# Aqua-pour Implications for NSTX-U Operations and Research Goals

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*for the NSTX-U Team*

**NSTX-U Team Meeting**
**August 15, 2014**

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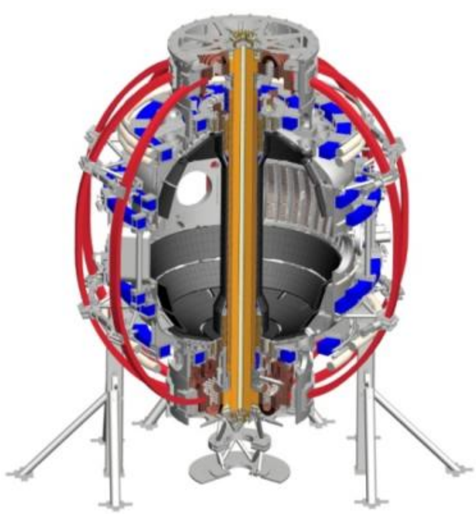

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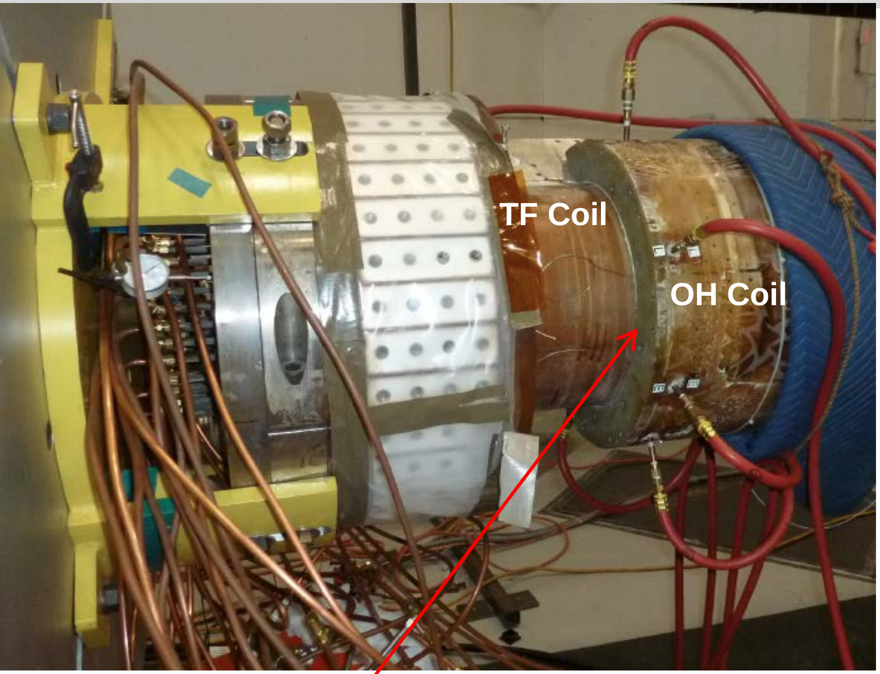
# Outline

- **Operational Implications (M. Ono)**
- **Research Program Implications (J. Menard)**

