Subject: Divertor conditioning with Li pellets in near double-null discharges
Group: Operations
Date: February 23, 2005

1. Purpose of Experiments
Include immediate goal of the experiments, scientific importance and/or programmatic relevance. Refer to any relevant program milestones.

The goal of the experiments is to investigate the efficacy of Li pellets to condition the region of the divertor near the outer strike point. This should contribute to the Level 1 JOULE milestone for FY05 and may provide an adjunct or alternative to boronization for wall conditioning.

2. Background
Discuss Physics Basis of the proposed research. Prior results at Alcator or elsewhere, and any related work being carried out separately.

Previous experience with the use of lithium for wall conditioning in tokamaks has been mixed. On TFTR, dramatic reductions in recycling were observed, first through Li pellet conditioning[1], and later with other techniques utilizing Li evaporation[2]. Target plasmas with reduced hydrogenic content following intensive Li conditioning were used as targets for beam fueling in the supershot regime, and led directly to the highest fusion performance discharges obtained on TFTR, including both D-D and D-T plasmas. Experiments on C-Mod[3] and DIII-D[4] showed little or no effect on wall conditioning and recycling after Li pellet injections. Since C-Mod has no carbon PFC’s, while TFTR used them exclusively, one conjecture for the differences between these two sets of experiments relates to wall chemistry. However, DIII-D also has carbon plasma-facing tiles, and so this does not yield a compelling explanation.

Recent C-Mod results on scrape-off-layer flows, and their dependence on separatrix topology[5], may provide a unifying explanation for these seemingly contradictory results. TFTR had no divertor, and the discharges were limited on the inner wall. For both DIII-D and C-Mod, previous Li wall conditioning attempts were carried out in single-null
divertor topology. Based on our current understanding of particle dynamics and SOL flows, we would expect that most of the lithium leaving the plasma following pellet injection will do so near the outboard midplane, and then will be deposited preferentially at the inner divertor strike point, on the high field side, carried by the strong asymmetric flows; additional Li might be deposited on the outboard limiters, due to the intermittent (“blob”) transport. However, little, or none of the Li would be expected to flow to the outer divertor leg, which is the region that sees the dominant heat flux in single null cases. This picture is also consistent with the results of post campaign tile analysis carried out by Dennis Whyte, showing that boron is eroded from the outer strike area, and deposited at the inner strike region. While we do not entirely know the overall dynamics, one explanation for the need to re-boronize after a few hundred discharges, is this erosion of the boron layer from the highest heat flux region of the outer divertor. $^{13}$C tracer experiments on DIII-D show similar results on erosion and deposition[6]. For the TFTR limited case, the Li should have been deposited on the inner wall, just in the regions that also experience the highest heat flux.

Based on our current understanding of the origin of the strong SOL flows, an approach which should allow for the escaping lithium to find the high heat flux outer divertor leg, is to inject pellets into double-null plasmas. In this case the flows cannot reach the inner leg, and particles leaving on the low-field side must end up on the outer legs (both upper and lower) and possibly the outboard limiters. This opens a new line of investigation, which might be fruitful for controlling molybdenum influx, and perhaps recycling as well, without the need for boronization.

3. Approach
Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

The approach would be to compare impurity levels (particularly Mo, but low Z species as well), in standard lower single null discharges, before, during and after conditioning with multiple Li pellets injected into double null plasmas. Gas inventory, fueling rates, radiated power, and H/(H+D) should also be monitored.

Each pellet injects about 1e20 Li atoms into the plasma. If all of these were to be deposited on the ~10 cm poloidal extent near the outer strike (the most important region is probably smaller than this), this would correspond to a surface density of 2e16 atoms/cm$^2$. The lithium can, however, be expected to only partly end up in this region, since some will also go to the upper outer strike, and some to the outer wall. Monolayer coverage corresponds to about 1e15 atoms/cm$^2$, so we can expect significant coverage from even a small number of pellets. Guessing that 1/3 of the Li goes to each strike point gives more than 5 monolayers per pellet.

