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A Comparison of Performance between Stilbene and ^{3}He Detectors for Neutron Sonde

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1. Introduction

Dual neutron logging system is used for lithology identification. Neutron logging detector, as called as neutron Sonde, measures porosity of strata and detects location of aquifer. Neutron Sonde mounts ^{3}He proportional counters for neutron detectors. However, the cost of ^{3}He detector is increasing in these days, because of ^{3}He shortage problem. To replace it, there is a stilbene scintillator, which is a solid-state fast neutron detector. In this study, Monte Carlo simulation is performed on neutron Sonde with the stilbene scintillator and ^{3}He proportional counters. Comparison between two detectors would contribute to overcome ^{3}He shortage problem.

2. Methods

2.1 Neutron Diffusion Equation

The neutron Sonde measures porosity by detecting neutron scattered from strata. The AmBe source in a Sonde emits fast neutrons and they are slowing down in strata until reaching neutron detectors. The ratio between near detector and far detector (25 cm and 40 cm offset from the source respectively), as called as near-far ratio, for each energy region, thermal neutrons and fast neutrons, can be driven as follows.[1] It comes from neutron diffusion equation with assumption of point source in infinite non-multiplying region.

$$\frac{\Phi_x(r_f)}{\Phi_x(r_n)} = \frac{r_n}{r_f} e^{\frac{r_n - r_f}{L_1}} \quad (1)$$

In the equation (1), Φ is neutron flux, L_1 is a slowing down length, r_n and r_f are distance from the source to near detector and far detector respectively. Subscripts x represent energy region: $x = 1$ for fast neutrons and $x = 2$ for thermal neutrons. Equation (1) means that near-far ratio is the function of a slowing down length. The slowing down length is determined by composition and porosity of strata.

2.1.1. ^{3}He thermal neutron detector

The dual neutron logging system mounts two ^{3}He detectors, one of them at close to the source is called as a near detector and the other is called as a far detector. ^{3}He proportional counter could detect thermal neutrons by (n, p) reaction. The thermal neutron flux at near and far detectors have relationship as the equation (1) with subscript $x = 2$. It means that the near-far ratio, $\frac{\Phi_x(r_f)}{\Phi_x(r_n)}$, of thermal neutron detectors is a function of slowing down length.

2.1.2. Stilbene fast neutron detector

Stilbene is organic material which contains many of hydrogen atoms. Therefore, stilbene scintillator could detect fast neutrons with elastic or inelastic scattering. The near-far ratio for fast neutrons is as the equation (1) with subscript $x = 1$. It has also function of slowing down length, depending on the porosity and rock type of strata. Therefore, both of neutron detectors, ^{3}He and stilbene, could measure porosity.

2.2 Monte Carlo Simulation

In this study, Monte Carlo simulation is performed with MCNP6.2. Dual Neutron Probe of Robertson Geo is used for the simulation geometry.[2] AmBe neutron source is assumed as 5 Ci activity of ^{241}Am. Rock types used in simulation are as followed: limestone, granite, sandstone, basalt, and shale. Compositions of them are modeled with PNNL's MCNP input data.[3] Borehole fluid is modeled as mud with density of 1.4 g/cc. Pore fluid, which fills in pore, is assumed as water that is moderator and absorber of neutrons. FM tally is used for simulation of neutron detection.[4]

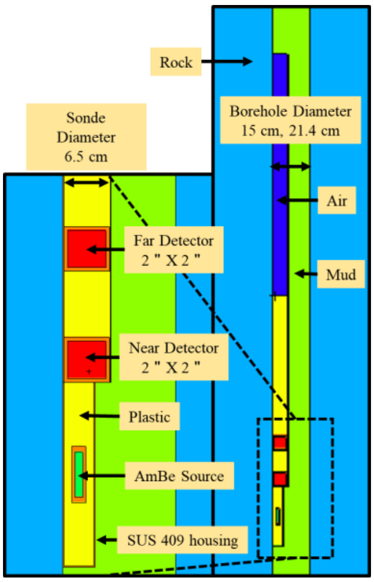

Fig. 1 Simulated neutron Sonde geometry

3. Result

3.1 Porosity Measurement

3.1.1. ^{3}He detector mounted neutron Sonde

Fig. 2 shows a calibration curve of neutron Sonde with ^{3}He detector, which refers to the relationship between porosity and near-far ratio by rock types. The near-far ratio differs depending on the rock type and porosity. As we expected in the equation (2), all of calibration curves appear exponential function of porosity.

