Integral Experiments to Test the Adequacy of Neutron Cross Sections for Simulation of Well-Logging Tools

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INTRODUCTION

Oil well logging tools traditionally use AmBe (α,n) and ^{137}Cs gamma sources to probe geological formations for the presence of hydrocarbons. A typical AmBe source for this application is a Category 2 source with an activity around 20 Ci[1]. A new approach replaces these sources with a DT generator. The approach, Monte Carlo Library Least-Squares (MCLLS), interprets well logs using linear combinations of elemental libraries from MCNP6 simulations.[2][3]. Several important isotopes' nuclear data evaluations are based on experimental data with high uncertainties and no covariance data. The perturbation capability of MCNP6 shows that the neutron and gamma fields can be significantly affected by those uncertainties. Several important lithologies in well logging will be irradiated with a DT generator at Georgia Tech to evaluate discrepancies between simulation and experiment. This work uses MCNP6 simulations with the approach to perturbation studies described by Favorite[4]. The results are used to plan measurements at Georgia Tech to determine the adequacy of nuclear data for the application of MCLLS to the end of well log interpretation.

CONSIDERATIONS FOR THE INTEGRAL EXPERIMENTS

Theory

This can be treated as a fixed-source problem. The D-T reaction,

$$^{2}H + {}^{3}H \rightarrow {}^{4}He + n \tag{1}$$

produces a nearly monoenergetic 14.1 MeV neutron.[5] Kinematic energy broadening is assumed to be negligible for this application. Well logging boreholes are typically full of fluid which includes large amounts of water. Significant moderation will take place such that prompt gamma production depends on a neutron flux which is not approximately monoenergetic. Prompt gammas are of great importance in the MCLLS approach. These are most important while delayed gammas are treated as background. The (n,γ) reaction rate from a 1D simulation of limestone mixed with water is shown in Figure 1. Gamma production is dominated by neutrons moderated in the surrounding medium.

Currently there is no capability in MCNP6 to propagate error from cross section tables to a final result. The error shown is only that from Monte Carlo variance. Perturbations to cross sections can be achieved in MCNP6, and sensitivity to error can be estimated. In this case, the estimations for several quantities show a linear relationship between a perturbed cross section and the magnitude of the perturbation. Figures 2 and 3 show how the Si-28 and Ca-40 radiative captures affect the neutron leakage from the tank. This trend is predicted

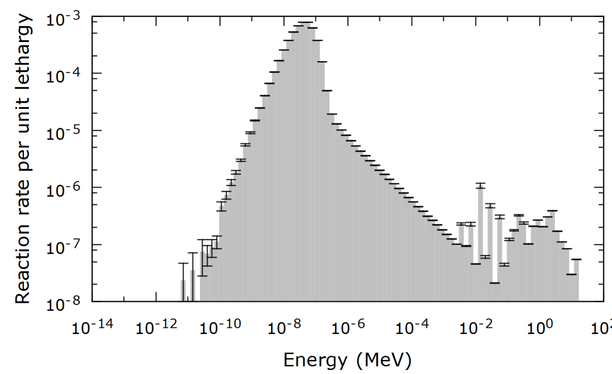

Fig. 1. Simulated radiative capture reaction rate per unit lethargy in limestone due to a 14.1 MeV neutron source.

for quantities that are easily measurable in a laboratory setting. Experimental benchmarks are necessary to verify these predictions.

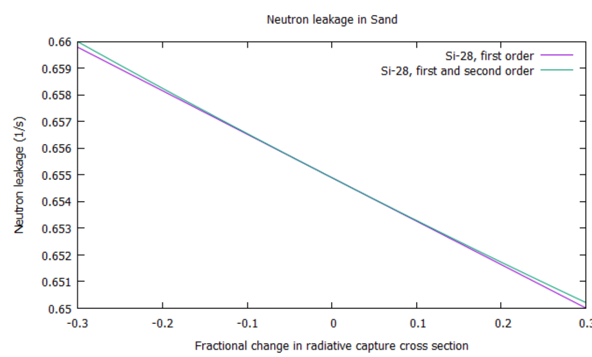

Fig. 2. Simulated neutron leakage in sand with perturbed Si-28 radiative capture cross section using the MCNP6 PERT card.

Methodology

An ideal experimental setup would deviate little from an infinite medium to emulate boreholes encountered in well logging. However, materials of interest for this project include sand, sandstone, limestone, and crude oil. Due to the cumbersome nature of these materials, a compact, multipurpose tank is a convenient apparatus. A tank was designed to be 2 feet by 4 feet with a height of 2 feet. The walls are made of aluminum with a thickness of 1 inch. The thickness of the actual tank once built will be around 5/8 inches, but additional thickness was used to account for bracing which is not finalized. Inside are three vertical, acrylic tubes to hold the DT generator and detectors. Each tube has an inner diameter of 4.5 inches. This is large enough for the Thermo P 211 neutron generator,

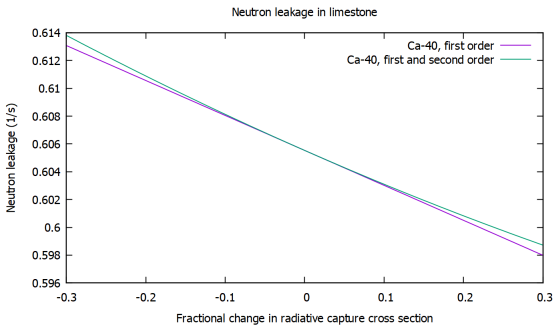

Fig. 3. Simulated neutron leakage in limestone with perturbed Ca-40 radiative capture cross section using the MCNP6 PERT card.

shown in Figure 4, and a wide array of detection instruments.

