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Development of Associated Particle Coincident Counting – Neutron Spectrometer toward Deuterium Plasma Diagnostics in LHD
LHD 重水素プラズマ診断のための共役粒子同時計数型中性子スペクトロメータの開発

Yuta Nakamura[a], Yosuke Yamamoto[a], Hideki Tomita[a], Mitsutaka Isobe[b], Kunihiro Ogawa[a], Sadayoshi Murakami[c], Jun Kawarabayashi[a] and Tetsuo Iguchi[a]
中村悠太[a], 山本洋輔[a], 富田英生[a], 磯部光孝[b], 小川国大[a], 村上定義[c], 河原林順[a], 井口哲夫[a]

[a] *Graduate School of Engineering Nagoya University Furo-tyo, Chikusa-ku, Nagoya 464-0073, Japan*
名古屋大学大学院工学研究科　〒464-8603　名古屋市千種区不老町
[b] *National Institute for Fusion Science, Oroshi-cho, Toki, 509-5292, Japan*
核融合科学研究所　〒509-5292　土岐市下石町
[c] *Graduate School of Engineering, Kyoto University, Yoshida-honmachi, Sakyo, Kyoto 606-8501, Japan*
京都大学大学院工学研究科　〒606-8501　京都市左京区吉田本町

Toward deuterium plasma diagnostics in LHD, we have developed a neutron spectrometer based on coincident detection of the scattered neutron and recoiled proton. To evaluate the applicability of the spectrometer, neutron energy spectrum was estimated using Monte Carlo simulation model based on FIT code. The predicted neutron yield in LHD indicated that a counting efficiency of the spectrometer should be above 10^{-6} counts/neutron to obtain the spectrum with statistical precision of less than 10% in the integration time of 1 s.

1. Introduction

In deuterium plasmas, neutrons around energy of 2.5 MeV (DD neutron) are emitted as accompanying products of DD fusion reaction (D+D→^{3}He+n). In the case that target deuterium plasma is heated by neutral beam injection (NBI) heating, the neutrons are mainly produced by beam-plasma interactions because of their high DD reaction rate. Thus, the neutron energy spectrum emitted from the deuterium plasma especially reflects the velocity distribution of fast ion in high-temperature plasma. For deuterium plasma experiments that are now being planned in the world largest heliotron device, Large Helical Device (LHD), at National Institute for Fusion Science (NIFS), Japan, we have proposed a neutron spectrometer based on coincident counting of associated particles [1]. We show the detection principle of the spectrometer and its basic specifications. And we discuss the expected neutron spectra from deuterium plasma heated by NBI in LHD by using Monte Carlo simulation model based on FIT code [2].

2. Detection Principle and Results from the Proto-type Spectrometer

Figure 1 shows schematic diagram of the proposed neutron spectrometer named "associated particle coincident counting – neutron spectrometer". The spectrometer is based on coincident detection of the scattered neutron and recoiled proton from a plastic scintillator as the incident neutron target, or a radiator. In the case of elastic scattering of neutron in the radiator, the neutron energy is derived from sum of the deposit energies in the radiator and the recoiled proton detector and the scattered neutron energy measured by a time-of-flight technique.

We made a prototype spectrometer and measured the detector response to monoenergetic DD neutron. The energy resolution of 6.3% and the detection efficiency of 3.3×10^{-7} counts/neutron were experimentally demonstrated for DD neutron, respectively.

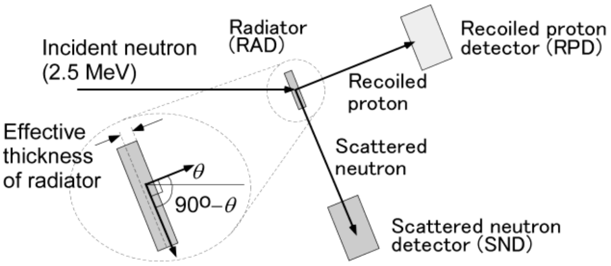

Fig. 1. Schematic diagram of the associated particle coincident counting – neutron spectrometer.

