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Multi-channel neutron emission and triton burn-up measurement on JT-60U using Digital-Signal-Processors

K. Ishii, K.Shinohara [a], M. Ishikawa [a], T. Okuji [b], M. Baba [b], M. Isobe [c], S. Kitajima, M. Sasao

Department of Quantum Science and Energy Engineering, Tohoku Univ., Sendai 980-8579, Japan

[a]Japan Atomic Energy Agency, 801-1, Mukoyama, Naka 311-0193, Japan

[b]Cyclotron and Radioisotope Center, Tohoku Univ., Sendai 980-8578, Japan

[c]National Institute for Fusion Science, 322-6 Oroshi-cho, Toki 509-5292, Japan

In JT-60U, the multi channel neutron profile monitor measured the line-integrated neutron emission. A digital-signal processing (DSP) system was applied to every neutron detector of the neutron profile monitor. A new 2D mapping method of DSP data analysis was developed to discriminate neutrons from γ-rays. The combination of DSP and the 2D map enabled the simultaneous measurement of DD and DT neutrons with one detector. The time evolution of DD and that of DT neutrons showed different response to the ITB formation, depending on the viewing chord.

Keywords: JT-60U, neutron diagnostics, Digital-signal-Procssors, triton burn-up

1. Introduction

The information on the energetic ion behavior in deuteron heated deuterium plasma can be obtained by measuring the line-integrated neutron emission rate with neutron detectors viewing the plasma along a number of chords (a neutron profile monitor) [1]. To avoid contamination of γ-rays and the scattering component in a neutron profile measurement, it is important to use a detector that discriminates neutrons from γ-rays and is insensitive to low-energy neutron. To discriminate neutrons from γ-rays, several kinds of scintillators, such as NE213, Stilben crystals, NE451 have been used [1], combined with sophisticated discrimination electronics, which require a finite process time and hence prevent the high counting rate measurement.

In JT-60U, a digital-signal processing (DSP) system was developed and applied to all neutron detectors of the multi channel neutron profile monitor of seven viewing chords [2-6], to overcome this problem in the count rate. Then, it is important to develop a fast and reliable n-γ discrimination logics and the software for the digital data analysis.

In the present study, a new 2D n-γ discrimination mapping method was introduced and applied to the DSP data from the neutron profile monitor of JT-60U. The neutron profile measurement was successfully carried out during the 2008 campaign of JT-60U, using this new system.

In JT-60U, DD neutrons were produced in a deuterium plasma heated by D^0-beams. The DT neutrons were produced as well by triton burn-up, and their time evolution can be used to predict 3.5MeV α-particle behavior in a fusion reactor. The separation of DT neutrons form that of DD was clearly performed, and the time evolutions of both DD and DT neutrons were obtained. They showed different behaviors depending on the viewing chord.

keiichi.ishii@ppl2.qse.tohoku.ac.jp

2. Neutron Profile Monitor of JT-60U

In JT-60U, the multi channel neutron profile monitor had seven viewing chords; six chords view the plasma poloidaly and one chord views vertically. Details of the viewing and collimation systems were described in Ref. 2.

2. 1 Hardwares

Each viewing chord equipped a neutron detector of stilben crystal. A stilben crystal is sensitive not only to neutrons but also to γ-rays. It is necessary to discriminate neutrons from γ-rays. An analog neutron-γ pulse shape discrimination circuit had been used in order to measure collimated neutron flux [2]. However, the maximum count rate of the analog n-γ discrimination circuit was limited below ~1×10^5 cps. To overcome this problem in the count rate, a digital-signal processing (DSP) system was developed for neutron detectors [3, 5]. In this DSP system, output pulses from an anode of a photo multiplier tube (PMT) of a detector are recorded as continuous waveform using a fast flash analog-to-digital converter (flash ADC) [6]. One pulse decayed typically within ~100ns. Therefore, the flash ADC was required with a nano-sec range sampling rate of digitizing outputs.

This DSP system had been extended to seven chords of the neutron collimator system [6]. The recorded data size was 7GB per discharge. A sampling rate was usually 200 M-samples/s, which was chosen from the optimization between the pulse shape discrimination quality and the time period covered by the system, though the maximum sampling rate was 5 G-samples/s [5,6]. With the ADC sampling rate of 200 M-samples/s, the time duration covered by the data acquisition scheme was about 2.68 s. A recorded data was stored once in the flash ADC, and it was transferred to a HDD of a PC after the measurement.

