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# Status of ITER neutron diagnostic development

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**Abstract**
Due to the high neutron yield and the large plasma size many ITER plasma parameters such as fusion power, power density, ion temperature, fast ion energy and their spatial distributions in the plasma core can be measured well by various neutron diagnostics. Neutron diagnostic systems under consideration and development for ITER include radial and vertical neutron cameras (RNC and VNC), internal and external neutron flux monitors (NFMs), neutron activation systems and neutron spectrometers. The two-dimensional neutron source strength and spectral measurements can be provided by the combined RNC and VNC. The NFMs need to meet the ITER requirement of time-resolved measurements of the neutron source strength and can provide the signals necessary for real-time control of the ITER fusion power. Compact and high throughput neutron spectrometers are under development. A concept for the absolute calibration of neutron diagnostic systems is proposed. The development, testing in existing experiments and the engineering integration of all neutron diagnostic systems into ITER are in progress and the main results are presented.

(Some figures in this article are in colour only in the electronic version)

## 1. Introduction

ITER will be the first burning plasma experiment with collective behaviour of the alpha particles and other fast and thermal ions. A wide range of plasma parameters must be measured to reach the ITER programme goals [1]. Due to the high neutron yield and the large plasma size many ITER plasma parameters, such as fusion power, power density, ion temperature, fast ion energy and their spatial distributions in the plasma core, can be measured well by means of neutron diagnostics. A set of neutron diagnostics is planned for ITER to meet the specified measurement requirements [2, 3]. In comparison with present-day experiments, the neutron diagnostics in ITER will be applied in a much more severe

**Table 1.** ITER measurement requirements for parameters measured by neutron diagnostics.

| | Category | Parameter | Parameter range | Spatial resolution | Time resolution | Accuracy |
|---|---|---|---|---|---|---|
| 1 | 1a | Fusion power or total neutron source strength | $\leqslant$1 GW $10^{14}$–$5 \times 10^{20}$ neutrons $s^{-1}$ | integral | 1 ms | 10% |
| 2 | 1b | Neutron/$\alpha$ source profile | $10^{14}$–$4 \times 10^{18}$ neutrons $s^{-1}$ $m^{-3}$ | $a/10$ | 1 ms | 10% |
| 3 | 1b | Ion temperature profile | 0.5–40 keV | $a/10$ | 100 ms | 10% |
| 4 | 1a | $n_T/n_D$ in plasma core | 0.1–10 | $a/10$ | 100 ms | 20% |
| 5 | 1b | Neutron fluence on the first wall | 0.1–1 MW y $m^{-2}$ | ~10 locations | 10 s | 10% |
| 6 | 2 | Confined $\alpha$-particle energy and spatial distributions | 0.1–4 MeV (0.1–2) $\times 10^{18}$ $m^{-3}$ | $a/10$ | 100 ms | 20% |
| 7 | 2 | Fast ion energy and spatial distributions | TBD | TBD | TBD | TBD |

nuclear environment. The necessity of using massive radiation shielding strongly influences the diagnostic designs, determines angular fields of view of the neutron cameras and spectrometers and gives rise to unavoidable difficulties in the absolute calibration [4, 5]. Neutron diagnostic systems under consideration and development for ITER include radial (RNC) [6, 7] and vertical (VNC) [8] neutron cameras, internal [9, 10], external [11–13] and divertor [12] neutron flux monitors (NFM), neutron activation systems [14–16] and neutron spectrometers [17–22].

## 2. Neutron diagnostic subsystems and measurement requirements

The plasma parameters to be measured in ITER with the required accuracies, ranges of measurements and resolutions have been determined. All parameters to be measured are categorized into three groups according to their role: (1a) measurements for machine protection and basic control, (1b) for advanced control and (2) for performance evaluation and physics. The measurement specifications related to neutron diagnostics are shown in table 1. The detailed requirements for the fast ion energy and two-dimensional (2D) spatial distribution measurements in the plasma core, especially during Alfvén eigenmodes (AE), fishbones and other MHD activity, are still under discussion [3]. The systems currently considered or included in the ITER neutron diagnostics set are presented in table 2.

