5.1	173.3	15.1	8.74
7.6	179.0	7.9	4.43
10.2	164.3	9.6	5.85
12.7	197.3	14.0	7.12
15.2	191.0	11.8	6.17
17.8	213.7	10.0	4.69
20.3	223.3	19.1	8.57
22.9	240.3	13.9	5.77
25.4	244.7	21.8	8.90
27.9	232.7	10.0	4.31
30.5	243.0	10.6	4.36
33.0	252.3	8.7	3.46
35.6	261.3	7.5	2.87
38.1	269.3	12.9	4.79
40.6	255.7	19.9	7.77
43.2	283.3	19.4	6.86
45.7	264.0	23.4	8.86
48.3	281.3	12.3	4.39
50.8	315.7	32.0	10.13
53.3	300.3	10.2	3.40
55.9	326.7	7.8	2.38
58.4	338.0	22.5	6.67
61.0	344.7	26.8	7.77
63.5	400.0	26.9	6.71
66.0	453.3	11.0	2.42
68.6	483.7	10.7	2.21
71.1	564.3	25.1	4.46
73.7	652.0	22.1	3.39
76.2	726.7	16.6	2.29
Standard Counts	14412		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	159.0	14.4	9.07
5.1	210.3	15.9	7.58
7.6	218.3	9.9	4.52
10.2	234.0	8.5	3.65
12.7	271.0	15.1	5.57
15.2	263.3	12.4	4.72
17.8	269.7	4.2	1.54
20.3	264.3	14.6	5.51
22.9	279.0	26.9	9.64
25.4	285.0	14.2	4.97
27.9	286.0	11.0	3.85
30.5	304.0	20.7	6.80
33.0	319.3	11.0	3.45
35.6	310.3	29.6	9.53
38.1	305.3	8.5	2.79
40.6	330.3	5.5	1.67
43.2	330.0	22.7	6.86
45.7	335.3	6.7	1.99
48.3	349.3	23.7	6.78
50.8	353.3	19.8	5.59
53.3	369.0	18.7	5.08
55.9	342.3	20.6	6.02
58.4	399.3	15.0	3.77
61.0	407.0	5.3	1.30
63.5	429.3	23.0	5.36
66.0	447.0	6.1	1.36
68.6	492.0	19.7	4.00
71.1	568.3	20.8	3.67
73.7	624.0	7.8	1.25
76.2	707.7	38.1	5.38
Standard Counts	14900		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	8148.7	174.3	2.14
5.1	11504.7	221.1	1.92
7.6	15157.7	31.1	0.21
10.2	18072.3	144.0	0.80
12.7	19817.3	108.0	0.54
15.2	21005.3	193.0	0.92
17.8	21776.3	117.7	0.54
20.3	21824.7	132.2	0.61
22.9	22049.0	98.9	0.45
25.4	22198.0	155.9	0.70
27.9	22249.0	208.5	0.94
30.5	22211.0	125.9	0.57
33.0	22212.0	298.4	1.34
35.6	21980.7	51.5	0.23
38.1	21885.7	328.0	1.50
40.6	21984.3	175.9	0.80
43.2	21775.0	221.8	1.02
45.7	21714.7	192.0	0.88
48.3	21725.0	78.6	0.36
50.8	21714.7	120.0	0.55
53.3	21488.7	24.0	0.11
55.9	21644.7	101.6	0.47
58.4	21476.7	106.2	0.49
61.0	21428.7	128.8	0.60
63.5	21375.0	59.1	0.28
66.0	21057.7	70.1	0.33
68.6	20575.0	322.5	1.57
71.1	19738.0	216.4	1.10
73.7	18454.7	105.6	0.57
76.2	15788.0	22.5	0.14
Standard Counts	14860		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	11359.7	235.9	2.08
5.1	15412.7	70.6	0.46
7.6	19639.3	87.0	0.44
10.2	22213.3	327.4	1.47
12.7	23855.0	268.5	1.13
15.2	24600.0	172.7	0.70
17.8	25287.7	37.7	0.15
20.3	25272.7	231.9	0.92
22.9	25125.0	130.4	0.52
25.4	25453.3	222.7	0.88
27.9	25517.0	118.7	0.47
30.5	25473.0	92.5	0.36
33.0	25504.3	22.9	0.09
35.6	25455.0	133.4	0.52
38.1	25384.0	311.0	1.22
40.6	25265.3	188.5	0.75
43.2	25210.0	182.9	0.73
45.7	24964.7	348.1	1.39
48.3	25163.7	280.5	1.11
50.8	25094.0	74.0	0.29
53.3	24982.7	54.1	0.22
55.9	24795.7	53.7	0.22
58.4	24994.7	64.6	0.26
61.0	24838.7	216.4	0.87
63.5	24610.3	127.2	0.52
66.0	24500.3	153.9	0.63
68.6	23521.0	87.9	0.37
71.1	22244.0	112.3	0.50
73.7	20504.7	204.2	1.00
76.2	17739.3	27.6	0.16
Standard Counts	14636		

Layton loamy fine sand sample with 6.4 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	341.0	17.1	5.01
5.1	359.7	25.5	7.10
7.6	452.0	38.2	8.44
10.2	545.0	21.5	3.95
12.7	690.0	16.1	2.33
15.2	750.0	32.4	4.32
17.8	782.0	30.3	3.87
20.3	846.3	12.6	1.49
22.9	908.7	35.6	3.91
25.4	930.7	6.8	0.73
27.9	986.3	5.5	0.56
30.5	1019.0	11.8	1.16
33.0	1032.0	26.1	2.52
35.6	1042.3	24.6	2.36
38.1	1053.3	60.6	5.75
40.6	1099.7	21.1	1.92
43.2	1092.7	27.8	2.54
45.7	1085.3	22.5	2.07
48.3	1108.3	11.0	0.99
50.8	1139.0	29.7	2.61
53.3	1083.7	39.6	3.65
55.9	1138.3	21.5	1.89
58.4	1114.0	30.4	2.73
61.0	1117.0	15.1	1.35
63.5	1142.7	31.1	2.72
66.0	1120.0	14.5	1.30
68.6	1171.3	29.5	2.52
71.1	1231.3	33.7	2.73
73.7	1233.3	73.7	5.98
76.2	1273.7	14.0	1.10
Standard Counts	14629		

Layton loamy fine sand sample with 6.4 cm diam access tube (saturated sample).

