FLASHLAMP CLEANING OF PLASMA-FACING TILES FROM THE JET TOKAMAK

J Paul Coad[1*], Glenn Counsell[1], Michael Forrest[1], David Hole[2] and JET EFDA contributors[**]

[1]EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, U.K.
[2]University of Sussex, Brighton, BN1 9QH, U.K.

ABSTRACT
Photon cleaning of divertor tiles using a flash-lamp to ablate deposited films has been successfully demonstrated *in-situ* in the JET tokamak using remote handling equipment. Detailed trials with the flash-lamp have also been carried out on tiles removed from the JET vessel. Tritium is released by high power pulses (150-300J), and thick films are visibly thinned by ablation. However, analysis shows not all the film is removed. At power densities below the ablation threshold, out-gassing is limited to the outermost ½ to 1 μm.

KEYWORDS **Tokamaks, tritium retention, de-tritiation, photon cleaning**

1. INTRODUCTION

The next Step in the development of fusion power is to build a power plant scale device (ITER). ITER is currently planning to use carbon target tiles in the divertor, and modelling suggests that carbon-based deposits will accumulate that trap tritium [1]. In order to limit the build-up of tritium to less than the allowable in-vessel limit, it will be necessary to remove such accumulations periodically. One way of removing the tritium is to either desorb the gas, or to ablate the deposits *in situ*, with a laser [2] or high power light source. In this work we report trials of the photon cleaning of divertor tiles by flash-lamp *in-situ* in the JET tokamak using remote handling equipment. Treatment of divertor tiles and poloidal limiter tiles has also been carried out in the Beryllium Handling Facility under controlled conditions.

2. EXPERIMENTAL

Photon cleaning has been developed as a low impact, environmentally friendly cleaning technique in the aerospace industry. Photon cleaning relies on applying intense but brief pulses of light to the contaminated surface. Depending on the wavelength of the light and the duration, intensity and frequency of the pulses it is possible to 'fine tune' the cleaning process (e.g. for sublimation, photo-acoustic shock, photo-chemical decomposition etc.) to optimise removal of a specific contamination whilst minimising or eliminating damage to the underlying substrate material.

Lasers (transmitted through fibre optics) have the advantage of being able to reach small spaces, but the disadvantage of providing only a small spot. Since early 2001, UKAEA Fusion has been exploring an alternative light source for photon cleaning based on the ultra-intense flash-lamps used for 'pumping' large laser cavities. These flash-lamps are capable of delivering several hundred Joules of UV, visible and IR radiation in periods of less than 100 μs. When focused onto an area of several square centimetres, they can provide a power density comparable to that of a laser, up to several GW/m^2, but over a much larger area than a typical laser spot. A flash-lamp based light source is therefore expected to enable a significantly improved cleaning rate over laser-based approaches. The use of flash-lamps for photon cleaning is already established in several non-fusion, specialist cleaning roles such as nuclear decommissioning, cleaning the wings of surveillance aircraft and art restoration.

The flash-lamp used at JET was based on a rapid charging capacitor bank to supply the flash-lamp discharge current at a maximum of 500 J, 5 Hz. At lower energies the maximum frequency can be increased up to 25 Hz, subject to a peak continuous power output of 2.5 kW. An integral 18 kV series trigger for the flash-lamp is provided and the power supply is equipped with a computer control system allowing full remote control over all functions. Under testing with the full length 18 m umbilical cable and impedance matched 500 J flash-lamp, the discharge pulse half-width was ~140 μs and maximum power had to be limited to 300J to avoid break-down during charging of the capacitor bank. The flash-lamp had a 6 mm discharge diameter and 150 mm discharge

[*] Tel: +44 1234 464478, Fax: +44 1235 464554, e-mail: Paul.Coad@jet.uk
[**] See appendix of J.Pamela et al., Fusion Energy 2004 (Proc. 20th Int. Conf. Vilamoura, 2004) IAEA, Vienna (2004)

length. A variety of optical techniques for focussing the flash-lamp were evaluated using ray tracing software. In an optimally focussed system the target area illuminated by the flash-lamp would be 900 mm^2. The modelling was thus aimed at maximising the flash-lamp energy deposited into this 900 mm^2 region whilst ensuring as even an energy distribution as possible.

During the 2004 shutdown of the JET tokamak (for fitting of extra diagnostics, heating systems, etc) the JET Remote Handling (RH) equipment was used for in-situ trials with the flash-lamp. The RH mascot gripped the flash-lamp head, which was connected to the power supplies and water cooling systems outside the vessel via an 18 m umbilical. The experiments were performed in air, and a vacuum cleaner was positioned near the head to minimise the likelihood of any dust produced during the ablation of the deposits spreading around the torus.

