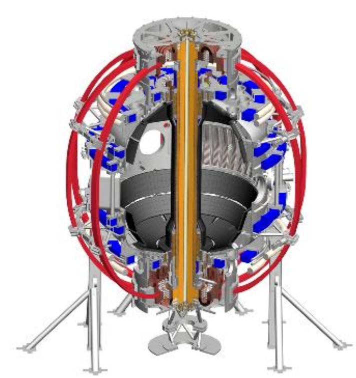
# NSTX-U High-Z Divertor Upgrade Phase 1
# Recap and Discussion of Alternative Scenarios

MA Jaworski

NSTX-U High-Z Discussion Meeting
August 11th, 2016
Control Room Annex



# Outline

- Overview of logic for high-Z upgrade program
- Quick status update on diagnostics
- Pros/Cons of alternative scenarios

# Topics previously addressed in PAC-37 talk

- Why must NSTX-U change its PFCs?
- How will the PFC modification be conducted while maintaining scientific productivity?
- Are we technically ready to move toward liquid lithium PFCs?
- Are we prepared to address the scientific challenges associated with the PFC changes?
- What strategies are being developed to mitigate risk?

# We do not have a definite reactor material after nearly 60 years of fusion research!

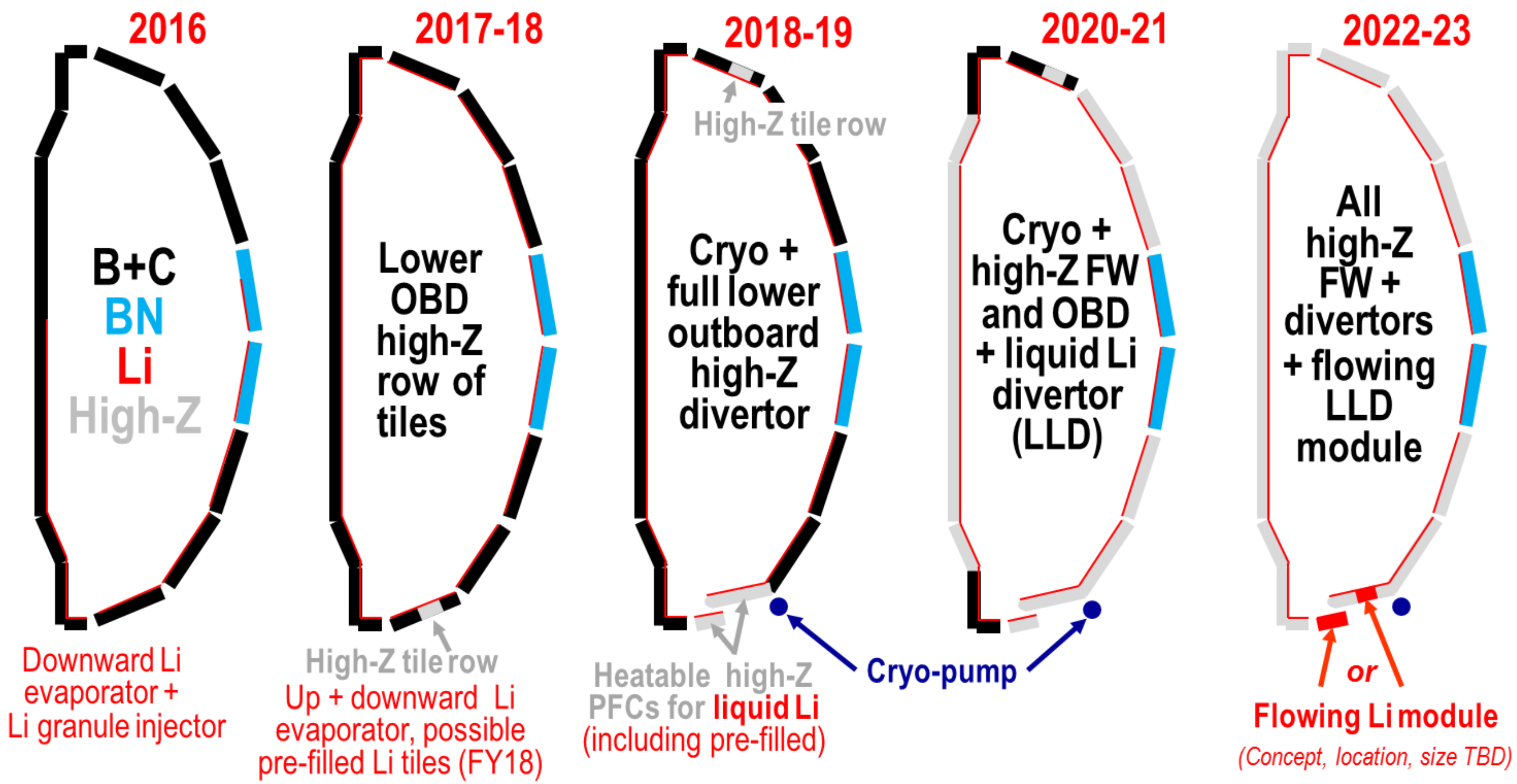
- Recent discussions from Fusion Materials Workshop (UTK/ORNL, July 2016):
  - Message from tungsten advocates: **Existing tungsten (monolithic) will not work in a reactor**
  - Message from liquid advocates: **No consensus on which liquid metal nor what configuration**

- Importance of integrated scenarios *including the wall materials* recently demonstrated (again) (i.e. JET-ILW)
  - Graphite is not considered viable for a fusion reactor (T retention/codeposits, n degradation)
  - Work on evaporated Li on graphite is not research on a reactor-relevant component or technology
  - Evaporated Li on graphite does not exhibit PMI processes expected in pure Li (e.g. dominant O-bonding vs. Li-D formation)