Prototypes of almost all the neutron diagnostic systems envisaged for ITER have been successfully applied in experiments on large tokamaks: TFTR (VNC, NFM, CNS, NAS), JET (RNC, VNC, NFM, LNS, CNS, KNS, NAS) and JT-60U (VNC, NFM, CNS, MFC, NAS). However, in ITER the design of the neutron diagnostic systems must accommodate their long time operation in much higher neutron fluxes and fluences (5 and $10^4$ times higher, respectively, than in JET) and overcome the constraints caused by the necessity of using massive radiation shielding. The requirement for a large thickness of radiation shielding around the plasma and the available port opening restricts the possible plasma coverage by the RNC and possible VNC lines of sight. This has a great effect on the accuracy of the fusion power calibration and on the spatial resolution of the neutron source profile measurements and requires that special measures to increase the plasma coverage be taken. Absolute calibration of the NFMs will also be a difficult task in ITER due to the thick shielding between them and the plasma. More detailed discussions about the status and development issues of individual neutron diagnostic systems are included in the following sections.

**Table 2.** ITER neutron diagnostic systems and plasma parameters to be measured according to numbering in table 1.

| | System | Parameters |
|---|---|---|
| 1 | Radial neutron camera (RNC) | 1, 2, 3, 5, 6, 7 |
| 2 | Vertical neutron camera (VNC) | 1, 2, 3, 5, 6, 7 |
| 3 | Micro-fission chambers (MFC—internal NFM) | 1, 5 |
| 4 | External neutron flux monitor (external NFM) | 1 |
| 5 | Neutron activation system (NAS) | 1, 5 |
| 6 | Divertor neutron flux monitor (divertor NFM) | 1, 5 |
| 7 | Large neutron spectrometer (LNS) | 1, 4, 6, 7 |
| 8 | Compact neutron spectrometers (CNS) | 1, 2, 3, 5, 6, 7 |
| 9 | Knock-on tail neutron spectrometer (KNS) | 6, 7 |

## 3. Radial and vertical neutron cameras

The necessity of 2D neutron profile measurements in ITER arises from the fact that, due to fast ion components, the neutron source profile may not be a constant on magnetic surfaces, especially during ion cyclotron resonance heating, neutral beam injection, sawteeth oscillations, AE modes and in advanced tokamak regimes with strongly negative magnetic shear. The JET results [20, 23] have clearly demonstrated the influence of fast particle populations on the 2D neutron emission profile. The 2D neutron source strength and spectral measurements in ITER with the required temporal and spatial resolutions can be made by joint application of RNC [2, 6, 7] including compact in-plug collimators [8] and VNC [2, 8].

The principal RNC design was proposed for ITER-98 [6]. There were no major changes in the RNC design [7] for the reduced size ITER (figure 1). The RNC consists of 12 × 3 fan-shaped arrays of neutron collimators viewing the plasma through a special shielding plug in an equatorial port. All channels penetrate through the vacuum vessel, cryostat and biological shield and cross through a single point. Stainless steel windows are used as vacuum barrier. Three separate collimator flight tubes (with different diameters in the range 10–40 mm) and detector housing for each poloidal angle offer a variety of choices of collimator/detector combinations to increase the dynamic range of RNC measurements. The 12 lines of sight of the RNC are equally spaced (by 30 cm at

