DSOL-37 Effects of 3-D fields on divertor conditions and plasma material interaction as compatibility issue of RMP ELM control in tokamaks

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| **TG priority:** High | **Start date:** 2016 | **Status:**  New | **Personnel exchange:**  yes |
| **IO priority:**   | **End date:** open | **Motivation:** Compatibility of RMP ELM control |

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| **Device /Association** | **ContactPerson** | **2016 TGRequest** | **Activity (from JEX/JA spreadsheet)** |
| **2016** | **2017** | **2018** | **2019** |
| UW Madison | O. Schmitz |  |  |  |  |  |
| AUG | T. Lunt | Desirable |   |   |   |   |
| COMPASS | P. Cahyna | Desirable |   |   |   |   |
| DIII-D | A. Briesemeister | Desirable |   |   |   |   |
| EAST | L. Wang | Desirable |   |   |   |   |
| JET | D. Harting | Desirable |   |   |   |   |
| KSTAR | S.-H. Hong | Desirable |  |  |  |  |
| LHD | M. Kobayashi | Desirable |  |  |  |  |
| MAST | A. Kirk | Desirable |  |  |  |  |
| NSTX-U | J.-W. Ahn | Desirable |   |   |   |   |
| W7-X | M. Jakubowski | Desirable |   |   |   |   |

**Purpose**

This new task will launch a coordinated activity to address the compatibility of ELM control by use of resonant magnetic perturbations (RMP) in tokamaks with the plasma boundary solution and the plasma material interface. The task is setup to address issues rose by the ITER STAC and is intended to complement and work alongside separate tasks that exist and will be established by the Pedestal TG. The approach taken will incorporate stellarator devices from the beginning to establish a common knowledgebase on 3-D field effects for divertor physics and plasma material interactions (PMI) and benefit from the existing large knowledge on the topic in the stellarator community.

The achievement of RMP ELM control on several large-scale tokamak devices was shown being connected to breaking of the assumed axisymmetry of the plasma boundary and the resulting PMI. Striated divertor target heat and particle flux pattern have been measured and modeled, deformations of the plasma electron density and temperature fields were shown and counter-streaming plasma flows are being predicted and have been observed. The impact of these combined experimental and numerical results pose the question to which extend these and more elements of the impact of RMP on the plasma boundary might alter the divertor conditions and eventually the PMI. The counter streaming plasma flows suggested by modeling for instance represent likely an enhanced momentum sink, which might affect the upstream/downstream momentum loss factor when approaching detachment. In stellarators, this was shown to facilitate detachment at higher temperatures before volume recombination becomes a crucial energy dissipation mechanism. This has the potential to stabilize detachment. At the same time, however, the level of 3-D structure obtained and the actual heat fluxes inside of the perturbed topology is likely to yield deposition of significant heat fluxes outside of the flux pattern expected in case toroidal axisymmetry is maintained which results in a rapid and toroidal symmetric decay of the heat flux deposition profile on the target. Last but not least, the 3-D divertor flux pattern is likely to alter the divertor erosion profile and also the migration of the eroded impurities, which will impact the deposition balance. The striated flux pattern feature a significant angle with respect to the toroidal guiding field, which can yield a decoupling of the erosion and prompt re-deposition location. This potentially can enhance the gross erosion and reduce divertor life-time. These examples give a framework of issues, which this new task will be concerned with. Concrete aspects are suggested below in style of deliverables to stimulate thinking on the most critical aspects to be addressed in this task and are ordered along the three spatial domain plasma edge, scrape-off layer and plasma material interface are:

* **Plasma edge domain (last closed flux surface inwards covering the perturbed magnetic topology)**
* Assess feedback of plasma response to the perturbed boundary structure and transport
* Assess the impact of the perturbed topology on the radial electric field and the toroidal flow patterns
* Assess connection of plasma edge response to global and local plasma response signatures (global 3-D equilibrium vs. local resonant screening possibly driving reconnection)
* Resolve the level of broadening of scrape-off layer into the formerly confined domain by magnetic field stochastization.
* **Scrape-off layer domain**
* Resolve existence of counter-streaming sonic flows and their relation to detachment.
* Assess impact of perturbed boundary on neutral and impurity (helium) fueling and exhaust.
* Assess impurity transport and divertor impurity retention with 3-D plasma boundaries.
* Resolve role of magnetic field structure for impurity radiation distribution and the impact on divertor power dissipation in radiative assisted divertor scenarios.
* Assess the role of increased radial electric field due to field stochastization on ExB particle drifts in the divertor including addressing the impact on detachment asymmetries.
* Assess compatibility of the 3-D boundary structure and its transport features with pellet fueling and ELM control by pellets.
* **Plasma material interface**
* Document and understand geometrical features of divertor flux striation and link to plasma response including assessment of heat vs. particle flux striation and their dependence of plasma collisionality in the divertor domain.
* Assess the plasma potential in front of the material surfaces with 3-D striated divertor flux pattern and assess impact on material erosion and re-deposition (possibly enhanced ExB drifts).
* Assess efficiency of rotation of the RMP fields for smearing of the striated heat and particle flux pattern and the resulting erosion.

