SOURCE-DETECTOR GEOMETRY IN RELATION TO NEUTRON PROBE CALIBRATION

By

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CHAPTER I

INTRODUCTION

The neutron soil moisture meter was first developed in the early 1950's. Neutron scattering is an excellant method of in situ soil moisture measurement because it permits repeated measurements from the same sample. It is not influenced by other soil factors such as soil temperature and salt concentration, and it gives an accurate indication of the soil moisture in a soil profile. The equipment utilized with the neutron scattering technique consists of a probe which contains a fast neutron source, slow neutron detector, and a preamplifier; a digital readout scaler or a ratemeter which counts the electrical pulses from the slow neutron detector; and a 6 volt battery and power supplies.

General recommendations at present are that the fast neutron source should be located at approximately the center of the sensitive length of the detector tube before calibration and periodic checks be made after calibration to insure that the calibration curve does not change. The location of the source may be critical. If so, minor differences in positioning may cause a difference in calibration curves of otherwise similar probes. Seven Nuclear-Chicago model P-19 neutron probes are used in the Oklahoma Experiment Station system and each probe has been found to require a different calibration curve. Identification of the factors causing such differences could lead to a method of arriving at a universal calibration curve.

There are several factors which can contribute to the variation among similar probes. Two factors can be suspected of having a pronounced effect. One is the geometry of the paraffin shield, which is commonly used as a standard in the ratio of soil:paraffin shield. The other factor is the location of the source with respect to the detector tube. The use of a large hydrogenous medium as the standard in place of the paraffin shield reduces the variation in calibration among probes by about one-half. This of course removes the variation due to small differences in geometry in the paraffin shields.

The objectives of this study were as follows:

1. To develop a procedure for determining the midpoint of the anode wire in the detector tube.
2. To determine the center of the sensitive volume of the detector tube.
3. To investigate the relation between the midpoint of the anode wire and the center of the sensitive volume of the detector tube.
4. To determine the effect of the location of the source on the calibration curve of a neutron probe with a side located source.

CHAPTER II

LITERATURE REVIEW

Numerous articles may be found in the literature describing the neutron method. Most of these are not related to principles involved in this study. The literature cited here is by no means intended to be exhaustive and represents approximately one-fourth of the literature relating to the neutron method.

The neutron scattering technique involves the placement of a source of fast neutrons within the medium to be monitored. As the fast neutrons emitted by the source traverse the medium they interact with the nuclei by elastic collisions, during which the neutrons change direction and loose energy resulting in moderation or slowing down, and by inelastic collisions which involves the capture of the neutron by the nuclei of some element in the soil. Elastic collisions are by far the most common in the soil. After the fast neutrons have undergone a sufficient number of these elastic collisions they become slow or thermal neutrons meaning that they are approaching the same mean energy level as other particles at the temperature of that medium (37). The names fast and slow neutrons are relative terms to classify them according to their energy status; a fast neutrons energy level is defined as greater than 10 keV while a slow neutron is less than 100 eV (15). As the moderating power of the material increases, the density of slow neutrons in the vicinity of the source of fast neutrons increases form-

ing a cloud of slow neutrons around the source. The density of this cloud does not continue to increase but reaches an equilibrium, for the particular material being monitored, in about a millionth of a second (37) after the source has been placed in the material.

The moderating power of the various components in the soil varies depending upon the scattering cross section of the element, usually expressed in barns (one barn being equal to 10^{-24} cm^2), and the number of collisions, between a neutron and the nuclei of the element, required to moderate a fast neutron. Hydrogen is the most effective moderator of the common components found in the soil because moderation requires about 18 collisions and H has a cross section of about 2.5 barns (8). The major portion of the hydrogen in the soil is in the form of water. Salt concentration and temperature does not affect the utilization of neutrons. Boron and chlorine do by capturing neutrons. Organic matter and other non-water hydrogen do because they introduce hydrogen that is not in water. Fortunately the boron and chlorine are not present in most soils in appreciable quantities. Concentrations as small as 100 PPM of boron and 1000 PPM of chlorine can have a pronounced effect (12, 37). The effect of non-water hydrogen is very small in comparison to water-bound hydrogen. The reason is not clear but Van Bavel (37) states that a possible reason is the difference in chemical binding between water and organic matter. Some soil components such as kaolinite do contain non-water hydrogen that significantly affects the background count. The general feeling seems to be that the non-water hydrogen is present in very small amounts as compared to the hydrogen present in the form of water. Since the moderation process is little affected except by water-bound hydrogen, then the slow neutron density in the vicinity of

the source can be considered as related to the soil water content. The essential components for soil water determination by neutron scattering are a source of fast neutrons, a slow neutron detector, and a counting mechanism. The source and detector usually being housed with a pre-amplifier circuit in one unit referred to as the probe.

