Tokamak neutron diagnostics based on the superheated fluid detector (SHFD)

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Outline

• The superheated fluid detectors (SHFD’s)

• Proposals for SHFD neutron measurements on JET

• SHFD spectrometric set for experiments on anomalous neutron emission on JET

• Experimental model for a one-channel SHFD detection unit

• Proposal for SHFD neutron measurements on FTU
Superheated fluid detectors (SHFD’s)

Suspensions of metastable droplets which readily vaporise into bubbles when they are nucleated by radiation interactions.

SHFD’s:
• Superheated drop detectors (1979)
• Superheated emulsion detectors
• Bubble detectors (1984)

Mixture of
• Nuclear interactions
• Thermodynamic behaviour
• Mechanical response

Neutron dosemeters: SHFD’s with volumetric, optical and acoustical counting

The characteristics and advantages of SHFD’s neutron detectors:

• Immediate, real time, visible response to neutrons
• High neutron sensitivity
• (Practically) Zero gamma sensitivity
• Lightweight, rugged and compact
Characteristics of the neutron detection process

- SHFD’s – microscopic bubble chambers
  - Energy transfer
  - Recoil nucleus range

- Threshold energies depending on:
  - droplet composition
  - operating temperature
  - operating pressure
Bubble formation in SHFD’s

Superheated drop
20–100 μm

Expanded bubble ~ 0.1–0.6 mm

Vapour embryo
< 0.1 μm

Radiation

[1]
Diameter: 15-20mm
Scanned images of bubble detectors (#1-6 & #8) exposed to Shot 2577

$$Y_n = 2.2 \times 10^{10} \text{ neutrons}$$

BD’s on the PF1000 PFD
[2]

EURATOM-MEdC Association Days, TUCN, Cluj-Napoca, 10-11 October 2006
Proposals for SHFD application on EU tokamaks

**Stage 1**
Neutron fluence measurements at a specific location on the tokamak

**Stage 2**
Spatial distribution of the neutron fluence around the tokamak
(Stage 1 done simultaneously, on one discharge, at various locations around tokamak installation)

**Stage 3**
Determination of the neutron energy spectrum (time-integrated over one or a few tokamak shots)

**Stage 4**
Time-resolved, energy-resolved neutron measurements using advanced SHFD’s (in the form of a SHFD Detection Unit)

**Stage 5**
Time- AND energy- AND space- resolved neutron measurements using advanced SHFD’s
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Task Force D

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Measurement of the anomalous neutron production using a spectrometric set of superheated fluid detectors (SHFD’s)
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Rationale

• Ability to measure neutron fluxes and spectra over a broad energy range (10 keV – 15 MeV): study different sources of the observed neutron emission (excess neutrons)

• ICRF-only heating scenarios: nuclear reactions between the accelerated light ions and bulk fuel ions (e.g. \( T(p,n)3He \) fusion reaction) or plasma impurities (e.g. \( ^9Be, ^{12}C \)) may contribute to the neutron yield significantly

• SHFD detectors provide spectrally resolved measurements also at low energies not covered by any of the existing JET neutron spectrometers

Direct interest for the C16 experiment H/S2-4.2 “Anomalous neutron production reactions in ICRH minority heated plasmas”
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Acceptance criteria

• High scientific importance: it addresses by means of a new approach a key issue related to the neutron field of the JET machine: the spectral characteristics of the non-fusion fuel neutron component.

• SHFD spectrometric set is a stand-alone equipment, implementation on JET with no interference with other machine components.

• No impact on the shutdown, preliminary tests can be accommodated within planned neutron diagnostics tests during JET restart operations.
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Technical details
- 36 detectors (6 detectors for each energy threshold)
- Very broad energy range: 10 keV – 15 MeV
- Six energy thresholds: 10 keV, 100 keV, 600 keV, 1MeV, 2.5 MeV, 10 MeV
- Overall dimensions of a 6 detector bundle: approximately 70mmx100mm (diameter x length)
- Install spectrometric SHFD set in the diagnostic hall, end of the KH2 beamline (well-collimated tangential view of the plasma through Octant 6 port)

Initial configuration: integrate the one-day JET neutron emission
Upgrade: (data acquisition components) integrate the neutron emission on a single JET discharge
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Work plan (agreed upon with JET TFD)

(i) Launch purchasing order for the spectrometric SHFD set: October 2005
(ii) Purchase of the spectrometric SHFD set: December 2005
(iii) Neutron spectrum measurements on JET using the spectrometric SHFD set: campaign C16: January 2006
(iv) Analysis and interpretation of the spectrometric SHFD set data: February 2006
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Implementation

(i) Launch purchasing order for the spectrometric SHFD set: October 2005
(ii) Purchase of the spectrometric SHFD set: December 2005

Done

However

Analysis done at JET (CSU, Task Force Diagnostics and JOC) at the end of 2005:
=> postpone implementation of the technique on JET until April 2006
JET problems during 2006: no chance!
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

36-detector spectrometric set
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

Detector reader unit
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

(18) Detector recompression chamber
Proposal for JET diagnostics

SHFD spectrometric set for the characterisation of the anomalous neutron emission

However

Two attempts: a set of detectors at the end of the KH2 beamline (March and April 2006)
Poor conditions on JET: the neutron emission was orders of magnitude lower than expected and no signals were obtained.

To allow for detector positions closer to the plasma:
- design and construct a detection channel that would make possible remote (up to about 50 m) reading and transfer of the SHFD detector image
As a first step it was decided to construct and test during 2006 a one-channel SHFD detection unit.
Neutron Generation → Neutron Flux → Neutron Detector Set (SHFD) → Image Focusing Optics → IEEE1394a Cable → CCD Image Detector → Dedicated PC

Block diagram for the experimental model of one-channel SHFD detection unit

EURATOM-MEdC Association Days, TUCN, Cluj-Napoca, 10-11 October 2006
Proposal for FTU diagnostics

High sensitivity SHFD set (four new detectors) and standard SHFD set (4-6 detectors)

Aims

Neutron fluence measurements (on single shot FTU discharges)
- at former foil activation locations
- at various locations around the machine

Different experimental setup (w.r.t. JET): FTU cryostat
Proposal for FTU diagnostics

Workplan

Experimental setup evaluation: February 2006

Neutron fluence measurements (I): March-April 2006

Neutron fluence measurements (II): (?) 2006
Conclusions

A SHFD spectrometric set for the characterisation of the anomalous neutron emission has been developed (method and device)

SHFD spectrometric set: awaiting to be applied on JET

An experimental model for a one-channel SHFD detection unit has been developed (method and device)

One-channel SHFD-DU: to be tested on a pulsed fusion neutron source
The reported work includes contributions from the following:

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References


Thank you!