SOIL WATER CONTENT MORE ACCURATELY BY NUCLEAR METHODS

Servo S. H. KASI
FIN-04230 Kajavankatu 6 B 45, Kerava, Finland

ABSTRACT

TDR (Time domain reflectometry) is — very popular today — a useful instrument to determine e.g. liquid water content in soil and snow, as also other capasitive measurements are in many cases. Many years neutron measurements have been used to determine the total water content. TDR depends on temperature and chemical bindings of matter, but neutron and gamma measurements almost not at all. Precision of neutron gage result is excellent. Uncorrect calibration can, however, cause remarkable systematic errors. Hydrogen content of dry soil, density (gamma gage determined) and thermal absorption cross section must be known in calibration. Gamma measurement can be used to determine water content, when density changes are caused by moisture. Narrow horizontal gamma beam gives vertical resolution in mm...cm class. Snow attenuates today, in addition to the natural gamma-radiation, also that of cesium in soil. Using both the radiations we measure the water equivalent and soil water content. The narrow beam attenuation (E_γ > 90 keV) and the last ray measurements depend on temperature and chemical bindings not at all.

DIELECTRIC CONTRA NUCLEAR METHODS

Materials consist of nuclii and electrons; the latter mainly are around the nuclii. The free electrons or mobile charged atoms (positive or negative ions) influence electric conductivity. Dielectricity of matter is determined by polarizability of the charges of atom or molecule. The positive charge of nucleus and the negative charge of electron cloud only around in the noble gases remain cocentric in any practical conditions. Variability of polarizations of matter is seen in variation of dielectric constant. Except of chemical composition it depends on temperature. In dry soils the dielectric constant varies 4...8 (Carlsson, 1998). Dielectric constant of water liquid is clearly higher, i.e. 82.19 at the temperature 15 °C and decreases with increasing temperature, 78.48 at 25 °C (Lück, 1964), see also Persson and Berndtsson (1998). However, for ice the dielectric constant is 3.2 (as well as it is low for with matrix bound water). Del Río and Whitaker (2000) consider the influence of porosity in electromagnetic operations as TDR in rigorous manner.

Neutron and gamma gages have been used for measurement of soil moisture, its water content. The displayed result of these meters may depend only on the atom composition of soil. In neutron and gamma gages the source of radiation has been capsulated in two-layer steel shelter relatively small in size.

Chemical bindings in matter and such conditions as temperature do not influence neutron and gamma measurements almost not at all. On the contrary they influence essentially electronic soil meters as TDR (Time Domain Reflectrometry), e.g. Carlsson (1998), Persson (1999) and Petersen et al. (1995).

Neutron and gamma used in the meters of water content have the energies 100 keV - 10 MeV; also smaller-energy photon sources can be used. Chemical binding energy is seldom above 10 eV. The binding energies of outer shell electrons or the ionisation energy of atom are in the same order. The binding energy of inner shell K-shell electron is larger (13.6 eV for hydrogen, 7 keV for iron, 9 10^4 eV for lead), but the iron atom is largest among common elements and the number of K-shell electrons is only 2.

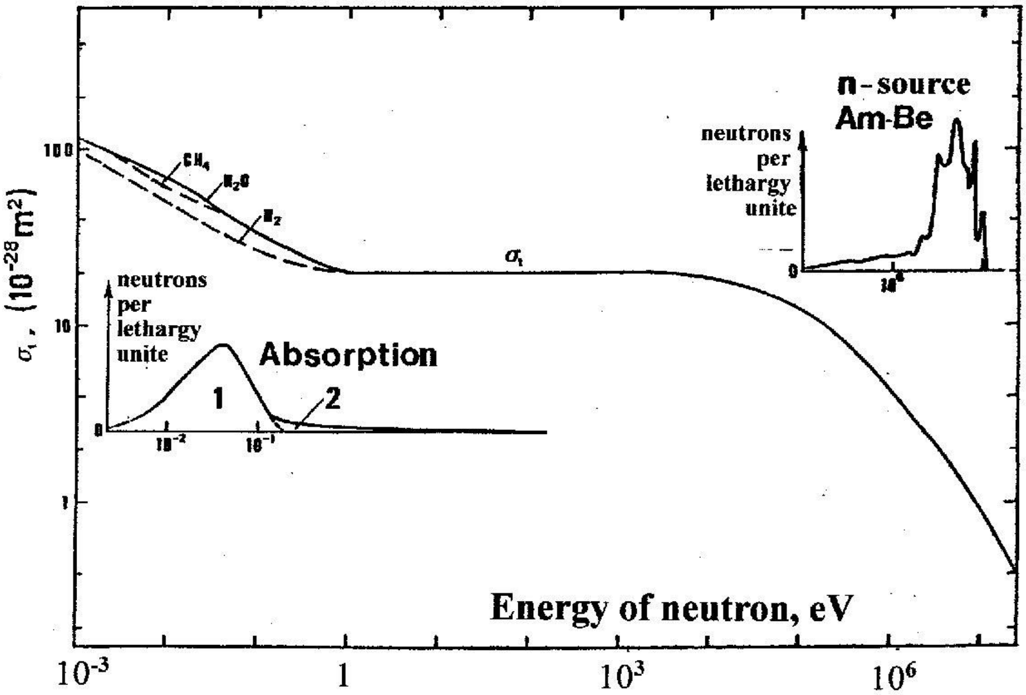
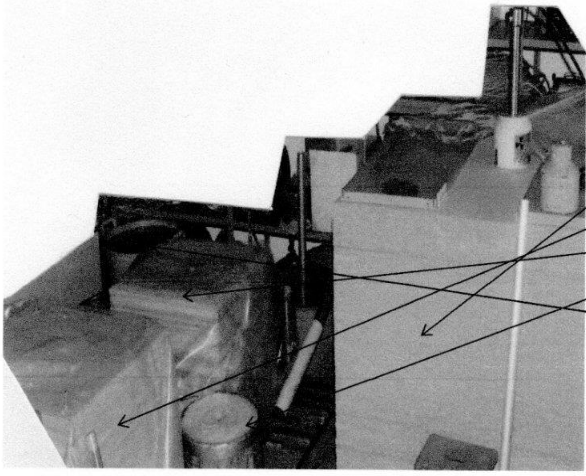


