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The JET Gas Baking Plant for DT Operation and Analysis of Tritium Permeation and Baking Gas Activation in DTE1

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ABSTRACT

The JET gas baking plant allows the vacuum vessel to be heated for conditioning and plasma operations. The vessel was maintained at 320^0C for the JET DT experiments (DTE 1). The design of the plant is outlined with particular reference to the features to provide compatibility with tritium operations. The experience of baking gas activation and tritium permeation into the plant are given. Developments to reduce the tritium permeation out of the vessel are considered.

1.0 INTRODUCTION

Baking is one of the essential vacuum and first wall conditioning techniques used on JET. The vacuum vessel is usually maintained at 320^0 C for plasma operations. Elevated wall temperature offers an improvement in plasma density control and pulse termination as well as giving the physical clearances necessary for full power operation. The vacuum vessel is of double walled construction and is heated by hot gas that is passed between the inner and outer shell. Ports on the vessel are heated by electrical heating. The original gas baking plant[1] has been enhanced, particularly to successfully bake the JET vessel throughout the latest tritium experiments (DTE 1).

2.0 DESIGN OF THE GAS BAKING PLANT

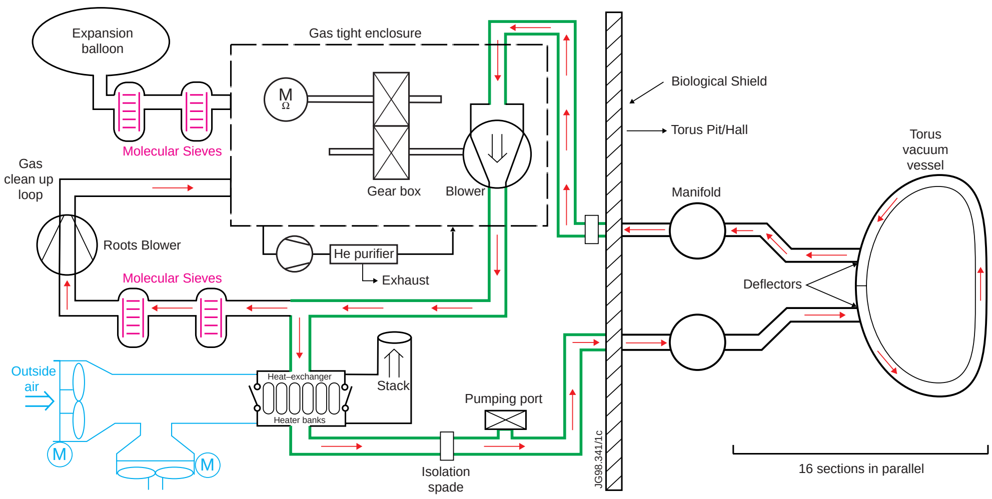

Fig.1 Overview of Gas Baking Plant.

The Gas Baking Plant (Fig.1), using a turbo-compressor, circulates gas through a tube bundle heat exchanger and back to the vessel. The system is operated at near atmospheric pressure. The high conductance path, to and from the vessel, ensures that the differential pressure across the compressor is less than 100 mbar. The blower is driven by a two speed motor giving a rotational speed of 20Hz or 40Hz and corresponding flows of $10m^3/s$ or $20m^3/s$. Heat input is through the compressor and through electrical heaters on the tube bundle heat exchanger. A total power of 1MW is available. A large and a small fan, with motor driven vanes, provide variable cooling.

The plant is controlled using PLCs. Cascade control is utilised to give accurate control of the torus temperature and a programmable profiler enables constant rates of heating and cooling. The torus temperature is computed by a high reliability measurement and interlock system from 16 thermocouples. Thermal interactions between the in-vessel components under fault conditions dictate a maximum safe mean temperature for the torus of 320^{o}C. This temperature can be maintained to within 1^{O} C by the control system. Vacuum leaks attributed to the thermal cycling of the vessel have been eliminated by keeping normal heating and cooling rates to 10^{o}C/hour.

