Research Article

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Neutron Measurement of Moisture in Mineral Matter: Modeling of the Gauge

Servo Kasi*

Aalto University and home: Fi-01360 Vantaa, Finland

Corresponding Author: Servo Kasi, Aalto University and home: Fi-01360 Vantaa, Finland.

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Abstract

Neutron radiation provides a non-destructive method for measuring moisture in mineral matter by detecting the content of hydrogen. This study focuses on developing a robust numerical model for a Neutron Moisture Gauge which utilizes a source of fast (MeV) neutrons and detects thermal or epithermal slowed-down neutrons. For accurate prediction of the gauge's response (counting rate), a Monte Carlo (MC) calculation based on a two-path method was performed. The model required multiplying the neutron slowing-down density with the detection probability and integrating the product to yield the total counting rate. Initial modeling found that the common assumption of spherical symmetry proved inapplicable to the physical geometry of the gauge. The gauge was successfully modeled using cylindrical geometry, confirming the viability of this computational approach for optimizing and calibrating mineral moisture sensors.

Keywords

Neutron Gauge, Moisture Measurement, MC Calculation, Cylindrical Geometry, Geometry Applications, Epithermal Neutrons

Introduction

Neutron techniques have been widely used to measure moisture content in materials [1-3]. This technique fundamentally determines the content of hydrogen, which has a unique property among common elements: its mass is nearly equal to that of a neutron, making it highly effective at slowing down fast neutrons. The energies of the source neutrons used in these gauges are typically in the MeV region (Figure 2). The necessary cross-section data for hydrogen were sourced from the ENDF/B-VIII.1 tabulations [4].

For the gauge I have made Monte Carlo (MC)- calculations [5], the first with Elliott and the last ones with MatLab in my computer [6]. In this paper I consider detection of epithermal neutrons, Fig. 2.

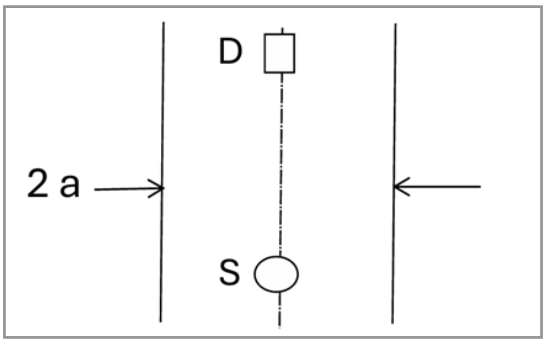

Figure 1: Essential parts of neutron gauge. S is the source and D detector of neutrons, 2a is the outer diameter of the access tube.

In the gauge we have source of fast neutrons and detector of thermal or epithermal neutrons. In good moisture measurements one then considers the parameters: hydrogen content, density and absorption cross section of the matter. The most significant absorption is that of thermal neutrons. The hydrogen cross section σt = σs + σa. These are scattering and absorption cross sections. σa << σs during the slowing down. Below 1 MeV other elements than hydrogen slow down negligibly. The most of gauges detects thermal neutrons.

Calculus

In the calculations, at first, I supposed that S and D are points in infinite homogeneous medium and in spherical geometries.. I took the AmLi source spectrum of neutrons to pick up the energy for each neutron [7].

The neutrons I follow downwards sequentially. They slow down into the energy E = 1 keV. qE is the slowing down density at the energy E.

Now also another MC-calculation is needed. Neutron comes to the detector. There is an event. The neutron has had a path. You can follow the path. This is MC calculation upwards in energy. You calculate the paths of the so-called pseudo-neutrons. In the first calculation the epithermal detection in D was selected, and the energy goes upwards. At E I find the value for $\Phi*E$, the adjoint or may be called the quantity of detection or the value of pseudo-neutrons. Now in a scattering event the energy and weight of pseudo-neutron grows. For hydrogen scattering E2=E1/r. r is random number (0…1].

The first adjoint MC program MCNA is from the year 1971 [8]. In Neutron 50 a Conference in 1982 in UK Cambridge I shew the idea of 2 particle clouds: one from the source, qE, and the other from the detector, the detection probability $\Phi*E$. We calculate the distributions of qE and $\Phi*E$ and integrate their multiplication.

$$C = \int_V \int_{4\pi} \Phi^*{}_E(\boldsymbol{r},\boldsymbol{\Omega}) q_E(\boldsymbol{r},\boldsymbol{\Omega}) d\boldsymbol{\Omega} d\boldsymbol{r}$$

In order to get the counting rate C [9]. V must be large enough. The unite vector $\boldsymbol{\Omega}$ of direction has the 3 components u, v and w, $u^2 + v^2 + w^2 = 1$. They are cos functions against x, y, and z axes, respectively [5]. In my calculation $\boldsymbol{\Omega}$ has 6 directions of w around the direction of r. I tried to find qE and $\Phi*E$ for a = 2.3 cm and over that, and shew those distributions $\Phi*E$ and qE (Figure 3) in ISRP 16 Symposium 2024 in Lisbon.