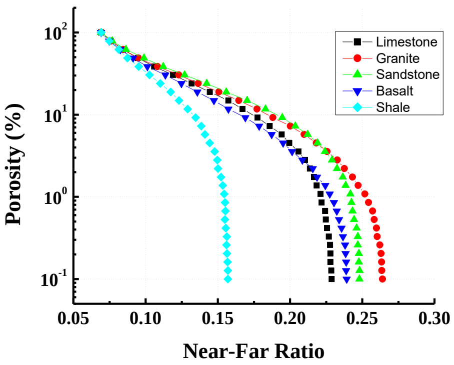

Fig. 2 Calibration curves for each rock type measured by neutron Sonde with ^{3}He detectors

3.1.2. Stilbene detector mounted neutron Sonde

Fig. 3 represents calibration curves for each rock type measured by neutron Sonde with stilbene. As in the equation (2), all of calibration curves also appear exponential function of porosity same as ^{3}He mounted one. The ratio value is lower about 0.03 than ^{3}He calibration curve, but this is rather the result of an increase in the detection efficiency of the near detector. As a result of simulation, the stilbene scintillator has same performance of porosity measurement to ^{3}He proportional counter.

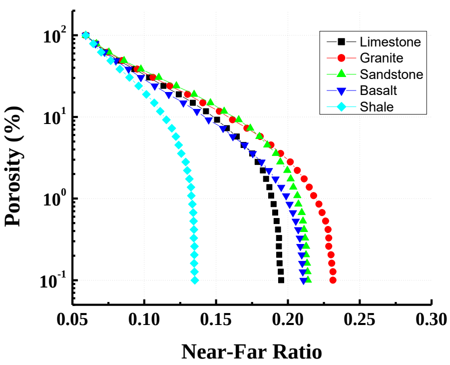

Fig. 3 Calibration curves for each rock type measured by neutron Sonde with stilbene detectors

3.2 Neutron Detection Efficiency

As shown in Fig.4, stilbene detector has a higher counts (1.24×10^6) than ^{3}He detector does (8.33×10^4) which means neutron detection efficiency of stilbene detectors is higher than ^{3}He detectors. The reason of detection efficiency is that the energy of neutron flux through strata is mainly fast neutron which stilbene can detect, but ^{3}He does not. Therefore, the neutron Sonde with stilbene detectors has lower statistical noise than ^{3}He detectors.

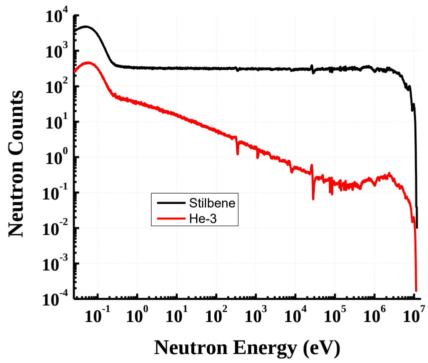

Fig. 4 Simulation data of neutron detector's counts distribution in strata of limestone of 0% porosity

4. Conclusions

In this study, Monte Carlo simulation is performed on the neutron Sonde with stilbene detectors. As a result, calibration curves for each rock types of neutron Sonde with stilbene have the equivalent performance as one with ^{3}He, which follows exponential function. In addition, neutron detection efficiency is higher with stilbene scintillator than ^{3}He gas proportional counter. Thus, dual neutron probes could mount stilbene detector for porosity measurement with more accurate neutron detection.

ACKNOWLEDGMENTS

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