CSCanada
Advances in Petroleum Exploration and Development
Vol. 6, No. 1, 2013, pp. 52-57
DOI:10.3968/j.aped.1925543820130601.1642

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
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Simulation of Logging While Drilling Tools Based on Amorphous Si:H and LaBr3:Ce Detectors

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Received 6 August 2013; accepted 12 September 2013

Abstract

Bore hole logging data represent the properties of rocks, such as porosity, density and constitutiveelements of formation, as a function of depth in a well. Properties of rocks are obtained from thermal neutron counting and gamma ray radiation due to neutron activation. Transport of neutrons, from an Am-Be source situated in a bore-hole tool, through rock media to detectors, has been simulated using a GEANT4 radiation transport code. The high precision GEANT4 cross section library was used to gain better analyses about well formation. In this paper we present the results of simulation of logging tools based on boron coated amorphous silicon detector for thermal neutron detection and LaBr3:Ce detector for gamma spectroscopy.

Key words: Well logging; Spectroscopy; GEANT4

Sani, V. E., Ashrafi, N. A., & Afarideh, H. (2013). Simulation of Logging While Drilling Tools Based on Amorphous Si:H and LaBr3:Ce Detectors. *Advances in Petroleum Exploration and Development*, *6*(1), 52-57. Available from: http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820130601.1642
DOI: http://dx.doi.org/10.3968/j.aped.1925543820130601.1642

INTRODUCTION

Logging While Drilling (LWD) tools provide a reliable measurement of various petrophysical properties of subsurface earth formations. Radiation and nuclear techniquesform the basis oil well logging tools such as density and porosity tools[1,2]. Logging tools take advantage of the interactions of neutron radiationwith formations and provide measurements such as formation type and porosity. Measurements by nuclear logging tools are taken in an oil well as a functionof depth. Finally a trace describing a vertical profile of the toolresponse throughout the rock formation is found. LWD tools include two different types of detector, a neutron detector for porosity determination and the gamma detector for neutron activation analysis.In this tools a given source emitting neutron radiation in to the rock and the thermalizedneutron that returnsto the bore-hole are detected for porosity estimationand hydrogen content determination (black tracks in Figure 1). On the other hand the detectedspectrumofgamma radiationsdue to neutron activation or thermal neutron capture interactions include rock formation proper ties such as density or rock type (white track in Figure 1)[3]. LWD measurements investigate those properties in the regions of the formation in which the incident radiation interacts. This method, known as neutron-neutron and neutron-gamma logging, uses several curies Am-Be source, which emits neutrons into the rock formation structure and detects the photons and thermal neutrons that return back into the bore-hole. The principle of neutron–neutron and neutron-gamma well logging tools are presented in Figure 1.

In this work instead of using ordinary neutron detector such as ^{3}He proportional counter, the amorphous silicon detector was used. The main advantage of using this detector is resistance against drilling shock. In this work also new generation of gamma detector was employed for neutron activation analysis with relatively higher performance than NaI detectors.

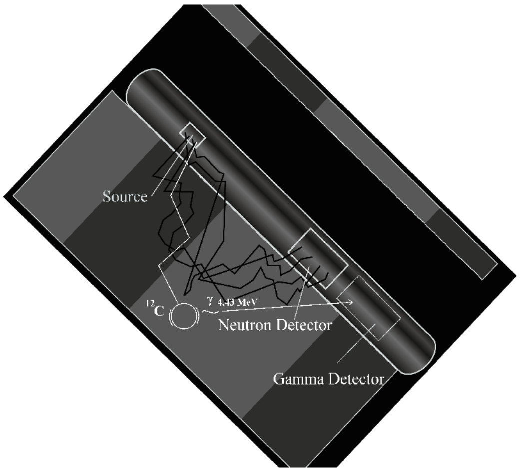

Figure 1
LWD Tools Including Two Kinds of Detectors (The neutron detector is used to detect thermal neutron for porosity estimation and determination of hydrogen content and gamma detector is used to detect gamma radiations due to neutron activation interaction in the formation.)

1. SIMULATION

The simulation code based on GEANT4 advanced neutron libraries is directed specifically to logging tools and is thus moreexact in application. The simulated tool was a cylinder with a diameter of 8 cm and 75 cm in length. Its main elements were the Am-Be source, the LaBr3:Ce gamma-ray detector for gamma spectroscopy analysis and hydrogenated amorphous silicon for porosity analysis. The neutron source was assumedto be a point, isotropic and emitting neutrons with energy spectra from 0 to 10 MeV. The simulated gamma detector has a cylindrical structure. The properties that make the LaBr3:Ce scintillator detector attractive for loggingapplication based on neutron activation analysis are:

(1) High temperature stability;

(2) Very good energy resolution;

(3) Very fast light output decay, enabling neutron activation applications;

(4) Promising technology for manufacturing crystal at larger sizes[4].