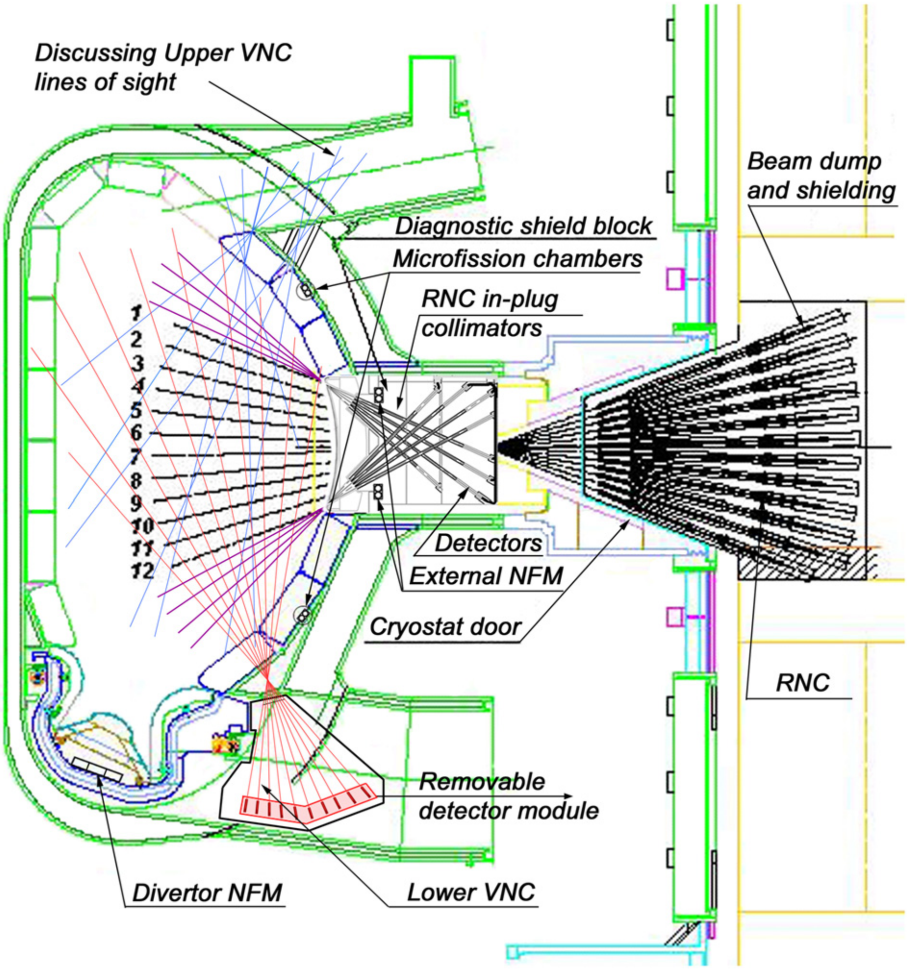


**Figure 1.** Arrangement of ITER neutron diagnostic systems integrated from several toroidal plans.

the plasma centre), symmetrically with respect to the plasma equatorial plane. The vertical extension of the plasma coverage by the RNC is 3.3 m (from $-0.5 \times b$ to $0.5 \times b$, where $b$ is the minor plasma radius in the vertical direction). Due to the limited plasma coverage by the RNC the fraction of neutrons not seen by the camera, because they are emitted from $\rho > 0.5$ magnetic surfaces, could reach 10–20% depending upon the neutron source profile. As a result the channels of the RNC directed to the port cell cannot provide the fusion power or total neutron source strength measurements with an accuracy of 10% in the case of rather flat emission profiles [3, 7].

To provide full plasma coverage in the vertical direction, additional channels placed inside equatorial port plug #1 (same port as standard RNC) are required [8]. These channels consist of a stainless steel plus water shielding block containing nine collimators of length ∼140 cm and diameter 4 cm. Four collimators view the plasma above the main external RNC fan of view and another four view below (see figure 1). In this way, the additional channels will provide the plasma coverage for $0.5 < \rho < 0.9$ in the upper and lower parts of the plasma. A ninth collimator viewing the plasma centre will be used for cross calibration of the external channels and the additional channels. The detector modules of the additional channels will be placed behind the collimators inside an in-plug shielding block. They will be ∼35 cm long and have a diameter of 6 cm. Due to the strong restriction in maintenance the most robust and radiation resistant detectors are under consideration for this application.