Tiles at the inner wall of the divertor, where some of the thickest deposits are found in JET [3], were treated. The movement of the flash-lamp head over the tile surface was controlled from the RH Control Room, whilst the pulsing of the flash-lamp was synchronised to the movements. Flash-lamp powers of up to 300J and for up to 150 pulses were applied to different areas. A continuous sweep over the tile surfaces with the lamp pulsing at between 1 and 10 Hz was also performed. The divertor tiles were in JET for the period 1998-2004, and plasmas run in JET during that period were normally fuelled with deuterium (D, or ^2H). A small amount of tritium (T, or ^3H) is generated by fusion reactions. Also, in 2003 up to100% T fuelling was used for a few JET discharges to study isotopic transport. Thus, the H isotopes trapped in deposits in the vessel (which are mostly located at the inner divertor) are predominantly D, but with a T admixture of the order of 1%. Analysis of either D or T can thus be used to evaluate the efficacy of the photon cleaning.

The intention was then to use the lamp at reduced power to de-tritiate different tiles by out-gassing, without ablating the surface films. The tiles selected were poloidal limiter tiles near the outer mid-plane of the vessel that had been in JET since 1994, thus including operations in 50% deuterium-50% tritium fuelling mixtures in 1997. However, after setting up the remote handling equipment, a failure of the water cooling system for the lamp curtailed operations. The trials on the poloidal limiters, together with the planned trials on divertor tiles that could not be accessed *in situ* by the cleaning head, were thus carried out manually in the Beryllium Handling Facility (BeHF) after removing the tiles from the vessel.

3. Results and discussion

Figure 1 is a photograph of the inner divertor tiles after *in situ* cleaning with the flash-lamp. The effect of the treatment is clearly visible on the tiles. Most of the deposited film on the divertor tiles appears to have been removed by ablation from the areas exposed to repeated pulses at 300J, since the fibre planes of the underlying CFC structure are visible in these regions. However, as will be shown later for the tiles treated in the BeHF, Ion Beam Analysis (IBA) using the Nuclear Reaction Analysis (NRA) technique shows that deuterium is absent from the outermost $^1/_2$ to 1 μm, but is at a similar level to the untreated regions beyond that depth.

Following the *in situ* cleaning trials many of the divertor tiles were removed from JET to allow fitting of diagnostics. More detailed trials were conducted on a removed base divertor tile in the BeHF, and this tile was then analysed by IBA, and compared with an untreated tile that was adjacent to the treated tile when in the torus. On these tiles, part of the surface that is shadowed from exposure to the plasma in coated with a thick (~100 μm [3]) film of deuterated carbon. Another region is exposed to the plasma and has a powdery layer ~200 μm thick [3]. Deuterium concentrations across the treated and untreated tiles, determined by NRA, are shown in Figure 2.

Figure 1. Photograph of the inner divertor tiles after cleaning with the flash-lamp

Although much of the shadowed region (distances along the tile from 0 to 50 mm in Fig. 2) was treated, and the underlying fibre planes have become visible, there only seems to be about a 20% reduction in the D content. However, NRA only analyses a surface layer about 7 µm thick. Furthermore, Figure 3 (an expansion of the characteristic D peak in the NRA spectrum) shows most of the reduction in the peak is at the left-hand side of the feature, which is the signal from the outermost ½ to 1 µm at the surface. (Note that the normalised D signal from the treated tile in Fig. 3 is increased by 16% to show the different peak shape more clearly.)