Fig. 1. Total cross section $\sigma_t(E)$ of hydrogen in H_2O and two other molecules over all neutron energies, *E*. On the right above the spectrum of source neutrons. On the left the energy distribution of absorption of thermal neutrons in the Maxwell presentation (1) and of epithermal neutrons (2) in homogeneous infinite mineral soil. Lethargy $u = ln\, E + u_0$.

Fig. 1 illustrates certain essential features of neutron measurements. The main curve σ_t is the cross section with which a hydrogen atom catches neutrons. The Am-Be source of neutrons is mainly used today, though the neutrons of the relatively expensive AmLi source had more appropriate energy for many moisture gagings and those of Cf source also, but less appropriate. Hydrogen atom mainly scatters neutrons and the source neutrons slow down just in the hydrogen scatterings. For AmBe-source about 19 hydrogen scatterings slow down neutrons to be thermal. The detector of thermal neutrons or of a little higher energy epithermal neutrons has been set near the neutron source. The hydrogen atoms, when slowing down neutrons, keep them near the source and detector.

CALIBRATION OF GAGES

Calibration of soil moisture meters (and any meter) demands very accura-



Substance	Density kg/m³	Char. in the chart
air	1.2	o
wood fibre brd	245±2	+
spruce plyw.	513±3	+
birch plywood	689±5	+
paraffine	906±10	◇
water	998±1	□

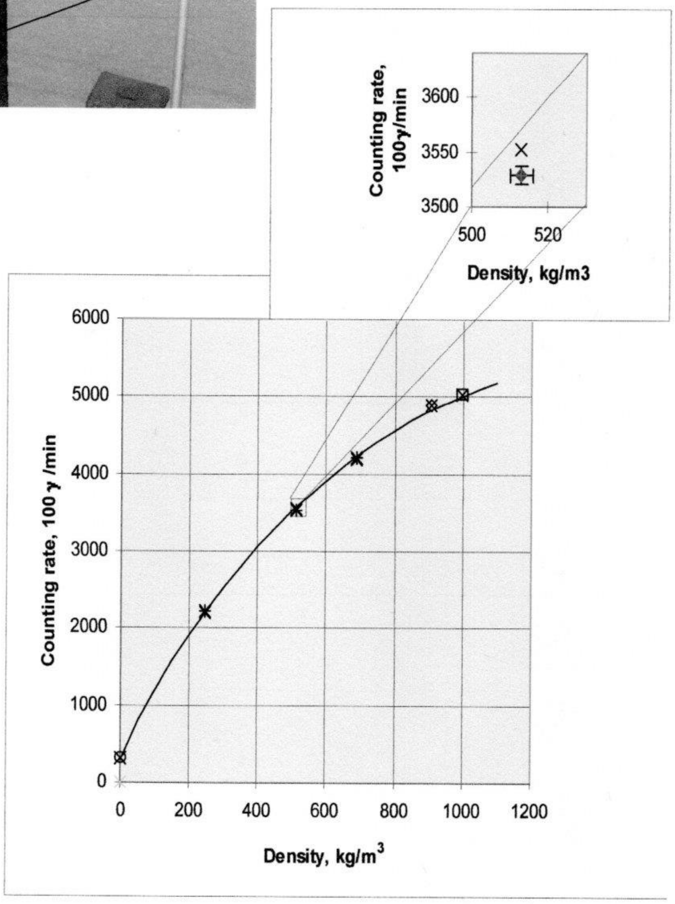


Fig. 2. Calibration of small-density cesium-137 gage. X are results of fitting calculation (Kasi, 1988) for the calibration substances used. Curve for peat.

tely fulfilled conditions. They generally can be achieved only in laboratory. Kasi (1988) tried to show the results of good calibration of a gamma meter using capsulated cesium-137 source and homogeneous materials, Fig. 2, which cover the whole range to be measured with the gage. The accuracy is better than 1 %. That the fitting in the extraction of Fig. 2 is not in the error limits of measurement, shows that the calibration can be improved. The inaccuracy is probably caused by rough theoretical model.

