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Simulation of a Diamond Detector installed in the CROCUS Reactor

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1. Introduction

Diamond detectors are being spotlighted for their strong radiation endurance. Researchers at École Polytechnique Fédérale de Lausanne (EPFL) have been conducting research on diamond detectors, focusing on recent experiments [1-2]. Recent studies have shown that the shape of a charge collection pulse varies depending on the type and energy of incident particles [3-4]. However, these experimental studies are limited to qualitative output, and the need for analysis of results through simulation was raised to overcome producing quantitative instead of qualitative information. In this study, only neutron effects were analyzed and the effect of gamma radiation will be addressed in a following study.

2. GEANT4 Simulation Results

2.1 Zero Power CROCUS Reactor Modeling

Fig. 1 shows a configuration of zero power CROCUS reactor plotted by visual MCNP6 editor [5]. The CROCUS reactor is 1 m high and 58 cm in diameter. It is composed of UO_2 fuel at the center and U-metal fuel surrounding it. The maximum power of the reactor is 100 W_{th} and the criticality is adjusted by water level.

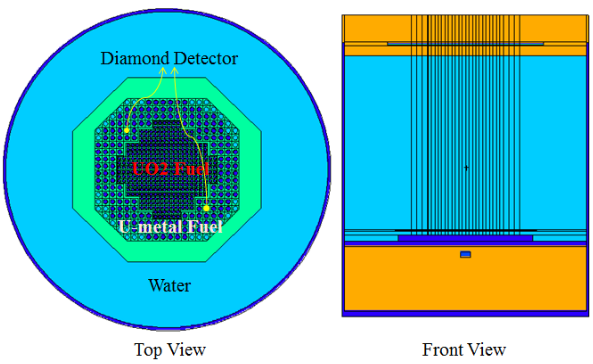

Fig. 1. Configuration of zero power CROCUS reactor.

MCNP6 was used for zero power CROCUS reactor modeling [6]. Fig. 2 shows the spectrum in the location of diamond detectors in CROCUS.

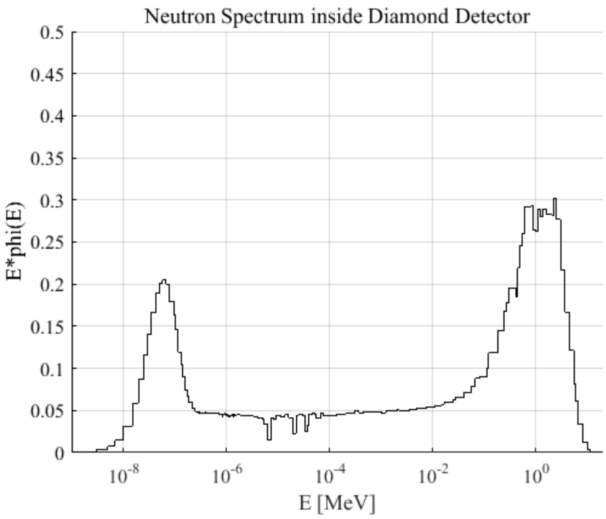

Fig. 2. Neutron spectrum in diamond detector.

2.2 Diamond Detector Modeling

Fig. 3 shows a configuration of the diamond detector. It is composed of a ^{6}LiF neutron converter, polyethylene collimators, an anode, a cathode, and a diamond sensor.

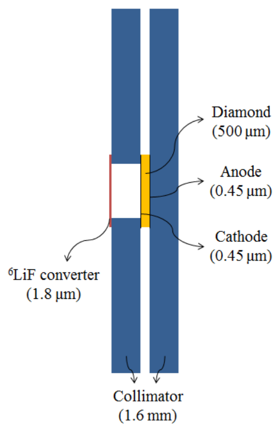

Fig. 3. Configuration of diamond detector.

GEANT4 v10.4.p02 was used for the diamond detector modeling [7]. An isotropic neutron source was used, assuming a spectrum representative of the location of insertion in CROCUS. The spectrum is shown in Fig. 2.

