Plans for Conditioning Plasma-Facing Components at Initiation of NSTX-U Operations

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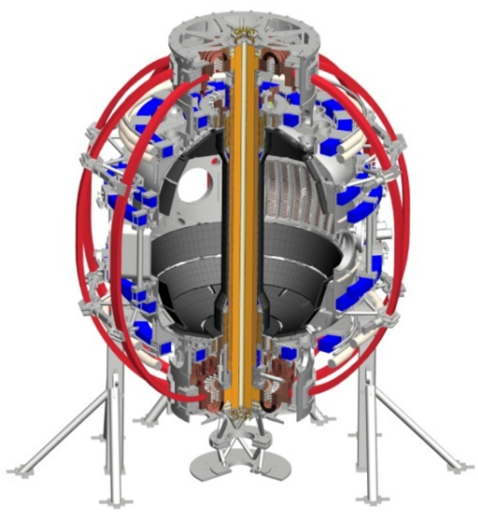

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Abstract

The conditioning of plasma-facing components (PFCs) has been critical to the achievement of high performance plasmas in fusion devices. The NSTX-U PFCs will initially consist of graphite. Well-established PFC conditioning will be applied, including high temperature bakeout and glow discharge cleaning (GDC). As in NSTX, the center stack (CS) will be electrically-isolated from the outer vacuum vessel in NSTX-U for coaxial helicity injection (CHI), and this also permits high currents to pass through the CS for baking. Other conditioning techniques are required to further reduce the dominant impurities, which are expected to be carbon and oxygen. Boronization will first be performed, where glow discharge cleaning (GDC) with a mixture of 95% helium and 5% deuterated trimethylborane (TMB) is followed by another period of helium GDC. This will be compared with lithiumization, where lithium vapor is evaporated directly on PFC surfaces. The effectiveness of both conditioning techniques has been inferred from plasma measurements subsequent to their application, but the link between them and actual PFC surface conditions has not been made. The new Materials Analysis and Particle Probe (MAPP) is intended to do this with in situ analysis of PFC samples exposed to NSTX-U plasmas.

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Plasma performance in fusion devices correlated with conditioning of plasma-facing components

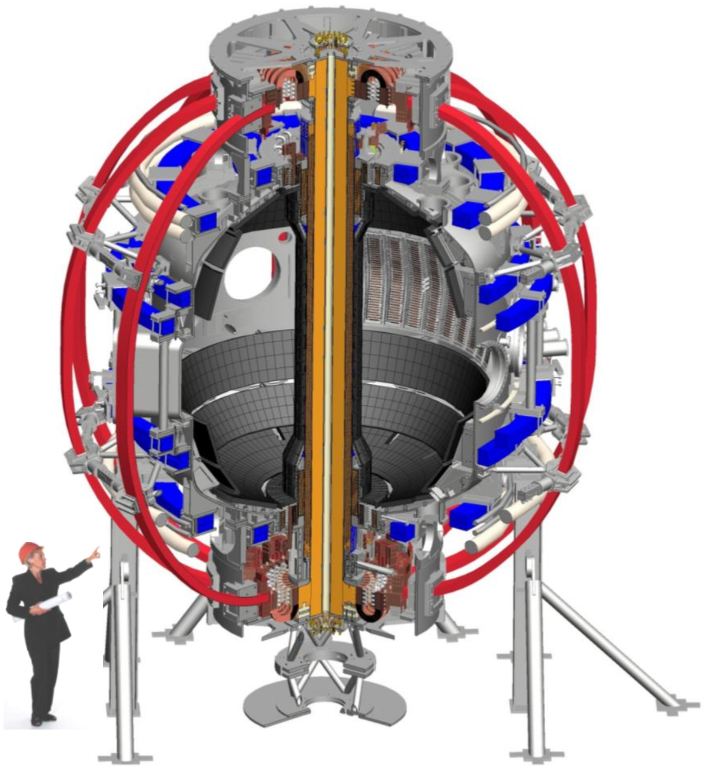
1. Water absorbed by plasma-facing components (PFCs) removed by heating ("bakeout")