# OH Aquapour Removal Activity

## Removal of Aquapour-epoxy mix in tight space proved to be highly challenging

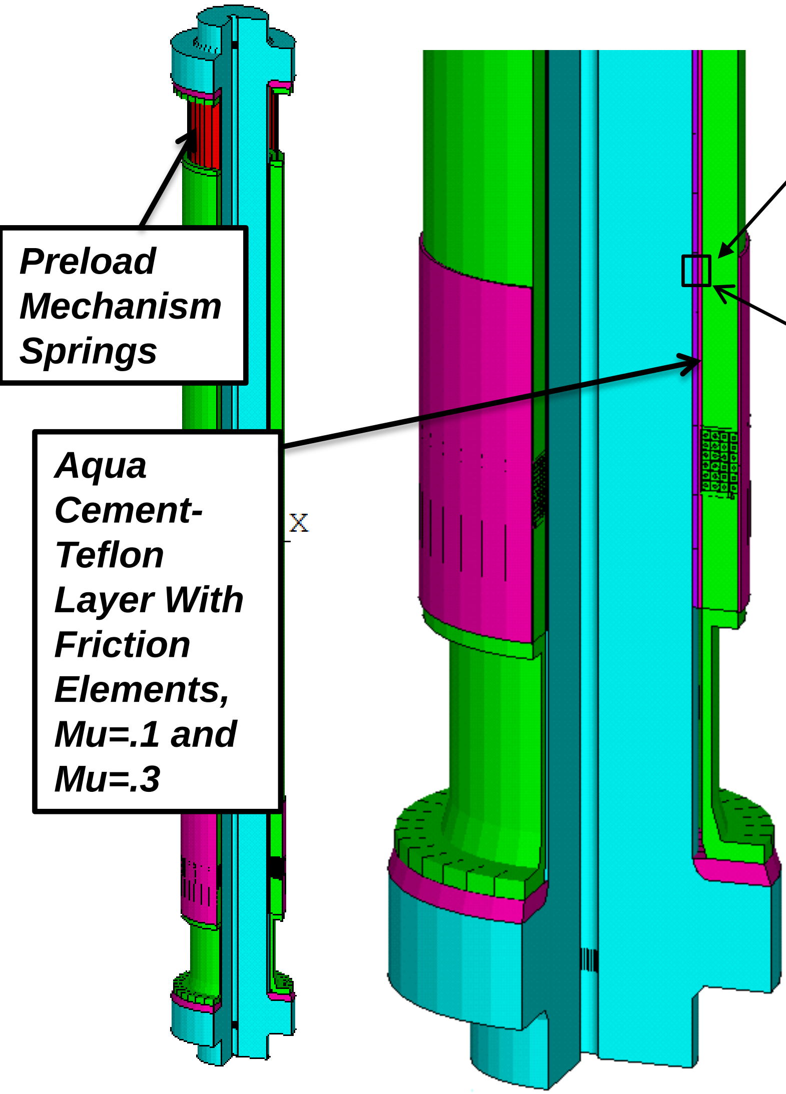


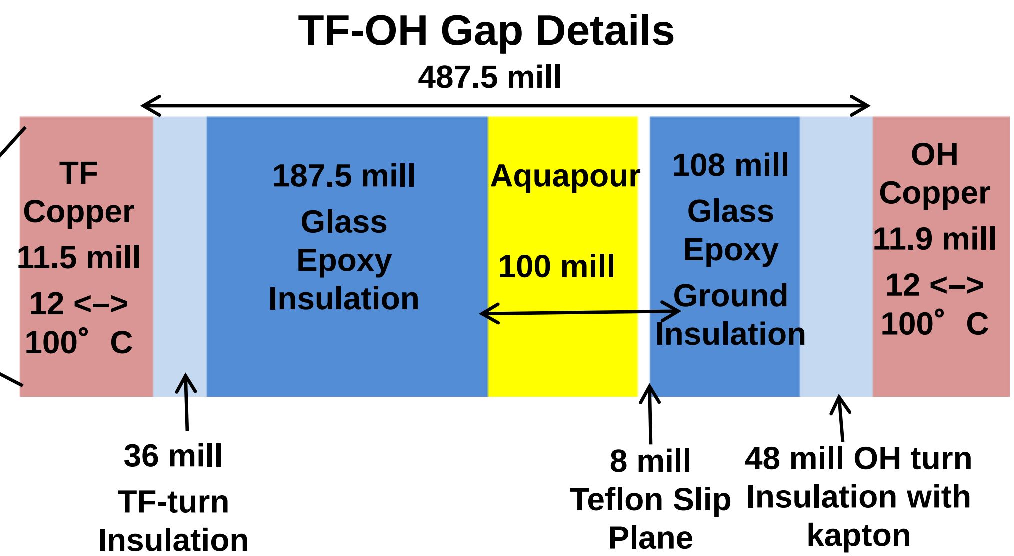

100 mill Aquapour gap

- During VPI CTD-425 epoxy was cured at ~ 170˚ C in oven
- Epoxy "barriers" were teflon sheets over aquapour and RTV silicon applied at the both ends.
- However during VPI, epoxy saturated the aquapour turning it into waster resistant substance.
- ~ two week of removal activities with various tools and methods only resulted in ~ 3" of removal.
- At the present time, there is no solution for removing the remaining aquapour- epoxy mixed material.
- TF/OH bundle was baked at 100 ˚ C in the oven overnight and it is being readied for electrical tests before being assembled.

# Schematics of OH-TF bundle configuration

## 100 mill gap between OH and TF to provide free OH-TF operation




- Both TF and OH expand about 12 mills during the full parameter operation reaching ~ 100 ° C from 12 ° C.
- If TF expands more than OH, the gap region could be compressed leading to insulation stress as the TF and OH grow radially and axially.
- The full 1 T, 2 MA, 5 sec (third year) scenario maybe affected since TF temperature could exceed OH by as much 19° C which could cause insulation stress.
- Bringing the temperature gap down to 10° C range reduces the stress to acceptable range.
- This can be accomplished by pre-heating the OH with respect to TF by ~ 10° C.

# Strategy for Achieving Full NSTX-U Parameters

## After CD-4, the plasma operation could quickly access new ST regimes

| | NSTX (Max.) | FY 2015 NSTX-U Operations | FY 2016 NSTX-U Operations | FY 2017 NSTX-U Operations | Ultimate Goal |
|---|---|---|---|---|---|
| $I_P$ [MA] | 1.2 | ~1.6 | 2.0 | 2.0 | 2.0 |
| $B_T$ [T] | 0.55 | ~0.8 | 1.0 | 1.0 | 1.0 |
| Allowed TF $I^2t$ [$MA^2s$] | 7.3 | 80 | 120 | 160 | 160 |
| Longest $I_P$ Flat-Top at max. $I^2t$, $I_P$, and $B_T$ [s] | ~0.4 | ~3.5 | ~3 | 5 | 5 |

1st year goal: operating points with forces up to ½ the way between NSTX and NSTX-U, ½ the design-point heating of any PF/TF coil (~75% for OH)

