Annual Report of ITPA Topical Group on Scrape off Layer and Divertor

For the period July 2010 to December 2011

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Executive Summary

The SOL/Div Topical Group held two meetings during the reporting period, in Seoul, Korea, October 18-20, 2010 and Helsinki, Finland, 16-19 May 2011. It should be noted that the DivSOL TG did not hold a fall 2011 meeting, as the 16th meeting took place in early January 2012 instead, in connection with the selection committee for the International Conference on Plasma Surface Interactions (PSI). This last meeting is not reported here.

The DivSOL TG maintained its structure in 5 topical groups (fuel retention and removal, tungsten R&D, dust, heat loads and material migration) over the period. The research plan within these 5 topical areas has been revised periodically, with sub tasks created or closed to address the ITER IO priorities. Progress in the different research areas is reported in Section 2 of this document. Specific ITER IO activities (status of the PFC design, modelling of material migration …) are regularly presented, providing up to date information to the TG experts.

Selected scientific highlights over the reporting period are given below in the five areas. More details can be found in the summary of the meetings in Section 1, or in the table compiling the progress on the research plan in Section 2.

- Fuel retention and removal (leaders R. Doerner, J. Roth)
  - A first attempt was achieved to bring the molecular dynamics community into our field to improve the modelling of fuel retention in PFC. Although the models do not have yet a predictive capability on the time/space scale needed for PWI issues, they can be key to interpretative modelling. Possible applications to modelling of H transport in tungsten grain boundaries were discussed.
  - Fuel removal using flash heating was studied for beryllium (Be) and tungsten (W). It was shown to be less efficient than baking. In addition, flash heating of Be/W is found to be less efficient than flash heating of carbon. This appears to demonstrate that controlled (by massive gas injection mitigation) disruptions will not be a vehicle with which significant quantities of trapped fuel could be removed. Whether flash heating tends to drive the fuel deeper into the material bulk is still an open issue.
  - Fuel retention in gaps is confirmed to be significant in present day devices using carbon PFCs, due to codeposition. Results with Be PFC are now expected from JET and PISCES.
- Tungsten R&D (leaders A. Kallenbach, Y. Ueda)
  - Tungsten cracking has been shown to appear earlier under high cycle conditions (typically above 0.1 MJ/m2 for 10^6 ELM events). While tungsten cracking is not an issue per se as long as the heat exhaust capability is not degraded, the effects from combined exposure to D/T, He, neutrons should be investigated.
  - Tungsten fuzz was observed for the first time in a tokamak (CMod), showing the complementarity between PWI simulators, in which this issue was first evidenced, and tokamaks.

        - Combined edge physics effects have been shown to impact the W erosion processes. For instance, in PWI simulators, additional arcing or melting under ELM events has been observed on samples pre loaded with He, preferential arcing has been noted on samples where W fuzz was grown, enhanced ELM erosion was measured on samples pre loaded with D.
    - Dust (leaders : N. Ashikawa, D. Rudakov)
        - Coordinated dust injection experiments have been completed in most tokamaks involved. The increasing database needs now consolidation and parametrisation, for modelling purposes.
        - Tools for dust monitoring in tokamaks are progressing (semi automatic analysis operational in AUG).
    - Heat loads (leaders : M. Lehnen, A. Leonard)
        - A large effort in EU and US was dedicated to a multi machine study of SOL width in attached low recycling regimes, using standardized analysis of inter ELM heat flux profiles. The SOL width scaling derived from this study shows a 1/Ip dependence, leading to narrow SOL predictions for ITER (λ_q~ 1-2 mm). Whether this value would be consistent with pedestal stability considerations is still an open issue. This work needs to be extended to high recycling/partially detached regimes.
        - First results on ELM mitigation were obtained in AUG, showing that mitigation is obtained with n=2 perturbation, in contrast with the simple criterion. No pump out is observed when N_2 seeding is used.
    - Material migration (leaders : V. Philipps, P. Stangeby)
        - Modelling of Be migration by IO shows concerns for the Be blanket lifetime : benchmarking experiments are under active preparation within the community (MAPES in EAST, JET ILW, PISCES) .
        - First Be exposure to ELM like heat loads were performed in QSPA, showing a melting threshold at 0.5 MJ/m^2.
        - Be seeding experiments in PISCES still show large uncertainties in Be erosion yield.

The status of collaborative DSOL experiments is reviewed in Section 1.3. 5 DSOL proposals are running, 6 were proposed for closure.