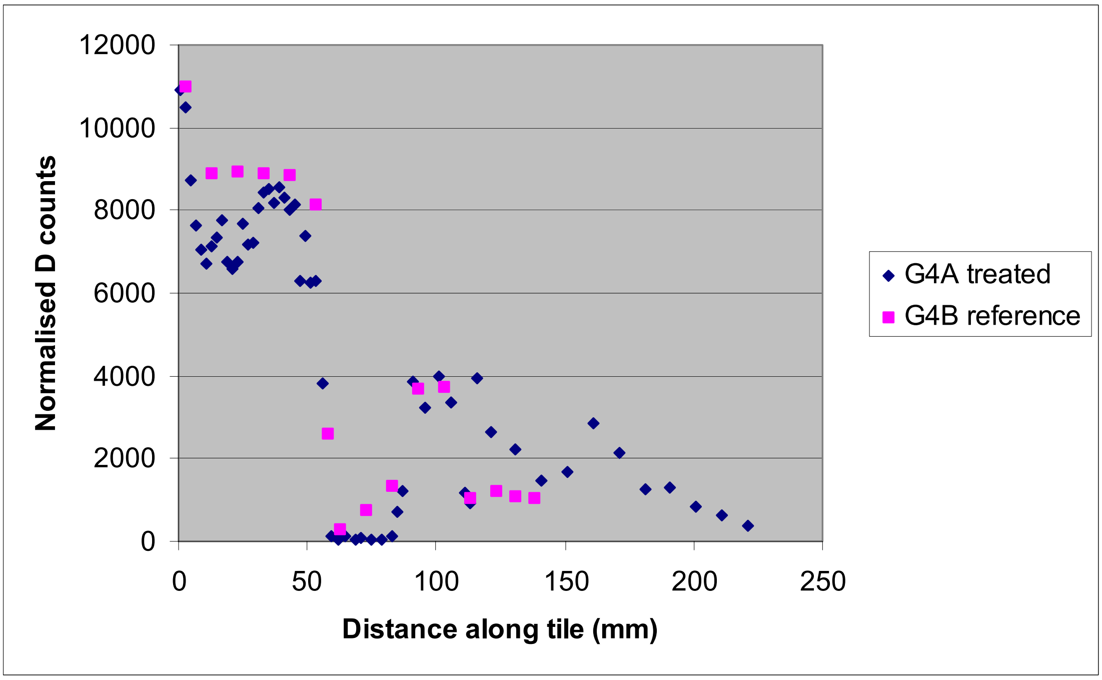

Figure 2. D levels along a photon treated divertor base tile compared with an untreated (reference) tile.

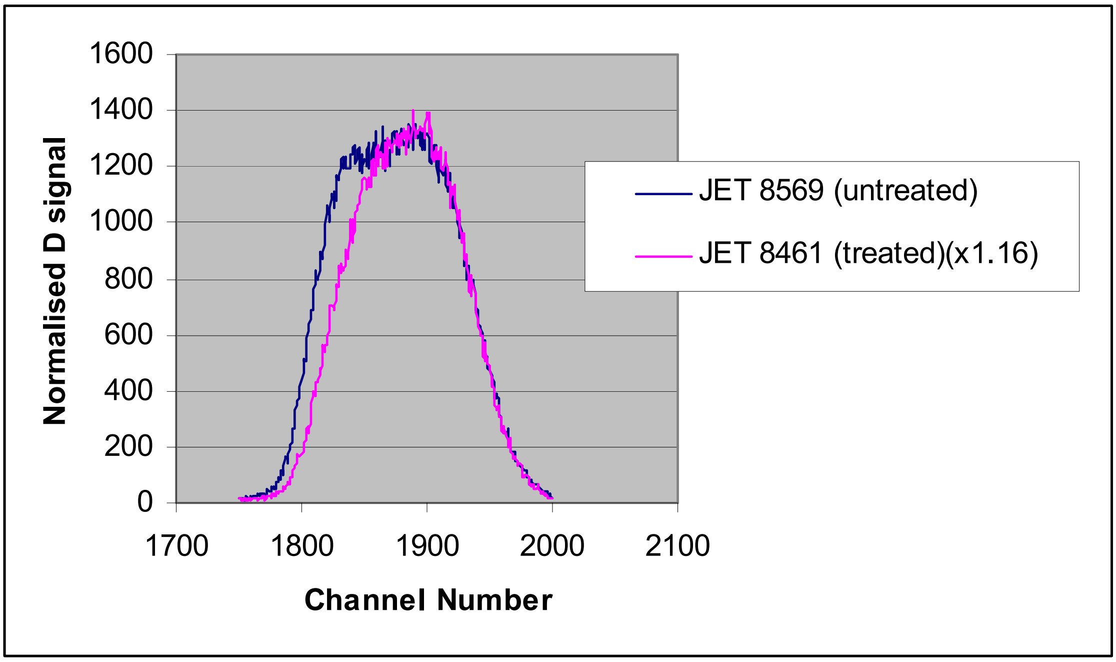

Figure 3. Details of the D features from the NRA spectra from points 23 mm from the edge of the treated and untreated tiles (The normalised D signal from the treated tile is increased by 16% to show the different peak shape more clearly.)