LWD tools include thermal neutron detector for formation porosity determination[1]. We propose boron coated amorphous silicon detector as an alternative for conventional thermal neutron detectors because of its temperature reliability, shock tolerance and low radiation damages. This geometry ensured that the detector's responses depend primarily on the characteristics of the rockmedium and that the influence of the borehole was negligible.The other parts of the probe volume (electronic systems, etc.) did not affect the detector responses and therefore were neglected insimulations. The simulated tool configuration and neutron tracksin rock formation are presented in Figure 2.

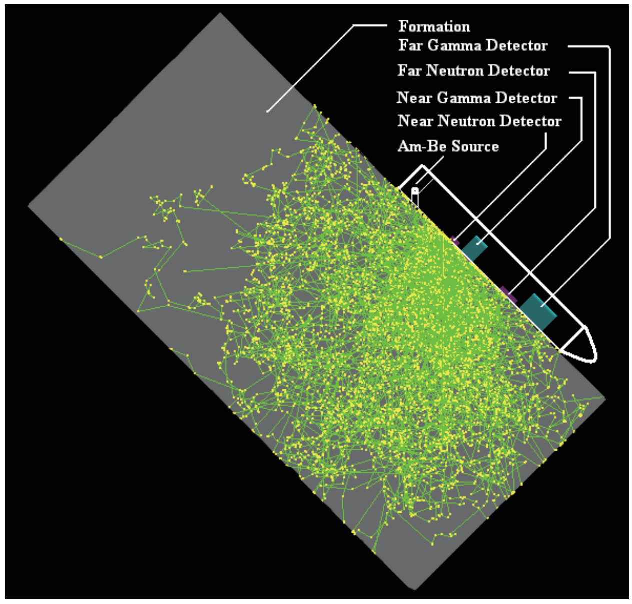

Figure 2
Am-Be Source, the LaBr3:Ce Gamma-Ray Detector and Hydrogenated Amorphous Silicon Detector for Neutron Detection are Embedded in Body

2. NEUTRON-GAMMA TOOLS SIMULATION BY GEANT4 AND RESULTS

Neutron activation analysis is especially valuable as a nondestructive nuclear method in the material analysis. Many review articles have been published on Neutron activation analysis and its applications[5].

The firstpublished tabulation of gamma-ray energies and intensities[6] led to a number of applications using NaI scintillation counters such as bore hole logging and planetary exploration[7,8].

Spectroscopy of gamma rays produced by subsequent thermal neutron capture reaction and fast neutron activation allows the detection of so important elements present in the formation.

In this work we propose to using the new generation of scintillator such as LaBr3:Ce as an alternative for NaI because of its higher light output, lower decay time, higher temperature stability and better resolution. We simulated LWD tools includes two near and far detectors for gamma spectroscopy. Near LaBr3:Ce scintillator detector has 3 cm diameter and 4 cm length and the far detector has 3 cm diameter and 6 cm length . The outputs of simulation code were the counting rate of prompt gamma reactions in the detector, per source neutrons. These gammas were the activation results from $MgCaCO_3$ formation and LaBr3:Ce detector materials. A view of produced gamma rays by neutron activation is presented in Figure 3. In one case for example, carbon is excited by the fast neutron and emits a gamma ray of 4.43 MeV. In other case, the oxygen is transmuted to nitrogen. It subsequently decays and emits a gamma ray of 6.13 MeV. Some of major interactions are listed in below:

$$^{12}C(n, n')\,^{12}C^{*}\;(\gamma\ 4.43\ \text{MeV})$$

$$^{16}O(n, p)\,^{16}N(\beta, \gamma)\;(6.129\ \text{MeV})$$

$$^{24}Mg\,(n, p)\,^{24}Na(\beta, \gamma)\;(2.75\ \text{MeV})$$

$$^{40}Ca\,(n, p)\,^{40}K(\beta, \gamma)\;(1.46\ \text{MeV})$$

This simulation is performed by GEANT4 based on G4NDL.4.0 library. The new library of GEANT takes advantage of high precision neutron cross section. Unfortunately there was a problem in cross section calling with GEANT4 core about Carbon element. Cross section file of carbon is named by Carbon_6_12.txt in GEANT libraries. As illustrated in Figure 3 the gamma produced in carbon inelastic reaction was not appeared in simulation output. We reconstructed this cross section file with data reported in National Nuclear Data Center(NNDC) and renamed the file in data library of GEANT4. As depicted in Figure 4, the 4.43 MeV and 3.21 MeV Carbon inelastic reaction gammas are produced in output of simulation.