After the January 2012 meeting, the next meeting of the Div/SOL Topical Group is planned in San Diego, US, October 2012, coordinated with the timing and location of the IAEA Conference. It will include joint sessions with other TGs (Pedestal, MHD, Energetic Particles).

Finally, the TG leadership changed on December 1st 2011 (new TG chair : E. Tsitrone, co chair : H. Guo, IO co chair : R. A. Pitts). The new leadership would like to take this opportunity to warmly thank the previous chair B. Lipschultz, who has been serving with talent, enthusiasm and dedication the DivSOL TG community for the last decade.

Contents

1. Meetings and reports

The summary report and all presentations given at the 14^{th} and 15^{th} meeting of the ITPA Div/SOL TG, can be found under the ITER IDM web site and only the executive summary is repeated here.

1.1 Report on the 14^{th} Meeting of the ITPA SOL and divertor physics Topical Group, Seoul, Korea

The meeting was held over the period October 18-20, 2010 in Seoul, South Korea. The local coordinator was Professor Na for the first day when the meeting was at Seoul National University. The second and third days of the meeting were held at Hanyang University, hosted by Professor Kyu-Sun Chung. We are in debt to both organizers for their efforts and those of their staff. The meeting lasted 3 days and was split between discussions on the SOL/Div R&D plans in support of ITER urgent needs and several research topics. There were over 50 participants.

ELM physics and ELM heat loads

A joint session between SOL/Div, MHD and Pedestal groups was held to review our current knowledge of edge localized mode (ELM) physics and their heat loads to material surfaces. The ITER assumption for rise/fall times of the divertor ELM heat load was a ratio of ~1, but the new data indicates a longer fall time thus lowering temperature rises. ITER has also been assuming that the heat load footprint on the divertor for type I ELMs was the same as between ELMs – the data indicated a scaling of broadening which increased with ELM energy. The implication of a combined scaling from DIII-D and JET tokamaks was that some broadening would occur (up to a factor of ~4). Any implied increase in the maximum allowed ELM power is still small compared to the projected 20 MJ ITER ELMs implying a strong need for continued development of ELM mitigation. What was very clear is that more heat load footprint data, both on the divertor plates AND on the first-wall, is needed in order to make better predictions of plasma-facing component (PFC) lifetime and the requirements on mitigation techniques and PFC design. The joint nature of the session will hopefully reinforce the collaboration amongst the various groups in designing IEA/ITPA proposals.

Disruption physics

A similar review of disruption physics was held jointly amongst the SOL/Div, MHD and Energetic Particle groups. The poloidal and toroidal asymmetries engendered during massive gas injection (MGI) mitigation of disruptions are much better characterized as a result of recent work – the concern appears largest for toroidal asymmetries (of order 2) in terms of the total energy asymmetry, with the asymmetry lasting through the thermal quench. The data from ASDEX-Upgrade (AUG) implies that the toroidal asymmetry is higher for He than for higher Z gases. Runaway electrons are much more poorly characterized, which is in contrast to the importance of the threat on ITER of melting deep within PFCs. There are several models (e.g. NIMROD), which may be applicable to predicting load amounts and locations. Several mitigation techniques were discussed including injection of gas, reversal of the loop voltage and stochastic magnetic fields.

Fueling

Fueling of the plasma was the subject of a short joint session amongst Div/SOL, Pedestal, Integrated Operation Scenarios (IOS) and, Transport groups. A working group is being formed by A. Loarte (ITER), and he will solicit representatives from all relevant ITPA groups.

Fuel removal

Ion cyclotron discharge cleaning (ICWC) has been the subject of major research effort over the last 3 years. Results were presented from KSTAR, which supported this removal rate. The maximum hydrogenic [and thus projected tritium (T)] removal efficiencies have been of the order of 10^{18} $T/m^2/s$, achieved both at high power with He-ICWC (e.g. Tore Supra) and also using the mixture of H-He ICWC (a number of tokamaks). Based on the session discussion it is not clear exactly how the ICWC works; chemical erosion leading to material removal for flakes or near surface cleaning through isotope exchange are leading explanations (in carbon dominated machines). It is also not clear how well ICWC will work with Be layers and how uniform in terms of ion fluxes the method is.