2. Impurity levels reduced by introduction of thin boron films on PFCs ("boronization")

3. Wall recycling reduced by creation of thin lithium films on PFCs ("lithiumization")

NSTX-U to begin operation with graphite plasma-facing components

Center Stack

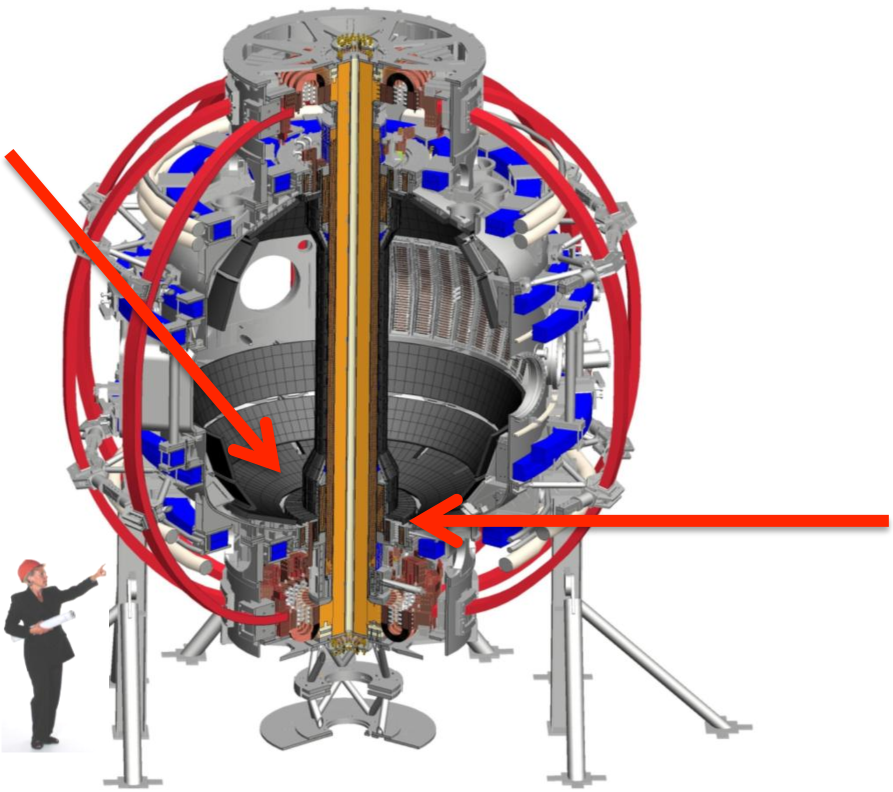


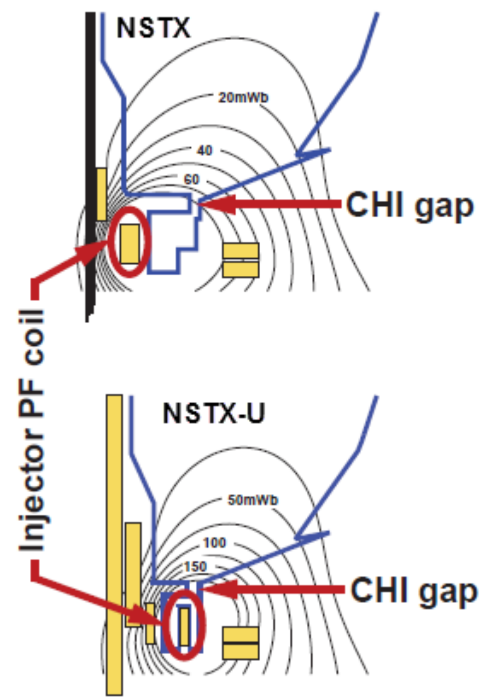
Graphite tiles forming PFCs on new NSTX-U center stack

Electrical isolation for coaxial helicity injection allows center-stack bakeout with resistive heating

1. Center stack resistively heated to 350C with external power supply
2. Outboard divertor tiles heated to 350C with helium gas
3. Stainless steel vacuum vessel kept at 150C with circulating water heating and cooling system
4. Partial pressure of water in low 10^{-6}T range achieved after ~3 weeks at bakeout temperature

