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Operating Experience with the JET Tritium Neutral Beam Injector

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1. INTRODUCTION

The JET device is equipped with two Neutral Beam (NB) heating systems, each with eight Positive Ion Neutral Injectors (PINIs) arranged in four pairs, or "quadrants", each with its own ion deflection magnet [1]. Two configurations of PINI are used, for acceleration voltages up to 85kV and 160kV respectively, and there is presently one entire NB system in each configuration. Both injection systems were modified for compatibility with tritium operation in preparation for JET's first full DT experimental campaign ("DTE1"). This involved a number of mostly minor design changes to the beamlines (such as use of all-metal seals, provision of pumped interspaces, etc.) [2]. The most extensive modification was the implementation of a Tritium-Deuterium Gas Introduction System (TDGIS), which is supplied from the central Active Gas Handling System (AGHS) [3], and delivers gas via a single ground-potential inlet on each PINI. The TDGIS, its incoming gas transfer lines and the AGHS share a common secondary containment envelope. The design, commissioning and initial operating experience of the TDGIS have been described in detail in [4]. Only the 160kV injector system was commissioned in tritium; the 160kV PINIs had been designed to operate using the full capability of the high-voltage power supplies (160kV/30A) in tritium, and were expected to deliver up to 12MW tritium beam power to the plasma. The other injection system can deliver up to 13MW at 80kV/55A in deuterium. This combination of tritium and deuterium beams is the most favourable in terms of total delivered power and also results in a reasonable balance in the relative D:T beam fuelling rates at full power. The flexibility to allow individual beamline quadrants to operate in different gases (deuterium or tritium) simultaneously was included in the design of the TDGIS; the problem of interaction between adjacent beamline deflection magnets, when set for different beam masses, had to be addressed and is discussed in detail in an accompanying paper [5]. The option to commission the 85kV injector in tritium was retained only as a backup in case (for example) it was required to achieve satisfactory plasma D:T mixture control; it did not however prove necessary to exercise this option. In the present work, the experience obtained over the different phases of commissioning and operation is presented and discussed: specific tritium-related commissioning using deuterium; initial commissioning of tritium beams; routine tritium beam operation and beamline de-tritiation after DTE1. An intervention to repair the tritium beamline, which interrupted the programme described in this work, is discussed in a separate paper [6].

2. PREPARATORY BEAMLINE COMMISSIONING USING DEUTERIUM

After setting up the TDGIS operating pressures and adjustment of the gas flows to all the PINIs, an extended period of routine operation of both NB injectors using deuterium supplied by the AGHS/TDGIS took place. Operating procedures were rehearsed and refined, including accounting of all gas transfers using PVT measurements and re-generation of the NB cryo-pumps and recovery of the re-generated gas by the AGHS. Some operational difficulties were encountered and eliminated during this period. The most serious was the tendency for the pneumatically operated on-off valves used in the TDGIS (located within the secondary containment envelope) to develop leaks across their all-metal sealing surfaces after a few hundred operating cycles. The degree of leakage was unacceptable and could have resulted in mixing of deuterium and tritium within the TDGIS. The solution was to remove the entire TDGIS assemblies and re-fit them with new valves incorporating ‘Vespel’ stem tips. After re-installation, the end-to-end tests of all the TDGIS instrumentation and control, and *in situ* flow regulation tests were repeated. Following vacuum leak-testing of the primary containment, the secondary containment envelope was finally closed. Low concentration (1% tritium in deuterium) mixtures were then progressively expanded from the AGHS into the distribution valve boxes, transfer lines and finally TDGIS in order to confirm the integrity of the primary containment. This was done by monitoring the nitrogen purge gas for traces of tritium flowing in the interspace between the primary and secondary containment.

2.1 PINI operation characteristics operating with the TDGIS in deuterium

The TDGIS gas flows are lower than the conventional gas supply (the latter using separate feeds to the ion source and neutraliser). Since the single ground-potential gas feed is located close to the PINI earth-grid [7] a lower flow-rate is necessary in order to reduce the pressure in the accelerator, through which the gas must flow to feed the plasma source. Based on previous results from the JET NB Test Bed, a nominal TDGIS flow of 25mbls^{-1} of D_2 per PINI was foreseen, compared with a total flow of 32mbls^{-1} of D_2 for the conventional gas feed. The flow-rate was optimised experimentally taking into account the effect on arc efficiency, neutralisation efficiency and reliability.

2.1.1 160kV injector

For this injector a gas flow-rate of 28±2 mbls^{-1} was adopted; the neutralisation efficiency was 6.5% lower than that measured using the conventional gas system for deuterium beams at 140kV. A reduction in arc efficiency was also observed, corresponding to an increase of approximately 24% in the required arc current. Otherwise, no particular difficulties were encountered.

