Issues on the Absolute Neutron Emission Measurement at ITER*)

Mamiko SASAO, Masao ISHIKAWA[1)], Guoliang YUAN[2)], Kaushal PATEL[3)], Shrichand JAKHAR[3)], Yuri KASHCHUK[3)] and Luciano BERTALOT[3)]

Organization for Research Initiatives and Development, Doshisha University, Kyotanabe, Kyoto 610-0321, Japan

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

[2)]Southwestern Institute of Physics, Chengdu, Sichuan 610041, China

[3)]ITER IO, Cadarache Centre, 13108 St Paul-Les-Durance Cedex, France

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Fusion power output of ITER is measured by a group of neutron flux monitors combined with a neutron activation system and neutron profile monitors. These systems should be absolutely calibrated by use of DD/DT generators moving inside the ITER vacuum vessel (in-situ calibration). Each neutron monitor has a limited measurement range of emission rate, but the ranges are connected by cross-calibration using the ITER plasma with at least one decade overlapping. The over all dynamic range covered by the group of neutron flux monitors is 10^{14} n/sec to 10^{21} n/sec. Effects of vertical/radial movement of plasma on the measurement accuracy were reviewed. It was found that cross-calibration using specially planned jog shots, and a vertical neutron camera is important to minimize the inaccuracy caused by the plasma movement.

Keywords: ITER, neutron diagnostics, calibration, dynamic range, fusion output

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1. Introduction

Neutron production rate from a fusion device indicates how closely a burning plasma approaches the ultimate goal of nuclear fusion reactor. Therefore, the absolute measurement of neutron emission rate from the whole ITER plasma is important as a fusion power monitor.

The fusion reaction rate of ITER will be determined by combination of (1) time-resolved neutron flux monitors (NFM) which are well calibrated onsite, combined with a neutron activation systems (NAS), neutron profile monitors (radial neutron camera, RNC and vertical neutron camera, VNC) [1, 2].

The neutron emission rate is ranging widely on ITER, in over 6 decades from 10^{14} n/s to 2.3×10^{20} n/s. The time resolution of 1 ms is also required for the machine protection and the plasma control. Table 1 summarizes requirements to the measurement of neutron source strength, measurement range, time resolution, and the accuracy for both DD and DT operations.

Table 1 Measurement requirements for neutron source strength.

	range	resolution time	resolution spatial	accuracy
Neutron flux (DT)	10^{14} n/s - 5×10^{20} n/s	1 ms	integral	10 %
Neutron flux (DD)	10^{14} n/s - 10^{18} n/s	1 ms	integral	20 %

The detectors for the neutron emission rate measurement must have wide dynamic range in counting rate, fast response time and also be resistant to spurious signals from hard X-rays and gamma rays. To fulfill these requirements simultaneously, a fast response neutron detector that uses fissile material and produces a large signal selectively for neutrons, such as ^{235}U fission chambers are used in combination of two operation modes: a pulse-counting-mode and a direct current–like mode.

On ITER, three sets of neutron flux monitors, neutron flux monitors on the equatorial plane (NFM EP1, NFM EP7, NFM EP8, NFM EP17) [3], micro-fisson chambers inside the vacuum vessel (MFC) [4–6], and diverter neutron flux monitors (DNFM) [7]. Detectors of these monitors use fissile material, such as ^{235}U or ^{238}U, except dummy detectors for background subtraction. Conceptual designs of most of these NFM's have been completed and reviewed by the end of 2012.

Major issues for NFM's are (a) the absolute calibration of the systems, and (b) the connection of dynamic ranges. Other issues are (c) evaluation of the plasma movement effect to the total neutron emission rate, and (d) robust design of in-vessel components of fission chambers, activation systems, and profile monitors, against neutron, X-rays and gamma rays radiation, heat flux, and thermal stress, and mechanical stress under electro-magnetic forces. In this paper these issues and the overall accuracy are discussed.

author's e-mail: mnsasao@yahoo.co.jp

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2. Calibration for Absolute Fusion Output Measurement

As shown in Table 1, the accuracy of 10% and 20% are demanded for DT and DD operations, respectively. On this mission, the ratio of each neutron monitor output to neutron emission rate from the whole plasma should be absolutely obtained. The ratio, i.e. the detection efficiency, contains complicated factors, because, firstly the plasma is a three-dimensionally extended source, and secondly the source is surrounded with many complicated and massive structures such as first wall, vacuum vessel, poloidal and toroidal coil. These materials act as neutron absorbers, scattering origins, and moderators. Those effects are severe for detectors with ^{235}U, because they are sensitive to thermal neutrons. This is the reason why in-situ calibration of NFM's by moving a neutron source such as a DD/DT generator, or a ^{252}Cf source is needed.

