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The ITER Radial Neutron Camera Detection System

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** See annex of M.L. Watkins et al, "Overview of JET Results ",*
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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^2s, 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 (1*ms*) 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 (Ø) are presently foreseen: 1*cm* ex-vessel & 2*cm* in-vessel and 2*cm* ex-vessel & 4 *cm* in-vessel. Considering a 1 *cm* 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 14*MeV n* fluxes and background (scattered *n* in the range 1-12.8*MeV*) at the detectors positions are reported in Fig.1b; a typical 14*MeV n* spectrum for an ex-vessel channel is reported in Fig.2, where also the estimated 2.5*MeV n* spectrum during *DT* operations is shown (evaluated scaling by $^1/_4$ the results obtained with *MCNP* for a pure *DD* plasma): the 2.5*MeV* peak is above the background produced by 14*MeV 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 (γ) 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 ~3% at 2.5*MeV* (energy threshold (bias) = 1*MeV*), and ~1% at 14 *MeV* (bias = 10*MeV*). They are sensitive both to *n* and γ and provide Pulse Height Spectra (*PHS*): Pulse Shape Discrimination (*PSD*) and unfolding techniques are needed to determine *n* and ≥ count rates and spectra (measured energy resolution with digital systems <4%@ 2.5*MeV* and <2% @14*MeV* [6]). Diamond detection, being based on the ^{12}C(n, α) reaction (threshold ~ 8*MeV*), is restricted to 14*MeV* neutrons. Diamonds have lower intrinsic efficiency than liquid scintillators (~0.01% for 500μ*m* thickness), higher radiation resistance, low γ sensitivity and directly provide *n* spectra (~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 > 1*MHz* (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]).

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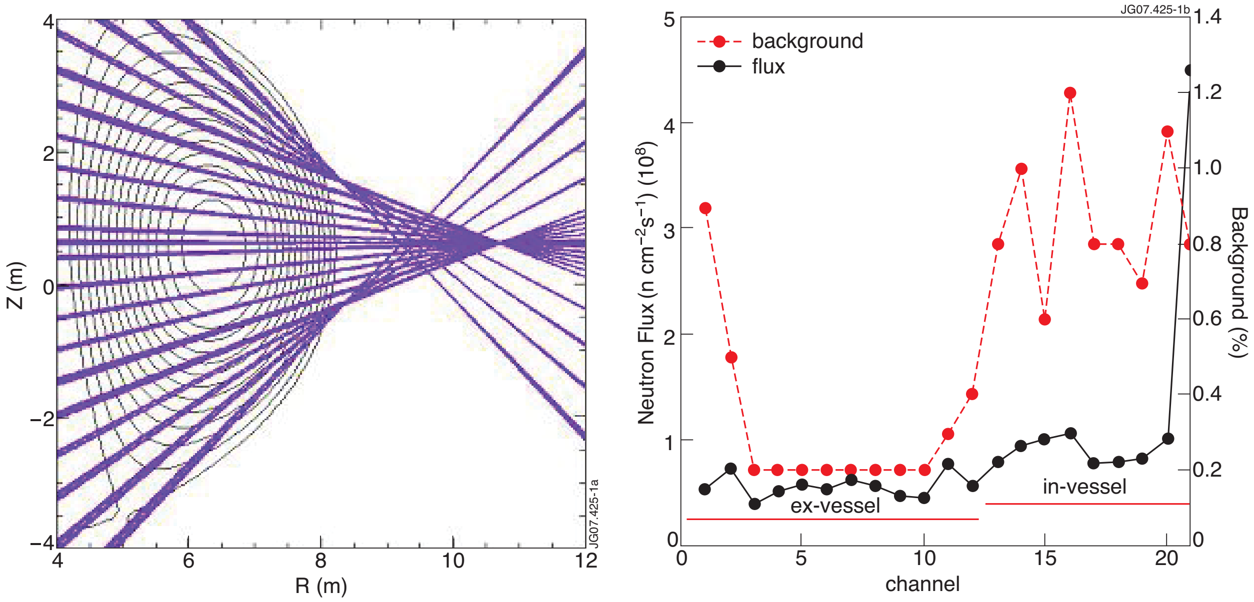


Figure 1: (a) Sketch of RNC lines of sight with actual field of views (1cm & 2cm Ø set); (b) expected 14MeV n fluxes and background at RNC detectors (MCNP calculations, ITER scenario 2 [3]).

