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First tritium operation of ITER-prototype VUV spectroscopy on JET

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Results from tritium operation of the VUV survey spectrometer on the JET tokamak are presented. The instrument, located outside the biological shield and offset from a direct plasma 1-o-s for maximum radiation protection, was operational during the trace tritium campaign (TTE) at JET. No discernible increase in detector background noise levels were detected for total neutron rates of up to 1×10^{17}/s, demonstrating the shielding effectiveness of the configuration. Some tritium retention in the detector microchannel plate was measurable, but has not hampered subsequent operations. As a reference the unshielded detector of a close-coupled XUV instrument was operated during TTE (the spectrometer itself was valved off from the JET vessel). This was exposed to neutron fluxes of $\sim 10^9/\mathrm{cm}^2$ s, in excess of those predicted for the corresponding instrument on ITER ($10^7 - 10^8/\mathrm{cm}^2$ s). A corresponding increase in the background level equivalent to ~5% of the detector dynamic range was measured. This demonstration of the shielding effectiveness of the SPRED configuration during DT operations, coupled with the tolerable noise levels measured in the SOXMOS detector, give confidence in the planned implementation of such instruments in ITER. [DOI: 10.1063/1.1781756]

I. INTRODUCTION

The JET VUV survey spectrometer (grazing incidence, McPherson model 251 SPRED-110–1100 Å) has been successfully operating with H, D, and He plasmas since 1998, using a geometry similar to that planned for the equivalent instrument on ITER.[1] The SPRED was relocated from the torus hall to a bunker outside the biological shield and offset from a direct plasma 1-o-s by 30° using a spherical, gold coated mirror (Fig. 1). Operation of the SPRED during the 2003 JET Trace Tritium Experiment (TTE) demonstrates a VUV spectrometer in such an ITER relevant configuration with DT plasmas. The only previous DT operation of a VUV spectrometer was in TFTR,[2] where the instrument was close coupled to the torus and required massive local shielding to maintain tolerable noise levels during high power DT pulses. Figure 2 shows the increased shielding achieved during D operations by relocating the SPRED. Equivalent signals from an XUV instrument (extreme grazing incidence, Schwob-Frankel, SOXMOS, 10–340 Å) which remains in the torus hall are shown. Both spectrometers have microchannel plate (MCP)/phosphor detectors fiber-optically coupled to identical Princeton Instruments Diode array cameras. The MCP coatings are different for each instrument to optimize for the differing wavelength coverage: CuI for the SPRED, and MgF_2 for the SOXMOS. A P-20 phosphor is utilized in both cases. With both instruments in the torus hall the background noise levels (derived by sampling a line-free spectral region) closely follow the neutron rate. After relocation the SPRED signal shows little or no correlation with the neutron rate.

[a)]See Appendix of paper by J. Pamela *et al.*, Fusion Energy 2002 IAEA, Vienna.

II. PERFORMANCE OF SPRED DURING DT PULSES

Tritium was injected either by neutral beams (NBI) or gas puffing. The TTE produced a total neutron yield of 4×10^{18} 14 MeV and 5.5×10^{18} 2.45 MeV neutrons and introduced ~380 mg of tritium by gas puffing. Figures 3 and 4 show the SPRED spectrum during tritium beam injection and tritium gas puffing pulses. There is no discernible increase in the noise levels in either case. The tritium beam injection pulse shown had the highest peak neutron yield of the TTE campaign. Data were taken with the main torus valve closed to further assess the effect of neutron induced noise. In Fig. 5 the background levels from 12 gas puffs and 17 T NBI pulses are separately summed. No correlation between the background noise levels and the neutron rate is observed, further indicating the effectiveness of the shielding (the average correlation coefficient was 0.01 ± 0.05 for the higher neutron yield tritium beam injection pulses). The slope in the

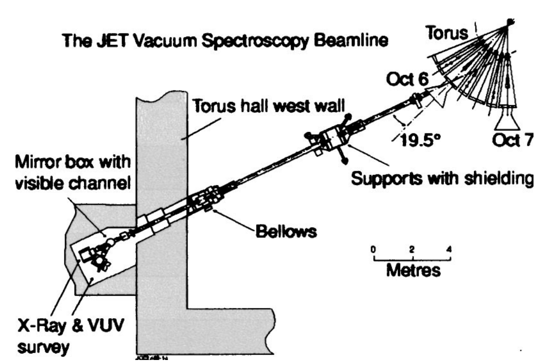

FIG. 1. Location of JET VUV survey spectrometer (SPRED). The bunker is shared with a Bragg rotor x-ray spectrometer and a visible channel.