Several possible arrangements of the VNC have been studied. A conceptual design with all VNC flight tubes viewing the plasma through a single vertical port was proposed for ITER-98 [2]. Unfortunately, the existing ITER design does not have vertical ports; so first a VNC concept with neutron collimators distributed over four different poloidal cross sections viewing the plasma from the top was proposed. This VNC design had interfaces with several tokamak systems including the blanket, vacuum vessel, inter-coil structure, correction coils, cryostat thermal shield, ribs and bridge structure. One of the major problems of this VNC design is related to the expected uncontrollable changes of the effective collimator cross sections, and hence the calibration coefficients, due to relative movement of the ITER components interfacing with VNC flight tubes during tokamak operation.

The possibility of arranging VNC collimators inside the upper port plugs (upper VNC) is under analysis. Unfortunately, the space is limited and so the lengths of upper VNC in-plug collimators will be short, and according to the results of the first Monte Carlo $N$-particle (MCNP) transport calculations [24] performed on the base of model taking into account a toroidal neutron source and scattering of the neutrons in the vacuum vessel, blanket modules and in-plug VNC shielding it will probably not be possible to achieve the required collimation efficiency (unscattered to scattered neutron flux ratio in the detector position). In order to increase the effective length of the collimators the possibility of arranging collimating openings in blanket modules #11 and 12 and in the vacuum vessel is under consideration. The corresponding concept of the upper VNC arrangement in two separate upper ports is shown in figure 1 by indicating the possible lines of sight that might be achieved.

Taking into account the expected performance difficulties of a distributed VNC and the issues of the upper VNC performance, a concept for a lower VNC is now being studied. The main concept of the lower VNC arrangement is to place the VNC shielding module inside a divertor port [8] with collimators viewing the plasma through the gaps in the divertor cassettes, the blanket modules and the triangular support. The lower VNC version shown in figure 1 has 10 collimators with diameter 35 mm and length ∼150 cm. The detector block is placed behind the collimators and is remotely removable for maintenance. Another option for the lower VNC, which is under consideration, is based on the location of a conceptually similar VNC inside a specially designed port on the divertor level. Discussed options have essential interfaces with other ITER systems, such as divertor cassette, rail, triangular support, blanket modules, vacuum vessel and thermal shield. The optimal VNC arrangement will be decided on the basis of on-going analysis.

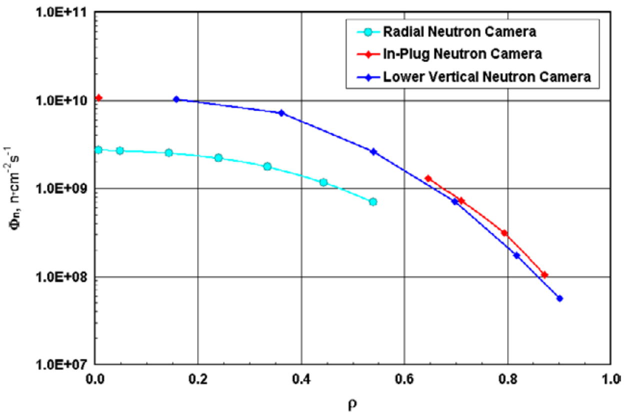


**Figure 2.** Unscattered neutron fluxes in detector locations for $P_{fus} = 400$ MW and RNC collimators ∅25 mm, in-plug RNC and lower VNC collimators ∅35 mm. The arrangement is shown in figure 1. $\rho$ on $x$-axis is minimum $\rho$ on respective line of sight.

Unscattered neutron fluxes at the detector positions integrated over the respective viewing cones of the external and internal channels of the RNC and the lower VNC collimators [25] are shown in figure 2. These data were obtained for a neutron source profile calculated by a 1.5D transport ASTRA code [26] for ITER reference scenario #2 ($Q = 10$, $P_{fus} = 400$ MW, $I_p = 15$ MA). Detectors that are under consideration for application in the ITER neutron cameras are presented in table 3 along with their performance characteristics.

