Scintillation detector for escaping alphas and tritons in TFTR

S. J. Zweben

Princeton Plasma Physics Laboratory, Princeton, New Jersey 08544

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A diagnostic for escaping charged fusion products is presently being tested on tokamak fusion test reactor (TFTR). It consists of a 1 × 1-in. ZnS scintillator screen located inside a movable probe at the bottom of the TFTR vacuum vessel. The alphas or tritons hit the scintillator screen where they create visible light pulses which are fiber-optically coupled to photomultiplier tubes and/or an intensified video camera for recording and analysis.

INTRODUCTION

Alpha particles are expected to be very well confined in tokamaks when the plasma current is above 2–3 MA.[1] However, this expectation is based on a neoclassical confinement model which may not be valid for these high-energy particles.[2] In tokamak fusion test reactor (TFTR), the plasma current can be varied from 0.5 MA (at which point there should be very poor alpha confinement) to 2.5 MA (at which point there should be almost complete alpha confinement), thus allowing a rather rigorous test of neoclassical confinement theory.

Since the diagnostics for confined alphas are quite difficult,[3] it seems appropriate to concentrate on simpler escaping alpha diagnostics for the first tests of the neoclassical confinement model. Escaping alphas are defined as those which leave the plasma and arrive at the chamber wall, where they can be directly detected through various standard techniques. A knowledge of the escaping alpha flux, along with a knowledge of alpha creation rates from the associated neutron production, should be sufficient to check most of the neoclassical predictions.

This paper describes an escaping alpha diagnostic which is based on the detection of scintillation light which is produced when the alphas hit a phosphor screen, typically ZnS (such as is used in cathode-ray tubes). Previous proposals for the use of this technique in tokamak have been made by Hendel and Seiler,[4] Miley and Kislev,[5] and Elevant[6]; however, this paper describes the first actual implementation of this idea in a tokamak.

The main motivation for using a scintillation detector rather than the conventional surface barrier detector is that the latter cannot be operated in the harsh neutron environment of the tokamak first wall. In addition to their radiation resistance, scintillation detectors have the following advantages with respect to other potential escaping alpha detectors: high detection efficiency ($\lesssim 1$ scintillation/alpha), good time resolution ($\sim 50\,\mu$s for ZnS), good spatial resolution (~ 10-μ grain size), multichannel capability through optical imaging of the scintillator screen, low electromagnetic interference when optical coupling is used, and good high-temperature and high-vacuum compatibility. Furthermore, there are many possible phosphors, any of which can be rather inexpensively coated onto a given substrate. On the other hand, the principle disadvantage of this method is the lack of intrinsic energy resolution, which is caused by the small and variable graininess of the phosphor, such that a monoenergetic alpha source produces a broad spectrum of scintillation pulse heights. This disadvantage can be overcome to some extent by using foil transmission or magnetic separation[7] for energy resolution.

I. DESIGN OF THE PROTOTYPE DETECTOR FOR TFTR

A schematic view of the first prototype detector for TFTR is shown in Fig. 1. The detector is configured as a probe which is inserted into the bottom of TFTR through a valve. The "head" or top of the probe contains the collimating apertures, the thin foils for blocking plasma light, and the scintillation screen itself. Behind the scintillation screen is a coherent optical conduit which carries the scintillation light