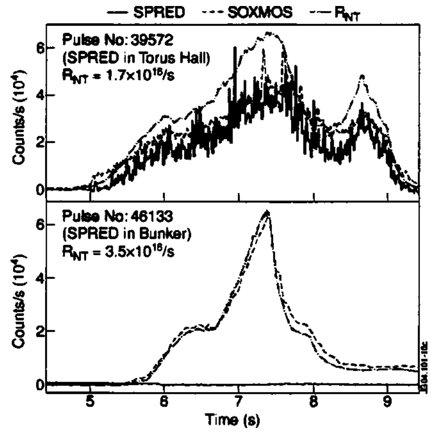

FIG. 2. Background noise reduction in SPRED after relocation to bunker. Peak R_{NT} values are quoted.

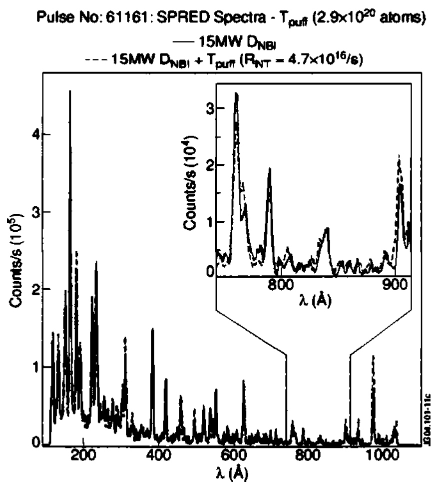

FIG. 3. SPRED spectra from T puff pulse showing no increase in background noise even at the time of the peak neutron rate.

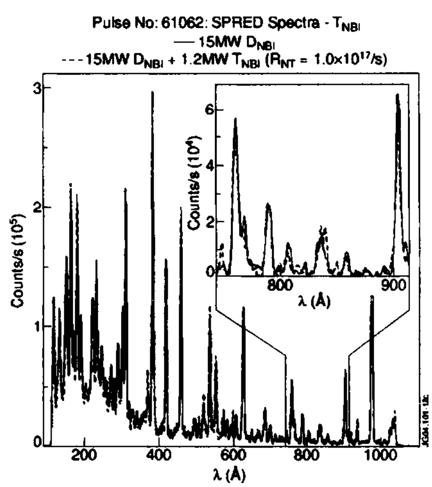

FIG. 4. SPRED spectra from T beam injection pulse showing no increase in background noise even at the time of the peak neutron rate (which was the highest for TTE).

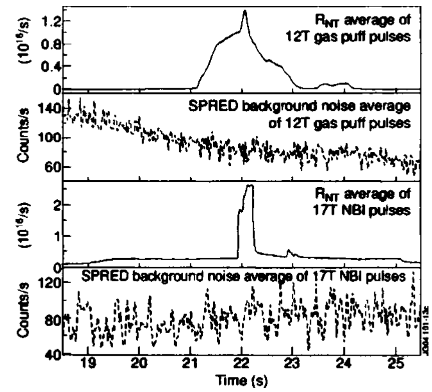

FIG. 5. SPRED background noise levels during tritium gas puffing and beam injection with instrument valved off from the torus.

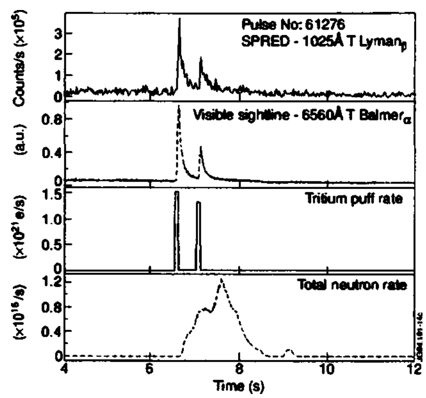

FIG. 6. Spectroscopic monitoring of tritium gas injection by both visible and VUV instruments; in this case a double T puff.

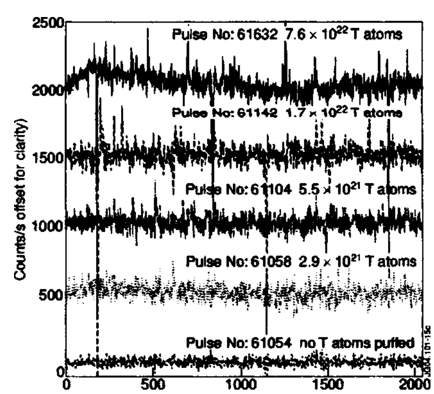

FIG. 7. Progression of tritium retention in the SPRED detector. Data From successive dry runs are shown. Total T atoms puffed prior to each pulse are indicated. Pulse 61632 occurs after TTE had concluded.