Tritium experiments provide the complications of tritium permeating into the baking gas from the hot torus and of baking gas activation by neutron bombardment. The baking plant is situated in an unshielded area, hence activation of the baking gas is undesirable. Helium is the preferred heat transfer medium as is not activated by neutron bombardment. Producing an effective shaft seal for the blower for helium and tritium containment is problematic, hence the motor, gearbox and oil system were enclosed in a gas tight enclosure. The impeller shaft 'seal' provides a route for gas to flow from the enclosure to the main baking loop. Expanding baking gas passes through molecular sieve to an expansion balloon. To facilitate tritium removal a roots blower, running at low speed, circulates gas from the main loop through a molecular sieve and back into the gas tight enclosure. The zeolite molecular is effective in removing HTO. Ion chambers are fitted either side of the molecular sieves for monitoring activity. The arrangement is designed to minimise the contamination in the enclosure and expansion balloon. When the process gas is changed from air to helium, the main loop is first isolated, evacuated and filled with helium. The purity is then further improved by a selective diffusion membrane and by dilution with pure helium. The lower heat capacity of helium over air dictates that a higher flow is required to maintain a differential temperature of $<70^{o}$C between the inlet and outlet of the torus inter-space.

3.0 OPERATION DURING DTE1

The baking gas was changed from air to helium for DTE1, and by doubling the speed of the turbo compressor the heat transfer characteristics of the plant were improved. Measurements on a thermal conductivity meter indicated a helium purity of better than 95% was achieved. The vessel was held at 320^{0}C for the DTE1 experiments.

3.1 Baking Gas Activation.

A time averaged radiological protection gamma monitor in the baking plant area gave an integrated dose reading of 0.4 μSv for the highest performance DTE1 pulse. The effectiveness of the change to helium is verified, with a comparison to the higher dose readings from the Preliminary Tritium Experiment (PTE), when air was used as the process gas. The levels indicated that <0.5% oxygen in helium had been achieved.

A gamma monitor, connected to a high-speed data acquisition system, was placed at the gas return pipe to give high sensitivity to baking gas activation. Fig 2 shows it's output with respect to the neutron rate for a DTE 1 pulse. The neutron activated slug of gas takes 2.5 seconds to reach the monitor, subsequent peaks become less defined as the activated gas becomes more mixed with the rest of the circulating gas. The half-life of the isotope is observed to be 7.1 seconds, which indicates it is entirely ^{16}N from activated oxygen. All other gamma emitting isotopes were below detect able limits. Ion chambers on the clean up loop, for monitoring tritium levels, gave a small indication of another isotope. The decay which dropped below detectable levels within 2 hours is best fitted by β^+ decay from ^{13}N.