Outboard divertor



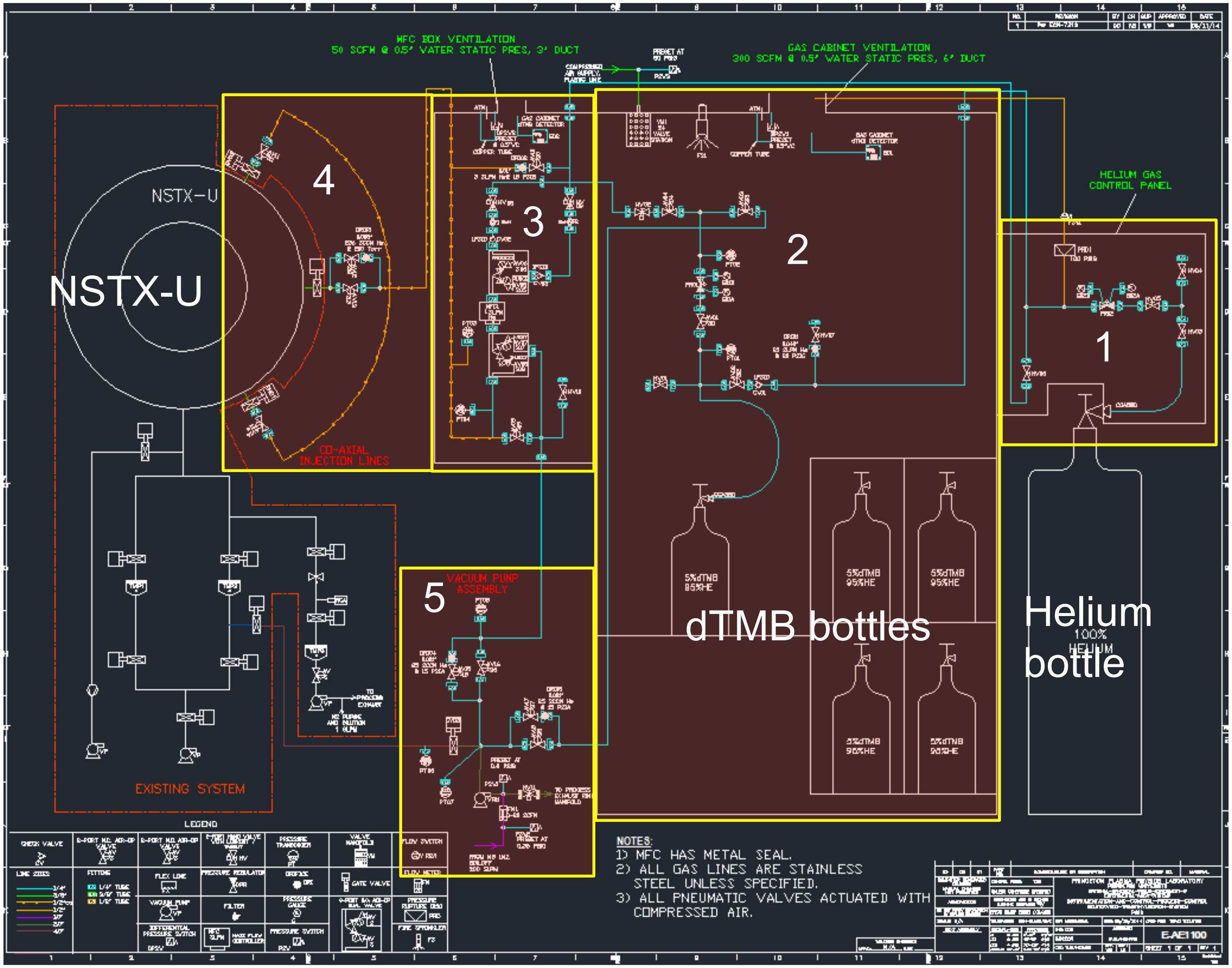


New boronization system to be available for conditioning with deuterated trimethylborane

Five major sub-assemblies:

1. **Helium control panel**
2. **dTMB gas cabinet**
3. **Master Flow Control (MFC) box**
4. **Coaxial injection lines**
5. **Vacuum pumping assemblies**

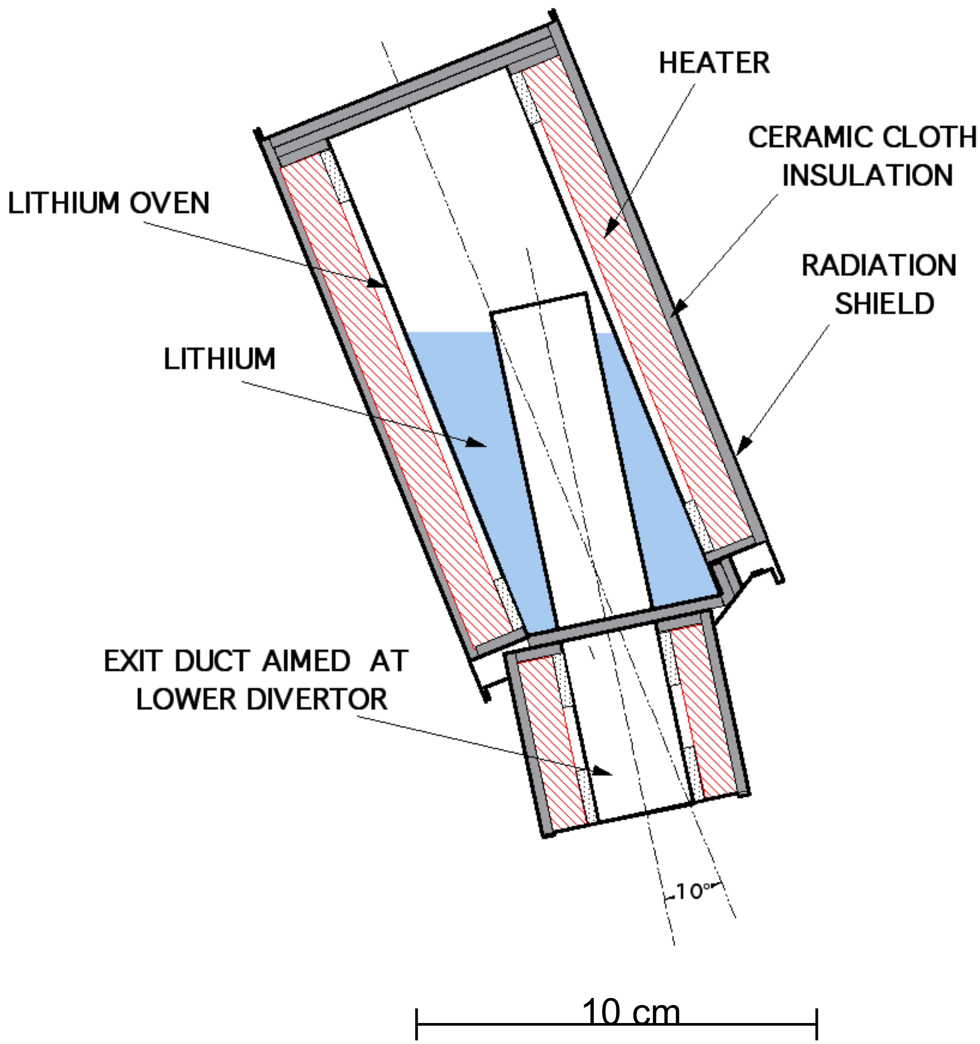
- D. Cai, dTMB System Final Design Review, September 17, 2014