It was suggested (V. Philipps) that that the ICWC cleaning efficiency could be improved through biasing of the important surfaces. A new technique, high-frequency glow discharge cleaning (HFGDC) was presented by EAST representatives which may be an alternative to ICWC for full-field surface conditioning, but it is not yet clear whether it can be made uniform nor what its T removal rate might be. It would have the advantage of control over the ion impact energies through the cathode bias.

Oxygen bake has been applied to multiple tokamaks over the last few years in addition to lab studies. The removal rates can be 2-3 orders of magnitude higher than ICWC but it was clear from this meeting's discussion that O-bake could only be used with great difficulty (and much added cost) on ITER due to the creation of non-negligible quantities of highly tritiated water and the considerable safety issues raised, none of which are included in the current ITER safety case. An alternative method was presented involving the use of NO_x such that tritiated water may not be an issue (still to be shown conclusively) and only the C removal rate was shown – more information is needed.

An update to the effect of the formation temperature on T retention and removal of mixed Be layers (with C and W) was presented. An IPP-Garching-PISCES study of the trade-offs between operating and baking temperatures is needed. An additional update on T retention in nuclear-damaged tungsten was also presented by the FOM group.

Tungsten

Crack growth on tungsten surfaces under ITER-relevant ELM repetitive heat loads in most cases saturates with the largest cracks forming at grain boundaries and small ones being intra-granular. Raising the surface temperature over a few hundred degrees C reduces crack growth. Modelling of the crack growth using the MEMOS code appears to do a reasonable job of matching the data. A new joint EU/Russian study using the Russian QSPA and e-beam facilities in TRINITI and Efremov to expose EU-supplied water cooled ITER W mono-block mock-ups to alternate transient (plasma ion) and steady state heat loads (electron beam) was reported at the meeting. Plasma-induced damage enhanced crack growth was observed, with the largest width cracks to date (0.3 mm) and less saturation of crack width. Detailed studies of melt layer formation in TEXTOR point towards J×B forces moving the melt layer, although the effect of plasma pressure cannot be ruled out under some conditions. Melt layer dynamics are also fairly well reproduced by modelling.

A study of blisters using a focused ion beam demonstrates that the blister cover tends to be ~one grain thick and can be elastic. It would imply that gas is accumulating along grain boundaries much farther into the surface than implantation (~5 nm). A new effort at the IPP-Jülich is experimentally determining S/XB rates from measurements of known W injection rates. New investigations of material migration were reported from JET (^{13}C) and C-Mod (tungsten). As has been observed before, most of the injected ^{13}C gas is either deposited locally near the injection point or pumped away. The JET results are still under analysis. The C-Mod results for toroidally uniform W source at the outer divertor point towards natural migration through the common SOL to the strike point, which means the W is finally deposited in the private flux region of the outer and inner divertor (likely E×B drifts transport the W to the inner divertor). An initial attempt at modelling Be migration to shadowed regions of shaped first wall panels in the secondary divertor regions of ITER was reported.

Dust collection

Results of dust collection efforts on a number of tokamaks (TEXTOR, JET, JT-60U) and PISCES-B were reported. As in previous meetings, the conversion of gross erosion to dust production is the measure that is needed at the moment. The data presented still supports values of the conversion factor << 1. More localized measurements are needed at least between discharges correlating transient events and the appearance of dust on some collection diagnostic. A novel automated SEM/EDX statistical analysis was performed on AUG dust. Most dust was composed of tungsten with other materials also present. The size distribution peaked around 0.2 microns.

1.2 Report on the 15th Meeting of the ITPA SOL and divertor physics Topical Group, Helsinki, Finland

For its 15th meeting, members of the ITPA Divertor and Scrape-off Layer (DivSOL) Topical Group (TG) gathered from 16 – 19 May in Espoo, Finland at the Dipoli Congress Centre. This is the first time the group has met in Finland and is a reflection of the now firmly established presence of the hosts, Aalto University and VTT Technical Research Center, in the field of plasma-wall interactions (PWI).

Meetings of the DivSOL TG are traditionally extremely well attended, reflecting the size of the PWI and edge physics community, and this 15th assembly was no exception, with more than 60 participants. The summary is divided into the main topics discussed at the meeting.

