Chapter 3

Installation of the Detector Modules in ITER and the *In-situ* Calibration Technique

Along the lines of the design consideration activity for the ITER equatorial ports, this chapter presents the consideration results on the installation places for the detector modules. The locations of the detector modules should be decided so that the dynamic range of this monitoring system can cover the whole phase of the ITER operation including the *in-situ* calibration (requirement (D) in section **2.1**). The expected performances of this system during the ITER operations have been estimated through the detailed MCNP calculations. An experimental method of the *in-situ* calibration using both DD and DT neutron sources is also discussed.

3.1 Distributions of the detector modules

3.1.1 Detector module for the DT phase

After the 9 years of the ITER Engineering Design Activities (EDA), ITER final design report was submitted by IAEA [1], which mentions the preliminary locations of the neutron yield monitors The plasma diagnostic systems and their integration issue have been discussed in the International Tokamak Physics Activity (ITPA). Figure 3.1 schematically shows the proposed integration strategy of the diagnostic tools including the ex-vessel neutron yield monitor [2]. The proposed location for the ex-vessel neutron yield monitor is Equatorial ports (Eq.) 8 and 17, just behind the Limiter module and its Alignment system. If the GMDM with two detectors designed in chapter **2** is incorporated in Eqs. 8 and 17 each as shown in Fig. 3.2, the ITER machine will have four fission chambers in total.

The neutron fluxes in the Eqs. 8 and 17 have been computed by a calculation code MCNP-4C2 [3] with ENDF/B-VI neutron data library and a detailed model of the ports configurations. The Blanket module, Limiter module, Alignment system and Shielding plug were modeled for the calculations. Because the structure of the Alignment system is too complicated to make a precise model, the whole body was divided into the several parts, and each part was modeled by a uniform material with a mean density of each port. Figure 3.3 shows the MCNP model. Figures 3.4 and 3.5 represent the calculated neutron fluxes and neutron energy spectrum in the port, respectively. Based on the calculated results, the expected count rates in the ITER DD and DT phases are estimated in Table 3.1. The prospective count rate of the detector module in the Eqs. 8 and 17 is $(6.24\pm0.16)\times10^7$ cps (for the fission chamber loaded with 200 mg $^{235}UO_2$ at the full reactor power (500 MW)), which can be recorded by the Campbelling mode (see section **2.2.2**). From the above calculation, it is expected that the set of 4 fission chambers can cover all of the neutron yields in the DT phase, if the amount of fissile material to be loaded on each detector is adjusted properly. A count rate more than 10^5 cps is required to satisfy a masurement accuracy of 10% under 1 ms sampling, which will be achievable for the GMDMs that are locate in the Eqs. 8 and 17. However, the count rate at the minimum reactor power will be around 0.1 cps, which is less than the requirement by 5 orderes or more, because more than 10^4 cps is need for the rquired accuracy of 20% in the DD phase. It is found that the GMDMs cannot be applied to the lower-neutron-emission phase and the *in-situ* calibrations. Another detector module needs to be placed as close to the plasma as possible to ensure sufficient detection efficiency for the *in-situ* calibration and the DD phase.

3.1.2 Detector module for the DD phase and the *in-situ* calibration

Because of their poor detection efficiency, GMDMs that will be installed in Eqs. 8 and 17 shown in Fig. 3.2 are not applied to the DD phase and the *in-situ* calibration. The lower-neutron-emission phase needs another detector with a much higher sensitivity, and the most promising way to achieve a higher sensitivity is to locate another detector module as close to the plasma as possible. However, it is difficult to place the GMDM (1,000 × 800 × 550 mm) adjacent to the plasma in these ports, because there is a requirement to install many kinds of instruments near the plasma, the number of detectors and the size of detector module at this place should be kept at a minimum. The small-size BMDM including 2 detectors, which has been design in section **2.2.5,** can be placed in Eq. 7 just behind the

Blanket module as shown in Fig. 3.6.

