ISOTOPES AND RADIATION

NUCLEAR TECHNIQUES IN GEOLOGIC, LUNAR, AND PLANETARY STUDIES I

2. Effects of Neutron Source Type on Soil Moisture Measurement, *Irving' Goldberg, Norman A. MacGillivray (Cal. State Dept. Water Resources), Robert R. Ziemer (USDA-Cal)*

A number of radioisotopes have recently become commercially available as alternatives to radium-225 in moisture gauging devices using alpha-neutron sources for determining soil moisture, for well logging, and for other industrial applications in which hydrogenous materials are measured. To date, little work has been reported on the comparability of data obtained with different sources when used in soil moisture meters of the same design. MacGillivray et al.[1] developed a tentative hypothesis that differences in "sphere of influence" due to different types of sources could account for anomalies they observed in correlating soil moisture data. This study investigates that hypothesis.

Measurements with six moisture meters having sim ilar geometry but different neutron sources [^{226}RaBe, ^{239}PuBe, and ^{241}AmBe (α n)] were made in noninfinite vol-umes of soil at three moisture contents (1, 43, and 48% by volume), and in an effectively infinite volume of water. Detectors were interchanged between source housings to eliminate differences attributable to detection systems. Thus, measurements were made using each of the six sources with each of the six detection systems in each of the four media, yielding 144 measurement combinations.

If differences in neutron energy between various sources influence the volume measured by the meter, then it would be expected that: 1) measurements made in the effectively infinite water medium would be unaffected; 2) there would be a minimum effect in the driest soil, since indicated moisture was near zero; and 3) the greatest difference would be observed in the mid-moisture range in noninfinite size containers. A straight line connecting the count rates obtained from the driest soil and from the water media for each meter would therefore not be affected by variability due to neutron energy differences. The deviation from that straight line of count rates obtained in the two intermediate moisture media, expressed as a percentage of the predicted count rate, is shown in Table I.

TABLE I
Percent Deviation of Observed from Predicted Count Rates

Source	$Ra\text{-}Be_1$	$Ra\text{-}Be_2$	$Am\text{-}Be_1$	$Am\text{-}Be_2$	$Pu\text{-}Be_1$	$Pu\text{-}Be_2$
Soil at 43% Moist	-2.9[a]	-3.3[a]	1.8[a]	0.2	0.4	0.1
Soil at 48% Moist	-2:2[a]	-2.6[a]	1.8[a]	0.3	0.0	0.1

[a]Significantly different from predicted count rate at both 95 and 99% level of. confidence.

The two Ra-Be sources were not significantly different from one another, and gave values about 3% lower than $Am\text{-}Be_2$ and the two Pu-Be sources, and 4.6% lower than $Am\text{-}Be_1$. The actual values of these differences are a function of the physical characteristics of our test media, and would not be applicable to any other environment. They do, however, confirm the hypothesis that the type of neutron source affects moisture determinations in noninfinite containers due to the larger volume sampled with the higher-energy Ra-Be neutron sources. Moisture determinations made in homogeneous media with an "infinite" volume would not be affected by different neutron sources.

Differences would be expected when sampling in heterogeneous media. If moisture meters equipped with different sources are to be used interchangeably in layered soils, or in soils with stones or large voids, the data should be carefully scrutinized for differences due to source before comparability is assumed.

1. N A. MacGILLIVRAY, L. R. GLANDON, and D. R. DAVIS, "Office Report on Vegetative Water Use Studies in the San Joaquin Valley, 1963" California Department of Water Resources, San Joaquin District (1967) (in press).

EFFECT OF NEUTRON SOURCE TYPE

ON SOIL MOISTURE MEASUREMENT*

by

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*Presented at the Thirteenth Annual Meeting of the American Nuclear Society, San Diego, California, June 12, 1967

INTRODUCTION

Neutron gauging has become an accepted and commonly used technique for rapid and precise determination of moisture content of granular material, such as soil. Because of the proliferation of instrumentation incorporating basic differences in design, the correlation of data collected with. such different neutron meters has become a matter for concern. Although. a number of investigations have been conducted to determine the effect of meter geometry upon soil moisture data,[1,2,3] only recently has interest been expressed on the comparability of different radioisotopes which may be used. as the neutron source[4].

Initially, most instruments were equipped with radium-beryllium as the neutron-source. The higher energy gamma radiation emitted by the Ra-Be source requires heavy shielding, which limits portability of the meter. Consequently, it is desirable to replace the Ra-Be source with one having a lower gamma/neutron flux ratio. Until recently, the high cost or limited availability of such alternative sources has restricted their use.

When this study was begun, neutron meters* containing sources with ^{226}Ra, $^{227}A_c$, ^{239}pu or ^{241}Am as the primary alpha emitting isotope were available for comparison.