Depth	**Sample Counts**		
(cm)	**Mean**	**Std Dev**	**CV**
2.5	4399.0	58.3	1.32
5.1	6684.7	107.3	1.60
7.6	10715.0	13.2	0.12
10.2	14391.7	178.6	1.24
12.7	17742.0	46.1	0.26
15.2	20148.3	142.4	0.71
17.8	21576.7	35.7	0.17
20.3	22380.7	73.0	0.33
22.9	22739.0	73.6	0.32
25.4	22962.0	188.3	0.82
27.9	22925.0	108.7	0.47
30.5	23073.3	101.0	0.44
33.0	22929.3	183.2	0.80
35.6	23044.7	275.5	1.20
38.1	22812.3	139.0	0.61
40.6	22923.7	247.2	1.08
43.2	22793.7	86.2	0.38
45.7	23075.3	109.5	0.47
48.3	23014.3	88.5	0.38
50.8	23141.7	127.8	0.55
53.3	23005.3	64.7	0.28
55.9	23079.7	211.4	0.92
58.4	23075.0	162.8	0.71
61.0	22994.7	152.2	0.66
63.5	22689.7	49.4	0.22
66.0	22485.0	149.0	0.66
68.6	22294.0	161.9	0.73
71.1	21714.3	77.2	0.36
73.7	20578.3	167.6	0.81
76.2	19328.3	135.5	0.70
Standard Counts	14498		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	356.0	16.5	4.62
5.1	471.7	8.6	1.83
7.6	554.3	15.8	2.85
10.2	654.3	9.0	1.38
12.7	742.3	21.2	2.86
15.2	860.0	69.7	8.11
17.8	909.7	24.5	2.70
20.3	982.3	31.8	3.24
22.9	997.3	29.5	2.96
25.4	1062.3	57.2	5.38
27.9	1085.7	37.9	3.49
30.5	1128.3	27.2	2.41
33.0	1159.3	7.5	0.65
35.6	1179.7	32.7	2.77
38.1	1194.0	14.4	1.21
40.6	1211.7	7.6	0.63
43.2	1208.0	61.0	5.05
45.7	1224.7	28.0	2.29
48.3	1275.0	13.2	1.04
50.8	1210.3	52.0	4.30
53.3	1232.3	32.4	2.63
55.9	1248.7	17.0	1.36
58.4	1219.7	15.3	1.25
61.0	1245.0	32.7	2.63
63.5	1212.7	25.7	2.12
66.0	1247.7	47.1	3.77
68.6	1238.7	17.2	1.39
71.1	1263.3	22.1	1.75
73.7	1279.3	41.0	3.21
76.2	1339.3	17.7	1.32
Standard Counts	14560		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	8941.3	164.1	1.84
5.1	13855.0	44.1	0.32
7.6	17912.7	167.0	0.93
10.2	20247.7	316.5	1.56
12.7	21610.3	172.0	0.80
15.2	22569.0	163.8	0.73
17.8	23117.3	69.7	0.30
20.3	23704.0	121.8	0.51
22.9	23715.0	100.2	0.42
25.4	24160.7	188.1	0.78
27.9	24245.3	137.1	0.57
30.5	24391.0	126.0	0.52
33.0	24608.0	186.2	0.76
35.6	24484.3	99.5	0.41
38.1	24586.3	161.0	0.65
40.6	24730.0	56.1	0.23
43.2	24725.0	302.9	1.22
45.7	24793.0	72.0	0.29
48.3	25040.7	235.4	0.94
50.8	25086.0	89.3	0.36
53.3	25140.0	178.1	0.71
55.9	25079.0	166.3	0.66
58.4	25470.0	196.3	0.77
61.0	25472.0	215.2	0.85
63.5	25617.7	44.7	0.17
66.0	25486.7	22.2	0.09
68.6	25334.7	143.0	0.56
71.1	25396.7	49.7	0.20
73.7	24485.3	131.3	0.54
76.2	23191.0	351.5	1.52
Standard Counts	14722		

Table A-4. Calibration Data for Neutron Probe With Serial Number 5254 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	82.0	4.0	4.88
5.1	82.7	4.7	5.72
7.6	94.7	6.1	6.45
10.2	92.0	8.2	8.90
12.7	91.7	4.0	4.41
15.2	101.3	5.0	4.97
17.8	93.7	3.8	4.04
20.3	101.0	4.0	3.96
22.9	99.3	9.6	9.67
25.4	104.0	7.0	6.73
27.9	102.7	7.5	7.31
30.5	96.0	9.5	9.94
33.0	110.7	17.6	15.92
35.6	101.0	9.5	9.44
38.1	113.7	17.0	14.99
40.6	108.7	4.5	4.15
43.2	96.0	11.3	11.74
45.7	104.0	16.8	16.18
48.3	116.0	12.3	10.59
50.8	110.7	10.1	9.14
53.3	122.7	9.3	7.57
55.9	112.0	12.3	10.97
58.4	113.3	11.0	9.68
61.0	120.0	15.5	12.94
63.5	124.0	10.4	8.38
Standard Counts	6691		

Crushed Tuff sample with 5.1 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	1692.7	87.5	5.17
5.1	2337.7	45.4	1.94
7.6	2608.3	39.5	1.51
10.2	2878.3	14.2	0.49
12.7	2917.3	46.5	1.60
15.2	2989.0	2.6	0.09
17.8	2990.7	72.3	2.42
20.3	3007.0	57.4	1.91
22.9	2972.0	29.0	0.98
25.4	2976.0	57.2	1.92
27.9	2947.0	21.0	0.71
30.5	2916.3	54.7	1.88
33.0	2816.3	51.0	1.81
35.6	2900.7	27.7	0.96
38.1	2976.0	41.1	1.38
40.6	2965.7	23.3	0.79
43.2	2923.7	86.5	2.96
45.7	2955.0	31.6	1.07
48.3	2985.7	5.0	0.17
50.8	2994.0	29.9	1.00
53.3	2984.0	55.2	1.85
55.9	3021.3	61.2	2.02
58.4	2961.3	21.7	0.73
61.0	2947.3	45.9	1.56
63.5	2916.3	9.3	0.32
Standard Counts	6612		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	132.7	18.2	13.74
5.1	125.7	10.6	8.43
7.6	119.7	17.5	14.63
10.2	135.3	23.8	17.58
12.7	134.7	33.5	24.88
15.2	165.7	5.7	3.43
17.8	159.3	9.8	6.16
20.3	147.0	9.5	6.49
22.9	153.0	15.4	10.06
25.4	161.0	14.7	9.15
27.9	178.7	5.9	3.28
30.5	163.3	12.6	7.70
33.0	162.0	6.0	3.70
35.6	171.3	3.5	2.05
38.1	151.7	16.8	11.06
40.6	158.0	7.8	4.94
43.2	167.3	12.5	7.47
45.7	169.0	20.0	11.82
48.3	176.7	4.5	2.55
50.8	187.7	9.5	5.06
53.3	198.0	5.6	2.81
55.9	197.3	7.0	3.56
58.4	212.0	39.0	18.38
61.0	221.7	12.1	5.46
63.5	247.7	34.8	14.04
Standard Counts	6638		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample)

Depth	**Sample Counts**		
(cm)	**Mean**	**Std Dev**	**CV**
2.5	1478.0	57.3	3.88
5.1	2017.3	31.8	1.58
7.6	2337.7	46.4	1.98
10.2	2571.7	64.8	2.52
12.7	2758.7	45.2	1.64
15.2	2865.0	55.5	1.94
17.8	2869.0	3.6	0.13
20.3	2843.3	13.0	0.46
22.9	2898.3	14.6	0.50
25.4	2933.3	30.6	1.04
27.9	2890.3	58.4	2.02
30.5	2922.3	64.8	2.22
33.0	2918.7	35.5	1.22
35.6	2852.0	94.4	3.31
38.1	2821.3	33.1	1.17
40.6	2882.0	33.6	1.17
43.2	2821.3	51.2	1.81
45.7	2892.0	65.2	2.25
48.3	2820.3	24.7	0.88
50.8	2866.0	75.7	2.64
53.3	2845.7	32.6	1.14
55.9	2877.7	25.7	0.89
58.4	2859.0	49.4	1.73
61.0	2838.3	51.9	1.83
63.5	2885.3	29.8	1.03
Standard Counts	6706		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	99.0	7.0	7.07
5.1	103.7	5.7	5.49
7.6	103.3	13.3	12.89
10.2	97.3	5.0	5.17
12.7	112.0	10.1	9.06
15.2	110.7	11.9	10.78
17.8	106.7	5.5	5.16
20.3	148.3	38.2	25.76
22.9	121.7	15.5	12.74
25.4	115.7	4.2	3.60
27.9	127.7	18.8	14.70
30.5	127.7	8.0	6.28
33.0	124.3	12.3	9.93
35.6	124.0	6.0	4.84
38.1	136.0	14.8	10.88
40.6	136.7	7.0	5.14
43.2	160.0	33.9	21.17
45.7	132.7	16.9	12.75
48.3	146.3	18.1	12.40
50.8	147.0	12.1	8.25
53.3	140.7	5.5	3.92
55.9	141.7	18.4	13.02
58.4	150.0	22.9	15.25
61.0	165.7	20.6	12.40
63.5	182.7	10.3	5.62
Standard Counts	6709		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	1912.3	69.2	3.62
5.1	2474.3	17.9	0.72
7.6	2921.0	21.7	0.74
10.2	3205.0	43.3	1.35
12.7	3390.0	99.7	2.94
15.2	3486.7	86.4	2.48
17.8	3488.0	43.6	1.25
20.3	3514.0	70.3	2.00
22.9	3509.3	27.8	0.79
25.4	3634.3	67.1	1.85
27.9	3444.0	10.4	0.30
30.5	3542.0	61.0	1.72
33.0	3501.0	42.5	1.21
35.6	3500.0	21.8	0.62
38.1	3430.3	57.7	1.68
40.6	3503.0	47.7	1.36
43.2	3448.7	60.3	1.75
45.7	3458.7	51.4	1.49
48.3	3373.3	44.9	1.33
50.8	3406.7	64.4	1.89
53.3	3365.0	128.9	3.83
55.9	3375.7	110.1	3.26
58.4	3437.7	30.5	0.89
61.0	3414.0	29.5	0.86
63.5	3491.3	50.5	1.45
Standard Counts	6676		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	114.3	9.1	7.94
5.1	123.7	18.9	15.29
7.6	136.3	2.1	1.53
10.2	158.0	5.6	3.52
12.7	163.7	18.8	11.47
15.2	185.3	12.7	6.83
17.8	213.0	13.7	6.45
20.3	195.7	13.3	6.81
22.9	221.0	15.4	6.97
25.4	226.0	6.6	2.90
27.9	220.0	8.2	3.72
30.5	226.7	17.2	7.59
33.0	229.3	8.5	3.71
35.6	238.0	15.0	6.30
38.1	246.7	31.7	12.86
40.6	241.7	17.6	7.29
43.2	287.3	5.0	1.75
45.7	268.0	29.5	11.01
48.3	277.7	28.0	10.09
50.8	271.7	9.9	3.63
53.3	277.7	12.4	4.47
55.9	288.0	19.7	6.83
58.4	316.0	26.1	8.25
61.0	301.7	22.0	7.30
63.5	372.3	24.7	6.63
Standard Counts	6650		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	2315.3	27.5	1.19
5.1	2629.3	20.8	0.79
7.6	2811.7	40.1	1.43
10.2	2939.3	89.1	3.03
12.7	3003.7	30.9	1.03
15.2	3035.7	56.2	1.85
17.8	3082.0	12.8	0.41
20.3	3060.0	73.1	2.39
22.9	3090.3	65.5	2.12
25.4	3138.3	78.6	2.50
27.9	3114.7	32.1	1.03
30.5	3206.7	65.2	2.03
33.0	3240.7	75.3	2.32
35.6	3251.3	98.9	3.04
38.1	3227.3	84.4	2.62
40.6	3253.0	23.5	0.72
43.2	3211.7	42.6	1.33
45.7	3250.0	51.5	1.58
48.3	3287.7	59.3	1.80
50.8	3307.7	59.2	1.79
53.3	3292.3	26.9	0.82
55.9	3407.0	66.4	1.95
58.4	3330.3	14.6	0.44
61.0	3364.3	27.0	0.80
63.5	3413.3	42.1	1.23
Standard Counts	6651		

