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EXPERIMENTAL SET-UP FOR GAS BALANCE MEASUREMENT AT JET

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Abstract

The JET experiment using tritium has to address the problem of tritium retention in the vessel walls. Therefore measurements to assess the first wall behaviour in respect to gas retention and gas release during and after tokamak pulses are already made in the deuterium phase of JET.

A pumping system parallel to the standard forevacuum system of JET has been installed to pump and store the discharged gas after each plasma shot. Using a timing sequence to operate valves, the normal mechanical forevacuum pumps are disconnected and a special cryogenic pumping set is used to collect the gas discharged by the torus turbomolecular pumps for a given time after each shot. A storage tank takes the collected gas from the cryogenic pump after a period of operation from where gas samples can be taken for analysis.

The paper describes the set-up, the type of the cryo-pump and also the various modes of operations of the experimental set-up.

The results obtained have shown that the Torus walls have a very strong retention capability. Depending on wall surfaces and plasma conditions release rates between 10% and 80% of injected gas have been measured.

A. Introduction

For a fusion experiment like JET which in the future intends to use tritium [1], it is of great importance to know how this radioactive and expensive process gas is behaving in respect to distribution, retention and recovery within the vacuum vessel. It is of special importance if the process gas is retained fully, partially or temporary or not at all by the vessel walls [2] [3] [4].

Therefore a diagnostic system is required to give answers to these questions and at JET an experimental set-up was installed to perform gas balance measurements already in the non-active phase of JET which means using only hydrogen or deuterium as process gas. This Gas Collecting System (GCS) has the task to measure the amount of gas being released from the torus after the plasma discharge for each shot individually or for a number of shots collectively. The results of these measurements are used to make a gas balance by comparing the measured release with the amount of gas being put into the plasma discharge itself. Furthermore the composition of the released gas is also of interest and therefore the possibility to take gas samples for further analysis is foreseen.

The tasks of the experiment can therefore be listed as follows:

- Set up a measuring unit which can account for the gas which is discharged from the torus and pumped by the high vacuum and forevacuum pumps of the JET vacuum system.
- Collect the gas in storage reservoirs after each shot or after a number of shots.
- Enable the taking of samples from the reservoir to analyse the composition of the gas collected.

B. Description of experimental set-up

1) Description of JET conventional vacuum system.

In Fig. 1 the conventional pumping system of JET is shown [5]. The turbomolecular pumps (T01-T06) discharge their gas into a crown - which in turn is evacuated by roughing pump units (RP) consisting of roots/rotary vane pumps installed outside the torus hall. The pumping speed of all turbopumps amounts to 10^4 ℓ/s for H_2 and each RP unit has a pumping speed of 1000 m^3/h in the forevacuum pressure range of the turbopumps ($<10^{-2}$ mbar).

2) Description of the Gas Collecting System (GCS)

As shown in Fig. 1 the Gas Collecting System is connected to the torus crown through a valve V_B. By operating the valves V_A and V_B gas in the torus crown can either be pumped by the roughing pumps RP or by the GCS.

Fig. 2 shows the schematic of the Gas Collection System of which the main component is a compound cryopump (CR) at LH_e temperature. It is made up as a cold finger from stainless steel flexible hose (NW40) welded to a sphere, filled with approximately 100g of activated charcoal and inserted into a 250 ℓ liquid helium Dewar. This cold-finger being at 4.2°K pumps all condensable gases including hydrogen and deuterium by cryocondensation. The charcoal pumps Helium by cryosorption. By warming up the cold finger the collected gas from the cryopump can be transferred into a storage tank of ~ 200 ℓ (R) for a total gas balance and for further analysis either by mass spectrometer or by taking of samples for gas chromatography.

The transfer pumps and vacuum components are selected to avoid contamination of the gas to be analysed. Therefore the installation is done with all-metal seals only and an all metal mechanical scroll pump (A) for the gas transfer and a turbomolecular pump (B) for prior evacuation are used.

Pressure measurements are performed with absolute (non gas dependent) capacitance manometers (Baratrons) (1, 2, 4, 6) and a mass spectrometer head is installed for analysis and leak detection purposes.

The main valves in the system (V_A and V_B) are all-metal pendulum valves pneumatically operated while the transfer valves etc. are manually operated angle valves.

The immersion of the cold finger into the H_e Dewar is achieved by raising the dewar on a lifting platform and inserting the cold finger into the liquid Helium.

