NSTX

Supported by

U.S. DEPARTMENT OF ENERGY | Office of Science

NSTX CSU Upgrade Overview

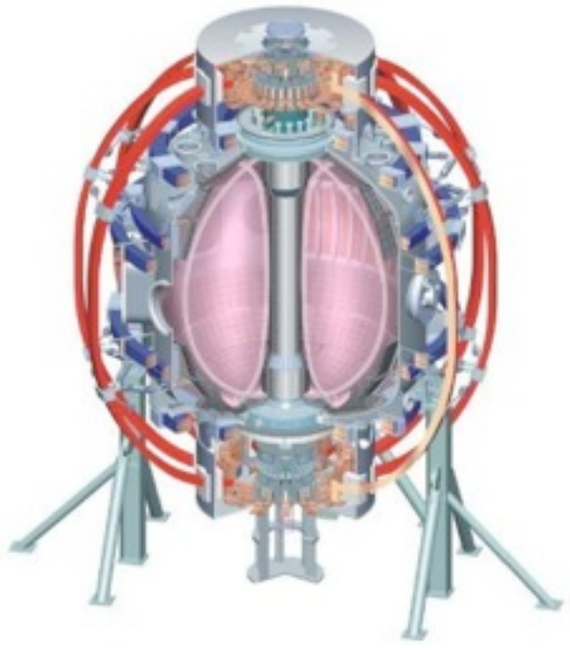
Larry Dudek

and the NSTX Upgrade Team

NSTX Upgrade Final Design Review
LSB B-318
June 22-24, 2011

College W&M
Colorado Sch Mines
Columbia U
CompX
General Atomics
INEL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
Old Dominion U
ORNL
PPPL
PSI
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
KBSI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep
U Quebec



Outline

- General Requirements
- Center Stack Upgrade Jobs
- FDR Deliverables
- Center Stack Upgrade Scope
- FDR Risks
- Chit Resolution
- Schedule
- Conclusion

General Requirements

- Program Physics Goals
  - Better understand causes of ST transport and scaling to next step devices
  - Address ST start-up, sustainment and boundary issues
- Centerstack Upgrade Requirements
  - Toroidal magnetic field at the major radius R0 of 1 Tesla (T) compared to 0.6T in the original NSTX
  - Plasma current Ip up to 2 Mega-Amp (MA) (presently 1MA rating)
  - Increase Pulse length from 0.5 to 5.0 seconds
  - Plasma facing components, internal hardware (PP, OBD), CSC, VV, and RF antennae shall be designed to withstand forces due to plasma disruption.

Center Stack Jobs

DESCRIPTION	Cog	ETC from 6/1 ($K)
Job: 3400 - Gas Delivery System Mods	Blanchard	67
Job: 1300 - Center Stack	Chrzanowski	718
Job: 1301 - Outer TF Coils	Chrzanowski	310
Job: 1302 - Center Stack Assembly	Chrzanowski	984
Job: 1304 - Inner TF Bundle (Ds/Fab)	Chrzanowski	1,967
Job: 1305 - OHMIC Heating Coil (OH)	Chrzanowski	3,178
Job: 1306 - Inner PF Coils	Chrzanowski	519
Job: 1307 - CS Casing Assembly	Chrzanowski	726
Job: 1310 - CSU Magnet Systems	Chrzanowski	-
Job: 3200 - Water Cooling System Mods	Denault	152
Job: 5200 - DCPS	Hatcher	2,106
Job: 4100 - Center Stack Diagnostics	Kaita	677
Job: 1303 - TF Joint Test Stand&Test	Kozub	4
Job: 4500 - MPTS VV Modification	Labik	579
Job: 3300 - Bakeout System Mods for CSU	Raki	73
Job: 5000 - CSU Power Systems	Raki	4,670
Job: 6100 - Control Sys Data Acquisition	Sichta	816
Job: 1200 - Structures and Supports	Smith	1,722
Job: 5501 - Coil Bus Runs-SMITH	Smith	1,159
Job: 1000 - CSU Analytical Support	Titus	670
Job: 1002 -Passive Plate Analysis &Upgrade	Titus	47
Job: 2300 - ECH Analysis-	Titus	15
Job: 1001 - CS Plasma Facing Components	Tresemer	1,332
Job: 8200 - CS & Coil Sprt Struc Install	Viola	9,545