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* Manufactured by the Nuclear-Chicago Corporation, Des Plaines Illinois. (Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the State of California or by the U. S. Department of Agriculture is implied.)

THE PROBLEM

Field studies made by one of the authors in 1963, for the purpose of comparing counting rates of ^{227}AcBe and ^{239}PuBe meters produced results that suggested a high degree of correlation. Included in these data, however, were a few instances where count rates differed significantly from the linear relationship. MacGillivray, et al[5], developed a tentative hypothesis suggesting that the Ac-Be meter might have a larger "sphere of influence" than the Pu-Be meter.

The work reported in this paper investigates the possibility that the type of neutron source may affect moisture determinations.

Factors Affecting Neutron Characteristics

Differences in the neutron energy distribution of different sealed sources resulting from bombardment of a beryllium target depend primarily upon incident alpha particle energy. Other factors affecting neutron energy distribution, such as the mixing of isotope with. target, and the construction of the meter, can be assumed to be of minor significance for meters of the same design and manufacture.

Although. energy spectra of specific alpha-neutron sources have not yet been precisely determined, the principal alpha energy range of each of the four available isotopes (Table I) suggests that they can be placed in two energy groups. In view of the dependence of neutron energy upon alpha energy, we should expect

TABLE I

NEUTRON SOURCE CHARACTERISTICS

Neutron Source	Half-life (years)	Specific activity (curies/gram)	Neutron yield (10^6 n/sec.Ci)	Gamma dose rate per 10^6 n/sec mrhm	Range of Principal Alpha Energy mev
^{226}RaBe	1,620	0.98	13.	6o.	4.78 - 7.68
^{227}AcBe	22	71.89	18.	8.	5.71 - 7.44
^{239}PuBe	24,360	0.06	1.4	1.7	5.15
^{24l}AmBe	458	3.24	2.7	1.0	5.48

the neutrons from Am-Be and Pu-Be sources to require fewer collisions to be reduced to a given energy than would be required for the higher energy neutrons from Ra-Be and Ac-Be sources. Hence, for a given density of moderating nuclei, the distance a neutron must travel before thermalization, and consequently the volume affected by the scattered neutrons, would be smaller for Am-Be and Pu-Be sources than from Ra-Be and Ac-Be sources.

These considerations lead to the conclusion that discrepancies in indicated soil moisture could occur when sampling in heterogeneous media, or in containers which have a finite diameter. For example, difficulties could be experienced when measurements are made in layered soils, or in soils with stones or large voids. Differences in moisture data due to neutron energy would not be expected to be significant in homogenous media of "infinite" volume.

METHODS AND RESULTS

Three experiments were conducted to test the hypothesis that soil moisture determination can be affected by different neutron sources, and to determine the magnitude and direction of any effect which may exist.

Experiment I: Measurements were made with four neutron meters in six 2-foot diameter containers, five filled with soils which had been uniformly mixed at different water contents (1, 5, 25, 43 and 48% by volume), and one filled with water. The media containing the soils were not infinite with respect to the volume affected by the neutron sources. The container of water, however, had been established as an effectively infinite medium. The neutron sources in the meters were ^{226}RaBe, ^{227}AcBe, ^{239}PuBe, and ^{241}AmBe (α, n). Ten replicated counts were made in each. soil with each meter. Results of this experiment are listed. in Table II, which shows ratios of mean count rates observed in each medium to the mean of the count rate measured in water.

The results of this experiment indicate that relatively small differences exist between the meters tested in these media. Ratios obtained using the instruments containing the ^{239}PuBe and the ^{241}AmBe sources are consistently higher than those for the ^{226}RaBe and ^{227}AcBe group, under the experimental conditions imposed. These data generally suggest confirmation of the hypothesis, which would result in separate groupings of the instruments containing the ^{226}RaBe and ^{227}AcBe sources, and those containing the ^{239}PuBe and. ^{241}AmBe sources. However, the method used did not allow for the precise evaluation of the contribution of the different detector systems, and their associated electronic circuitry, to the observed differences. This experiment also did not eliminate the possibility that the differences observed are characteristic of the individual sources tested, and not of the specific alpha-emitting isotope in each source.