Will permit up to ~5 second operation at $B_T$~0.65

2nd year goal: Full field and current, but still limiting the PF/TF coil heating

Will revisit year 2 parameters once year 1 data has been accumulated

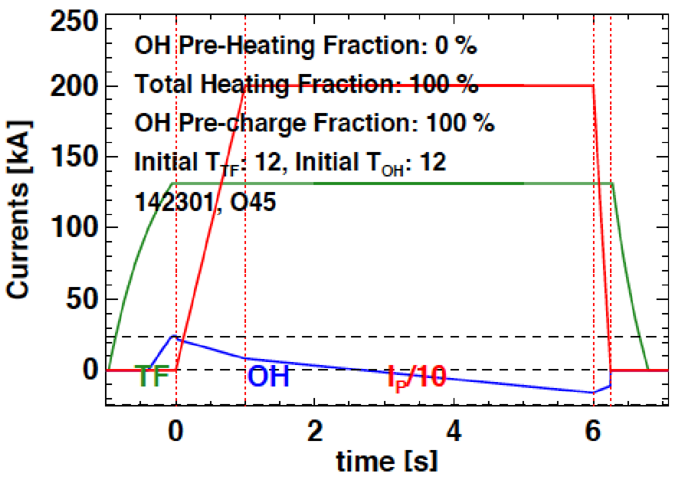
3rd year goal: Full capability

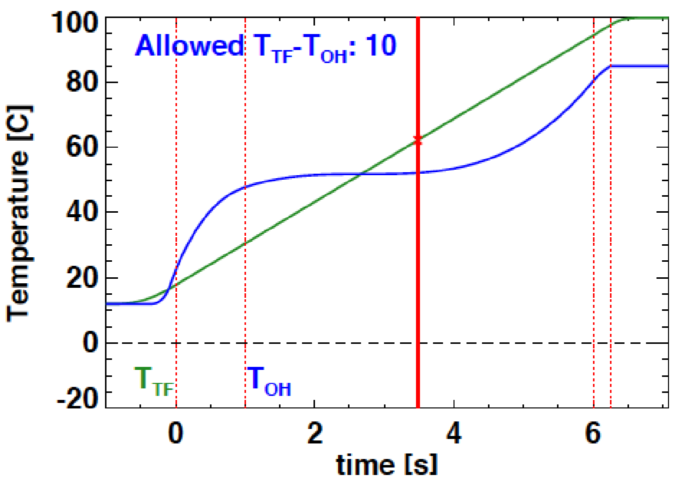
**This scenario most likely to be affected**

**1st and 2nd year goals not affected materially (see Jon's slides).**

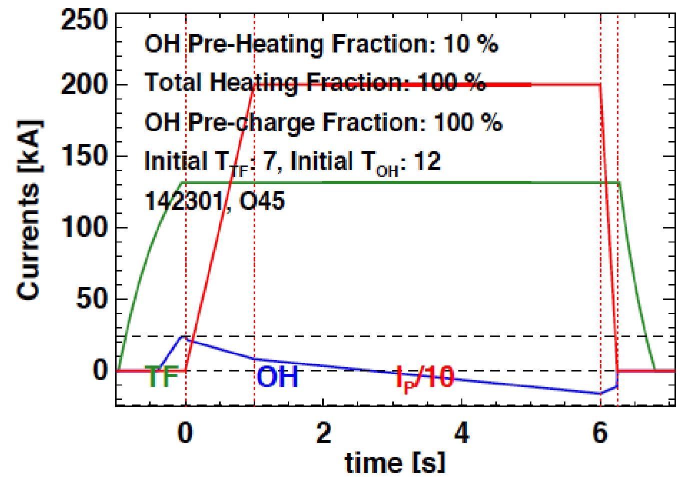
# 2 MA, 1 T, Partial Inductive (Later Years, 80 kV beams)
# (Favorable Profiles and H~1.05, 142301)

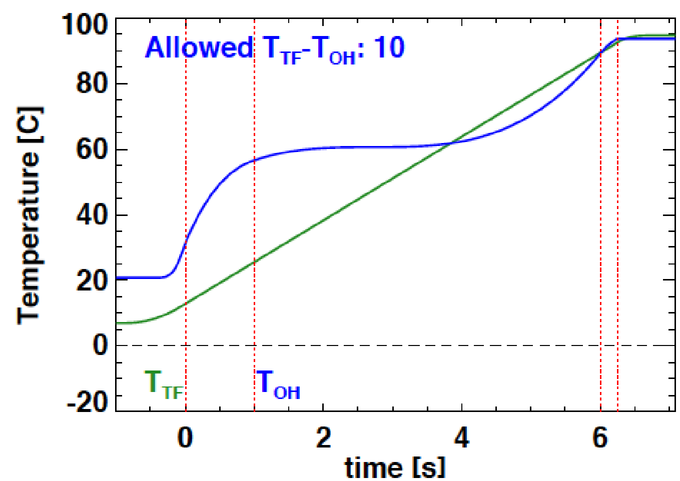
- **If we do nothing, allowed temperature limit reached at t = 3 s.**




- **10% pre-heat and 7° C TF pre-cooling case allows 5 s at 1 T and 2 MA.**

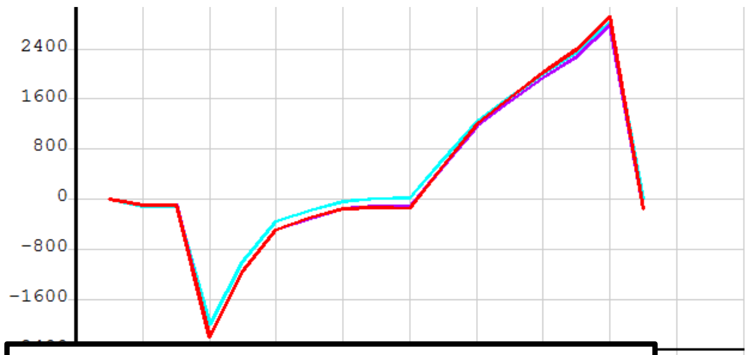


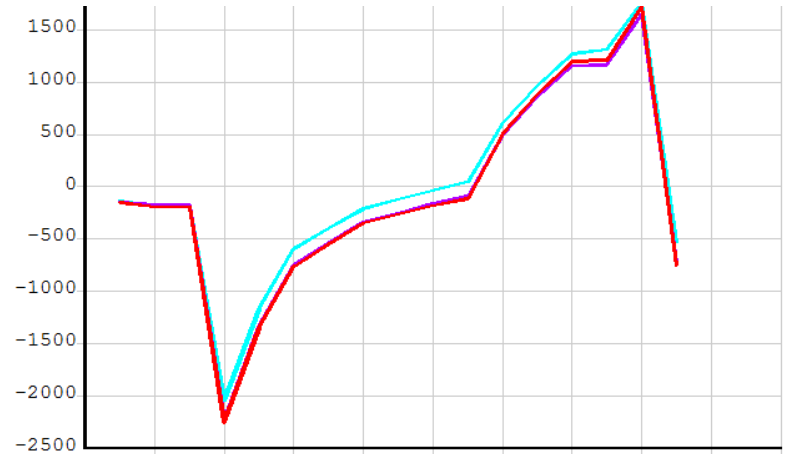
# Stress Analyses for 2 MA, 1 T, Partial Inductive Case