Neutron fluxes in the Eq. 7 has been calculated by MCNP-4C2 with ENDF/B-VI neutron data library. Figure 3.7 shows the MCNP calculation model. The calculated neutron fluxes in this port is presented in Fig. 3.8, and the typical neutron spectrum is in Fig. 3.9. Besides, the expected count rates for this detector module is tabulated in Table 3.2. At the minimum reactor power of 100 W, the count rate of $(2.24 \pm 0.28) \times 10^4\ s^{-1}$ will be produced by the fission chamber loaded with 4 g $^{235}UO_2$, which reaches to the necessary count rate to satisfy the required accuracy. The two detectors in the BMDM having different amounts of fissile material expand the dynamic range to the DD phase and realize a plasma monitoring with a mesurement accuracy of 20% under sampling time of 1 ms. The *in-situ* calibration using a neutron generator with a generation rate of 10^{11} n/s for DD, 10^{13} n/s for DT is able to have a count rate of about 10 cps at most, which is a resonable eficiency for the *in-situ* calibration.

3.2 Dynamic range of the proposed system

As described above, the installation positions of the two GMDMs and one BMDM have been determined as illustrated in Fig. 3.10 in order to cover the whole operation range of ITER. The GMDM will be located in the Eqs. 8 and 17 each to mainly monitor the fusion plasma in the DT phase. Meanwhile, the BMDM will be installed in the Eq. 7 just behind the Blanket module for the monitoring of the DD phase plasma and for the purpose of the *in-situ* calibrations. The 6 detectors will be installed in the ITER machine in total. The dynamic ranges of each detector can be extended up to 9 orders under the combined operation including pulse and Campbelling modes. Besides, taking advantage of neutron shielding effect of the port plugs themselves and adjustment of the amount of fissile material to be loaded with each detector, the sensitivities of each detector can be set surely to cover the ITER dynamic range. Figure 3.11 shows the efficiency adjustments and estimation of the count rates that is expected in each detector. It has been confirmed that the present system can realize the required dynamic range with full redundancy and adequate overlaps of dynamic range from the *in-situ* calibration to the full power operation. In addition, each ITER experimental phase has at least one detector that can be operated in pulse counting mode. Besides, the expected count rate at the DT phase is more than 10^5 cps, that is sufficient for satisfaction of the required time resolution of 1 ms under the measurement accuracy of 10%.

3.3 Various performances

3.3.1 γ-ray effect

The fission chambers will be surrounded by several kinds of thick-stainless steels after the integration into the ITER machine. Plasma neutrons have to pass through the ITER structure before entering the detectors and will induce secondary γ-rays with high flux. It is needed to confirm the feasibility of neutron/γ-ray discrimination in pulse counting and Campbelling modes. The γ-ray spectrum in Eqs. 8, 17 and 7 during the ITER operations has been calculated by MCNP-4C2 with ENDF/B-VI neutron data library. The computed results are in Figs. 3.12 and 3.13. The spectrum in Fig. 3.12 is expected for the locations of GMDMs in Eqs. 8 and 17 at the ITER full power operation. BMDM will be exposed to the γ-ray field that is presented in Fig. 3.13 at the minimum power of the DT phase. It has been confirmed that the maximum γ-ray energies at both locations are around 10 MeV. Meanwhile, an average energy deposition of the fission fragments in the counting gas is 40 MeV for the typical fission chambers. The signals of neutron and γ-ray will be distinguished each other by a simple pulse height discrimination circuit. As described in section **2.2.2**, Campbelling mode generally has a neutron/γ-ray discrimination characteristic. The contributions of γ-rays to the Campbelling mode signal are estimated in Table 3.3 using the γ-ray spectrum in Figs. 3.12 and 3.13. They are negligible in comparison with the contributions of neutrons.

3.3.2 Time resolution

The fission chambers are surrounded by a lot of materials such as the neutron moderator, lead layer for γ-ray shielding and a thick stainless steal of the ITER machine structure, and will be installed far from the plasma. Neutrons fly a long distance and cause many collisions before entering the detectors. The practical time response of the detector for plasma variances is inferior to that of the original specification and results in a deterioration of time resolution or a loss of plasma information.