<u>Experiment II</u>: To isolate possible effects of the detector systems and of variability in individual source type, an additional experiment was performed. Three pairs of moisture meters, having similar geometry, were available. Meters comprising each pair contained the same type of neutron source (^{226}RaBe, ^{239}PuBe, and ^{241}AmBe (α, n)), Measurements were made in non-infinite volumes

TABLE II

Ratio of Mean Count Rate in Various Media,to Mean Count Rate in Water, for Neutron Meters Containing Different Sources

(Moisture content, % by volume)

Source	Medium 1%	5%	25%	43%	48%	100%
^{226}RaBe	.027	.068	.358	.494	.560	1.000
^{227}AcBe	.025	.o68	.370	.486	.559	1.000
^{239}PuBe	.028	.082	.387	.497	.571	1.000
^{241}AmBe	.028	.077	.385	.514	.574	1.000

of soil at three moisture contents (l, 43 and 48% by volume), and in an effectively infinite volume of water. Detectors were interchanged between source housings to eliminate any differences attributable to detection systems. Thus, measurements were made using each of the six sources with each of the six detection systems in each of the four media, yielding 144 measurement combinations. The sequence of the readings was randomized to eliminate any bias associated with time. Ten 1-minute counts were taken for each of the 144 combinations. The probes were rotated after each observation to eliminate any effect of probe direction.

Table III is a summary of the results of this experiment. An analysis of variance, pooling all detector systems, showed that data collected using ^{239}PuBe and ^{241}AmBe sources gave results which were consistently higher than the ^{226}RaBe sources at the 99 percent level of significance, in the mid-moisture range.

It is observed that the two ^{226}RaBe sources were not significantly different from one another, and gave values which were about 3 percent lower than the two ^{239}PuBe sources and one of the ^{241}AmBe sources, and about 5 percent lower than the other ^{241}AmBe source. These differences are significant at the 99 percent level of confidence.

The actual values of these differences are a function of the physical characteristics of the test media used, and would not be applicable to any other environment. They do, however, confirm the hypothesis that the type of neutron source affects moisture determination in non-infinite containers due to the larger volume

TABLE III

Ratio of Mean Count Rate in Various Media, to Mean Count Rate in Water, for Neutron Meters Containing Different Sources*

(Moisture content, % by volume)

Source	Medium			
	1%	43%	48%	100%
Ra_1	.027	.498	.564	1.000
Ra_2	.027	.496	.562	1.000
Pu_1	.026	.514**	.577**	1.000
Pu_2	.027	.513**	.577**	1.000
Am_1	.028	.522**	.588**	1.000
Am_2	.027	.514**	.578**	1.000

* Measurements made with all detection systems and pooled to obtain means

** Significant deviation from source Ra_1 and Ra_2 at the 99% level of confidence.

sampled with the higher-energy neutrons from the $^{226}RaBe$ sources. Moisture determinations made in homogeneous media with an "infinite" volume would not be affected by different neutron sources.

It is further revealed by the statistical analysis that no significant differences exist among the two $^{239}PuBe$ sources and one of the $^{241}AmBe$ sources. The other $^{241}AmBe$ source shows ratios which vary significantly from all the other sources used. It should be noted that the two $^{241}AmBe$ sources were fabricated by different manufacturers. This indicates that it is possible to find apparent differences in results, attributable to individual sources, even of the same type.

Experiment III: In an effort to determine the effects of neutron source type on vertical resolution of soil moisture meters, tests were made in 2-foot diameter containers of sand, water and paraffin. Meters equipped with $^{226}RaBe$, $^{227}AcBe$, $^{239}PuBe$ and $^{241}AmBe$ sources were used. Measurements were taken at one inch intervals from the bottom of the containers to the surface of the sand and water media, and at one-half inch intervals in the paraffin medium. Figure 1 depicts the results of this experiment.

The count rates began to decrease when the sources were approximately 8.00, 5.70, and 4.75 inches below the surfaces of the sand, water, and paraffin media, respectively. The depth at which the instruments detected the surface of a given medium is not precisely the same for all sources. Therefore, it appears that vertical resolution of the instruments in the media used may be dependent on source type.