## Warmer OH and cooler TF help reduce peak tension

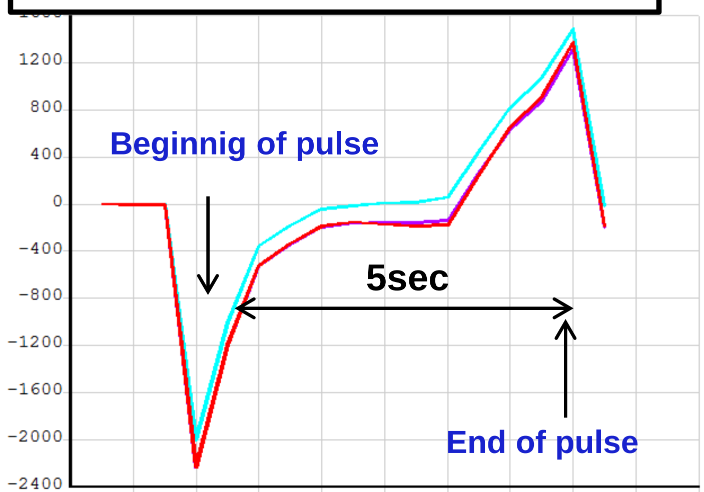
**Nominal Scenario,**
**OH,  Peak Tension=28 MPa**



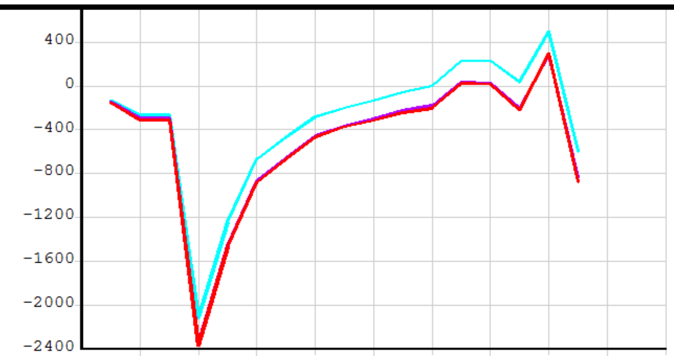

**Nominal Scenario With -5 deg C TF Bias,**
**OH Peak Tension=17.5 MPa**




**+10C OH Thermal Bias,**
**OH, Peak Tension=12 MPa**




**-5C TF Bias, +10C OH Thermal Bias, OH, Peak Tension=4 MPa**



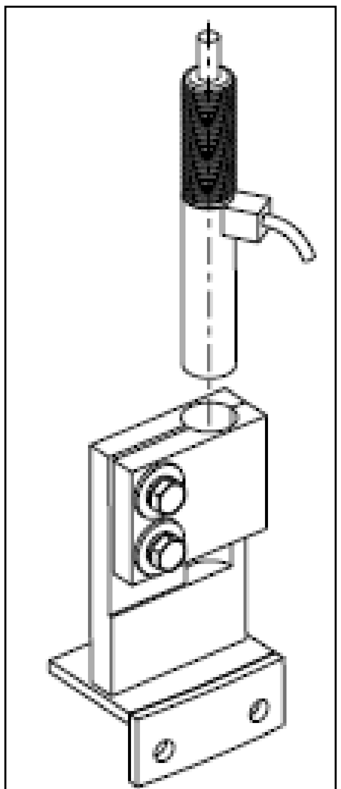

**Mu=.3**

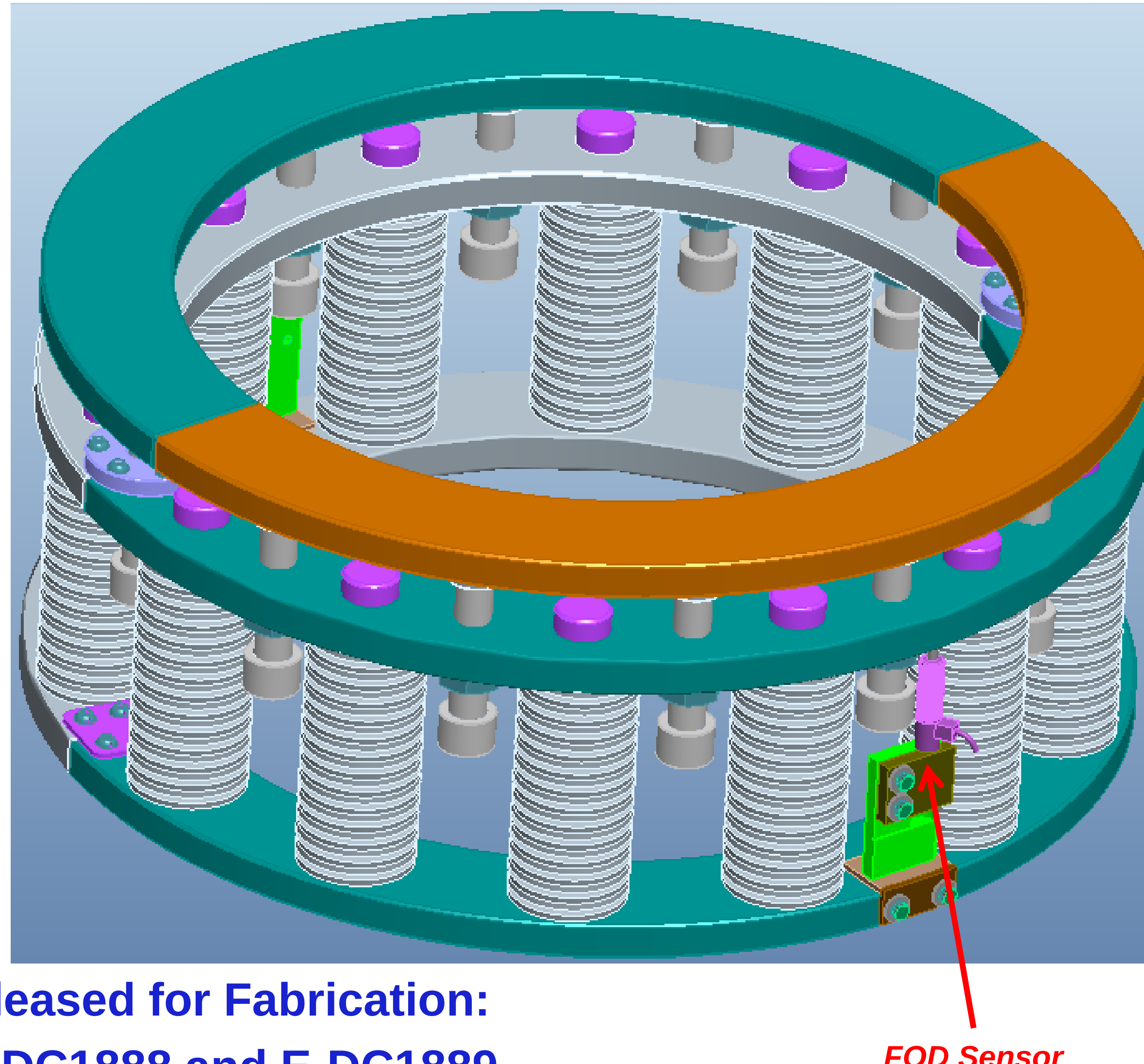
# OH Solenoid Thermal Growth Sensors Implemented