The instrument above is applicable for peat soils and also for snow density measuring. It can be used for all substances, in which the density is below 1200 kg/m^3. In 1984 during the field excursion of the Fifth Nothern Research Basins Symposium a similar gauge was presented by Kasi for snow density gaging, but it has a smaller probe than the peat instrument.

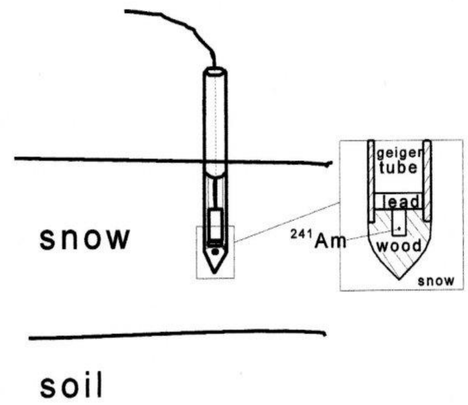


Fig. 3. Cheap snow density gage using 60 keV americium-241 gamma source.

Gamma measurement can be used to determine water content, when density changes are caused by moisture. Narrow horizontal gamma beam gives vertical resolution even below 1 cm (Hooli and Kasi, 1975). When the photon energy $E_\gamma > 90$ keV then even lead cannot cause any chemical effects in γ-photon interactions. In the interesting work (1986) Touma and Vauclin determined water content by the ^{241}Am photon attenuation.

The method for the good calibration of neutron gage of moisture has been described e.g. by Kasi (1986, 1988). Hydrogen content of dry soil, density (gamma gage determined) and thermal absorption cross section must be known. These quantities can be determined when the access tube for measurements is installed, from soil samples, or using auxliary gagings in the access tube, e.g. gamma-gaging for density profile determination. The theory of n-measuring is more complicated than that of γ-measuring, because the number of scatterings is much bigger. However the rough three-group diffusion calculation is probably as good as the gamma-theory used in the example above. The parameters of the theoretical model of the gage can be determined with the same kind of method as in the figure 2. I have tried to perform such accurate laboratory measurements but the proposals for good calibration materials are the only steps in the way to progress. The practical use of neutron gages of soil moisture has already many decades. I state that the results of these moisture measurements have unnecessary systematic errors.

RADIATION SAFETY

The permissible dose rate for a person in the radioactive work (in the nuclear reactors, hospitals, industries, etc.) is 20 mSv/a (maximum mean in 5 years) and for a member of population it is 1 mSv/a. The radiation sources of the soil moisture and density measurements are so strong that their users and, of course, their preparers, must be under radiation dose control. However, these sources are so small that the dose of the user is easily at the level of the common person and therefore almost not at all above the level caused by natural background radiation.

ACTUAL MEASUREMENTS

Kasi (1998) shows how deposition of cesium-137 after Chernobyl catastrophy is possible to utilize, because it forms a gamma plane source close to soil surface. About in half of the Nordic countries the intensity of cesium radiation is in the order or above the higher-energy radiation of potassium-40. With these two types of radiation (measured in airplanes, terrain tops with sight onto ground below, on snow moving vehicles or in certain points just above snow) snow water equivalent and moisture content near soil surface can be measured repeatably in any time during winter. These measurements depend not at all on temperature and chemical bindings of atoms, because the 662 keV of cesium and 1460 keV of potassium sources are also the energies to be detected in these measurements, and because the contribution of scattered photons is itself very small.

The theoretical consideration of Kasi (1998) used the form $D=D_0 \cos\theta$ of the so-called detector function for the 6 Na(Tl) scintillators. Recently Allyson and Sanderson (1998) have the result which shows that the form $D=D_0 \cos\theta + D_1$ is more appropriate. However $D_1 < D_0$. This improvement of Kasi (1998) treatment does not change any essential in the considerations above and in Kasi (1998). Earlier also the case of the constant detector function has been treated, because it is a rough theory in the cases of small cylinderical detectors.

CONCLUSION

Temperature and chemical bindings have less effects in n- and γ-gages. Certain n- and γ-arrangements have these effects not at all. Their possible small effects in n-gages are eliminated when epithermal neutrons are gaged. In the horizontal-beam γ-measurements and when surveying and utilizing γ-radiation which without scatterings comes from radioactive nuclides in soil, the temperature and chemical bindings have no disturbing and deteriorating effects.

γ-gaging with terrestrial ^{137}Cs 662 keV radiation transmission technique, hopefully only in these years applicable, is useful in snow and probably in, generally problematic, surface soil moisture surveying.

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