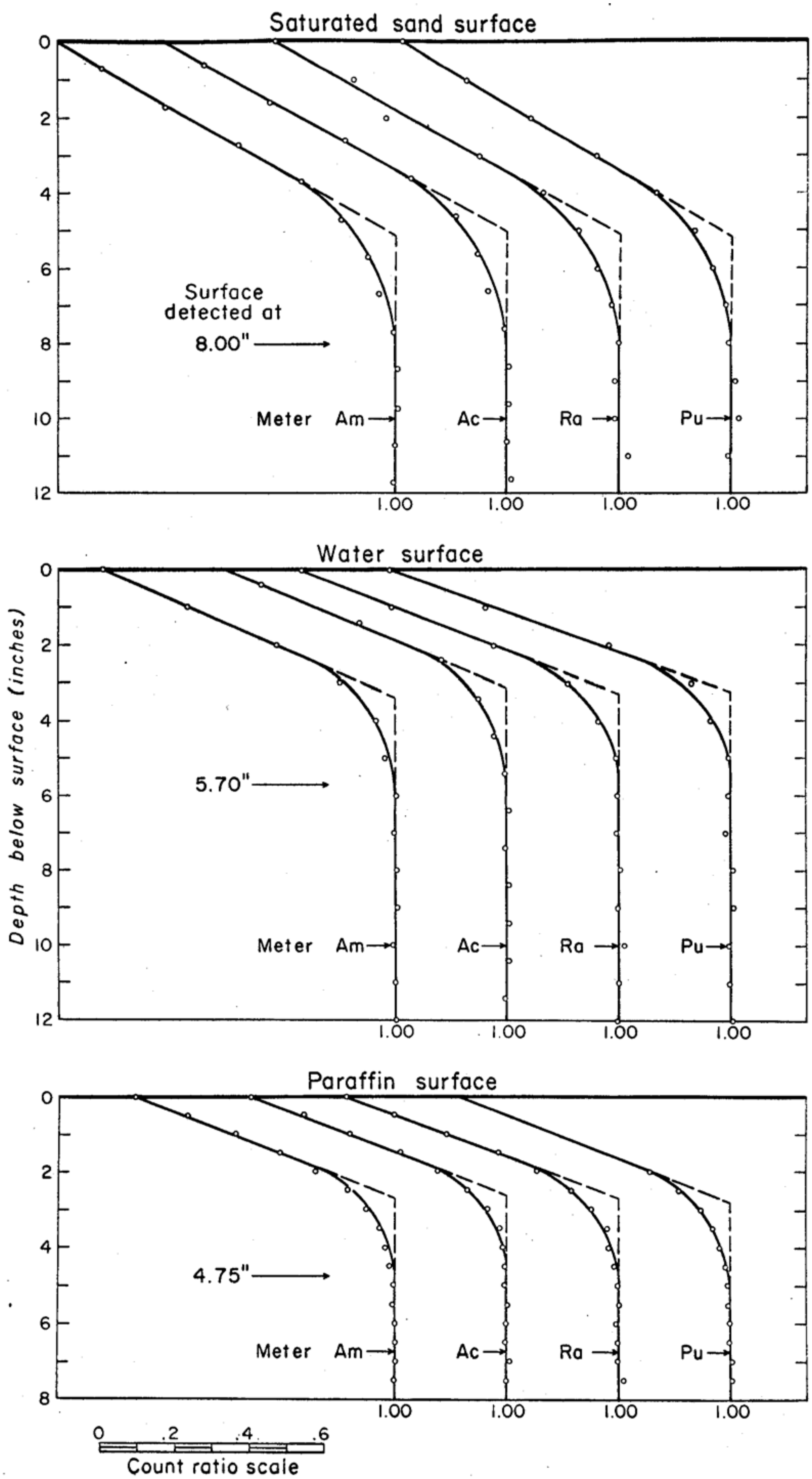

Figure 1.--Effect of moderating medium and source upon depth at which surface is detected. (1.00 equals mean count ratio unaffected by surface.)

It should be noted, however, that while these observa tions appear to lend support to the hypothesis that there are effects on vertical resolution due to source type, the experimental conditions did not entirely rule out some other effects which might account for the differences. The principal source of the difference might have been due to the fact that the neutron sources used were not point sources. There is a distinct possibility that significant differences exist in the vertical length of the actual radioactive alloy contained in the inner capsule of the double-encapsulated sources. Because the physical limitations of source construction do not allow for much variability in diameter of the alloy, the differences in specific activity of each radionuclide, and therefore the different mass of material required to obtain the desired neutron flux, is reflected in their vertical dimension. This might, therefore, account to some extent for observed differences in vertical resolution. Additional experimentation will be required to resolve this problem.

SUMMARY AND CONCLUSIONS

The effects on soil moisture determination of four different alpha-neutron sources (^{226}RaBe, ^{227}AcBe, ^{239}PuBe, and ^{241}AmBe (α, n)) used in neutron meters in homogeneous media, effectively infinite in size, are unaffected by type of neutron source. In media effectively non-infinite in size, horizontal resolution was found to be a function of source type.

The neutron sources used appeared to fall into two distinct groups: Meters containing ^{239}PuBe and ^{241}AmBe sources gave count ratios which were consistently higher than the ^{226}RaBe and ^{227}AcBe sources. No significant differences were observed between the two ^{226}RaBe sources used, or between the two ^{239}PuBe sources. There was, however, a difference between the two ^{241}AmBe sources.

Although the results inferred that vertical resolution may also be a function of source type, it is not possible at this time to draw as definite a conclusion from this observation, since the effect of the departure from point sources of the neutron sources used was not evaluated.

The results of these experiments confirm the hypothesis that average neutron energies of the different types of alpha neutron sources used in soil moisture meters result in a significant effect in moisture determinations in heterogeneous media.

If moisture meters equipped with different sources are to be used interchangeably in layered soils, or in soils with stones or large voids, the data should be carefully scrutinized for differences due to source before comparability is assumed.

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