No essential restrictions for detector operation exist in external RNC, so a number of scintillator and diamond detectors and compact spectrometers are under consideration for application there (see table 3). From the other side in internal RNC and lower VNC detectors will operate in magnetic field ∼1 T and with essentially restricted maintenance. For these reasons the most robust and radiation resistant $^{238}$U fission chambers and diamond detectors and compact spectrometers are under consideration for application there. Most of the considered detectors will provide neutron/gamma-ray separation (NE-213 and stilbene compact spectrometer by the shape of pulse, diamond detectors and compact spectrometers by pulse amplitude and $^{238}$U fission chambers and ZnS scintillators have extremely low sensitivity to gamma-rays). Developed and tested in fusion plasma experiments, prototypes of natural diamond and stilbene compact neutron spectrometers and U-238 fission chamber are presented in figure 3 together with compact DT neutron source ING-07 (yield $10^9$ neutron/s) used for detector energy resolution and sensitivity measurements. DT neutron energy distributions of ING-07 measured with a stilbene neutron spectrometer (efficiency of 14 MeV neutron measurements

**Table 3.** Detectors considered for application in ITER neutron cameras.

| Detector | Housing ∅ × $l$ (cm$^3$) | Sensitivity (cm$^2$ neutrons$^{-1}$) | Dynamic range for 1 ms time window | Life time | Neutron camera |
|---|---|---|---|---|---|
| | | | For maximum flux $5 \times 10^9$ neutrons cm$^{-2}$ s$^{-1}$ | | |
| Stilbene / NE-213 compact spectrometer [19, 20] /monitor [27] | ∅5 × 40 | $10^{-3}$–1 | 10 (digital spectrometer for 100 ms time window) 100 (digital monitor) | ? | RNC ext |
| Natural diamond detector (NDD) [18]—compact spectrometer | ∅1 × 2 | $2 \times 10^{-5}$ for single NDD | 20 (for 100 ms time window) | $10^4$ full power seconds | RNC ext RNC int, VNC |
| NDD—flux monitor [18, 28] | ∅1 × 2 | $10^{-3}$ for single NDD | 50 | $2 \times 10^6$ full power seconds | RNC ext RNC int, VNC |
| | | $2n \times 10^{-3}$ for n NDD+radiator | $100 \times n$ | ∼$10^6$ full power seconds | |
| CVD diamond detector [29] | ∅3 × 3 | $2 \times 10^{-2}$ for detector ∅25 × 0.2 mm$^3$ | 1000 | $2 \times 10^6$ full power seconds | RNC ext RNC int, VNC |
| $^{238}$U fission chamber [30] | ∅3 × 35 | $3 \times 10^{-4}$ | 20 | forever | RNC int, VNC |
| ZnS | ∅5 × 30 | $10^{-3}$–$10^{-1}$ | 1 | ? | RNC ext |
| Fast plastic scintillator | ∅5 × 30 | $10^{-3}$–1 | 100–300 | ? | RNC ext |

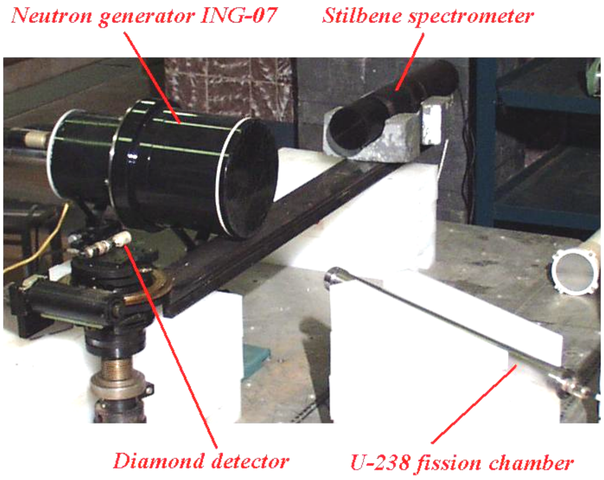


**Figure 3.** Natural diamond and stilbene compact neutron spectrometers and U-238 fission chamber installed for absolute calibration at compact DT neutron source ING-07.