A recorded data was analyzed with an off line software, (1) to discriminate neutrons from γ-rays, (2) to obtain a pulse height spectrum to separate DD and DT neutrons in every time bin, typically 10 ms, and (3) to obtain the time evolution for both DD and DT neutrons.

2.2 Pulse shape analysis

To discriminate neutrons from γ-rays, a charge integration method was used in the software, using the difference in the decay time of an output pulse. This system successfully achieved the counting rate capability higher than ~1x10^5 counts/s [5]. The software for the pulse shape analysis had following function: (1) catches the maximum of the digitized pulse height for each pulse, and saves it as "height", (2) produces 3 integrals "fast", "slow", and "total", (3) rejects pile up events. The neutron-γ-rays (n-γ) discrimination was done using the charge integration method in which each pulse is was integrated for two time intervals as shown in functions of software. The integral for the time interval near the pulse peak was defined as "fast", and the other was called "slow". A value of "total" was integrated from the time when pulse rises up to the end of the interval for the slow.

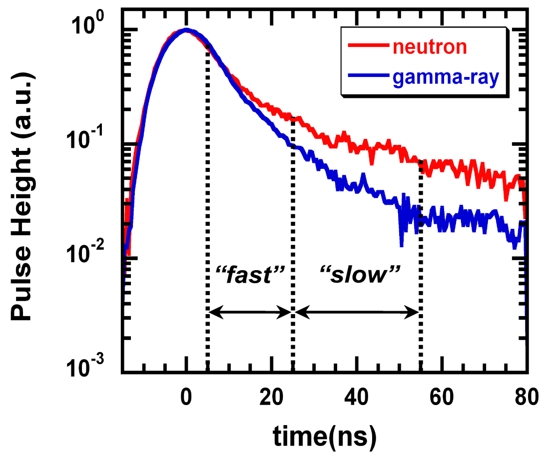

Fig.1 An example of a pulse shape digitized with 2 G-samples/s. Time intervals of fast and slow are indicated by dotted lines. The decay time of neutron is longer than that of γ-ray.

Fig.1 shows pulse shape digitized in 2 G-samples/s, and time intervals of fast and slow. As shown in Fig.1, a decay time of neutron is longer than that of γ-ray. In the other word, charges of neutron are lager than that of γ-rays which has the same pulse height as that of neutron. Using three values, "fast", "slow", and "height" for one pulse, a two dimensional (2D) map in height–slow normalized with (fast+slow) space can be plotted to discriminate neutrons as shown in Fig.2. One dot is plotted against one pulse. Neutrons are discriminated graphically using this 2D map.

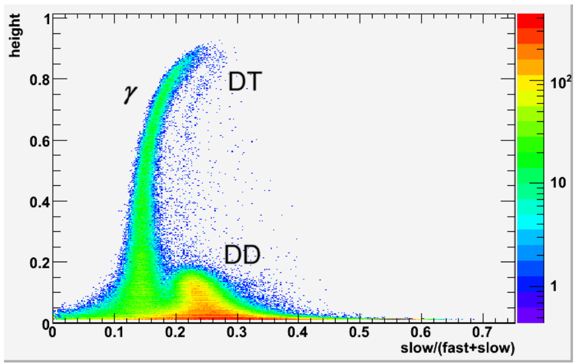

Fig.2 A 2D map in height – slow space for n-γ discrimination.

In Fig.2, there are two peaks at ~0.15 and ~0.25 of the normalized slow. The peak that has small charge is γ-ray. Most of pulses due to neutrons are distributed in low height region below the height of 0.2. Pulses distributes in this region is considered as DD neutrons. A few neutrons distributed above the height of 0.2 can be DT neutrons, which are produced in the DT fusion reaction emitting 14 MeV. In figure 2, neutron events are not separated from that of γ-rays in the low energy of the height below 0.05, and in the high energy region above 0.7. To solve the problem in the low energy region, a value of "total", which was the integration over the whole pulse, was used. fast/total and slow/total were used as the parameters of a 2D map shown in Fig.3.

There are two groups in Fig.3, and neutrons are discriminated clearly from γ-rays comparing with Fig.2. To investigate feature of a new n-γdiscrimination, we selected neutron region in Fig.3 and plotted these pulses again in the conventional 2D map whose parameter was height and slow/(fast+slow). As a result, the separation was successful for low energy. However, it was found that some high-energy γ-rays were counted as neutron. Therefore, a conventional height–slow space discrimination was further done for the neutron events selected by the new 2D map of the normalized fast-slow space (double 2D discrimination).