Hydrogenic retention in materials

The primary modeling done by our ITPA members to estimate tritium (T) retention in tungsten is based on diffusion trapping codes. These are empirical based models using assumed activation energies for the hydrogenic (H) traps and their number density. While such codes can treat the large time and spatial scales of retention in W tiles, they are limited in the proper treatment of the various sinks and transport of H in the lattice. At this meeting we asked another class of modellers to join

and educate us about more basic codes - ones that utilize molecular dynamics (MD) or density functional theory (DFT) approaches. The DFT calculations work at the smallest spatial and time scales to provide a basic modeling of the electrostatic lattice potentials for different situations (e.g., different kinds of traps in W and different atomic lattice potentials for He or H). The MD models can use the potential information to model the evolution of the traps – their diffusion, growth and annihilation. The drawbacks are their short timescales (ps) and spatial sizes (e.g.100s of atoms). For example, the size of the area modeled does not allow for grain boundaries. It is difficult (not possible yet) to derive the lattice potentials for high-Z materials. There is also no model for what happens to the lattice near the surface where the H implantation flux is so high that the local neutral density is much higher than the solute-allowable density. All of the above limitations appear to be under study at the many institutions worldwide but it is not clear how long it will take to address such limitations. On the other hand we were told that a more integrated approach of bringing models together having different time and spatial scales (e.g., the work by the Helsinki group presented by Heinola) is our current best possibility of taking into account microscopic attributes of the material on the spatial and timescales needed for fusion. There were also detailed discussions of how MD models could be applied to graphites and processes of carbon/hydrogenic co-deposition.
There were several experimental investigations of fuel retention and removal reported. More recent work showed that the retention properties of the material were not altered by the surface heating. Laser heating of co-deposited H-C has been shown to be quite efficient. More recent work showed that the retention properties of the material were not altered by the surface heating. Laser heating of W and Be plasma-facing component (PFC) surfaces has also been investigated. The fuel removal efficiency is not as good as for laser heating of C in that the fraction of retained H that was removed was typically below 50% (sometimes closer to 10%). Modelling of flash heating of W with absorbed H indicated that the heating may cause the H fuel to be driven further into the bulk instead of to the surface and released. A new study of H retention at neutron damage sites was reported with results similar to past studies for ion-induced damage. It is hoped that the next meeting will have presentations on the use of isotope exchange for fuel removal from laboratory experiments.
Fuel retention in the gaps between tiles is clearly a significant fraction of fuel retention in current tokamaks and likely will be for ITER. Previous studies showed that the retention is dominated by co-deposition (when C is present); the areal density drops off as a function of distance from the front surface along the tile side, yielding an e-folding decay length of several times the gap width. The newest study from JT-60U confirms these characteristic of retention in tile gaps. Assuming toroidal symmetry, it is inferred that the amount of T in gaps would be roughly 1/5 of that on the front surface. It is not clear how this projects to ITER. Further work with Be (e.g.,in JET) will determine if the co-deposition of fuel with Be has the same properties as for H-C layers.

Dust formation and transport
The investigation of dust has been primarily through two avenues: analysis (postcampaign) of the dust found in the tokamak, and experimental observations of the trajectories of injected dust (DSOL-21). An automatic procedure of a SEM/EDX device has been developed (IPP-Garching) to obtain statistically relevant distributions of dust, allowing a reconstruct of the distribution function for different species of dust. This technique has been applied to ASDEX-Upgrade (AUG) and will be applied to dust from other tokamaks. New dust collection diagnostics are being installed on a few tokamaks as well. The experimental work of DSOL-21 is now done as the last experiments with the same pre-characterized dust on LHD, DIII-D and Textor are completed. The next step in the dust work is comparison to code results and models.

Heat flux width on divertor plates
Over the past year there have been parallel efforts in the EU and US to coordinate research on divertor-plate heat flux widths in current machines in order to identify the most important factors

determining the width, thus helping understand the physics of heat transport across and parallel to the magnetic field. There is general consensus across the machines (AUG, C-Mod, DIII-D, JET) that the steady state (between ELM) divertor footprint scales inversely with plasma current (Ip), and in this first analysis, independent of device size. More work is needed to bring all contributions to these scalings into line as to how the widths are measured and entered into the database. Furthermore, the discussion resulted in general consensus that the upstream profiles are needed for the same discharges to better understand the heat transport both parallel and across the magnetic field.
The analysis of heat load footprints during ELMs is less developed. While data has been collected at a number of machines, there was only one presentation of an initial analysis of DIII-D data.
One session was dedicated to models of the steady-state heat footprint. The general review of models applied to JET data found some that led to scalings that roughly approximated the data. The best overall match to data was with a combination of parallel electron conduction and drift ordered (Gyro-Bohm) radial convection. One particular drift-based model (Goldston) appeared to match JET and AUG data very well and also, when applied to the US and EU data gave a good match. This model reproduced the 1/Ip scaling observed in experiment.