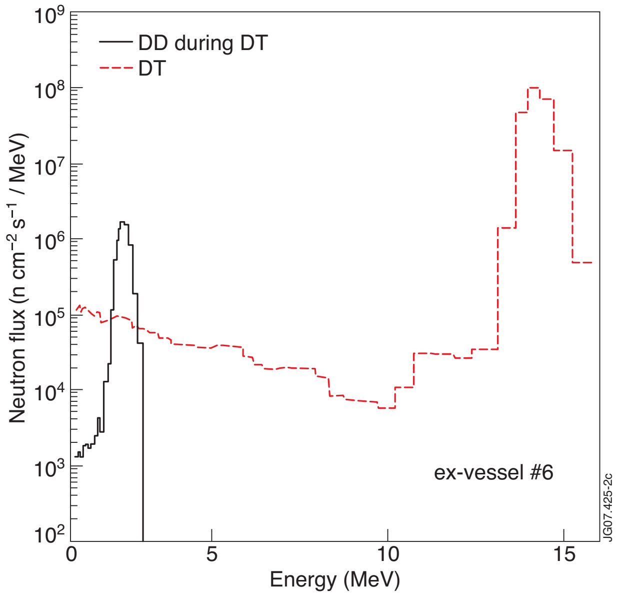


Figure 2: Comparison of 14MeV and 2.5MeV n spectra during DT operations for RNC ex-vessel line of sight #6.

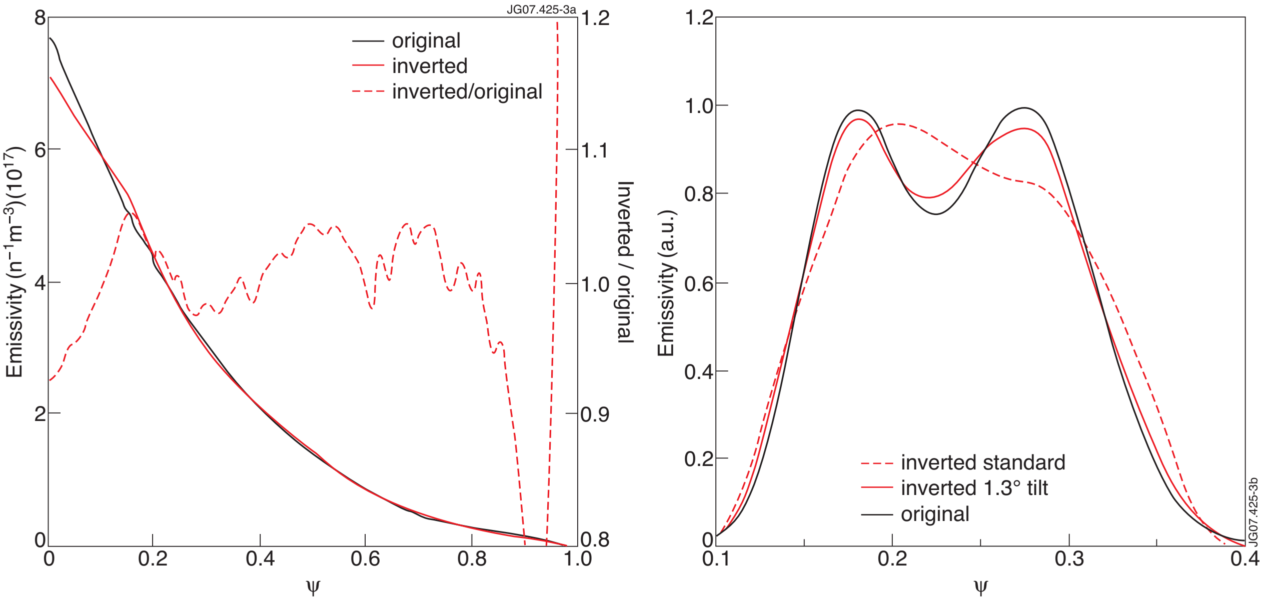
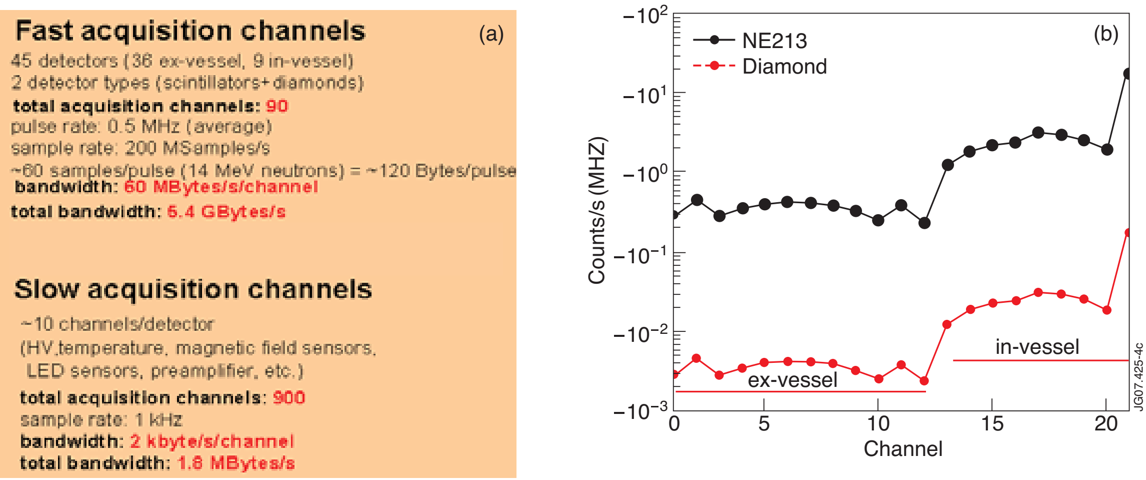


