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INTRODUCTION

Long-burn D-T discharges in ITER will rely on spectroscopy for real-time monitoring and control of impurity production and He-ash retention, for basic machine protection and for ion temperature measurements. Data will only be reliable if the integrity of calibration of the diagnostics is preserved. This is difficult in the hostile environment inside the vacuum vessel. The optical properties of mirrors and windows may be seriously degraded due to irradiation by neutrons and γ-rays, bombardment by energetic particles and deposition of eroded material. Also, radiation-induced absorption and luminescence may compromise signal transmission through quartz or fused silica windows.

As sensitive components such as detectors will be located outside the biological shield, the optical systems will be distributed. Hence, maintaining alignment will be paramount when various supporting structures are moving differentially. The use of fibres can ease the problem at optical wavelengths. However, because of the long lengths used, near the machine fibres will exhibit the same effects when irradiated as quartz windows.

The two tokamaks that have operated with a D-T mixture under conditions closest to those envisaged in ITER are JET and TFTR. However, in ITER a number of key parameters will be enhanced by significant factors, eg neutral particle fluxes by ~5, neutron fluxes by ~10, pulse lengths by ~100 and neutron fluences by ~10,000. On JET and TFTR, a number of methods were implemented to maintain reliable spectroscopic calibration. Several of these techniques, and other approaches, are reviewed here. They fall into two categories: those which eliminate the effects or reduce them to a tolerable level and those which employ in-situ monitoring of optical performance or compensation techniques.

1. ELIMINATION OR REDUCTION OF DELETERIOUS EFFECTS

Due to the intense neutron radiation, all optical systems will incorporate shielding labyrinths, in which mirrors are used both as a plasma-facing element and to fold the optical path to the window. This path will be enveloped by radiation-absorbing material. The first mirror will be subject to intense particle bombardment which can degrade the optical performance of all but the most resilient materials, [1]. Single-crystal mirrors of Mo or W retain high optical quality even after erosion of a layer several μm thick. However, the deposition of a thin film of contaminant of thickness 10 nm, or more, can seriously reduce reflectivity. Of particular concern is the divertor region, where there is potential for a high rate of deposition of material eroded from the target plates and walls. Screening techniques will be required, eg the use of baffles and shutters, and, probably also, cleaning techniques.

Material deposited on windows used for Thomson scattering measurements at JET has been periodically removed using the system's ruby laser, [2]. Three or four pulses of energy density 0.25 J/cm^2 cleaned a window area the size of the laser beam, before it was directed to a fresh area using the steering mirror. By this means, all six collection windows could be cleaned in a few hours. The technique could be useful for cleaning windows on ITER. It also has potential in removing deposition from first-mirror surfaces.

At the vacuum boundary, although viewing the plasma indirectly, windows will still be subject to intense irradiation unless there is adequate shielding. In the wavelength range ~400nm to 5μm, by careful shielding and by suitable choice of material, eg KU1 fused silica, radiation-induced absorption and luminescence can be reduced to tolerable levels. At shorter wavelengths these effects could still pose a problem. However, induced absorption can be significantly reduced by heating the windows to temperatures of 350 - 600^{o}C, [1,3], to enhance the rate of thermal annealing.

At JET, a 20m-long beam line directly coupled to the vacuum vessel is used to make measurements in the X-ray, VUV and visible regions, [4]. Inside the mirror box, Figure 1, the available aperture is divided into three parts by two suitably-angled mirrors; the third part of the beam passing through undeflected. One mirror deflects part of the beam onto a telescope coupled via an optical fibre to a grating spectrometer, covering the spectral range 350 – 700nm. The second mirror, at grazing angle 15^{o}, reflects another part to a VUV spectrometer, covering the range 10 – 110nm. Finally, the undeflected part of the beam enters an X-ray spectrometer, covering the range 0.1 – 10nm. As none of the detectors views the plasma directly, each can be shielded from ionising radiation. The long path length ensures negligible deposition on the mirrors and diffractors. Branching-ratio cross-calibration from visible to VUV is straightforward due to the common sight line. If used on ITER, tritium must not contaminate the system to the extent that the detectors are poisoned. A regular gas purge coupled with strong differential pumping is a potential solution.

Because of the long lengths employed, in the vicinity of the machine optical fibres are particularly sensitive to radiation. Nevertheless, the degree of induced absorption can be minimised by an appropriate choice of materials. A good candidate is an all-silica fibre with low levels of chlorine and OH as contaminants, comprising a pure silica core and a cladding doped with fluorine. During D-T operation at TFTR, the induced absorption in such a fibre with aluminium jacket was reduced by ~100 by heating to 400^{o}C, [5]. This technique was applied to diagnostic fibres at JET during the 1997 D-T campaign. Recent studies show that the resistance of this fibre type can be further improved by ~10 by loading it with hydrogen, [6]. Other approaches worth exploring to reduce the build-up of induced absorption are radiation hardening of fibres prior to installation and in-situ photobleaching, [7,8].