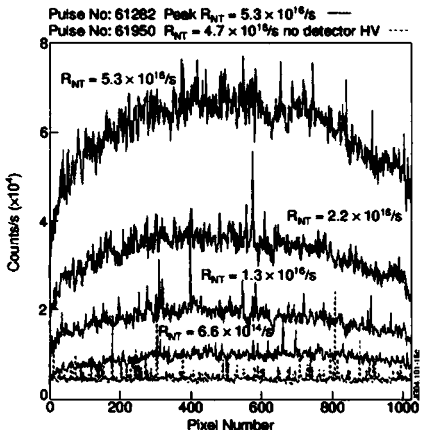

FIG. 8. Increase in SOXMOS detector background with neutron yield. The lowest trace has no detector high voltage applied and shows the noise level in the diode array alone.

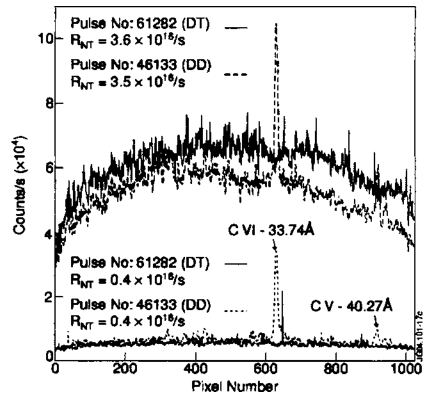

FIG. 9. Effect of 2.5 MeV DD neutrons (torus valve open) and 14 MeV DT neutrons (torus valve closed) on the SOXMOS background levels for equivalent total neutron rates.

background of the T puffing case is a slow signal decay due to saturation of the diode array just before the data were taken.

III. TRITIUM RETENTION IN SPRED SPECTROMETER

The tritium gas injection module (GIM) is located at the torus end of the SPRED beamline. This allows monitoring of the tritium source function via both visible and VUV spectroscopy (Fig. 6). However an estimated 1.9% of the injected tritium is pumped by the beamline, and $\sim 1 \times 10^{-4}\%$ enters the SPRED chamber (the entrance slit to the SPRED is an effective vacuum limiting aperture). During the entire TTE this is equivalent to $\sim 8 \times 10^{16}$ atoms entering the SPRED chamber. After the first tritium puffs contamination of the SPRED MCP detector was evident from β-decay events as shown in Fig. 7. In these dry run pulses (test pulses with no fueling) the increase in these events is evident as TTE progresses (and hence the total amount of T puffed increases). It should be noted that the data from each pulse (apart from the pre-T puffing pulse) has been offset in the Y axis for clarity (500 counts/s for each successive case). The average background level did not increase as a consequence of the T puffing. The total noise level from T contamination after TTE was still insignificant relative to the normal spectral line intensities (Figs. 3 and 4) and has not hampered subsequent operations. The data from pulse 61632 were taken just a few days after the TTE had finished. Comparing this with the data from the most recent JET pulse, some four months later, there is no obvious decrease in the number of β-decay events, giving no indication at present of any reduction of the amount of T retained in the instrument. During the 2004 shutdown period it will be possible to measure surface contamination in the SPRED, and a pump/purge of the chamber is planned to try and reduce the T inventory in the instrument. Further work needs to be done to assess the issue of tritium retention in the ITER case.

IV. NEUTRON INDUCED NOISE IN SOXMOS SPECTROMETER

The close-coupled SOXMOS XUV spectrometer (valved off during TTE) has a similar detector setup to the SPRED and hence provides a reference for detector noise levels. Local neutron fluxes at the detector of $\sim 10^{-9}/\text{cm}^2$ s were well in excess of those expected at the equivalent instrument position on ITER $(10^7 - 10^8/\text{cm}^2\ \text{s})$.[3] The relationship between the total neutron rate and the flux at the detector position is given by:[4] $R_{NT}(DT) = 1 \times 10^{16}/\text{s} \equiv 7.0 \times 10^8/\text{cm}^2$ s, and $R_{NT}(DD) = 1 \times 10^{16}/\text{s} \equiv 3.5 \times 10^8/\text{cm}^2$ s. In Fig. 8 the rise in background level in the SOXMOS detector, which is linear with increasing neutron rate, is shown. The shape of the background level is due to the nonuniformity of the MCP/phosphor gain across the detector. The largest measured background level was around 5% of the total dynamic range of the detector, for a neutron rate $R_{NT} = 5.3 \times 10^{16}/\text{s} \equiv 3.7 \times 10^9/\text{cm}^2$ s. Removing the applied high voltage to the detector MCP/phosphor enables the induced noise in the diode array camera alone to be distinguished (Fig. 8, lower trace). Comparing the TTE data with a similar DD neutron yield pulse (Fig. 9) shows little dependence on neutron energy. Previous work on JET[5] showed a factor of ~ 7 reduction in the background level for such an instrument by installing 15 cm stainless steel shielding around the detector. This additional level of shielding should be possible to implement for ITER.

ACKNOWLEDGMENTS

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[5] R. C. Wolf *et al.*, JET Report JET=P (95) 34 (1995).