TOKAMAK NEUTRON DIAGNOSTICS BASED ON THE SUPER-HEATED FLUID DETECTOR (SHFD)

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1. Introduction

Neutron diagnostics techniques based on a new type of detector (the super-heated fluid detector – SHFD) have been tested on the JET tokamak for the characterisation of the neutron emission. The super-heated fluid detectors (also known as "bubble detectors") were found to be of particular interest due to their particular characteristics: immediate, visible response; high neutron efficiency, (practically) zero gamma sensitivity; lightweight, rugged and compact; broad energy range spectrometric capability [1,2].

2. Superheated fluid detectors (SHFDs)

Super-heated fluid detectors 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 (20-50 μm) droplets suspended within an elastic polymer (Fig. 1) [3].

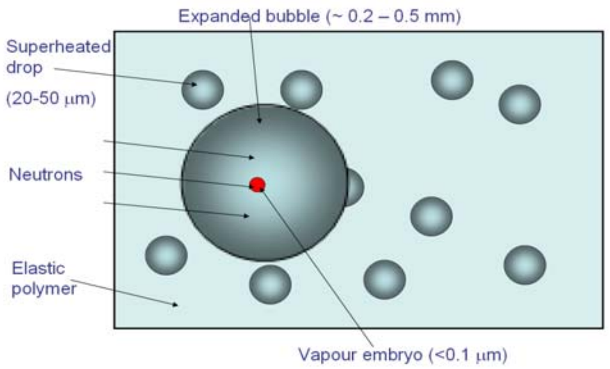

Figure 1. The basic operation of Super-Heated Fluid Detector(Bubbles detector)

The process of neutron detection by a SHFD resides in 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 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 – 0.5 mm) bubble. The bubbles generated in the detector are counted by various means: eye counting for up to a few tens of bubbles per detector, automatic counting through processing of the detector image, acoustical detection of the bubble formation. The number of bubbles generated within a given volume of the detector is simply and directly related to the neutron fluence (neutrons per unit area).

The SHFD's have a threshold-type energy response. The threshold energy depends on: droplet composition, detector operating temperature, and detector operating pressure. For a standard bubble detector like the BD-PND(*) type the energy response is approximately flat within the range 0.3-10 MeV (Fig. 2). Using detectors with different energy thresholds, a bubble detector spectrometer (BDS(*)) is obtained. The BDS covers a broad energy range (0.01 – 20 MeV) and provides six energy thresholds in that range (Fig. 3).

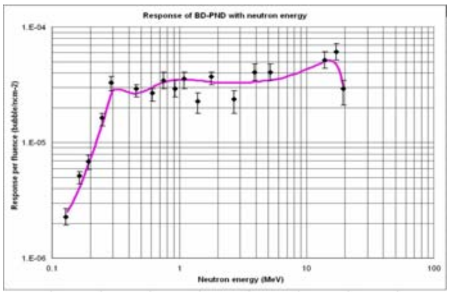

Figure 2. Energy response of BN-PND –type detector

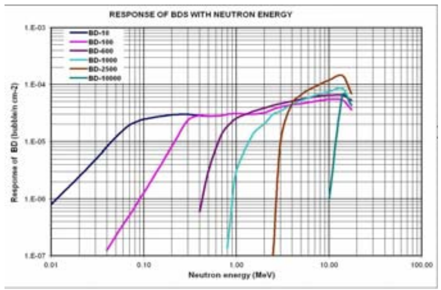

Figure 3. Energy response of BDS-type detector

3. SHFD neutron measurements at JET

Three types of SHFD's (BD-PND, BDS and DEFENDER(*)) (Fig. 4) have been used for neutron measurements at JET during the 2007 experimental campaigns (C18-C19). The BD-PND's type detectors have been used for neutron fluence measurements, high sensitivity DEFENDER-type detectors for neutron beam imaging and the BDS type detectors have been used for neutron energy distribution measurements.

(a) (b) (c)

Figure 4. (a) BD-PND-type detectors for neutron fluence measurements; (b) BDS-type detectors for neutron energy distribution; (c) DEFENDER-type detectors for neutron beam imaging.

All measurements have been done at the end of the KM11 diagnostics line-of-sight, above the TOFOR neutron time-of-flight spectrometer. The SHFD detectors have been placed in front of the vertical NaI(Tl) gamma-ray spectrometer.

