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Fluka Monte-Carlo simulations of Neutron Detection for Fusion Reactors

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Tritium is essential for fueling fusion reactions in plasma machines like tokamaks. Its production, primarily through neutron interactions with lithium in the Breeding Blanket (BB), is a critical aspect of fusion energy development. Testing and validating BB designs is challenging due to the lack of volumetric neutron sources with fluences comparable to those in a tokamak. Fast neutron detectors are essential for validating neutron multiplication rates and measuring the statistical relevance of tritium-producing reactions. While diamond detectors have been used in Joint European Taurus and are part of future tokamak designs, their performance declines at higher temperatures. Silicon Carbide (SiC) detectors have been characterized as potential candidates for neutron detection into tokamak environments. Neutrons, being neutral, can only interact with a lattice nuclei: this produces charged particles (either alphas, betas, protons and/or displaced nuclei) which, in turn, ionize the semiconductor. The kinetic energy of the neutron (E_N) is partially transferred to the products of the interaction, the so called "deposited energy" (E_D). E_D will spread out to the lattice atoms, ultimately causing several ionizations. The promotion of several electrons to the conduction band changes the resistivity of the junction, which is a macroscopic parameter and, thus, can be easily detected and registered. Charged particles generated by neutron interactions in the detector material can travel short distances before losing their kinetic energy through collisions. The distance these particles travel depends on their energy and the material which they traverse. For heavy ions, alpha particles, and protons with MeV energies, their paths can be on the order of µm to mm. Silicon Carbide neutron detectors typically have thicknesses ranging from tens to hundreds of µm. This thickness is comparable to the range of alpha particles produced by certain neutron reactions, such as $^{12}C(n,\alpha)^{9}Be$ and $^{28}Si(n,\alpha)^{25}Mg$. As a result, a significant fraction of alpha particles may undergo partial deposition within the detector material. The objective of the proposed work is to study Neutron Detection through simulations with Fluka, in order to compare the efficiency in the neutron detection of a large volume Silicon Carbide (SiC) detectors for 14.1 MeV neutrons and a fluence of 4.45 · 1011 (n/cm^2). The two simulated detectors present physical structures with an active thickness of 100 µm and 250 µm, and an active area of 25 mm^2 and 12.5 mm^2, respectively. From these simulations, the neutron fluence is much higher in the active thickness of 250 µm. Of course, the area of the detector cannot be increased over a certain value because very thick epitaxial layers could produce several types of crystallographic defects, decreasing the detector production yield, with a subsequent increase of the detectors cost. Furthermore, increasing the epitaxial layer thickness produce an increase of reverse bias needed to deplete the layer.

For this reason, we have also proposed preliminary study of neutron detection, considering modulator detector consists into SiC detectors with 100 µm thick active thickness and active area of 25 mm^2, in order to study the neutron fluence within the active volume.