Fig. 3 and 4 show the installation of the GCS.

The control of the GCS consists of a programmable control-unit, a data-logger to record pressure values and operate timers, and valve controllers to open and close the main system valves V_A and V_B.

Fig. 5 shows the control cubicle with these control units and the control instruments for the Baratrons.

C. Operation modes of the experiment

To perform the measurements some preparatory conditions have to be established. With the valve V_B closed the GCS has to be evacuated using the turbopump set. After the pressure is brought down to $<10^{-3}$ mbar and the storage reservoir disconnected the cold-finger is cooled down to LHe temperature. The system is now ready for operation.

After starting the controller manually the measurement of the exhaust gas is then done automatically.

a) Short-term measurements

The JET pulse countdown sequence also starts the measurement sequence of the GCS. The measurement itself is done in the following way:

- switch on control sequence at the beginning of the day
- close valve V_A and open valve V_B
- start the pressure recording
- JET pulse trigger starts timer and closes V_B
- for 600 sec - (fastest repetition rate of JET pulses) all gas discharged is collected in the calibrated torus crown volume V_1 (6 m^3)
- pressure rise is recorded with gauge (2)
- after 600 sec valve V_B is opened and the collected gas is pumped by the cold finger. Pressure is recorded with gauge (1) and (2)
- new JET pulse closes valve V_B and starts new sequence

- after the operational day the GCS is switched off which closes valve V_B and opens valve V_A
- the collected gas can now be transferred by warming up the cold finger and pump the released gas with the transfer pump (A) into the storage volume (R).

The results of the measurement are obtained quantitatively by evaluating the pressure rise in a known volume for a defined time (600 sec) and qualitatively by mass-spectrometer measurements and sample analysis by means of gas chromatography after transfer of gas samples from the storage reservoir to sample flasks.

For safety reasons an interlock is installed to open valve V_A and close V_B in case the pressure in the volume V_1 exceeds a preset value of 10^{-1} mbar.

Fig. 6 shows the pressure recording for some measurement sequences as described.

b) Long-term measurement.

To assess the long-term release of gas from the torus some measurements have been made by pumping with the cold finger also overnight. This meant that the valve V_A was closed and valve V_B open for the whole of the measuring period.

D. Result of the measurements

The measurements described were performed for many hundred plasma discharges in JET. The results [6] were analysed for many different operation conditions with the aim to find out the ratio of the gas molecules released within 600 sec after the pulse to the total amount of molecules put into the vacuum vessel.

The input was obtained by adding up the number of particles put into the tokamak by gas filling (prefill and density feed back), by injection of neutral particles through additional heating systems or by injection of particles through fuelling pellets.

The output is determined by the pressure rise in the calibrated volume V_1.

The accuracy of the measurements is estimated to be ± 5% for the input measurements (± 10% for pellet fuelled discharges) and ≦ ± 5% for the output measurement.

The results were analysed for the various types of discharges, depending on plasma current levels, heated or not heated plasmas (up to 20 MW additional heating) or plasma configurations, e.g. limiter plasmas, inner-wall plasmas or X-point plasmas. Also vacuum vessel temperature variations (300°C or 350°C) were analysed.

Fig. 7 shows the result of the evaluation of the measurements for various operation modes of the JET machine with Deuterium gas and with graphite walls. It shows that the gas released after 600 sec can vary from ~ 10% to >100% with a strong dependency on the gas input. The more gas you put in, the lower the fraction you get out. In general it can be said that a release of more than 50% only occurs in very low density discharges. The average value of release within 600 sec after the shot lies between 10% and 40%.

No dependence however has been found on plasma current, plasma duration, total power input or plasma configuration.

The gas amount released after a plasma disruption however is higher than after a normally ramped-down plasma shot. The average recovery for disrupted shots lies at about 80% of the injected gas, but can vary between 50% and 500%. These are again figures for measurements within 600 sec after the pulse.

Compared to the total amount-of gas in the plasma - the gas inventory - at the time of the disruption it was found that the amount released and collected after such disrupted shots was always greater. But there was no clear relationship between gas release and plasma current or power input at the time of the disruption.

The gas release appears to depend more on the dynamics of the disruption and the local power deposition rather than on the total energy content of the plasma.

