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Strategy for the absolute neutron emission measurement on ITER[a)]

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Accuracy of 10% is demanded to the absolute fusion measurement on ITER. To achieve this accuracy, a functional combination of several types of neutron measurement subsystem, cross calibration among them, and *in situ* calibration are needed. Neutron transport calculation shows the suitable calibration source is a DT/DD neutron generator of source strength higher than 10^{10} n/s (neutron/second) for DT and 10^8 n/s for DD. It will take eight weeks at the minimum with this source to calibrate flux monitors, profile monitors, and the activation system. © *2010 American Institute of Physics.* [doi:10.1063/1.3491049]

I. INTRODUCTION

The fusion output and its time evolution on ITER will be measured by the neutron diagnostics. Because the accuracy of 10% is demanded on ITER, the relation between the neutron monitor outputs to the neutron emission rate from the whole plasma should be absolutely obtained with the accuracy much better than 10%. This relation, that is, namely, detection efficiency, is affected by the fact that the plasma is a three-dimensionally extended neutron source, and by the fact that the source is surrounded with many complicated and massive structures, all of which act as neutron absorbers, scattering origins, and moderators. The neutron emission rate is ranging widely on ITER, from $\sim 10^8$ n/s (neutron/second) of DD neutrons due to D fraction of natural abundance in hydrogen, to $\sim 10^{20}$ n/s of full DT operation, which is $\sim 10^{10}$ higher than an available neutron calibration source. The connection of monitors with different sensitivity would be done through cross calibration process using the ITER plasma itself.[1]

Considering these difficulties, the mission of 10% accuracy in fusion output measurement would be accomplished by (1) a functional link of several types of neutron measurement system, (2) series of well-planned *in situ* calibration process,[2] and (3) an accurate neutron transport study. The accuracy of transport calculation will be checked by the *in situ* calibration, and then it will be used to cross-check between different monitors, to estimate effect of machine changes to the calibration factor, so on.

II. NEUTRON DIAGNOSTIC COMPLEX

Neutron diagnostics subsystems are listed in Table I. They can be grouped into four: (A) neutron flux monitors (NFM), (B) activation system, (C) neutron camera, and (D) neutron spectrometer, as shown in Table I. Parameters to be measured by neutron diagnostic systems are fusion output, namely, neutron source strength, neutron/alpha-particle source profile, and the fuel ratio (n_T/n_D). The relation between these parameters and neutron subsystem is shown in Fig. 1. Each parameter is measured by one or two primary systems, but it should be supported by other supporting subsystems to guarantee the required accuracy. For example, the fusion reaction rate or fusion output can be determined by combination of (A) time-resolved neutron flux monitors 1, 2, and 4 in Table I, which are well calibrated onsite, but is supported by (C) profile monitors (5 and 6) and (D) neutron spectrometers (7 and 8). Sensitivity of flux monitors might change during the whole ITER life: therefore, the fusion output is measured by activation system (B) because this is the most reliable system free from the electromagnetic noise contamination, although the time evolution during a discharge is not resolved. Correction due to plasma position and neutron source profile changes should be carried out using the information provided by profile monitors (C). A particular type of high resolution neutron spectrometer, which is independent measurement, does not need an *in situ* calibration to provide information on the fusion output.[3] It, however, samples a line-integrated volume near the center.

TABLE I. Subsystems organizing the neutron diagnostic complex.

Number	Group	Subsystems
1	A	Microfission chamber (in vessel NFM)
2	A	External neutron flux monitor (in port NFM)
3	B	Activation systems
4	A	Diverter neutron flux monitor
5	C	RNC
6	C	VNC
7	D	Compact neutron spectrometer
8	D	High resolution neutron spectrometer

