Designing neutron shielding for a CENNS experiment

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Abstract

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is also a neutrino source. These particular neutrinos provide an optimal opportunity for the observation of coherent elastic neutrino-nucleus scattering (CENNS), a process that has been predicted but never observed. The detector configuration must involve some lead shielding surrounding the CENNS detector to block background radiation. However, the neutrinos must pass through this lead shielding to reach the detector, and doing so may produce neutrino-induced neutrons that can enter the detector and create a false signal. The Geant4 simulation toolkit was used to study neutron shielding and the neutron energy deposition in the detector volume.

1 Introduction

2 Simulation set up

The Geant4 simulation toolkit was used to reproduce the results of. The detector set up can be seen in figure **??**. The detector's core consists of a lead cube (50 cm edge-length) with 4 holes that hold one EJ-301 scintillator, each. These are frustums of a cone and are made of pure liquid EJ-301 (C_8H_{10}). The sides and the bottom of the lead cube are covered with a 1 cm thick layer of EJ-200 a solid plastic scintillator ($C_{10}H_{11}$]). Above the lead cube is a gap of 21 cm followed by an Al-7075 plate with a thickness of 2 cm. This plate shall reduce signals of cosmic neutrinos in the real detector. The whole setup is enclosed by a $1\,\text{m}^3$ water cube.

Neutrons are being generated randomly inside the lead with a random direction.

If a particle enters one of the scintillators and deposits energy, that amount will be converted into electron-equivalent energy by using the graph in figure 1.
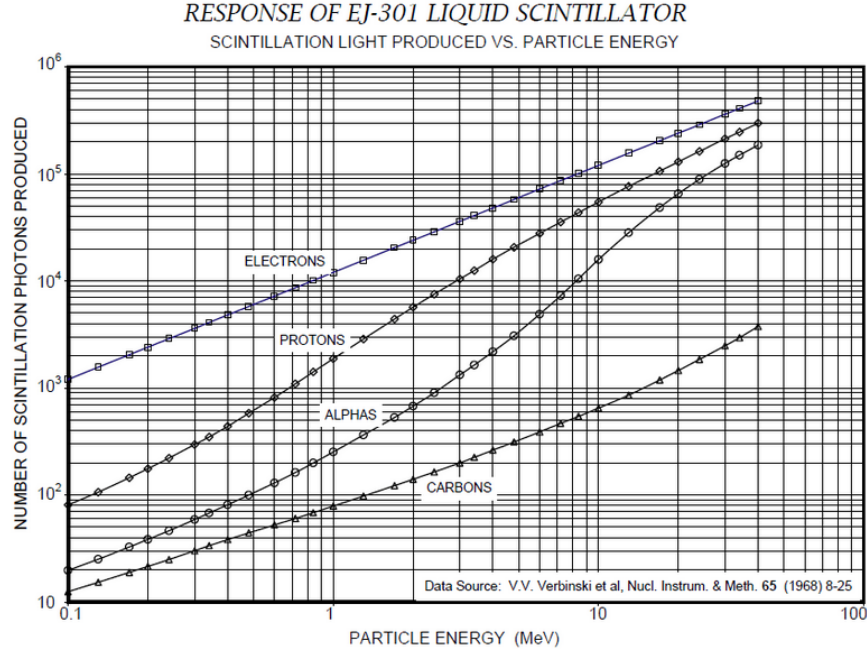

Figure 1: Photon response of the EJ-301 scintillator.

In addition to the four particles mentioned in this graph there is also a number of γ, e^+ and deuterons that enter the scintillator. Since e^+ have the same mass and charge as electrons and γ will decay into $e^- + e^+$, both are treated as electrons. Deuterons will approximately emit a number of photons that lies in the middle between p and α. In approx. 0.5% of the events the reaction

$$n_0^1 + C_6^{12} \longrightarrow C_6^{13} \longrightarrow B_4^9 + \alpha_2^4 \tag{1}$$
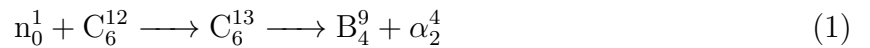
can occur. Because this effect should be negligible, the electron-equivalent energy of the beryllium nucleus will not be calculated this case.

3   Results and Discussion

3.1   Correct set up

First of all, it was necessary to verify that the neutrons were generated in the correct volume. Figure **??** and **??** show that the particles were generated only inside the lead and not inside the holes which contain the scintillators. Figure **??** and **??** show that the direction of the neutrons is equally distributed.