Table A-5. Calibration Data for Neutron Probe With Serial Number 7832 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	65.3	7.6	11.59
5.1	94.0	5.2	5.53
7.6	92.7	7.2	7.81
10.2	101.3	3.2	3.17
12.7	98.3	9.3	9.45
15.2	105.7	7.2	6.85
17.8	115.0	4.6	3.98
20.3	131.0	10.4	7.97
22.9	121.3	7.6	6.24
25.4	130.0	5.6	4.28
27.9	122.7	8.5	6.93
30.5	138.0	8.9	6.44
33.0	139.7	3.5	2.51
35.6	143.0	2.6	1.85
38.1	146.7	5.0	3.43
40.6	140.0	12.0	8.57
43.2	157.3	12.2	7.77
45.7	155.7	9.9	6.34
48.3	161.0	15.9	9.86
50.8	177.7	6.7	3.75
53.3	168.3	11.0	6.52
55.9	172.3	8.6	5.00
58.4	183.3	12.7	6.91
61.0	194.7	19.6	10.04
63.5	211.7	15.0	7.11
66.0	225.0	7.0	3.11
68.6	257.7	6.1	2.37
71.1	284.7	24.5	8.61
73.7	318.3	25.4	7.98
76.2	359.3	13.4	3.74
Standard Counts	7176		

Crushed Tuff sample with 5.1 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	5316.3	144.8	2.72
5.1	7143.3	93.4	1.31
7.6	8642.7	68.5	0.79
10.2	9837.7	8.3	0.08
12.7	10527.0	63.5	0.60
15.2	10732.0	83.4	0.78
17.8	10881.7	28.7	0.26
20.3	10957.3	99.4	0.91
22.9	11047.7	195.1	1.77
25.4	10919.0	188.1	1.72
27.9	10946.0	58.3	0.53
30.5	10832.3	45.7	0.42
33.0	10778.3	59.6	0.55
35.6	10892.3	123.6	1.13
38.1	10833.0	220.6	2.04
40.6	10687.3	48.2	0.45
43.2	10827.7	16.2	0.15
45.7	10920.0	65.2	0.60
48.3	10936.0	137.9	1.26
50.8	11019.7	77.8	0.71
53.3	10958.0	96.7	0.88
55.9	11015.3	79.6	0.72
58.4	10971.3	28.0	0.26
61.0	10972.7	35.1	0.32
63.5	11047.7	29.7	0.27
66.0	10807.0	70.4	0.65
68.6	10763.3	137.5	1.28
71.1	10296.3	126.8	1.23
73.7	9779.3	76.5	0.78
76.2	8793.0	164.8	1.87
Standard Counts	7152		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	85.0	5.2	6.11
5.1	76.7	11.0	14.37
7.6	93.7	6.7	7.11
10.2	99.7	14.5	14.52
12.7	105.7	7.2	6.85
15.2	106.0	8.7	8.22
17.8	113.0	3.5	3.07
20.3	111.7	12.5	11.20
22.9	117.0	5.3	4.52
25.4	102.7	19.2	18.72
27.9	116.0	5.0	4.31
30.5	110.0	11.8	10.72
33.0	104.7	6.0	5.76
35.6	113.3	4.0	3.57
38.1	105.0	6.6	6.25
40.6	136.0	1.7	1.27
43.2	115.7	6.7	5.76
45.7	124.0	14.1	11.38
48.3	133.7	9.1	6.79
50.8	130.7	7.1	5.43
53.3	150.0	6.6	4.37
55.9	147.3	11.1	7.51
58.4	160.0	13.5	8.41
61.0	168.3	12.4	7.38
63.5	176.3	10.2	5.79
66.0	213.3	18.8	8.80
68.6	248.7	6.7	2.68
71.1	271.7	26.5	9.76
73.7	297.7	4.5	1.51
76.2	366.7	61.2	16.68
Standard Counts	7148		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	4235.7	114.7	2.71
5.1	5935.3	73.9	1.24
7.6	7775.7	72.4	0.93
10.2	9204.0	123.2	1.34
12.7	10033.3	134.3	1.34
15.2	10521.0	76.7	0.73
17.8	10922.0	52.3	0.48
20.3	11010.3	97.1	0.88
22.9	11128.3	205.8	1.85
25.4	11137.0	110.6	0.99
27.9	11114.0	172.0	1.55
30.5	11072.3	94.1	0.85
33.0	11140.7	63.8	0.57
35.6	11040.7	118.9	1.08
38.1	11093.0	55.8	0.50
40.6	10956.7	36.1	0.33
43.2	10936.0	63.0	0.58
45.7	10914.7	17.0	0.16
48.3	11016.7	94.3	0.86
50.8	10862.0	178.0	1.64
53.3	10926.7	29.3	0.27
55.9	10887.7	88.5	0.81
58.4	10832.3	46.0	0.42
61.0	10703.0	54.1	0.51
63.5	10652.3	83.5	0.78
66.0	10521.0	246.2	2.34
68.6	10235.0	54.8	0.54
71.1	9858.3	67.5	0.68
73.7	9120.7	93.2	1.02
76.2	7796.7	124.3	1.59
Standard Counts	7102		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	76.3	6.4	8.42
5.1	96.0	7.9	8.27
7.6	93.0	4.4	4.69
10.2	99.0	3.6	3.64
12.7	123.3	11.1	8.97
15.2	103.7	13.2	12.74
17.8	122.0	12.8	10.46
20.3	121.0	10.6	8.75
22.9	138.3	3.5	2.54
25.4	139.7	16.3	11.64
27.9	143.7	12.9	8.95
30.5	148.0	6.2	4.22
33.0	161.7	23.3	14.41
35.6	159.0	7.0	4.40
38.1	154.3	12.1	7.81
40.6	146.7	10.3	7.00
43.2	151.0	6.9	4.59
45.7	152.7	19.1	12.54
48.3	159.0	13.9	8.74
50.8	155.7	14.6	9.40
53.3	172.7	16.6	9.59
55.9	168.0	5.3	3.15
58.4	185.0	21.7	11.71
61.0	180.0	10.6	5.88
63.5	200.3	10.6	5.29
66.0	204.3	6.4	3.11
68.6	235.0	3.5	1.47
71.1	286.7	14.7	5.14
73.7	316.7	4.0	1.28
76.2	359.0	36.4	10.13
Standard Counts	7109		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	5724.0	36.7	0.64
5.1	7946.7	19.5	0.25
7.6	9945.0	55.9	0.56
10.2	11262.7	80.4	0.71
12.7	11967.3	46.0	0.38
15.2	12242.7	129.2	1.06
17.8	12635.3	75.0	0.59
20.3	12792.7	68.2	0.53
22.9	12692.7	177.0	1.39
25.4	12846.7	10.2	0.08
27.9	12835.0	89.4	0.70
30.5	12802.0	62.2	0.49
33.0	12809.3	122.6	0.96
35.6	12681.3	114.9	0.91
38.1	12743.0	6.1	0.05
40.6	12808.0	191.1	1.49
43.2	12707.3	76.6	0.60
45.7	12629.7	89.8	0.71
48.3	12646.3	160.4	1.27
50.8	12703.7	180.5	1.42
53.3	12612.3	122.3	0.97
55.9	12565.0	126.5	1.01
58.4	12517.7	155.5	1.24
61.0	12530.3	120.3	0.96
63.5	12339.0	72.9	0.59
66.0	12174.3	37.8	0.31
68.6	11830.7	29.6	0.25
71.1	11197.7	95.7	0.85
73.7	10449.7	103.5	0.99
76.2	8805.7	120.1	1.36
Standard Counts	7196		