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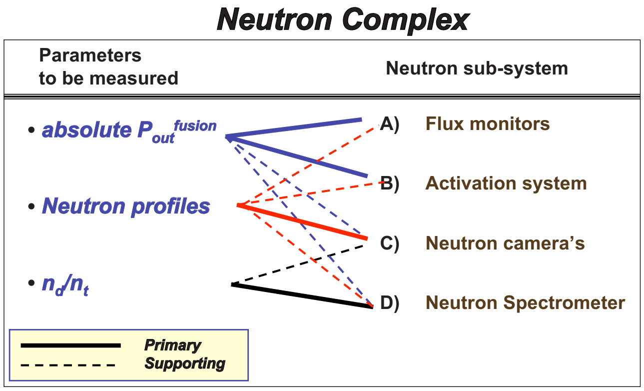

FIG. 1. (Color online) The relation between the parameters to be measured and neutron subsystem to be used. Each parameter is measured by one or two primary systems as connected by a solid line, but it should be supported by other supporting subsystems as connected by dashed lines to guarantee the required accuracy.

III. GENERAL CALIBRATION STRATEGY

The absolute calibration of the neutron diagnostic systems includes characterization of system components at the manufacturer and calibration at the neutron test area on site, followed by *in situ* calibration after their installation on ITER. During this process, the most sensitive RNC and VNC detectors and NFM detectors are calibrated after their installation on ITER, using a calibration source. The source will be moved inside the vacuum vessel in toroidal direction along several rings or it will be fixed at several points in one poloidal cross section.

The absolute measurement of fusion output also involves detailed neutron transport analysis [such as Monte Carlo *N*-particle (MCNP)]. The situation of calibration should be the same as that of real plasma operation, but something such as device temperature and liquid helium density might not be reproduced. In addition, ITER device components such as heating systems or test blanket modules may be added or modified during the whole ITER life, but a new *in situ* calibration will not be possible. These device differences have an influence on the calibration coefficients and they will be checked by the MCNP analysis.

The cross calibration of the least sensitive detectors against more sensitive calibrated detectors should be carried out using ITER plasma as the calibration source because it is impossible to make an absolute calibration over the full dynamic range. This procedure should be performed with careful consideration to the ratio of DD neutrons to DT neutrons with support of MCNP analysis because the relative detection efficiency of the each neutron monitor to these two components depends on the detector location, and type of fissile materials used for neutron detection.

IV. CALIBRATION SOURCE

In Table II, source strength, source shape, neutron energy spectra, angular distribution of neutron emission, and possible self-shielding mass of candidate calibration sources are compared with the ITER plasma.

One of the issues to be studied is the effect of source energy spectrum to the neutron detection efficiency, which depends on the neutron influx spectrum onto the detector. A neutron transport calculation has been carried by MCNP transport code developed in Los Alamos National Laboratory.[4] In this study, the version of MCNP4C2, combined with the nuclear data library JENDL-3.2 and JENDL-3.3, was used. The ITER was simplified into a torus with an ellipse cross section,[5] as shown in Fig. 2(a). Here, the first wall, blankets, equatorial ports, blanket shield, and vacuum vessel structures are considered. As the representative flux monitors, we consider microfission chambers located at the upper and lower position in blanket shields. The location is indicated in Fig. 2(a). Here ^{252}Cf was considered as an example. The calculated neutron influx onto the detector with a ^{252}Cf source which is rotating on a magnetic axis, and that with a DT or DD source, are compared in Fig. 2(b), as a function of neutron energy, where the neutron sensitive regions of ^{235}U and ^{238}U are shown by arrows. Both ^{235}U microfission chamber (FC-235) and ^{238}U microfission chamber (FC-238) are more sensitive to the DT source, than to a ^{252}Cf source, as shown by a dashed line. For a DD source, the response of FC-238 is quite different from that to the ^{252}Cf source.

The self-shield effect by an accelerator itself was also evaluated with this model, and it turned out that a DT generator of 30 kg, which generates 10^{10}/s neutrons, might not effect to the neutron influx. Recently, the effect of the rail for moving the generator was studied with more precise model: Alite-ITER model.[6] The details will be published as a separate paper, but it shows that the effect is not negligible.