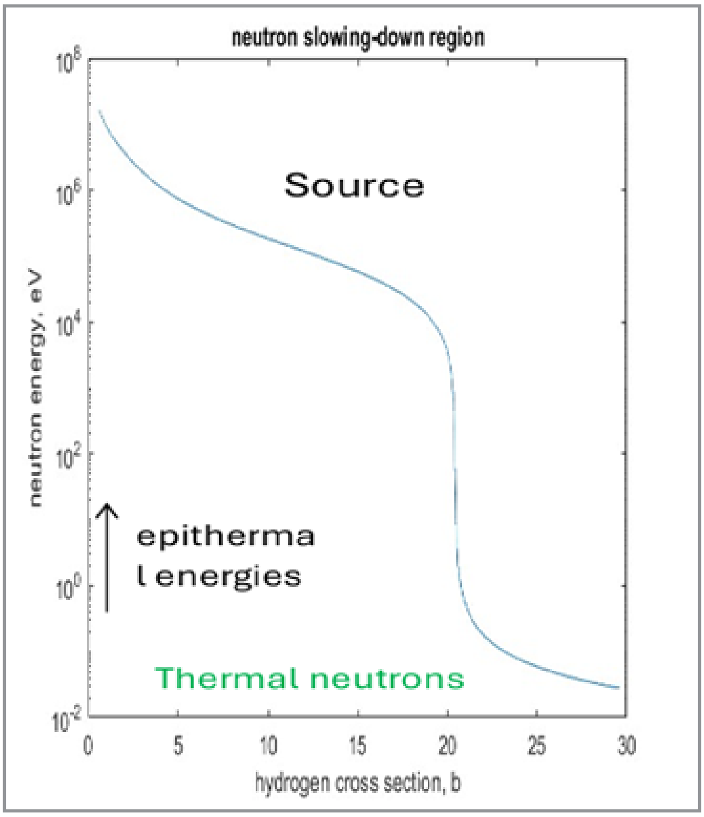

Figure 2: Fast neutrons slow-down in matter. Scattering cross section of hydrogen is then considerable.

Results

I supposed, that point S and D are in infinite soil. Around the points there are shells. But the shells from S and from D do not coincide. Therefore I set the distance d = SD = 0. I try to find the good shell radia. Now r = 0, 1.19, 1.42, 1.69, 2.02 = a, 2.40, etc.

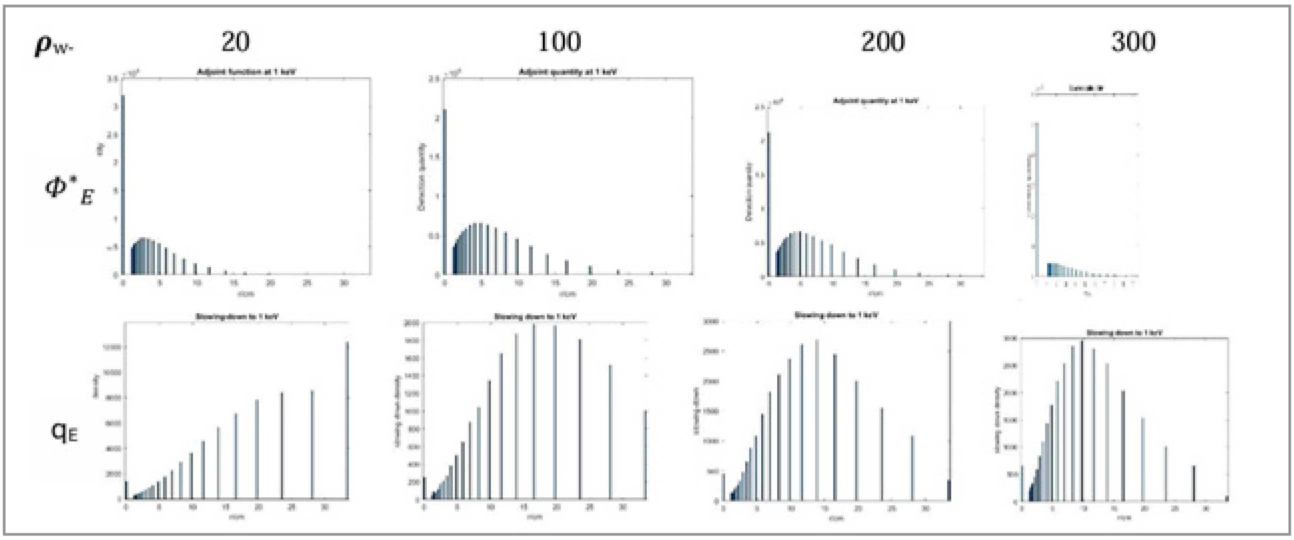

Figure 3: The first distributions $\Phi*E$ and qE for comparing. pw-is water content in kg/m3. In figures the horizontal variable r is the same in both (and all) rows.