A dynamically-stabilised optical link between torus hall and roof laboratory has been used at JET, [9]. A laser maintained alignment of the four-mirror relay system over the 30m path from the torus window to two grating spectrometers, through a labyrinth in the biological shield. Using this arrangement the low wavelength cut-off is ~200nm, compared with ~400nm for an optical fibre link. Such a scheme has potential for use on ITER.

2. IN-SITU MONITORING OF CALIBRATION OR COMPENSATION TECHNIQUES

At TFTR, a second sacrificial window in the form of a shutter was used to monitor transmission changes due to deposition; periodically the shutter was opened to record the signal through the clean window only, [10]. This technique has potential for use on ITER.

Radiation-induced luminescence is little affected by heating optical fibres to 400^{o}C, at most the reduction is ≤10%, [5]. On JET, the luminescence added to plasma signals in the irradiated relay fibres has been compensated by recording extra signals from ’blind’ fibres. These follow the same path as the relay fibres but have no view of the plasma, [11]. Where constraints prevent adequate shielding, luminescence from an ITER window could be similarly compensated, ie two adjacent windows are used with one blind to plasma emission.

A novel proposal from JET for in-situ calibration of the CXRS diagnostic is by means of beam emission spectroscopy. A beam of energetic helium atoms is injected at periodic intervals during the plasma burn. This can be achieved by doping a positive ion source, used to produce a deuterium beam for diagnosis, with up to 10% He without altering the injector operating parameters. Interaction of the plasma electrons with the helium in the beam causes emission at discrete wavelengths over the spectrum of interest for CXRS, Figure 2. As the beam emission is Doppler shifted it is not blended with the background emission from helium ash. Also, the helium lines from the beam emission are well separated from the common impurity lines arising from charge exchange reactions. As long as the electron density profile is reproducible shot-by-shot, BES can be used to monitor changes in performance of the optics of the CXRS system. Changes in the transmission characteristics of other sight lines with identical geometry, which do not view the beam, may be monitored by comparing the visible bremsstrahlung signals with that in the BES channel.

SUMMARY AND CONCLUSIONS

The harsh environmental conditions foreseen in ITER have been outlined and their impact on spectroscopic measurements described. A number of methods to preserve the integrity of diagnostic calibration have been reviewed. Careful system design with appropriate choice of materials can maintain adequate optical performance over periods that are relevant to the ITER experimental programme.

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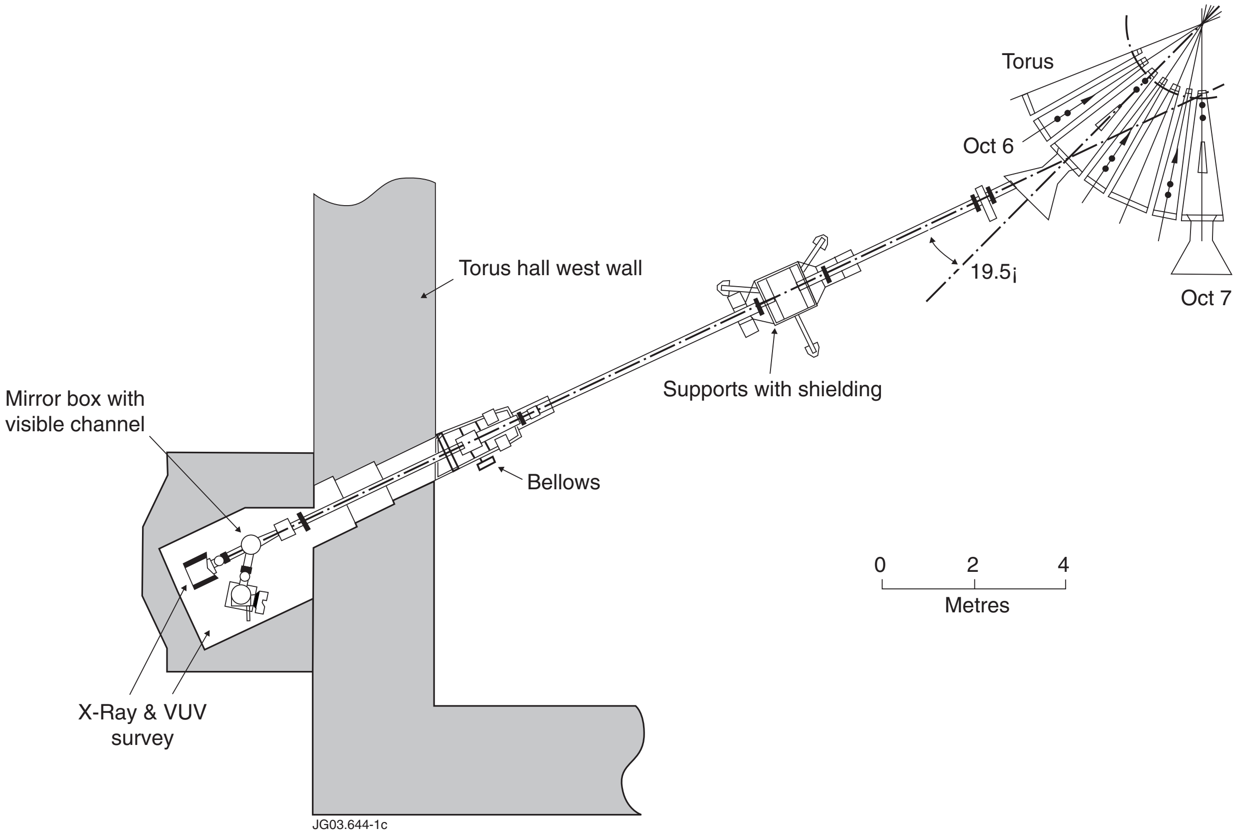