- PAC-37 talk laid out program to upgrade and evaluate high-Z *and* liquid approaches leveraging NSTX-U's unique capabilities and flexibility

# Staged conversion mitigates risk and enables comparative assessment of both high-Z and liquid Li

- Open divertor and flexible magnetic configuration enables multiple studies and material selection
- Single-variable experiment *in single campaign* enabled by conversion (i.e. high-Z vs. lithium PFCs)

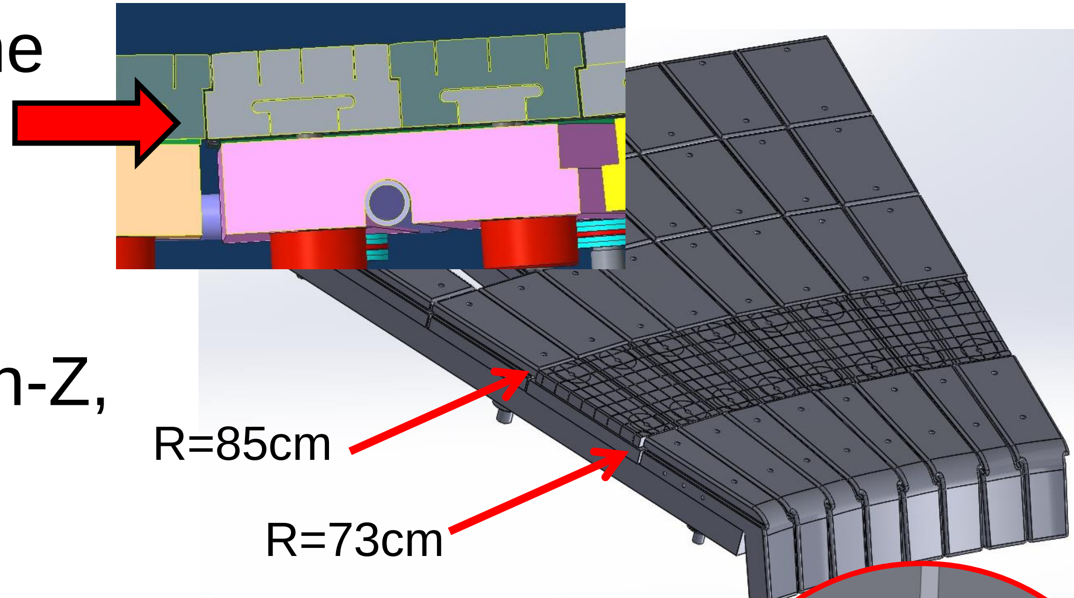


# High-Z tile row will provide design and engineering assessments

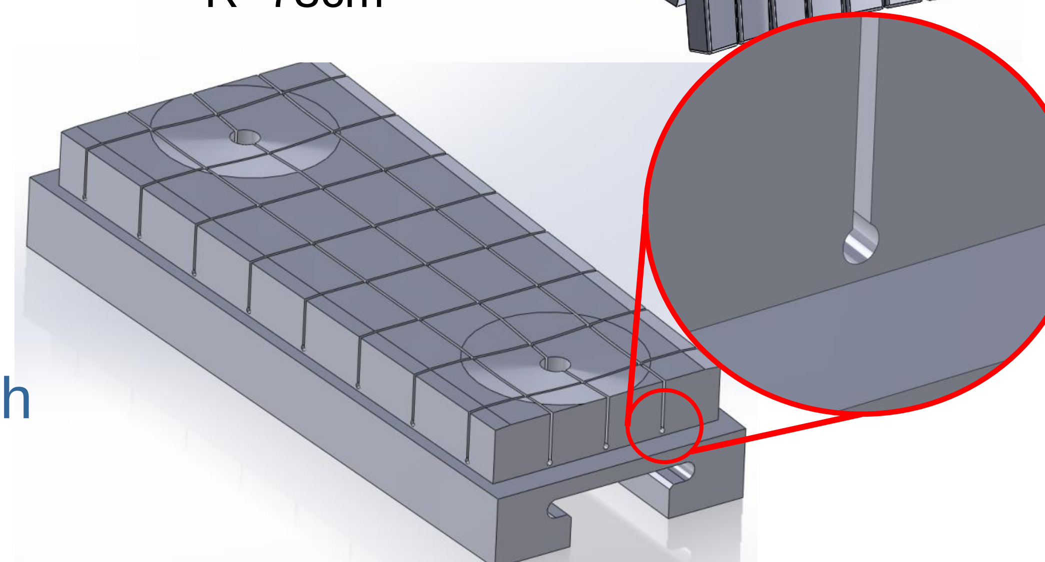
- Replace continuous row of graphite tiles with high-Z
  - Avoid Li substrate diffusion for longer-pulse experiments
  - Examine protection of high-Z substrate w/ low-Z coatings
- Provide operational experience and validate engineering design and analysis with an eye to future deployments of metallic PFCs
- Continue experiments on evaporated Li films on high-Z substrate in diverted configuration

# Rapid experiments facilitated by direct replacement of graphite tiles

- Machine installation time minimized with 1-for-1 replacement




- TZM-alloy provides high-Z, Li-compatible substrate and machinability
- Nominal heat-flux impact factor of 10 MJ/($m^2$ $s^{1/2}$) capability
  - Leading edges mitigated with chamfering
  - Requires careful alignment