Divertor-plasma detachment
We received an update on the status of modeling of divertor-plasma detachment. There are some hints that variations in classical particle drifts and chemical sputtering rates offers a better match for the onset of detachment at the inner and outer divertor plates as well as the details of the detached plasma (e.g., amount of recombination light and location of the ionization front). However, there was general agreement that it was very possible that some basic physics is missing from the codes. The suggestions of missing physics centered around cross-field transport – due to turbulence (using the Braginskii fluid equations), which could lead to large convective transport. Such processes would have the effect of reducing the heat arriving at the strike point region, thus bringing on the detachment onset at earlier separatrix densities.

Impurity production at material surfaces
With respect to general modeling issues, a review was presented of the sheath treatment of impurities coming from a surface and the formation of the magnetic presheath. In the last year has been surge of activity in the area of modeling material erosion and subsequent impurity migration. The most important aspects of the new plasma transport code development concerned extending the grids to the PFC and wall surfaces, and having local models for the plasma wall interaction. These two aspects are crucial to determine what the relative fraction of local re-deposition of eroded material vs long distance migration is occurs. The local geometry of the surfaces and the density of the plasma (setting how far from the plate the neutral goes before being ionized) are the primary determining factors involved, and it was agreed that better investigation of local density and source rates are needed to be coupled to the codes for benchmarking them and reducing the current large uncertainties in predictions. The local plasma surface interaction models used varied from point models (0D with local sections of the wall connected by probabilities in WallDyn) to local 3D Monte Carlo with ERO.

Tungsten damage
A number of experiments aimed at examining damage W under heat loads were reported. When the number of repetitive heat loads (ELM-like) is in the range of 10^5 to 10^6, the energy threshold for crack formation drops as low as 0.13 MJ/m2. Such cracks, by themselves, may not be a concern in that they effectively form castellations on the surface.
Of more concern is the effect of melting. Laboratory experiments aimed at understanding melt-layer evolution continue to identify JxB forces as the primary force moving molten W around on the surface. Modelling reproduces the basic aspects of this movement. Unfortunately, in addition to

raised surfaces which become leading edges, melting also leads to degraded bulk material characteristics such as grain structure, creation of voids, and general decrease in ductility (more cracking and potential for failure). It was also found that pre-exposure of materials to He ion fluences reduced the melting threshold in W and Mo.

1.3 IEA/ITPA multi-machine collaborations

A detailed DSOL report for 2011 and DSOL proposals for 2012 have been provided for the Coordinating Committee meeting in December 2011.

The status of the DSOL experiments is summarized below, in the 5 topical areas of the DivSOL TG. The color coding is the following : red : closed DSOL, blue : ongoing DSOL, green : new DSOL since last report.

Fuel retention and removal

DSOL-12 Reactive gas wall cleaning (P. Stangeby), closed

DSOL-23 Efficiency of ICRF Conditioning (D. Douai), ongoing

Proposal : JET, AUG, TEXTOR, KSTAR and TORE SUPRA

DSOL-27 Mitigation of fuel accumulation and impurity deposition in the gaps of castellated structures (A. Litnovsky), ongoing

Proposal : DIII-D, TEXTOR, ASDEX Upgrade, EAST, LHD, KSTAR, Tore Supra and Pilot PSI/Magnum PSI.

Dust

DSOL-21 Introduction of pre-characterized dust for dust transport studies (D. Rudakov), closed

Heat loads

DSOL-20 Transient divertor reattachment (R. Pitts), closed

DSOL-24 Disruption heat loads (E. Hollmann), ongoing

Proposal : ASDEX-U, C-MOD, DIII-D, JET, MAST, NSTX, TEXTOR, and Tore-Supra

Material migration

DSOL-2 Injection to quantify chemical erosion (S. Brezinsek), closed

DSOL-9 Tracer injection experiments to understand material migration (V. Philipps), closed

DSOL-26 Marker experiments to study material migration (S. Brezinsek), ongoing

Proposal : JET, ASDEX-Upgrade, DIII-D, TEXTOR, C-MOD

Tungsten

DSOL-25 Melt layer motion and disintegration, droplet propagation and resulting impact on plasma performance (J. Coenen), ongoing

Proposal : ASDEX-Upgrade, TEXTOR, C-MOD, LHD, JET (2012-2013)

