FIRST EXPERIMENTAL VALIDATION OF THE PROTOTYPE ITER HARD X-RAY MONITOR FOR RUNAWAY ELECTRON STUDIES IN ADITYA-U TOKAMAK

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SYNOPSIS: Experimental and theoretical studies on runaway electrons (REs) in tokamaks are a major focus of current fusion research [1], particularly for high-plasma-current devices like ITER and next-generation fusion reactors. Controlling Runaway Electron (RE) loads during plasma disruptions is essential, as their localized energy deposition can severely damage in-vessel components, necessitating continuous monitoring and control throughout plasma discharges. Among various detection methods, bremsstrahlung emission (both thin and thick targets) in the hard X-ray (HXR) energy-range is widely used to diagnose REs. Unlike conventional HXR monitors (HXRM) in present tokamaks, the ITER-HXRM is specifically designed to withstand extreme load conditions expected during plasma operations and accidental events while providing a wide measurement range [2]. This paper presents the first successful experimental validation of the prototype ITER-HXRM on the ADITYA-U tokamak, demonstrating its effectiveness in RE detection and analysis, with results showing agreement with RE simulations. The HXRM was added to the baseline diagnostics in ITER for a measurement role limited to the non-nuclear phase of plasma operations. During the nuclear phase, HXRM has no measurement role, and it will remain captive (non-maintainable) but must stay structurally stable. The ITER HXRM is designed to operate in harsh environmental conditions and provides information on runaway electrons across a wide dynamic range of RE energy and RE current [3]. To meet these requirements, unlike conventional HXRM systems, as shown in Fig.1 (left), the scintillator crystal in the ITER HXRM is decoupled from the photomultiplier tube (PMT), with scintillation photons guided via optical components to PMTs located in the port-cell area [4, 5].

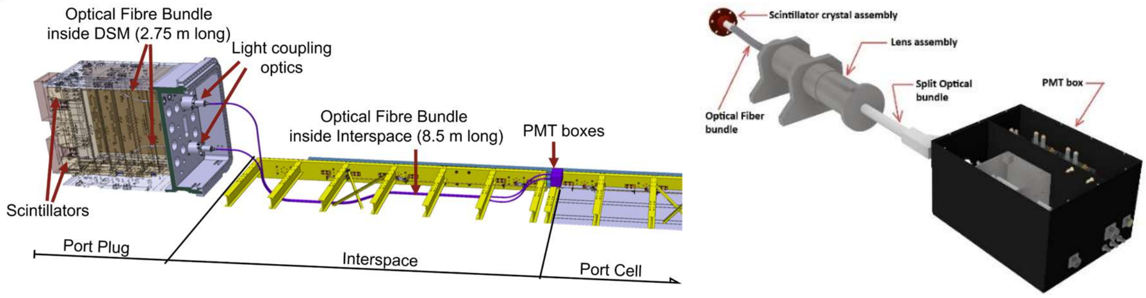

Figure 1: Schematic layout of the designed HXR Monitor for the ITER Tokamak, to be located in Equatorial Port Plug #12 (left), and the prototype HXR Monitor installed in the ADITYA-U Tokamak (right).

The light output from the scintillator crystal is split into a 90:9:1 light distribution ratio, where 90% of the light is coupled to a PMT operating in counting mode to perform pulse height analysis for energy-resolved measurements, which is particularly effective during low-counting-rate RE-events. The remaining 9% of the light is coupled to a PMT operating in current mode for non-energy-resolved measurements. This mode remains active throughout the entire plasma discharge but it can be tuned to provide a signal as soon as the counting-mode PMT saturates due to pulse pileups (when it can no longer resolve energy). Finally, the last fraction of 1% light is connected to an LED module (the design is yet to be finalized) for verifying the HXRM optical chain integrity and the functionality of the PMTs.