The detector time response at Eqs. 8 and 17 has been estimated. The decay time of fission reaction rate of fissile material in the detector has been calculated by MCNP-4C2 with the ENDF/B-VI neutron data library under the mock up model presented in Fig. 3.3. The incident neutron impulse is generated at the position of the plasma core. Figure 3.14 is the calculation result, and the fission rate is exponentially decayed with a time constant of 3 μs. The typical charge collecting time for electrons in a fission chamber is around 1 μs. The present system is expected to monitor the neutron yield with time resolution of the order of microseconds at maximum. In addition, detectors D8.2 and D17.2 will produce a count rate of 10^5 cps or more under the pulse counting mode in the DT phase, which is compatible with the characteristics estimated here. The enough count rates more than 10^5 cps will be secured to attain the required measurement accuracy of 10% with a time resolution better than 1 ms.

3.3.3 Detector life time

The life time of fission chambers critically depends on the neutron fluence by which they are exposed. The fission chamber produces electrical pulses following the ionizations of its counting gas due to fission fragments from the loaded fissile material. The amount of fissile material or 90% enriched $^{235}UO_2$ decreases and the detector sensitivity varies according to increase of the total neutron fluence. The possible causes for this sensitivity change are fission reaction and neutron capture. Fission reaction is a dominant factor for the sensitivity change, because it has a much larger cross section than neutron capture reaction. The deterioration of the detector sensitivity has been estimated for the fission chamber in the BMDM just behind the Blanket module, which will be exposed to a higher neutron flux. Equation (3.1) gives the number of ^{235}U nuclei during the detector operation.

$$\frac{\mathrm{d}}{\mathrm{d}t} N_{^{235}\mathrm{U}} = -N_{^{235}\mathrm{U}} \phi \sigma_{^{235}\mathrm{U\,fission}} \quad , \tag{3.1}$$

where $N_{^{235}\mathrm{U}}$ is the number of ^{235}U nuclei, ϕ is incident neutron flux and $\sigma_{^{235}\mathrm{U\,fission}}$ is fission cross section of ^{235}U. Though the sensitivity change is derived from this differential equation exactly, it also can be estimated from the fission reaction rate of the $^{235}UO_2$ contained in the detectors of interest. The expected fission reaction rates of the detectors in the BMDM, which will be exposed to the highest neutron fluence over the whole ITER experiment, have been calculated in section **3.1.1** and **3.1.2.** Fission reaction of 3.7×10^{11} s^{-1} will occur in the 200 mg $^{235}UO_2$ layer of the fission chamber in the BMDM at the ITER 500 MW operation. This accounts for 1.2×10^{19} fissions for 500 MW·year, while the 200 mg $^{235}UO_2$ layer has 4.3×10^{20} ^{235}U-nuclei. Thus the sensitivity of this detector will not be deteriorated more than 2.8% over the ITER life time, and the fission chambers can be used without their replacements throughout the whole ITER operations.

3.4 *In-situ* calibration

3.4.1 General technique of the *in-situ* calibration

The practical purpose of the *in-situ* calibration of the neutron yield monitoring system is to obtain a calibration factor for the detectors, which is the ratio of detector efficiency to the actual neutron production rate. The *in-situ* calibration is the most important to realize the required measurement accuracy. This calibration factor depends on the source spectrum, scattering and shielding effect due to the reactor structure itself and detector energy response. The measurement accuracy of this system is dominated by the *in-situ* calibration procedures. Moreover, the *in-situ* calibration is necessary to make sure that the absolute measurements of the neutron yield are traceable to the primary standard value. Because it is generally difficult to establish accurate calculation models that can simulate neutron behaviors in large devices, this calibration factor should be experimentally estimated using a standard neutron source without relying on computer simulations.

