DSOL-31 Leading edge power loading and divertor mono-block shaping

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| **TG priority:** Critical | **Start date:** 2014 | **Status:**  New | **Personnel exchange:**  Yes |
| **IO priority:**   | **End date:** 2016 | **Motivation:** Engineering Design Support |

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| **Device /****Association** | **Contact****Person** | **2016 TGRequest** | **Activity (from JEX/JA spreadsheet)** |
| **2015** | **2016** | **2017** |
| ITER | R. A. Pitts | Desirable |   |   |   |
| AUG | K. KriegerJ. Coenen | Desirable | Committed |   |   |
| JET | G. MatthewsJ. Coenen | Desirable | Committed |   |   |
| KSTAR | S.-H. Hong | Desirable |   |   |   |
| DIII-D | D. Rudakov | Desirable | Committed |   |   |
| Pilot-PSI | T. Morgan | Shutdown |   |   |   |
| COMPASS | R. Dejarnac | Desirable |   |   |   |
| NSTX-U | M. Jaworski | Not doing | Committed |   |   |
| LHD | S. Masusaki | Shutdown |   |   |   |

**Purpose**

In support of the ITER tungsten divertor design, for which a decision on monoblock front surface shaping design must be taken in early 2016, make the strongest effort possible to understand the physics of power loading around leading edges. Analysis, performed throughout 2014, of the W melt experiment on JET in July 2013 has shown that there appear to be missing elements in the physics understanding of leading edge power loading at grazing incidence and high parallel heat fluxes. On the other hand, new experiments in October 2014 on Magnum-PSI, at somewhat lower parallel heat flux density, tend to show that there are no anomalies in edge power loading and that it proceeds according to simple (geometrical) expectations. This may in large part be due to the geometry of the experiment: JET made its leading edge by forming a recessed surface just in front of the protruding lamella whilst in Magnum-PSI the edge was purely protruding, with no hollowed out area before the edge. It is critically important to try and resolve these discrepancies in order for ITER to be able to decide to which extent the analytical/numerical techniques which have been developed to assist in the shaping design can be adopted.