## FOD sensors will monitor OH solenoid growth in real time

Two Fiber Optic Displacement (FOD) sensors to be installed at 180° apart.

The fixtures can be installed now and the sensors will be installed after the center stack is installed.






**Drawings Released for Fabrication:**

**E-DC1887, C-DC1888 and E-DC1889**

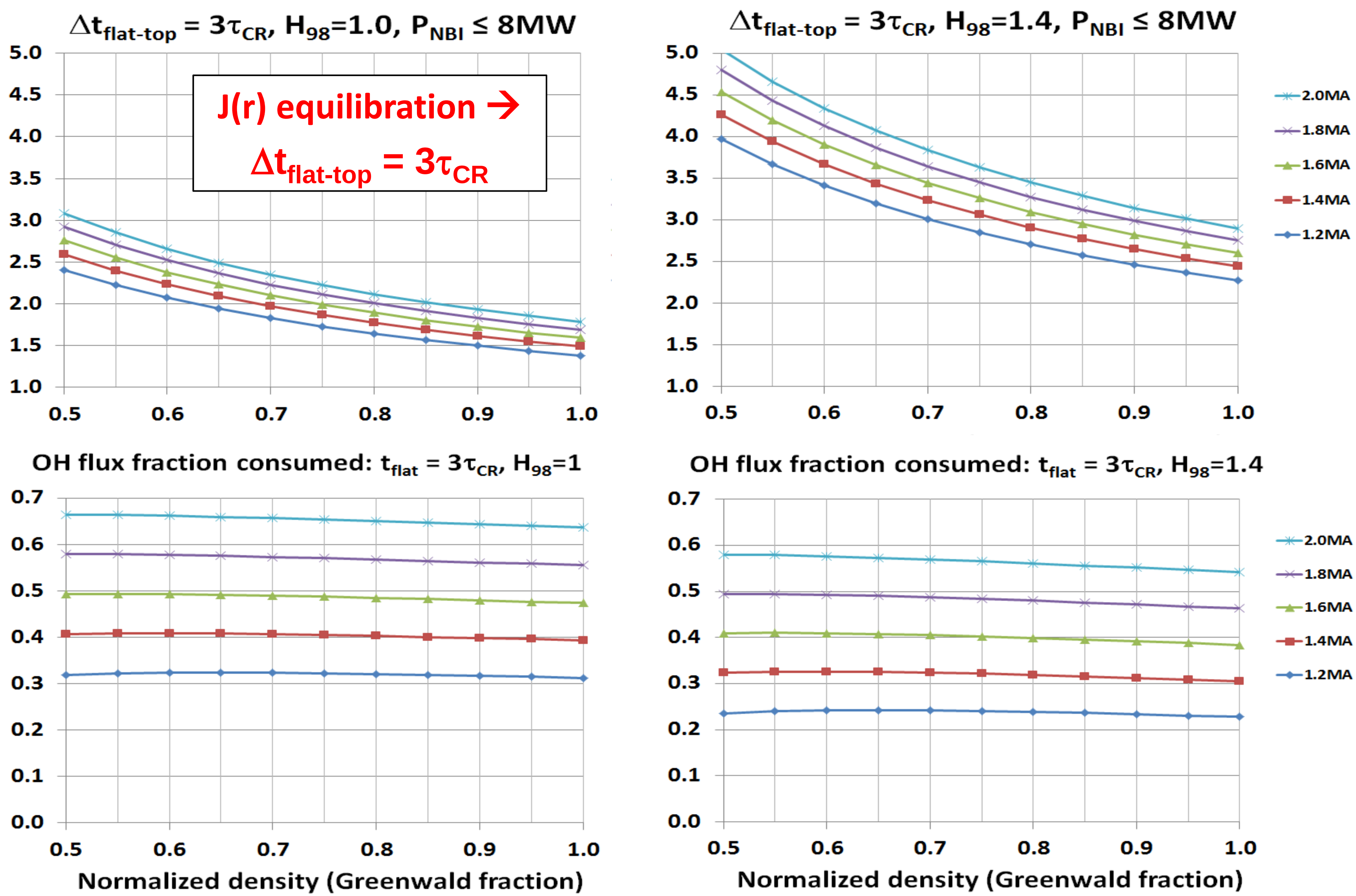
# Possible Future Engineering Improvements

## Which could increase operational and physics flexibility

1. Through engineering test specimens, it may be shown that the stress concerns may be greatly reduced or entirely eliminated.
2. Raise the OH operational allowable temperature limit to 110 °C from the present 100 °C
3. Consider pre-cooling TF by ~5 °C from present 12 °C to 7 °C.
4. Consider pre-heating the OH coil by increasing the OH cooling water temperature
5. Delay OH cooling during the initial OH-TF cool--down period to insure the TF coil cools down sufficiently.