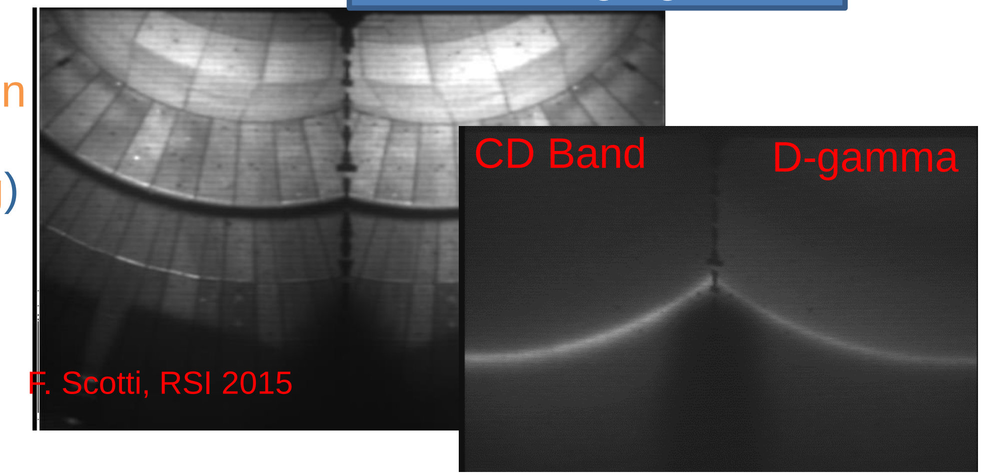
# High-Z project status

- High-Z PFCs separated into two components: base tiles and diagnostic tiles
- Successful FDR held February 29
  - Proceeded to put out bids for base-tile fabrication job
  - Bid awarded ~April; Delivery originally scheduled August 5
- Successful PDR for diagnostic and experimental variant tiles held on June 15
  - Added to original bid
- Installation scheduled to take 5wks of machine-tech time
- Ops-guidance document to be provided to Team
  - Non-zero XP planning impact
  - Shots with <2MW/m2 on tiles, no problem.  Shots >2MW/m2 on tiles would require review to evaluate damage potential to tiles

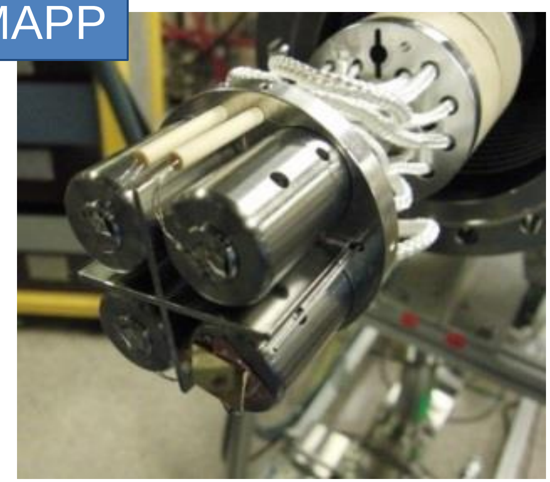
# Diagnostic and operations support for high-Z studies

- Traditional PMI diagnostics and status:
  - ☆ Filtered imaging (operating)
  - Divertor Langmuir probes (half-resolution set operating as of June 23)
  - ☆ Lower IR thermography (commissioning)
  - ☆ Spectroscopy (DIMS lower needing support; UTK upper - commissioning)
- ☆ MAPP studies operating all year (Bedoya & Skinner)
- ☆ Material erosion coupons (Wright/MIT) – to be ready for Fall installation
- ☆ Material sample exposure coupons (UTK/ORNL) – developing to be ready for Fall installation
- ☆ In-tile calorimeters (ORNL) (concept designs complete)
- ☆ High-resolution IR thermography (ORNL) (in development)