Layton loamy fine sand sample with 6.4 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	159.7	10.4	6.52
5.1	173.0	8.7	5.01
7.6	229.3	7.5	3.27
10.2	304.0	10.8	3.56
12.7	334.7	11.5	3.44
15.2	388.7	16.4	4.23
17.8	420.3	24.4	5.80
20.3	396.7	15.5	3.91
22.9	469.7	10.8	2.30
25.4	494.3	32.1	6.50
27.9	498.3	13.3	2.67
30.5	514.0	13.9	2.70
33.0	509.0	20.1	3.94
35.6	564.7	41.7	7.38
38.1	527.3	42.5	8.07
40.6	533.0	24.2	4.55
43.2	546.3	44.2	8.08
45.7	559.3	15.5	2.77
48.3	575.0	19.3	3.36
50.8	561.0	8.7	1.55
53.3	547.3	9.6	1.76
55.9	563.3	19.3	3.43
58.4	570.0	19.5	3.42
61.0	571.3	19.1	3.35
63.5	571.7	4.2	0.73
66.0	584.0	63.2	10.82
68.6	598.0	59.9	10.02
71.1	602.0	26.2	4.34
73.7	636.3	45.5	7.15
76.2	676.7	29.3	4.32
Standard Counts	7155		

Layton loamy fine sand sample with 6.4 cm diam access tube (saturated sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	2832.0	51.3	1.81
5.1	4673.7	59.1	1.27
7.6	6409.7	20.8	0.33
10.2	8314.7	69.6	0.84
12.7	9688.7	77.2	0.80
15.2	10487.7	7.5	0.07
17.8	11033.0	114.5	1.04
20.3	11303.7	51.7	0.46
22.9	11405.0	103.3	0.91
25.4	11511.7	180.1	1.56
27.9	11509.0	118.2	1.03
30.5	11660.0	96.0	0.82
33.0	11639.7	60.1	0.52
35.6	11500.3	160.2	1.39
38.1	11576.3	97.3	0.84
40.6	11565.0	7.8	0.07
43.2	11491.0	73.7	0.64
45.7	11639.7	42.2	0.36
48.3	11515.7	50.6	0.44
50.8	11623.7	83.2	0.72
53.3	11598.3	203.0	1.75
55.9	11775.0	151.9	1.29
58.4	11668.7	105.6	0.91
61.0	11532.3	73.1	0.63
63.5	11395.3	46.4	0.41
66.0	11202.7	40.1	0.36
68.6	11018.7	91.9	0.83
71.1	10743.0	58.7	0.55
73.7	10087.3	52.7	0.52
76.2	9782.3	156.1	1.60
Standard Counts	7165		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	469.0	10.6	2.26
5.1	405.3	24.2	5.96
7.6	385.0	28.1	7.29
10.2	401.3	17.0	4.25
12.7	431.3	22.8	5.29
15.2	431.0	17.4	4.05
17.8	483.0	39.5	8.18
20.3	500.7	15.6	3.11
22.9	509.3	31.7	6.22
25.4	541.7	18.0	3.32
27.9	551.7	26.0	4.71
30.5	563.0	33.9	6.02
33.0	555.3	12.6	2.27
35.6	561.3	36.3	6.47
38.1	570.0	8.9	1.56
40.6	613.7	44.0	7.18
43.2	590.0	23.0	3.90
45.7	621.3	14.2	2.28
48.3	600.0	24.6	4.10
50.8	591.0	31.2	5.28
53.3	599.0	2.6	0.44
55.9	610.7	23.1	3.78
58.4	607.7	22.1	3.64
61.0	575.3	12.0	2.09
63.5	613.3	12.0	1.96
66.0	616.3	37.3	6.05
68.6	614.3	15.0	2.45
71.1	615.3	12.6	2.04
73.7	641.0	35.5	5.54
76.2	659.0	42.0	6.38
Standard Counts	7073		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	4902.0	137.1	2.80
5.1	6927.7	131.1	1.89
7.6	8858.7	297.1	3.35
10.2	10139.3	105.6	1.04
12.7	10886.7	93.5	0.86
15.2	11330.7	129.4	1.14
17.8	11708.7	54.9	0.47
20.3	11740.3	146.0	1.24
22.9	12093.0	37.0	0.31
25.4	12175.3	86.1	0.71
27.9	12221.0	91.0	0.74
30.5	12203.0	62.4	0.51
33.0	12346.0	75.9	0.61
35.6	12344.0	71.2	0.58
38.1	12438.3	100.9	0.81
40.6	12433.7	170.1	1.37
43.2	12580.7	59.5	0.47
45.7	12355.0	141.2	1.14
48.3	12531.7	84.9	0.68
50.8	12651.7	83.3	0.66
53.3	12660.0	128.3	1.01
55.9	12684.3	105.0	0.83
58.4	12692.3	147.8	1.16
61.0	12695.3	11.9	0.09
63.5	12801.3	23.5	0.18
66.0	12801.7	109.5	0.86
68.6	12747.3	91.3	0.72
71.1	12890.0	90.1	0.70
73.7	12420.0	188.9	1.52
76.2	11714.3	44.1	0.38
Standard Counts	7158		

Table A-6. Calibration Data for Neutron Probe With Serial Number 8459 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	77.3	15.2	19.63
5.1	88.3	5.7	6.44
7.6	105.0	21.7	20.67
10.2	107.3	3.1	2.85
12.7	113.7	10.2	8.99
15.2	119.3	10.8	9.04
17.8	130.7	10.5	8.04
20.3	128.3	10.4	8.11
22.9	136.0	6.1	4.47
25.4	150.0	9.6	6.43
27.9	141.7	7.4	5.20
30.5	152.0	18.7	12.29
33.0	164.3	6.7	4.05
35.6	162.3	14.2	8.72
38.1	181.0	16.7	9.23
40.6	187.3	13.1	6.97
43.2	169.7	10.5	6.19
45.7	184.0	12.0	6.52
48.3	207.0	12.8	6.17
50.8	217.3	12.4	5.72
53.3	221.0	4.6	2.07
55.9	240.0	29.5	12.31
58.4	264.7	39.6	14.95
61.0	284.7	2.9	1.01
63.5	325.0	11.3	3.47
66.0	386.0	15.6	4.04
68.6	480.0	7.9	1.65
71.1	584.3	23.1	3.96
73.7	709.3	24.3	3.43
76.2	866.3	25.1	2.90
Standard Counts	7911		