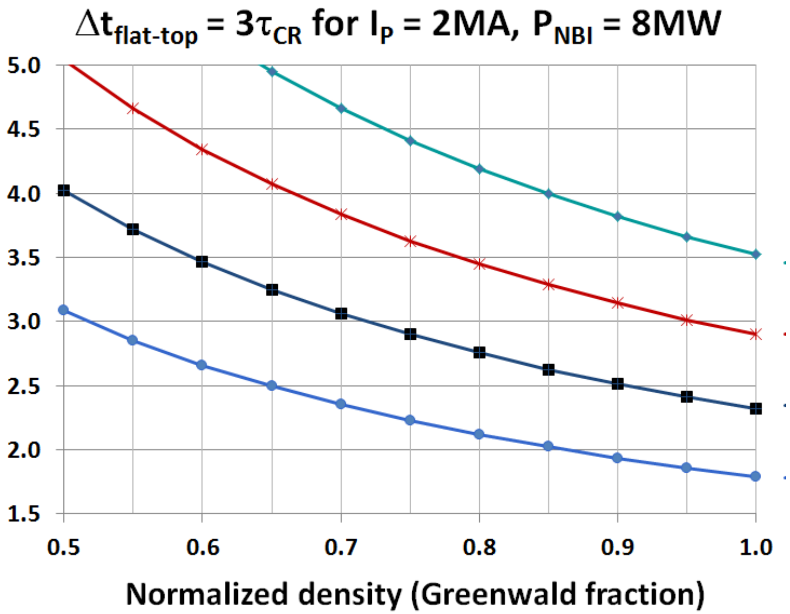
It should be noted that if potential solutions 1 and/or 2 above are proven to be feasible, then the need for the further engineering system implementation indicated in 3 - 5 would be greatly reduced or eliminated entirely.

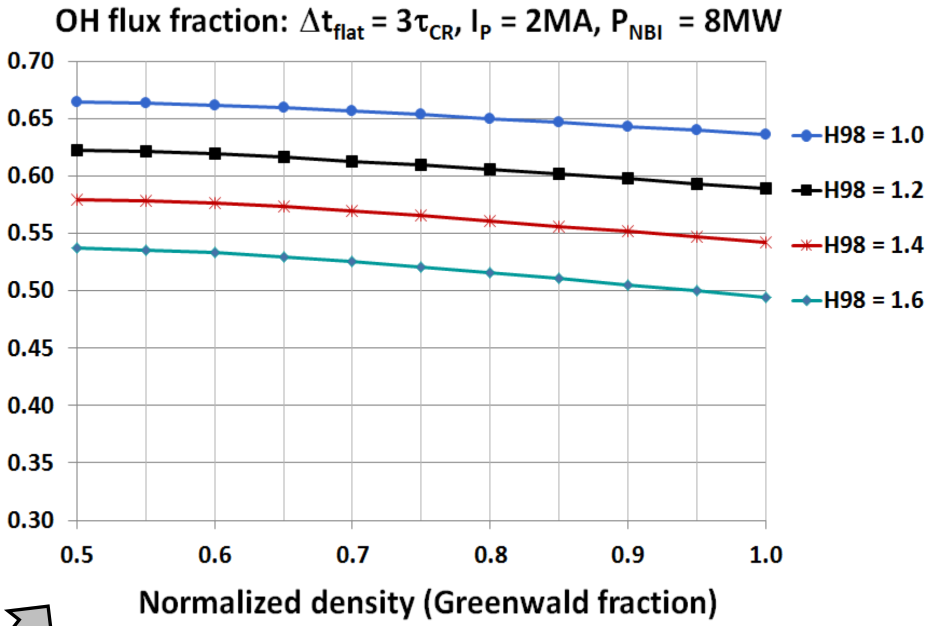
# J(r) equilibration varies most strongly with $n/n_{Greenwald}$ and $H_{98}$ and weakly with $I_P$, flux consumption depends on flat-top $I_P$



# Physics requirement to achieve J profile equilibration at $I_P$ = 2MA should be feasible for broad range of $\tau_E$, $n_e$