Material clearly was ablated/out-gassed from the divertor tile during treatment with the flash-lamp, because large quantities of T were seen at the exhaust duct from the BeHF. Thus it may be that although at least 7 µm remains of the deposited film (through which the outline of the fibre planes can be seen), most of the original ~100 µm may have been ablated. Total T analyses, and SIMS profiling measurements, are in hand to determine just how much of the film has been ablated.

Extensive treatment was applied to the powdery deposit that had been exposed to the plasma (~60 to 80 mm from the tile edge in Fig. 2). The D content in this film is anyway low due to heating by the plasma, but following treatment was reduced much further. It is believed that most of this powdery deposit has been removed by the photon cleaning, but this can only be confirmed by T analysis and SIMS profiling.

During treatment of the poloidal limiter tiles at lower power no T release was observed, nor any visible changes to the tile surfaces. NRA shows that there are deposited films towards one end of the tiles of a few microns in thickness. However, Figure 4 shows no overall reduction in D content, indeed the levels are greater for the treated tiles, but this is probably a statistical variation between tiles, which do not have such exact symmetry with respect to the plasma as do the divertor tiles.

Once again, though, the surface $^{1}/_{2}$ to 1 µm is depleted of D, as shown in Figure 5. At high power, each flash-lamp pulse ablates a thin layer from the surface, but because of the short duration of the power flux, only a depth <1 µm in advance of the ablation front is heated enough to desorb deuterium. At lower power, when there is no ablation, only the same thin layer is heated at each pulse. The penetration of the heat pulse into the surface is determined by the pulse length. The pulse lengths in this work were made as short as possible, in order to be able to focus the available power into a short enough period to reach the ablation temperature. In order to de-tritiate to a greater depth a longer pulse length will be required.

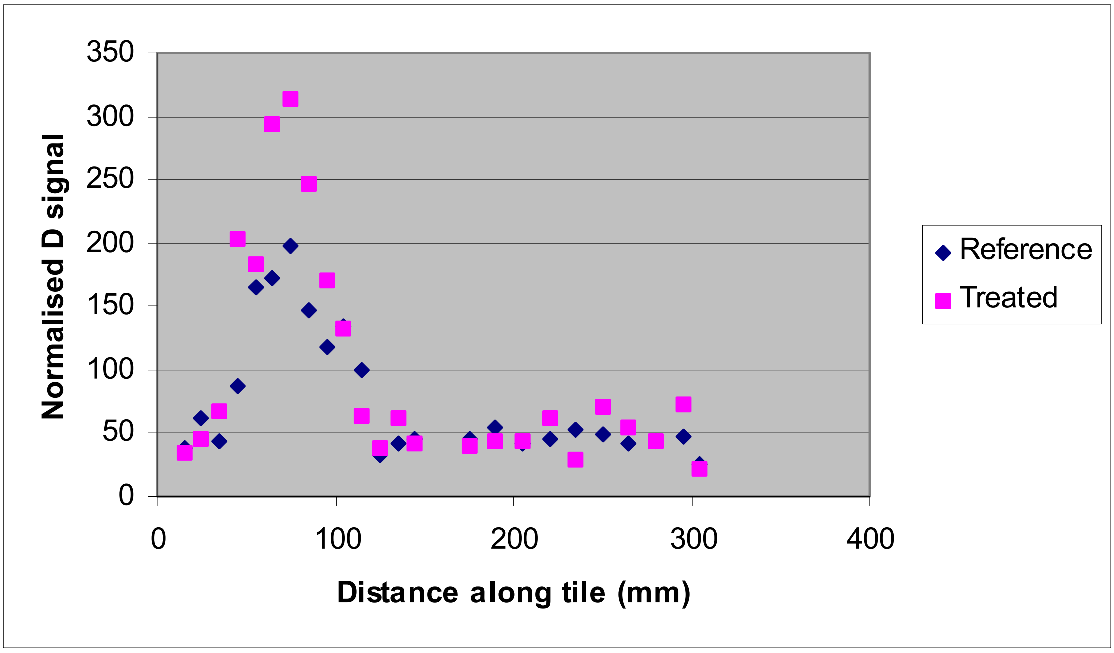

Figure 4. Variation in D level along a treated poloidal limiter tile and an adjacent untreated tile, and a cross-section of a tile on a similar scale