4. Resources

4.1 Machine and Plasma Parameters
Give values or range for:

Toroidal Field: 5.3
Plasma Current: 0.8 MA
Working Gas Species: D₂
Density: \(n_{\text{tot}} = 1 \times 10^{20} \text{ m}^{-3}\)

Equilibrium configuration (if possible, refer to database equilibria): standard lower single null configuration (e.g. similar to 1031125008) up to 1.0 seconds; after that, move to balanced double null, as determined from SOL and core flow measurements (e.g. similar to 1031125014) and inject 3 Li pellets between 1.1 and 1.55 seconds before ramping down.

4.2 Auxiliary Systems

RF Power, pulse length, phasing: ~2.5 MW, .4 seconds, heating phase, ~80 MHz
Pellet Injection (species): Lithium
Impurity blow-off injection: N/A
Diagnostic Neutral Beam: If available; not required
Special gas puffing: none
Non-axisymmetric Coils (Connections, Current): standard config for error field suppression
Other: Gate valves closed before and after pulse to monitor pressure evolution

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

HIREX, H/D, Thomson, ECE, bolometry, TCI, Edge flow probe(s), McPherson (if available), Chromex looking near the outer strike point (Li I at 670.8 nm, Li II at 548.5 nm) would be highly desirable.

5. Experimental Plan

Both sections must be filled in.

5.1 Run sequence Plan
Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period – 10 hours maximum – etc.
Requires 1 standard run. Should be scheduled either: a) before the first boronization, but after the machine is reasonably clean and H-modes are reliably obtained with ICRF; or b) after boronization, when it appears that the boronization is wearing off, and we are due for a new boronization (based on Mo levels, plasma performance, increased hydrogen fraction).

5.2 Shot sequence plan
For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.
Start from a standard .8 MA SNL shot. Apply RF from .6 to 1.0 seconds, to obtain H-Mode(s) (ELM free or EDA). Tune to double null by about 1.1 seconds, monitoring SOL
flows to find the SSEP that corresponds to the stagnated double-null. Use multiple probe plunges as possible and appropriate. (4 shots)

Keep SSEP fixed at that value until 1.55 seconds. Add Li pellet injection, 3 pellets per discharge, injected at 1.1, 1.25 and 1.4 seconds. This gives enough time for most of the lithium to leave the discharge before the subsequent pellet is injected or the equilibrium changes.

Monitor discharge conditions (impurities, etc.), particularly during the RF phase of each subsequent discharge, continuing to inject Li pellets during the double-null phase of the discharges. (15 shots)

Continue to run the same plasma, but without Li injection, again monitoring all relevant parameters (5 shots).

6. Anticipated Results
Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

Developing alternate wall conditioning techniques could lead to improved control without the need for frequent boronization, which would be a boon to operational efficiency, and might remove one of the ambiguities concerning the “all-metal” status of the C-Mod plasma facing components. We would of course still have a very small amount of low Z metal. If successful, these experiments would provide an explanation for a long-standing puzzle: the seemingly contradictory results from TFTR compared to C-Mod and DIII-D on the efficacy of lithium wall conditioning using pellets. In all of these cases, we would expect to publish the results. These experiments could also provide additional validation of our particle transport paradigm. Information gleaned from this experiment could contribute to the FY05 Level 1 JOULE milestone. The development of in-situ wall conditioning techniques that can be used during plasma operation would be of great benefit for future experiments, where pulses approaching steady-state are envisioned and the entire concept of between-shot or between-run conditioning is of questionable relevance. These experiments could also be relevant to the planned C-Mod application of the boron dust injector (salt-shaker) for boronization, where many of the same considerations apply.

7. References
Include references both to external and internal literature or communications which bear on this proposal. See Section 2.

[3] See runs 941221, 950331