Figure 3: (a) comparison of ITER scenario 2 emissivity (original) and inverted emissivity with counting statistics error (NE213 detector 10MeV threshold, 1ms time resolution), background and 5% random noise (the inverted/ original ratio is also reported); (b) comparison between double gaussian emissivity test function (original, peak1 @ $R=5.6$ m, peak2 @ $R=5.4$ m, $\sigma=7$cm), inverted emissivity with the standard RNC layout and inverted emissivity with opposite tilting ($\pm 1.3^o$) of two of the tree ex-vessel detector sets. ψ = normalized poloidal magnetic flux.



Fast acquisition channels (a)

45 detectors (36 ex-vessel, 9 in-vessel)

2 detector types (scintillators+diamonds)

total acquisition channels: 90

pulse rate: 0.5 MHz (average)

sample rate: 200 MSamples/s

~60 samples/pulse (14 MeV neutrons) = ~120 Bytes/pulse

bandwidth: 60 MBytes/s/channel

total bandwidth: 6.4 GBytes/s

Slow acquisition channels

~10 channels/detector

(HV,temperature, magnetic field sensors, LED sensors, preamplifier, etc.)

total acquisition channels: 900

sample rate: 1 kHz

bandwidth: 2 kbyte/s/channel

total bandwidth: 1.8 MBytes/s

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).

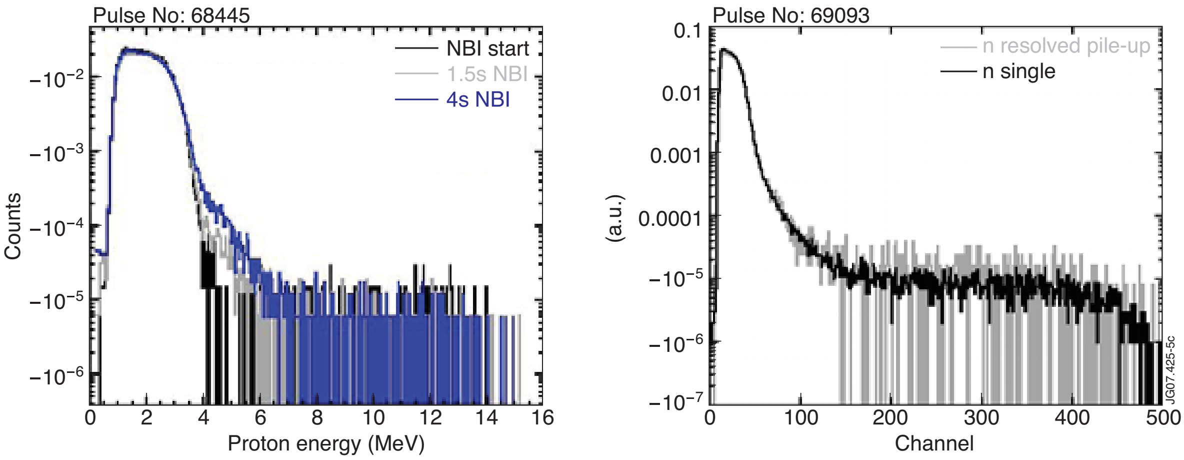


Figure 5: n PHS of plasma discharges obtained with digitizers coupled to JET neutron profile monitor scintillators: (a) time resolved n PHS of a NBI heated discharge (1 s time integration); (b) single and resolved pile-up n PHS (from [5]).