Boronization well-established as wall conditioning technique but not without limitations

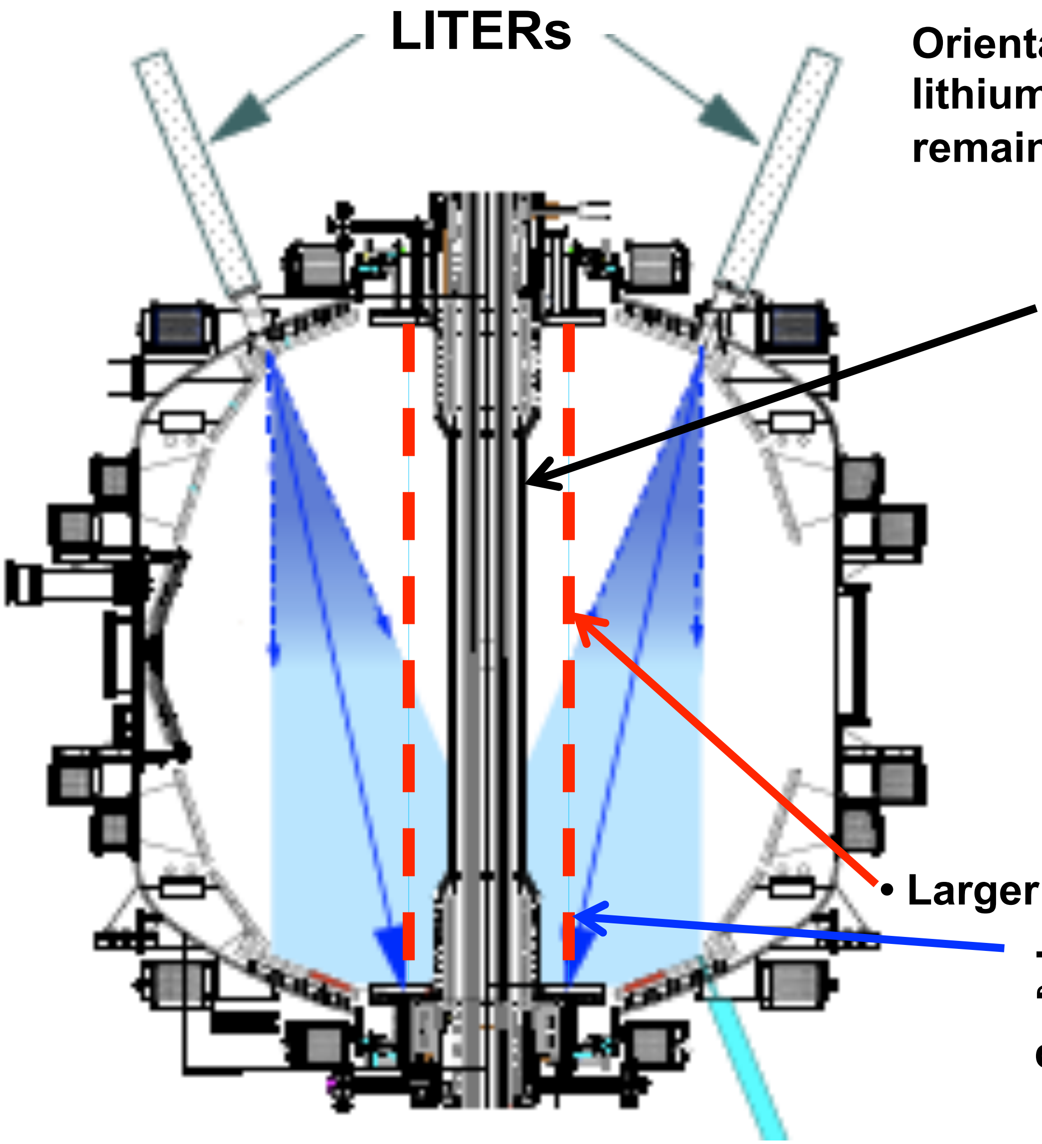
1. Boronization procedure:
   - Helium glow discharge cleaning (He-GDC) initiated
   - Gas mixture of 95% helium and 5% deuterated trimethyl boron (dTMB) of $B(CH_3)_3$ added to gas feed for He-GDC
   - Boronization continued for ~160 minutes until 90% of gas bottle containing 10g of dTMB consumed
   - Film on order of tens of nanometers consisting of boron, carbon, and deuterium resulted
2. Multiple boronizations may be required to achieve high-performance plasmas