3.2   Efficiency

An event will be marked as "valid" once the energy deposition in a single scintillator exceeds a given threshold in keVee. Figure 2 and 3 show the percentage of events which were marked as "valid" at a given energy of the primary particle with an energy threshold of 30 keVee and 100 keVee.
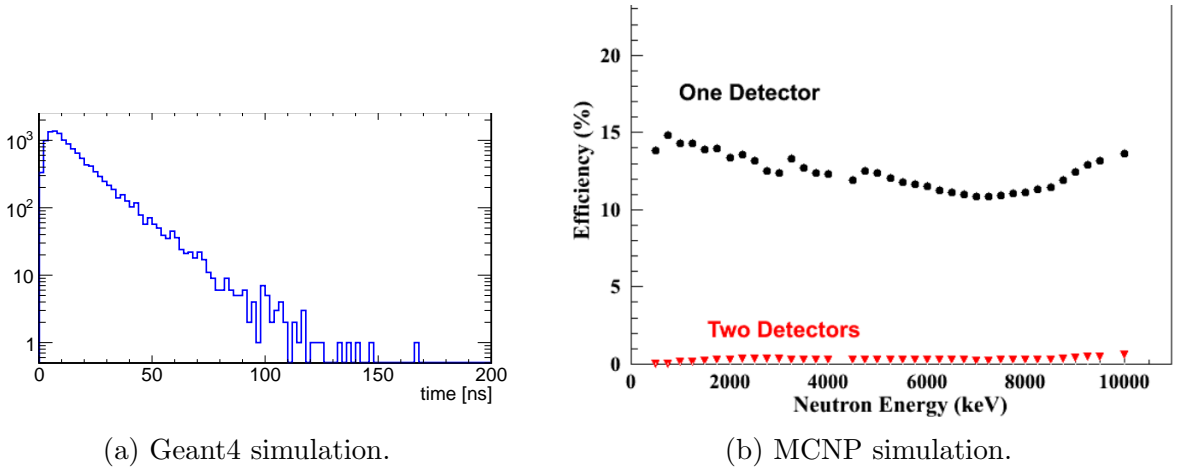

(a) Geant4 simulation.

(b) MCNP simulation.

Figure 2: Percentage of "valid" events for given monochromatic primary particles with a 30 keVee threshold.

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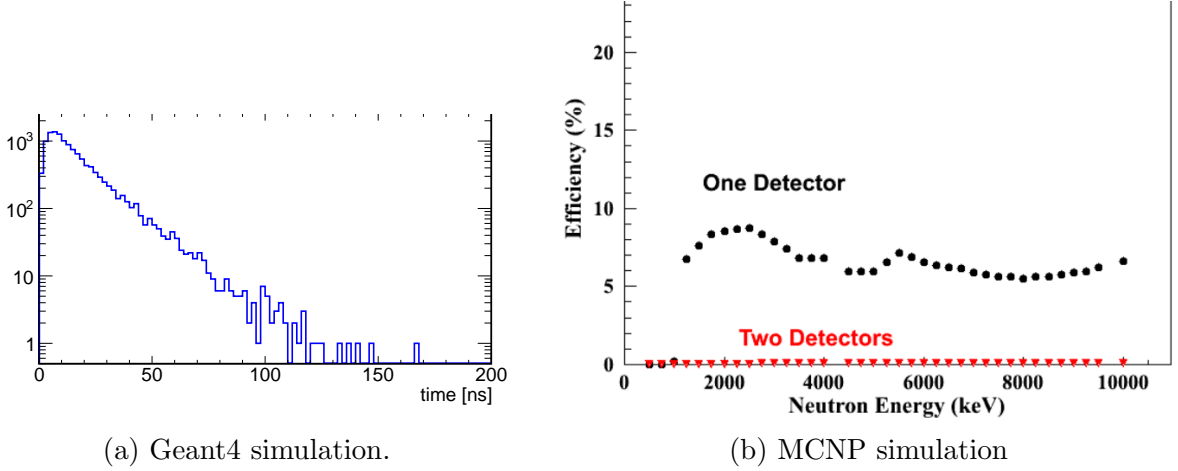(a) Geant4 simulation.

(b) MCNP simulation

Figure 3: Percentage of "valid" events for given monochromatic primary particles with a 100 keVee threshold.

The efficiency of the Geant4 simulation is about 5% higher. This might be a result of the superior tracking algorithms of Geant which will also track secondaries, whereas the MCNP simulation was run in neutron and photon mode only **??**.