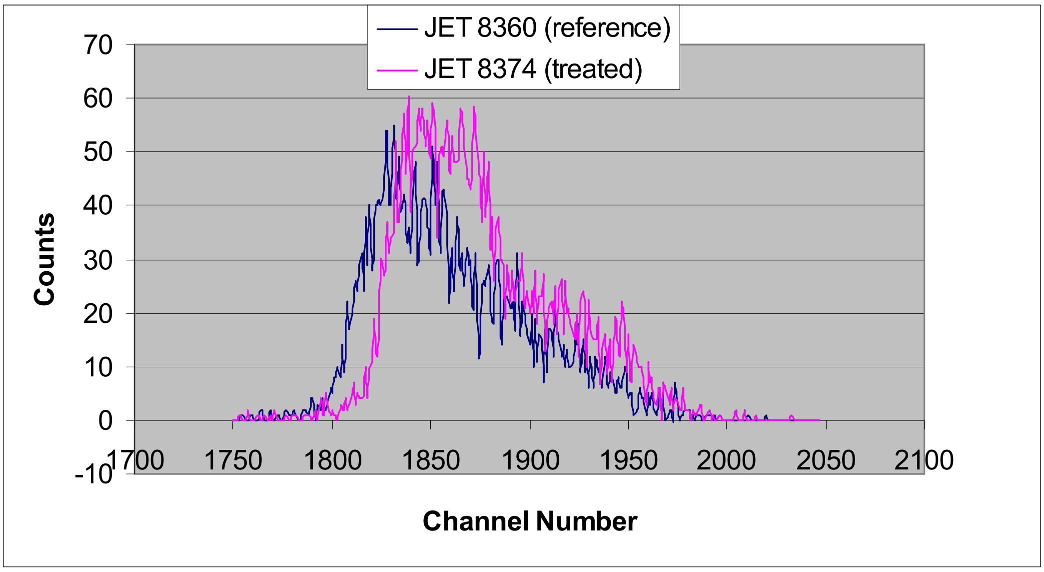

Figure 5. NRA D features recorded 55 mm along poloidal limiter tiles (see Fig.4) showing that the signal from the lowest channels is greatly reduced following treatment

4. CONCLUSIONS AND FUTURE WORK

The flash-lamp was successfully operated *in-situ* in JET under remote control, and delivered pulses of up to 300J in ~140 μs with a repetition rate of ~1Hz. At the highest energies (>150J) deposited material was clearly ablated from tile surfaces, since there were visible changes to the divertor tiles following treatment and large releases of tritium were observed during the photon cleaning of the divertor tile in the BeHF. However, Ion Beam Analysis shows that although deuterium is absent from the very surface ($^1/_2$ to 1 μm in depth), for the next ~6 μm at least it remains at a similar level to the untreated regions, so not all the film is removed. Further analysis by SIMS and of total tritium content should elucidate matters.

The poloidal limiter tiles were treated at lower energies (<100J), and this was expected to desorb hydrogen isotopes rather than ablate the surface films. The surface $^1/_2$ to 1 μm was again depleted of D, but there were no other changes visible. At high power, each flash-lamp pulse ablates a thin layer from the surface, but because of the short duration of the power flux, only a depth <1 μm in advance of the ablation front is heated enough to desorb deuterium (which requires ~700K). At lower power, when there is no ablation, presumably only the same outer $^1/_2$ to 1 μm layer is heated at each pulse.

One future development for the photon cleaning is to re-configure the power supply so that a lower power can be delivered for a longer period. This should allow the lamp to be used for de-gassing from the surface to a greater depth than seen in these trials.

Studies are also in hand for comparative tests using lasers, and to see if the deposits can be removed by baking in oxygen. Since carbon-based deposits are the principle trap for tritium, EFDA also plans to equip JET with a beryllium wall and a tungsten divertor (an option for ITER) to demonstrate the resulting reduction in T-retention.

5. ACKNOWLEDGEMENT

This work has been conducted under the European Fusion Development Agreement and is partly funded by EURATOM and the UK Engineering and Physical Sciences Research Council

6. REFERENCES

[1] G Federici, C H Skinner, J N Brooks, J P Coad, C Grisolia, A A Haasz, C S Pitcher, J Roth, W R Wampler and D G Whyte, Nuclear Fusion, **41** (2001) 1967-2137

[2] C H Skinner, C A Gentile, N Bekris and J P Coad, 44th APS Conference on Plasma Physics, Orlando, USA, Nov 2002.

[3] J. P. Coad, P L Andrew, D Hole, S Lehto, J Likonen, G Matthews, M Rubel and contibutors to the EFDA-JET work-programme, J Nuclear Materials **313-316** (2003) 419-423