JET–CP(98)50

Diagnostic Experience during Deuterium–Tritium Experiments in JET, Techniques and Measurements

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1. INTRODUCTION

During 1997, JET was operated for an extensive period using a DT mixture. One of the areas of concern in the preparation for this phase was the interface of diagnostic systems to the vacuum vessel in a tritium environment. The experience obtained on diagnostic systems and the methods of measurement of the tritium concentration are described in this paper.

2. DESCRIPTION OF SYSTEMS AND PREPARATIONS FOR DTE1

All diagnostics which have a direct interface to the main JET vacuum can be isolated by a valve. They were fitted with tritium compatible turbo molecular pumps and backing pumps. Their exhaust was routed to the Active Gas Handling System (AGHS) where the tritium can be recovered [1].

All items on the torus which can lead to a significant leak were required to have double containment. By this means, if the primary side develops a leak there is a secondary barrier to prevent ingress of air and egress of tritium. All windows, and a majority of bellows and feedthroughs, have a double barrier, making a total of ~330 interspaces. Each interspace is backfilled with 500 mbar of neon to provide a trace gas indication on the torus mass spectrometer in case of a leak. Pressure gauges are also fitted, the pressure dropping to 0 bar when the leak is to the primary side and rising to 1 bar when the leak is on the secondary side of the interspace.

Periscopes are used at JET to view the main plasma and divertor emissions in the visible light region. The light is transmitted through fibres to detecting equipment outside the torus hall. Fibre loops and blind fibres running right up to the optical heads of several diagnostics were used to measure the transmission losses and the luminescence produced in these fibres by the neutron bombardment [2-4]. The aluminium clad, wet fibres used showed no detectable long term transmission losses provided they were kept at ~250ºC. A special electrically heated hose with thermocouples was used, which kept the fibres at 250ºC. Experiments during the DTE1 campaign with unheated fibres show only a small luminescence signal due to the relatively large distance to the plasma (fig.1). Nevertheless, the unheated fibre shows clearly increasing transmission losses in the course of the pulse reaching a maximum of ~0.7% towards the end of the pulse. At room temperature it takes about 7s until the transmission losses have reduced to about 0.2%.

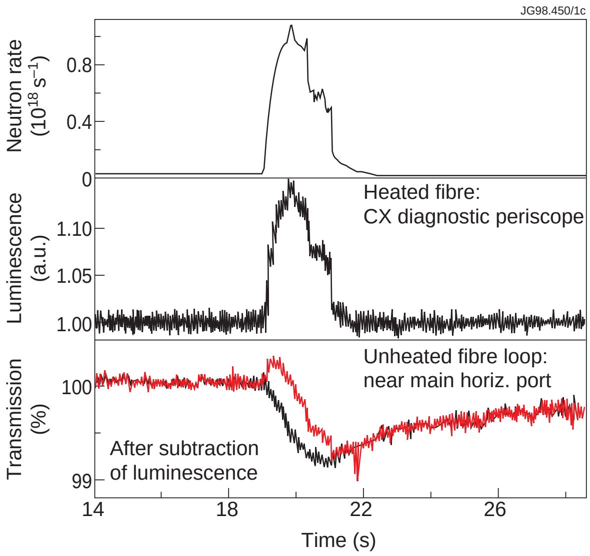

Fig.1. Neutron induced luminescence and transmission losses in an optical fibre for a JET tritium pulse

It was essential to provide a wide-angle view of the plasma that would survive throughout the DTE1 campaign. The anticipated neutron damage to the camera for the DTE1 campaign was about 120 times greater than in one of the preceding DD campaigns. A black and white CID (charge injection device) camera, more resilient to radiation effects, replaced the colour CCD camera normally used. This CID camera remained operational throughout DTE1, though there was a significant increase in dark current by the end of the campaign. For DTE1 the two monochrome video cameras which formerly viewed the divertor directly through a window were rearranged to view via a mirror.

The In Vessel Inspection System (IVIS) at JET consists of four cameras and accompanying lights in alternate octants. During DTE1 one camera was left on the machine to investigate the effect of the radiation. The IVIS camera is retracted during plasma operation behind a valve and the fluence of neutrons to the camera is low. After DTE1 the camera was found to be in good working order.

Extra shielding was installed on a number of diagnostic systems to cope with the increased neutron production. The Neutral Particle Analyser (NPA) is equipped with channeltrons, sensitive to neutrons. The channeltrons lose gain when their count rate exceeds 10^6 s^{-1}. The analyser was, therefore, placed in a shield tank consisting of polythene (180 mm), lead (70 mm) and stainless steel (6 mm). To suppress neutrons that enter the instrument directly through the beam line, an additional collimator-like shielding tube (720 mm long stainless steel) was installed. Useful NPA measurements have been obtained throughout DTE1 (section 3).