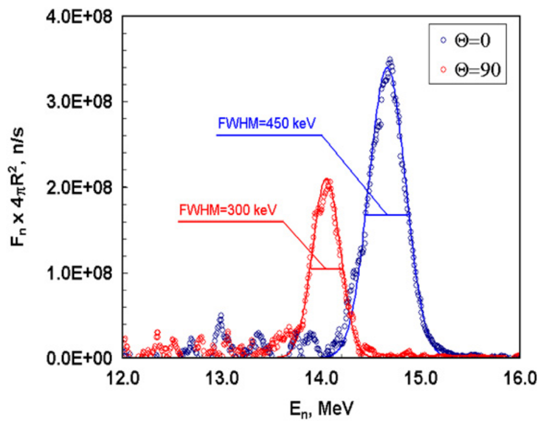


**Figure 4.** Energy distribution of the ING-07 DT neutron source measured by a compact stilbene neutron spectrometer with energy resolution ⩽300 keV at angles (Θ) 90° (as shown in figure 3) and 0° with respect to generator beam direction.

$3 \times 10^{-2}$ and stilbene crystal sizes ∅30 mm × 30 mm) are shown in figure 4.

MCNP calculations performed using the above mentioned model were performed to estimate unscattered to scattered neutron flux ratios in the detector positions of lower VNC. Fluxes of scattered neutrons have been calculated for energy ranges above thresholds of considered detectors: 1 MeV ($^{238}$U fission chamber) and 7 MeV (diamond detector). The results of the MCNP calculations demonstrated that the discussed lower VNC arrangement could provide well-collimated neutron source measurements [24].

## 4. Neutron flux monitors

The ITER NFMs system will include internal nfm, external nfm and divertor NFM. The internal NFM will consist of a set of detector blocks containing an $^{235}$U MFC and a complete similar fissile-material-free 'blank' detector and will be installed inside the vacuum vessel behind the blanket modules #11 and #16 (see figure 1) in two toroidal cross sections for redundancy [9, 10]. The poloidal positions were selected on the basis of MCNP calculations to make the internal NFM almost insensitive to changes in plasma position and peaking factor. The 'blank' detector will be used to eliminate $\gamma$-rays and electrical noises. Pencil size commercially available MFCs with 10 mg of $^{235}$U yielding a fission reaction rate of $\sim 3 \times 10^8$ s$^{-1}$ in a total neutron flux of $\sim 3 \times 10^{11}$ s$^{-1}$ cm$^{-2}$ at maximum fusion power will be used in counting mode up to a count rate of $10^6$ s$^{-1}$ and in Campbelling mode from a count rate of $10^5$ s$^{-1}$. So the ITER requirements of fusion power measurements with 1 ms time resolution and 10% accuracy will be fulfilled in a dynamic range of $3 \times 10^3$. The dynamic range could be increased by the application of FC with a larger amount of $^{235}$U material. A set of MFC prototypes was tested for the vacuum leak rate of the chamber with the mineral insulated cable, resistances and mechanical strength up to 50 g acceleration to meet design criteria. On the basis of an MFC test at a $^{60}$Co $\gamma$-ray facility it was estimated that the $\gamma$-ray influence will be less than 0.1% of the neutron signal in the current mode. The MFC linearity in a neutron flux dynamic range of $10^7$ was demonstrated on a fission reactor [9] and during tests on JT-60U [31]. The MFC linearity was also confirmed in the temperature range of 20–250 °C in DT neutron fluxes of the Fusion Neutronic Source [10].