A source of fast neutrons can be prepared by mixing an alpha particle emitting element with beryllium (15,37) then encapsulating the mixture in a metal container. A neutron source prepared in this manner that is capable of emitting 10^4 neutrons per second can be contained in a .95 cm by .95 cm right cylinder. Intimate mixing of the two substances is essential for maximum utilization of the alpha particle source because of the limited range of the alpha particle. The energy characteristics of the neutrons depend on the alpha emitter thus the proper selection is very important. Four different alpha particle sources have primarily been used for soil moisture determination: polonium-210, radium-226, plutonium-239, and Americium-241. Polonium-210 and plutonium-239 are not commonly used because polonium has a very short half life (138 days) and plutonium results in a very bulkly source because of its low activity (15). Radium-beryllium sources (37) have been often utilized because of their long half life (1620 years) and the ease with which they can be obtained although radium does have a rather high gamma radiation level which does present a health hazard. Americium-beryllium (38) sources are increasing in use because of some advantageous characteristics such as the elimination of gamma radiation. This can result in a reduction of the weight of the probe, since less lead shielding is required for operator protection. An increase in counting rate and an increased depth resolution have been observed with

Americium partially because of the lower energy of the neutrons emitted by a source of this type.

Detection of slow neutrons presents a problem because the neutron is an uncharged particle and for detection must be entered into a nuclear reaction that produces a detectable charged particle. Normally neutrons are counted by the use of boron (enriched with boron-10) lined or boron trifluoride gas (enriched with boron-10) filled proportional counter tubes (15,30,37). The enrichment with boron-10 is necessary because it has a much larger neutron capture cross section than boron-11. These tubes consist of a thin wire centrally located and completely insulated from the outer walls of the tube with a voltage drop of 1000 to 1500 volts between the outside wall and the wire. The detection of neutron occurs by a boron-10 nuclei absorbing a neutron then emitting an alpha particle which produces an ionized track in the gas filled chamber, resulting in a discharge pulse (37). The discharge pulses are almost instantaneous (approximately 100 μ seconds) and do not limit the counts per unit of time that would normally be encountered in soil moisture measurements. The boron-10 reaction is selective for slow neutrons and ignores the fast neutrons; thus, a count per unit time of the discharge pulses from the detector tube gives a neasure of the slow neutron density in vicinity of the source and detector tube. The discharge pulses from the detector tube can be counted by a rate meter as described by Underwood et al. (32) or by a digital read-out scaler as described by Holmes and Turner (13) and Stone et al. (30).

One of the most important factors to consider when using the neutron probe is the initial calibration because all future moisture measurements depend on this calibration. Certain steps must be taken

to insure that the calibration curve obtained is the most accurate possible and remains so during use.

According to Cohen (4) two features of the probe must be determined before a field calibration can be made: the effective volume of soil measured by the probe and the point on the probe which determines the center of this effective volume during measurements. The thickness of the layer of influence depends somewhat on the moisture conditions of the soil but 15 cm is the value most commonly used in soil moisture studies. This is despite the fact that readings taken in successive 15 cm increments have been shown to be less than an infinite volume for laboratory calibrations. For laboratory calibrations a container at least 91 cm in diameter filled with soil as described by Van Bavel et al. (36) is recommended. Some investigators (4,28) have determined the sampling center, which they refer to as the sensitive center, which they used as a reference point to measure depth for different probes of the side located type. Cohen found the sensitive center to be different for two similar probes and that the source was not located at the sensitive center. He also observed that with a change of the detector tube to a different model the sensitive center changed. The most common reference point for depth measurements has been the center of the source. Some workers (10,36) recommend that the source should be located before calibration approximately at the center of the sensitive volume of the detector tube for a probe with a side located source. By this method the detector tube is symmetrically located within the layer of influence. By using the center of the source and the center of the sensitive volume to reference depth measurements the best indication of the soil profile moisture conditions can be obtained.

After the calibration has been completed, periodic checks should be made to ensure the validity of the calibration curve against drift.

Drift from the calibration curve may occur for reasons such as change in the source strength, change in the source or detector position, decreased in efficiency of the boron trifluoride tube, variation in the voltage applied to the detector tube, or faults in the counting equipment (2). A simple method of determining if the calibration curve has changed involves the utilization of a series of standards which might be polyethylene cylinders (33), cadmium shields (2), or salt solutions (36).

A very important feature of any type of equipment is its sensitivity and the neutron probe has been considered to be sensitive to changes in soil moisture and being able to determine the soil moisture content to within one or two percent on the volume basis (37). Van Bavel (34,35) has discussed the efficiency of a probe which is defined by the equation $a=N/s\theta$ where N=counts per minute, s=source strength in millicuries and θ=water content on a volume basis. Multipling both sides of this equation by s gives sensitivity $S=sa=N/\theta$. Meriam and Copeland (20,21) relate sensitivity to the slope of the calibration curve with counts per minute plotted against water content by volume. This gives sensitivity the same dimensions as the above equation which is the most commonly accepted definition of sensitivity.

From the above, it has been recommended that the neutron source should be located approximately at the center of the sensitive length of the detector tube. However the effect of the source not being located at the center of the sensitive length has not been reported. The literature also states that steps should be taken to maintain the source at the same location after calibration. Again, the deviation from the original source location has not been studied as to how a change in source location might affect the calibration curve.

CHAPTER III

MATERIALS AND METHODS

Detector: The soil moisture measuring probe utilized in these studies was the Nuclear-Chicago Corporation model P-19. Longitudinal and transverse cross sections of this probe are shown in Figure 1. This probe employed a detector tube designated as Nuclear-Chicago model NC-213 boron trifluoride proportional counter tube. This tube was described by Nuclear-Chicago as having an 8.75 inch (22.3 cm) length; 1 inch (2.54 cm) diameter with an active length of 4 inches (10.14 cm) and an active diameter 15/16 inch (2.38 cm). It was filled with 96% enriched ^{10}B in BF_3 filled to a pressure of 30 cm Hg. The operating voltage was 1400 on a tungsten anode with a plateau slope of 3% and a connector type UG-560/U. The cathode was optionally of copper or brass. The anode diameter was .001 inch (25μ).

