§23. Development of Compact Neutron Camera with Nuclear Emulsion for Energetic-ion Profile Diagnostics

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During neutral beam injection heating of magnetically confined deuterium plasma, the emission profile of fusion neutrons, *i.e.* 2.5 MeV neutron from DD reaction (DD neutron), depends on the profile of energetic ions in the plasma. The neutron emission profile monitor based on multi-channel scintillator array with collimator is planned to install in LHD for coming deuterium plasma experiments. As a complemental neutron profile monitor, we have proposed a compact neutron pinhole camera based on state-of-the-art nuclear emulsion technique. The camera consists of a pinhole collimator made of tungsten alloy and stacked nuclear emulsions. We have demonstrated point-spread function of the neutron pinhole camera for DT neutron source. In this report, we describe an experimental evaluation of the canera response function for DD neutron and the first experimental data from fusion deuterium plasma of Korea Superconducting Tokamak Advanced Research (KSTAR) at National Fusion Research Institute, Republic of Korea.

We evaluated the response function of pinhole imaging system using the accelerator based DD neutron point source at Fusion Neutron Source (FNS), Japan Atomic Energy Agency. The pinhole camera was set up at 1510 mm far from a water-cooled deuterium target of 80 degree beam line. DD neutrons generated by deuterium ion beam injection into the target were incident to the camera. Behind of the pinhole collimator made of tungsten alloy, a nuclear emulsion, OPERA film was irradiated by DD neutrons and then developed to make visible image of tracks. After development, the recoiled proton tracks in the nuclear emulsion were analyzed by a nuclear emulsion analyzing system, called "S-UTS". Figure 1 shows an emission profile of track density obtained through S-UTS analysis. Calculated profile of the track density based on Monte Carlo simulation using PHITS code was also shown in Fig. 1. The FWHMs in the profiles obtained by the experiment and calculation were estimated around 4.2mm, which have shown good agreement.

In addition, the nuclear emulsion was applied to deuterium plasma experiments at KSTAR. The emulsion with the pinhole collimator was installed on J-port of KSTAR, at 4 m far from the plasma, and irradiated for several shots. Figure 2 shows the track density in the emulsion for shot #8963 - #8969. The background from scattered neutrons and X-rays could be reduced by using the proper development condition. Using the nuclear emulsion with the pinhole collimator, the first measurement of DD neutrons from fusion deuterium plasma at KSTAR was preliminary obtained. The detailed analysis and further measurements will be made to demonstrate the DD neutron imaging capability by the improved camera system.

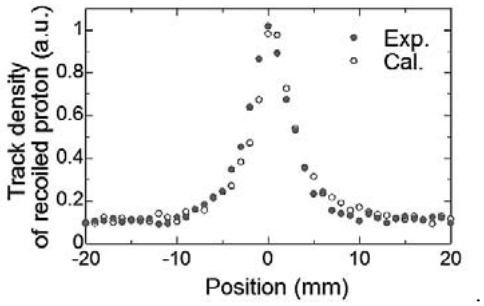

Fig. 1 Profiles of track density in the emulsion obtained by experiment using DD neutron point source and calculation based on Monte Carlo simulation using PHITS code.

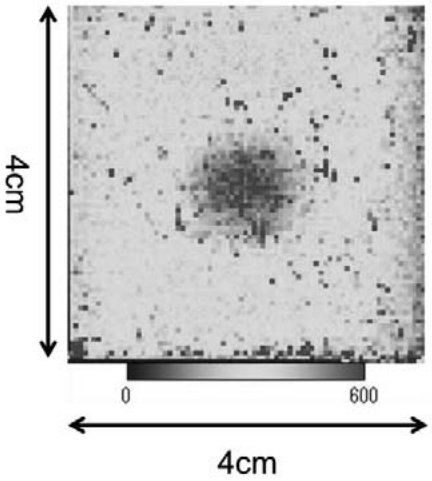

Fig. 2 Track density in the emulsion for shot #8963-#8969 of KSTAR deuterium plasma.

[List of Publications]

1) H. Tomita *et al.*, "Nuclear Emulsion Technique for Fast Neutron Measurement using Automatic Track Analysis System" The 1st Conference on Laser and Accelerator Neutron Sources and Applications, LANSA6-4, Pacifico Yokohama, Apr. 25, 2013.
2) Y. Nakayama, *et al.*, "Development of Fusion Neutron Emission Profile Monitor by Nuclear Emulsion", 45th Chubu-Branch meeting of Atomic Energy Society of Japan, R06, Nagoya Univ., Dec. 17-18, 2013.
3) Y. Sakai, *et al.*, "Development of Fast Neutron Spectrometry based on Automatic Recognition of Recoiled Proton Track in Nuclear Emulsion", The 61st JSAP spring meeting, 19a-PA1-17, Aoyama Gakuin Univ., Mar. 19, 2014.
4) H. Tomita *et al.*, "Development of Fusion Neutron Pinhole Imaging using Nuclear Emulsions for Energetic Ion Diagnostics", Plasma and Fusion Research, **8** (2013) 2406095.
5) M. Isobe, *et al.*, "Application of nuclear emulsion to neutron emission profile diagnostics in National Spherical Torus Experiment", Plasma and Fusion Research, **8** (2013) 2402068.