MLEM-based Image Reconstruction Algorithm for Fast Neutron Scattering Imaging

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Fast neutrons preserve the initial source information (e.g., position, energy, and time) due to their relatively low interaction probability with surrounding materials and their straight track. When measuring fast neutrons using scattering reactions, there is no need to be slowed down to thermal neutrons. This allows for more accurate information to be obtained. A neutron scattering imager consists of two pixelated scatter detectors. The energy and scattering angle of the neutrons can be determined from the energy of the protons produced by the scattering reaction in the first detector, the time of flight between the two detectors, and the distance between the interaction positions. From these measured quantities, the conical surface can be determined and the position of the source can be estimated roughly from the overlapped conical surfaces corresponding to all reactions. Maximum Likelihood Expectation Maximization (MLEM) is an iterative statistical algorithm to reconstruct the source distribution from the measured events in the neutron scattering imager. It finds the most probable source distribution through iterative process of projection and back-projection [1-3]. In this study, we developed MLEM for reconstructing fast neutron scattering images using system matrix with scattering cross-section and angular resolution. The system matrix which is the probability that a particle emitted in the image space will reach the first scatter detector without being absorbed by the surrounding materials, and then scatter at a given angle to reach the

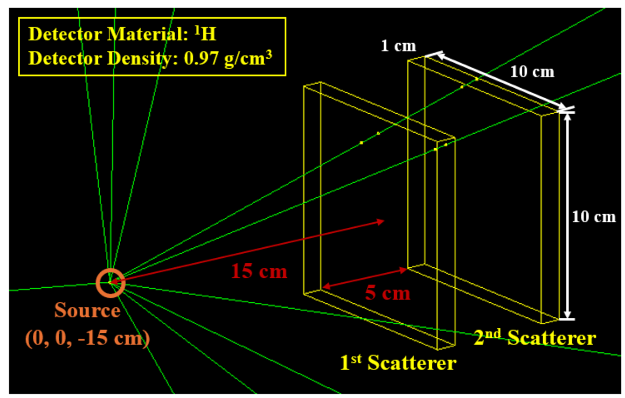

Figure. 1. Geant4 simulation conditions for acquiring fast neutron scattering data

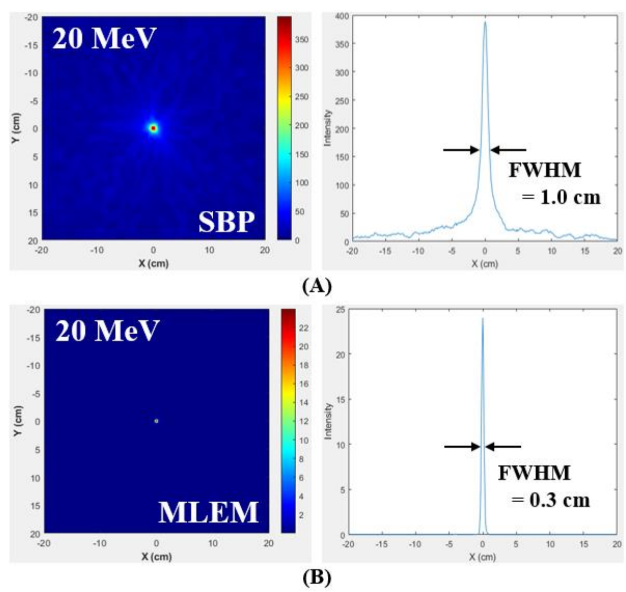

Figure. 2. Comparison of reconstructed image resolution by SBP (A) and MLEM (B)

second scatter detector [4]. In the case of neutrons up to 20 MeV, the scattering cross-sections for each angle was obtained from ENDF, while those for higher energy neutrons can be obtained using physics models such as the INC model, Glauber-Gribov, or phase shift analysis. Since the scattering angle of a neutron is determined from the measured energy of the scattered neutron, the angular resolution depends on the energy resolution and the uncertainty of the neutron reaction position. It can therefore be calculated by considering the energy resolution of the detector to be used, the uncertainty of the reaction position due to the pixel size, and the time resolution of the detection system [5]. Finally, the argument for normalisation (i.e., sensitivity image) is the probability that the radiation emitted in image space is measured somewhere in the detector. It is calculated by taking into account the probability that the radiation is emitted toward the detector and the probability that the radiation emitted in image space is not absorbed before reaching the detector. Therefore, it is equal to the sum of the system matrix values of all detector pixels [6]. The fast neutron scattering data were obtained using the Geant4 code [7]. The simulation conditions are shown in Fig. 1. The MLEM reconstruction is shown in Fig. 2(B) and its FWHM is more than three times better than the reconstruction using simple back-projection (SBP) (Fig. 2(A)). MLEM for fast neutron scattering imaging can be useful in many fields such as spent nuclear fuel verification and hadron therapy.

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