Lithium to be applied to PFCs with evaporators with same exit duct as NSTX for directing lithium vapor



- **Capacity: 90 g Li**
- **Oven Temp: 600-680°C**
- **Rate: 1mg/min - 80mg/min**

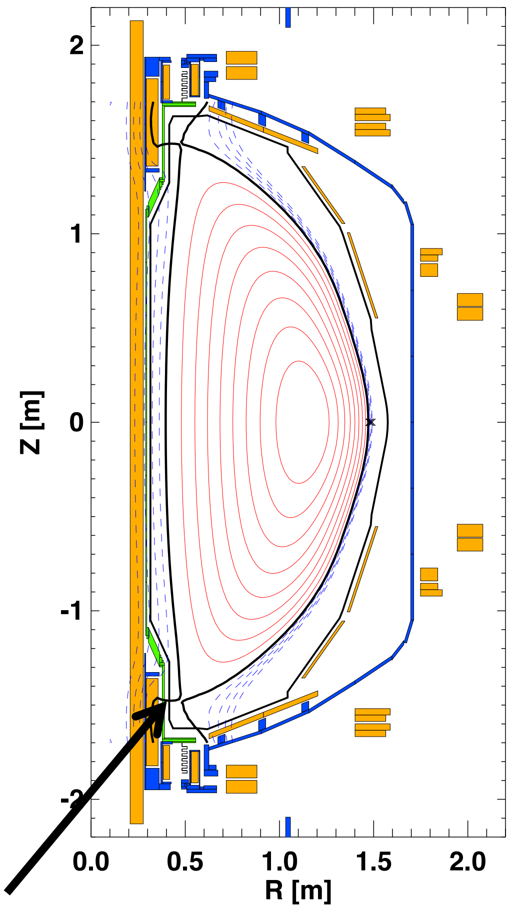
Larger diameter center stack means new lithium deposition pattern on PFCs

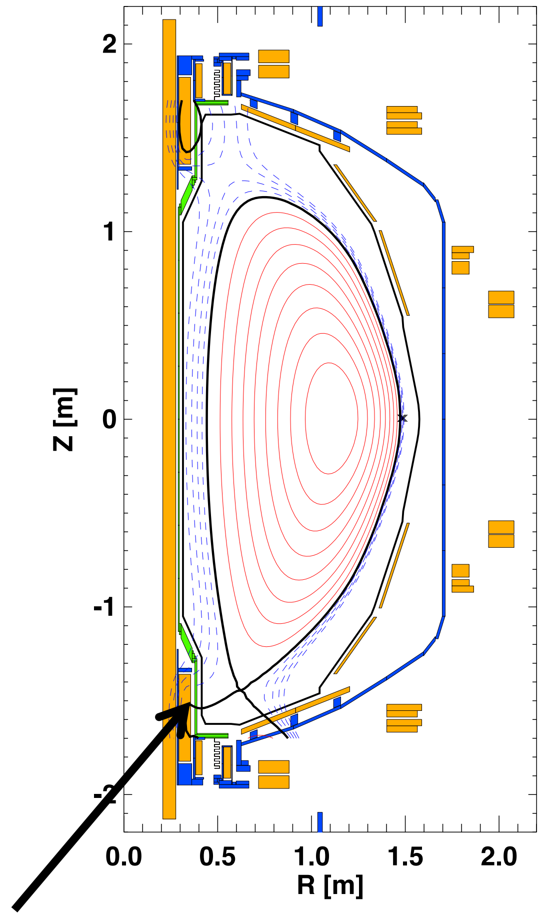


Orientation of exit tubes for lithium evaporators – LITERs – to remain unchanged for NSTX-U