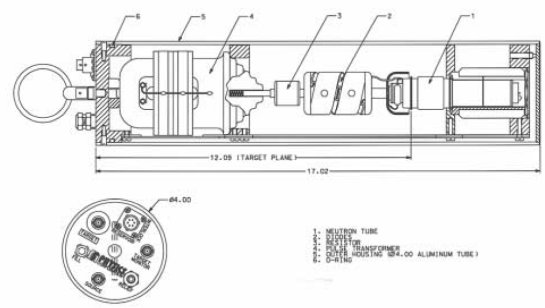

Fig. 4. Thermo P 211 Pulsed Neutron Generator

Figures 5 and 6 show the neutron generator placed in the tank. The distances to the other instrument tubes were based on the distance of instrument to source in a prototype well logging tool built at Kansas State. The neutron generator is filled with the FC-77 dielectric fluid. This is a proprietary fluid composed of carbon, fluorine, and oxygen.[6]

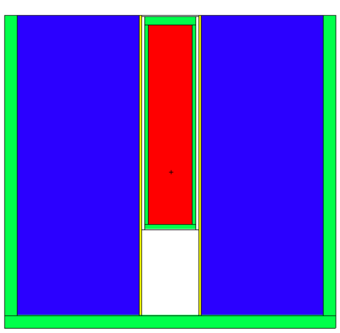

Fig. 5. Cross section of neutron generator vertically oriented in the measurement tank instrument tube.

RESULTS

Elements of interest in this study exist as several isotopes in nature. Effects from each isotope should be considered separately. Ca-40 is by far the most abundant isotope of calcium. However, Ca-43 has a much larger radiative capture cross section.[7] Figure 7 shows the photon leakage perturbed separately for Ca-40 and Ca-43. Despite the larger cross section, sensitivity to Ca-43 is negligible.

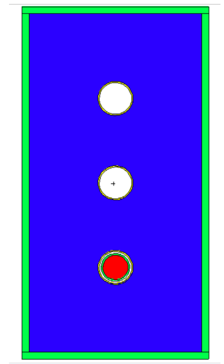

Fig. 6. Top-down view of the measurement tank and instrument tubes. Neutron generator in bottom tube.

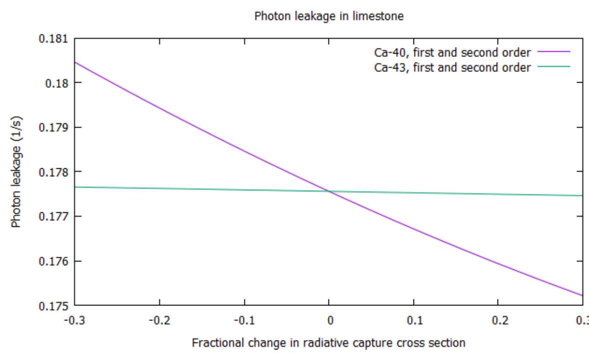

Fig. 7. Simulated photon leakage current in limestone. Ca-40 and Ca-43 perturbations performed separately.

To evaluate geometric effects due to the finite volume of the tank, an MCNP model was used to place the DT tube in a large sphere with a 2 m radius. This configuration has little leakage from the medium. The 2 ft x 4 ft x 2 ft tank is compared with this configuration in Figure 8. Both configurations use water as the medium. The plot shows some spectral changes which arise from the reduction in volume. Most prominent in the tank configuration is the greater ratio of fast neutrons to thermal neutrons. Both groups must be represented. The MCLLS approach takes advantage of the pulsed DT source by measuring delayed gamma background while the source is off. The presence of both fast and thermal groups is crucial to provide data for the approach.

CONCLUSIONS

Several cross sections important for well logging simulations have high uncertainty and must be tested for adequacy in the new MCLLS approach. A small experimental apparatus and approach designed at Georgia Tech are adequate to test the MCLLS sensitivity to cross section uncertainties and to benchmark the cross sections in MCNP6 used to support the

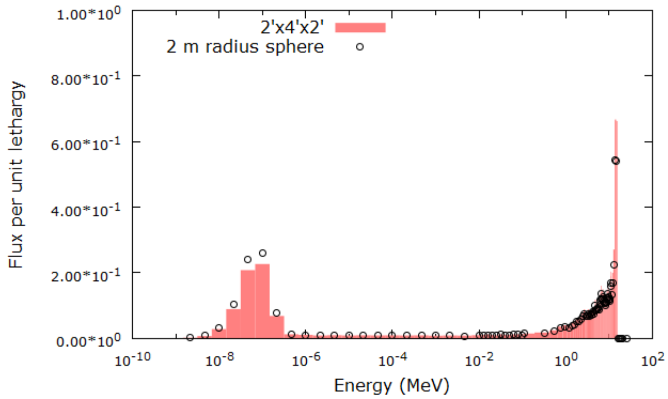

Fig. 8. Monte Carlo comparison of DT neutron spectrum in water for a large 2 m radius sphere and a 2 ft x 4 ft x 2 ft aluminum tank.

MCLLS approach. Several quantities including neutron leakage, photon leakage, and their change with material density are predicted to significant enough to measure directly with this apparatus. The measured data can then be used to supplement Monte Carlo libraries used with the MCLLS approach.

ACKNOWLEDGMENTS

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