Compared to these short-term release figures - for a period of 600 sec after the shot - the long-term measurements and global balance and corrections gave the following results:

- the gas recovered during a full day of operation was on average ≤50% of the input.
- An additional few percent were recovered overnight (8-12 h after the last shot of the day) when the temperature of vessel wall and internal limiter were kept constant.
- the chemical analysis showed that the main impurities released from the vacuum vessel are hydrocarbons of various orders, dominated by CD_4 (~ 2% of the molecules) and carbon monoxide (~ 1%). Therefore one has to apply a correction factor on the amount of deuterium released from the tokamak of + 8%.

Taking all these factors into account, the overall total percentage of the gas recovered from the gas introduced adds up to about 60%.

- A further release could be achieved by increasing the temperature of the internal limiter.

Fig. 8 shows results of long time release and temperature variation.

All the results reported have been obtained with the vacuum vessel and limiter walls being covered with graphite tiles. Since the beginning of June 1989 this has changed when the internal surfaces were covered with a beryllium coating.

This new surface improved not only the plasma behaviour and plasma parameter considerably, but also changed the retention of gas by the walls.

The results of these recent measurements are not yet fully analysed but as a global statement it can be said that for high density discharges the release rate has increased from ~10% for graphite to ~30% for beryllium (Fig. 9) and also the recovery rate during a full day of operation was up to ~ 80%. This is a considerable improvement and if future measurements confirm these initial results, a total recovery rate of up to 90% could be expected (including long term outgassing and corrections for impurities etc.).

Taking into account these results an assessment about the tritium inventory in walls shows that, for example, for 100 high density plasma discharges a total of 7.5 g tritium are required of which about 0.75 g are trapped in beryllium walls compared to more then 3 g in graphite walls.

Further tests are still necessary and also the installation of solid beryllium tiles for the limiters might bring an improvement in the release rate. Other physical or chemical processes for tritium recovery (e.g. glow discharge cleaning with deuterium) should also be exploited to improve the recovery even further.

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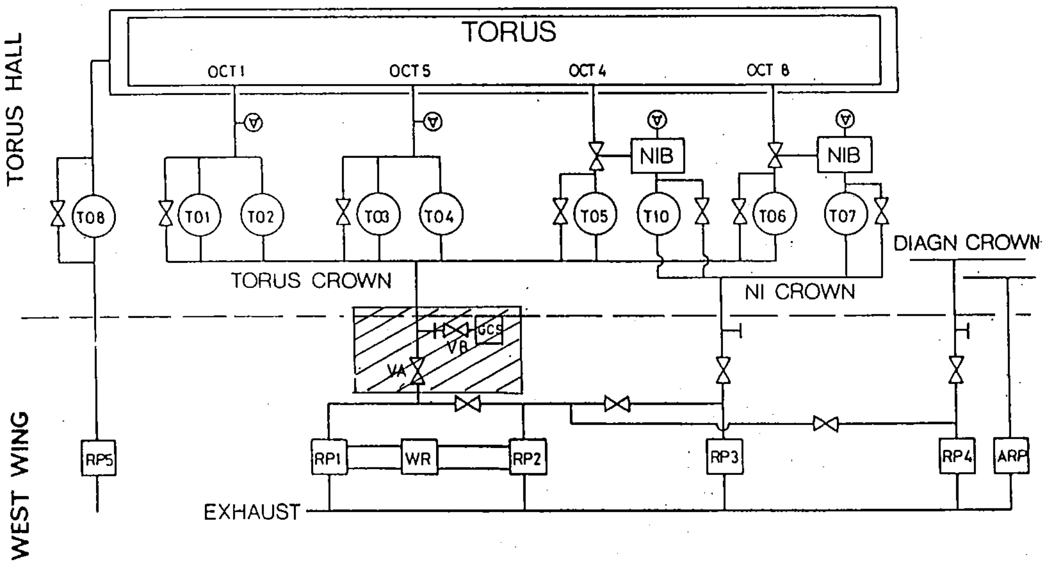

Fig. 1 Schematic of JET conventional vacuum system.

