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ABSTRACT.
A neutron diagnostics technique based on the bubble detectors has been used for measurements during the JET experimental campaigns of 2008 and 2009. The main aim of these measurements was the determination of the neutron field characteristics in high performance discharges which produce neutron yields in the range $(3\text{-}5)\times10^{16}$ neutrons per pulse.

The neutron field parameters at a specific location above a narrow collimating channel in the ceiling of the JET Torus Hall (behind the TOFOR [1] time-of-flight spectrometer) have been measured simultaneously by two independent techniques: super-heated fluid detectors or "bubble detectors" and time-of-flight."

1. INTRODUCTION

The bubble detectors (Super-Heated Fluid Detectors - SHFFD's) are suspensions of metastable droplets which readily vaporise into bubbles when they are nucleated by radiation interactions. The active detecting medium is in the form of microscopic (20-50μm) droplets suspended within an elastic polymer. The phenomenon of neutron detection by a SHFD is a mixture of nuclear interactions (neutron collisions with nuclei of the active medium), thermodynamic behaviour of the detecting medium (the super-heated fluid), and the mechanical response of the elastic polymer. If sufficient energy is transferred from the colliding neutron to the nucleus of one of the elements in the composition of the active medium, the recoil nucleus will initiate the generation of a vapour embryo of sub-micron dimensions. Under proper conditions (that depend on the thermodynamics of the active medium) the vapour embryo will lead to the vaporisation of the super-heated droplet with the subsequent expansion into a macroscopic (0.2–0.5mm) bubble.

The bubble detectors show the following particular characteristics: high neutron detection efficiency (counts/ unit fluence) that ranges from about 4×10^{-2} to 4×10^{-5}; almost flat, threshold-type energy response over a broad energy range (10's keV to 10's MeV), having any energy threshold in that range; practically zero sensitivity to gamma-radiation; good spatial resolution (sub-centimetre resolution in the image plane).

The particular features of the bubble detectors recommended the technique for applications on nuclear fusion devices with the aim of determining the neutron field characteristics in high performance (i.e., high neutron yield) discharges [2, 3].

2. EXPERIMENTAL SETUP

The experimental setup [4, 5] used for the bubble detector neutron measurements at JET is shown schematically in Figure 1. The bubble detectors (Super-Heated Fluid Detectors – SHFD's) are installed at the end of the JET KM11 neutron diagnostics line-of-sight, above the TOFOR neutron time-of-flight spectrometer (Figures 1 and insert). The field-of-view is defined by a variable pre-collimator located on top of the JET tokamak. The distance from SHFD location to the TOFOR first scintillator detector (S1) is approximately 3.5m and the distance to the torus mid-plane is approximately 20m.

3. DETERMINATION OF NEUTRON FIELDS CHARACTERISTICS AT JET USING BUBBLE DETECTORS

The bubble detectors technique has been used for measurements on JET tokamak machine during the JET experimental campaigns of 2008 and 2009. The main aim of these measurements was the determination of the neutron field characteristics in high performance discharges, such as those produced in experiments on the development of the steady state scenario at high beta normalised [2]. Such discharges produce neutron yields in the range $(3-5)\times10^{16}$ neutrons per pulse. Two types of SHFD's have been used on the JET tokamak for neutron measurements during the 2008 and 2009 experimental campaigns: sets of BD-PND* type detectors (absolutely calibrated) for absolute neutron fluence measurements and sets of high sensitivity DEFENDER* type detectors for neutron beam imaging (determination of the neutron beam footprint);

By using high sensitivity DEFENDER detectors the spatial distribution of the neutron beam propagating along the collimated vertical line-of-sight of the KM11 diagnostics was obtained. A set of six DEFENDER type detectors have been used during the JET Pulse No: 72737 and a spatial distribution with radial and toroidal resolution has been obtained (Figure 2).

Another set of measurements done in one session during the experimental campaigns provided the neutron fluence distributions on six discharges, with the TOFOR pre-collimator position as follows: "fully open"(pre-collimator opening ~100%), ~40% open and ~60% open, with two measurements for each position, using BD-PND type detectors. It also provided the spatial distribution of the neutron fluence on two discharges with the TOFOR pre-collimator position "fully closed", using DEFENDER type detectors.