2-color simultaneous imaging



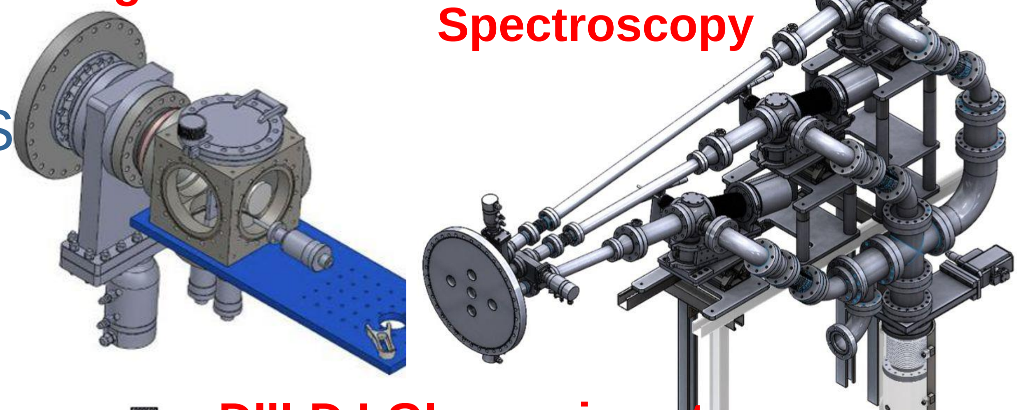

MAPP

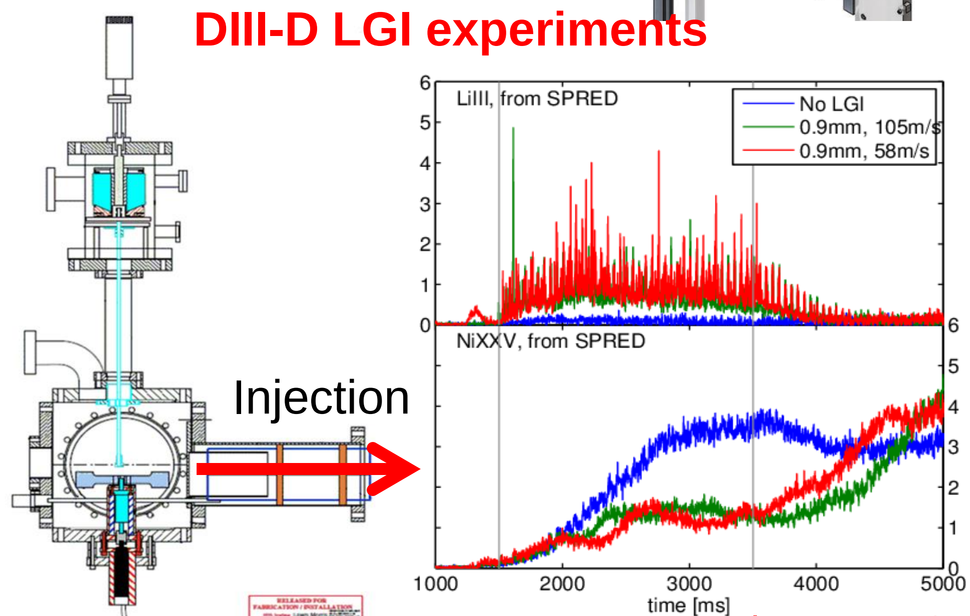


# Core transport toolset of diagnostics and actuators in development

- VUV/SXR spectroscopy to track core high-Z contamination
  - ★ MONA-LISA, XEUS, LoWEUS (Commissioning?)
- New full-midplane core resistive bolometer system ★ (Designed)
- **Granule Injector system on cusp of operating before shut-down**
  - Potential impurity-flushing actuator

M. Weller




Bortolon & Lunsford

# Consideration of Alternative plans

1. Full install according to original plan
2. Partial install on lower divertor
3. No installation of any high-Z
4. Full installation on upper divertor

# 1. Full install on lower divertor

## Pros

- Gain design and ops guidance with high-Z to prepare for future upgrades
- Move Li studies to more reactor-relevant tech.
- Enhance collaborator activities
- LITER & BZN available to coat surfaces

## Cons

- No high-δ shape yet developed
- Creates heat-flux operating restrictions for discharges
- Unknown impurity influx and impact with and w/o coatings (part of experiment)

# 2. Partial install on lower divertor

## Pros

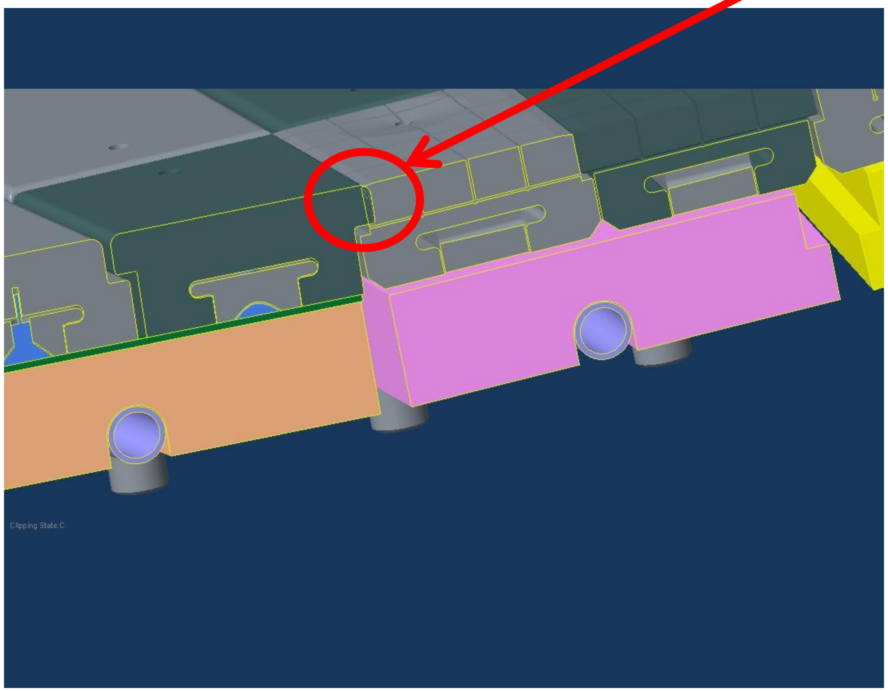
- Gain design and ops guidance with high-Z to prepare for future upgrades
- Move Li studies to more reactor-relevant tech.
- Enhance collaborator activities
- LITER & BZN available to coat surfaces

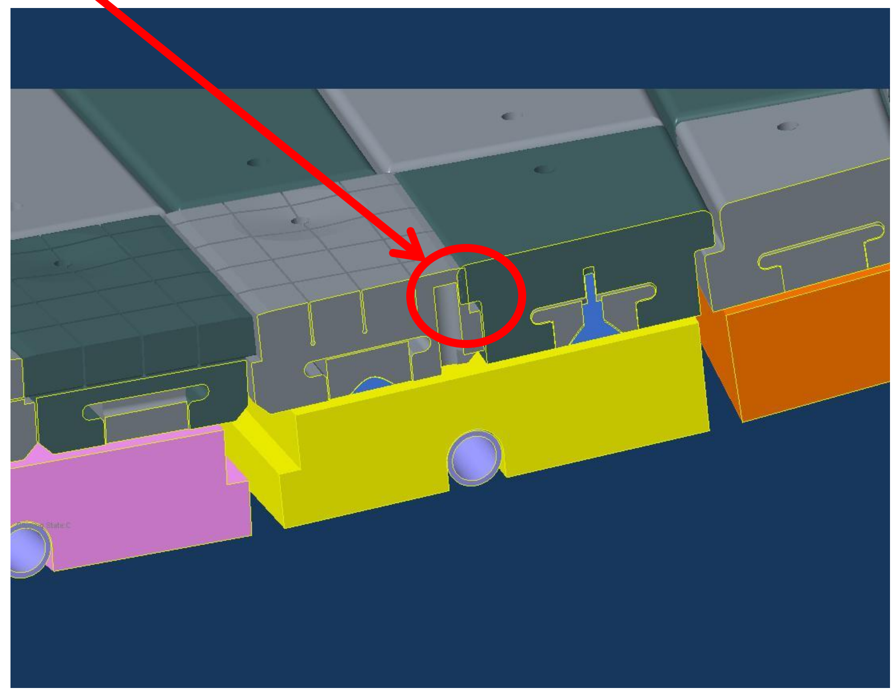
## Cons

- No high-δ shape yet developed
- Creates heat-flux operating restrictions for discharges
- Unknown impurity influx and impact (part of experiment
- Science results weakened due to greater impurity (C) content in near-surface plasma and 3D effects
- Increased sputtering with greater impurity content may mitigate reduced area of high-Z
- Modification of adjacent graphite tiles necessary

