Comments on 2nd NIFS-CRC Symposium on Plasma-Surface Interactions

R. Kaita

NSTX Physics Meeting
LSB, B318
February 1, 2010

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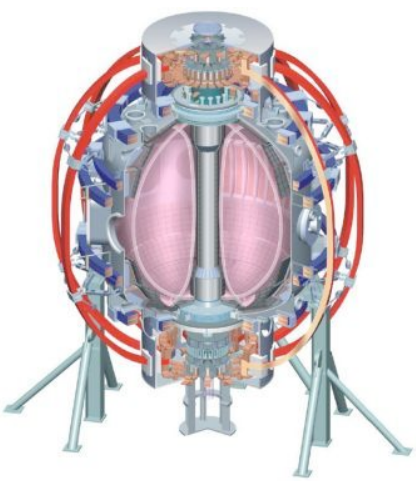

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PPPL lithium research well represented

I. PPPL Presentations:

1) J. Canik (ORNL) – *Effects of Lithium Coatings on ELM Stability in NSTX*
2) R. Kaita – *Experiments with Liquid Metal Walls: Status of the Lithium Tokamak Experiment*
3) H. Kugel – *Lithium Surface Coatings on NSTX Plasma Facing Components and its Effects on Plasma Performance*
4) D. Mansfield – *A Simple Apparatus for the Injection of Lithium Aerosol into the Scrape-off Layer of Fusion Research Devices*
5) M. Ono – *Possible Implications of NSTX Lithium Experimental Results on Magnetic Fusion Research*
6) C. Skinner - *Deuterium Retention with Lithium Conditioned Walls in NSTX [presented by H. Kugel]*
7) L. Zakharov – *Li Wall Fusion – New Concept of Magnetic Fusion*

Growing "maturity" of lithium researchers recognized by symposium organizers

Entire first day of three-day symposium devoted to lithium application to boundary control

- Hu – “Liquid lithium limiter and coating experiments in HT-7”
  - Performance improvement observed
    - H recycling measured by H_α intensity reduced by a factor of 4
    - Carbon and oxygen impurities measured by CIII and OV spectroscopy decreased
    - Loop voltage had a slight decline
    - Core electron temperature slightly increased
    - Particle confinement time increased by a factor of 2
    - Energy confinement time increased from 25.86ms to 30.04ms
  - Not clear about surface conditions of liquid lithium limiter or operation independent of evaporation
    - No information about edge parameters (and possible efficacy of plasma operations for “cleaning” lithium surfaces)
  - Observed unipolar arcing and “droplet ejection” as seen with liquid lithium rail limiter on CDX-U

- Hirooka – “A review of the boundary control effects on core plasma confinement and its implications to influence stead-state magnetic fusion experiments”
  - Suppression of PWI’s by materials selection
    - Low-Z C with high-Z W: not attractive
  - Change edge parameters
    - “Old” TFTR (supershot) and “new” LHD (superdense core mode) both have reduced edge density for improved confinement
    - “Circular cause and consequence” - reduce edge density to improve confinement which reduces density further and suppresses PWI’s
      - Requires wall to be kept from saturation
        - » Conditioned PFC’s means only pulsed operation
        - » Moving surface needed for CW operation
          - » Moving solid surface
          - » Continuous deposition and liquid convention
          - » Moving liquid surface

- Hirooka (continued) –
  - Solid target coated with lithium
    - 10 rotations per second
    - Trapping efficiencies: H/Li about 1 and He/Li about 0.01 (could be physically trapped)
  - LiH diffusion in liquid Li – rapidity due to Einstein-Stokes diffusion
  - CPD at Kyushu University
    - Li-gettered rotating poloidal limiter

- Tsuchiya – “Development of lithium vapor injectors for boundary control”
  - Technical issue: how to put lithium on complex LHD divertor
    - Solution: inject Li vapor
      - Li transported to divertor along open field lines
  - Prototype made
    - Nozzle with 50 mm diameter
    - Heating to 650 degrees C
      - “Stick” heater (250V, 1000W)
    - Test results
      - Heater broke down at 567 degrees C
      - Beam profile made at 50 cm from nozzle end with thickness meter
      - Ejected lithium smaller than expected from simulation
        - » XPS indicated presence of significant lithium oxide quantity (only 1.2 percent lithium)
      - Lithium beam profile is wider than expected by 25%
        - » May be due to collisional effects

- Ashikawa – “Surface chemical/binding reaction of coated Li layer by lithium vapor injectors in LIGHT-1”
  - Carbon impurities observed on surface only prior to application of plasma
    - Difference in lithium oxide between “uncoated” and “coated” lithium samples similar to observations by Allain
  - Hydrogen glow discharge cleaning (2 hours) of “coated” Li: qualitatively similar to “clean” Li but with
  - Shifted and broadened Li(1s) and O(1s) (“oxide”) peaks provides measure of lithium oxide thickness
    - Decreases going from argon glow for wall conditioning to hydrogen glow to argon plasma