Source-detector geometry: The sensitive portion of a proportional detector generally coincides with the position of the anode wire, with due allowance for "end effect". In order to be able to refer measurements in this study to the position of the anode wire in the detector tube, a defunct tube was dismantled to ascertain its dimensions. For comparison an X-ray radiograph also was made of the actual detector used in this study. This permitted verification of the position of the anode wire. Calculations of the position of the wire reported in this study were made from the radiograph by triangulation. The end insulators

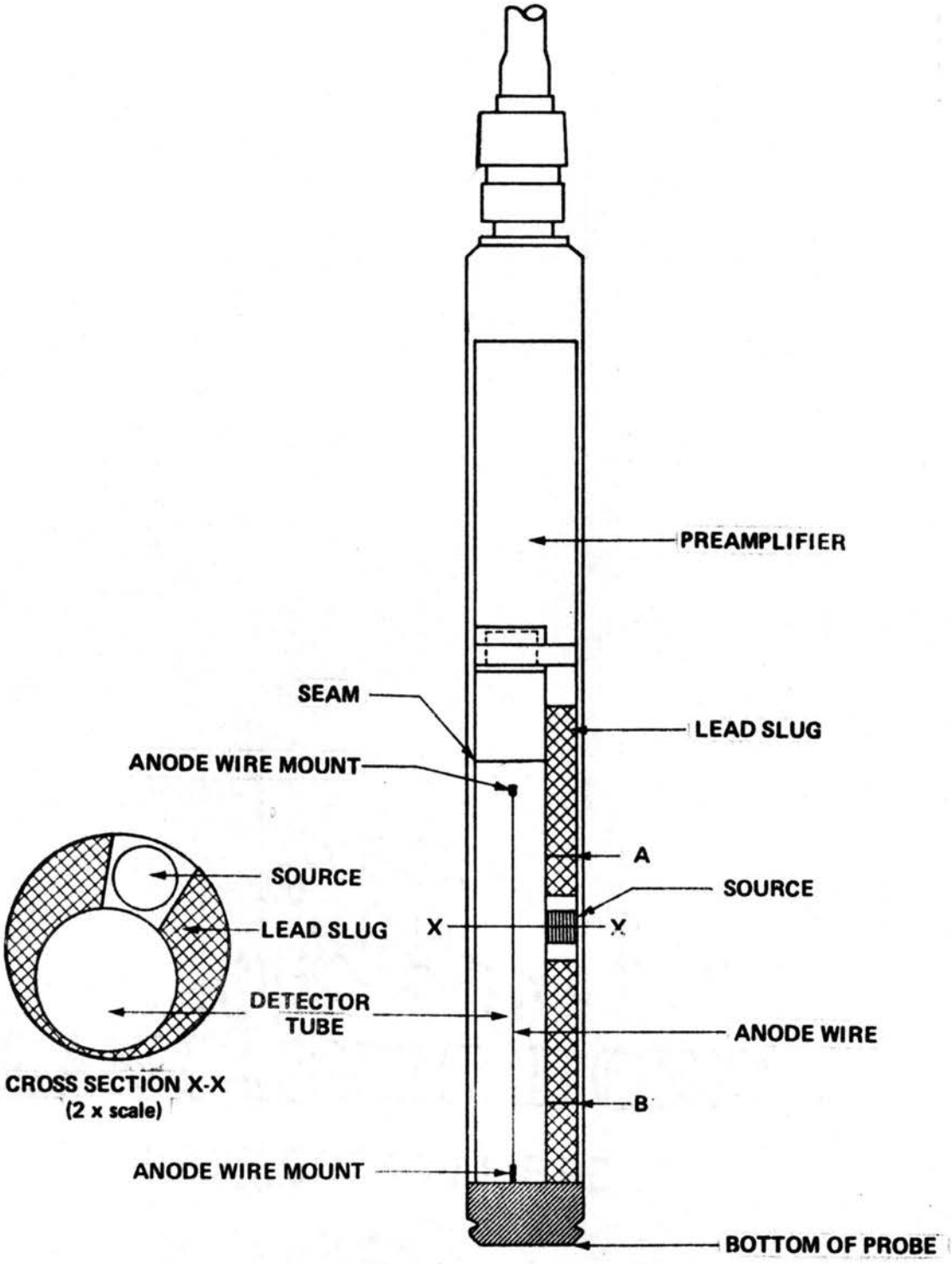

Figure 1. Longitudinal and transverse cross sectional views of a neutron probe. The source is shown positioned above the midpoint of the anode wire.

supporting the anode wire were clearly recognizable in the radiographs although the anode wire itself was not. In these comparisons the positions of the anode wires were not discernably different. The detector tubes in the other probes reported in this study were not X-rayed (all used the NC-213 detector tube).