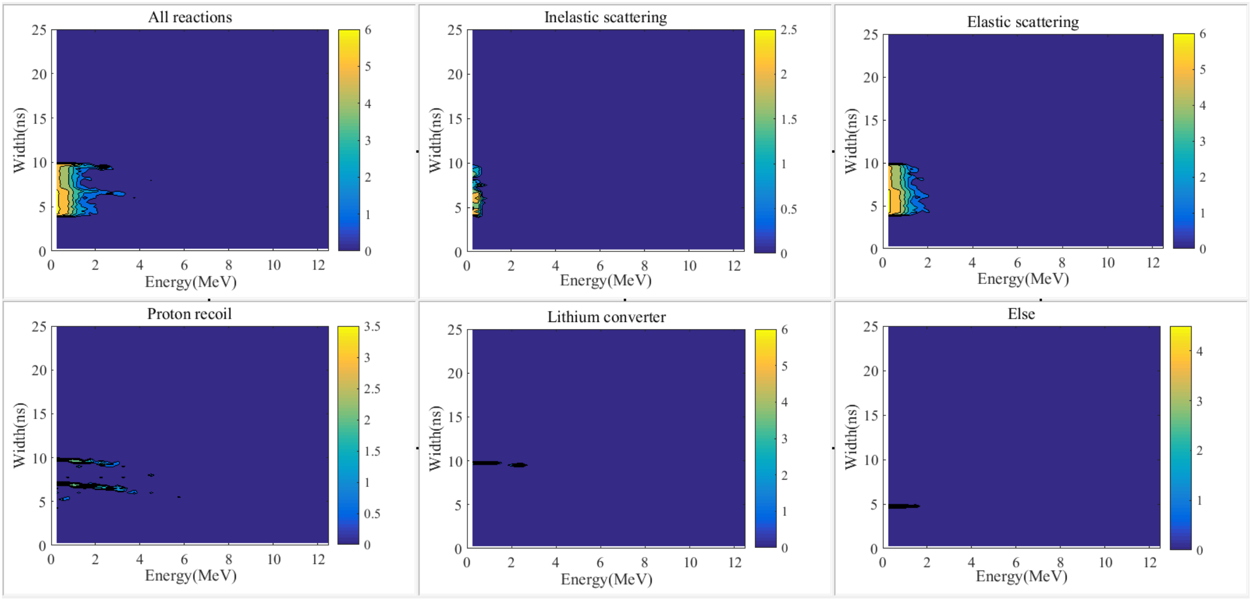

Fig. 4. Scatter plot of GEANT4 v10.4.p02.

2.3 Results

Fig. 4 shows the scatter plot between the deposited energy and the charge collection pulse width. It is shown that the scatter plots tend to vary depending on the type of interaction of neutrons with the detector. ‘Inelastic scattering’ means that a neutron directly causes an inelastic scattering with a carbon atom of the diamond detector. ‘Elastic scattering’ means that a neutron directly causes an elastic scattering with a carbon atom of the diamond detector. ‘Proton recoil’ means that the energy is deposited in the diamond crystal by a proton ejected from the polyethylene collimator by a neutron collision. ‘Lithium converter’ means the response in which the energy is deposited by an alpha or a triton produced by the reaction between ^{6}Li and a thermal neutron. ‘Else’ refers to other cases and ‘All reactions’ refers to the sum of all cases. The color bar represents the count and is the log scale.

In Fig. 4, it is shown that there is a large amount of elastic scattering with carbon atoms. Mainly neutrons that have less than 1 MeV of energy cause elastic collisions. Since the responses occur overall inside the diamond sensor, the charge collection pulse width is evenly distributed between 4 and 10 ns. With a bias voltage of 400 V, the electron drift velocity is around 50 μm/ns and the hole velocity around 70 μm/ns. While the hole drift and electron drift velocity contribute to the signals observed between 4 and 7 ns, only electron drift contributes to pulse width between 7 and 10 ns.

In the case of the proton recoil, two bands appear, one by protons impacting the anode and the other by protons impacting the cathode. Protons entering the cathode produce electrons and holes, of which only electrons flow towards the anode to absorb energy. Protons entering the anode also produce both electrons and holes, of which only holes move towards the cathode to absorb energy. Due to the velocity difference between electrons and holes, a band is formed at different widths, one at 7 ns and the other at 10 ns.

When a neutron reacts to the lithium converter, a pair of alpha and triton is created, one of which is then reactive at the cathode when the particle enters the diamond sensor. Since alpha or triton always reacts only on the cathode side, only electron drift is generated producing a pulse of 10 ns at all times.