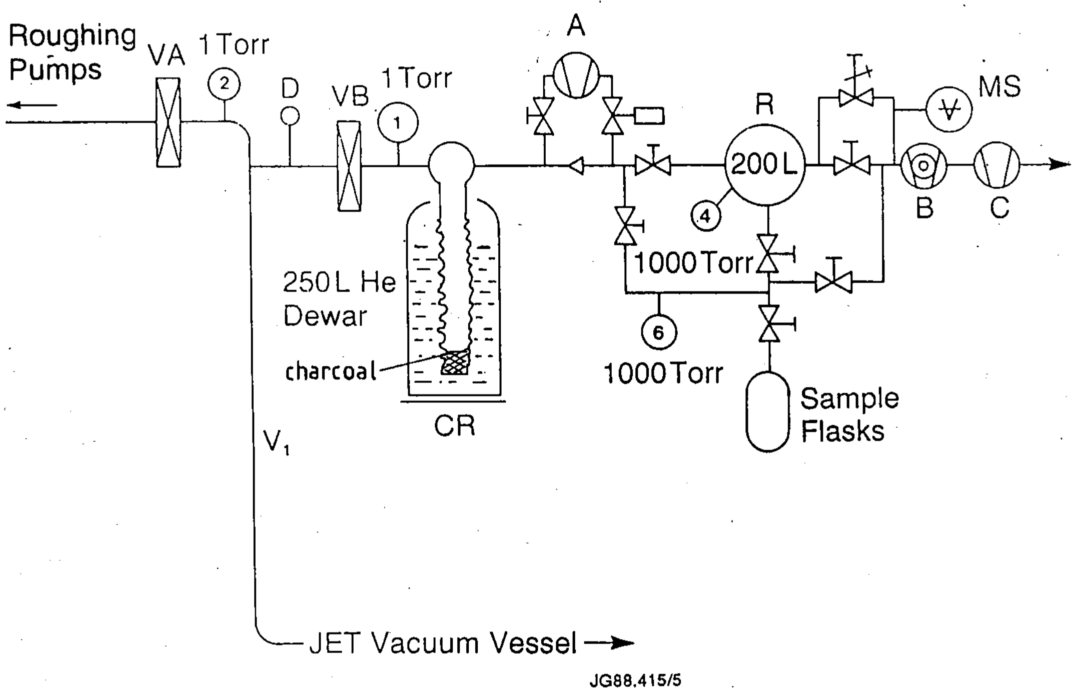

Fig. 2 Schematic of Gas Collection System (GCS).

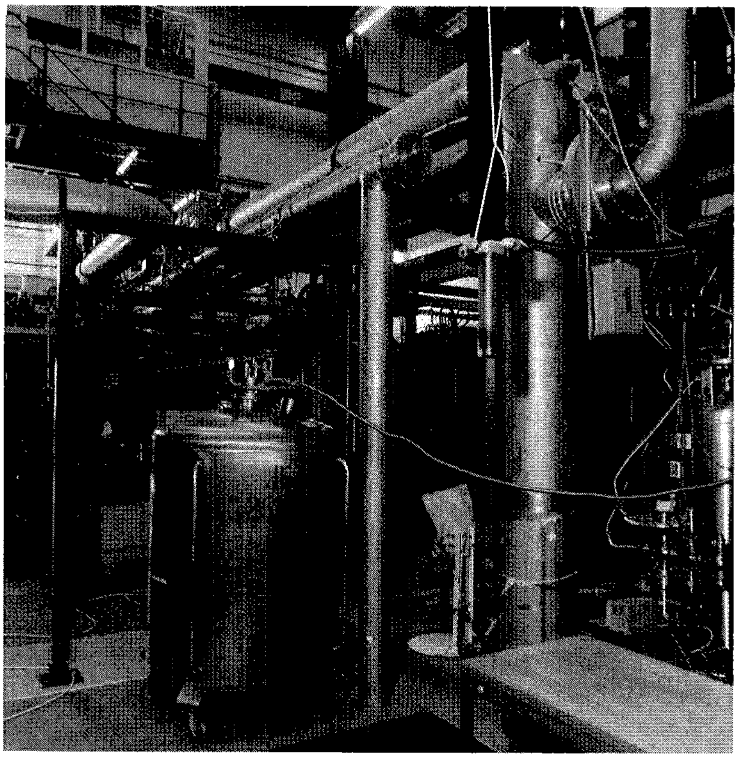

Fig. 3 View of connection of GCS to JET forevacuum pumps.