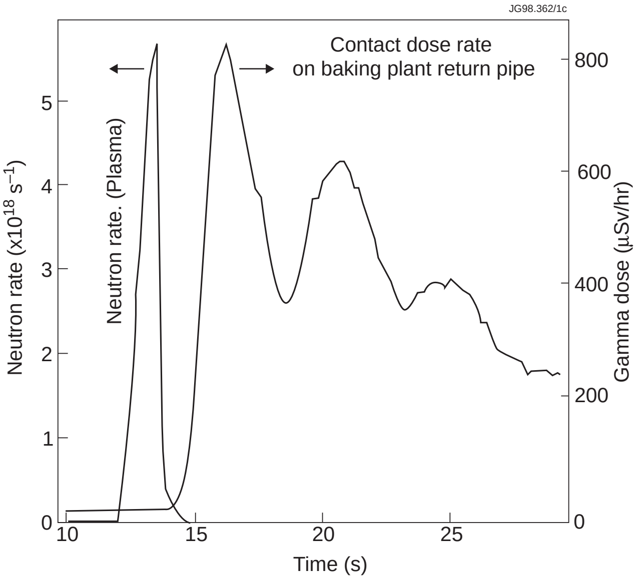

Fig.2 Baking Gas Activation for Pulse 42976

3.2 Tritium Permeation

The main permeation path for tritium out of the JET vessel is through the 2mm thick inconel bellows sections of the inner shell[2] which have a total surface area of 236m^2. Increases in the activity of the baking gas were only observed as result of regenerations of the in-vessel divertor cryo-pump and not from plasma operations. Fig.3 shows four regenerations and the resulting increase in baking gas activity. Accurate accounting, using ion chambers, of the total amount of tritium permeated into the baking gas is difficult due to contamination and the Jesse effect [3]. A rough estimate gives 40TBq for the duration of DTE1, which is 0.3% of the torus tritium throughput. Improved accounting will be obtained when the molecular sieves are regenerated.

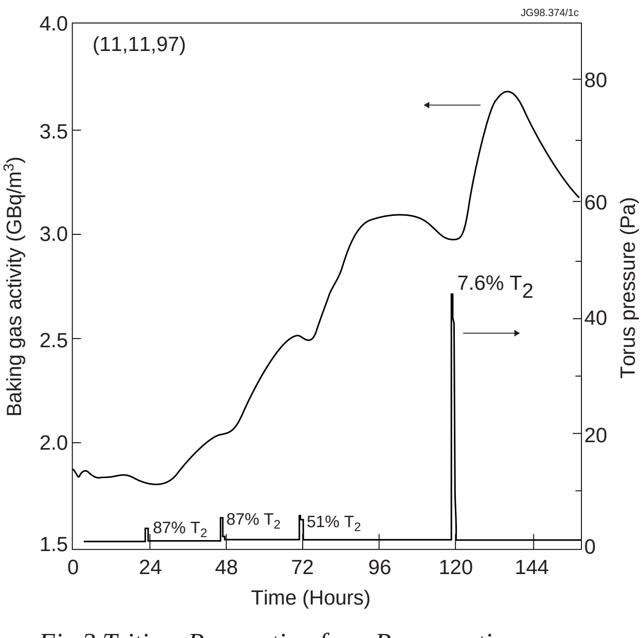

Fig.3 Tritium Permeation from Regenerations.

Results from discriminating samplers from the PTE (where there was no clean up loop) showed that tritium was first measured in the baking loop in the ratio 1000:1 HTO to HT. The HT in the loop, in time, subsequently oxidised. During DTE 1 ratio of HTO to HT was measured at varying levels between 70:1 and 400:1. The difference in the results, compared to the PTE, is explained by operation of the clean up loop, which only removes HTO, and possibly by the reduced amount of oxygen and water in the baking gas. It was observed that reducing the baking temperature caused a slight increase in the HT level. Introducing a small amount of water vapour to the loop increased the HTO measurement and reduced the HT level. The operation of the $200m^3/s$ in-vessel divertor cryo-pump is critical to tritium permeation at JET.

The pump was operated, with helium at super critical pressure, for most of the DTE1 campaign, resulting in an average torus tritium partial pressure of $< 10^{-4}$ Pa. Taking the surface limited permeability of Inconel 600 at 600K to be 1.2×10^{14}atoms $m^{-2}s^{-1}Pa^{-1}$[4] results in a steady state permeation rate of 16 MBq/hour, around 3 orders of magnitude below the maximum observed. To limit the in-vessel tritium inventory, the divertor cryo-pump was regenerated after each day of tritium operation. The sequence applied allowed time, to confirm the pump was fully regenerated and then further time to enable the regenerated gas to be analysed before it was pumped by the JET active gas handling system. This resulted in the Torus being at high pressure for a period of around 1 hour. The maximum regeneration pressure was 45Pa, but 5Pa was more normal. Result were analysed using the time-dependant concentration profile described by Crank[5]. Taking the fourth regeneration of Fig. 3, and applying the literature value for the diffusion coefficient for Inconel 600 at 600K of $8\times10^{-11}m^2/s$ [5], an increase in permeation rate would be expected after 0.5 hours and this would be expected to peak 1.5 hours after the start of exposure at 27 GBq/hr. The actual permeation rate starts to increase 1.75 hours after the start of the torus pressure rise and peaks at 8 GBq/hr (above background) after 6 hours. This gives an effective diffusion coefficient of about 0.25 of the literature value and an effective permeability of 2.6×10^{11} atoms/msPa$^{1/2}$ some 0.7 of the literature value. Using these coefficients, Fig. 4 gives predicted permeation rate profile for a typical regeneration. Good agreement is found with observed values with the exception of higher actual background levels. There are a number of contributions to the measured background permeation rate: the permeation tail through the bellows from previous regenerations; continuing bulk loading during the pump down time; contributions from thicker parts of the wall(12,16,and 20mm); ion chamber memory effects.