- Larger diameter of new center stack
  - More lithium coverage for “vertical” section of inboard divertor

Effect of increased lithium coverage for vertical section of inboard divertor to be studied in NSTX-U





Inboard strike point occurs on vertical section of inboard divertor for both single and double null plasma equilibria

Lithiumization also well-established for wall conditioning

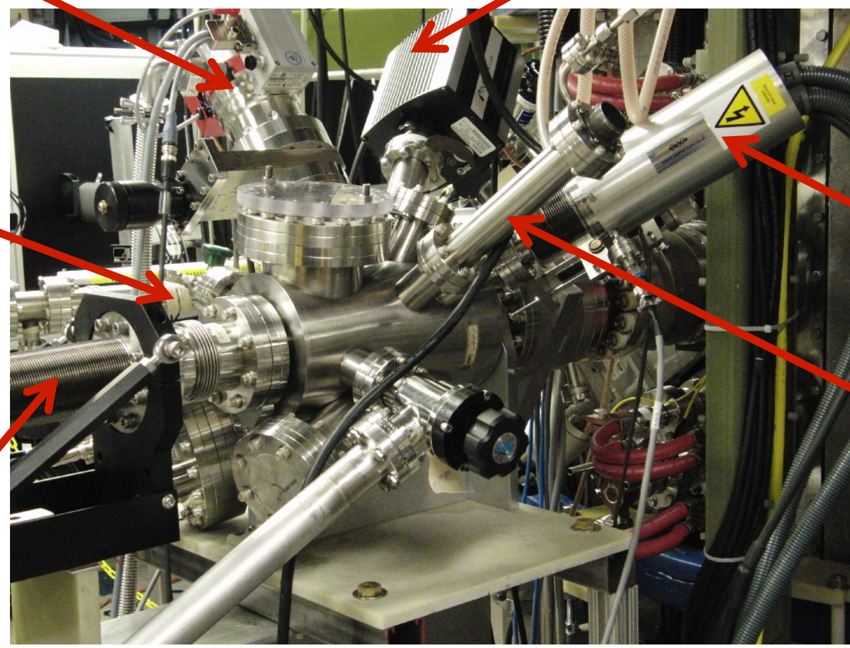
1. PFC conditioning with lithium evaporation – lithiumization – requires much less time than boronization
   - Lithium films can be created on PFCs in minutes – between shots – rather than hours
   - Adequacy of "backfilling" with argon minimizes time to recover from vents that do not require entry into vacuum vessel (i. e., service and/or replacement of components at vacuum boundary)
2. Requirements for lithium "passivation" prior to vacuum vessel entry and PFC cleanup after entry adds significantly to time required for in-vessel access and recovery for plasma operations

Benefits of boronization and lithiumization inferred primarily from plasma performance

1. Measurements with residual gas analyzer (RGA) indicated reduced levels of water, carbon monoxide, and carbon dioxide after boronization
   - Relationship between RGA measurements and surface chemistry and morphology of PFC surfaces is not known
2. Lithium is applied to PFC surfaces because high chemical reactivity expected to bind hydrogenic species and impurities
   - Lithium oxide layers on PFCs typically formed in ~200s which is less than time between NSTX plasmas
   - Lithiumization effectiveness despite rapid oxide formation means surface chemistry details not known

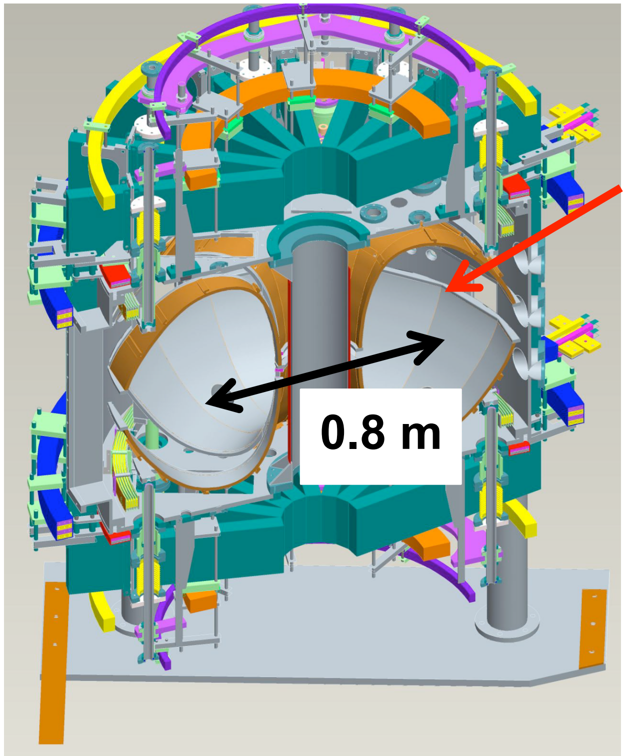
See invited talk by A. Capece on Friday morning (YI2.5)