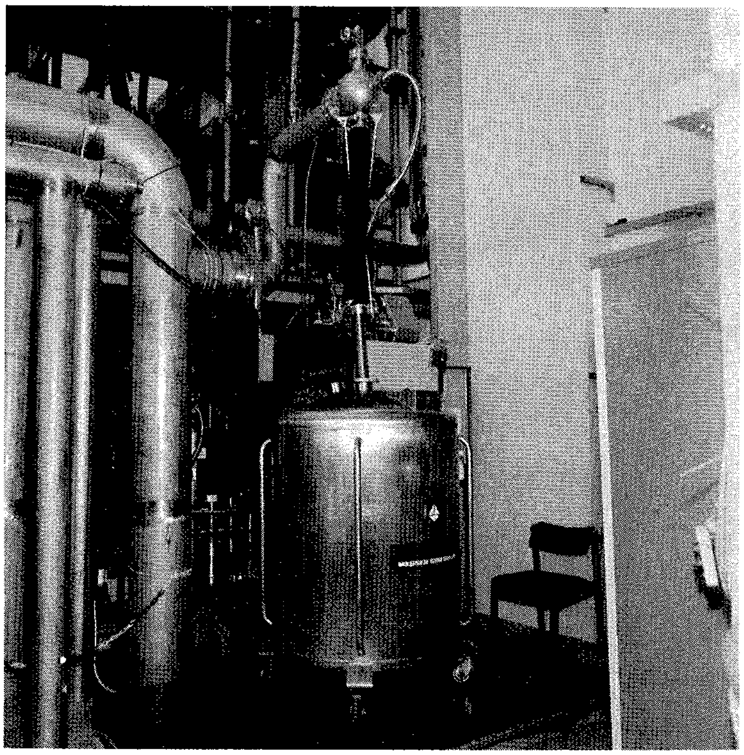

Fig. 4 View of GCS installation.

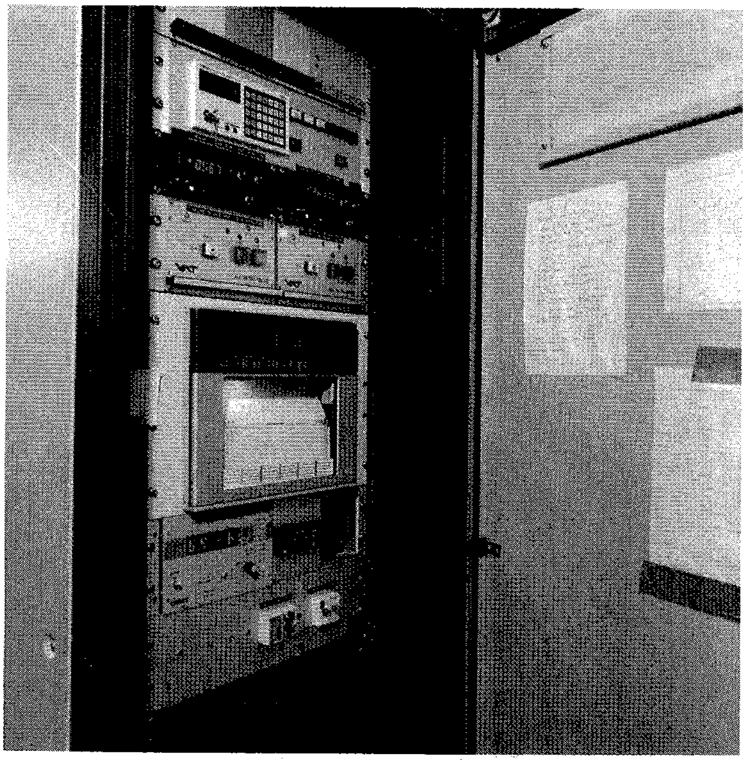

Fig. 5 View of Control Cubicle of GCS.