Crushed Tuff sample with 5.1 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	5606.7	93.5	1.67
5.1	7668.7	88.5	1.15
7.6	9674.7	162.4	1.68
10.2	10867.7	100.5	0.93
12.7	11659.3	128.7	1.10
15.2	12020.3	173.1	1.44
17.8	12351.0	88.0	0.71
20.3	12430.0	11.3	0.09
22.9	12490.3	87.8	0.70
25.4	12355.7	129.3	1.05
27.9	12291.7	37.6	0.31
30.5	12302.3	90.8	0.74
33.0	12258.3	44.3	0.36
35.6	12294.7	31.6	0.26
38.1	12253.3	77.9	0.64
40.6	12226.0	81.2	0.66
43.2	12287.3	222.1	1.81
45.7	12369.7	148.2	1.20
48.3	12254.3	46.7	0.38
50.8	12250.3	46.8	0.38
53.3	12301.3	127.1	1.03
55.9	12238.0	110.0	0.90
58.4	12276.3	87.1	0.71
61.0	12269.0	39.1	0.32
63.5	12279.0	43.7	0.36
66.0	12413.0	243.8	1.96
68.6	12535.7	98.2	0.78
71.1	12701.3	189.9	1.50
73.7	12769.3	76.7	0.60
76.2	13071.7	66.5	0.51
Standard Counts	6786		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	129.7	5.5	4.25
5.1	129.3	5.8	4.46
7.6	133.0	19.0	14.29
10.2	139.7	16.7	11.99
12.7	140.3	5.9	4.18
15.2	151.3	22.2	14.66
17.8	149.3	9.1	6.08
20.3	157.0	19.5	12.40
22.9	172.0	3.6	2.10
25.4	187.0	10.6	5.66
27.9	197.0	14.2	7.20
30.5	187.0	10.8	5.78
33.0	181.3	14.0	7.75
35.6	193.7	7.4	3.81
38.1	208.3	27.5	13.18
40.6	223.3	20.6	9.25
43.2	206.0	14.5	7.05
45.7	221.0	11.0	4.98
48.3	260.0	7.0	2.69
50.8	262.3	22.2	8.48
53.3	251.3	33.7	13.42
55.9	280.0	13.9	4.96
58.4	301.0	11.3	3.74
61.0	322.7	25.1	7.78
63.5	370.3	7.1	1.92
66.0	428.7	23.7	5.52
68.6	538.3	40.6	7.54
71.1	612.7	26.1	4.26
73.7	732.3	15.3	2.09
76.2	950.7	8.3	0.88
Standard Counts	8058		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	4647.0	83.1	1.79
5.1	6477.0	61.5	0.95
7.6	8695.3	40.1	0.46
10.2	9975.7	150.2	1.51
12.7	10797.7	38.0	0.35
15.2	11454.0	103.1	0.90
17.8	11744.7	22.4	0.19
20:3	11953.0	71.0	0.59
22.9	11897.7	216.8	1.82
25.4	12038.7	86.8	0.72
27.9	12150.7	39.6	0.33
30.5	12029.0	87.8	0.73
33.0	12022.7	32.7	0.27
35.6	12220.7	162.3	1.33
38.1	12123.3	23.2	0.19
40.6	11977.7	66.5	0.56
43.2	12045.0	171.7	1.43
45.7	12093.0	17.8	0.15
48.3	11896.0	85.8	0.72
50.8	11873.0	42.6	0.36
53.3	11841.7	51.1	0.43
55.9	11986.3	18.1	0.15
58.4	11922.7	117.1	0.98
61.0	11979.3	123.8	1.03
63.5	11948.7	119.3	1.00
66.0	12231.7	66.0	0.54
68.6	11965.3	135.7	1.13
71.1	12025.0	73.8	0.61
73.7	11786.3	121.0	1.03
76.2	11533.7	82.0	0.71
Standard Counts	8157		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	112.0	4.6	4.09
5.1	114.3	17.6	15.41
7.6	136.0	14.0	10.29
10.2	157.7	11.6	7.35
12.7	160.7	10.4	6.48
15.2	176.3	26.3	14.90
17.8	196.0	4.4	2.22
20.3	193.7	8.5	4.39
22.9	205.7	4.0	1.97
25.4	218.7	9.1	4.15
27.9	209.7	9.3	4.43
30.5	204.3	7.2	3.54
33.0	222.3	6.8	3.06
35.6	241.0	30.6	12.70
38.1	229.3	9.3	4.05
40.6	248.0	33.9	13.66
43.2	254.7	8.0	3.15
45.7	247.0	19.7	7.97
48.3	287.7	17.6	6.12
50.8	280.0	14.0	5.00
53.3	303.0	22.6	7.46
55.9	309.7	24.0	7.76
58.4	351.0	20.4	5.82
61.0	381.3	27.1	7.10
63.5	415.0	10.5	2.54
66.0	465.3	5.5	1.18
68.6	562.0	15.1	2.69
71.1	687.0	2.6	0.39
73.7	786.7	15.9	2.03
76.2	976.0	40.5	4.15
Standard Counts	7091		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	5958.0	39.2	0.66
5.1	8018.0	36.0	0.45
7.6	10403.0	111.5	1.07
10.2	11873.0	76.1	0.64
12.7	12666.3	124.6	0.98
15.2	13457.0	148.7	1.11
17.8	13860.3	124.4	0.90
20.3	14045.0	140.3	1.00
22.9	14156.7	39.3	0.28
25.4	14249.7	118.4	0.83
27.9	14216.3	83.1	0.58
30.5	14304.3	104.4	0.73
33.0	14226.7	51.7	0.36
35.6	14171.3	161.8	1.14
38.1	14041.0	171.5	1.22
40.6	14023.3	100.8	0.72
43.2	14014.7	84.0	0.60
45.7	13916.7	105.3	0.76
48.3	13879.0	139.7	1.01
50.8	13841.3	89.6	0.65
53.3	13874.3	123.0	0.89
55.9	13823.3	95.1	0.69
58.4	13926.7	68.4	0.49
61.0	13945.7	108.9	0.78
63.5	14030.0	115.5	0.82
66.0	14056.0	47.7	0.34
68.6	13969.3	98.5	0.71
71.1	13946.7	36.3	0.26
73.7	13600.7	159.1	1.17
76.2	13640.3	117.3	0.86
Standard Counts	8116		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	260.7	18.0	6.92
5.1	324.7	9.6	2.96
7.6	410.0	6.9	1.69
10.2	468.0	25.5	5.46
12.7	541.3	39.6	7.31
15.2	580.3	28.3	4.88
17.8	649.7	16.3	2.50
20.3	728.7	23.3	3.20
22.9	735.7	21.9	2.98
25.4	792.7	39.8	5.03
27.9	824.7	18.6	2.26
30.5	790.3	19.0	2.41
33.0	789.0	17.1	2.17
35.6	834.3	9.1	1.09
38.1	818.3	20.6	2.52
40.6	833.3	43.7	5.24
43.2	811.3	21.5	2.66
45.7	796.3	20.6	2.58
48.3	773.7	37.1	4.80
50.8	803.3	42.0	5.22
53.3	795.7	2.5	0.32
55.9	804.7	4.7	0.59
58.4	805.3	18.0	2.23
61.0	820.7	19.1	2.33
63.5	897.0	27.0	3.01
66.0	930.3	36.5	3.93
68.6	994.0	40.4	4.07
71.1	1038.3	51.1	4.92
73.7	1207.0	48.1	3.99
76.2	1430.3	36.1	2.53
Standard Counts	8056		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	6694.7	99.4	1.49
5.1	9004.0	104.5	1.16
7.6	10772.0	81.0	0.75
10.2	11543.3	161.0	1.40
12.7	11943.7	25.3	0.21
15.2	12236.7	66.1	0.54
17.8	12372.7	93.7	0.76
20.3	12593.0	163.1	1.30
22.9	12628.3	70.7	0.56
25.4	12640.3	86.0	0.68
27.9	12646.3	109.6	0.87
30.5	12679.3	99.9	0.79
33.0	12755.7	66.0	0.52
35.6	12774.7	82.0	0.64
38.1	12699.3	121.1	0.95
40.6	12959.0	142.6	1.10
43.2	12970.7	63.2	0.49
45.7	13013.7	126.8	0.97
48.3	13129.3	145.1	1.11
50.8	13119.3	179.8	1.37
53.3	13170.0	19.9	0.15
55.9	13386.3	146.8	1.10
58.4	13428.0	100.6	0.75
61.0	13536.3	100.2	0.74
63.5	13652.0	155.2	1.14
66.0	13794.7	99.7	0.72
68.6	13753.7	220.8	1.61
71.1	13888.7	57.0	0.41
73.7	14099.3	96.4	0.68
76.2	14162.0	238.5	1.68
Standard Counts	7096		