A number of external NFM conceptual designs were developed [11–13]. The integration of NFM detector blocks consisting of a set of $^{235}$U and $^{238}$U FCs of different sensitivity into the stainless steel + water shielding modules of the limiter moving mechanism inside equatorial ports #8 and #17 was performed, taking into account the neutron transport calculations with an MCNP code [12]. External NFM detector blocks based on a set of $^{235}$U FCs of different sensitivities surrounded by beryllium and graphite moderators were also proposed for integration into limiter port (equatorial #8 and #17) plugs and equatorial port #1 [13]. Prototypes of detectors consisting of two FCs containing 1.5 g and 2 mg of $^{235}$U and having sensitivity to thermal neutrons of $\sim 1.3$ cm$^{-2}$ and $\sim 1.6 \times 10^{-3}$ cm$^{-2}$ and two other FCs containing 1.5 g and 2 mg of $^{238}$U and having sensitivity to fast neutrons of $\sim 10^{-3}$ cm$^{-2}$ and $\sim 10^{-6}$ cm$^{-2}$ were manufactured [12, 30].

To provide as large as possible a dynamic range of the measurement of the neutron source strength and its absolute calibration it has been suggested [12] to also locate a detector module of an NFM inside a divertor cassette (see figure 1), where the neutron flux will be ∼20 times higher than in other possible NFM positions. The design of this divertor NFM detector module is based on the combined application of two $^{238}$U and two $^{235}$U FCs. The amount of $^{235}$U and $^{238}$U fissile material will be in the range of a few milligrams–few grams to provide an adequate overlap of the linear operation ranges and allow for the FC cross calibration to one another. The FCs will operate in counting, Campbelling and current modes. The $^{235}$U FCs will be surrounded by a water moderator to provide a flat energy response. The $^{238}$U FCs will be surrounded by a $B_4C$ screen of thermal neutrons. 'Blank' detectors will be included in the detector module to identify gamma-ray and noise related signals. Three detector modules will be installed in three toroidal cross sections for redundancy. The divertor NFMs will meet the ITER requirements of time-resolved neutron source strength measurements in the dynamic range of $10^{14}$–$5 \times 10^{20}$ neutrons $s^{-1}$ with 1ms temporal resolution and 10% accuracy and can provide the signals necessary for real-time control of the ITER fusion power.

## 5. Neutron activation system

The neutron activation system will be dedicated to the robust fusion energy measurements for all plasma conditions and to obtaining an absolute calibration for all other neutron diagnostics. One planned system [14] is similar to those successfully used at JET and TFTR and is based on the pneumatic transfer of a set of encapsulated activation samples from the irradiation station to remote counting stations, where the sample activation will be measured. The irradiation stations will be located inside some of the permanent filler modules and will view the plasma from the outside wall, inside wall, top and bottom through gaps between blanket modules. Transfer lines driven with He gas at ∼0.06 MPa will be arranged in upper ports #6 and 11, equatorial ports #7 and 17 and divertor ports #6, 12 and 18. A neutron activation system based on flowing water which will provide a time resolution of ∼50 ms with ∼1 s delay time of the measurements is also being designed [15]. Water pipes with ∅20 mm will be arranged in upper ports #1 and 5 and equatorial ports #7 and 17. A detailed MCNP analysis will be used to establish the relation between the total neutron yield and the neutron fluence and spectrum at the point of irradiation.

## 6. Neutron spectrometers

Compact neutron spectrometers (diamond [18], stilbene [19] (see figures 3 and 4) and NE-213 [20] detectors) placed inside the collimators of the RNC and VNC will provide the measurements of ion temperature in the range $T_i >$ 5 keV, fast deuteron and triton energy distribution and poloidal rotation profiles. Neutron spectrometry using the magnetic proton recoil [17] and time of flight [32] techniques is also under consideration for $n_T/n_D$ ratio, plasma toroidal rotation and fast ion energy distribution measurements. Possible approaches to neutron knock-on tail measurements, which should provide information about the confined-alpha-particle density and energy distribution, include an MPR [17], bubble chamber neutron spectrometers [21] and recoil tracks in nuclear emulsions [22].

## 7. Neutron diagnostic calibration

A strategy for the absolute calibration of the neutron diagnostic systems [4, 5] is being developed. It includes absolute calibration of all detectors at the manufacturer and calibration on site in a purpose built laboratory. Several different methods will be used for absolute *in situ* calibration of the fusion power and power density measurements.