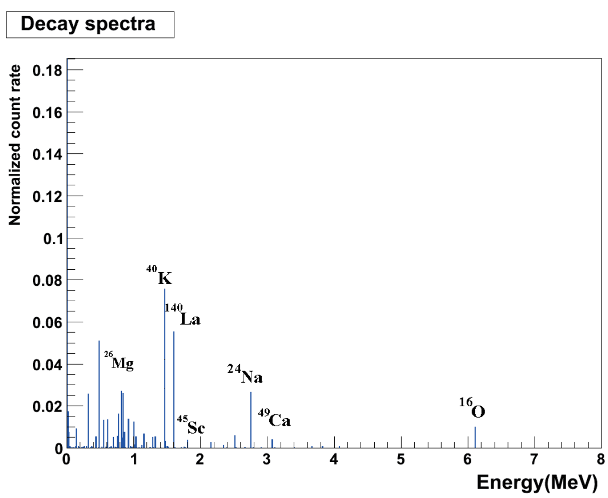

Figure 3
Activation Result and Decay Spectra of a Calcite Formation and Gamma Detector with Structure of LaBr3:Ce (As illustrated in figure gammas produced in Carbon inelastic reaction is not appeared in output of simulation.)

Spectroscopy of gamma rays produced by subsequent thermal neutron capture reaction and fast neutron activation in calcite (MgCaCO3) is illustrated in Figure 5 and Figure 6. These spectra allow the detection of so important elements present in the formation. Extracted peaks in spectra are corresponding to produced gammas by neutron activation.

Comparing between the spectroscopy of formation using near detector and far detector presents the higher count and lower resolution in near detector. On the other hand we can see the associated peak with carbon and oxygen is sensible in spectra of far detector. In far detector spectra, we can see a shift in all of peaks that is related with density of formation and gamma rays arriving from far distant. The number of gamma rays arriving at the far detector is inversely proportional to the electron density of the rock[2].

We repeated our simulations with a NaI detector. Spectra of same formation using NaI is presented in Figure 7. As illustrated in this figure the extracted spectra by LaBr3:Ce has better resolution and efficiency than NaI detector. For example the peak related with oxygen is not sensible in the case of NaI detector. On the other hand one of the disadvantages of using LaBr3:Ce detector is higher background because of Lanthanum decay by emitting 1.59 MeV.

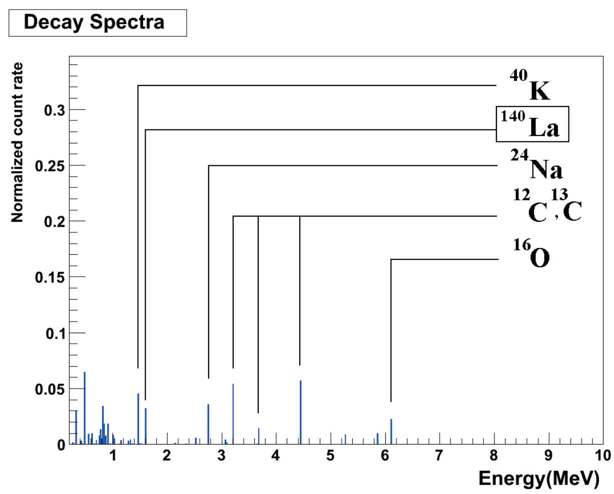

Figure 4
Activation Result and Decay Spectra of a Calcite Formation and Gamma Detector with Structure of LaBr3:Ce (As illustrated in figure Lanthanum has an undesirable gamma with energy of 1.59 MeV. This type of detectors in activation applications should be shielded from neutron radiation.)