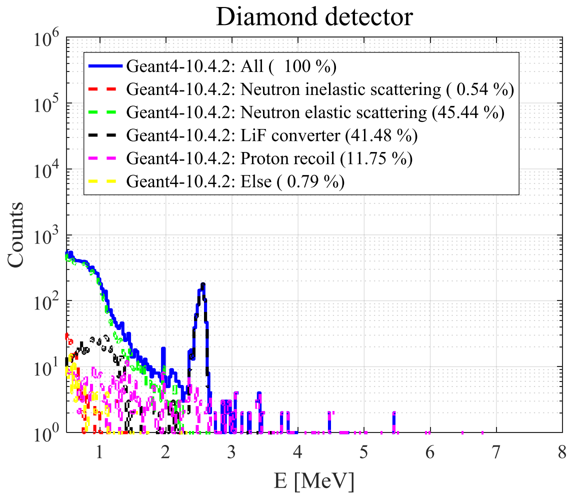

Fig. 5. Deposited energy of GEANT4 v10.4.p02

Fig. 5 shows the deposited energies through each type of interaction with the diamond detector. The percentage was calculated for interactions that result in more than 1 MeV of energy absorbed in the crystal.

In Fig. 5, it is shown that the neutron elastic scattering and the ^{6}LiF converter reaction occurred 45.44% and 41.48%, respectively. Another 11.75% of the total interactions are due to protons.

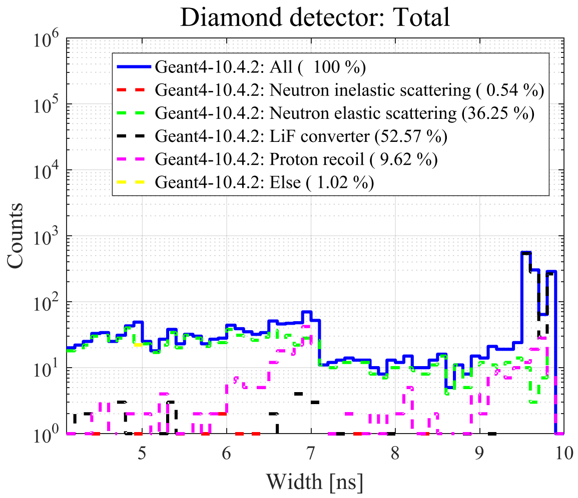

Fig. 6. Pulse width of GEANT4 v.10.4.p02

Fig. 6 shows the charge collection pulse widths by each response inside the diamond detector. 4 to 7 ns indicates the effect of the electron drift and the hole drift, and 7 to 10 ns indicates the effect of the electron drift only. In the case of the ^{6}LiF converter response, it is distributed between 9.5 and 10 ns since it occurred on the cathode side only. For the proton recoil, the response increased when 6 to 7 ns and 9 to 10 ns, respectively, indicating that the reaction occurred near the anode and the cathode sides.

3. Conclusions

A diamond detector installed in the zero power CROCUS reactor of the École Polytechnique Fédérale de Lausanne (EPFL) has been modelled by GEANT4 v10.4.p02. The energy deposition in the diamond crystal though neutron interactions were analyzed. Reponses are divided into four categories: an inelastic scattering, an elastic scattering, a lithium converter response, and a proton recoil.

For neutrons above 1 MeV, three types of interaction account for more than 98% (the lithium converter response of 41.48%, the elastic scattering of 45.44%, and the proton recoil of 11.75%, respectively). Among these, the lithium converter and proton recoil interactions occurred mainly at the electrodes, while the elastic and inelastic scattering collisions occurred anywhere. In the scatter plot, the lithium converter reaction showed a 10 ns band, which means the electron drift, along with the triton 1 MeV peak and the alpha 2.5 MeV peak. The proton recoil reaction showed the 7 ns band representing the hole drift and the 10 ns band representing the electron drift. The elastic scattering showed even distribution between 4 and 10 ns. Among them, 4 to 7 ns is where the hole drift and the electron drift coexist, and 7 to 10 ns shows the electron drift only.

In future studies, the effect of gamma radiation on the diamond detector will be addressed. In addition, the effects of neutrons and gamma rays will be combined and compared to experimental results generated with CROCUS.

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