In order to validate the design of the ITER HXRM, a dedicated test program was started and ongoing, in which each individual component, the integrated assembly, and prototypes (Fig.1 (right)) were tested in a lab environment using radioactive sources with low count rates [6]. However, to gain further experience in a real tokamak environment and high-count-rate conditions, the prototype assembly was tested and validated for the first time on the Aditya-U tokamak [7]. The Aditya-U tokamak offers flexibility for quick installation of system configurations and easy accessibility, allowing necessary modifications and system tuning between each plasma discharge. Compared to ITER disruption scenarios, the RE current produced in the Aditya-U tokamak is relatively low. However, it provides a unique opportunity to test the sensitivity of the designed HXRM for relatively low-RE-energy and low-RE-current conditions expected in ITER's start-up phase, as well as to evaluate the electronics and data processing algorithms. For cross-validation, two types of HXRM configurations were tested simultaneously on Aditya-U tokamak: a conventional setup, where the scintillator crystal's light output is directly coupled to the PMT, and the prototype ITER HXRM, where the light is coupled to the PMT using relay optics. Fig. 2(a-b) compares the time- and energy-resolved HXR count rate during plasma discharge #38661, obtained through the counting-mode PMT, showing good agreement between both setups. Similarly, Fig. 2(c) depicts the time evolution of HXR spectra by performing pulse height analysis of counts integrated for every 10 ms time interval during the plasma discharge #38661. The prototype HXRM system has demonstrated a maximum counting capability of ~2 MHz.. Fig. 2(d) compares the output signal from the current-mode PMT for these two setups during plasma discharge #38692, with results consistent with the existing HXRM installed on the Aditya-U tokamak.

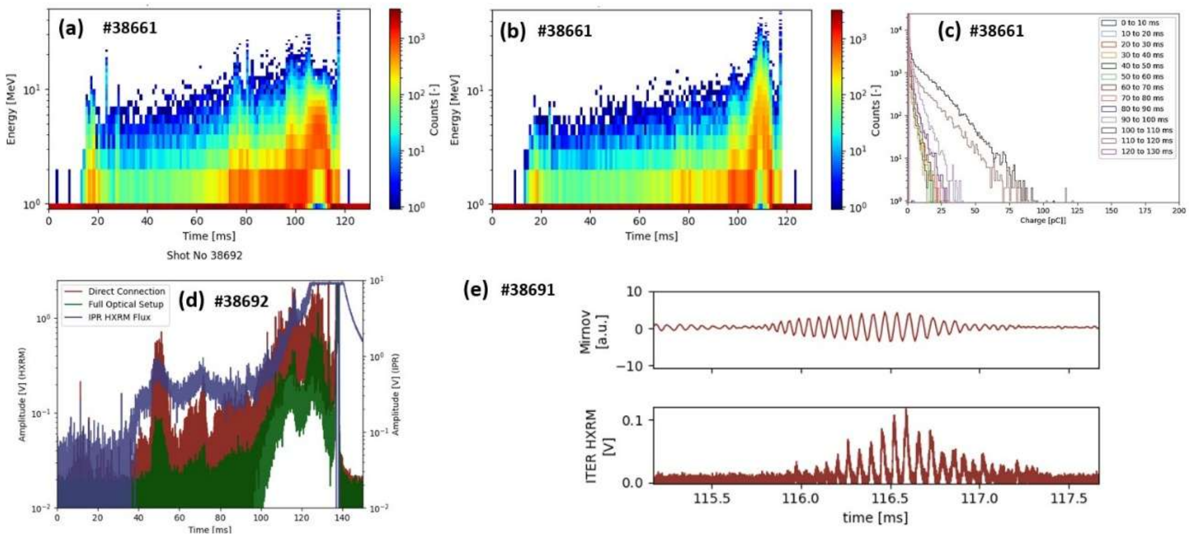

Figure 2: Time and energy resolved count rate registered by HXRM systems during a plasma discharge in conventional configuration in (a) and prototype ITER HXRM in (b), (c) Evolution of HXR spectra at every 10 ms time interval during a plasma discharge, (d) Comparison of the current mode PMT signal output during a plasma discharge for conventional configuration and for the prototype ITER HXRM, (e) HXR signal modulation during MHD activities.

Several RE physics studies have been performed using the prototype ITER HXRM, including the effects of plasma density, gas puffing, and MHD activities on HXR signals (e.g. Fig. 2(e)), in both counting and current modes, as well as changes in the HXR spectrum during these activities. The time evolution of runaway electron distribution functions is to be reconstructed as the next step using a de-convolution algorithm [5], demonstrating the capability of the designed system. Finally, a comparison was made with preliminary RE simulation results obtained using the PREDICT code [2] for different plasma scenarios.

Disclaimer: *The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.*

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