The challenge of surface and materials model validation in a tokamak

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1. Motivation

Plasma-facing materials and their modeling becomes an increasingly more important and difficult question as we move towards a fusion reactor. To date, excellent progress has been made in refining the physics contained within materials models through experimentation on linear plasma devices. Linear plasma devices offer some key advantages for model validation such as independent parameter control as well as flexible and extensive diagnostic access. US linear plasma devices such as PISCES, TPE, DIONISOS and others are integrated well with other devices in operation around the world such as MAGNUM-PSI, NAGDIS, and PSI-2 for coverage of a wide parameter space. Interactions and collaborations with these plasma devices and modelers have lead to a better coupling of materials and surfaces with edge plasma and impurity transport codes ([1] for example). However, linear devices are not perfect divertor simulators nor represent a complex and integrated environment such as a tokamak. While linear devices will continue to help refine these models, the next major challenge will be to validate surface and materials models in a tokamak.

In an integrated tokamak scenario, the strengths gained from linear plasma devices now become weaknesses. It can be difficult to do independent parameter scans in a tokamak, especially in the edge plasma where the plasma heat flux is linked to PFC surface temperature. Perhaps the greater challenge to materials model validation in a tokamak is the dearth of in-situ, materials diagnostics. In order to validate models in a tokamak, one would expect experimental data over a large area of the tokamak with *at least* a shot-by-shot time resolution. Currently the only material or surface diagnostics that can achieve anything close to this would be AIMS [2] in Alcator C-Mod, MAPP [3] in NSTX-U, quartz microbalances which can give real-time data on net deposition (or erosion) rates but only in remote locations, and some laser-based diagnostic techniques such as LIBS and LIDS. With the exception of AIMS and possibly the laser-based techniques, all these diagnostics, as well as materials evaluation systems such as DIMES and MIMES on DIII-D, are limited to a single location making even poloidal coverage difficult.

With limited diagnostic access and options for materials in a tokamak, validation of materials models in a tokamak will be a major challenge towards putting them in an integrated simulation. This is an area that needs to be addressed, as materials models will be of great importance on the path towards a fusion reactor since ITER will *not* create a "reactor-like" environment to understand material response.

2. Key Questions

The challenge of validation of materials and surface modeling in a tokamak can be broken down into three key questions for both the experimental and modeling communities:

i. *Is validation of these models in a tokamak even necessary?*

Can the entirety of the relevant physics and integration with edge-like plasmas be captured in current LPDs and/or other alternative platforms (e.g. e-beams, surface science stations, etc)?

ii. ***If there are key physics gaps between validation on LPDs and a tokamak, what are they and can these be filled by more advanced LPDs?***

What would be required of a LPD in terms of plasma parameters and operating space and geometry to close the identified key physics gaps? Can we envision a non-tokamak plasma device or combination of devices that could give sufficient model validation for implementation into a more integrated core/edge/wall simulation package?

iii. ***How can these models be validated and verified on a tokamak given the current limited scope and availability of in-situ, shot-by-shot discriminating material and surface diagnostics in tokamaks?***

Materials and surface modeling has to cover time and length scales across roughly 10 orders of magnitude to fully cover the important physics for integration into a tokamak and plasma edge scenario [4]. To be validated or verified in a tokamak, materials models need to reach time and spatial scales that are feasible to measure in a tokamak (100-1000 ms, 10-1000 μm) and integrate a "back and forth" between materials and plasma models. The dearth of in-situ diagnostics is a challenge for the experimental and diagnostics community but input from the modeling community is important to understand the priorities and need for specific measurements and resolutions. Perhaps measurements of direct material response is not needed and measurement of the plasma response to evolving materials is sufficient (i.e. the WallDYN concept)?

3. Impact

Model validation is important to identify and tackle key issues when projecting from current devices, and even ITER, towards a reactor environment. Materials modeling will be a key driver in setting the parameters and capabilities of a Fusion Nuclear Science Facility (FNSF) or a Component Test Facility (CTF). A fully integrated materials model would be invaluable in evaluating the feasibility of newly developed materials specifically engineered to withstand these extreme conditions. The limited scope of in-situ materials diagnostics in tokamaks is a serious challenge impacting both the experimental and modeling communities.

Failure to meet this challenge will lead to a hole in our understanding and predictive capability of materials issues for future devices and could seriously inhibit our progress towards a fusion reactor or any device beyond ITER. It is likely that operational experience on ITER will not help fill these holes since ITER is very non-reactor-like from a materials standpoint. ITER has water-cooled components, a mixed-material wall, pulse operation and a reduced neutron yield, none of which is expected in a reactor.

4. References

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