Joint Modelling :

DSOL-22 Multi-code validation against experiment for improved detachment modelling (M. Wischmeier):

Unfortunately, due to issues mostly connected with resources and to some disaccord as to exactly how the benchmarking should be performed, this joint modeling initiative has not progressed beyond the initial stages of model set-up and some joint video-conferences among the involved partners. We have thus decided to close it and the activity has restarted but this time under the auspices of collaborative work at JET, with several ITPA regular members contributing in addition to IO staff. Comparisons are being made between the codes EDGE2D-Eirene and SOLPS (B2 or B2.5 coupled with Eirene) for JET high and low triangularity configurations and for pure vertical target equilibria with both carbon walls and in the ITER Like Wall environment (Be/W). First results from this exercise will be presented at the 2012 PSI Conference.

Ongoing DSOL, with new experiments planned in 2012, include : DSOL23 on ICRF conditionning, DSOL24 on disruption heat loads, DSOL25 on melt layer motion and impact on plasma operation, DSOL26 on marker experiments for material migration studies, and DSOL27 on fuel accumulation in gaps of castellated PFC structures.

DSOL2, 9, 12, 20, 21, 22 have been closed.

2. High Priority Research Areas

As in the previous report, the DivSOL group has maintained a core activity in the current period along the same five priority areas identified at the beginning three-year plan leading up to the end of 2011. These are Fuel Retention, Heat Fluxes, Tungsten, Dust and Migration. Special Working Group Leaders were appointed at the beginning of this period, to follow through on a series of sub-tasks selected on the basis of the IO Research Plan priorities set out in 2009. The tables below have been selected from the report delivered to the ITPA CC in Dec. 2011 (on IDM at: https://portal.iter.org/departments/POP/ITPA/CC/CCCTP/Documents/2/Presentations/03-01-Lipschultz.pdf) which provided a review of the progress made over the reporting period in the five priority areas. The colour coding follows the same convention as that adopted from the beginning of this system within the Topical Group. Namely green cell colours correspond to areas where significant progress has been achieved since the Task Groups were established, orange to areas in need of re-energising or re-orientation and grey to subtasks whose objectives have been reached and the task is proposed for closure. As before, the priority indicator in the final column remains unchanged from the 2009 report and is derived from the priorities set in the IO PWI research plan on which the R&D tasks are based. The comments accompanying each column give more detail of the specific topics covered in each research area.

Tritium retention and removal

	R&D type	Timescale
1	Report	Short (1-2 yr)
2	DSOL	Medium (2-4 yr)
3	DSOL-12	Medium (2-4 yr)
4	DSOL	Medium (2-4 yr)
5	Report	Short (1-2 yr)
6	DSOL	Short (1-2 yr)
7	Collaboration	Short (1-2 yr)
8	DSOL-27	Medium (2-4 yr)
9	Collaboration	Short (1-2 yr)

1. Refine ITER prediction (MIT mini-meeting)
   - Report completed, closed
2. Fuel retention machine database
   - Ok for carbon machines, metal machines starting
3. Ion cyclotron wall cleaning
   - Disruption recovery. HF Glow discharge? DSOL-23
4. Disruption flash heating
   - No significant release from Be/W → closing
5. Capability and risks of removing carbon
   - O baking performed - Report to be prepared → closing
6. Isotope exchange
   - Ongoing. Lab experiments to be reported in next SOL/Div mtg
7. T removal by heating to 350°C
   - Sufficient progress : closed
8. Retention in gaps
   - New focus on mitigation of fuel retention in gaps (DSOL-27)
9. Influence of mixed species on retention
   - Sufficient progress : closed

Dust

R&D type	Timescale
Tok. expts. & post-mortem studies	Medium (2-4 yr)
IO coordinated	Short (1-2 yr)
Lab. collaboration	Medium (2-4 yr)
DSOL-21	Short (1-2 yr)
Coordinated diag. development and code testing	Short (1-2 yr)

1. Characterization of dust production rates, conversion factor of erosion/damage to dust production
   - dust collection ongoing (JET) but no progress on production rate. PSI simulators ?
2. Characterization of ejection velocities, molten droplet size & morphology/size distributions of dust with high load
   - Results from QSPA but wider participation needed
3. Study the role of T-removal techniques in dust creation
   - No obvious progress → closing ?
4. Cross-machine studies of dust injection
   - Good progress – energised by DSOL – most experiments performed, modelling effort ongoing - closing
5. Dust measurements and modeling
   - New diags being installed, to be reported at next meeting