# Tile modifications required for partial installation

0.08” (2mm) interference





J. Winkelman

# 3. No installation of any high-Z

## Pros

- No heat-flux operating limits
- Carbon+friends impurity production (the devil you know)
- LOTS of time for diagnostics to come up

## Cons

- No advanced information for high-Z upgrade of machine
- Long-run scenario means no high-Z this side of cryo-pump (~3 yrs program delay)

# “Mitigation” scenarios for case 3

- Continue diagnostic and engineering design validation on available high-heat flux facilities
  - Magnum-PSI and/or proto-MPEX plasma tests of leading-edges, Li PMI interactions
  - ORNL light-source high-heat flux facility for thermomechanical cycling; calorimeter testing and calibration

- Implement sample exposure “ring” to still implement some high-Z in machine (Kaita)
  - Sample exposure tiles are variant of existing graphite tiles – have drawings done
  - Include multiple tiles at larger major radius (e.g. Row 3 or 4)

# 4. Full install on ~~lower~~ upper divertor

## Pros

- Gain design and ops guidance with high-Z to prepare for future upgrades
- Move Li studies to more reactor-relevant tech.
- Enhance collaborator activities
- LITER & BZN available to coat surfaces
- Reduced impact on LSN scenarios
- Already planned for cryo-pump upgrade

## Cons

- Reduced diagnostic coverage
- Debated change in installation time for upper install (5-8wks estimated)
- LITER indirectly coats or need upward evap.

# Additional comments on diagnostics and installation issues

- Input from Filippo: camera for upper div. less sensitive and single band – might be doable; consider moving TWICE system; upper 1D CCD not installed – needs support
- Input from Vlad: DIMS doesn't view upper divertor
- Input from Travis: lower divertor view prioritized this past year – needs support for upper view
- Input from Kaifu in absentia: UTK spectrometer has sight-lines of upper divertor
- Input from Jaworski: Upper divertor probes symmetric with lower divertor – same operability for two systems
- Input from Skinner: BZN can be biased upward or downward with gas injector selection; diffusive LITER does coat surfaces, but did not improve performance
- Input from Loesser: quick look indicates weight increase on upper divertor support structures not an issue. Estimates 5-8 wks installation
- Input from Perry via Gerhardt: unity multiplier on installation time needed (i.e. 5 wks)

# Jaworski additional comments

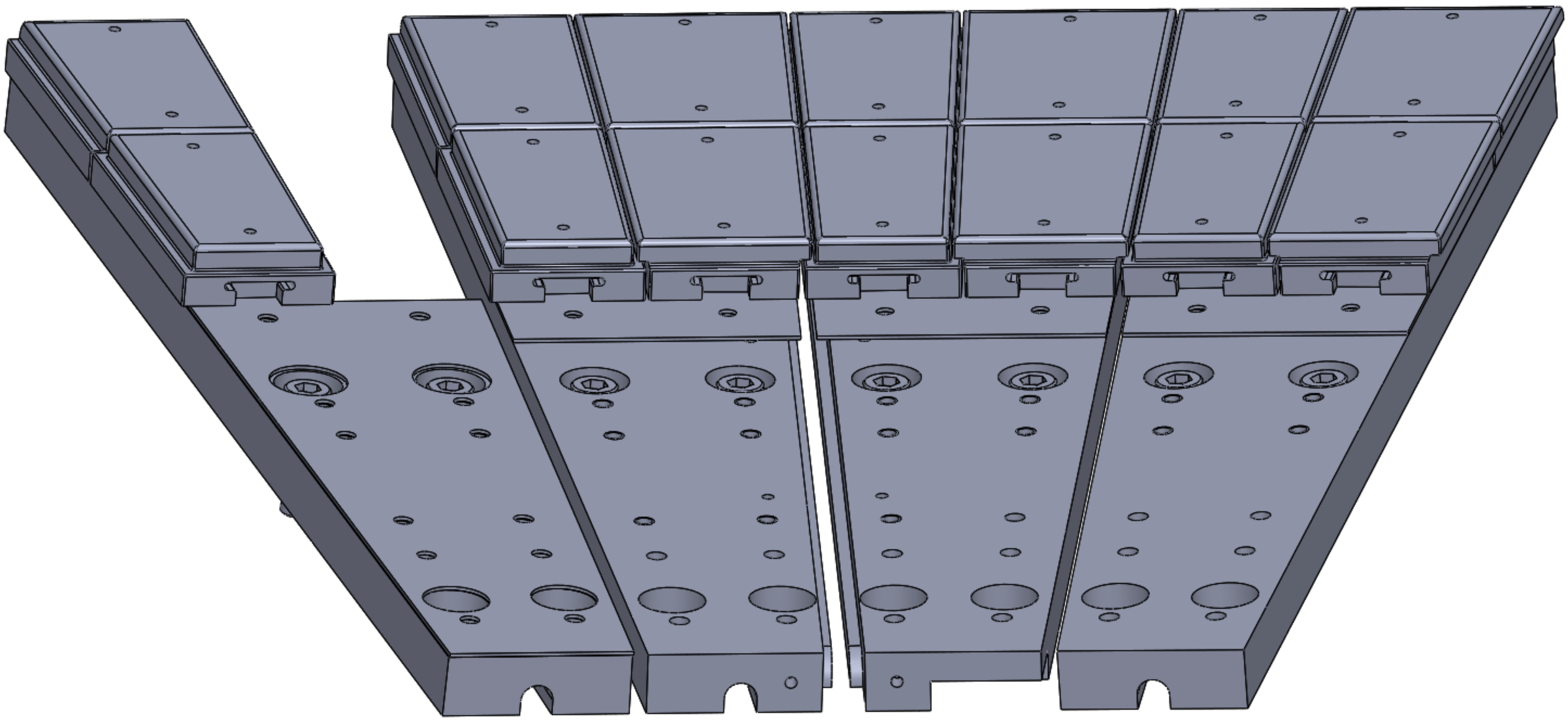
- Shut-down of CMOD leaves the domestic program lacking a high-Z machine
- PMI community downgrading carbon machines as being impactful
- NSTX-U only “applied” home for liquid PFC development in US; likely to lose ground to CN and EU with 3-year delay