Layton loamy fine sand sample with 6.4 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	151.3	16.0	10.60
5.1	166.0	6.2	3.76
7.6	225.7	16.8	7.45
10.2	284.3	21.4	7.51
12.7	341.3	24.0	7.03
15.2	408.0	6.1	1.49
17.8	437.0	9.5	2.18
20.3	493.7	31.3	6.33
22.9	500.7	10.7	2.14
25.4	540.0	8.7	1.61
27.9	603.3	2.1	0.35
30.5	627.7	16.2	2.58
33.0	620.3	25.5	4.11
35.6	610.3	18.8	3.08
38.1	640.3	19.0	2.97
40.6	640.7	41.1	6.42
43.2	652.0	46.5	7.13
45.7	673.3	23.1	3.43
48.3	685.0	6.6	0.96
50.8	670.0	53.5	7.99
53.3	646.3	30.7	4.74
55.9	668.0	17.6	2.63
58.4	662.3	41.4	6.24
61.0	693.3	12.0	1.73
63.5	681.0	18.1	2.66
66.0	687.7	35.0	5.09
68.6	688.0	14.1	2.05
71.1	701.3	14.5	2.06
73.7	694.3	8.4	1.21
76.2	734.7	37.2	5.06
Standard Counts	7870		

Layton loamy fine sand sample with 6.4 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	1860.3	42.9	2.31
5.1	3100.0	44.3	1.43
7.6	5241.0	20.3	0.39
10.2	7500.7	101.8	1.36
12.7	9357.7	76.8	0.82
15.2	10862.0	12.1	0.11
17.8	11445.7	136.9	1.20
20.3	11843.7	31.6	0.27
22.9	12046.0	19.1	0.16
25.4	12053.3	78.8	0.65
27.9	11817.0	84.9	0.72
30.5	11855.3	87.8	0.74
33.0	11498.0	33.1	0.29
35.6	11581.0	89.8	0.78
38.1	11422.7	79.2	0.69
40.6	11311.7	29.8	0.26
43.2	11170.3	54.1	0.48
45.7	11236.3	22.1	0.20
48.3	11363.3	53.3	0.47
50.8	11284.0	63.7	0.56
53.3	11242.3	76.8	0.68
55.9	11180.3	141.6	1.27
58.4	11143.0	82.8	0.74
61.0	11143.0	63.5	0.57
63.5	11163.0	108.0	0.97
66.0	11093.7	81.9	0.74
68.6	10827.3	177.3	1.64
71.1	10563.3	83.2	0.79
73.7	10125.7	98.5	0.97
76.2	9437.0	26.5	0.28
Standard Counts	7827		

Bentonite/Powell Gray subsoil mix sample with 6.4 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	173.3	7.2	4.17
5.1	199.7	3.2	1.61
7.6	202.0	3.6	1.78
10.2	225.7	11.0	4.86
12.7	284.3	11.1	3.89
15.2	330.0	20.9	6.33
17.8	387.7	23.2	5.98
20.3	520.7	4.7	0.91
22.9	699.3	26.5	3.79
25.4	931.7	28.0	3.01
27.9	1154.7	14.3	1.24
30.5	1399.0	27.8	1.99
33.0	1597.7	5.9	0.37
35.6	1802.3	11.4	0.63
38.1	1931.7	12.0	0.62
40.6	2029.3	53.1	2.62
43.2	2119.3	63.5	3.00
45.7	2171.7	80.7	3.72
48.3	2133.0	19.5	0.92
50.8	2164.0	54.0	2.50
53.3	2136.7	41.0	1.92
55.9	2112.7	37.0	1.75
Standard Counts	7853		

Bentonite/Powell Gray subsoil mix sample with 6.4 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	370.3	10.0	2.71
5.1	468.0	6.2	1.33
7.6	588.7	5.1	0.87
10.2	990.7	53.6	5.41
12.7	1959.7	11.9	0.61
15.2	3644.0	17.0	0.47
17.8	5013.0	66.6	1.33
20.3	7543.7	93.9	1.24
22.9	10009.0	97.7	0.98
25.4	11128.7	98.2	0.88
27.9	11903.0	106.7	0.90
30.5	12229.0	78.8	0.65
33.0	12451.0	43.6	0.35
35.6	12495.7	91.0	0.73
38.1	12576.3	143.6	1.14
40.6	12699.3	104.9	0.83
43.2	12556.3	75.5	0.60
45.7	12496.7	85.4	0.68
48.3	12680.7	110.5	0.87
50.8	12621.3	25.3	0.20
53.3	12810.0	158.4	1.24
55.9	13315.3	118.1	0.89
Standard Counts	8101		

Table A-7. Calibration Data for Neutron Probe With Serial Number 8460 (sample count means represent the average of three determinations per depth).

Crushed Tuff sample with 5.1 cm diam access tube (dry sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	100.3	13.1	13.01
5.1	96.0	4.4	4.54
7.6	113.7	6.4	5.66
10.2	128.7	2.5	1.96
12.7	127.0	4.6	3.61
15.2	143.0	2.6	1.85
17.8	140.3	2.5	1.79
20.3	138.7	11.0	7.94
22.9	144.7	21.5	14.86
25.4	149.7	6.4	4.24
27.9	142.3	6.7	4.68
30.5	160.3	11.0	6.84
33.0	161.3	8.7	5.42
35.6	172.0	12.5	7.29
38.1	170.3	11.7	6.88
40.6	180.3	17.0	9.43
43.2	190.0	7.0	3.68
45.7	186.7	1.2	0.62
48.3	192.3	7.5	3.90
50.8	214.7	18.0	8.39
53.3	222.3	7.2	3.25
55.9	250.3	46.7	18.65
58.4	241.0	2.0	0.83
61.0	297.7	15.0	5.04
63.5	330.0	19.1	5.78
66.0	373.7	1.5	0.41
68.6	419.0	27.5	6.56
71.1	568.7	31.0	5.46
73.7	693.0	26.5	3.83
76.2	890.3	31.8	3.57
Standard Counts	8194		

Crushed Tuff sample with 5.1 cm diam access tube (saturated sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	5538.0	30.6	0.55
5.1	8131.7	76.5	0.94
7.6	10108.0	82.7	0.82
10.2	11196.0	109.0	0.97
12.7	11938.7	146.6	1.23
15.2	12499.7	203.4	1.63
17.8	12546.7	42.4	0.34
20.3	12735.7	46.3	0.36
22.9	12684.3	68.1	0.54
25.4	12555.3	58.0	0.46
27.9	12609.0	34.7	0.28
30.5	12619.3	15.5	0.12
33.0	12511.0	65.4	0.52
35.6	12567.3	110.6	0.88
38.1	12540.3	118.9	0.95
40.6	12518.0	47.0	0.38
43.2	12423.0	35.6	0.29
45.7	12648.3	74.2	0.59
48.3	12575.0	73.1	0.58
50.8	12532.7	122.0	0.97
53.3	12509.3	66.3	0.53
55.9	12583.3	90.6	0.72
58.4	12554.0	108.4	0.86
61.0	12642.3	39.8	0.32
63.5	12545.7	166.7	1.33
66.0	12634.0	39.6	0.31
68.6	12785.7	62.1	0.49
71.1	12891.0	120.4	0.93
73.7	12997.3	35.2	0.27
76.2	13084.7	129.5	0.99
Standard Counts	8262		