The P-19 probe contains the detector tube, the neutron source and a preamplifier. The source is positioned at the side of the detector tube. The volume between the detector tube and the probe casing is filled with a lead slug whose transverse cross-section describes a crescent as can be seen in Figure 1. The source is positioned in a slot in this slug. The source is a .95 cm by .95 cm right cylinder. The slot in the slug is a nominal .95 cm wide and 2.5 cm long. The source is held in this slot by a spring-loaded clip (dropping the probe onto a firm surface can cause the source to be repositioned in the slot). The lead slug in the probe studied was 16.1 cm long. This dimension was found to vary among probes. The slug was shortened by 2.5 cm at each end to provide the freedom of movement to position the source at any point between 8.3 cm and 18.9 cm from the outside bottom of the probe (from A to B in Figure 1.) The volume of lead slug thus sacrificed was replaced by spacers of aluminum of similar cross-sectional shape. These spacers were of various heights in multiples of 1 mm. Changing the position of the source required dismantling of the probe and rearranging the spacers. This technique permitted holding the source firmly in place during a set of measurements and proved a positive means of positioning the source to within 1 mm of the desired position. The slot in the lead slug was modified by filling the portions beyond the dimensions of the source with lead, thus preventing the

possibility of the source being moved within the slot.

Hydrogenous Media: Readings were made in four hydrogenous materials: the paraffin shield supplied with the probe; urea, fertilizer grade, (NH_2CONH_2) which appeared to the probe as about 19% water by volume; ground aluminum sulfate, technical grade, ($AL_2(SO_4)_3 \cdot 18H_2O$) which appeared to the probe as about 49% water by volume; and water. The urea and aluminum sulfate were contained in 210 l drums fitted with 3.8 cm O.D. steel access tubes mounted on the center axis of the drum. (These were obtained from an electrical supply company as "1½-inch E.M.T.".) The drums were filled to a depth slightly exceeding the diameter (57 cm) of the drum. Both of these compounds were in a dry crystalline form. The drums were fitted with a 75μ plastic liner which was folded to the center at the top of the material and taped to the access tube, as to completely enclose the materials in a plastic container, which prevented the entry of any foreign material including water vapor. The water medium was contained in a 76 l GI can with the same kind of access tube mounted at the axial center of the can. A layer of mineral oil over the surface prevented evaporation of water. The access tube was mounted to protrude through the lid of the can. The seams were taped to prevent entry of any foreign material. All three containers were placed 15 cm above a concrete floor on open-type concrete blocks. A plug was placed in each of the three access tubes so that the probe could be reproducibly and accurately placed at the center of the hydrogenous medium by the lowering the probe in the tube until it rested on the plug.

Counting: At least 100,000 counts were taken during each reading. Therefore the coefficient of variation due to random counting was .003.

To permit the detection of a malfunction during this extended count period the 100,000 counts were taken in five consecutive portions, each of which was approximately 20,000 counts. Thus, the count rate of any one counting segment differing significantly from the others was an indication of a malfunction. The Nuclear-Chicago model 2800B scaler was used to record the count and a Monsanto Electronics model 100B counter-timer was used to record the counting interval. The scaler and the counter-timer were wired to a common on-off switch to permit simultaneous switching. Counting results were expressed as counts per minute.

Once the source was mounted at a desired position in the probe the 100,000 count readings were made in each of the four hydrogenous media before changing the source-detector geometry. The order of reading in the four media was initially randomized, but the same order was followed thereafter. The probe was not moved to a succeeding medium until all 100,000 counts were obtained. The total elapsed time for reading in all four media was generally 3 hours. On several occasions excessive drift in count rate or complete failure of a component occurred necessitating repairs so that several days lapse of time might occur in a set of readings. The order of reading the positions of the source from 8.3 to 18.9 cm was a random selection. Subsequent to this set of readings a second and third set were taken. These sets did not include the entire range of positions but concentrated on the middle one-third to accurately locate the peaks of the response curves.

Adjustment of Data: Counting drift caused by the extended period of time for the sets of measurements caused vertical displacement in the response curves in the several sets of readings in the hydrogenous

media. However, the peaks of these curves generally appeared to be at the same abscissa when plotting count rate versus distance of the source from the bottom of the probe. A procedure was developed to adjust these data for count rate drift effect. While the shape of the curve resulting from positioning the source along the detector tube would be expected to be bell-shaped in general, the resulting curves were parabolic. Evidently the source was not positioned far enough in this study for the bell-shaped characteristic to develop. Thus, a second degree polynomial was fit by least squares to the individual runs. The resulting equations were solved for the maxima. The abscissas of the computed maxima for a set of runs in a given medium were approximately equal. Since the data obtained in the first set covered the widest range of source positions it was used as the reference curve. The count rate of each point in the second two runs in each medium were then each adjusted by the fractional amount of displacement between the count rate at the maximum point for the curve for the particular set from the reference curve. This procedure of adjustment resulted in four sets of data, one for each hydrogenous medium. A second degree polynomial was then fit by least squares to each of these four sets of adjusted data. The abscissas of the maxima of these four curves were again approximately equal.

The drift effect that caused the various runs to be different could also cause the comparisons between hydrogenous media to be different so adjustment was made for this also. To achieve this adjustment the source was adjusted to a position corresponding to the maxima on the four curves. Readings with this positioning were then made in the four media in a randomized block design with four replications. Thus,

any drift in count rate would be confounded with replications. The ratios between the average count rates in the four media were computed and the equations for the four parabolic curves were again adjusted so that the ratios between the maximum corresponded to those in this randomized block determination.

As can be seen above, all the adjustments were made on the ordinate values only. The procedure was designed to remove only count-rate drift effects.