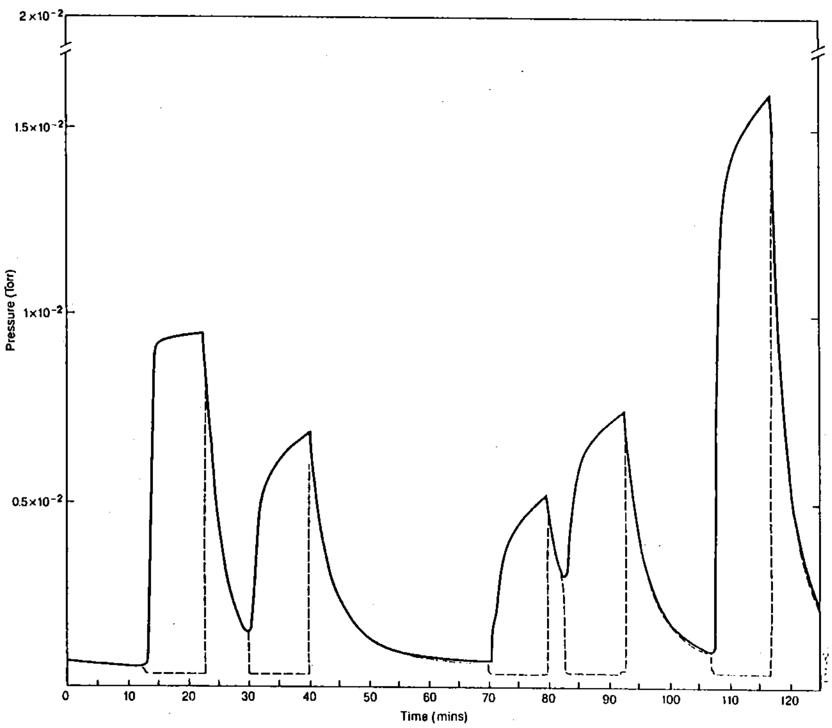

Fig. 6 Pressure recording in GCS for several sequences ———— gauge 2 --------- gauge 1

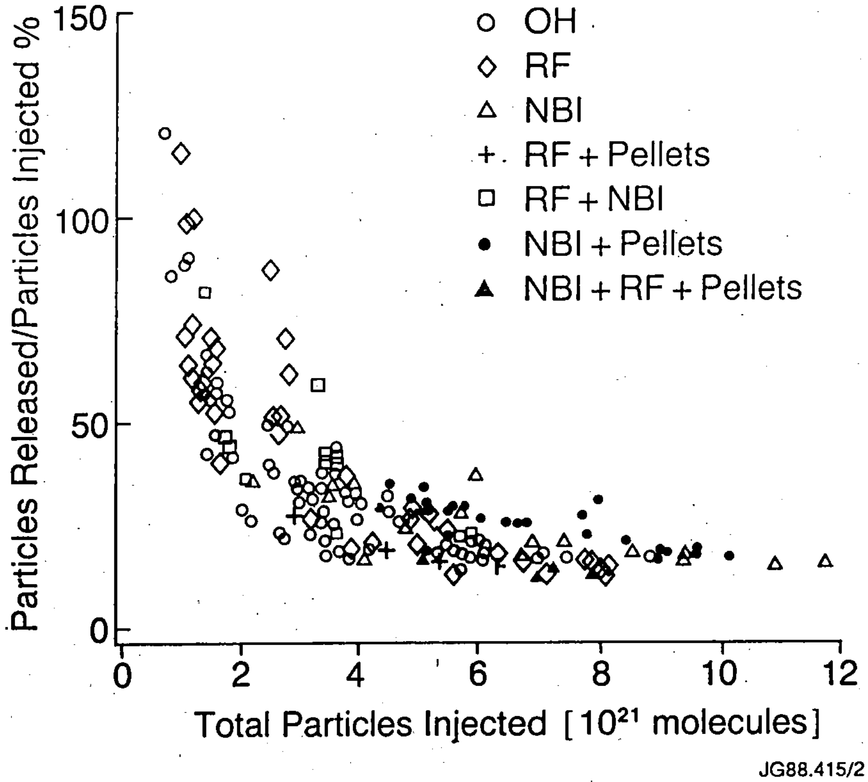

Fig. 7 Fraction P of particles released 600s after JET pulse as a function of number of particles injected.