Conclusion

This study successfully modeled the response of a neutron moisture gauge using the Monte Carlo two-path methodology under the appropriate cylindrical geometry. The initial finding that the common, simpler assumption of spherical symmetry is not applicable to this gauge geometry was confirmed by inconsistent simulation results. By adopting a cylindrical model that accurately represents the physical placement of the source and detector, we have validated a computational approach for determining the gauge's counting rate, which can be directly related to the mineral matter's moisture content.

It seems to select: E to be higher, is better. Because the bad distributions and, maybe spherical models, the integration for C was not valid to make. The spherical geometry now does not seem applicable.

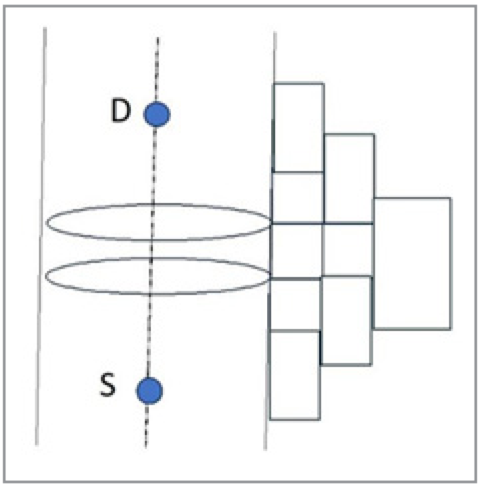

Figure 4: Rings around the tube. Each ring has its own r.

I have continued in cylindrical geometry. Further I have the epithermal detection. The model of thermal detection gauge should be calculated, too. The components S and D are mostly cylindrical.

References

1. International Atomic Energy Agency, Neutron Moisture Gauges: A Guidebook. Vienna, Austria: IAEA, 1970. https://inis.iaea.org/collection/NCLCollectionStore/_Public/01/001/1001730.pdf
2. Neutron Moisture Meters, Texas A&M AgriLife Research & Extension Center - San Angelo. https://sanangelo.tamu.edu/agronomy/agronomy-publications/grain-sorghum-production-in-west-central-texas/how-to-estimate-soil-moisture-by-feel/soil-moisture-measuring-devices/neutron-moisture-meters/

3. International Atomic Energy Agency, Cosmic Ray Neutron Sensing: Use, Calibration and Validation for Soil Moisture Estimation, IAEA-TECDOC-1809, ISBN 978-92-0-101017-9. Vienna, Austria: IAEA, 2017. https://www.iaea.org/publications/11097/cosmic-ray-neutron-sensing-use-calibration-and-validation-for-soil-moisture-estimation
4. National Nuclear Data Center, “Evaluated Nuclear Data File (ENDF),” Brookhaven National Laboratory, Upton, NY, USA. Accessed: Nov. 14, 2025. https://www.nndc.bnl.gov/endf/
5. E. D. Cashwell and C. J. Everett, A Practical Manual on the Monte Carlo Method for Random Walk Problems. Los Alamos, NM, USA: Los Alamos Scientific Laboratory of the University of California, 1957, 228 pp.
6. S. Kasi and H. Koskinen, “Analysis, calculations and measurements concerning the moisture measuring by the neutron method,” Nuclear Engineering and Design, vol. 3, no. 1, pp. 74–82, Jan. 1966, doi: 10.1016/0029-5493(66)90150-6.
7. A. V. Mozhayev, M. E. Moore, and E. K. Mace, “Characterization of two extraordinary AmLi neutron sources,” Applied Radiation and Isotopes, vol. 168, p. 109472, Feb. 2021, doi: 10.1016/j.apradiso.2020.109472.
8. J. Josey and A. Sood, A Review of 70 Years of Monte Carlo Development at Los Alamos: 1953–2023, LA-UR-23-27907. Los Alamos, NM, USA: Los Alamos National Laboratory, Jul. 2023.
9. G. I. Bell and S. Glasstone, Nuclear Reactor Theory. New York, NY, USA: Van Nostrand Reinhold, 1970.