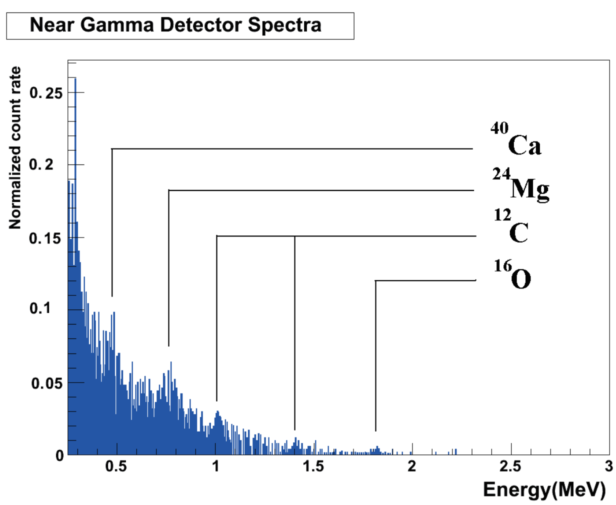

Figure 5
Spectra of Gamma Radiation of Calcite ($MgCaCO_3$) Activated by Am-Be Source in Near Detector

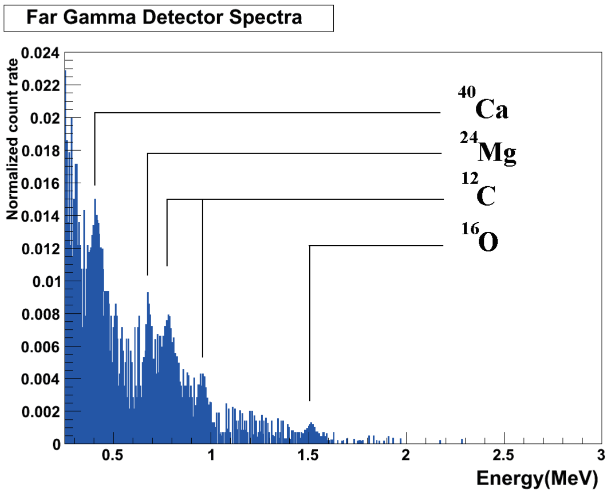

Figure 6
Spectra of Gamma Radiation of Calcite ($CaMgCO_3$) Activated by Am-Be Source in Far Detector

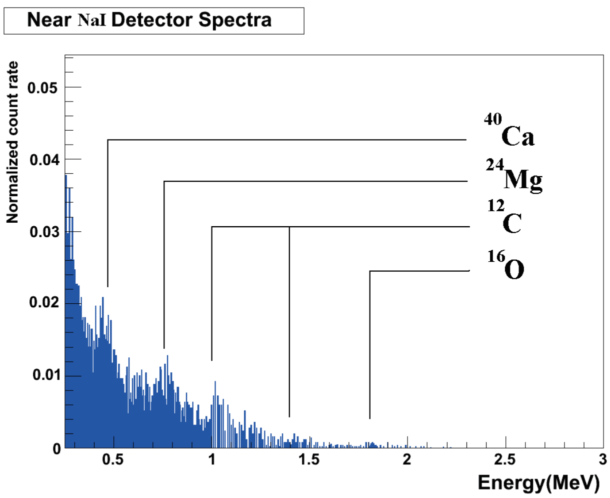

Figure 7
Spectra of Gamma Radiation of Calcite ($CaMgCO_3$) Activated by Am-Be Source in NaI Near Detector

3. NEUTRON–NEUTRON TOOLS SIMULATION BY GEANT4 AND RESULTS

The neutron logging tool was the first nuclear device to be used to obtainan estimate of formation porosity. The principle of porosity measurement is based on the fact that hydrogen, with its large scattering cross section and small mass, is very affective in the slowing-down of fast neutrons. A measurement of the thermal neutrons resulting from the interaction of fast neutrons with a formation can be related to its hydrogen content. Since hydrogen in the formation is sometimes in the form of hydrocarbons or water and tends to occur in the pore spaces, the correlation with formation porosity is easily made. One common source in use in neutron logging is Am-Be.

Semiconductor diode detectors coated with neutron reactive material are presently under investigation for various uses. Semiconductors coated with a thin film of neutron reactive materials, such as 10B, 6LiF, Gd, or plastics present a method of realizing compact and rugged detectors for thermal and fast neutrons[9]. The entire detector, depending upon the configuration, can be less than 1 mm thick while allowing for thermal neutron efficiencies of 4% or greater[10]. In this paper, amorphous Si:H is under investigation because of the their good radiation hardness, their operational simplicity and good temperature reliability.