CHAPTER IV

RESULTS AND DISCUSSION

The adjusted curves describing the counts in the four hydrogenous media are shown in Figure 2 and the coefficients and other statistical data for the curves are shown in Table 1. The adjusted data points for all the individual readings in the urea are shown. This grouping of points was typical of those in the other media as can be seen from the range of the standard error of determination shown on each curve. It is plotted at the mathematical maximum for each curve. The vertical distance between the bars is 2 times this standard error. The values for the abscissa of the maxima for the water, aluminum sulfate, shield and urea were in close agreement, they were 13.6 cm, 13.4 cm, 13.3 cm and 13.6 cm, respectively. Obviously these curves show a pronounced effect of source positioning with respect to the detector. A shift in position of as small as .5 cm would provide a significant difference in count-rate in a given medium. The greater the hydrogen concentration of the medium, the greater the steepness of the curve leaving the peak as is seen by contrasting the curves for urea, aluminum sulfate and water. The paraffin shield is of course a finite, anisotropic moderating system, but also exhibits the characteristic peak. The uniformity of the position of the peak of the curves implies a center of the sensitive volume of the detector tube. This center would be expected to be at the midpoint of the anode wire in a symmetrically constructed detector tube. (This means the anode wire is centered in the gas tube.)

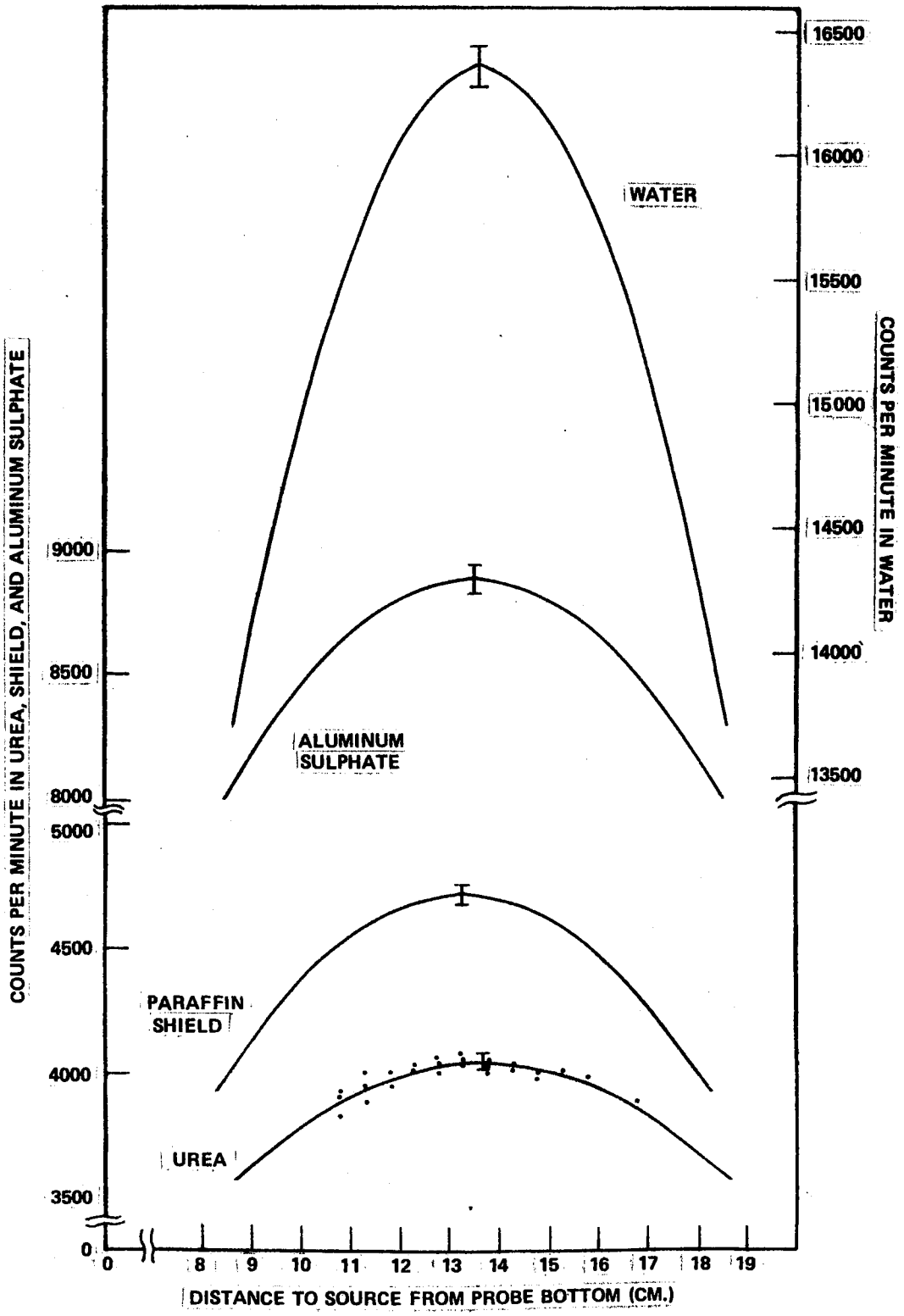

Figure 2. Second degree polynomial curves of count rate vs. source position for four hydrogenous materials. The adjusted data points are shown for urea. The vertical bars are two times the standard error and are plotted at the maximum of each curve.