To obtain the profile of DT neutron emission rate, it is important to discriminate DT neutrons for all detectors. The time interval of the charge integration method was the same value for all detectors on supposition that all detectors had the same pulse shape. However, some detectors did not discriminate DT neutrons from energetic γ-rays. To solve this problem, the pulse shape analysis was done using pulses recoded in high sampling rate (2 G-samples/s). As a result, it was found that pulse shape was different for each detector. The time intervals were changed for each detector in the software, and then all detectors achieved success in discriminating DT neutrons from energetic γ-rays.

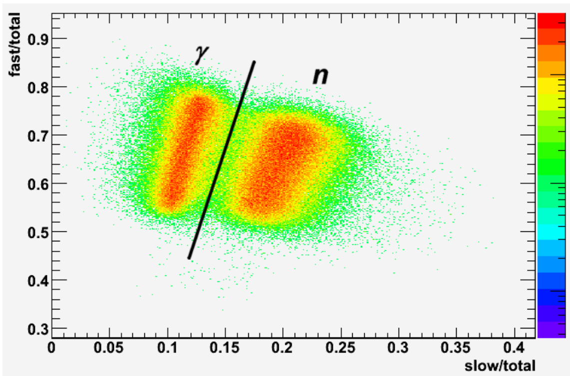

Fig.3 A new 2D map in fast-slow space normalized with total. Neutrons are discriminated from γ-rays clearly.

3. Triton burn-up

In JT-60U, DD neutron was measured mainly because energetic deuterium was injected as neutral beam (NB) into the deuterium plasma. Not only 2.5 MeV neutrons but also 1MeV tritons are produced through the DD fusion reaction. When tritons are confined in the bulk plasma and slow down to the energy region suitable for DT reaction by collision with mainly electrons, they may react with deuteron and then produces 14.1MeV neutron. In the DSP system, DT neutron was measured as well as DD neutron simultaneously using the same detector. Fig.4 shows a pulse height distribution of neutrons that is discriminated from γ-rays using the double 2D discrimination. In Fig.4, the edge near 0.15 of height is considered as the DD neutron edge. The counts distributing above 0.15 are DT neutrons, showing that the DSP system successfully achieves DT neutron detection. High neutron counts in the low energy region is considered to be scattered neutron component.

To obtain the time evolution of DD neutrons and DT neutrons respectively, two regions were defined in the height distribution. As shown in Fig.4, one region defined for DD neutrons is from 0.05 to 0.15, the region for DT neutrons is above 0.4. A histogram of neutron in the each region is produced against time, and then the time distribution of neutrons is obtain as shown in Fig.5 (e) - (h). The DT neutron emission rate is less than that of the DD neutron by the order of 2-3 in Fig.4, similar to the ratio reported from other large tokamaks [1]. Therefore, it is necessary that a counting time interval of DT neutron is longer than that of DD neutron to raise statistical precision. In Fig.5, the time interval for DT neutron is ten times longer than that for the DD neutron. Therefore, the time evolution of DT neutron is shown with dots due to low time resolution. If the DT neutron emission rate is higher, the time resolution can be higher.

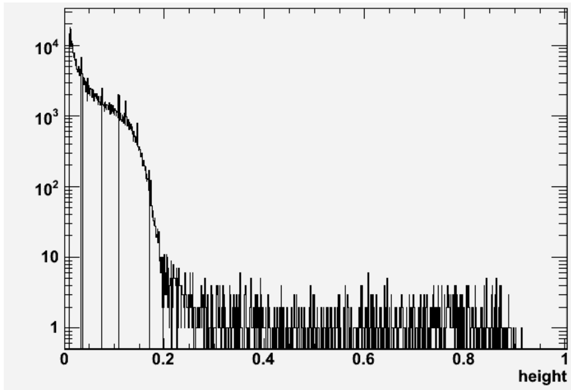

Fig.4 A height distribution of neutrons discriminated from γ-rays. In the DSP system, DT neutron is measured as well as DD neutron simultaneously using the same detector.