The front-end electronics for the soft X-ray diagnostic are positioned in the Torus Hall close to the tokamak. Radiation damage effects were first seen during the initial D-T runs in the summer of 1997 in the cubicle closest to the JET tokamak (some 7.5 m from the plasma centre). A number of optical components in the electronics already showed clear radiation damage effects. Although a number of opto-isolators were used, only certain types were seen to fail. In August 1997 the cubicle closest to the tokamak was removed and replaced with a 0.5 m thick concrete block to shield the cubicle behind. This reduced the neutron flux by over two orders of magnitude and as a result the electronics in this cubicle survived through to the end of DTE1, at which time the effects of radiation damage were just starting to become apparent.

For technical and practical reasons a number of diagnostic systems were removed or isolated from the tokamak before the start of DTE1. More than 300 fibres associated with these diagnostic systems were withdrawn behind the biological shield. Eight vacuum ultra-violet spectrometers were removed to prevent damage to their sensitive detector assemblies utilising channel plates.

3. MEASUREMENTS OF TRITIUM

In DTE1 the plasma tritium fraction covered a range of concentrations, including those relevant for a fusion reactor. Several diagnostic measurements of the plasma tritium fraction have been used.

The D-T ratio in the plasma scrape-off layer can be determined by spectroscopic observation of the Balmer D_α and T_α lines. Telescopes collect light from several lines-of-sight looking into the divertor and heated optical fibres transfer this light to the spectrometers in the Diagnostic Hall. The close proximity in wavelength of the lines ($\Delta\lambda$ ~ 0.06 nm) makes line separation difficult at low ratios of T/D, because of blending due to Doppler broadening.

The blending problem can be overcome by using a Penning discharge to analyse the spectrum of the gas exhaust from the divertor; the low temperature of the discharge leads to a reduced Doppler broadening. The pressure range over which measurements can be made is ~10^{-5} to 2 10^{-3} mbar. Over this range, the light intensity from the Penning discharge varies linearly with the pressure of the gas (or gas mixture) being studied. The light from three Penning discharges in the subdivertor volume is collected by 4 telescopes.

The JET low energy NPA has a line of sight that points horizontally along the major radius to the plasma axis. The charge exchange neutral flux exiting the plasma is measured as a function of energy by means of electrostatic selection after stripping of the neutrals. Mass selection is achieved by time of flight measurements using a delayed coincidence technique. This has a high noise rejection capability and the possibility of registering three different masses simultaneously. An example of the results from the NPA is given in fig.2 for different energy channels.

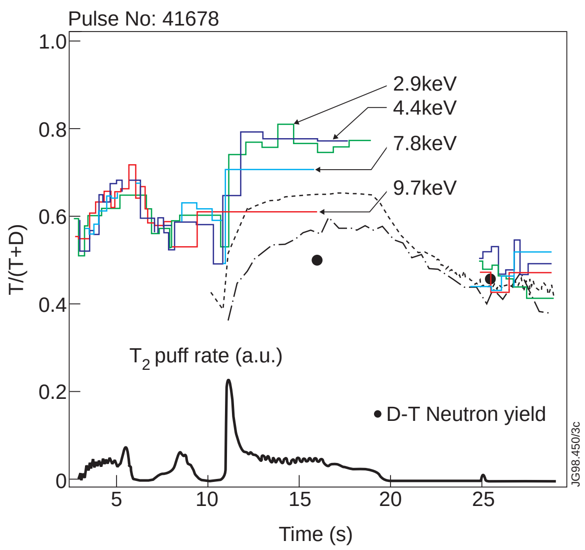

Fig.2. Measurements using the NPA (solid lines), edge spectroscopy (dashed line), spectroscopy of the Penning gauge (dotted line).

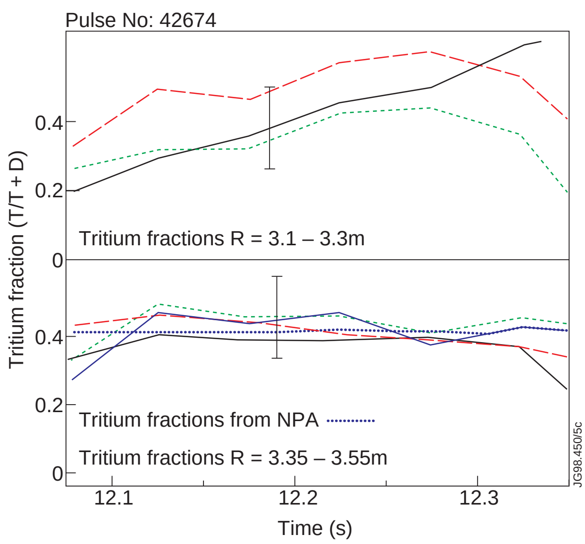

Fig.3. Tritium fraction versus time for 7 radial positions as measured by active Balmer α charge exchange spectroscopy.