TABLE I

COEFFICIENTS FOR LEAST SQUARES FIT SECOND DEGREE POLYNOMIAL EQUATIONS AND STATISTICAL ESTIMATORS*

Medium	a	b	c	r	r^2	s
Paraffin shield	510.0	730.0	- 31.6	0.88	0.77	38
Urea	1400.0	441.0	- 18.6	0.88	0.77	28
Aluminum sulphate	4050.0	824.0	- 35.1	0.82	0.67	61
Water	1430.0	2530.0	-107.0	0.96	0.92	82

*Equations are for the curves of Figure 1. Equations were obtained by least squares analysis of the adjusted data. Coefficients are for the model $Y=a + bX + cX^2$ where Y is counts per minute and X is the distance (cm) between the center of the source and the bottom of the probe. The r, r^2 and s are the correlation coefficient, index and standard error of determination, respectively.

The length of the anode wire on the model NC-213 detector tube as determined from the radiograph was 12.2 cm. The end of the wire is 2.3 cm from the bottom of the detector tube and the end of the detector tube is 4.9 cm from the bottom of the probe which will be the reference point for all positioning measurements in this paper. Thus, the anode wire midpoint is 13.3 cm (12.2±2cm / 2.3 cm / 4.9 cm) from the bottom of the probe. While making measurements from the radiograph and from the dismantled detector tube a simpler estimate of the midpoint of the anode wire was noted. This point was the midpoint between the bottom of the detector tube and the seam on the upper part of the tube shown in Figure 1. This seam is between the detector portion of the housing for the anode connector and the coaxial connector. This dimension was a constant for the four NC-213 detector tubes measured in this study. The validity of this dimension in estimating the geometric center of the anode wire was confirmed by a manufacturer* of detector tubes to be a representative feature of detector tubes similar to the model NC-213 as well as all tubes suitable for use in the P-19 probe made by them. Using one half the distance from the tube bottom to the seam, 17.1 cm, to estimate the center of the anode wire, 8.6 cm, added to 4.9 cm gives 13.5 cm from the reference point. Thus, it is seen from the above results that the two methods of estimating the geometrical center of the anode wire agree very closely; and comparing these with the four estimates of the center of the sensitive volume of the detector tube, the midpoint of the anode is seen to determine the center of the sensitive volume of the detector tube.

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To evaluate the effect of the source location on the calibration curve of a probe it is necessary to change counts per minute for urea and aluminum sulfate to a ratio that is comparable with the soil:paraffin shield ratio used in the calibration. This is done by dividing the counts per minute for urea and aluminum sulfate at a given source-detector location by the counts per minute for the paraffin shield at the same location. Thus the urea:paraffin shield ratio and aluminum sulfate:paraffin shield ratio are determined for a given displacement from the center of the sensitive volume. If a probe were calibrated with the source at one location, and later the source shifts position, the result, as shown in Figure 3, would be a shift in the calibration curve. The solid line represents an arbitrary calibration with the source at the center of the sensitive volume. The points above the curve at 18.7% and 49.3% show the result if the source moves 1.5, 3, 4 or 5 cm above or below the center of the sensitive volume of the detector tube. It is seen from the figure that the same displacement of the source results in a greater deviation from the original curve at the higher moisture content than at the lower moisture content. This indicates that the calibration curve tends to remain constant at the intercept and tilts upward increasing the slope as the source moves up or down from the center of the sensitive volume. The fact that the slope increases as the source moves from the center of the sensitive volume should not be misinterpreted to mean an increased sensitivity. The effects of the paraffin shield have to be considered before reaching a conclusion on sensitivity. By comparing the curve for the paraffin shield to the curves for the other hydrogenous media it is seen that the paraffin shield does not behave as the apparent water content would