**Brief Summary of results from 2015**

* JET: a new special W lamella has been designed and installed into the same location as the previous deliberately misaligned component. The new lamella has a small elevated poloidal portion with a well-defined inclination angle, which will allow clear measurements of whether or not the projected surface area yields the expected power flux density. Moreover, the inclination angle should be sufficient to allow full surface melting due to large ELMs (as opposed to edge localized melting in the first experiment). Experiments are being conducted under EUROFusion Expt. Number: M15-32, with 3 JET sessions programmed in late Nov. and mid Dec. A final session is programmed in Jan. 2016.
* AUG: analysis has been performed of power deposition in shadowed regions of the main bulk W tiles of the outer divertor. Under normal steady state loading, no thermal plasma power should reach these regions, but during ELMs, orbit calculations show that the higher energy ELM ions have Larmor orbits sufficient to penetrate into these shadowed regions. The analysis seems to demonstrate that this is in fact occurring, though not at the level expected from orbit calculations. Marker layers have also been used to study possible ELM-induced erosion in these shadowed regions using the divertor manipulator II to insert the special marker tiles in the outer divertor for dedicated H-mode discharges (the IR thermal power measurements between tile gaps were done observing different tiles than those inserted by the manipulator). No clear evidence for erosion in the shadowed regions has been found. Throughout 2015, preparations have been underway for a new castellation experiment similar to the one planned at JET, but using the divertor manipulator to insert the tiles and including current measurements to investigate thermoelectric currents during melt events. These experiments will be performed inside the EUROFusion programme in Spring 2016.
* Pilot-PSI: experiments performed on a new specially designed inclined target with misaligned W and Al blocks to study the edge heat loading during pulsed, ELM-like transients in the presence of stationary background plasma loading. The experiments on Al were designed to investigate steady state and ELM-induced melting, but loading on the W blocks (leading edges of 0.3 mm and 1.0 mm and incidence angles of 3° and 5°), has been possible during transients but without melting. Note that although the energy densities are relevant to mitigated ELMs on ITER, these Pilot-PSI transient pulses do not match the high ELM ion energies expected on ITER. Analysis of the new pulsed edge loading data is underway.
* KSTAR: two new special tiles have been installed in the central divertor area, consisting of a very extensive set of special tungsten elements with a variety of leading edges, chamfers and top surface shaping. These new W castellations have been designed in full consultation with the IO and may be considered as proxies for geometries of monoblocks currently being considered for the ITER divertor. The special tiles are observed by high resolution IR, looking from the top of the machine. In fact, the IR camera resolution has been specially improved (installation of new zoom optics) for this purpose. First experiments were performed in Sept. during the main KSTAR 2015 campaign. Useful data were obtained in NBI heated H-mode plasmas, with large enough FoV to see several different misaligned edges in the special tiles and perhaps with sufficient time resolution to derive some results for ELM edge loading. However, the data are fresh and there is no previously established IR analysis infrastructure at KSTAR so many software tools require development. A full assessment of the data quality likely only in 2016.
* DIII-D: experiments have been performed using the DiMES divertor manipulator facility to expose misaligned W blocks (0.3 mm and 1.0 mm) to the outer divertor plasma of a few L-mode discharges with top viewing high resolution IR. The experiments were successful, but unfortunately issues with IR defocusing rendered a final conclusion impossible. There are strong indications, however, that the derived edge heat fluxes are consistent with geometrical expectations. Similar experiments in H-mode are difficult on DIII-D owing to difficulties with neutron irradiation of the IR system, but further experiments were planned in He H-mode plasmas near the end of 2015. Unfortunately, DIII-D hardware issues meant that the He campaign is moved to 2016.
* COMPASS: there have been a large number of dedicated experiments performed on a specially designed inner wall graphite limiter tile in which a variety of poloidal gaps are machined to produce several different leading edges from 0 through ITER relevant (0.3 mm) to large edges (1 mm) similar to those used in the original JET lamella experiment. The limiter tile is viewed by high resolution IR and experiments are run with ohmic inner wall limiter plasmas so that the LCFS intersects the special tile at grazing incidence. The special tile has a chamfered, rooftop-like design with face angles of 5° and 10° to provide well defined total incidence angles. Particle-in-cell simulations using the in-house code SPICE have been used to model the expected edge loading and have been compared with the IR measurements, themselves corrected using deconvolution methods (CEA/IRFM) to account for the smoothing effect of finite IR spatial resolution in the presence of very peaked surface temperatures at the gap edges. The results demonstrate that the edge loading can be explained by classical ion orbit physics (including also an electron heat contribution, behaving purely geometrically), in contrast to the original JET misaligned lamella experiment. Guided by these first experiments, a new tile has been designed and experiments are planned in late November. This second iteration uses constant misaligned edges (compared with the poloidally varying leading edge in the first design), reduces the chamfer angle to 2.5° and includes larger surface areas without gaps to allow for better IR measurements of the background heat flux. One of the gaps is also preceded by a hollowed-out region to simulate the situation in the first JET lamella experiment and study whether or not this geometrical aspect might have been responsible for the anomalous edge loading found in those experiments.

**Plans for 2016**

* JET: experiments on the new special lamella begun in late 2015 (3 sessions) will be completed in early 2016 (experiment M15-32). No further experiments planned beyond this, but analysis of the new experiment expected to require most of 2016.
* AUG: 16 shots are planned within the EUROFusion experiment AUG15-2.2-1 to be executed in April 2016 during which the castellations similar to that installed on JET will be exposed in the outer divertor manipulator.
* KSTAR: further experimental time to be requested in the 2016 campaigns to improve on the initial results in 2015.
* DIII-D: exposures of a modified castellation set on the DiMES probe have been requested in the He campaigns to be executed in 2016. Issues of IR defocus have been resolved and the aim will be to repeat the initial L-mode plasmas and study ELM edge heat loading during He H-modes.
* Pilot-PSI: the device has been decommissioned following the move of DIFFER to Univ. Eindhoven. No new experiments possible in 2016.
* COMPASS: further experiments are planned using a retarding field analyser mounted in a new central column special tile, hopefully allowing study of the local ion parameters and to confirm or rule out the presence of epithermal electrons in support of code modelling and deeper physics understanding of the edge loading physics.

**Note on DSOL closure**

* Since the IO expects to decide on the W divertor monoblock surface shaping in the autumn of 2016, this DSOL coordinated task will be closed by the end of the year.