In the typical *in-situ* calibration experiments for large Tokamaks such as JT-60U, JET and TFTR, a ^{252}Cf point neutron source is placed inside the Vacuum vessel at plasma center position and remotely moved in toroidal direction [4-6] as shown in Fig. 3.15**.** It is a time-consuming procedure, because the *in-situ* calibration needs more than a few tens of mapping points for the neutron source. A detailed consideration on calibration strategy is necessary to realize the required measurement accuracy efficiently.

3.4.2 Neutron source for the *in-situ* calibration

Because of the following reasons, this system should be calibrated using both DD and DT neutron generators. Firstly, it is difficult to secure a neutron generation rate more than 10^{11}

n/s for a ^{252}Cf. Though ^{252}Cf neutron source can generate isotropically and has ever been used in Tokamak devices, its typical source strength is 10^7 - 10^8 n/s. The source strength than 10^{11} n/s is preferable for this system. Secondly, the neutron behavior in the materials of the reactor components, such as Blanket, Vacuum vessel, Shielding plug, etc., varies depending on its energy, and the neutron detector response also depends on neutron energy. As described in the following sections **3.4.3** and **3.5.3** in detail, the most sensitive detector D7.1 will be calibrated directly and other detectors will be cross-calibrated to the D7.1 during the plasma burning experiments. This cross-calibration will be conducted in the DD phase first for the detectors with higher sensitivities, and the cross-calibrated detectors will be applied to the DT phase after a compensation of the calibration factor. The compensation needs the efficiency difference between the DD and DT neutrons, which can be determined by the *in-situ* calibration with both DD and DT neutron sources. Thirdly, in the high-density D plasma phase, which is called "advanced DD phase", the plasma becomes a two-component (DD and DT) neutron source, because of the high-energy triton production from one branch of the DD reaction. It has been reported that the neutron intensity ratio (DT/DD) of the two-component neutron source can be increased up to 1 [7]. Taking into consideration the two kinds of neutrons, the neutron diagnostic system should be calibrated to both DD and DT neutrons, otherwise the measurement system would suffer from significant measurement uncertainties. Besides, the DD and DT neutron generators are superior to the ^{252}Cf neutron source in radiation safety and can be operated continuously or pulsed, which serves to estimate the time resolutions of the detectors.

Because of the poor neutron yield of the existing DD neutron generators and the high shielding effect of the ITER Blanket and Vacuum vessel, it has been considered that the *in-situ* calibration experiment with both DD and DT neutron generators takes a long measurement time to accumulate sufficient counts. Development of high-yield DD (and also DT) neutron generators has been required to improve the efficiency of the *in-situ* calibration. In recent years, DD neutron generators with high yield more than 10^{10} n/s have been developed for the purpose of Boron Neutron Capture Therapy (BNCT), Neutron Activation Analysis (NAA) and Prompt Gamma Activation Analysis (PGAA) [8, 9]. Under these circumstances, it is possible to make the *in-situ* calibration for the ITER neutron diagnostic system with a DD neutron generator within a realistic measurement time.

3.4.3 *In-situ* calibration procedure for this system

This section describes an effective method to calibrate this system to both the DD and DT neutrons. In the ITER experiments, the most suitable period for the *in-situ* calibration of the neutron diagnostic systems is considered to be the end of the hydrogen plasma phase, after the test of the characteristics of in-vessel system. This system will employ the typical procedure as described in section **3.4.1** and will use both DD and DT neutron sources. Since the *in-situ* calibration needs more than few tens of mapping positions for neutron source, the measurement time for each source position should be optimized. The measurement time to be needed is determined from the aspect of statistics for each source position. The present neutron yield monitoring system has the 6 fission chambers with different sensitivities. It is unrealistic to calibrate all detectors directly in the *in-situ* calibration, because some of the detectors to be installed have poor sensitivities. The detectors that can be calibrated directly are restricted by their sensitivities. The possible detector that can be calibrated directly in this way is the most sensitive detector named as D7.1, which is moderated by beryllium and will be installed at Eq. 7 as shown in Figs. 2.11 and 3.6. The rest of detectors will be cross-calibrated to the primarily-calibrated detector D7.1 in the actual plasma experiments.