Also, the scintillators were simulated as frustums of a cone instead as frustums of a hexagonal pyramid. This increases the cross-sectional area of each scintillator slightly and might result in more valid events.

3.3 Timing

Figure 4 and **??** show a distribution of the arrival time of a signal. The neutron is being generated at $t = 0$ ns and a signal arrives once the energy deposition one scintillator exceeds a given threshold (30 keVee or 100 keVee) for the first time.

(a) Timing of Geant4 simulation.

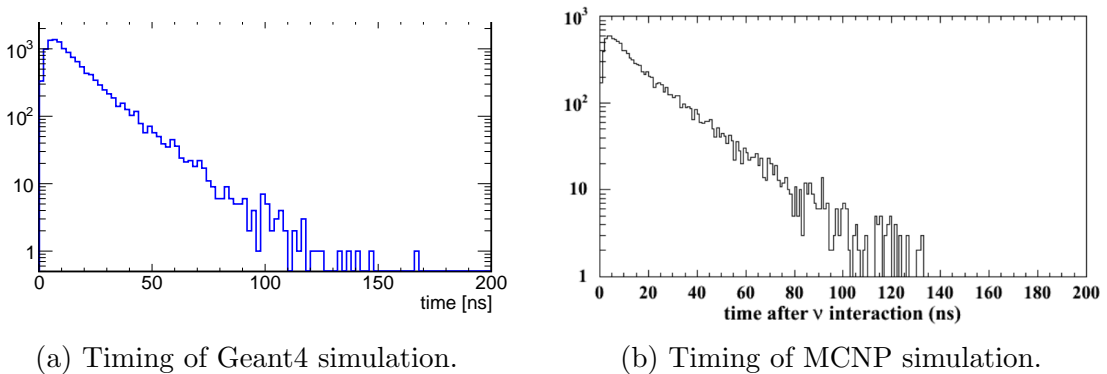(b) Timing of MCNP simulation.

Figure 4: Threshold 30 keVee

The timing graphs of both, Geant4 and MCNP simulation, show a dropoff at 0 ns due to the threshold and end somewhere between 100 ns and 140 ns.

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3.4   Energy deposition

Finally, the energy deposition of both simulations are being compared. Figure 1 provided the necessary data to convert the energy to keV electron equivalent (keVee). As mentioned before, γ and e^+ are treated as e^- and deuterons lie in the middle between p and α. Seldom particles like beryllium will be ignored.

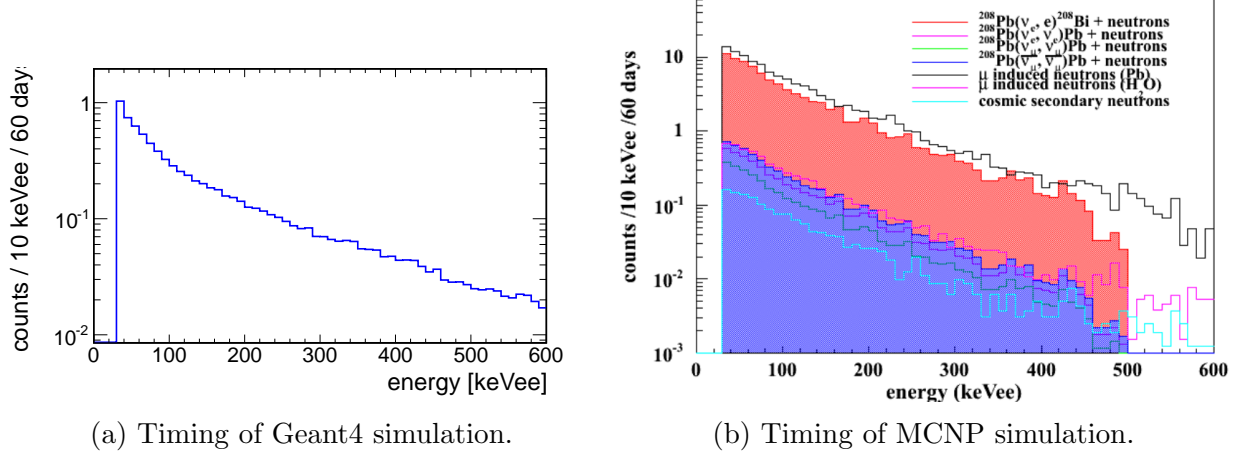(a) Timing of Geant4 simulation.

(b) Timing of MCNP simulation.

Figure 5: Threshold 30 keVee

4   Conclusion

Acknowledgments

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References

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