The radial distribution of the neutron fluence using BD-PND-type detectors for three pulses in session for different pre-collimator openings is shown in Figure 3. The dependence of the radial profile on the pre-collimator opening shows that the bubble detector array configuration operates as a neutron pinhole camera. From the geometry of the experimental setup it follows that this neutron "pinhole camera" has a magnification of about 3.5. It means that the bubble detector array can provide a spatial (radial) resolution of approximately 55 mm at the vacuum chamber mid-plane.

4. COMPARISON BETWEEN BUBBLE DETECTORS AND TOFOR NEUTRON MEASUREMENTS

A comparison between bubble detectors and TOFOR neutron measurements of neutron flux per pulse was done for six pulses during the same JET experimental session. The number of neutrons detected by the calibrated bubble detector array (eight BD-PND type detectors) was calculated by integrating the fluence distribution over the determined "neutron spot" area (the so-called "Area Iintegrated Fluence", (AIF)), obtained by means of high sensitivity DEFENDER type detectors.

**All detectors used in this work were manufactured and calibrated by Bubble Technology Industries, Chalk River, Canada*

The area integrated fluence was plotted against the TOFOR neutron flux (the number of neutrons estimated to have entered the TOFOR line-of-sight) and a linear fit with a correlation factor of ~0.99 was obtained.

CONCLUSIONS

Spatial (radial and toroidal) distributions of the neutron fluence at the end of the JET KM11 neutron line-of-sight have been obtained by measurements performed on high neutron yield discharges during the two experimental sessions, such as those produced in experiments on the development of the steady state scenario at high beta normalized [2]. The operation of the bubble detector array as a neutron pinhole camera having a radial resolution at the vacuum chamber mid-plane of about 55 mm was clearly demonstrated in measurements using various openings of the KM11 pre-collimator. The comparison of the area integrated fluence determined by means of the bubble detector array with the TOFOR neutron flux has shown a good correlation factor of about 0.99.

ACKNOWLEDGEMENTS

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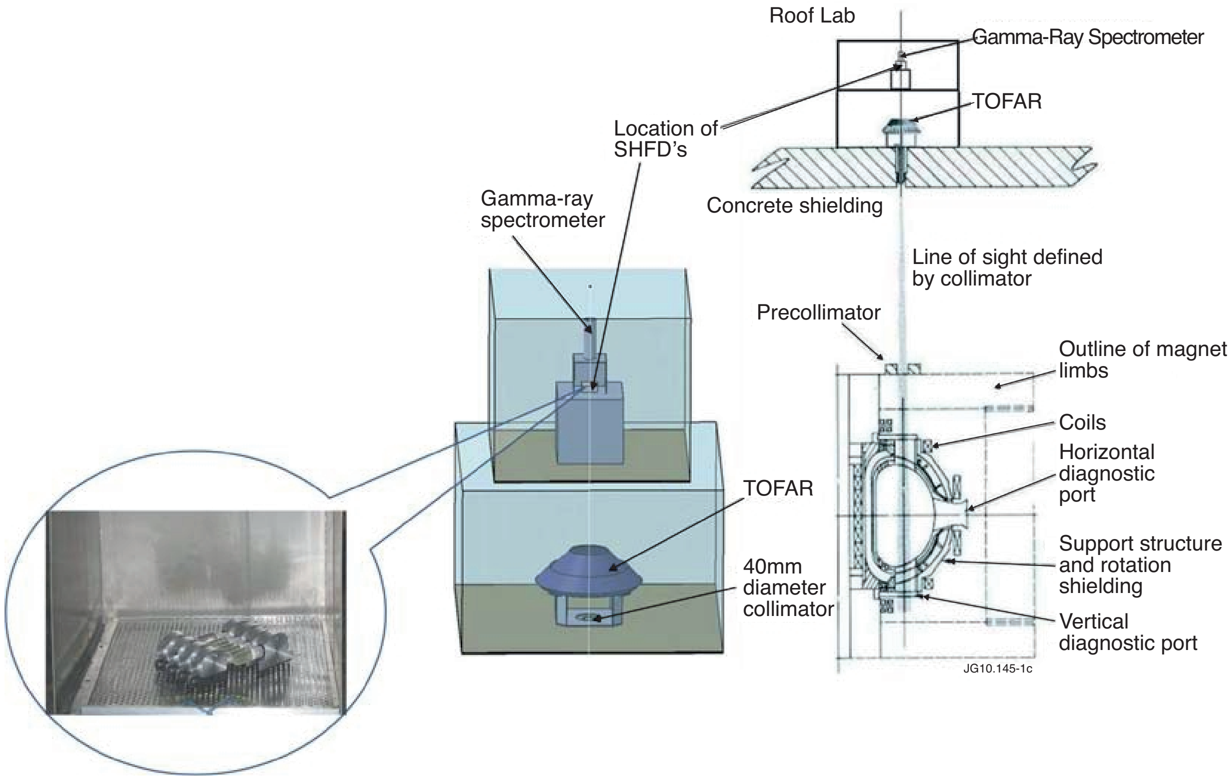

Figure 1: Experimental setup for SHFD neutron measurements along the JET KM11 Line-of-Sight. (insert) Bubble detectors (SHFD's) set installed on the KM11 neutron beam line-of-sight.