An isotope source is not suitable for DT neutron calibration, because the initial energy difference changes the scattering and energy moderation effects, hence, causes inaccuracy of detection efficiencies. A massive and heavy neutron generator should be avoided, because the generator itself, and the supporting/moving structures themselves also affect to the scattering and energy moderation effects. One of the calibration issues is optimization of the calibration source strength to avoid the shadow effect and calibration time.

The detectors of NFM's, all RNC, VNC detectors [8], and gamma detectors for NAS [9–11] will be tested at the beginning by manufacturer (factory test). Before installation on ITER, the all detectors will be tested at Neutron Test Area (NTA) on ITER site.

After the installation to ITER, a short in-situ calibration test is proposed to check the calibration procedure and the accuracy of neutron transport calculation, which is essential to estimate the effect of a self-shadowing, and various massive modification of ITER hardware.

Full in-situ calibration experiments is planned before the beginning of the ITER nuclear phase. In this procedure, a DD neutron generator (and/or a ^{252}Cf source), and a DT neutron generator will be moved inside the ITER vacuum vessel around different poloidal and toroidal positions to calibrate the most sensitive detectors of Neutron Flux Monitors, the Radial and Vertical Neutron Cameras (RNC, VNC), and some irradiation samples of the Foils Neutron Activation system. The DT source strength will be 10^{10} n/s (a compact DT generator) - 10^{11} n/s (the limit of portable DT generator). Considering the effect of self-shadow effects from generators itself, and that of supporting and movement structure, a compact generator is preferable, as mentioned above. Because the accumulation time will be 10^3 - 10^4 sec, which is 10^6 - 10^7 larger, monitors which have capability at 10^{14} n/s - 10^{17} n/s DT operation can be directly in-situ calibrated. Figure 1 shows the dynamic ranges covered by detectors in NFM EP1, NFM EP7, NFM EP8, NFM EP17, and DNFM, and MFC during DT operation. The most sensitive detectors on the equatorial plane, in the DNFM, and micro fission chambers inside the vacuum vessel can be directly calibrated. One of the shaded areas (left, in blue) in Fig. 1 shows that is attainable in calibration experiments with a generator of 10^{10} n/s and 10^4 sec accumulation.

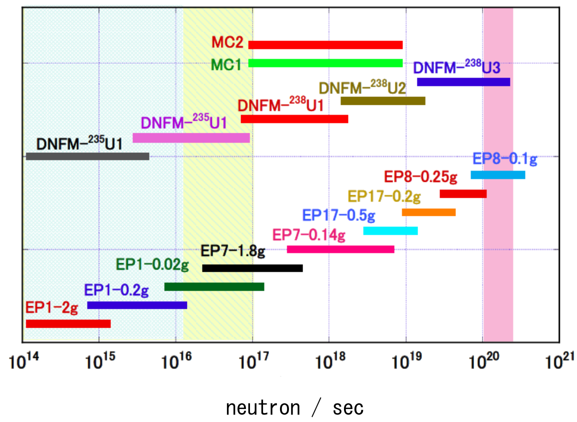

Fig. 1 Dynamic ranges covered by neutron flux monitors in counting mode, with time-resolution of 1 ms. With time resolution of 10 ms, ranges extend to the regions of one-order lower. The left shadowed area (blue) shows that is attainable in calibration experiments with a generator of 10^{10} n/s in 10^4 sec. The right shadowed area (pink) shows the region of the high performance DT operation.

The source strength of a DD generator is two orders less than a DT generator. For DD operation, monitors which have capability in 10^{14} n/s - 10^{15} n/s can be directly in-situ calibrated. In this case, an isotope source can be considered, because it has a merit that the self-shadow effect from the source and the supporting/moving structures might be much less.