Heat fluxes

	R&D type	Timescale
1	Tok. expts., collab. PEP?	Medium (2-4 yr)
2	Tok. expts., model development	Short (1-2 yr)
3	DSOL-20	Medium (2-4 yr)
4	Tok expts	Medium (2-4 yr)
5	Tok. expts., database + PEP collab. + US ReNeW	Short (1-2 yr)
6	New DivSOL task force	Medium (2-4 yr)
7	IO coordinated	Short (1-2 yr)

1. Natural and mitigated ELM characteristics
   - Results from DIIID and AUG. Broadening vs ELM size? Consistent analysis needed (AUG, JET, DIIID) to build ELM heat flux database
2. Disruption heat loads
   - New data reported at next meeting. Coordinated with MDC ITPA
3. Transient detachment control
   - No new data : stimulation required (concern if narrow SOL). Plans for C-Mod and DIIID. JET ILW?
4. Far-SOL heat and particle fluxes
   - No progress. Encourage data during ELM mitigation experiments.
5. Divertor and SOL inter-ELM heat fluxes
   - Good progress in inter ELM target data for low recycling (US and EU effort). Upstream profile + high recycling
6. Modelling detachment
   - No consensus on best approach to improve detachement modeling. AUG/JET/ITER modelers will continue: closed
7. Ramp-up/ramp-down heat loads
   - Data reported from TS. New data now from JET. Multi machine comparison to be initiated (RAP)

Material migration

R&D type	Timescale
Tok. expts., + modelling DSOL-09	Medium (2-4 yr)
Tok. expts., + modelling	Short (1-2 yr)
Tok. expts., + modelling	Medium (2-4 yr)
DSOL27 + modelling	Medium (2-4 yr)

1. Cross machine comparisons of main wall erosion and local re-erosion and co-deposition
   - Marker tiles + tracer injection (^{13}C, WF_6). Awaiting post mortem analysis
   - First result on Be migration from JET ILW
2. Development of local models taking into account surface shaping and attempting to predict the observed deposition patterns for both steady (diverted operation) and limiter start-up/ramp down phases
   - Modeling effort started (wall models applied to JET and ITER)
   - Dedicated EAST migration experiment
3. Characterise outer and inner divertor erosion as well as the movement of impurities from main chamber to divertor and from divertor to divertor
   - No new data reported
4. Understand driver of fuel retention in gaps – dependence on material, flux, temperature
   - Comparison carbon / metals

Tungsten

R&D type	Timescale
Model, design, report	Medium (1-2 yr)
DSOL-25	Short (1-2 yr)
Lab. expts., report	Medium (2-4 yr)
Lab. Tok. expts., report	Medium (2-4 yr)
Tok. expts., report	Short (1-2 yr)
Tok. expts., report	Medium (2-4 yr)
Code development	Medium (2-4 yr)
Lab. expts., report	Short (1-2 yr)

1. Impurity production by ICRH
   - Experiments on AUG, C-Mod started – new antenna designs
2. Effect of divertor target damage on device operability
   - Experiments performed in linear devices + TEXTOR, AUG, LHD. Further experiments planned in AUG and JET
3. Tritium permeability and retention in neutron-damaged W
   - More an issue for DEMO than ITER ? Closed
4. Investigation of surface morphology changes (W fuzz, cracking), blisters and material mixing
   - Closed
5. ELM impurity sources vs. flushing
   - driven more now by pedestal TG and new ITER Contract: closed
6. Power load control by low-Z seeding
   - Different impact on confinement depending on impurity / device: further studies needed w/pedestal group
7. Edge modeling including W and Be/W
   - Ongoing, but difficult task, to be handled with material migration
8. Mixed impacting ions species and H retention
   - See Migration work plan

3. Future meetings

The 16th DivSOL meeting took place in Juelich, Germany, in January 2012. The next meeting of the Div/SOL Topical Group will take place in San Diego, USA, in October 2012, coordinated with the timing and location of the IAEA Conference. The Div/SOL TG is aiming at organizing targeted working sessions in small groups with other TGs, rather than plenary joint sessions. Proposed common topics could include disruptions, with a particular focus on runaway electrons (with energetic particles and MHD), SOL width (with Pedestal) and ELMs (with MHD and Pedestal).

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K Krieger, T Lunt et al.
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