- Chung – “Distribution of lithium neutrals and ions in hydrogen and helium background”
  - Injected lithium treated as neutrals
    - Collisionless model: depends on “disk” of radius “z” (criterion for flux conservation)
    - “Semi-collisionless” model: requires “source” to be physically reasonable (sink is formation of lithium hydride)
  - Work in progress: assume cylindrical approximation for large aspect ratio and axisymmetric source
    - Classical diffusion assumed for neutrals and ions in un-magnetized and magnetized plasmas
      - Focus of simulations to date – qualitatively matches trends in data and Monte-Carlo calculations
    - Anomalous diffusion broadens profiles

- Shoji – “Fluctuations of intrinsic magnetic field line structures on lithium ion transport in the LHD plasma periphery”
  - Closed Helical Divertor (CHD) for LHD
    - Ergodic layer formed around main plasma confinement region
    - Curved structure of divertor legs toward vacuum vessel
    - Highly ergodized divertor legs in inboard side of torus
  - Local Island Divertor (LID)
    - m=1 magnetic island formed in plasma periphery
    - Leads to excessive local heating on LID “head”
  - CHD
    - Baffle plates and additional vacuum pumps added to divertor region

- Shoji (continued) –
  - Density profile of impurity (Li) atoms
    - Assumed to originate from physical sputtering
      - Appears not to be problem even with liquid Li (sputtering two orders of magnitude higher relative to solid)
      - Li "swept away" to divertor region
    - Li transport in divertor legs calculated
      - Li does not flow to plasma core because of dominance of "friction force" over thermal force
      - Implies "practicality" of effectively coating divertor plates with Li (vapor injection method as possibility)

Second day included PSI in steady-state devices and additional talks on Li application to boundary control

- Tabarés – “Overview of TJ-II performance under lithiated wall conditions”
  - Need for lithium in stellarators
    - Neoclassical transport tends to cause impurity accumulation
      - Low recycling and low Z_{eff} needed
  - TJ-II PFC’s
    - Two graphite limiters
    - First-wall boronization
  - TJ-II “lithization” results
    - Lowered recycling (10% for H and 82% for He)
    - Development of peaked profiles
    - Particle confinement time of 7 ms observed after end of gas puffing in ECRH plasmas
      - Longer with NBI but recycling still low
        - » Particle confinement time measured with gas pulse introduced during NBI phase

- Tabarés (continued) –
  - “Bell” and “dome” profiles occur under same “lithization” conditions
    - “Bell”
      - Non-collapsing
      - Higher temperature and lower density
    - “Dome”
      - Collapsing
      - Higher density and lower temperature
  - Boronization tried on top of lithium
    - Reduced recycling still observed (10% for H)

- Taffala – “Wall conditioning strategies in the stellarator TJ-II”
  - Wall conditioning (1998-2001)
    - Stainless steel walls
    - He GDC overnight between operational days
      - Removes H accumulated in walls
      - Reduces residual water
      - Affects density control due to He from walls
        - » Mitigated by Ar GDC for 30 minutes after He GDC
  - Boronization started in 2001
    - Low-Z conditions needed for plasmas with NBI
    - Carborane vapor in He GDC
      - Followed by 30 minutes of He GDC to remove H trapped in film
    - Particle balance is problem
      - Saturation of H content means loss of density control
      - Requires He GDC after about twenty shots

- Taffala (continued) –
  - Lithization
    - Plasma redistributes lithium from four symmetrically-located ovens (6 g capacity each) operated at 600 degrees C
    - Getters oxygen and water (effect lasts longer than with boron coatings)
    - Boronization improves “longevity” of lithium coating
      - “Full” wall coverage achieved with boronization occurring during glow discharge
      - Reduces oxygen available to interact with lithium subsequently evaporated onto vacuum vessel walls

- Mazzitelli – "Review of FTU results with liquid lithium limiter"
  - Peaked electron densities achieved
    - Narrower than in pellet case because of lithium edge pumping
    - Exceeds Greenwald limit by 30% but at 7.2 T magnetic field
      - Record value for gas puffing
    - Confinement time threshold raised from 50 ms to 70 ms at 0.5 MA
  - ECRH + LH discharges
    - P(ECH) = 0.8 MW and P(LH) = 0.75 MW with Li creates "strong and wide" ITB in plasmas with electron temperatures higher than discharges with around 50% more RF power
      - Reason appears to be related to impurities (lower Z(eff) with Li – no impurity lines)
        - » Means LH is more effective
        - » Z(eff) of about 2 means 50% dilution (strong reduction in neutron signal) but becomes negligible at high density
  - Edge modification permits LH operation at "ITER-relevant" densities

- Tudisco – “Peaked density profiles and MHD activity on FTU in lithium dominated discharges”
  - Hardware description
    - Scanning interferometer used to obtain density data
    - Stainless steel “liner” and toroidal molybdenum limiter
  - Density scanned at different currents and fields
    - Density peaking achieved in 6T, 0.5 MA discharges when “MARFE’s” start being seen on interferometer
      - “Onset” appears later at 7T
    - Temperature “shrinks” before density rises
      - Profiles of line-averaged density indicate internal transport barrier
    - Peaking decreases with collisionality without MARFE’s while opposite trend appears with MARFE’s
  - MHD activity reduction
    - “Mild” effect most likely due to change in plasma resistivity