During ITER life the characteristics of the detectors may vary due to environmental changes. These changes have to be tracked by measurements using weak neutron sources, and cross-calibration with activation measurement (Long-term and periodic calibration).

3. Dynamic Range Coverage and Connection of Dynamic Ranges by Cross-Calibration

The less sensitive NFM detectors will be cross-calibrated against detectors that are in-situ calibrated. Connection of dynamic range requires at least one decade overlapping. The dynamic ranges in Fig. 1 indicate those with time-resolution of 1 ms. With time resolution of 10 ms, ranges extend to the regions of one-order lower, and it is possible to overlap at least one decade only in count mode operation. Here, it is important the connection can be done among monitors in the equatorial plane, because a cross calibration among monitors at different location might be affected by the plasma movement.

The less number of connection is preferable considering the error propagation. The number of connection is 2 for DNFM, i. e. DNFM-^{238}U1 that is directly in-situ calibrated, and connected to DNFM-^{238}U2, and DNFM-^{238}U2 to DNFM-^{238}U3. The Campbelling mode can be used as well for the cross calibration with real plasma discharges. The MFC's will cover the DT dynamic range from 10^{17} n/s - 10^{21} n/s without the connection by using the Campbelling mode.

4. Profile Changes and Vertical/Radial Movement

The neutron emission profiles and the plasma movement will be measured by RNC and VNC [8]. Dynamic ranges of these profile monitors, and the time resolution depend on the type of detectors and diameters of collimator. In the present design, 2-3 types of detectors, organic scintillator, diamond detectors, and ^{238}U fission chambers are set in line in a collimator. The time resolution of 1 - 2.5 ms might be possible from 7×10^{15} n/s [8].

The effect of vertical plasma movement was studied for DNFM's [4]. The ±10 cm vertical movement will affect to the DNFM detection efficiency in ±5%. However, The vertical movement can be monitored with a good accuracy by RNC, and by the yield ratio of upper and lower MFC's.

Most of neutron detectors, detectors in the equatorial plane NFM's, MFC's, and detectors of RNC are located outboard side of the torus, and efficiency might change by radial movement. Simulation results indicate that MFC and DNFM signals have relatively low sensitivities to the radial plasma movement. By the movement from −30 cm up to +20 cm, the detection efficiency varies in the range of ±2%. The absolute detection efficiency of RNC is sensitive to the radial movement. The cross-calibration using specially planned jog shots will be needed to make correction of fusion output measurement due to the movement effect, and to check the simulation results. Activation System might support to verify the effect, with 10 sec time resolution.

These corrections should be carefully taken into account for data used in the process of dynamic range connection, because errors propagate to the final fusion output evaluation. This is the reason why a VNC is strongly demanded.

5. Issues on Hardware's

While conceptual design review processes for most of neutron diagnostics are completed, there are generic hardware issues to be solved. They are vacuum feed-through's for cables, cabling routs and interferences with other systems, operation under high magnetic field (0.5 T) and transient magnetic field (10 T/s), high temperature (100^0 C) during normal operation and baking (240^0 C), operation of preamplifiers and fast electronics under high gamma background, and neutron scattering from surrounding structural materials and neutron streaming.

6. Summary

The absolute fusion output of ITER can be measured by neutron flux monitors combined with the activation system and neutron profile monitors, when a well planed calibration procedures are carried out. It is important to select a suitable calibration source to minimize the self-shadowing effect.

The NFM's in the equatorial plane will totally cover dynamic range from 10^{14} n/s - 3×10^{20} n/s in count mode operation, while they can be in situ calibrated up to 10^{17} n/s. DNFM system will cover dynamic range of more than 6 decades, 10^{14} n/s - 2×10^{20} n/s in counting mode operation. The MFC's will cover the DT dynamic range from 10^{17} n/s - 10^{21} n/s. The coverage of the activation system will be 10^{14} n/s - 10^{21} n/s.

To minimize the inaccuracy caused by the plasma movement, a vertical neutron camera, as well as cross-calibration experiments using specially planned jog shots is important.

The views and opinions expressed herein do not necessarily reflect those of the ITER organization.

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