

## Long plasma duration operation analyses with an international multi-machines (tokamaks and stellarators) database

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Combined high fusion performance and Long Pulse Operation (LPO) is one of the key integration challenges for fusion energy development in magnetic devices. Solving this problem requires a comprehensive vision of the physical and engineering aspects to simultaneously increase the duration and performance of fusion. Significant progress has been made in tokamaks and stellarators, including very recent advances in duration and/or performance. These progresses are reviewed by analyzing the experimental data (109 pulses / 3200 entries) provided by 10 tokamaks (ASDEX Upgrade, DIII-D, EAST, JET, JT60-U, KSTAR, TCV, TFTR, Tore Supra, WEST) and two stellarators (LHD and W7-X) expanding the pioneering work of M. Kikuchi [Frontiers in Fusion Research, Springer]. Data have been gathered and coordination has been provided by the recently created IEA-IAEA international CICLOP group (Coordination on International Challenges on Long duration Operation).

Using the international multi-machines database, the latest achievements will be reviewed in terms of input energy (for example, 1730 MJ in L-mode, 425 MJ in H-mode), duration (1056s in L-mode, 101s in H-mode), input power and sustained performance. Progress has been made in maintaining the LPO in tokamaks and stellarators with superconducting coils, actively cooled components and/or with metal walls. The graph of the dependence of the triple fusion products on the duration shows a sharp decrease by at least two orders of magnitude with an increase in the plasma duration from less than one second to 100s. Indeed, LPO is usually reached in dominant electron-heating modes at reduced density (current drive optimization) but with low ion temperatures ranging from 1 to 3keV for discharges above 100s. Difficulties in extending the duration may arise from coupling high heating powers over long duration and the evolving plasma-wall interaction towards an instable operational domain. Possible causes limiting the duration will be reported and analyzed as critical issues to be addressed prior ITER operation and DEMO design.

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