The first of them will be based on the absolute *in situ* calibration of the most sensitive RNC, VNC and NFM detectors after their installation on ITER, using a radionuclide neutron source and a DT neutron generator having a neutron output of about $5 \times 10^{10}$–$10^{11}$ neutrons/s. The source will be moved inside the vacuum vessel in toroidal and poloidal directions. The application of an additional neutron source based on a target irradiated by the ITER deuterium neutral beam has also been proposed [5]. The most suitable period for *in situ* calibration will be the end of the hydrogen plasma phase, when the in-vessel system characterization and tests would have been completed. Careful characterization of the neutron generator emission strength, directionality and the energy spectrum must be made before the calibration. This method also involves a detailed MCNP analysis of the neutron fluxes and spectra in the RNC, VNC and NFM detector positions and cross calibration of the least sensitive detectors against more sensitive calibrated detectors using the plasma as the source. The cross calibration is necessary because it is impossible to make an absolute calibration over the full dynamic range. In addition, some of the calibrated neutron detectors and ITER construction elements that have an influence on the calibration coefficients may be changed or modified during tokamak operation, and a new *in situ* calibration will not be possible.

The second method of absolute calibration of the fusion power and power density measurements will be based on the absolute calibration of RNC and VNC measurements using well-characterized most sensitive compact spectrometers. It will be based on the application of DT neutron generator with intensity of about $5 \times 10^{10}$–$10^{11}$ neutrons/s and detailed MCNP calculations. The compact spectrometers (stilbene, NE-213, diamond, silicon detectors) must be characterized on accelerator facilities and/or 2.5 and 14 MeV neutron generators in terms of absolute efficiency and neutron response function for different neutron and gamma-ray energies. DT neutron generator will be moved inside vacuum vessel and inside and close to the cones of measurements of RNC and VNC. Measured by compact spectrometers, neutron fluxes and spectra in the energy range around 14 MeV will be compared with detailed MCNP calculations. In such a way the calibration factors can be determined for the most sensitive compact spectrometers. The least sensitive compact spectrometers will be cross calibrated against more sensitive ones using the plasma as the source. Gamma sources, 2.5 and 14 MeV neutron generators and/or AmBe $n/\gamma$ sources should be built in the detector or should be periodically applied during maintenance for energy calibration and stability control of the compact spectrometers.

Another independent method to absolutely calibrate the fusion power will be based on the foil activation system. The advantages of this method are the intrinsic linearity and time stability. Its main weakness is the necessity of the essential MCNP calculations, especially for the region close to the irradiation stations. At ITER the irradiation station cannot be located close to the first wall, so the MCNP calculations will be time consuming and their accuracy will depend strongly on the machine components and detailed modelling around the irradiation stations. Using activation foil materials with a range of threshold energies will increase the confidence of the MCNP calculations. The neutron activation system will be used to check any change of calibration during ITER operation. In addition, it will provide the linearity and stability of the NFMs and the neutron cameras.

## 8. Conclusions

Most of the ITER neutron diagnostic systems have been selected and conceptually designed. Integration of the neutron diagnostic systems into the machine design is well advanced but further activity is required. The main characteristics of the systems are well determined and the ITER measurement requirements for parameters accessible with neutron diagnostics can be largely met: fusion power, neutron/$\alpha$ source profile, neutron fluence on the first wall and ion temperature profile in the range $T_i > 5$ keV. It is shown that joint application of RNC and VNC will provide a measurement of the 2D spatial distribution of the neutron emission and in particular the fast ion energy and 2D spatial distributions, but optimal integration of both neutron cameras is still in progress. Methods and possible arrangement of neutron spectrometry for the $n_T/n_D$ ratio and for the energy and spatial distribution of confined $\alpha$-particles are under study. The strategy of neutron diagnostic calibration has been developed but a lot of work in detailed calibration procedure and required hardware development is needed.

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