In order to link results on these deliverables (and more) between participating devices and ultimately make extrapolations to ITER, suitable modeling approaches have to be available. One goal of establishing this task is to asses which models are available, being applied and validated against experiments and in how far it is possible to establish a common suite of models on all participating devices to reduce systematic uncertainties from modeling when comparing results. This approach would at the same time establish a path to setup a modeling suite, which enables more robust extrapolations towards ITER.

The goal of the initial phase of this task is to assess where the devices involved stand with respect to these aspects (and more to be discussed on the ITPA DSOL meeting where the task will be launched). This shall happen in form of direct input from the representatives of the different devices and also by literature survey. Within the first half-year period, this assessment will be finished and the framework plan presented here will be enriched with concrete deliverables on the specific topics settled on.

The devices involved have complimentary capabilities with respect to RMP setups, plasma regime, wall material and divertor shape and diagnostic capabilities. We expect that this setup will enable obtaining a more coherent picture about the actual impact of 3-D fields on the divertor conditions and PMI. The analysis of these data, which will be gathered by toroidal localized diagnostics in a 3-D environment, requires appropriate full 3-D modeling of plasma transport and also of the resulting PMI. The EMC3-EIRENE fully 3-D plasma fluid and kinetic neutral transport code will be used. A critical element of this task is to validate the model against the targeted data sets obtained and provide input for further code improvement and development. Also, the data set obtained will serve as basis for development of new approaches to deal with fully 3-D modeling of the PMI. While many sophisticated PMI models like ERO, DIVIMP, MCI and others are intrinsically fully 3-D, the plasma wall geometry and plasma background used is mostly simplified under the assumption to axisymmetry. In this regard, the models available are numerically capable to asses PMI in full 3-D and moderate enhancements are likely being sufficient to bring those models to full 3-D capacity for analysis of the data sets obtained. A validated code or code set addressing 3-D edge transport, divertor fluxes and the resulting PMI will enable to extrapolate the results from this task towards ITER.

***Modeling representatives:*** *the role of the modeling representatives will be to be point of contact for the models listed and coordinate inclusion of the specific modeling efforts into the work under this task. Main goal of this approach is to attempt a common development of all numerical tools listed (and additional which might be identified by or even emerge from action) for coherent analysis and interpretation through modeling as well as developing capability for more robust extrapolation towards ITER.*

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| **Model** | **Purpose** | **Representative** | **Users**  |
| EMC3-EIRENE | 3-D edge plasma fluid and kinetic neutral transport, trace impurity | Y. Feng | Frerichs, Hasenbeck, Hinson, Hoelbe, Kobayashi, Lore, Lunt, Rack, Schmitz, Waters, … |
| ERO | 3-D PMI and trace impurity, dynamic surface model available | A. Kirschner | Borodin, Ding, … |
| DIVIMP | 3-D impurity transport | P. Stangeby | ? |
| MCI | 3-D PMI and 3-D impurity transport | T. Evans |  Starting again |
| M3D-C1 | Plasma response, single and two fluid MHD | N. Ferraro | Canal, …. |
| JOREK | Plasma response, two fluid extended MHD | M. Becoulet | Orain, … |
| MARS | Plasma response, two fluid extended MHD | ? | ? |

**Plans for 2016**

Immediate plans for the first year are mainly focused on a coherent assessment of the status of work in the field on all devices. We want to find out across which divertor regimes which trends have been found with respect to canonical observations, which will be our guideline assessment for the effects of 3-D fields. The following spreadsheet shows a layout of the critical observations and parameters we want to use in this initial survey, which will establish the basis for the future work.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Device** | **Striation** | **e\* dep.?** | **plasma response** | **pump out** | **energy loss** | **impurity content** | **impurity source** | **EMC3-EIRENE** | **PMI modeling** |
| **ASDEX-Upgrade** |  |  |  |  |  |  |  |  |  |
| **COMPASS** |  |  |  |  |  |  |  |  |  |
| **DIII-D** | yes | yes | relevant | yes | some | constant | increase | Yes, regular | starting |
| **EAST** |  |  |  |  |  |  |  |  |  |
| **JET** |  |  |  |  |  |  |  |  |  |
| **KSTAR** |  |  |  |  |  |  |  |  |  |
| **LHD** |  |  |  |  |  |  |  |  |  |
| **MAST** |  |  |  |  |  |  |  |  |  |
| **NSTX-U** |  |  |  |  |  |  |  |  |  |
| **W7-X** |  |  |  |  |  |  |  |  |  |

This survey will be accompanied by attempts on the devices involved to fill in gaps into this initial assessment and start to complete the database in particular with respect to modeling. This also involves comparison of available modeling results from EMC3-EIRENE or other codes on these devices and on the state of PMI research with 3-D fields.

* **ASDEX-Upgrade:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **COMPASS:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **DIII-D:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **EAST:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **JET:**
* B15-10 (Effect of divertor plasma ergodization on radiative edge volume in the edgde, SC D. Harting)
* **KSTAR:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **LHD:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **MAST:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **NSTX-U:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited
* **W7-X:** experiments …. to address …. in 2016; status: planned, proposed, to be solicited