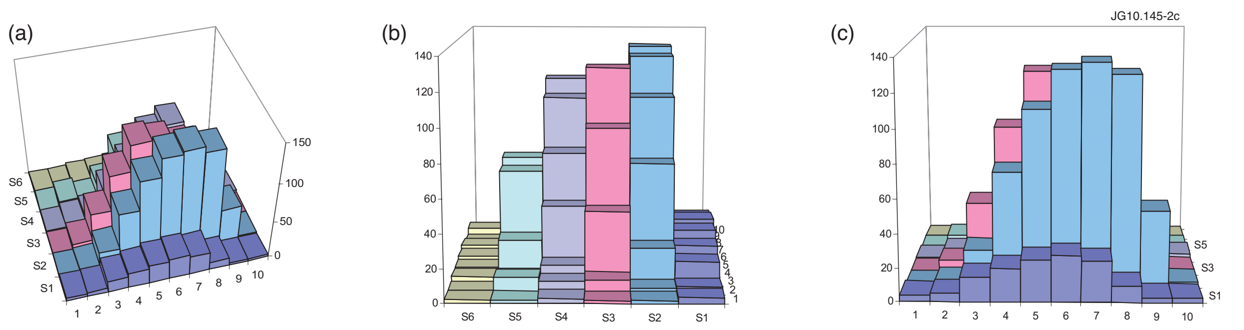

Figure 2: Spatial distribution of the neutron fluence. (a): 2D distribution; (b): radial distribution (machine centre is on the left hand side); (c): toroidal distribution.

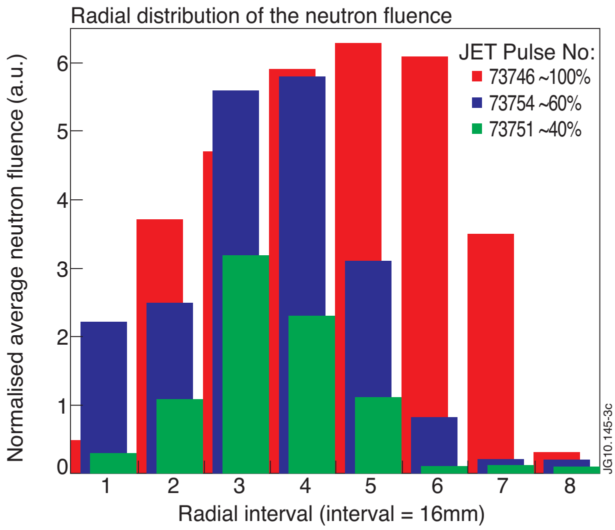

Figure 3: Radial distribution of the neutron fluence for three different pre-collimator openings.

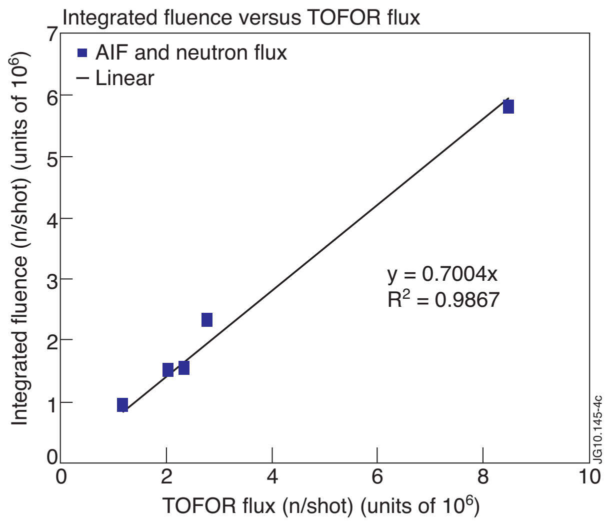

Figure 4: Area Integrated Fluence (AIF) versus the TOFOR flux.