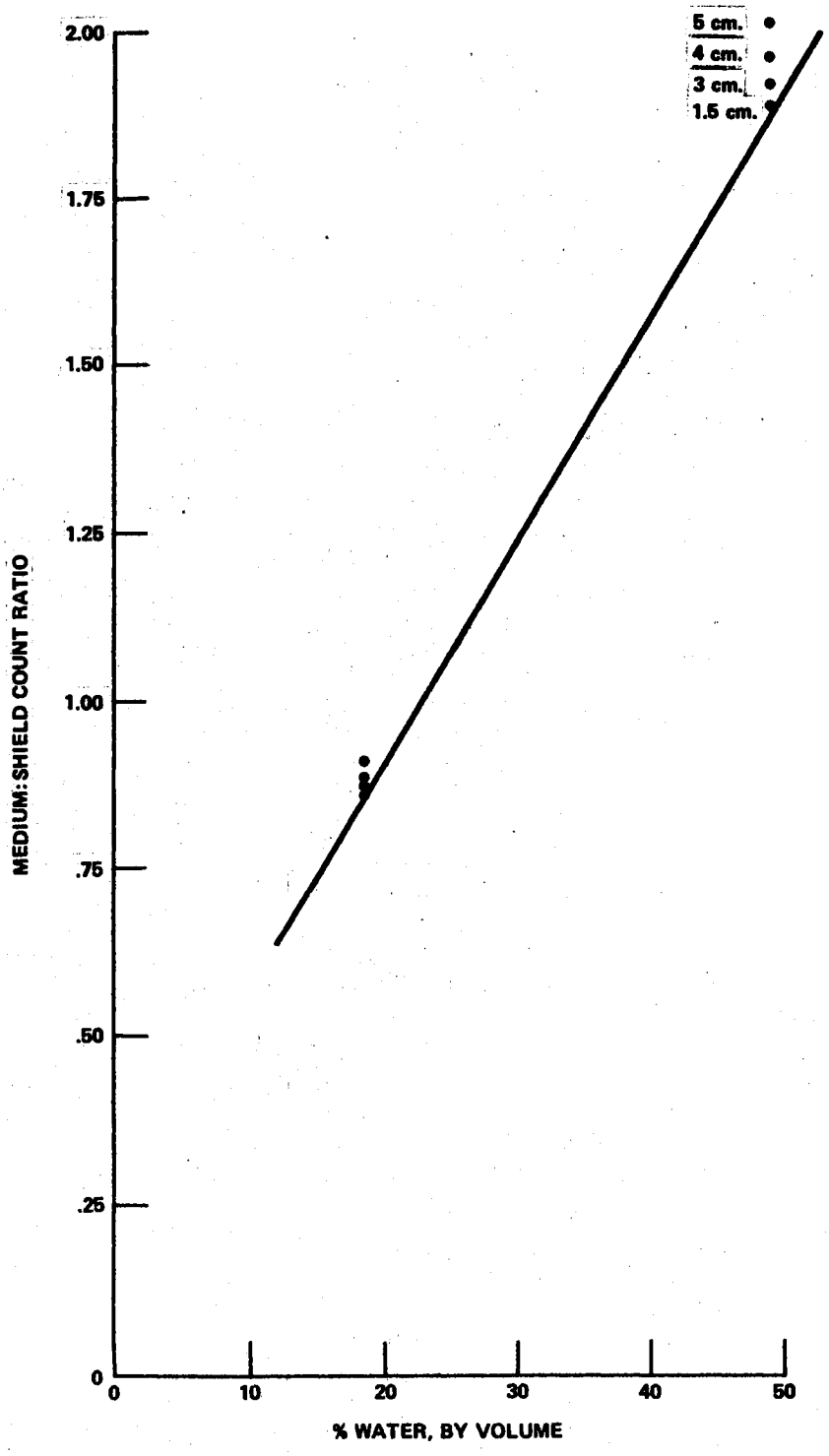

Figure 3. Arbitrary calibration curve and diviations at two water contents resulting from movement of the source from the center of the sensitive volume. The numbers by the upper points indicate the displacement (cm) of the source from the center of the sensitive volume. The lower points are in the same order.

indicate. Rather it has a greater change in counts per minute for a given change in the source location. This is largely a result of the strictly finite dimensions of the container. Thus, these dimensions cause the increased slope of the calibration curve rather than an increased water resolving power of the probe. The sensitivity which will be defined here as $S=dN/d\theta$ where N is the counts per minute and θ is the water content on a volume basis. Sensitivity expressed in this manner agrees with the analysis of van Bavel (35) and Merriam and Copeland (21). In regard to the sensitivity of the probe consider the graphs of the polynomial curves plotted in Figure 2 where counts per minute is plotted against distance from the center of the sensitive volume of the detector tube. From the foregoing equation, it is seen then that the greatest sensitivity results from positioning the source at the center of the sensitive volume of the detector and the sensitivity decreases as the source is moved above or below the center of the sensitive volume. Additionally, the source should be located no more than .5 cm above or below the center of the sensitive volume and should be permitted to move no more than about 1 mm from this position thereafter or the calibration will significantly change. Such changes can be detected with periodic checks made by using some of several standard materials such as those reported here and elsewhere (2,33,36).

Since the source location does affect sensitivity and calibration of a probe, then great care must be exercised in manufacture and subsequent handling. Three probes were examined for the location of the source with respect to the midpoint of the anode wire which has been shown to be a good estimate of the center of the sensitive volume. The source positions with respect to the anode wire midpoint were .64 cm

below, .25 cm above and 2.54 cm below. This would indicate that the variation in source location could be a serious problem among operational probes. Furthermore, it even seems advisable to check source position prior to calibrating a new probe.

Calibration curves for several P-19 probes are shown in Figure 4. It will be noted that the trend of greater difference at higher moisture content which was seen in Figure 3 appears in Figure 4 also. This indicates that variation in source location may be a component of this variation. Probes 194, 301 and 249 were the three cited in the preceding paragraph. Probe 121 is the one on which the detailed measurements were made in this study. Considering the measurements on the positioning in the previous paragraph and the degree of change predicted in Figure 3, it is obvious that at least a second source of variation is present. The remaining variation is approximately the amount due to the variation between readings in the paraffin shields mentioned in the introduction. The variation due to these two sources does not completely account for the spread of the calibration curves in Figure 4. Measurements of source-detector geometry were not made at the time of acquisition of these probes so there is no way to determine the geometry at the time of initial calibration. However it can be said with certainty that the combination of differences due to source-detector variation and variation in readings in the paraffin shields are in the order of magnitude of the range of differences noted in Figure 4.

