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The ITER Radial Neutron Camera Detection System

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ABSTRACT.
A multichannel neutron detection system (Radial Neutron Camera, RNC) will be installed on the ITER equatorial port plug 1 for total neutron source strength, neutron emissivity/ion temperature profiles and $n_t/n_d$ ratio measurements [1]. The system is composed by two fan shaped collimating structures: an ex-vessel structure, looking at the plasma core, containing tree sets of 12 collimators (each set lying on a different toroidal plane), and an in-vessel structure, containing 9 collimators, for plasma edge coverage. The RNC detecting system will work in a harsh environment (neutron flux up to $10^8 - 10^9 n/cm^2 s$, magnetic field $>0.5 T$ for in-vessel detectors), should provide both counting and spectrometric information and should be flexible enough to cover the high neutron flux dynamic range expected during the different ITER operation phases. ENEA has been involved in several activities related to RNC design and optimization [2,3]. In the present paper the up-to-date design and the neutron emissivity reconstruction capabilities of the RNC will be described. Different options for detectors suitable for spectrometry and counting (e.g. scintillators and diamonds) focusing on the implications in terms of overall RNC performance will be discussed. The increase of the RNC capabilities offered by the use of new digital data acquisition systems will be also addressed.

1. RNC LAYOUT
A 3D MCNP model of the ITER RNC and a Measurement Simulation Software Tool (MSST), performing asymmetric Abel inversion of the RNC integrated data, have been developed in ENEA [2,3]; these tools were jointly used to refine RNC layout and check whether it satisfies the ITER measurement requirements for neutron ($n$) emissivity profile (10% accuracy), spatial resolution (SR) ($a/10$ with $a =$ minor radius), time resolution (1ms) and total neutron strength (10% accuracy) [1].

A sketch of the RNC lines of sight is shown in Fig.1a: the 3 set of 12 ex-vessel channels will be located on different toroidal planes ($1^o$ separation), embedded in a concrete shielding block anchored to the port plug; upper, lower and central (in9) in-vessel channels will lay in the port plug, each on a different toroidal plane; in-vessel detectors will be accommodated inside removable cassettes outside the machine vacuum in order to allow substitution/repair. Two possible sets of collimator diameters ($\mathcal{O}$) are presently foreseen: $1cm$ ex-vessel & $2cm$ in-vessel and $2cm$ ex-vessel & $4cm$ in-vessel. Considering a $1cm$ thick NE213 scintillator as detector (see section 2), the first set appears more appropriate for full power DT operation (and will be discussed in the present paper) and the second one for full power DD operation.

MCNP results for $14MeV n$ fluxes and background (scattered $n$ in the range 1-12.8MeV) at the detectors positions are reported in Fig.1b; a typical $14MeV n$ spectrum for an ex-vessel channel is reported in Fig.2, where also the estimated $2.5MeV n$ spectrum during DT operations is shown (evaluated scaling by $1/4$ the results obtained with MCNP for a pure DD plasma): the $2.5MeV$ peak is above the background produced by $14MeV n$ indicating the measurability of the $n_d/n_t$ ratio. More detailed analysis is needed to assess such result for all RNC channels. MCNP also indicates the gamma ($\gamma$) contribution to the total flux to be 3-20% depending on the line of sight [2].
The RNC neutron emissivity reconstruction capability has been analyzed with MSST considering background, counting statistics and random errors. Results for 1 cm thick NE213 detector (see section 2) are reported in Fig.3a showing that 10% accuracy should be obtainable except that at the very plasma edge. SR has been investigated using double Gaussian emissivity test functions (separated by \( a/10 \)) moved along the minor radius. With the standard RNC layout the \( a/10 \) condition appears to be roughly achievable and a radial dependence of SR is observed [3]; the analysis also indicates that opposite tilting of two of the three ex-vessel channel sets should increase the achievable SR (Fig.3b).