By using a set of four DEFENDER detectors the profile of the neutron beam propagating along the collimated vertical line-of-sight of the KM11 diagnostics was obtained.

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

The radial distribution of the neutron fluence in the neutron beam at a distance of about 3 m from the exit of the 40 mm diameter KM11 collimator was obtained with a spatial resolution of less than one centimetre (Fig. 5). As an immediate effect of this measurement a better alignment of the vertical NaI(Tl) gamma-ray spectrometer was obtained.

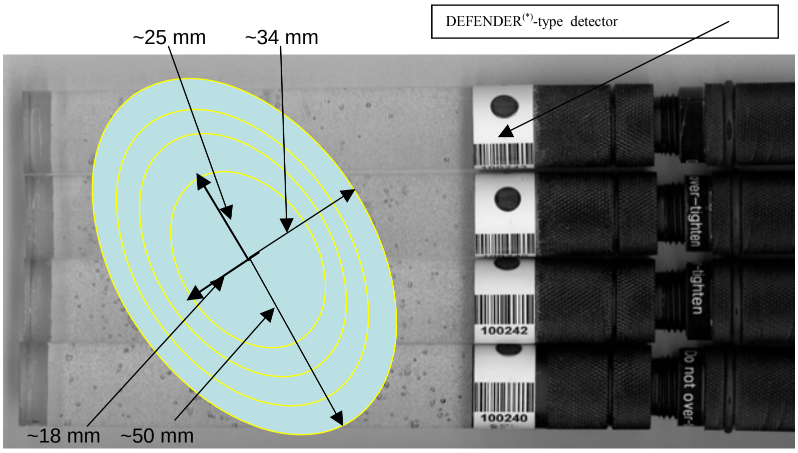

Figure 5. The radial distribution of the neutron fluence in the KM11 neutron beam.

The cross-section of the neutron beam is determined by the diameter of the floor-collimating hole. The Full Width at Half Maximum (FWHM) of the beam profile is approximately 40 mm [4].

The neutron energy distribution at the end of the KM11 line-of-sight was obtained over a broad energy range (six energy bins, defined by the energy thresholds: 0.01; 0.1; 0.6; 1.0; 2.5; 10.0 MeV).

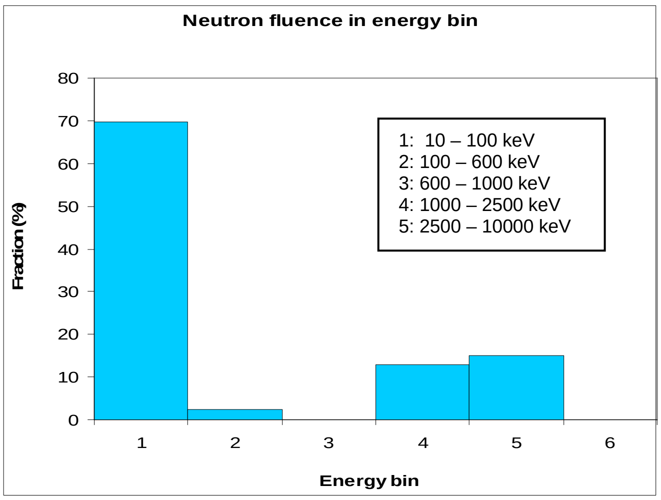

Figure 6. Neutron energy distribution determined by bubble detector spectrometer (BDS).

The measurement was done during a Ripple H-mode Study session (JET pulse numbers: 70656-70660). The energy distribution (Fig. 6) shows an energy component around the 2.5 MeV value (DD fusion neutrons) and a large low energy component, most probably generated by the scattering of the fusion neutrons in the collimating structures.

3. Conclusion

A neutron diagnostics technique based on the super-heated fluid detectors (SHFD's or "bubble detectors") has been successfully tested at JET on various types of discharges during Campaigns C17-C19. It provided new information about the following characteristics of the neutron field at the end of the KM11 line-of-sight: fluence, beam profile, broadband energy distribution.

The results (although quite encouraging) are of preliminary nature and they should be checked and confirmed in better-defined and suitably controlled measurements during Campaigns C20-C25. This technique for determining the neutron field characteristics could be applicable for high performance discharges (neutron yields of $5x10^{16}$) and it was proposed to be used in the next campaigns together with other two different and independent methods: bubble detectors, neutron activation and time-of-flight spectrometry.

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References:

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