- Murakami – "Atomic and molecular processes with lithium in peripheral plasmas"
  - First investigated for modeling early universe
    - Rate depends on temperature (linear and inverse exponential)
      - Based on atomic data below 1 eV but may still be generally valid
  - Reaction "network" considered
    - Charge states of elemental lithium and lithium hydride
    - Includes collisional effects, recombination, radiative attachment of electrons, charge transfer, mutual neutralization, radiative association, dissociative recombination, and exchange processes but data are limited
  - Calculations for peripheral region of plasma
    - $dn(i)/dt = \Sigma W(i,j)n(j)$ – matrix elements are rate coefficients
    - Test case – one zone model without sink or source terms in rate equations
    - Shows reasonable trend with number density decreasing as every other species increases with time

- Kato – “Linear polarization of photon emissions from reflected neutrals of atomic hydrogen at metal PFC’s”
  - Accurate determination of recycling coefficient requires means of identifying photon emission due to reflected hydrogen neutrals
  - Model under development that takes into account large electron source in conduction band of metal PFC’s
    - Includes shifted Fermi level by proton motion
      - Leads to “Doppler shift” that allows resonance above “static” Fermi level
      - Results suggest that photon emission from surface electron capture should have finite polarization

Final day included more talks on Li application to boundary control and recommendations for future research

- Mirnov – “Experiments at the T-11M device in support of the tokamak concept with closed Li cycle”
  - New DT-fusion paradigm – fusion for fission
    - Pure fusion development time scale too long
    - Cost of uranium expected to increase rapidly
    - Radiation danger of “minor actinides” must be mitigated
      - Can be achieved at fusion power levels five times lower than on ITER
  - Avoid use of tungsten because of problems with long-term exposure to high radiation – consider Cu-Li alloys
  - “Emitter-collector” tokamak liquid metal limiter
    - Lithium evaporated from CPS goes to collector
  - Russian test facilities
    - Concept tested on T-11M with evaporation from “center” and collection at “edges” of CPM
      - “Circulation” provided by capillary structure that leads to motion of liquid lithium
      - Propose hydrogen operation on T-15 for next “zero-power” step

- Lyublinski – “Experience and technical issues of liquid lithium application as PFM in tokamaks”
  - Metal-fiber (as opposed to sintered) materials most preferable
  - Stainless steel (like CDX-U L3) and refractory metals and alloys
    - CFC fiber and SiC not compatible with liquid lithium
  - Stationary heat flux tests performed with e-beam at Kurchatov (SPRUT-4)
    - 8 keV, 15 cm^2, 1 – 50 MW/m^2
    - No damage in contrast with solid target or mesh sample without lithium at same exposure level
      - Shielding layer formed in 5 ms near Li CPS
  - Tests on tokamaks revealed same dependence on CPS “protection” with Li
    - “Splashing” suppressed with CPS

- Lyublinski (continued) –
  - New Li limiter w/active cooling under development
    - Needed for 10 MW/m^2 for 5 s operation on FTU
  - KTM project at Kurchatov City in East Kazakhstan
    - 10 MW/m^2 for 5 s operation
    - New flexible W "mesh"
    - Na-K alloy for cooling

Technical issues and recommendations for future research (beyond ITER)

- Materials compatibility problem (corrosion, etc.)
  - Compatibility with Cu (gaskets) at high temperatures?
  - Li purity effects (O, C, N, Be,…) on corrosion?
  - Neutron effects on chemical compatibilities?
  - Data need for compatibility with ceramics (Al_2O_3)?
  - Compatibility with Zeolite on cryopanel?
  - Compatibility with mechanical pump lubricants?
    - Consider inviting participants from blanket technology, IFMIF, etc. communities to next workshop
- Tritium retention (site-dependent)
  - Retention in Li-deposits at low temperature (first wall)?
  - Thermal desorption data from Li-deposits?
  - Impurity effects (C, O, Be, He bubbles, etc.)?
  - Circulation PFC system concepts

- EM force
  - Electromagnetic force on liquid lithium flow in the system?
  - Need data on TEM force
    - Consider inviting participants from blanket, tritium, etc. communities to next workshop
- Air exposure
  - Air exposure to liquid lithium flow
  - Accidental water leak to liquid lithium flow
  - ES&H database

Future workshop locations proposed and symposium presentations posted

- Proposal – “interleave” future Li workshops with PSI conferences
  - 2011 – NIFS
  - 2013 – Frascati
  - 2015 – Madrid
  - 2017 – Princeton
  - 2019 – Moscow

- Website for viewing presentations
  - http://dpsalvia.nifs.ac.jp/~hirooka/2nd-NIFS-CRC-Symposium/