## ~3x current redistribution time $\tau_{CR}$ < 5s for lower $H_{98}$ and higher density values



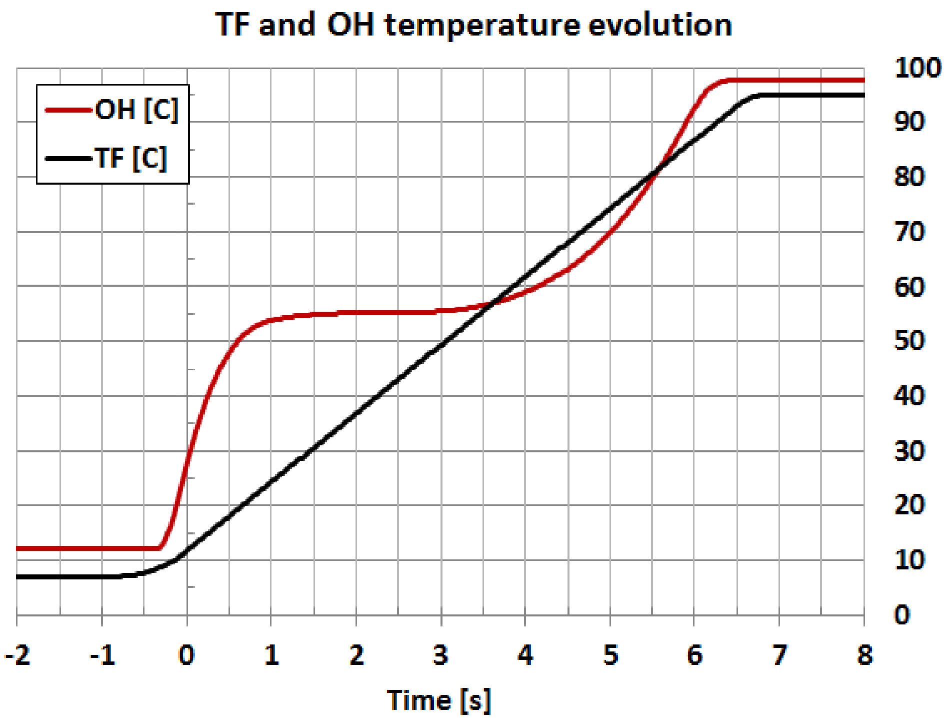

## OH flux fraction < 0.7 → $I_{OH}$ > -10kA for $\Delta t_{flat} = 3\tau_{CR}$ → possible to achieve $T_{TF} < T_{OH}$ < 100C

# For ITER-like confinement, good density control ($n/n_{Greenwald}$ ~ 0.5 ) facilitates 2MA, 5s flat-tops with $T_{OH} \geq T_{TF}$