Crushed Tuff sample with 6.4 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	104.3	18.5	17.73
5.1	107.3	8.7	8.14
7.6	121.7	10.7	8.79
10.2	109.0	10.5	9.67
12.7	124.7	7.5	6.02
15.2	120.7	14.5	12.02
17.8	133.3	16.0	12.03
20.3	138.0	6.1	4.41
22.9	140.7	7.6	5.43
25.4	149.0	8.7	5.81
27.9	154.0	14.0	9.09
30.5	159.0	21.3	13.39
33.0	171.7	1.5	0.89
35.6	163.3	19.6	11.97
38.1	184.0	8.7	4.71
40.6	171.7	13.1	7.60
43.2	167.3	13.9	8.29
45.7	176.3	17.0	9.66
48.3	183.3	15.3	8.35
50.8	200.0	8.9	4.44
53.3	205.0	5.3	2.58
55.9	224.0	8.9	3.97
58.4	233.3	26.5	11.36
61.0	267.3	23.4	8.74
63.5	382.0	14.1	3.69
66.0	375.0	11.4	3.03
68.6	415.0	42.9	10.35
71.1	513.7	25.3	4.93
73.7	644.7	25.1	3.89
76.2	789.3	21.4	2.71
Standard Counts	8274		

Crushed Tuff sample with 6.4 cm diam access tube (saturated sample)

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	5018.7	38.4	0.77
5.1	6991.7	24.1	0.35
7.6	9347.0	65.1	0.70
10.2	10648.3	156.5	1.47
12.7	11117.0	86.5	0.78
15.2	11772.0	77.3	0.66
17.8	11954.3	102.6	0.86
20.3	12217.3	59.8	0.49
22.9	12321.0	67.3	0.55
25.4	12349.3	95.9	0.78
27.9	12448.3	83.2	0.67
30.5	12396.0	69.7	0.56
33.0	12418.7	53.7	0.43
35.6	12347.3	93.2	0.76
38.1	12388.3	134.8	1.09
40.6	12292.0	135.9	1.11
43.2	12386.0	69.2	0.56
45.7	12367.0	74.1	0.60
48.3	12210.7	83.4	0.68
50.8	12214.7	123.4	1.01
53.3	12330.3	129.7	1.05
55.9	12257.3	138.0	1.13
58.4	12318.3	96.3	0.78
61.0	12362.0	143.4	1.16
63.5	12366.7	58.0	0.47
66.0	12369.7	94.3	0.76
68.6	12362.0	85.5	0.69
71.1	12281.3	72.1	0.59
73.7	12072.7	115.1	0.95
76.2	11834.7	77.2	0.65
Standard Counts	8150		

Fine sand sample with 5.1 cm diam access tube (dry sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	105.7	24.6	23.27
5.1	156.7	15.8	10.10
7.6	136.3	8.0	5.88
10.2	157.7	12.6	7.98
12.7	172.7	6.1	3.54
15.2	189.7	19.1	10.09
17.8	195.7	4.7	2.42
20.3	211.7	14.0	6.62
22.9	228.3	8.7	3.83
25.4	223.0	9.5	4.28
27.9	223.7	24.6	10.99
30.5	257.7	17.9	6.96
33.0	263.0	26.5	10.06
35.6	277.3	13.3	4.80
38.1	274.7	11.5	4.20
40.6	292.7	24.0	8.20
43.2	296.0	16.5	5.56
45.7	309.0	7.6	2.44
48.3	317.3	27.1	8.53
50.8	327.3	34.1	10.41
53.3	372.0	26.3	7.07
55.9	365.3	6.5	1.78
58.4	394.3	7.5	1.90
61.0	428.3	28.4	6.64
63.5	478.7	13.1	2.73
66.0	540.0	37.0	6.86
68.6	675.3	17.4	2.58
71.1	731.7	27.5	3.75
73.7	887.0	26.2	2.96
76.2	1113.3	41.9	3.76
Standard Counts	8210		

Fine sand sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	6600.3	81.8	1.24
5.1	8878.0	78.6	0.89
7.6	11071.7	71.7	0.65
10.2	12478.3	106.8	0.86
12.7	13328.3	121.1	0.91
15.2	13808.7	79.4	0.58
17.8	14185.0	209.5	1.48
20.3	14338.7	73.1	0.51
22.9	14333.3	191.3	1.34
25.4	14532.0	93.0	0.64
27.9	14470.7	183.7	1.27
30.5	14447.7	39.5	0.27
33.0	14352.0	315.2	2.20
35.6	14385.7	173.1	1.20
38.1	14241.7	165.1	1.16
40.6	14270.0	106.6	0.75
43.2	14156.7	35.6	0.25
45.7	14239.7	205.4	1.44
48.3	14266.7	113.9	0.80
50.8	14136.3	92.7	0.66
53.3	14143.0	167.0	1.18
55.9	14056.0	30.8	0.22
58.4	14291.3	42.4	0.30
61.0	14270.7	89.3	0.63
63.5	14164.0	98.5	0.70
66.0	14263.7	91.4	0.64
68.6	14231.0	98.0	0.69
71.1	14308.7	110.2	0.77
73.7	14043.7	75.0	0.53
76.2	13815.7	133.4	0.97
Standard Counts	8232		

Hackroy clay loam sample with 5.1 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	239.7	2.5	1.05
5.1	312.0	19.5	6.24
7.6	405.0	6.6	1.62
10.2	491.0	22.5	4.59
12.7	547.7	38.6	7.04
15.2	633.0	26.2	4.13
17.8	674.0	1.7	0.26
20.3	718.7	16.4	2.29
22.9	746.3	18.6	2.49
25.4	764.0	25.5	3.34
27.9	787.3	10.0	1.27
30.5	792.3	14.0	1.77
33.0	835.0	9.6	1.16
35.6	817.3	35.4	4.33
38.1	810.3	32.6	4.02
40.6	828.7	13.7	1.65
43.2	791.0	4.4	0.55
45.7	764.0	8.0	1.05
48.3	804.7	18.8	2.33
50.8	804.7	53.4	6.64
53.3	815.7	15.5	1.90
55.9	831.3	40.1	4.82
58.4	872.7	30.5	3.50
61.0	873.7	22.8	2.61
63.5	885.7	18.5	2.09
66.0	920.7	3.8	0.41
68.6	988.7	42.7	4.32
71.1	1119.0	26.5	2.36
73.7	1257.0	18.7	1.49
76.2	1375.3	11.2	0.82
Standard Counts	8203		

Hackroy clay loam sample with 5.1 cm diam access tube (saturated sample).

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	8262.7	143.6	1.74
5.1	10403.0	90.8	0.87
7.6	11378.7	139.8	1.23
10.2	12042.3	142.6	1.18
12.7	12260.0	40.8	0.33
15.2	12505.7	110.8	0.89
17.8	12653.3	75.3	0.60
20.3	12740.0	146.1	1.15
22.9	12809.7	59.3	0.46
25.4	12950.0	121.4	0.94
27.9	12953.0	128.7	0.99
30.5	12990.3	59.0	0.45
33.0	12971.0	101.0	0.78
35.6	13119.3	77.6	0.59
38.1	13206.7	259.2	1.96
40.6	13182.0	99.7	0.76
43.2	13148.7	85.2	0.65
45.7	13334.0	137.8	1.03
48.3	13237.7	195.6	1.48
50.8	13390.7	148.7	1.11
53.3	13533.3	134.8	1.00
55.9	13600.0	135.5	1.00
58.4	13635.7	46.3	0.34
61.0	13792.7	157.1	1.14
63.5	13866.0	225.6	1.63
66.0	14066.7	63.5	0.45
68.6	13993.7	53.0	0.38
71.1	14298.0	134.8	0.94
73.7	14471.3	135.7	0.94
76.2	14413.7	148.7	1.03
Standard Counts	8227		

Layton loamy fine sand sample with 6.4 cm diam access tube (dry sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	134.0	5.6	4.16
5.1	146.0	21.4	14.64
7.6	214.0	3.6	1.68
10.2	271.0	7.9	2.93
12.7	320.7	12.5	3.90
15.2	356.7	27.5	7.70
17.8	409.0	4.4	1.07
20.3	451.0	21.7	4.80
22.9	496.3	33.5	6.76
25.4	530.3	2.1	0.39
27.9	562.7	21.8	3.87
30.5	549.7	12.2	2.22
33.0	602.7	13.6	2.25
35.6	621.7	26.2	4.21
38.1	612.3	26.6	4.34
40.6	601.0	17.3	2.89
43.2	635.7	46.7	7.35
45.7	641.0	25.5	3.98
48.3	631.0	31.2	4.95
50.8	645.3	53.6	8.31
53.3	631.7	29.5	4.67
55.9	664.3	21.8	3.29
58.4	635.7	13.7	2.15
61.0	651.3	18.0	2.77
63.5	614.7	18.8	3.06
66.0	631.0	35.4	5.61
68.6	656.3	36.8	5.61
71.1	696.0	39.2	5.63
73.7	676.3	22.0	3.25
76.2	706.7	26.3	3.72
Standard Counts	8024		

Layton loamy fine sand sample with 6.4 cm diam access tube (saturated sample).