2.1.2 80kV injector

Since the beam current is much higher on this injector, the source pressure is further reduced compared with the 160kV system. This resulted in a substantial overshoot of the beam current in the first few milliseconds whilst the pressure in the source re-equilibrated after the start of beam extraction, leading to very poor reliability. Increasing the TDGIS flows caused several PINIs to become inoperable due to HV breakdowns often associated with pre-cursor current excursions observed on the gradient-grid, whose potential is disturbed since it is fed from a resistive potential divider. In practice, it was not possible to achieve reliable operation above approximately

70kV and it was decided to revert to the conventional gas handling system on this injector system.

2.2 Conditioning to 160kV

The maximum power supply current is 60A and each pair of PINIs on a quadrant of the high voltage injector is connected electrically in parallel. For deuterium operation the optimum perveance condition is 140kV/30A per PINI and this is the normal maximum operating voltage. The system was conditioned to 160kV/37A in deuterium by energising only a single plasma source on each quadrant. Approximately 200×0.7second conditioning pulses were required to obtain reliable operation at 160kV.

3. COMMISSIONING OF TRITIUM BEAMS

3.1 Commissioning with injector isolated from torus

Isotopic changeover was performed by running a sequence of three filament-only pulses without gas present then two arc-only pulses on each PINI in tritium. No increase of vacuum base pressure was observed due to any traces of ^{3}He. The arc struck 300ms later than in deuterium, attributed to longer gas transit time through the 20m pipework between the TDGIS and PINIs. The first 0.3s beam extraction (with deflection magnets energised) was carried out at 120kV. The arc parameters were set assuming the same arc efficiency as deuterium, scaling the perveance by $\sqrt{(2/3)}$. Having checked the beam profiles on the beamline calorimeter, the pulse length was increased to 0.7s and a three-point perveance scan carried out; only a slight adjustment to the arc current relative to the scaled deuterium value was required since the arc efficiency for tritium was indeed similar to deuterium at 17A extracted current. Eleven pulses were then expended on conditioning to higher voltage in tritium, achieving 157-160kV on six PINIs, the remaining pair achieving 140kV reliably. This stage was achieved one day following first admission of 100% tritium into the TDGIS. After further conditioning a perveance scan was obtained at 150kV on all PINIs, followed by conditioning to 160kV at optimum perveance. The arc efficiency was lower for tritium compared with deuterium for >25A extracted current; this can be understood quantitatively in terms of reduced conductance for the heavier gas. Measurements of the neutral power to the calorimeter corresponded to a similar neutraliser target thickness as in deuterium.

3.2 First tritium beam injection into plasma

Before proceeding to full pulse length and power, the beam alignment, power loading on beam scrapers and drift-duct pressure evolution were all assessed by short injection pulses at reduced power. The first test pulse was at 120kV (the same neutral beam power as the standard 140kV deuterium case). The timing of each quadrant was separated to allow each pair of beams to be assessed individually, using firstly 0.5s then 1s duration pulses. By scaling the measured power loadings, it was shown that a full power 160kV pulse should be within safe component limits. The process was repeated at 150kV and finally a demonstration pulse with six PINIs at 160kV and two at 150kV was performed confirming safe component power loadings. The entire tritium beam commissioning procedure took 6 operational days and used 46.7 bl (11.6g) of tritium.

4. ROUTINE TRITIUM BEAM OPERATION

After the first tritium beam commissioning had been completed, routine gas changeovers were carried out by evacuating the TDGIS output manifold prior to selecting the new gas, performing filament and arc pulses as described above, then proceeding to beam extraction using the arc setpoints previously established. The only significant difficulty encountered was a tendency for the state of HV conditioning to deteriorate above 155kV throughout the DTE1 campaign. Tritium supply inventory constraints limited the number of conditioning pulses in tritium. For reliable operation, the tritium beam energy was limited to 155kV. Fig 1 shows the distribution of delivered power for the tritium injector alone; the maximum power delivered was 10.9MW and the longest duration pulse (at 10.6MW) was 5s. In combination with the deuterium injector the maximum power delivered was 22.3MW, a JET record.

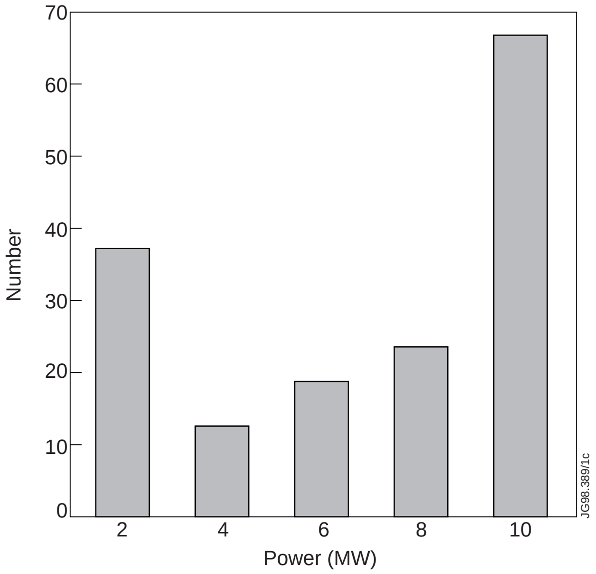

Fig.1 Distribution of pulses by power level for tritium NB injection. The majority of pulses were in the 9-11MW band.

