Simulation of the neutron response function of diamond detectors

Detectors based on single crystal synthetic diamond are well suited for high resolution spectrometry of fast neutrons in extreme conditions. Their use for diagnostics purposes requires good knowledge of the response matrix of the detector over a wide energy range. We have modified the Monte Carlo particle transport code NRESP, which was originally developed at PTB for scintillation detectors, for the calculation of the neutron response functions of diamond detectors in the energy range 7 MeV < E_n *< 16 MeV. Simulated response functions were compared to measurements in quasi-mono-energetic neutron fields performed at the PTB Ion Accelerator Facility.*

Radiation detectors based on synthetic single crystal diamond have shown a great potential for high resolution spectrometry of fast neutrons in harsh environments. In particular, their good energy resolution, fast signal response and high radiation hardness make diamond detectors suitable for neutron plasma diagnostics for the fusion project ITER. The task of plasma diagnostics via high resolution neutron spectrometry requires good knowledge of the response matrix of the detector over a broad range of neutron energies 2 MeV < E_n < 20 MeV. Such a response matrix is needed for the unfolding of the measured pulse height spectra (PHS) in order to extract the full information about the incident neutrons.

In a diamond detector neutrons are detected via interactions with carbon nuclei. Depending on the incident energy E_n, a fast neutron can undergo a number of nuclear reactions ranging from elastic scattering to ^{12}C(n,p)^{12}B and ^{12}C(n,d)^{11}B reactions followed by emission of proton and deuteron, respectively. Depending on the diamond crystal thickness, the charged products of the reactions deposit a fraction of their energy inside the crystal. In general, sharp peaks in a measured PHS are observed only in case of reactions with charged particles in the exit channels. The remaining reactions with a neutron in the exit channel give rise to wide distributions with characteristic edges. An example of two PHS measured in mono-energetic neutron fields is shown in Figure 1.

As it is rather laborious to determine the complete response matrix experimentally, detailed simulations of the neutron response functions of diamond detectors are required. Standard neutron transport codes like MCNP are not well suited for this task as they cannot transport particles beyond the mass number of α particles. This is a severe limitation for the simulation of a diamond detector in which e.g. ^{9}Be ions are created in the reaction ^{12}C(n,α)^{9}Be for neutrons of energies E_n > 7.2 MeV.

We have used the Monte Carlo particle transport code NRESP for the calculation of the neutron response functions of diamond detectors in the energy range 7 MeV < E_n < 16 MeV. The NRESP code, originally developed at the PTB for the calculation of the neutron response functions of liquid scintillation detectors, was improved and adapted for the simulation of a diamond detector.

The simulations were benchmarked with a set of nine experimental PHS measured in quasi-mono-energetic neutron fields. The fields were produced with deuteron beams from the PTB cyclotron incident on a deuterium gas target. Mono-energetic neutrons from the D(d,n)^{3}He reaction were selected using the time-of-flight method. Figure 2 depicts the comparison between the simulated and measured PHS for E_n = 16.0 MeV.

The simulation benchmark suggests that two-body reactions $^{12}C(n,\alpha)^{9}Be$, $^{12}C(n,p)^{12}B$ and $^{12}C(n,d)^{11}B$ are well described in our simulations. Significant discrepancies are observed in the case of broad distributions which do not describe the measurements well. With a detailed modeling of the individual neutron-induced reactions on an event-by-event basis we achieve a reasonable agreement between the simulated and measured PHS which is qualitatively better than in previous works found in literature. However, more reliable differential cross section data are still needed for reactions with three α particles in the exit channel. In addition, a more detailed simulation including the charge collection properties of the diamond detectors is needed in order to better understand the experimental PHS.

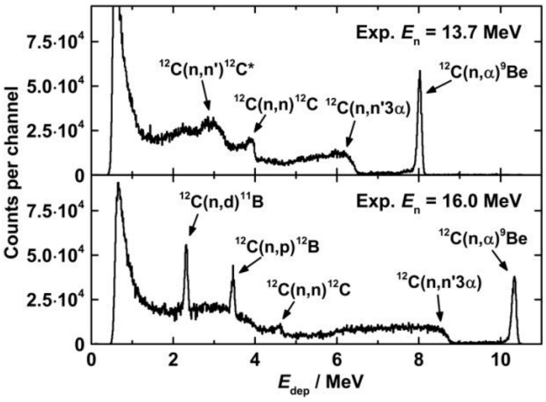

Figure 1: Two experimental PHS measured in mono-energetic neutron reference fields of E_n = 13.7 and 16.0 MeV, respectively. The individual neutron-induced reactions are assigned to the corresponding structures observed in the spectra. Clearly visible in the lower plot is the shift of the spectrum with the increased E_n and also the appearance of two peaks not present in the upper plot. These peaks are caused by the $^{12}C(n,p)^{12}B$ and $^{12}C(n,d)^{11}B$ reactions which have an energy threshold of E_n = 15.1 MeV and 15.8 MeV, respectively.

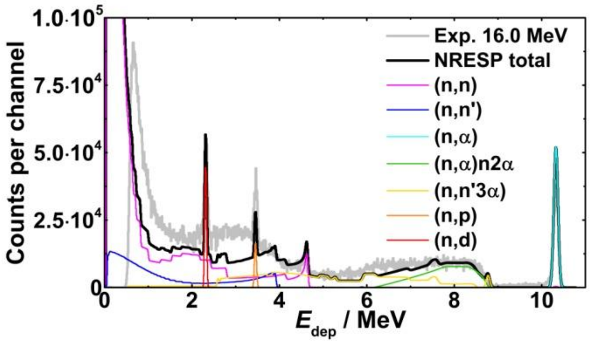

Figure 2: Comparison of the NRESP simulation (black line) to the experimental PHS (grey line) measured at E_n = 16.0 MeV. The color-coded lines denote the individual contributions to the simulated total PHS, sorted according to the first interaction of the incident neutron.

Contact Peron

M. Zboril, Department 6.4, Working Group 6.46, e-mail: miroslav.zboril@ptb.de