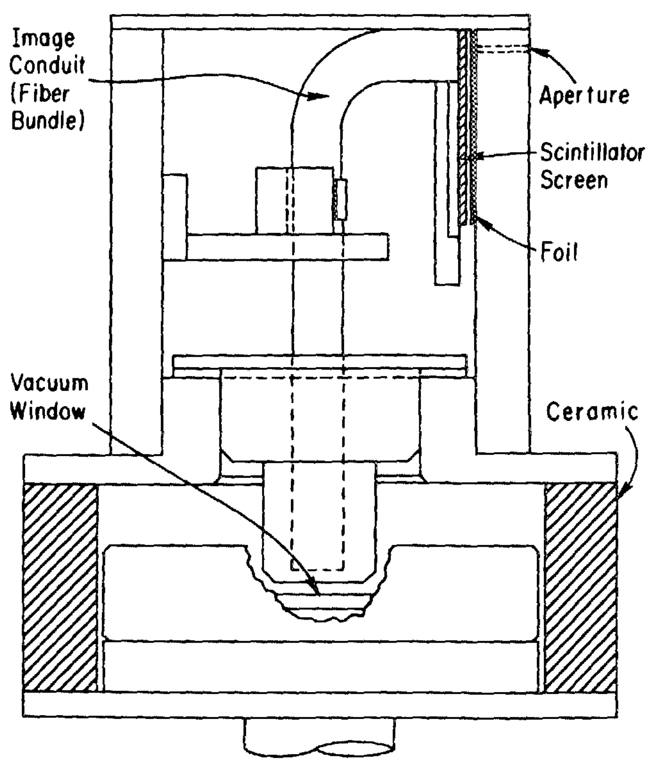

FIG. 1. Prototype alpha detector for TFTR. The alphas enter through the apertures and create scintillations which are fiber-optically coupled to the detection system.

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to the vacuum window located at the bottom of the probe head. The image at the bottom of the optical conduit is focused onto a set of individual optical fibers located outside the main vacuum system. From there the optical fibers pass down the probe shaft, go through a secondary vacuum seal, and terminate about 15 m away at the detector rack, which is located behind the neutron shield around TFTR.

Some details concerning the components of this prototype are as follows:

(a) Collimating apertures: the first prototype has four individual detector channels in a square array, consisting of three 1-mm-diameter collimating apertures and a fourth channel with no aperture for background checks. No attempt at pitch angle resolution is made in this first prototype, which is expected to see only particles at about 90° pitch angle.

(b) Foils: Behind two of the three open apertures is a 3-μ-thick aluminum foil used to block plasma light and low-energy plasma particles from the scintillator. The 3.5-MeV alphas will lose about 0.6 MeV in passing through this foil, while the 1.0-MeV tritons will lose about 0.3 MeV. Behind the third aperture is a 21-μ foil used to stop alphas and tritons but to pass 3-MeV protons.

(c) Scintillator: For the first prototype we are using a ZnS(Ag) phosphor with grain size $\sim 10\mu$ and thickness ~ 6 mg/cm^2. This is the "blue screen" P11 phosphor used in high-speed ocsilloscopes, which gives about a factor of 2 more signal than the "green screen" P31 phosphor when used with a standard photomultiplier tube. Typical scintillation efficiency should be $\sim$10%–20% light output/kinetic energy input, i.e., approximately 10^5 blue photons per 3.5-MeV alpha.

This phosphor was coated onto a thin glass plate, and then overcoated with $\sim$5000-Å vapor-deposited aluminum. The aluminum provides extra plasma light protection and also increases the scintillation light output by reflection. Alternate phosphors include ZnO (P24) and YtAl(Ce) (P46), which both have faster time constants but lower scintillation efficiency.

(d) Optical Conduit: For the first prototype this component is made from a 1/4-in.-diam coherent glass fiber bundle with 100-μ fiber size. The normal plastic-clad or jacketed quartz fibers could not be used, since no plastics are permitted in the TFTR vacuum system. The glass bundle can be bent to shape after heating; however, the glass is not radiation resistant and so must eventually be replaced by quartz fibers or a relay lens/mirror system.

(e) Lens: The imaging lens is 1.2-cm-diam coated glass with a focal length of 0.9 cm, aligned for $\times 1$ magnification.

(f) External fiber optics: The four fibers in the first prototype are 1000-μ quartz core fibers with silicone cladding. Large core fibers are necessary in the pulse counting mode in order to collect the maximum number of photons for each scintillation event, given the finite focusing spot size of the thick lens.

(g) Photomultiplier detectors: Four standard PM tubes (RCA 6342A) are used to monitor the four channels of the first prototype.

(h) Video camera: In addition to the PM tubes, the four channels can be monitored by an intensified video camera with a sensitivity of 10^{-5} fc (XYBION MODEL ISG-01). This camera will eventually be used to accommodate the expansion of the system to several multichannel detectors, all of which can be viewed in parallel. The fibers are proximity focused at the camera's photocathode, and the image is recorded on videotape for later analysis.

