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Neutron fluctuation measurements on TFTR

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Measurements of fluctuations in the neutron yield are made on the tokamak fusion test reactor (TFTR) with plastic scintillators. Light from the scintillators is coupled through acrylic rods or fiber-optic cables to photomultipliers operated in current mode. Discrimination against hard x rays is accomplished through comparison with the signal from a $\text{ZnS}(^6\text{Li})$ scintillator. These measurements are useful in studies of deuterium pellet deposition, of the acceleration of beam ions during major radial compression, and of MHD instabilities. Techniques for measuring the neutral beam density profile and Q_{di}^{equiv} using neutron fluctuation measurements during pellet injection also have been proposed.

Neutron fluctuation measurements using plastic scintillators have been used to study the sawtooth instability on the Princeton Large, Torus (PLT) tokamak² and the fishbone instability on the Princeton Divertor Experiment (PDX) tokamak.² Detectors similar to the PDX detectors were installed on the tokamak fusion test reactor (TFTR) during the 1985 experimental run period (Fig. 1). The principal advantage of these detectors relative to epithermal neutron detectors is their frequency response (typically limited by counting statistics to ≤ 100 kHz). On TFTR, scintillator measurements have been used to study sawteeth, the acceleration of beam ions during major radial compression,^{3,4} and deuterium pellet deposition.⁵ The primary motivation for neutron fluctuation studies on TFTR is to study any plasma instabilities that expel deuterium beam ions. A poloidal array of scintillators (Fig. 2) is presently under fabrication for installation during the 1986 run period. This array of scintillators, together with a sixth detector positioned 108° around the machine toroidally, will be used to assist in mode identification of any observed instabilities. The array is located beside the pellet injector so it will also be useful for ongoing studies of pellet deposition. Additionally, it is planned to use fast neutron measurements during pellet injection to improve the accuracy of determination of the equivalent fusion Q_{di}^{equiv} [$Q \approx (\text{fusion power out})/(\text{heating power in})$] and to measure the beam-ion density profile.⁶

Technically, the fluctuation detectors are relatively simple. The scintillators are plastic (e.g., Bicron BC-400). Fast neutrons incident on the plastic produce recoil protons that generate photons in the blue (~ 420 nm). Roughly 2000 photons are produced per recoil proton. The scintillators are thick enough (typically 4 in.) to stop most incident fast neutrons ($\lambda_{mp} \approx 5$ cm) but kept thin to minimize spurious counts from any gammas that originate around the scintillator. To achieve good counting statistics, it is desirable that the scintillator be close to the plasma and of large area (typically 3–5 in. diameter). To date, we have used uncollimated detectors positioned just outside the vacuum vessel midway between toroidal field coils. It is estimated that most of the neutrons detected on TFTR have undergone little scattering.⁴ From the scintillator, the light passes through a conical transition piece to a light guide that carries the light to a

shielded photomultiplier situated in a region where the stray magnetic fields are ≤ 500 G. In order not to degrade the signal-to-noise ratio of the system, the light guide ideally should transmit more than ~ 4 photons to the photomultiplier per recoil proton, which implies a collection efficiency of $\geq 2 \times 10^{-3}$. On PDX straight 2-in. diam acrylic rods in approximately 3.5-m lengths were used as light guides. These rods have a photon collection efficiency of about 10^{-2} . In most locations on TFTR, straight light guides are not feasible so fiber-optic cables will be used instead. An additional consideration on TFTR is resistance to radiation damage. Fused silica fibers can withstand high radiation lev-

FIG. 1. Neutron fluctuation detectors on TFTR during 1985. Two scintillators [one plastic and one $\text{ZnS}(^6\text{Li})$] were mounted at the midplane adjacent to the pellet injector. A third plastic scintillator with a fiber-optic bundle was situated on the midplane 108° away from the pellet injector.

FIG. 2. Poloidal array of neutron fluctuation detectors being installed on TFTR in 1986. The photomultipliers are located in the basement beneath TFTR. One fiber-optic bundle is fused silica; the others are plastic. A sixth plastic scintillator is situated 108° degrees toroidally from the poloidal array.

els⁷ but they are expensive. Initially, we have purchased one $\frac{1}{2}$ -in. diam bundle that will have a collection efficiency of about 2×10^{-3} . The other bundles will be $\frac{5}{8}$ -in. diam bundles of ESKA plastic fibers with a collection efficiency of only about 7×10^{-5} . The plastic fibers will suffer only minor radiation damage during deuterium operation but will have to be replaced for tritium experiments. During the 1985 run period, a prototype detector was operated with a glass fiber-optic bundle that had a collection efficiency of about 9×10^{-5} . As expected, this detector had a signal-to-noise ratio about five times smaller than the detector with the acrylic rod.

X-ray discrimination is achieved by comparing the signal from the plastic scintillator to the signal from a $\text{ZnS}(^6\text{Li})$ scintillator (2 in. of wax is placed in front of the scintillator to moderate the neutrons) that is mounted beside the plastic

FIG. 3. Signals from adjacent scintillators during a TFTR discharge with appreciable runaway electrons. A deuterium pellet was injected at 1.8 s.

FIG. 4. Signals from adjacent scintillators during an instability at high β on the PBX tokamak. Two tangential beams injected 2.7 MW.

scintillator assembly. An example of hard x-ray contamination of the signal is shown in Fig. 3. In this discharge, the hard x-ray production peaked at 1.2 s then gradually fell until a pellet was injected at 1.8 s, which resulted in a large jump in the signal (as runaway electrons collided with the pellet). In contrast, the time evolution of the signal from the $\text{ZnS}(^6\text{Li})$ scintillator (Fig. 3) followed closely the neutron production measured by a fission detector; no spike was observed when the pellet was injected. A second example of hard x-ray discrimination is shown in Fig. 4. During neutral beam injection in the PBX tokamak, instabilities sometimes expelled beam ions from the plasma, resulting in a rapid drop in neutron emission. Occasionally, a burst of hard x rays was observed at the peak of the instability; the burst was typically 30 times smaller on the $\text{ZnS}(^6\text{Li})$ detector. [Because of its low neutron sensitivity, the relative sensitivity of $\text{ZnS}(\text{H})$ scintillators to x rays is about the same as for plastic scintillators.] Also evident in Fig. 4 is the superior time resolution obtained using plastic scintillators. Because it measures moderated neutrons, the $\text{ZnS}(^6\text{Li})$ scintillator has a time response of about 0.2 ms. The intrinsic response of a NE102A plastic scintillator is $\sim 0.1 \mu\text{s}$.

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