# Thank you!

# Installation Procedure Overview

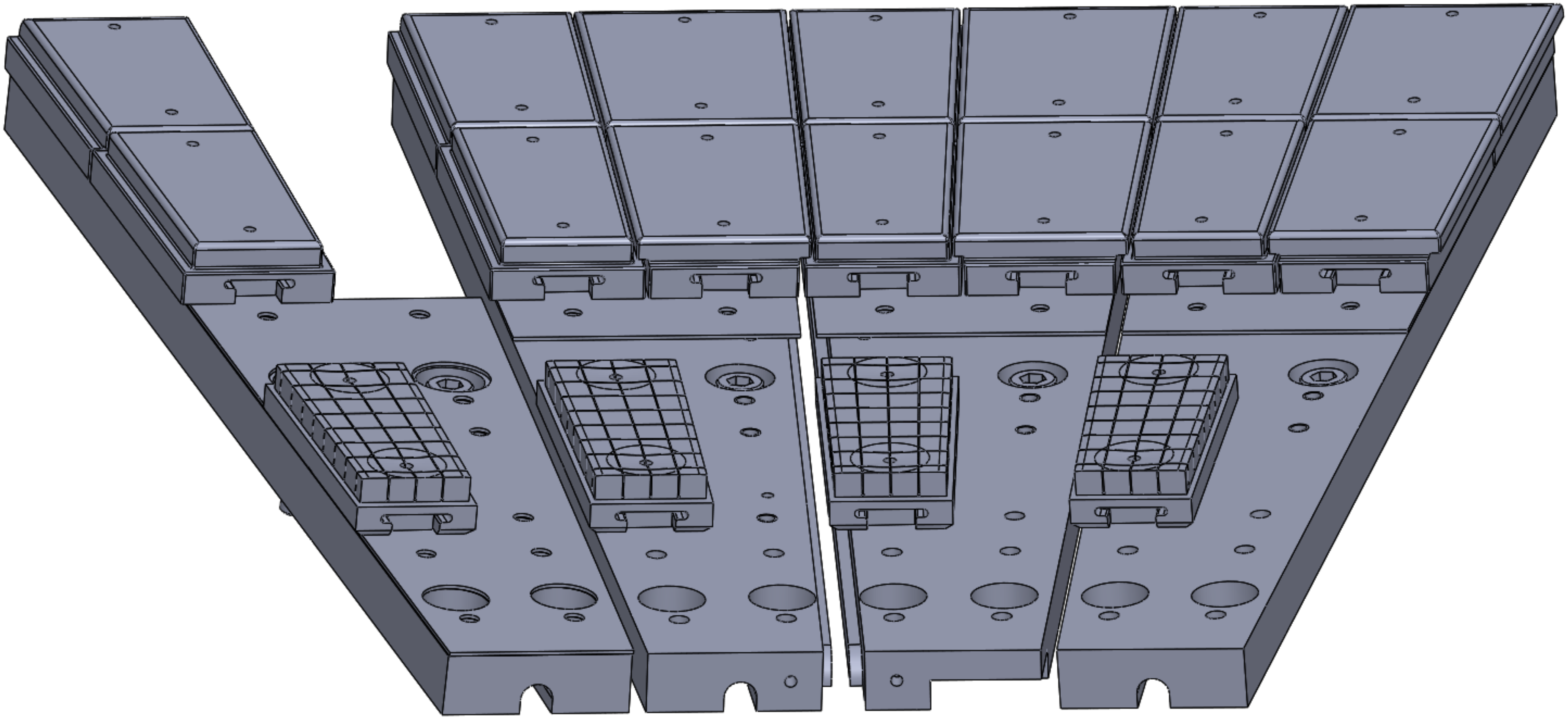
# Vessel opens, OBD rows 1 – 3 are removed

- Care should be taken to record what shims are beneath each tile in Row 1.
  - There is already a .060” thick grafoil sheet beneath these tiles, but special shimming was done during NSTX-U Installation.
  - At this point, it would be extremely helpful to have metrology of these surfaces to help with vertical fitup