Materials Analysis and Particle Probe to be used for sample analysis immediately after exposure to PFC conditioning



Analysis Technique	Fundamental Information	Status
X-ray photoelectron spec. (XPS)	Elemental/chemical state analysis	Operational
Thermal desorption spec. (TDS)	Binding E of surface volatiles	In development
Low-E ion scattering spec. (LEISS)	Top ML of surface, including H	In development

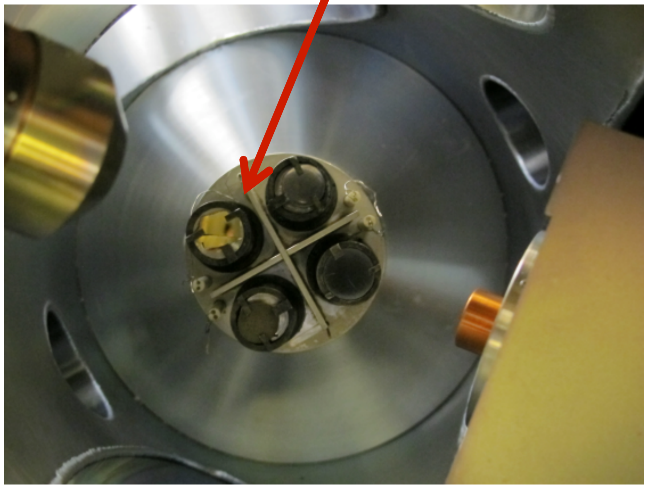
MAPP capable of exposing up to four different PFC materials to plasmas at same time



Conducting shell

Lithium Tokamak Experiment - LTX

Gold Sample

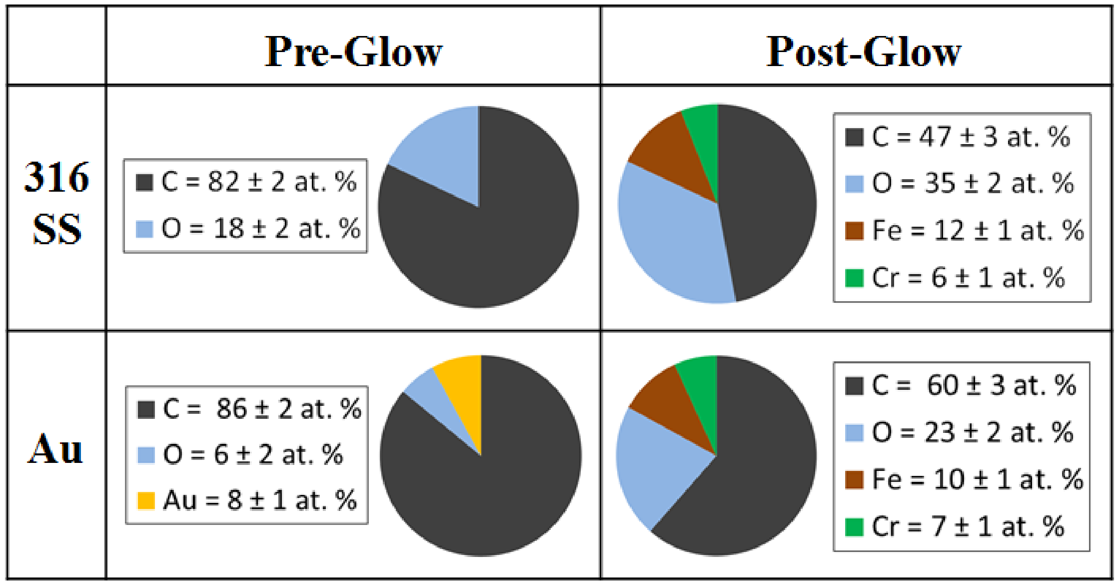


MAPP Sample Holder
as viewed from plasma

Samples used in studies on LTX included stainless steel to match PFC of conducting shell inside vacuum vessel and gold for calibration

See posters F. Bedoya et al. (PP8.88), M. Lucia et al. (PP8.89), and D. St-Onge et al. (PP8.90)