Thermal neutron absorption cross section (σ) for 10B is 3840 barns, which is one of the main reasons why 10B is used for thermal neutron detection[11]. The (n,α)7Li reaction leads to the following products[12]:

$$^{10}B + {}^{1}_{0}n \rightarrow \left\{ \begin{array}{l} ^{7}Li(\text{at } 1.015\text{MeV}) + \alpha(\text{at } 1.777\text{MeV}) \\ ^{7}Li*(\text{at } 0.840\text{MeV}) + \alpha(\text{at } 1.470\text{MeV}) \end{array} \right\}$$

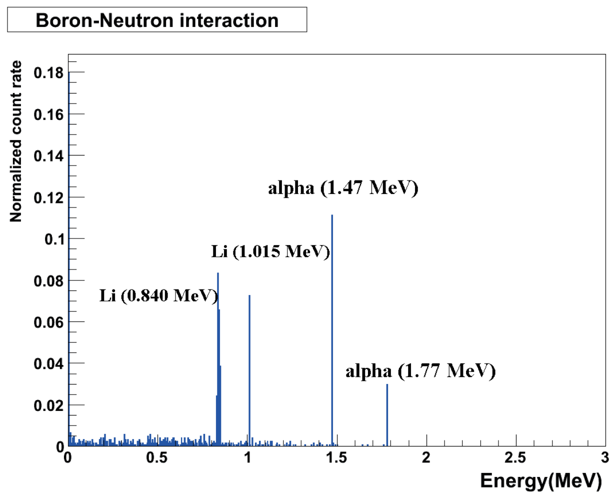

Figure 8
Simulation of Neutron-Boron Interaction by GEANT4

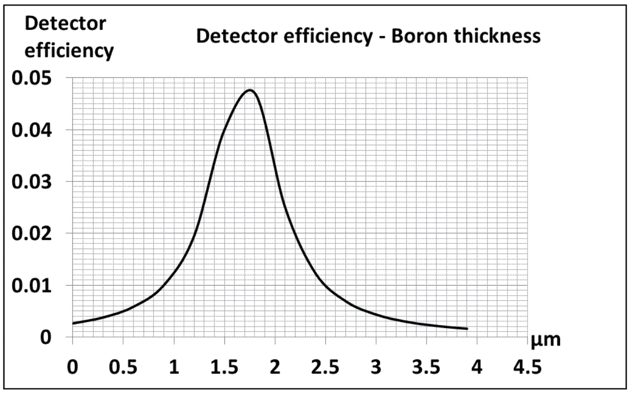

Figure 9
Optimum Thickness of Boron to Have a Tradeoff Between Reaction Probability and Enough Energy to Reach Detector with Acceptable Energy for Detection

Neutron-Boron interaction is simulated by GEANT4 (Figure 8). Either an α-particle or a 7Li ion reaction product may reach the detector after a 10B(n,α)7Li reaction. The original particle energy minus the energy absorbed in the boron film is deposited in detector. The average range for a 1.47 MeV α-particle in pure 10B is 3.6 μm[10]. At the end of the average range, the charged particle no longer has any energy and cannot be detected. We simulated the detectable α particle of Boron-Neutron reaction versus thickness of boron film that is presented in Figure 9. As shown in the figure, the thickness about 1.8 exhibits maximum output.

For porosity simulation, a formation with embedded spherical holes is reconstructed (Figure 10). Spherical holes contain water and they act as a percentage of porosity in the formation. In this simulation the percentage of porosity in the formation is increased from zero to 60 percent.

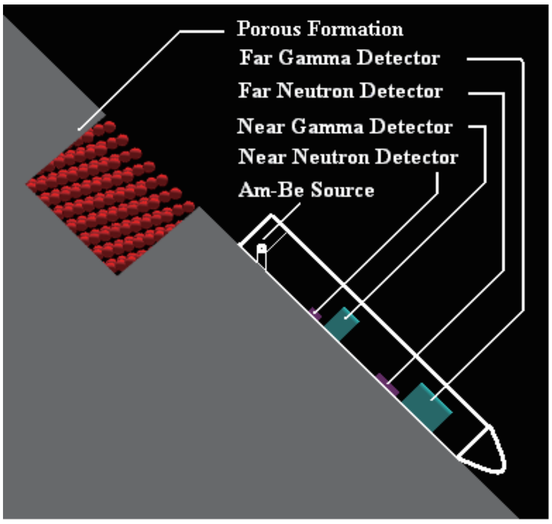

Figure 10
Construction of Porous Formation for Simulation of Relation Between Porosity Percentage and Thermal Neutron Count Rate

