# ANALYSIS OF FUEL RETENTION AND RECOVERY IN JET WITH BE-W WALL

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JET tokamak is the only fusion experiment to date that operated with large quantities of tritium (T) fusion fuel in all-metal wall configuration, establishing a new world record of 69 MJ fusion energy produced in sustained reproducible T-rich scenario plasma pulse [1, 2, 3]. Extended operations with tritium and deuterium-tritium (DT) plasmas provided, among others, unique opportunities for assessing and comparing the in-vessel retention of different hydrogen isotopes. Subsequent dedicated T clean-up campaigns implementing specially design operation sequences aimed at reducing the in-vessel T retention, especially in view of T outgassing during D plasma operations and T content in the exhaust gas, and provided valuable input for the development of fuel retention mitigation and recovery strategies in ITER [4]. Details of these T clean-up experiments, including pilot experiments prior to T operations, were reported earlier [5, 6], and an overview of fuel retention and recovery in all-metal JET showing preliminary results of gas balance analysis and implementation of laser-based diagnostics has been presented recently [7]. So far only qualitative results on the isotope dependence of fuel retention deduced from in-vessel gas balance analysis and on the local fuel removal by laser-induced desorption [8] could be reported. In this contribution we summarize the respective research activities and related set of findings, advancing the analysis to provide a more quantitative picture and expanding the results with more recent datasets from in-vessel laser-based diagnostics performed after the end of JET operations.

As reported in [7], several attempts to perform ex-vessel gas balance analysis during recent T operations in JET turned out to be inconclusive, in contrast to earlier successful gas balance measurements during D operations [9]. Such results are attributed to different, tritium compatible gas routing during T operations and related technical complexity on the side of the tritium processing plant. The in-vessel gas balance analysis was developed as a more accessible and lower-effort alternative, which however demonstrated a rather high level of measurement uncertainties associated with observed variability in the calibration procedure results. Thus only qualitative comparison of fuel retention in D, T and DT plasmas could be made so far (figure 1). To address these uncertainties that are believed to be related to gas temperature gradients between the main chamber and the location of pressure measurements, dedicated simulations with the gas transport code DIVGAS [10] have been initiated. Ongoing analysis that will be presented in the contribution helps to extract additional information from the available calibration data and improves the reliability of fuel retention measurements.

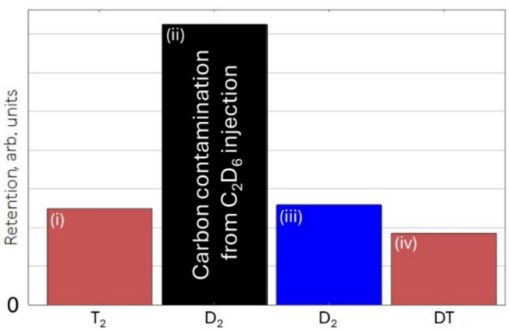


Figure 1. Qualitative comparison of fuel retention deduced from in-vessel gas balance after a day of plasma operation in (i) full T, (ii) full D preceded by injection of hydrocarbon species, (iii) full D, and (iv) DT

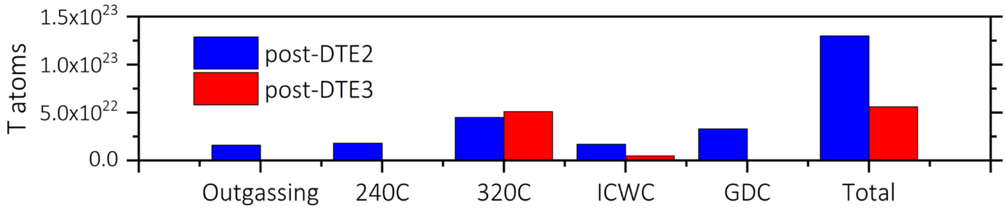


Figure 2. Comparison of recovered tritium amounts by different methods during the initial T clean-up experiments following the 2nd (post-DTE2, 2022) and the 3rd (post-DTE3, 2023) Deuterium-Tritium Experiments in JET. The shown methods include vessel baking at different temperatures and operations with Ion-Cyclotron Wall Conditioning (ICWC) and Glow Discharge Conditioning (GDC) plasmas.

In view of fuel removal, the strategy presented in [5, 6] comprised initial vessel baking followed by Ion-Cyclotron Wall Conditioning (ICWC) and Glow Discharge Conditioning (GDC) plasma operation, while the vessel remained at baking temperature. To remove fuel from co-deposited layers formed predominantly in the inner divertor [11], a special plasma configuration with raised inner strike point (RISP) was developed [5, 6] and successfully applied. Detailed evaluation of T removal after the 2nd Deuterium-Tritium Experiment in JET (DTE2) was reported in [6]. The same analysis has been recently applied to T clean-up after the 3rd DT experiment (DTE3). Figure 2 shows a preliminary comparison of T recovery by baking, ICWC and GDC in post-DTE2 and post-DTE3 T clean-up. In particular, fuel recovery by ICWC relies on in-vessel gas balance measurements and will be revisited with new information from DIVGAS simulations. The total amounts of recovered T after the two campaigns are consistent with about factor 2.3 less inventory (T injected into the torus) in DTE3 compared to DTE2 and full-T campaigns. Detailed revised results summarizing fuel recovery in both clean-up campaigns will be presented in the contribution.

Laser-based diagnostic methods such as laser-induced desorption with detection by quadrupole mass spectrometry (LID-QMS) and laser-induced breakdown spectroscopy (LIBS) offer the possibility of local in-vessel and time resolved measurements of fuel content in plasma-facing materials and deposited layers. LID-QMS system was in operation during DTE3, monitoring the evolution of fuel retention at upper tiles in the inner divertor, as well as in the post-DTE3 clean-up, providing the evaluation of local fuel removal, especially by the RISP plasmas. Preliminary results reported in [7, 8] demonstrated a strong reduction of T-related LID-QMS signals from the inner divertor after the RISP plasma operation. These results are now being extended with comprehensive analysis of measurement uncertainties and complemented by new results from in-vessel survey of fuel retention by LIBS performed from a robotic arm.

## ACKNOWLEDGEMENTS

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