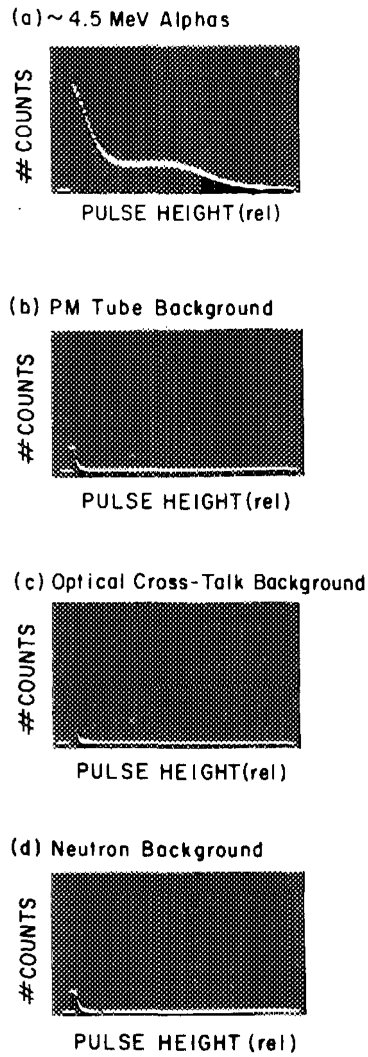

FIG. 2. Bench tests of the TFTR prototype detector showing (a) pulse-height spectrum of alphas from an ^{241}Am source, (b) pulse-height spectrum of the PM tube noise background, (c) pulse-height spectrum of optical cross talk in the presence of the alpha source in (a) in an adjacent channel, (d) pulse-height spectrum due to a neutron source of flux approximately equal to the alpha flux in (a).

II. PERFORMANCE OF THE PROTOTYPE DETECTOR

The performance of this detection system was checked using an ^{241}Am source, which emits alphas of $\sim$4.5 MeV (after passage through a gold coating). This source produces $\sim 10^6$ alphas/cm^2 s, i.e, $\sim 10^4$ alphas/s into each of the 1-mm detector apertures. The resulting pulse-height spectrum as seen by one of the PM tubes is shown in Fig. 2(a). The spectrum is broad, as expected for this scintillator, but the signals are easily detectable over the background PM tube noise spectrum, which is shown in Fig. 2(b) for the same counting interval as for Fig. 2(a). The maximum pulse height for the 4.5-MeV alphas is ~50 times the height of single-photoelectron noise in the PM tube. For normal operation in the pulse counting mode a discriminator level can be set at about 0.5-MeV equivalent energy with almost no background (~1 background count/min), or at ~0.25-MeV equivalent for a 1 count/s background, as illustrated for the latter case by the discriminator setting in Fig. 2(b). This system should thus be capable of detecting the relatively low-energy tritons, which will have an energy of about 0.7 MeV after passage through the foil.

In Fig. 2(c) is a pulse-height spectrum for the background channel (which is blocked by a thick foil) obtained when the alpha source is producing scintillations in two other channels similarly to Fig. 2(a). There is an increased background of low-energy counts due to slight cross talk in the optical system; however, this background can be eliminated at a discriminator setting of ~0.5 MeV.

In Fig. 2(d) is a background spectrum similar to Fig. 2(b) but taken with a 1000-mCi PuBe neutron source located about 1 cm in front of the scintillator. For this neutron flux of $\sim 10^6$ n/cm^2 s there is no perceptible increase in the background pulse spectrum, as expected for the very small cross section for stopping neutrons in this thin scintillator.[8]

The scintillation light can also be monitored in the flux mode either by the same PM tubes or by the Xybion camera. This will be particularly useful at high count rates for alphas or tritons, and also for 3-MeV proton detection for which the expected pulse heights are $\leqslant$0.5-MeV equivalent energy (due to the large range of these particles compared to the scintillator grain size). The Xybion camera is sensitive enough to image the light from the ^{241}Am test with $\sim 10^4$ alphas/s.

III. FIRST TESTS IN TFTR

The prototype described in Secs. I and II has recently been installed in TFTR. It will first be used to check *in situ* the neutron and gamma backgrounds, and then will be inserted to a point 112 cm below the plasma center (the plasma radius is 83 cm). At this point the expected flux of tritons into a 1-mm detector aperture is $\sim 10^5$ t/s at a plasma current of 1 MA, and $\sim 10^3$ t/s at a plasma current of 2 MA, both evaluated for a total thermonuclear reaction rate of 10^{15} D/D reactons/s. This first test should provide a direct check of the current dependence of triton confinement according to neoclassical theory.

Since 1.0–MeV tritons have almost identically the same gyroradius and neoclassical confinement as 3.5-MeV alphas, this test will also implicitly give information on alpha confinement. However, direct tests will also be made using the 3.7-MeV alpha created during D/^{3}He operation, which should be easier to measure due to its larger scintillation light output.

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