Depth	Sample Counts		
(cm)	Mean	Std Dev	CV
2.5	1853.7	93.9	5.07
5.1	3551.3	120.8	3.40
7.6	6703.7	440.9	6.58
10.2	8202.0	46.4	0.57
12.7	9953.7	58.0	0.58
15.2	11057.0	122.5	1.11
17.8	11862.7	152.1	1.28
20.3	12210.0	93.2	0.76
22.9	12289.3	38.7	0.31
25.4	12091.0	140.3	1.16
27.9	12056.7	54.2	0.45
30.5	11884.0	185.0	1.56
33.0	11760.3	42.4	0.36
35.6	11630.7	12.6	0.11
38.1	11518.0	80.5	0.70
40.6	11462.0	75.4	0.66
43.2	11286.7	74.5	0.66
45.7	11356.0	139.6	1.23
48.3	11438.3	66.9	0.58
50.8	11388.3	146.7	1.29
53.3	11501.7	66.5	0.58
55.9	11463.3	268.4	2.34
58.4	11308.0	123.0	1.09
61.0	11328.0	57.8	0.51
63.5	11343.7	137.8	1.22
66.0	11150.0	145.5	1.30
68.6	11077.0	56.6	0.51
71.1	10824.3	171.2	1.58
73.7	10403.3	119.5	1.15
76.2	9362.0	94.3	1.01
Standard Counts	7921		

Bentonite/Powell Gray subsoil mix sample with 6.4 cm diam access tube (dry sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	207.7	9.3	4.47
5.1	170.3	18.5	10.86
7.6	194.0	27.1	13.95
10.2	222.0	6.1	2.74
12.7	247.0	10.6	4.28
15.2	298.0	18.7	6.29
17.8	381.3	24.4	6.41
20.3	540.3	12.2	2.26
22.9	706.0	21.3	3.01
25.4	917.3	6.4	0.69
27.9	1174.3	52.0	4.43
30.5	1408.7	47.5	3.37
33.0	1645.7	71.9	4.37
35.6	1778.7	20.6	1.16
38.1	1947.7	33.7	1.73
40.6	2031.7	30.1	1.48
43.2	2127.0	53.1	2.50
45.7	2181.0	7.8	0.36
48.3	2204.3	38.7	1.75
50.8	2216.3	19.1	0.86
53.3	2161.7	38.7	1.79
55.9	2108.7	27.5	1.30
Standard Counts	7962		

Bentonite/Powell Gray subsoil mix sample with 6.4 cm diam access tube (saturated sample)

Depth (cm)	Sample Counts Mean	Std Dev	CV
2.5	446.3	29.6	6.63
5.1	579.0	13.5	2.34
7.6	735.0	14.8	2.01
10.2	1123.0	29.6	2.64
12.7	1773.7	15.5	0.88
15.2	3577.0	54.4	1.52
17.8	5924.3	58.6	0.99
20.3	8472.3	65.3	0.77
22.9	10460.3	83.1	0.79
25.4	11742.0	13.5	0.12
27.9	12356.0	56.7	0.46
30.5	12634.7	125.9	1.00
33.0	12849.7	156.7	1.22
35.6	12846.7	99.5	0.78
38.1	12761.0	69.5	0.55
40.6	12926.7	73.8	0.57
43.2	12819.0	84.3	0.66
45.7	12972.7	88.7	0.68
48.3	12870.3	17.0	0.13
50.8	13094.0	90.6	0.69
53.3	13540.0	44.8	0.33
55.9	13656.3	69.0	0.51
Standard Counts	8250		

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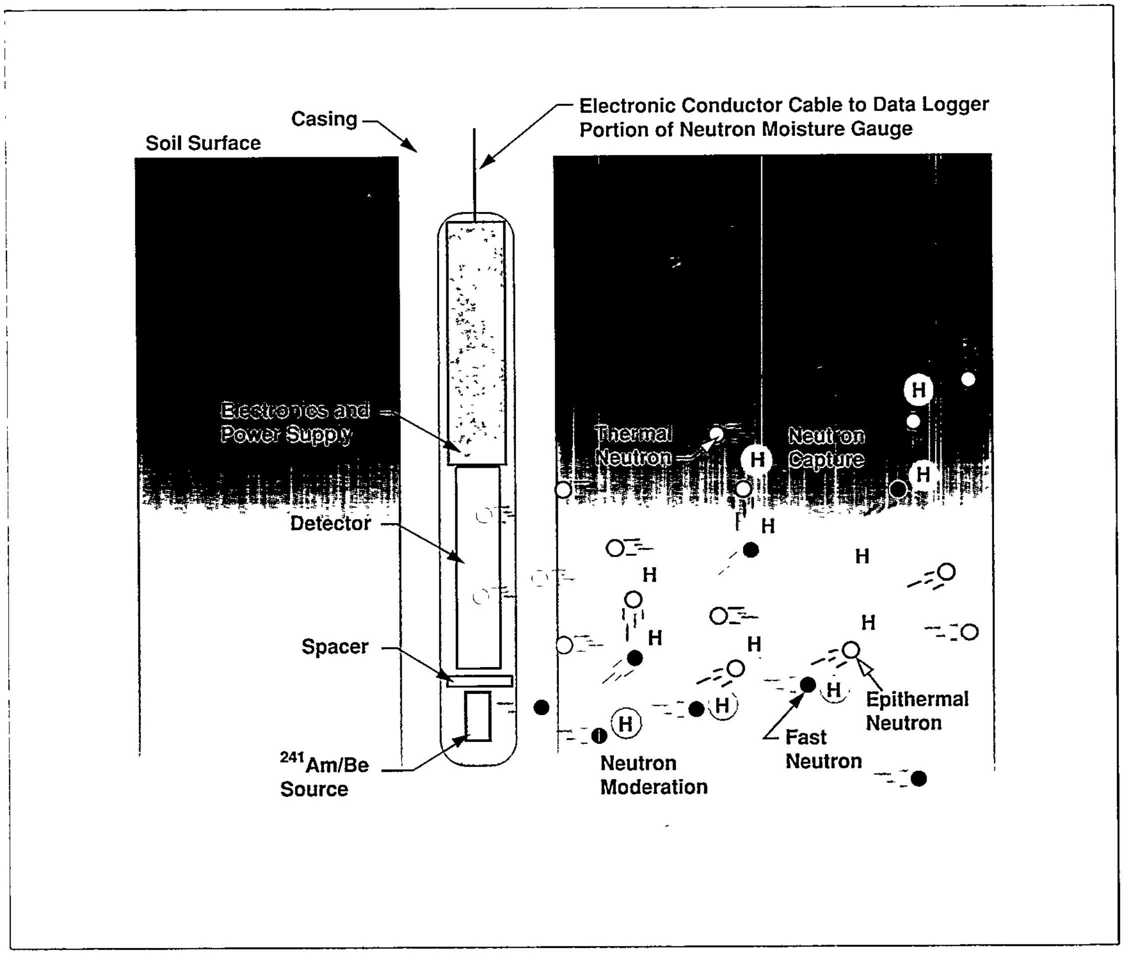

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