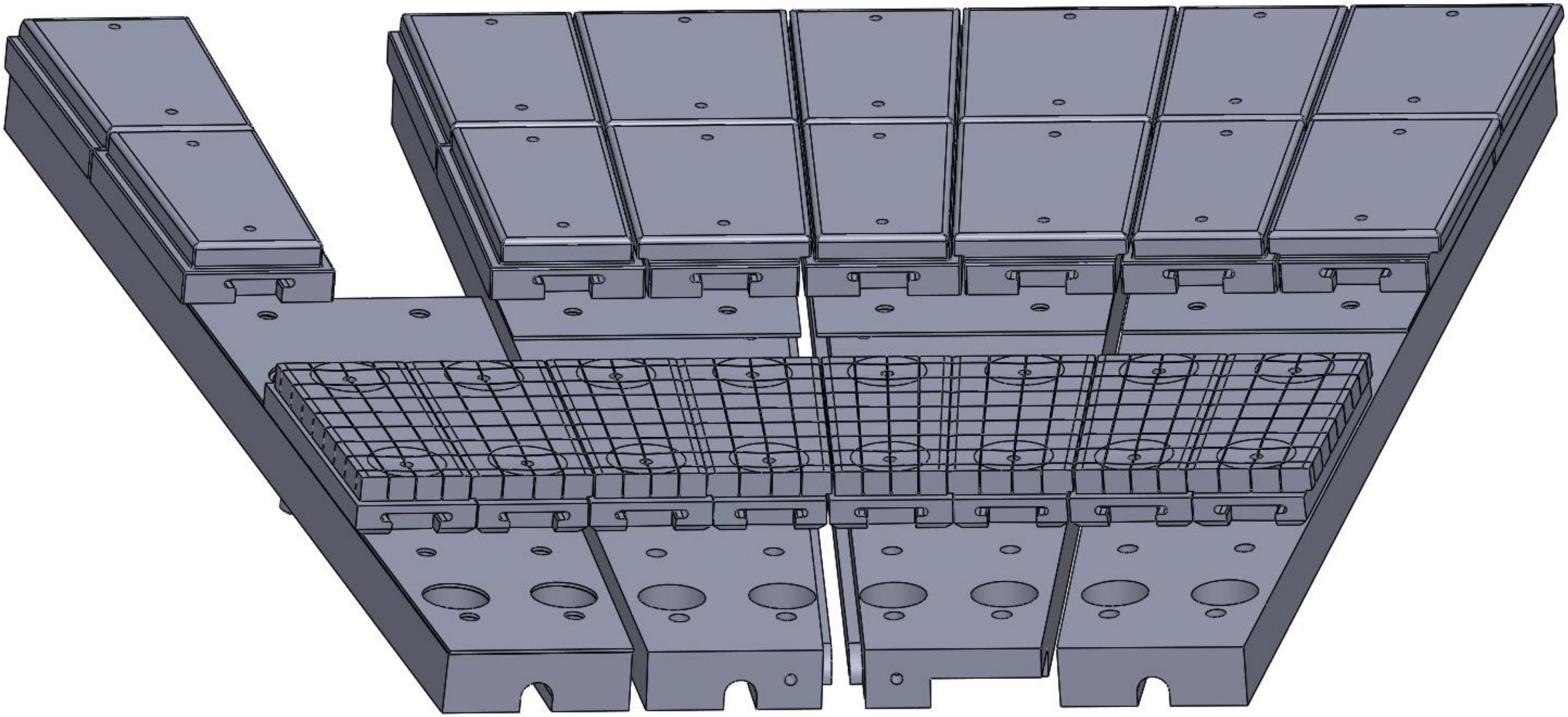
# Row 2 "under" tiles are installed

- By using .012" shims on either side of the tbar slot, horizontal tile position is idealized. These shims are only for installation.
  - Vertical positioning will be much more difficult, but with metrology, we should be able to estimate "ballpark" for the trouble areas.



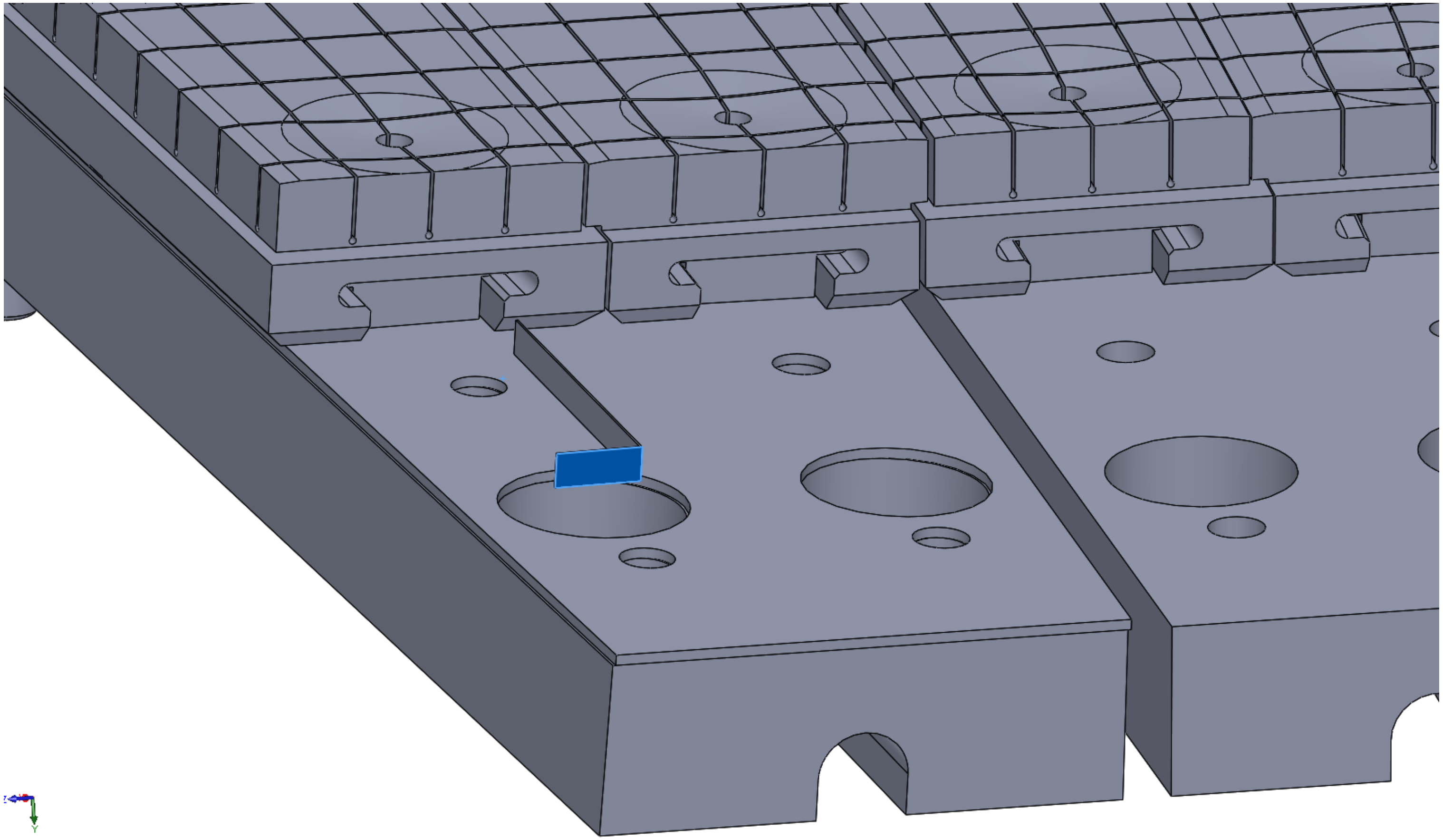
# Row 2 “over” tiles are fit up, installed