3.4.4 Monte Carlo simulations on the *in-situ* calibration

To verify the feasibility of the *in-situ* calibration using DT and DD neutron generators, an *in-situ* calibration procedure has been considered under an assumption that generation rates of the neutron generators are 10^{11} n/s for DD and 10^{13} n/s for DT. MCNP calculations on the *in-situ* calibration have been made for the most sensitive detector D7.1. The MCNP model is shown in Fig. 3.15, this model is a full torus shape, which includes a Vacuum vessel, First wall, Blanket, Toroidal field coils, Poroidal field coils, Central solenoid coil, Equatorial ports and Biological shield. In the simulation, the neutron source was moved roundly by 10 degree in toroidal direction. The expected detection efficiency of D7.1 for each toroidal angle θ has been calculated. Figure 3.16 shows the calculated results, and the total detection efficiency of the detector for a torus shape neutron source is derived from integrating the detection efficiencies for each source position. As shown in Fig. 3.17, toroidal angle range of $|\theta| \leq 100$ degree has a contribution of over 98% to the total detection efficiency. The calibration factor of this detector is determined by the ratio of the total detection efficiency to the actual neutron yield in the calibration measurement.

3.4.5 Measurement time in the *in-situ* calibration

The total accidental uncertainty is derived from root-mean-square of each accidental uncertainty factor including counting statistics. Since uncertainty factors other than counting statistics are around 2-5% as listed in section **3.5.1** and Table 3.6, the counting statistical uncertainty within 1% does not deteriorate the total measurement uncertainty. In ITER, it is preferable that the total calibration measurement is within 1 week. The statistical uncertainty in the angle range $|\theta| \leq 100$ degree described in Fig. 3.16 is dominant for the total counting statistical uncertainty. The measurement time of each source position in this angle range has been arranged in order to make a total counting statistical uncertainty better than 1%. As the counting statistics of the other region (100 degree $\leq |\theta|$) are hardly reflected in the total counting statistical uncertainty, the assigned time to this region will be restricted up to the available time, because it is preferable to complete all of the calibration procedures including the source shifting process within a few weeks so that the calibration experiments can be accommodated to the ITER scenario without disturbing the main tasks. As a result, the detector D7.1 to be directly calibrated will have a statistical uncertainty of 0.10% using a DT neutron generator (10^{13} n/s) for 36 measurement points in about 6 hours measurement, while approximately 25 hours will be necessary for the DD neutron calibration to obtain a statistical uncertainty of 1.0%. The total measurement time for both the DD and DT neutron calibration is about 30 hours. The overall calibration procedure within 2 weeks is possible. The expected count rate, statistical uncertainties and measurement time for each source position are presented in Table 3.4.

3.5 Measurement accuracy of this system

3.5.1 Calibration uncertainty sources

The calibration uncertainty for the D7.1, which will be calibrated directly, depends on the following factors. These factors are classified into accidental uncertainties and a systematic error.

a. Statistical uncertainty (accidental)

The count rate of the detector D7.1 in the *in-situ* calibration decides this value, see section **3.4.4** and **3.4.5**. The statistical uncertainties of 0.10% for the DT calibration and 1.0% for the DD calibration are expected.

b. Calibration hardware scattering due to a device for source mapping (accidental)

This factor means the contribution of neutron scattering with the hardware to hold the calibration source inside the Vacuum vessel. It was experimentally estimated in TFTR, and the contribution rate of 2% was reported [5].

c. Plasma center fluctuation (accidental)

The experimental verification of this effect is difficult and will be estimated based on simulations. The contribution due to the shift of plasma center was computed for JT-60U and TFTR. They were 2% and 1.5%, respectively [5, 6].

d. Neutron emission profile (systematic)

The actual plasma has poroidal distribution with a parabolic profile, whereas a point source will be used in the *in-situ* calibration. The uncertainties of 5.5% and 5% due to the plasma profile have been reported in JT-60U and TFTR, respectively [5, 6]. This factor is considered as a systematic error and can be compensated by neutron emission profile monitoring to some extent. In this thesis, this factor is treated separately.