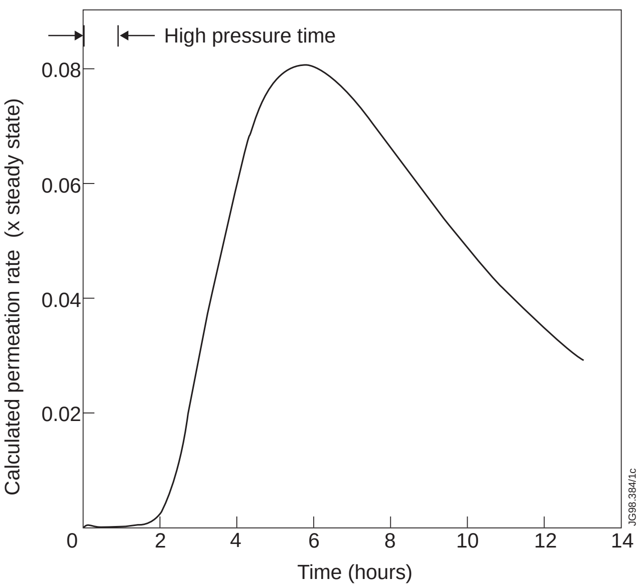

Fig.4 Permeation for 1 hour regeneration normalised to the calculated steady state permeation rate.

JET was baked for many years using air as the baking gas; the internal walls of the vessel inter-spaces are likely to be highly oxidised. The internal walls of the vessel are well conditioned and hence unlikely to be significantly oxidised. Oxide layers are a possible explanation for actual permeation rate being lower than calculated, though the effect is not as marked as has been predicted[6]. This may be due to cracks in the oxide layers in the flexible bellows sections. Permeation of tritium into the baking plant loop has made the plant more difficult to maintain.

4.0 FUTURE DEVELOPMENTS

The plant is essential for JET operations, hence, the aim is to install relevant diagnostics to move from a traditional deterministic maintenance programme to a predictive programme. Permeation into the many other inter-spaces on the JET machine hinders maintenance and enhancement, particularly of JET diagnostics. The highest level observed, in a dead inter-space following DTE1, was 40GBq/m^3. A reduction in tritium permeation is desirable and achievable with procedural changes to the regeneration sequence to reduce the time that high pressure is present in the torus. This time could be further reduced by changing the current conventional turbomolecular pumps on the torus to high throughput turbo drag pumps. With this future development, all of the gas from the regenerating divertor cryo-pump can be removed from hot torus and compressed into the cold 11m^3 fore-vacuum line for analysis, before pumping and processing.

5.0 CONCLUSIONS

The JET tokomak was successfully baked for DTE1 with helium as the heat transfer medium. Activation of the baking gas by neutron bombardment was minimal. Tritium permeation resulting from the regenerations of in-vessel cryo-pumps was totally dominated over the steady state. Tritium permeation from the vessel could be significantly reduced, in future, by reducing the residence time and pressure of regenerated gas in the hot torus.

6.0 REFERENCES

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