5. TRITIUM USAGE AND RECOVERY

PINI operation was optimised to economise on use of tritium. The arc stabilisation time was minimised before beam extraction. A 5s beam pulse from a 155kV/28A PINI pulse (delivering 1.4MW in the neutral beam) consumed 0.3 bl (80mg) of gas. Fig. 2 shows the integrated supply and recovery of tritium for the 160kV injector, as measured in the AGHS plant. The equivalent of 2.5 bl of tritium was injected into the plasma as neutral beam; it will be noted, however, that the amount recovered slightly exceeds that supplied. This is due to tritium, which had been supplied as gas to the torus, pumped by the beamline cryo-pumps (the beamline fast-shutters were permanently open due to reliability problems associated with their flexible hose connections [6]). A similar effect can be seen in the tritium recovery from the deuterium injector. In the immediate post-DTE1 period (in late November 1997) a period of intensive deuterium operation was carried out to drive out implanted tritium from dumps, calorimeter etc. The progress of this de-tritiation was monitored using beamline neutron emission measurements [8], indicating that >80% of implanted tritium was removed. Tritium adsorbed or condensed (e.g. as tritiated hydrocarbons) onto the large-area aluminium, liquid nitrogen filled, panels was released by warming these structures up to room temperature at the end of January 1998. In subsequent re-generations of the cryo-pumps, approximately 0.05 bl of tritium was recovered *from each injector*, dominated by tritium from the torus pumped by the injector cryo-pumps. During the most recent shutdown, both injectors were vented to atmospheric air and, on evacuation, the tritium injector was found to contain 2 TBq (=0.054g or 0.02bl tritium equivalent) after standing for three months.

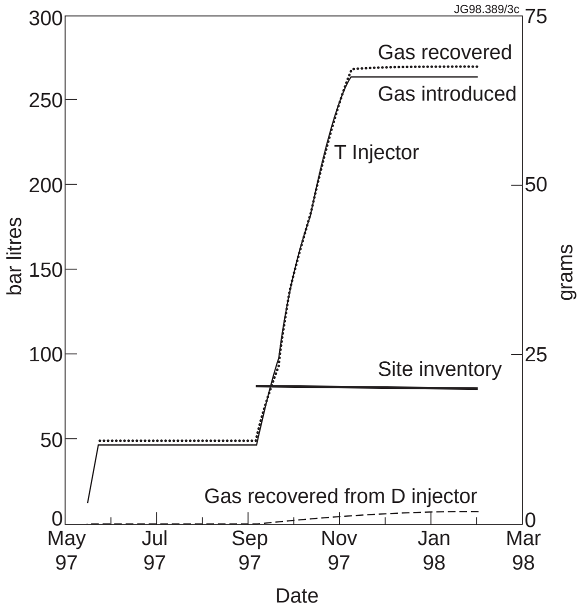

Fig.2 Cumulative tritium supply and recovery data for each JET NB injection system. The total site inventory is indicated for reference.

6. REFERENCES

[1] Duesing, G., et al., *Fusion Technology* **11** 163-202 (1987)

[2] The JET Team (presented by D.Stork), “JET Engineering Development towards D-T Operations in an ITER-like Machine Configuration”, in Proceedings of the Symposium on Fusion Engineering (1997), to be published.

[3] Lässer, R., et al., “Latest Results of Tritium Commissioning of the JET Active Gas Handling Plant”, in Proceedings of the Symposium on Fusion Engineering (1997), to be published.

[4] Svensson, L., et al., “The JET Active Phase Gas Introduction Systems for Neutral Beam Injection and Beamline Commissioning and Operation with Tritium”, in Proceedings of the Symposium on Fusion Engineering (1997), to be published.

[5] de Esch, H.P.L., “Compensation for Non-linear Interaction between JET NBI Deflection Magnets for Simultaneous D_2/T_2 Beamline Operation”, these Proceedings.

[6] Watson, M.J., et al., “Intervention to Repair a Tritiated JET Neutral Beam Injector”, these Proceedings.

[7] Massmann, P., et al., “Modifications and Characteristics of the JET Positive Ion Neutral Injectors for the First Tritium Experiment”, in Proceedings of the Symposium on Fusion Technology (1992).

[8] Ciric, D., et al., “Isotope Exchange in High Heat-flux Components of the JET Tritium Neutral Beam Injector”, these Proceedings.