e. Cross calibration uncertainty between pulse counting mode and Campbelling mode (accidental)

As described in section **2.2.2**, the combined operation mode has been used in the existing Tokamak devices and experimentally tested. The typical value for this factor is 5% including Campbelling mode linearity [11].

f. Fluctuation of neutron source intensity (accidental)

Fluctuation of 5% has been assumed in this study based on reference 10.

g. Neutron energy spectrum (energy dependence of the detector response) (accidental)

The expected deviation from the true value of the neutron yield measurement due to the energy dependence of the detector response has been estimated in Table 3.5, assuming that 1% of DD and DT neutrons are contained in the DT phase and the early stage of the DD phase, respectively. The tritium concentration in the advanced DD phase considerably varies according to the tritium removal efficiency, the intensity ratio of DT and DD neutron 0.2-1 in this phase was quoted from reference 7. In this phase, the plasma neutron source becomes a two-component neutron source consisting of DD and DT neutrons. The deviations in the DT phase and in the early stage of the DD phase will be reduced to an acceptable level by calibrating the system to both DD and DT neutron. As shown in Table 3.5, single calibration with either DD or DT neutron generator leads to an appreciable deviation for the two-component neutron source in the advanced DD phase. The cause for such large deviations in this phase is the energy difference between DD and DT neutrons. As shown in Fig. 2.10, the response of detector D7.1, which is moderated by beryllium and the primary detector of this calibration strategy, considerably depends on neutron energy.

3.5.2 Improvement of the uncertainty due to neutron energy spectrum

An improvement of the energy dependence for the advanced DD phase has been considered. In this case, this neutron yield monitoring system should be calibrated to a two-component neutron source as well as to each single-component neutron source. Although the *in-situ* calibration using an actual two-component neutron source is difficult, a sum of each single calibration results for the DT and DD neutron with an appropriate contribution ratio can serve as a calibration curve for the two-component neutron source without actual experiments. The contribution ratio in the summed calibration curve is directly reflected in the measurement accuracy. The relationship between the contribution ratio, DT calibration/DD calibration, in the summed calibration curve and deviations of the expected measurement results from the true value is shown in Fig. 3.18. The hatched region represents the possible deviations of this system as a function of the contribution ratios in the summed calibration curves. It is reasonable to adopt a contribution ratio of 0.5, which corresponds to a deviation within ±22 %. The most suitable calibration curve for the two-component neutron source in the advanced DD phase is provided in Fig. 3.19 by summing the DD and DT neutron calibration curves in the appropriate ratio (DT calibration/DD calibration=0.5).

3.5.3 Estimation of the calibration uncertainty

The required measurement accuracies of the ITER neutron yield monitoring system are 10%. The total calibration uncertainty of the detector D7.1 has been evaluated in Table 3.6 and the calibration uncertainty factors described in section **3.5.1** are also presented. Accidental calibration uncertainties acceptable for obtaining the required measurement accuracies have been achieved in the DT phase and the early stage of the DD phase. A total accidental calibration uncertainty up to 24% can still occur in the advanced DD phase, even after improvement by the use of the summed calibration curve that is prepared for the two-component neutron source. The major cause of the persistent uncertainty is the difference between the contribution ratio DT/DD of the summed calibration curve and the actual DT/DD neutron ratio in the plasma. The contribution ratio of the summed calibration curve (DT/DD=0.5) has been assumed uniformly, while the actual plasma neutron ratio may fluctuate from 0.2 to 1 [7] along with the ITER plasma variances. A real time feedback of DT/DD neutron intensity ratio, in the advanced DD phase, if possible, would enable further uncertainty improvement.

3.5.4 Cross calibration and expected measurement accuracy

As describe in section **3.4.3**, the detector D7.1 is the primary detector of this calibration strategy, which means that other 5 detectors will be cross-calibrated to D7.1 in the actual ITER plasma experiments in turn as reactor power increases. Figure 3.20 shows a conceptual diagram for the procedure of the cross-calibration. Since the calibration uncertainties of the cross-calibrated detectors depend on the accuracy of the primary detector, the most accurate detector should be chosen out of possible detectors that can be operated properly at the reactor phase in which the cross-calibration is implemented.