V. CALIBRATION TIME

In order to estimate the calibration time, MCNP calculation has been performed for the microfission chambers at the current installation positions[7] using the Alite-ITER model. If we want to calibrate the upper and lower microfission cham-

TABLE II. Comparison of calibration sources with ITER burning plasma.

Neutron source	ITER burning plasma	Isotope source	DD/DT generator
Strength	5×10^{20}/s max. for DT, 10^{18}/s max. for DD	$\sim10^{11}$/s, but is limited to $\sim10^{9}$/s, by handling	10^{10}/s max. for DT, 10^{8}/s max. for DD ($\sim$30 kg, dc, lifetime $>10^{3}$ h, commercially available)
Source shape	Extended in torus shape	Point source	Almost point source
Energy spectra	Monoenergetic $\sim$14–2.5 MeV	Broad $E_{av}\sim2$ MeV	Monoenergetic $\sim$14–2.5 MeV
Angular distribution	Isotropic	Isotropic	Nonisotropic
Mass of self-shield	No	A rail for rotation of supporting beams	A rail for rotation and supporting beams for a generator (30–200 kg)

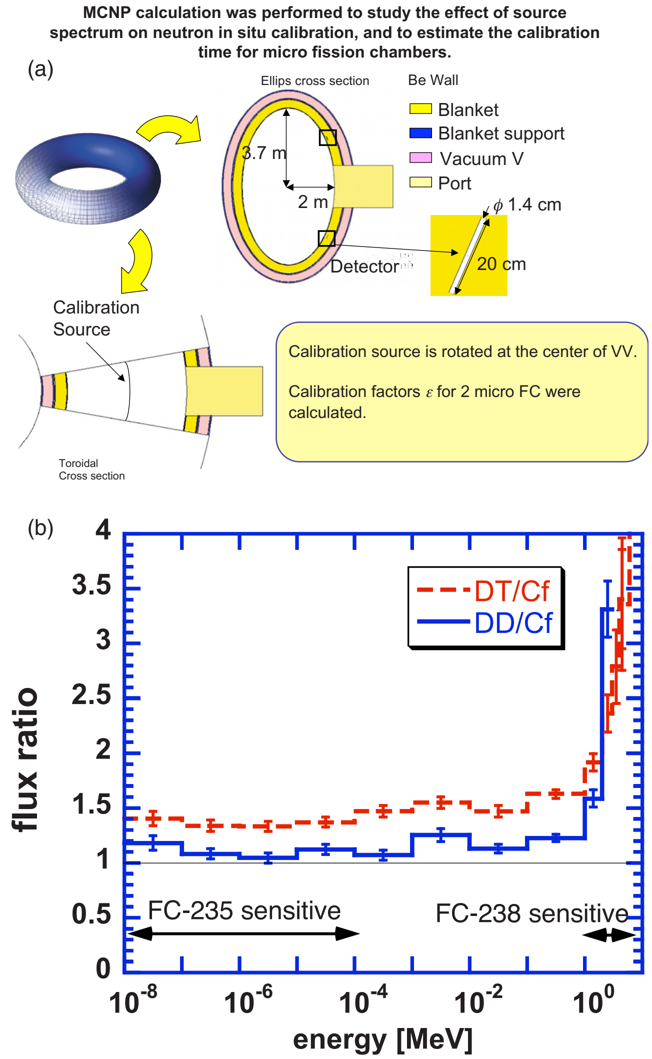

FIG. 2. (Color online) (a) Poloidal cross section of the ITER simplified model for MCNP calculation. (b) The ratio of the neutron influx spectrum onto the detector from a DT source plasma to that from a ^{252}Cf source (dashed line), and the ratio from a DD source to that from a ^{252}Cf source (solid line).

bers with a DT source of 10^{10} n/s, calibration time to obtain the necessary number of counts [1000 (3%) statistics, 10 000 (1% statistics)] would be 3 and 30 h, respectively. As the plasma itself is an extended source of changing and moving profiles, it is wanted to rotate the calibration source not only on the plasma axis but also on other several axes. Then it will take about two weeks. Other flux monitors can be calibrated simultaneously, and the statistics might be enough because they are more sensitive than the microfission chambers. Similar calibration is needed for DD neutrons. With a generator of present technology (the strength is two orders of magnitude less), 3% accuracy can be achieved by two-week rotation on the magnetic axis.