Fig.5 shows the time evolution of neutron emission rate measured by the DSP system and plasma parameters. In this discharge, the plasma was heated by the 13 MW positive ion based neutral beams (PNBI) and ~2.9 MW electron cyclotron heating (ECH). The plasma current was 1.2MA and the toroidal magnetic field was 3.7T. The plasma was disrupted at 7.4s.

The DSP system measured the line-integrated neutron emissivity, not local neutron emissivity. An absolute value of the line-integrated neutron emission rate in a chord cannot be compared with that in others because the geometrical efficiency and the detection efficiency have not yet considered. During the measurement of the DSP system, power of PNB was almost constant and ECH was injected from 6.0 s. Electron temperature and density increased remarkably from 6.3 s in the core region. Namely an internal transport barrier (ITB) was formed. Total neutron emission rate measured by the fission chamber increased gradually from 6.5s until the disruption. The time evolution of DD neutron measured by DSP system is similar to that of fission chamber. However, the DD neutron emission rate in the central chord (chord 7) increased more than that in the peripheral chord (chord 6) after the ITB formation. It is considered that the DD neutron emission reflected the density almost linearity because the dominant DD fusion component was not the thermal but that of the beam-plasma interaction and the input power of PNB was almost constant.

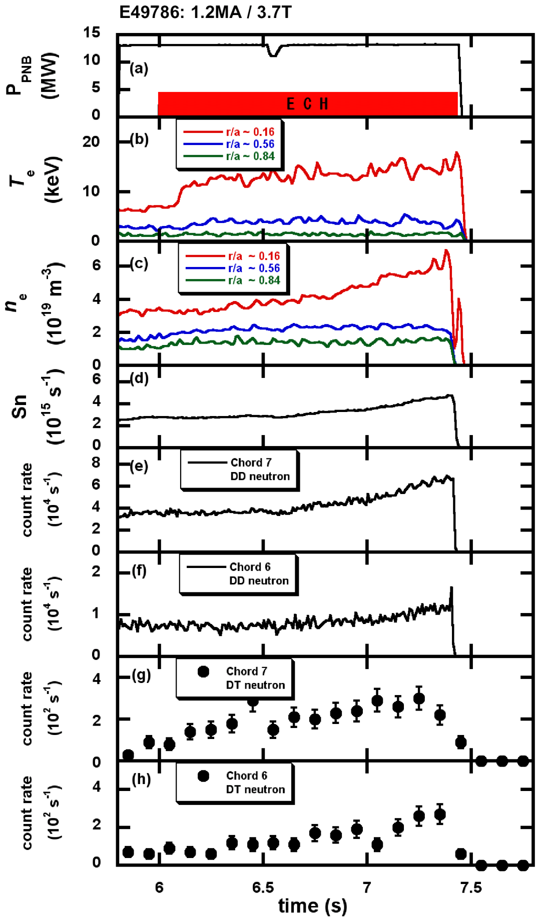

Fig.5 The time evolution of: (a) input power of PNB and ECH, (b) electron temperature, (c) electron density, (d) total neutron emission rate measured by a fission chamber, (e) count rate of DD neutron in chord 7 which views the core region of plasma, (f) count rate of DD neutron in chord 6 viewing the edge region, (g) count rate of DT neutron in chord 7 and (h) count rate of DT neutron in chord 6.

The DT neutron emission showed the different time evolution in each chord. In chord 7, the count rate of DT increased more than a factor 3 after ITB formation. The DT emission rate in every chord changed time to time more the statictics, and it was less steady than the DD emission. In general the time response of DT neutrons is delayed by the slowing down time, typically over 1 second in the present case, and therefore it is affected by the change of diffusion, MHD instability, stochasity and so on [7]. In the present case, the change of classical diffusion can be excluded because the typical deflection time is longer than 1second. Further analysis of discharges and the study of relation with various parameters are needed.

4. Summary

A digital-signal processing (DSP) system was applied to every neutron detector of the neutron profile monitor of JT-60U. A double n-γ discrimination mapping method of DSP data analysis was developed, where a new 2D map in a fast-slow space normalized with total was introduced. By using this system, DT neutrons were measured as well as DD neutrons in the DD plasma simultaneously with a same detector. The time evolution of DT neutron was obtained for all chords.

DD neutron emission rate in central chord increased more than that in the chord viewing the edge region after appearance of the ITB. The time evolution of DT neutron showed the difference for each chord, which can nor be explained by the classical energetic ion diffusion.

Acknowledgments

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