Figure 1: The JET Vacuum Spectroscopy Beamline

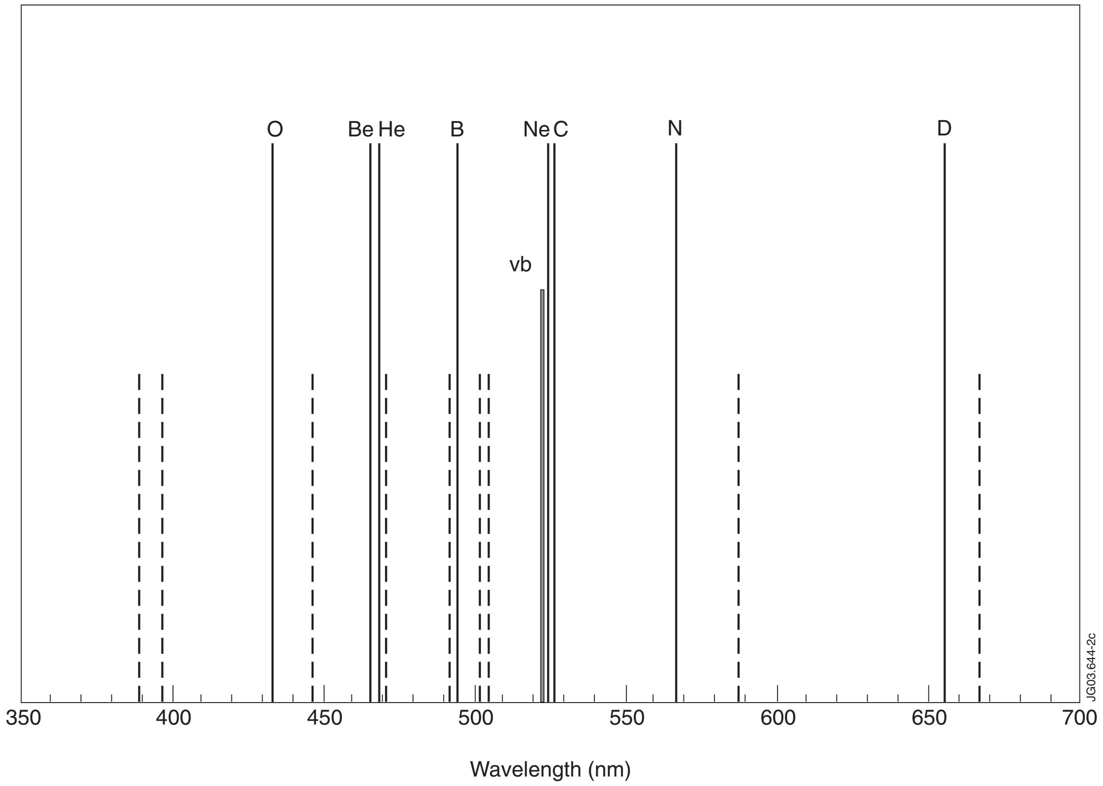

Figure 2: He lines from BES (dotted) and lines from CXRS (solid)