The neutron activation system needs a separate calibration. The calibration of niobium foil with the reaction ^{93}Nb$(n,2n)$ ^{92}Nb will take about four days using a 14 MeV neutron generator of 10^{10} n/s fixed at one position. Because at least one or two more source positions are needed, it will take totally about two weeks. For the calibration in the DD neutron energy region, development of a DD generator of $>10^{10}$ n/s is needed.

The absolute observation volume, scattering effect, and cross-talks of each collimator of RNC and VNC of the profile monitor should be *in situ* calibrated. The number of calibration source point depends on the collimator size, and would be decided in the future. This calibration procedure will be carried out with the most sensitive camera detectors. If we assume 100 source points and 3 h for each point, then it will take about two weeks.

Prior to the full *in situ* calibration, a short *in situ* calibration is needed before the heating system commissions, but after the installation of full blankets, port plugs, diverters, and the major heating systems. The source would be fixed at one or several positions near the equatorial port 1, so that most of neutron detectors could be tested. This procedure would be a mockup experiment of the full calibration, and the accuracy of the MCNP model will be checked.

VI. SUMMARY

In order to achieve the 10% accuracy of fusion power measurement, a functional combination of several types of neutron measurement subsystem, cross calibration among them, and eight-week *in-situ* calibration using a DT generator of 10^{10}, and DD of 10^{8} n/s are required. Development of a stronger neutron generator and its supporting structure without serious effect to the neutron transport is demanded.

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T. Iguchi, M. Ishikawa, T. Nishitani, M. Sasao, Y. Kaschuk, A. Krasilnikov, V. Zaveriaev, B. Esposito, G. Gorini, G. Ericsson, V. Kiptily, S. Popovichev, C. Fiore, L. Roquemore, W. Heidbrink, R. Fisher, Jinwei Yang, Yubao Zhu, CVS Rao, A. Shyam, and L. Bertalot.

[1] A. Krasilnikov, M. Sasao, Yu. A. Kaschuck, T. Nishitani, P. Batistoni, V. S. Zaveryaev, S. Popovichev, T. Iguchi, O. N. Jarvis, J. Källne, C. L. Fiore, A. L. Roquemore, W. W. Heidbrink, R. Fisher, G. Gorini, D. V. Prosvirin, A. Yu. Tsutskikh, A. J. H. Donné, A. E. Costley, and C. I. Walker, Nucl. Fusion **45**, 1503 (2005).
[2] J. D. Strachan, J. M. Adams, C. W. Barnes, P. Batistoni, H. S. Bosch, J. S. Brzosko, A. C. England, C. L. Fiore, R. S. Granetz, H. W. Hendel, F. Hoenen, O. N. Jarvis, D. L. Jassby, L. P. Ku, P. Liu, G. Martin, S. McCauley, R. W. Motley, T. Nishitani, B. V. Robouch, T. Saito, M. Sasao, R. D. Stav, and P. L. Taylor, Rev. Sci. Instrum. **61**, 3501 (1990).
[3] H. Sjostrand *et al.*, Fusion Sci. Technol. **57**, 162 (2009).
[4] *A General Monte Carlo N*-Particle Transport Code, LA-12625-M, edited by J. B. Briesmeister (Los Alamos National Laboratory, Los Alamos, 1997).
[5] T. Nishitani, K. Ebisawa, T. Iguchi, and T. Matoba, Fusion Eng. Des. **34–35**, 567 (1997).
[6] Developed as a collaborative effort between the FDS team of ASIPP China, ENEA Frascati, JAEA Naka, UKAEA, and the ITER Organization.
[7] M. Ishikawa, T. Kondoh, T. Nishitani, and Y. Kusama, "Effect of thermal neutrons on fusion power measurement using the microfission chamber in ITER," Fusion Eng. Des. (submitted).