**$H_{98}$ = 1.05**

**$f_{Greenwald}$ = 0.6**

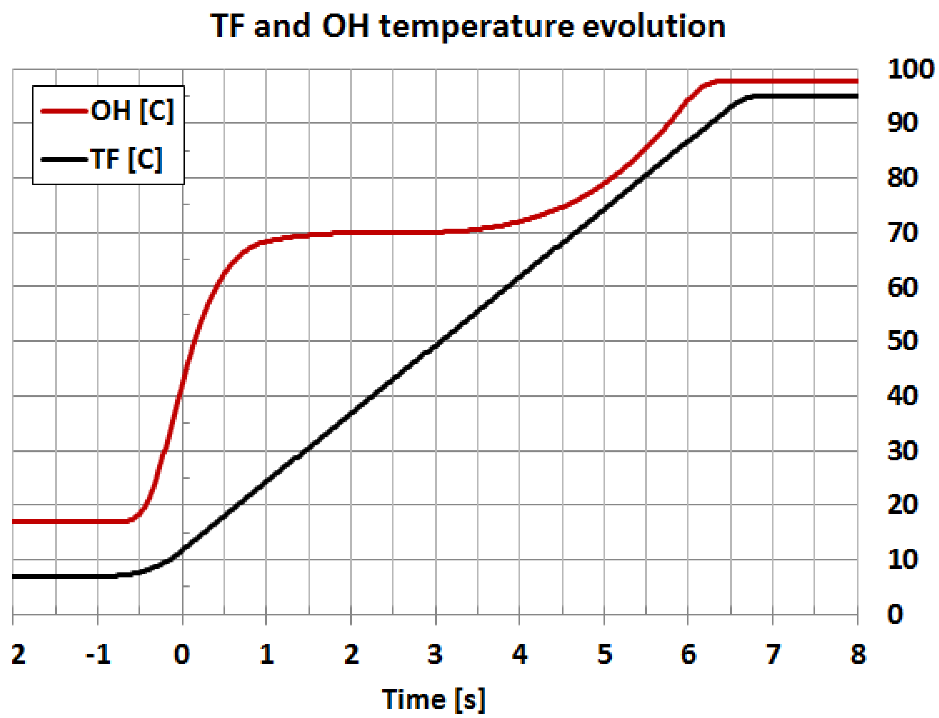
**$P_{NBI}$ = 8MW, $\beta_N$ = 3.8**




**$H_{98}$ = 1.05**

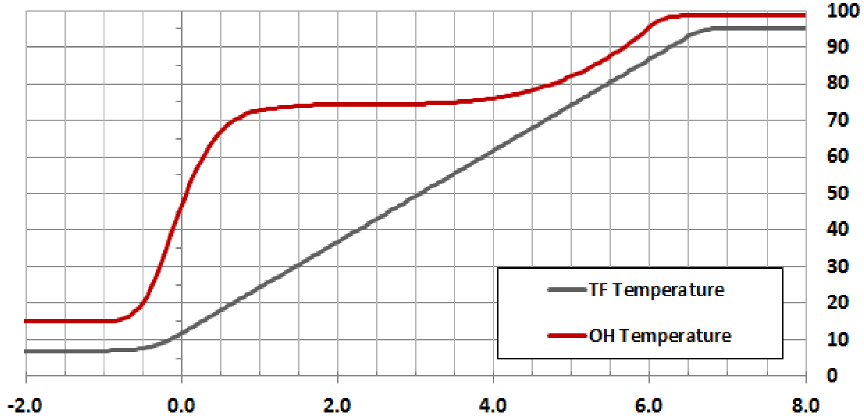
**$f_{Greenwald}$ = 0.5**

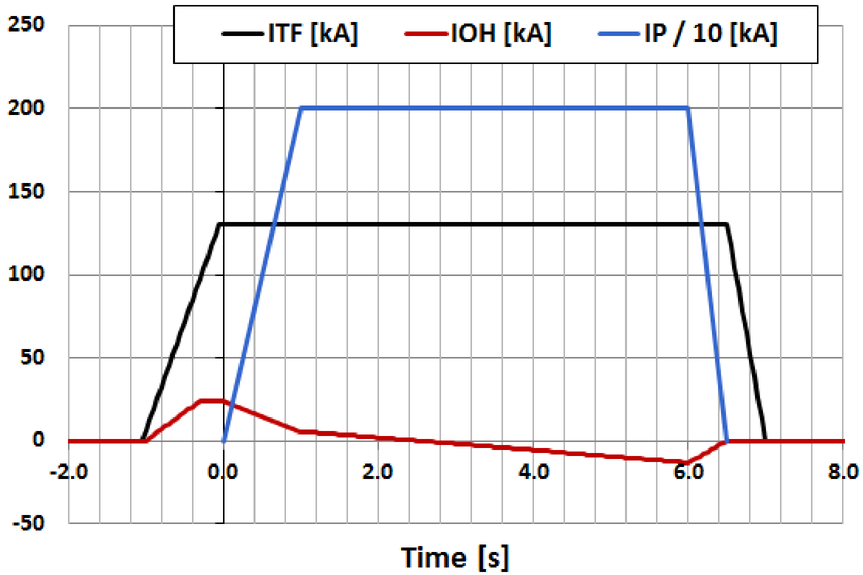
**$P_{NBI}$ = 8MW, $\beta_N$ = 3.7**



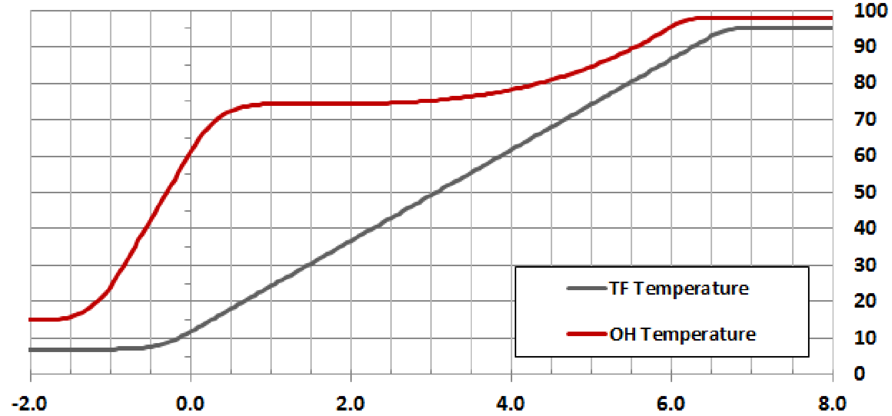
# Higher confinement enables 2MA, 5s flat-tops with $T_{OH} \geq T_{TF}$ even with higher density

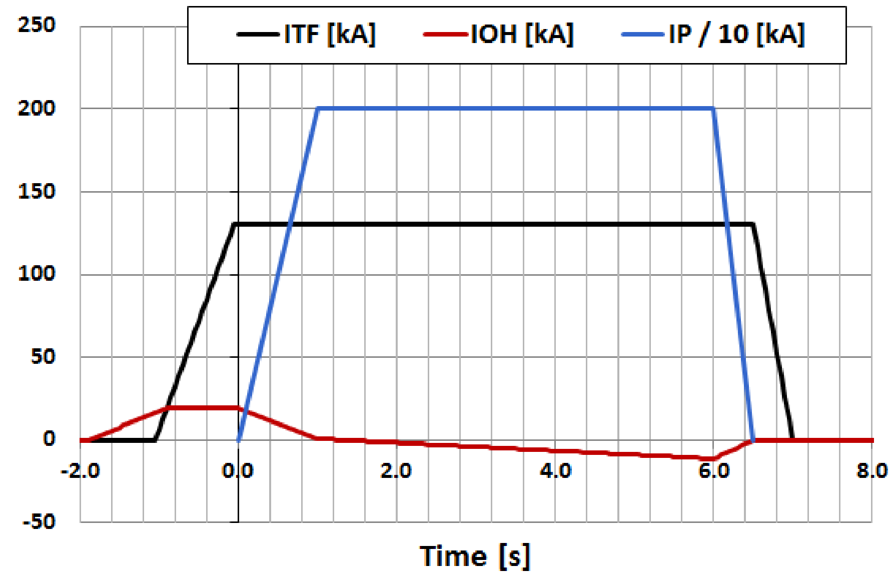
**$H_{98} = 1.2$, $f_{Greenwald} = 0.75$, $P_{NBI} = 8MW$, $\beta_N = 4.6$**




**$H_{98} = 1.4$, $f_{Greenwald} = 0.75$, $P_{NBI} = 8MW$, $\beta_N = 5.3$**



# Summary – Research Impact

- With a high degree of confidence, we believe we can meet all of the physics objectives in the machine with the Aquament filling the TF-OH gap
- Research milestones for FY2015-16 unchanged
- More shot pre-planning and development needed to get maximum plasma pulse length at full current
  - Planned improvements in stored energy / $\beta_N$ control, and implementation of line-average density control (likely requiring cryo-pump) will greatly aid shot reproducibility, scenario development
- Can readily meet each of the PEP parameters individually
  - Combination of parameters (2MA, 1T, 5s) may require additional engineering systems (initial $\Delta$T for OH and TF) and administrative controls (operational procedures), DCPS modifications
- Planning to get a 10C T initial differential between the OH and TF with TF initially colder.  Evaluating details of impact.

# Discussion of options and risks/benefits

1. Continue as is (our recommended option)
   – No down-side for first 2 years of operations
   – Performance acceptable for physics goals and for year ≥ 3
   – Narrower operating windows for 2MA, 5s operations
      • Improved density/confinement control can likely mitigate this
      • Higher $\tau_E$ scenarios beneficial (also needed for FNSF!)
2. Keep trying to remove the Aquament (mostly risks)
   – More delays to first plasma, research operations
   – No guarantee can be removed in near future
   – Potential for causing damage to the coils
3. Remove the OH and try again (mostly risks)
   – Tremendous delays in schedule and cost impact
   – No guarantee of an alternative method succeeding (R&D)

# Summary – Upgrade Path Forward

- Continuing with Assembly; expect first plasma before the end of February
- Start-up in Feb would allow between 12-16 run weeks
- Additional engineered systems and administrative controls not needed for CD-4 or first 1-2 of yrs of ops
  - Evaluating best method for T differential control. As part of that, exploring ways to control humidity in the test cell.
- Will continue to evaluate options in the longer-term for removing the Aquament