- Vertical shimming will take place during this step, using .030” spacers to maintain gaps, then tiles will be bolted,.
  - Will suggest running diagnostic wireways under backing plates at this time, testing.



# Horizontal Gap must be maintained due to edge impingement issues.

- Once tiles are where we want them, a single .01” thick L-shim is slid along one side of the tbar and tacked into place.
  - Trapped by OBD Row 1 tiles, reduces alignment slip, critical to edge performance.



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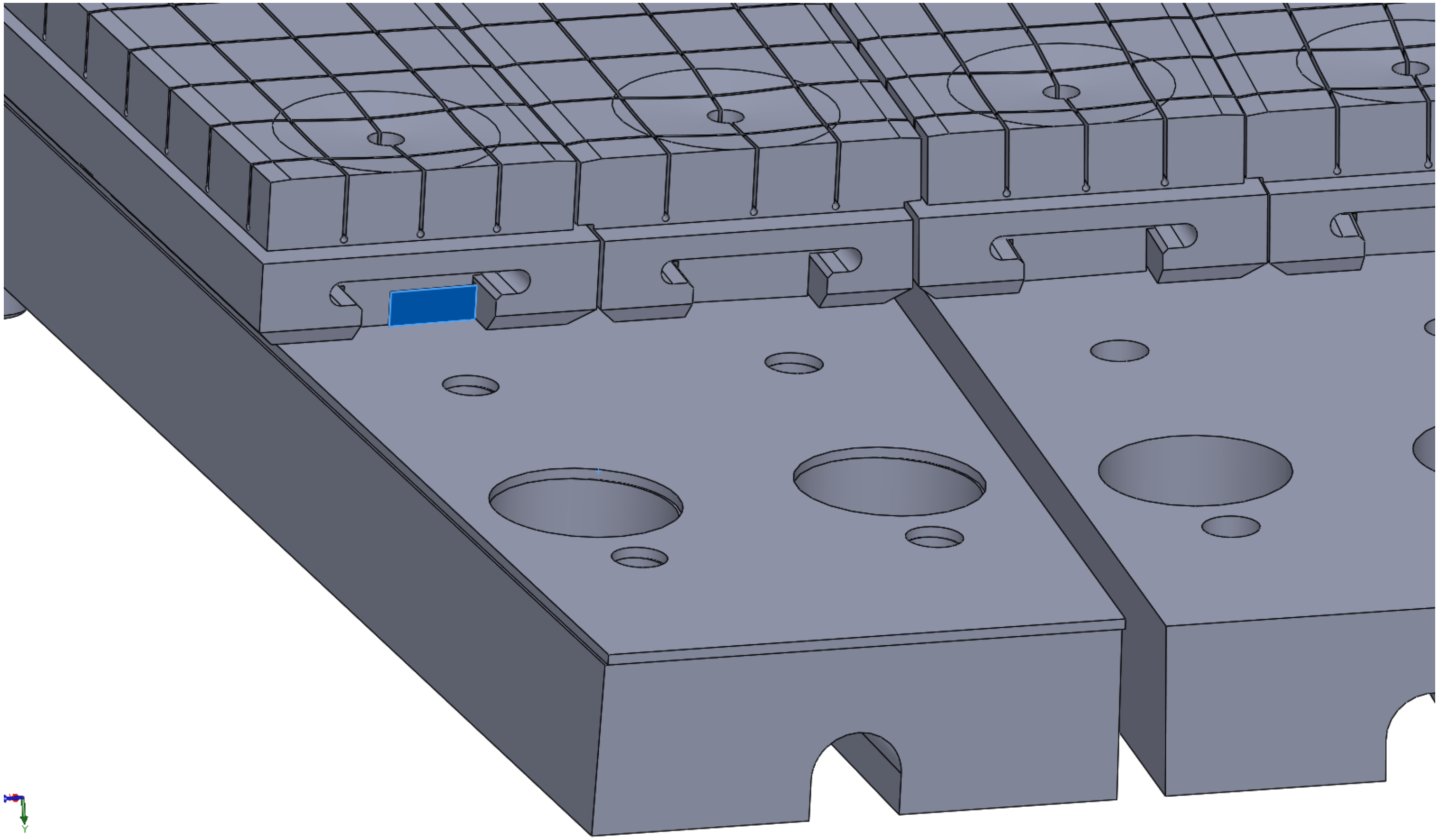

# Rows 1 & 3 are re-installed.

- Consider taking one last metrology measurement of the new TZM surfaces.
- Need high-resolution photographs of post-installation tiles, all 360 deg.