PAC-35 responses: M&P and Liquid Metals

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Detailed investigation of each wall-conditioning step & advanced planning

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is not sufficient to understand in detail the impact of the various wall conditions and coatings. The PAC recommends more thorough analysis, planning, and preparations that factor in the diagnostic and control capabilities required to support detailed investigation of each of the wall condition operational steps noted above. To support this, we recommend developing metrics for gauging success at each step in wall condition. We also recommend producing a thorough plan and anticipated schedule well in advance of the Research Forum, in part to maximally inform collaborator research proposal preparations. We note that the next opportunity for careful diagnosis of steps in wall conditions like this will not occur until 2018.

- I stick by my answer given at the PAC meeting:
  - The transition from one state of the machine to the next determined by run-time requests for different wall conditions.
  - We want to get TMB and LITER ready on day one so the physics experiments are not driven by the tool availability.

- Plasma conditions achievable by each conditioning step in this *new machine* will be established in the first run year (XPs should be realistic)

- Add to the XP planning process whether a researcher specifically requires pure-C, B, or Li-conditioning and run-coordinator schedules as appropriate (isn't this already done?)

Surface science experiments need to reflect tokamak conditions…

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performance. Therefore, it is critical for surface science laboratories to complement experiments in NSTX-U and in particular to the extent possible provide for conditions relevant to plasma shot operation (e.g. D energy, fluence, temperature, etc.). Therefore, experiments planned for lithium coating deposition at high temperature should be conducted closer to NSTX-U wall operation conditions, e.g. including D irradiation, to understand effects on hydrogen dynamic retention. It

- Agree that the collaborating groups with surface-science laboratory studies should conduct research relevant to understanding PMI processes with these mixed materials/complex situations

- But: *Understanding* the processes often means experiments in highly controlled conditions (e.g. single crystals) so appropriate models can be developed (e.g. understanding multicrystalline systems from single-crystal effects)

- (Feed-back for me that I should have made a stronger connection in this regard…)

Systematic approach to address wall conditioning…

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realistic materials systems), a systematic approach to connect plasma performance to the interface of the plasma and the wall surface must be established carefully. In particular, with an essentially new device in NSTX-U, erosion and re-deposition conditions must be identified with new plasma configurations. Whereas fast start-up and plasma confinement studies by wall conditioning such as the Li evaporation systems (LITERs) will be in high demand, systematic investigation of the effects of lithium deposition (amount and coverage) on the scrape-off layer (SOL), divertor, and pedestal plasma is important, i.e. providing enough time of initial operation with Li-free conditions for FY15, in particular in the context of boronization steps.

- See Stefan's answer.

- An efficient approach:
  - Suggest that the first run-year of "essentially new device" provide the base data (i.e. "catalogue approach") and accommodate specific run time requests as appropriate to the research milestones
    - E.g. some optimization with TMB should happen to validate cryo-design input data
    - E.g. but fishing trips for performance with "pure" C tiles might not be justified
  - FY16 run can perform more "hypothesis-driven" experiments of wall-conditioning systems based on FY15 base data set

Sufficient time for systematic studies…

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would be desirable. This approach is important both in the assessment of the impact of more lithium coverage (e.g. with the introduction of the granule injector and upward-facing evaporator system) and running fiducial experimental shots that elucidate boronization contemplating future use of a cryo-pump. From the standpoint of the engineering design of a cryo-pump system planned for FY17, it will be critical to evaluate particle balance under both non-lithiated conditions and those with different Li coating conditions providing a unique database that steps into FY16, which will focus on the introduction of the high-Z material tiles (i.e. introduces yet another PFC interface with the plasma). From the standpoint of the edge plasma, non-Li wall

- Agree good idea to perform fiducial studies in FY15 and compare to FY16 high-Z upgrades (already the research plan)
- Agree we should confirm near- and far-SOL particle flux estimates utilized for Canik cryo-pump physics study (e.g. probe data used in that study was from lithiated ops)
- ELM-pacing issues with dropper/injector vs. LITER left to A. Diallo…