The only direct approach to core isotope measurements is active Balmer α charge exchange spectroscopy, which measures the hydrogenic charge exchange lines at several radial positions. The tritium fraction derived from the fitted charge exchange fluxes for a plasma with a nominal tritium fraction of 40% is shown in fig.3. The accuracy of the measurement, derived from errors on the fitted charge exchange components, is better than 30%.

The primary measurement of the neutron emission intensity from JET discharges is provided by a set of fission chambers. It is not possible to measure directly a small flux of DD or TT neutrons in the presence of a significantly stronger flux of DT neutrons. The count rate information from the 19 lines-of-sight of the neutron profile monitor has been used to compute the total volume-integrated 14 MeV neutron-strength of the plasma. The integral of the emissivity is seen to agree closely with the global neutron emission deduced from the fission chamber measurements. For low tritium concentrations the tritium to deuterium density ratio can be derived by measuring the ratio of 14 MeV to 2.5 MeV neutron emissivities. For greater tritium concentrations, the 14 MeV neutron emission is indicative of the tritium concentration but detailed plasma modelling is required to extract the desired information (fig.4).

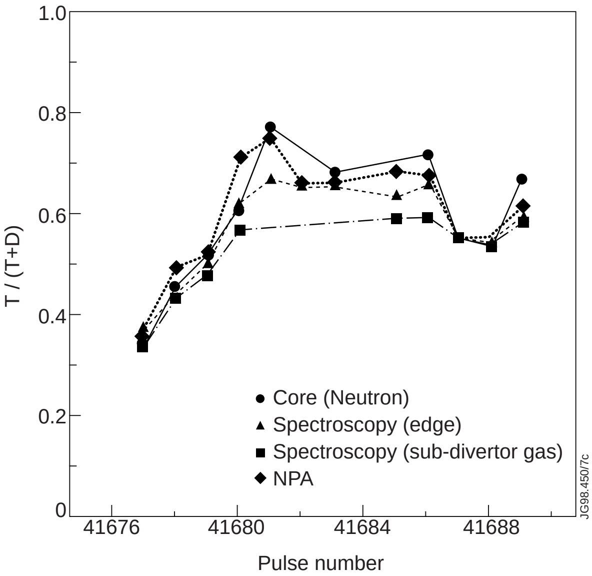

Fig.4: Tritium concentration measured late in a discharge, for the first series of high tritium concentration discharges.

Results at JET have clearly indicated that hydrogenic isotope mixtures as derived from spectroscopic measurements at the plasma edge do not necessarily represent the mixture established within the confined plasmas region. The NPA results do not provide local data and details of the radial profile need to be derived by a different technique. A concerted effort encompassing a combination of passive emission spectroscopy, active charge exchange spectroscopy, beam emission spectroscopy and neutral particle analysis is being undertaken[5]. The validity of each method is assessed essentially by modelling the total neutron yield making use of either flat or radially changing tritium concentration profiles and deriving the thermal-thermal and beam-thermal neutron rates. For trace tritium experiments [6] the modelling of the observed neutron profile signals [7] allows the indirect deduction of local concentrations.

At very high concentration levels this method fails due to the insensitivity of the total neutron yield to variations in the tritium target concentration. Any change in the tritium concentration leads to a redistribution of neutrons between the beam-thermal and thermal-thermal processes.

4. CONCLUSIONS

The technical preparation of the diagnostics before the start of DTE1 was successful. The double-barrier windows and feedthroughs proved to be robust. During DTE1 three leaks were detected using the interspace system without the need to stop operating JET. The use of heated optical fibres has ensured that many diagnostics remained operational and continued to provide useful data. The CID camera survived and a wide-angle view of the plasma has been obtained in all pulses during and after DTE1. Extra shielding and the installation of a collimator-like shielding tube in the beam-line of the NPA have ensured its operation even during high performance discharges.

The methods used to measure the tritium fraction show good agreement for a wide range of ohmic discharges and show differences consistent with the expected tritium radial profiles in other discharges. The tritium fraction was measured with an accuracy between 1 and 5% depending on concentration and the method used. Simulation of the neutron profiles from other plasma parameters allow the deduction of time resolved tritium concentration profiles for lower tritium concentrations.

5. REFERENCES

[1] Lässer, R., et al., this conference

[2] Morgan, P.D., 'Irradation of optical fibres at JET through 14MeV neutron production', 17th SOFT, Rome, Sept 14-18, 1992, p.722

[3] Ramsey, A.T., *Rev. Sci. Instrum.* **66**, 971 (1995)

[4] Ramsey, A.T., Tighe, W., Bartolick, J., *Rev. Sci. Instrum.* **68**, 632 (1997)

[5] von Hellermann, M.G., et al., to be published

[6] Zastrow, K-D., et al., 'Particle transport in steady-state ELMy H-modes studied by trace tritium injection during the JET DTE1 experiments', 25th EPS, Prague, June 29-July 3, 1998, to be published

[7] Jarvis, O.N., et al., *Nuclear Fusion* **30**, 307 (1990)