2 DETECTORS AND ACQUISITION SYSTEM

Detectors with both flux and spectra measurement capability coupled to digital acquisition systems (FPGA-based, 200 MSamples/s sampling rate, 14-bit resolution, PCI-express data transfer to PC; see Fig.4a for data acquisition requirements) are presently foreseen for acquisition of RNC signals: liquid organic scintillators (such as NE213) and diamonds (natural (ND) or Chemical Vapor Deposited (CVD)) are the main candidates as RNC detectors; a prototype of the digital acquisition system has been developed in ENEA-Frascati and tested both on the JET neutron profile monitor and at PTB (Physikalisch - Technische Bundesanstalt, Braunschweig, Germany) accelerator [4, 5, 6].

Liquid organic scintillators can provide a simultaneous measurement of the 2.5\( MeV \) and 14 \( MeV \) \( n \) flux with a single detector unit: they have typical efficiency (with 1 cm thickness) of \( \sim 3\% \) at 2.5\( MeV \) (energy threshold (bias) = 1\( MeV \)), and \( \sim 1\% \) at 14 \( MeV \) (bias = 10\( MeV \)). They are sensitive both to \( n \) and \( \gamma \) and provide Pulse Height Spectra (PHS): Pulse Shape Discrimination (PSD) and unfolding techniques are needed to determine \( n \) and \( \gamma \) count rates and spectra (measured energy resolution with digital systems <4\% @ 2.5MeV and <2\% @ 14MeV [6]). Diamond detection, being based on the \(^{12}\text{C}(n, \alpha)\) reaction (threshold \( \sim 8\text{MeV} \)), is restricted to 14\( MeV \) neutrons. Diamonds have lower intrinsic efficiency than liquid scintillators (\( \sim 0.01\% \) for 500\( \mu\text{m} \) thickness), higher radiation resistance, low \( \gamma \) sensitivity and directly provide \( n \) spectra (\( \sim 1\% \) resolution @14\( MeV \)). Expected RNC 14\( MeV \) \( n \) count rates both with NE213 and diamonds are reported in Fig.4b for ITER scenario 2.

The chosen digital acquisition system will provide several improvements compared to analog systems: handling of count rates > 1MHz (foreseen in in-vessel channels with NE213 (see Fig.4b)); storing of pulse data for off-line reprocessing; off-line pile-up elaboration; time resolved \( n \) pulse height spectra; real time control applications. Measurements performed on the JET neutron profile monitor with the ENEA digitizers have shown the possibility to follow the time evolution of high-energy neutron tails produced by NBI heating (Fig.4a) and to resolve with good accuracy pile-ups by fitting procedures (Fig.4b [5]).

REFERENCES


Figure 1: (a) Sketch of RNC lines of sight with actual field of views (1cm & 2cm Ø set); (b) expected 14MeV n fluxes and background at RNC detectors (MCNP calculations, ITER scenario 2 [3]).
Figure 2: Comparison of 14MeV and 2.5MeV n spectra during DT operations for RNC ex-vessel line of sight #6.

Figure 3: (a) comparison of ITER scenario 2 emissivity (original) and inverted emissivity with counting statistics error (NE213 detector 10MeV threshold, 1ms time resolution), background and 5% random noise (the inverted/original ratio is also reported); (b) comparison between double gaussian emissivity test function (original, peak1 @ R=5.6 m, peak2 @ R=5.4 m, σ=7cm), inverted emissivity with the standard RNC layout and inverted emissivity with opposite tilting (±1.3°) of two of the three ex-vessel detector sets. ψ = normalized poloidal magnetic flux.
Figure 4: (a) RNC data acquisition requirements; (b) expected 14MeV n count rates with NE213 (1% efficiency) and diamonds (0.01% efficiency) for ITER scenario2 (MCNP calculations).

Figure 5: n PHS of plasma discharges obtained with digitizers coupled to JET neutron profile monitor scintillators: (a) time resolved n PHS of a NBI heated discharge (1 s time integration); (b) single and resolved pile-up n PHS (from [5]).