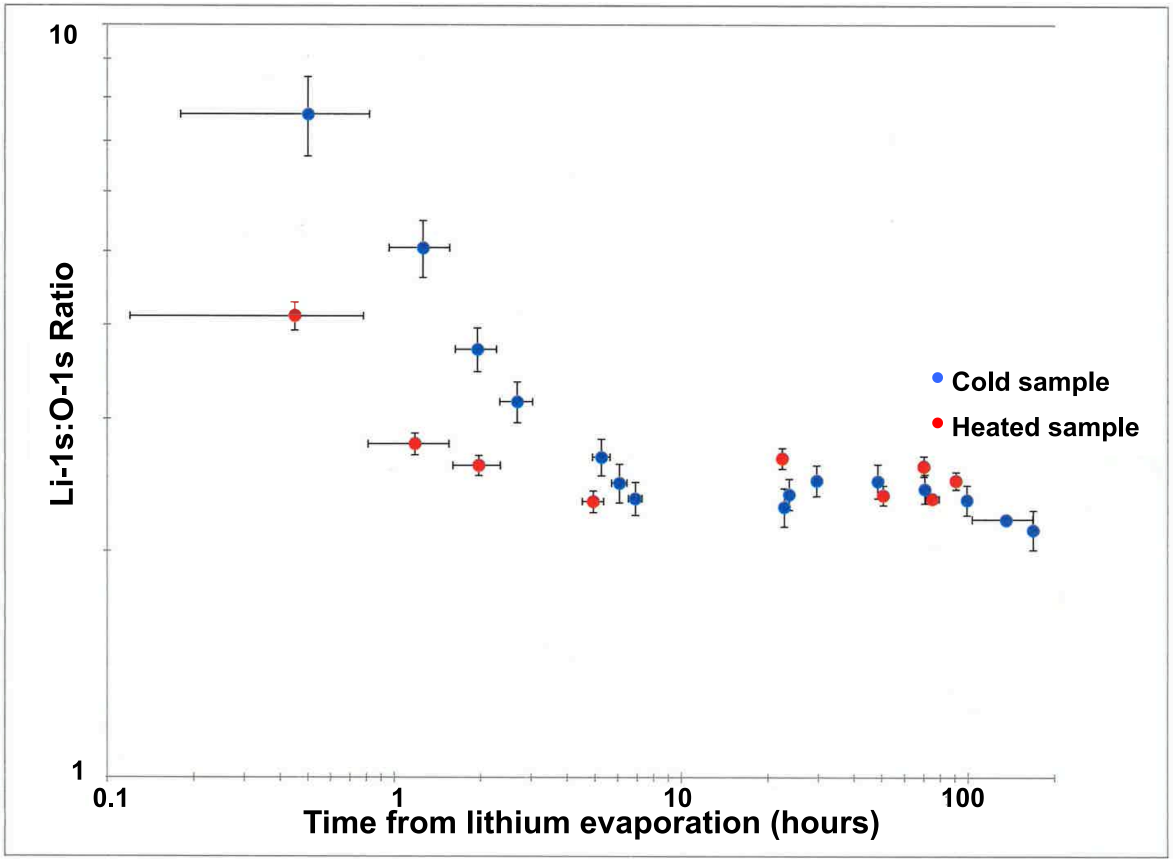
MAPP data LTX provide information on effects of wall conditioning from samples analyzed before and after GDC



- **XPS analysis of "clean" samples prior to exposure to GDC showed large percentage of carbon**
- **No evidence of gold from XPS analysis after exposure to GDC – possibly from sputtering and redeposition from PFCs during GDC**
- **Suggests complexity of "established" conditioning techniques**

See M. Lucia et al., 21st International Conference on Plasma Surface Interactions 2014, Paper P3-097, to be published in Journal of Nuclear Materials

Analysis of MAPP samples coated with lithium suggests mechanism for hydrogen retention long after "passivation"



- **XPS analysis shows "equilibration" of lithium oxide formation well before degradation of "cold PFC" plasma performance on LTX**
- **Suggests role of oxygen in retaining hydrogen in high-Z PFCs**

See invited talk by A. Capece on Friday morning (YI2.5)

Summary

- Well-established wall conditioning techniques to be used on NSTX-U when plasma operations begin in 2015
  - Bakeout by PFC heating
  - Boronization with dTMB in He-GDC
  - Lithiumization with lithium evaporators
- Characteristics of PFCs could only be indirectly inferred in past applications of wall conditioning techniques to tokamaks
  - Gap in knowledge to be addressed with Materials Analysis and Particle Probe – MAPP – to be available at start of NSTX-U operations
  - MAPP data will help optimize frequency of boronization and lithium evaporation rate during lithiumization on conditioning of PFCs made of carbon and high-Z as planned for NSTX-U