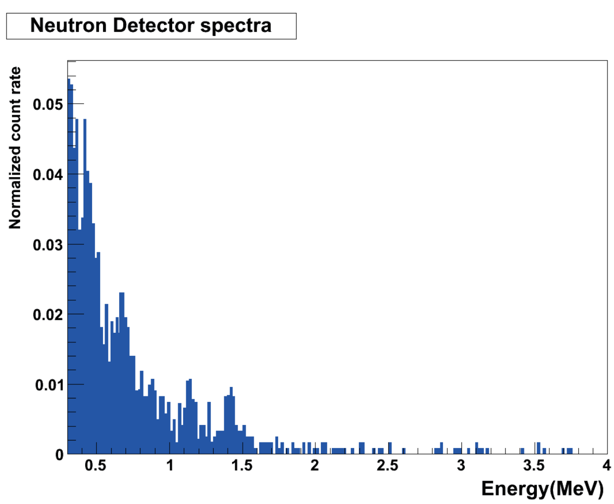

Figure 11
Spectra of Neutron-Boron Reaction Products (Alpha and Li) Emitted from Boron Layer to Amorphous Silicon Detector

We simulated a LWD includes two near and far detectors for porosity detection. Near amorphous Si:H has 200 μm thickness and 2 cm length and the far detector has 200 μm thickness and 3 cm length . The outputs of simulation code were the counting rate of thermal neutron reactions in the detector, per source neutrons. Since hydrogen in the form of hydrocarbons or water tends to occur in the pore spaces, detected thermal neutrons have correlation with formation porosity. A view of the detected neutrons presented in Figure 8.

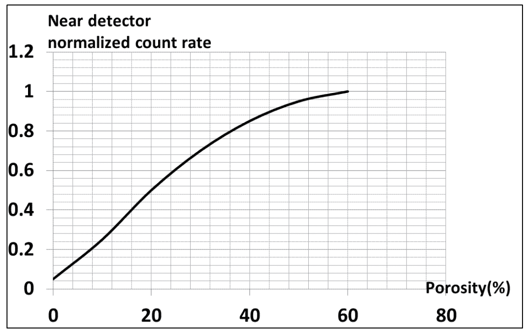

Figure 12
Thermal Neutron Detection of Near Detector as a Function of Porosity Percentage

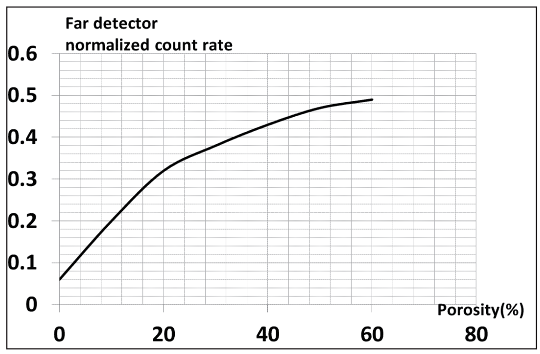

Figure 13
Thermal Neutron Detection of Far Detector as a Function of Porosity Percentage

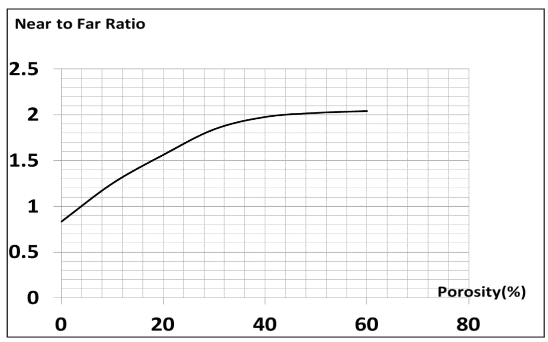

Figure 14 The Near/Far Thermal Neutron Detection Ratio

Count rates of neutron detector have a relation with formation porosity. Whit any porosity presence in formation the count rate of thermal neutrons in detectors is very low and with porous formation contents water the count rate of thermal neutrons increases. Simulation of porosity and count rate relation has very important role in tools calibration. The behavior of thermal neutron detector in various porosity percentages is presented in Figures 12-14.

These figures are normalized to count rate of detector in a formation with porosity of 60 percent.

CONCLUSION

The Li deposition on amorphous silicon needs to have optimum thickness which is about 1.8 . The predicted gamma spectra by LaBr3:Ce detector reveals higher resolution than NaI detectors. The listed detectors are recommended for use as a safe alternative to current detectors in the oil industry.

Entering the various percentages of porosity in different type of formations can be used to investigate the performance of these tools. These simulations have a very prominent role in calibration of these tools.

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