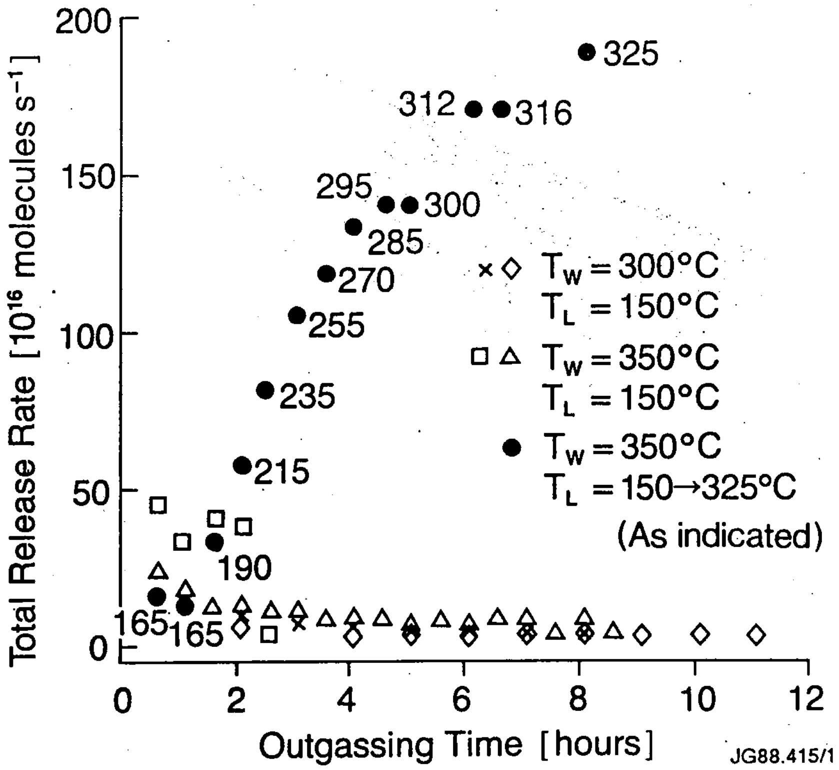

Fig. 8 Total particle release rate R as a function of time for different temperatures of vessel wall and limiter.

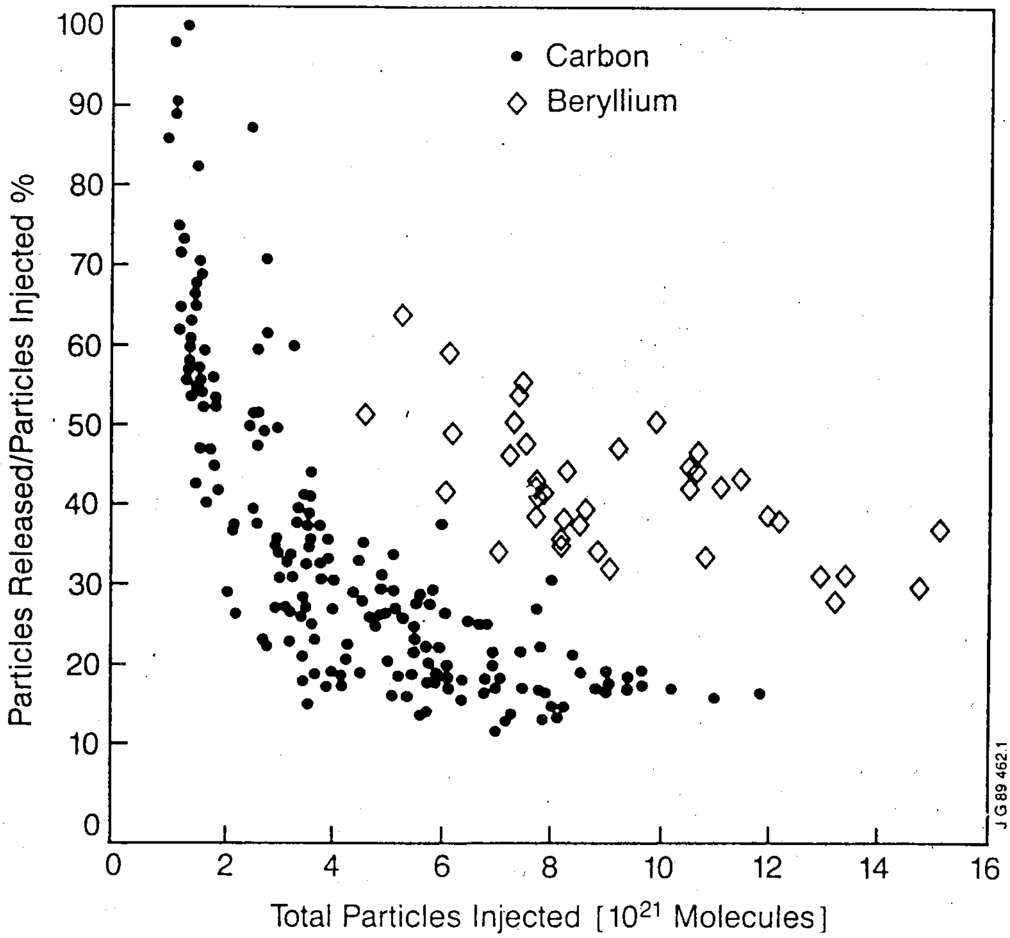

Fig. 9 Fraction P of particles released 600s after JET pulse as a function of number of particles injected for different wall materials.