Edge studies should be coordinated

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collaborations to compare edge/wall computational modeling (WallDYN) with plasma edge diagnostics. This requires a high level of coordination and it is recommended that all those involved, including those operating plasma-edge diagnostics (e.g. optical spectroscopy systems including those with optical chords to MAPP samples, MAPP and in-situ QCMs), work closely together in designing experimental proposals that methodically work from non-Li conditions to predominantly lithium-based surfaces in NSTX-U. It is also not clear how various computational modeling codes will be used and specifically the surface response where the lithium and boron chemistry with graphite can be complex. This should be clarified.

- Agree that all of the edge models benefit strongly from as many experimental constraints as possible and having the data available from day 1 would help with transitions

- Agree it would be good to have which codes for modeling surface responses.
  - PMI/evolution models are intrinsic in WallDYN and are being developed.
  - MD/DFT/etc. codes are often helpful and could be developed by NSTX-U collaborators (and possibly PPPL theory?)

Strategy and plan for vapor-shielding "success" should be developed

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Similar to our comments above, it would be desirable to provide enough coordination with surface-response models and plasma edge models to elucidate the role of Li coatings at high temperature on high-Z substrates, ultimately leading to an assessment of the vapor-shielded regime. A strategy and plan with metrics should be developed to verify the success of vapor-shielded regime and the role of carbon and other impurities on Li coatings integrated to high-Z substrates.

- Agree
- Performance metrics for the regime could include radiated power, change in incident heat-flux, reduction in ionic fluxes, degree of divertor impurity trapping
- Indications that carbon is present to sufficient degree to change performance will be important to identify in FY16 if possible

Additional comment on high-Z studies

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The present plan should provide useful data on the mechanical stability of the new tiles but limited and perhaps confusing information on plasma-material interactions owing to the small surface area available. The initial coverage (presently only one row in outboard lower divertor in

- Presence of low-Z impurities complicates picture, however
  - High-Z tiles provide a location of initial source term for wall-evolution codes validated with material migration diagnostics – still useful for PMI studies
- Limited surface area of high-Z also limits (eliminates) sweeping statements about core-edge integrated scenarios until more complete coverage is present

Consider expanded coverage…

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surface area available. The initial coverage (presently only one row in outboard lower divertor in FY16) should be reconsidered before installation in FY16. The detailed shaping of W-lamellae should also be considered. Different options to consider include: 1) expand the poloidal coverage to more than one toroidal row in FY16 and 2) add toroidally separated high-Z tiles at various wall locations to better validate the lamellae design in a variety of loading condition (i.e., small-scale melting has tended to be the most limiting factor in W PFC deployment). Study of W transport and control, such as melting layer and accumulation control, will be necessary before major replacement of wall PFCs (FY19). These results will also contribute to ITER/ITPA R&D. In addition, installation of the laser blow-off system for FY16 would allow important controlled injection of high-Z to study its transport throughout the discharge.

- Agree: expanded coverage would be useful
- Should decide coverage after reliable cost estimates are created (see next section)
- W/Mo melting considered but rejected for FY16
  - Considering pre-filled LM targets for droplet emission studies that could inform ITER/ITPA R&D
- Agree: discrete installation locations could be useful for impurity generation experiments and laser blow-off

High-Z design and coverage plan (developed w/ K. Tresemer)

- Physics definition of eng. Reqs. (complete by mid-Nov.)
  - ISOLVER studies for row 2 and row 3 options
  - Plasma/heat flux estimates building from NSTX database
  - PFC response estimates of energy limitations (*a la* JET-ILW administrative limits)
  - Pre-filled LM targets design parallel effort (Eindhoven student)
- Conceptual Design Review (mid-Dec.)
  - Possible decision point for expanded coverage here
- Engineering analysis and design refinement (3 mos)
  - EM analysis to define eddy-current loads
  - Structural and thermomechanical analysis
  - Design iterations as necessary
- Final Design Review (April)
- Facility milestone of May 2015

Envelope sketch of concept