The second sensitive detector named as D7.2 will be calibrated to D7.1 at the fusion power region of a few kW in the DD phase. Now since D7.2 will be placed in the same detector module as D7.1, the difference of the calibration factors for the DD neutron and DT neutron can be confirmed experimentally through the *in-situ* calibration. It is possible to relate detector response of D7.2 to the total neutron yield absolutely at the DT phase using the calibration factor difference. The rest of the cross-calibration chain can be repeated in each phase not directly relying on D7.1.

Taking into consideration the statistical uncertainties due to the cross-calibration, the ultimate measurement accuracy (accidental uncertainty) for each ITER operation phase has been estimated in Fig. 3.21. Here 1% of statistical fluctuation was assumed for the respective cross-calibrations. Note that this estimation only involves the accidental uncertainty factors out of the all calibration uncertainty sources and counting statistics during the actual operation. The systematic error that will be caused by neutron emission profile, which is predicted within 5.5% should be added to this results. Provided this factor is directly reflected to the measurement accuracy by root-mean-square, the accuracy will be deteriorated about 1%. In addition, since the influence due to this factor can be compensated to some extent considering the plasma profile or density distribution, this contribution would be negligible. In the DT phase and the early stage of the DD phase, monitoring with a measurement accuracy of around 10% will be possible. However, in the advanced DD phase, the expected accuracy is 25%. The main factor of this large uncertainty is the energy dependence of the primary detector D7.1.

3.6 Summary

The appropriate locations for the detector modules have been selected based on the Monte Carlo simulations on the neutron shielding effects of the ITER port plugs. The Graphite Moderated Detector Module (GMDM) will be located at Eqs. 8 and 17 each for the DT phase, the Beryllium Moderated Detector Module (BMDM) will be at Eq. 7 just behind the Blanket module to be applied to the DD phase and for the purpose of the *in-situ* calibration.

Through Monte Carlo neutron transport (MCNP) calculations, it has been confirmed that the present system can cover all the neutron yields encountered in the ITER experiments including the *in-situ* calibrations without a detector replacement over the whole ITER experiments. Besides, count rate more than 10^5 cps will be secured, and the time responses of the detectors are a few microseconds at most, therefore, the required time resolution of 1 ms will be satisfied.

To ensure the required accuracy for diagnosing both DD and DT phases, it is preferable to calibrate this system to both DD and DT neutrons. In this chapter, the feasibility of the two kinds of calibration has been verified through the MCNP simulations, and the *in-situ* calibration procedures have also been discussed. The most sensitive detector D7.1 in the BMDM can be calibrated directly, and other detectors will be calibrated to it during the actual plasma burning experiment as the generation rate of plasma neutron increases. The total measurement time of both the DD and DT neutron calibrations is about 30 hours, and sufficient statistics better than 1.0% will be achieved.

Finally, the expected measurement accuracy of this system has been estimated taking account of the calibration factors that were reported in the existing large Tokamak devices. The required measurement accuracy is 10% for the DT phase. The uncertainty factors that much contribute to measurement accuracy have been classified into accidental uncertainty factors and systematic error. The systematic error will be caused by plasma profile and can be compensated using information of plasma profile that can be provided by a few diagnostic tools such as a neutron emission profile monitor. The measurement uncertainties have been estimated by the accidental uncertainty factors. The required 10% accuracy will be secured in the DT phase and the early stage of DD phase. In the advanced DD phase, however, which produces an appreciable amount of DT neutron secondarily, about 40% uncertainty will be probable if the system uses the DD and DT calibration results independently. For an improvement of the measurement accuracy in the advanced DD phase, the calibration curve including both contributions of DD and DT neutrons is helpful. The measurement uncertainty in the advanced DD phase can be maintained within ±25% using the calibration curve with contribution ratio DT/DD=0.5.

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