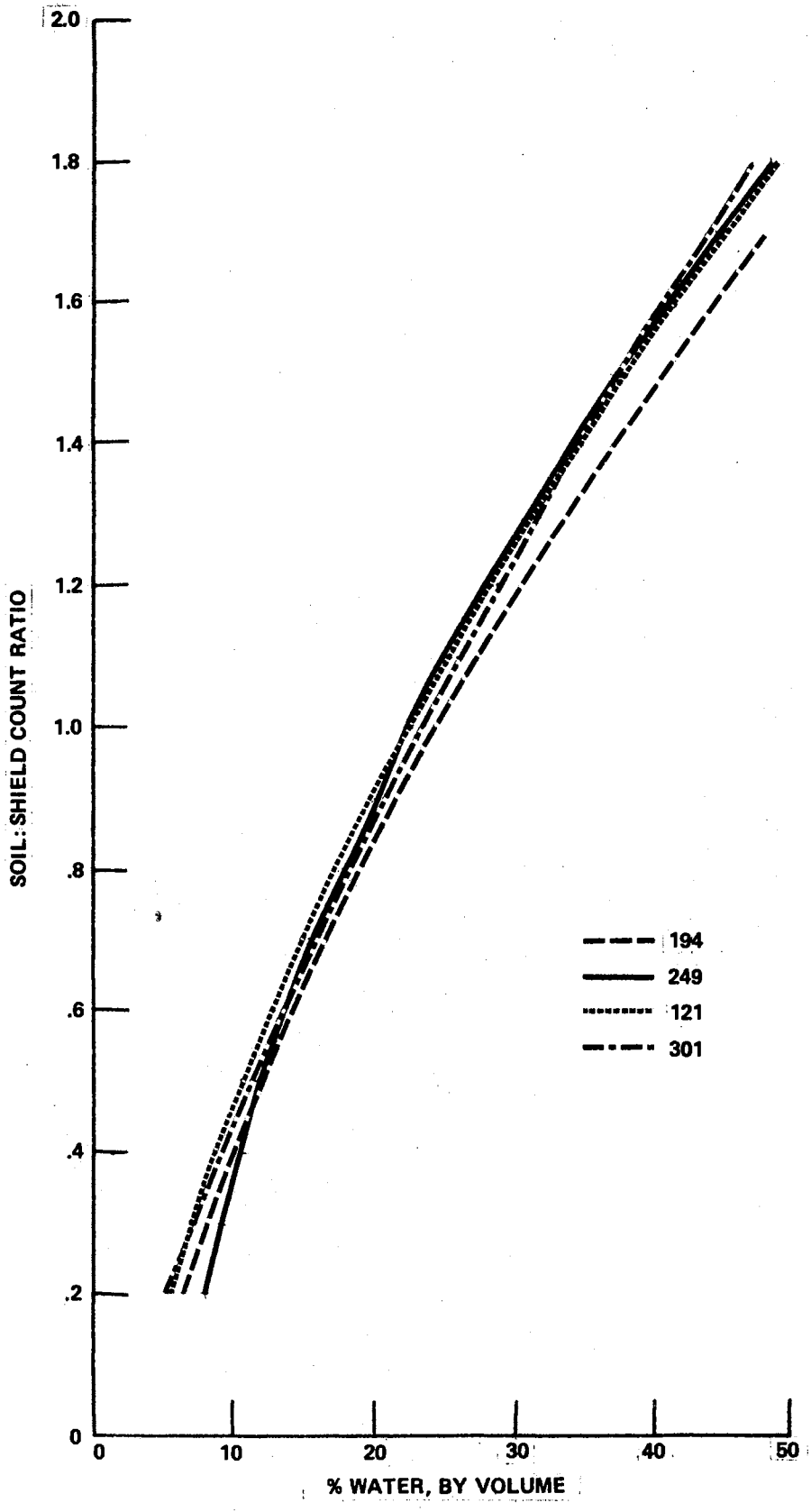

Figure 4. Calibration curves for four different P-19 neutron probes.

CHAPTER V

SUMMARY AND CONCLUSIONS

The above results lead to the following conclusions:

1. The position of the source with respect to the detector tube has a pronounced influence on the count rate. A displacement of the source in the order of 1 mm is detectable from the change in count rate.
2. For maximum sensitivity from a probe with a side located source, the source should be placed directly opposite the center of the sensitive volume of the detector tube.
3. The center of the sensitive volume of the detector tube is at the midpoint of the anode wire in a symmetrically constructed detector tube.
4. A change in the calibration will result from a change of source location as small as 1 mm.

Vigilance to any possible change is essential to ensure the validity of the calibration curve. To increase the precision of the neutron probe the following procedures are recommended:

1. Find the center of the sensitive volume of the detector by measuring from the seam on the detector to the bottom. The center of the sensitive volume should be at the midpoint of this portion of the detector. This can be checked with X-ray radiograph if there is doubt as to

the symmetry of the detector. The insulators and supporting stems for the anode wire should be clearly recognizable in the radiograph.

2. Determine that the source is immobile in the lead slug (or whatever positioning device employed) and that it is mounted exactly opposite the center of the sensitive volume of the detector. Then reposition the source to the centered position if necessary using shims at the top or bottom of the mounting slug. If the slot accomodating the source is of significantly larger dimension than the source, fill the excess space with material of the same composition as the slug.
3. Use the location of the accurately-positioned source as the reporting depth for measurements in the soil.
4. Make periodic check readings in large containers of hydrogenous media. The media reported in this study have worked well for many years. Some investigators prefer to use large cylinders of polyethylene or some other plastic material which will not change composition or shape with time. Any change in the ratios between readings in such media will be a indication of a change in the calibration of the detector. Such change would likely be due to a change in the source-detector geometry. This might be caused by accidental movement of the source or could result when a faulty detector tube is replaced with a detector tube of different geometry.

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