3. Model Calculation of Neutron Spectrum in LHD

We developed a detailed Monte Carlo simulation model for the neutron energy spectrum based on FIT code [2]. The FIT code analyzes an energy deposition and a slowing down process of a high energy ion based on its birth profile and plasma temperature and density profiles. Here, the slowing down process is treated by the steady state solution of

Fokker-Plank equation. On each position in the plasma *i.e.* the normalized minor radius ρ, the maximum velocity of the fast ion, the pitch angle of the fast ion averaged over magnetic surface (reprehensive pitch angle), and the fast ion density were obtained by the FIT-DD code. The energy of neutron emitted from the plasma and reached to the spectrometer was calculated by

$$\begin{aligned} E_n &= \frac{1}{2} m_n u_n^2 \\ &= \frac{1}{2} m_n V^2 + \frac{m_{3He}}{m_{3He} + m_n} (Q + K) \\ &\quad + \cos\theta V \sqrt{\frac{2 m_n m_{3He}}{(m_n + m_{3He})} (Q + K)} \end{aligned} \quad (1)$$

where m_i is the mass of ion i, V is the relative velocity of ion and K is the energy of ion before reaction.

Figure 2 shows arrangement of neutral beam injectors in LHD and a position of the spectrometer considered in this calculation. Figure 3 shows the typical calculated spectrum on the tangentially viewing spectrometer at 6-T port. In this calculation, deuterium plasma (the ion density of 1.7×10^{19} m^{-3}) was heated by one neutral beam injection (NB#2) with an acceleration voltage of 150 keV and a port-through injection power of 2.75 MW. The maximum neutron yield was roughly estimated to be about 10^8 neutrons/s at the position of the spectrometer. Thus, a counting efficiency of the spectrometer should be above 10^{-6} counts/neutron to obtain the spectrum with statistical precision of less than 10% in the integration time of 1 s, *i.e.* counting rate of more than 10^2 counts/s.

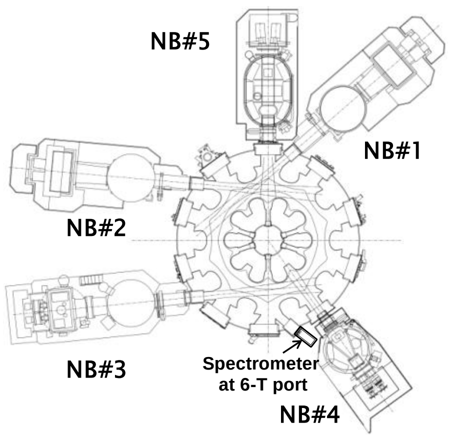

Fig. 2. Arrangement of neutral beam injectors in LHD and a position of the spectrometer in this calculation.

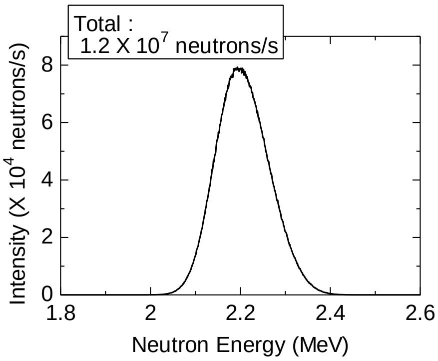

Fig. 3. Typical calculated spectrum on the tangentially viewing spectrometer at 6-T port with the neutral beam injection heating of NB#2.

4. Conclusions

We have developed the associated particle coincident counting – neutron spectrometer as a useful diagnostic tool for dynamics of fast ions in LHD deuterium plasma. The Monte Carlo simulation model for the neutron energy spectrum based on FIT code predicted the neutron yield as about 10^8 neutrons/s at 6-T port in LHD. Thus, a counting efficiency of the spectrometer should be above 10^{-6} counts/neutron to obtain the spectrum with statistical precision of less than 10% in the integration time of 1 s. To achieve the detection efficiency of 10^{-6} counts/neutron, we will consider the install of additional set of three detectors to a whole spectrometer system. In addition, we will estimate the applicability of the proposed spectrometer based on the model calculation.

Acknowledgments

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References

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