Analysis of the response function of liquid scintillators to neutron emission in fusion devices

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Liquid scintillators are one of the most commonly employed neutron detectors in fusion devices. The detection principle is based on the elastic scattering of neutron with protons in a thick scatterer material. Part of the energy deposited by the recoil proton in the scatterer medium is converted into fluorescence light which is then detected with a photomultiplier. The response function of a liquid scintillator to even a simple mono-energetic neutron source can be rather complicated due to non-linearities in the light output function and the gain in the photo-multiplier at high count rates, the role of multiple elastic scattering collisions, the presence of additional elements other than hydrogen, the role of neutron induced nuclear reactions, the light transport and self-absorption in the scattering medium and last but not least in magnetic confinement fusion devices the role of stray magnetic fields. Additional complicating factors are represented by the broad neutron energy spectrum typically present in fusion devices due to the presence, in addition to the DD and DT neutron emission, of scattered neutrons, physical processes in the plasma (for example plasma rotation or addition plasma heating) and the fusion reaction cross-section anisotropy. Response functions are typically calculated by Monte Carlo codes such as MCNP and GEANT4 which include a description of the neutron source, the geometry and material composition of the fusion device and of the neutron diagnostic (i.e. shielding, collimator line of sight and neutron detector) and all (or most) of the involved physical processes. The output from such codes are then compared with experimental observations to extract information on the plasma properties (for example ion temperature) and on and processes occurring in the plasma (for example plasma rotation). It is obvious that the agreement between simulations and experimental observations strongly depends on how well both the underlying physical processes in the plasma responsible for the neutron emission and the detector response function are understood and modeled. This “forward” modeling (from the neutron source to the simulated detector measurement) allows to extract information on the physical processes occurring in the plasma.

This paper reviews in details all the physical processes affecting the response function of liquid scintillator to a mono-energetic and to a typical fusion plasma neutron sources including a detailed analytical derivation of the effect of neutron multiple elastic scattering on hydrogen and carbon which allows the correct interpretation of the different components in the response function calculated by Monte Carlo simulations. An example on how the derived response function can be used to interpret experimental observations is discussed in detailed based on neutron emission measurements on the Mega Ampere Spherical Tokamak device.