FDR Deliverables

Group	Owner	SubGroup	Required	Prepared	Comment
Calculations & analyses	Titus	--	49	43	
PFC's (ca 1001)	Tresemer	Part Files	66	66	
PFC's (ca 1001)	Tresemer	Drawings	105	63	
PFC's (ca 1001)	Tresemer	R&D Tasks	1	0	
PFC's (ca 1001)	Tresemer	Updated SRD	1	1	
Center stack (ca 13xx)	Chrzanowski	Drawings	175	173	Critical Path
Center stack (ca 13xx)	Chrzanowski	R&D Tasks	16	15	Critical Path
Center stack (ca 13xx)	Chrzanowski	Updated SRD	1	0	
Supports (ca 12xx)	Smith	Drawings/Models	106	106	
Supports (ca 12xx)	Smith	R&D Tasks	0	0	
Supports (ca 12xx)	Smith	Updated SRD	1	1	
Internals ie Passive Plates (ca ?)	Atnafu	Drawings/Models	2	0	
Auxiliary Systems (ca 3XXX)	Blanchard	Gas Injection	6	2	
Auxiliary Systems (ca 3XXX)	Denault	Water System	3	1	
Auxiliary Systems (ca 3XXX)	Denault/Blanchard	R&D Tasks	1	1	
Diagnostics (ca 4100)	Kaita	Drawings	8	8	
MPTS VV interface (ca 4500)	Labik	Drawings/Models	60	45	At PDR Level, optimization in progress
Power systems (ca 5000)	Raki	Drawings	45	43	
Power systems (ca 5000)	Raki	Updated SRD	1	1	
Coil Bus (ca 5500)	Smith	Drawings/Models	187	187	
Controls (ca 6100)	Sichta	Drawings/Models	35	15	
Controls (ca 6100)	Sichta	R&D Tasks	1	1	
			870	**771**	

- *~90% of the Center Stack Design final design documents are ready for approval upon completion of the FDR*
- *Critical Path design work is 96% complete*

CS Upgrade Scope
Machine Core / Coils (Chrzanowski)

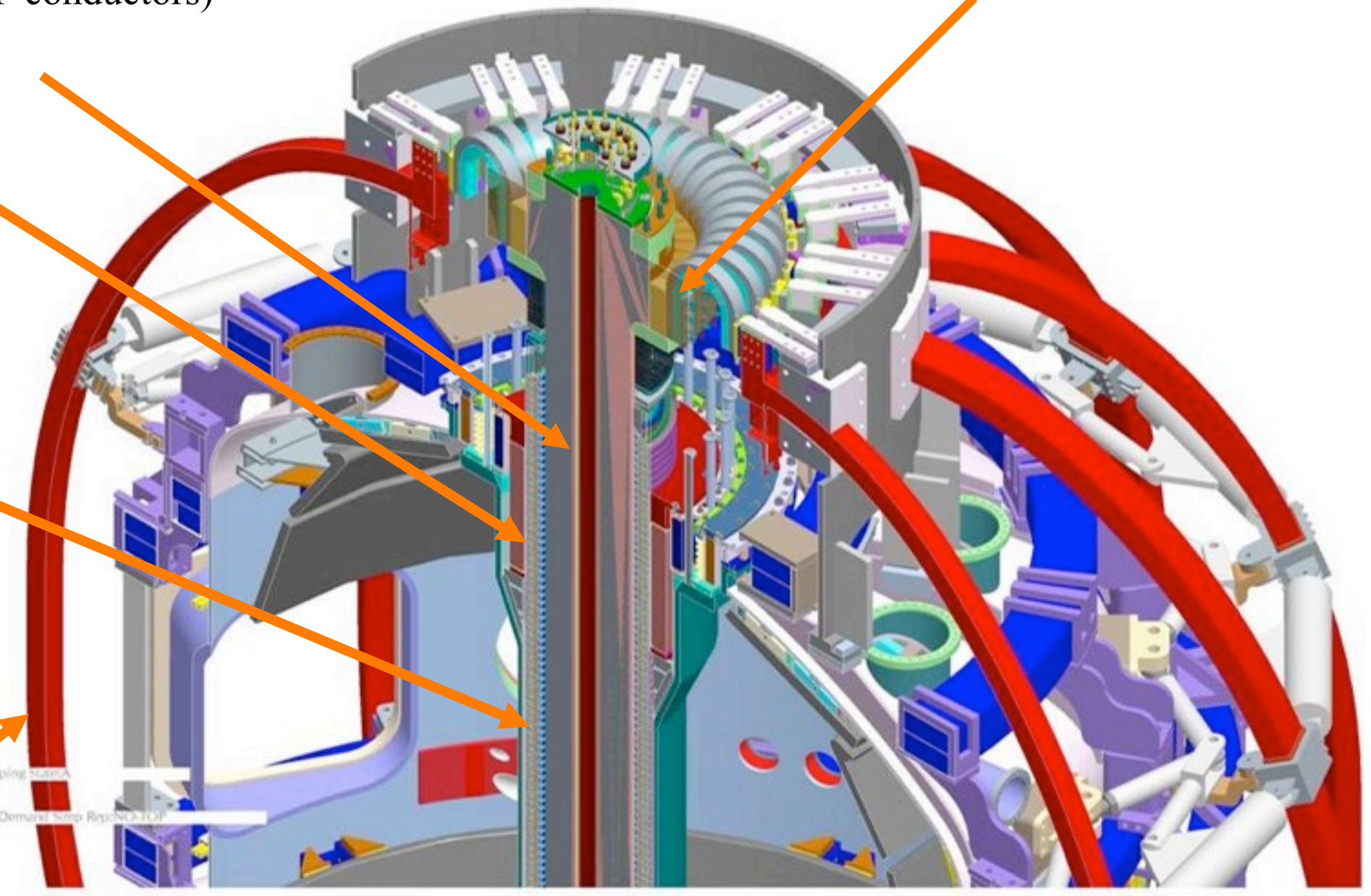
Simpler Inner TF design
(single layer of TF conductors)

Improved Joint Design

OH coil wound
on TF

New
Centerstack
Casing and Tiles

Existing outer
TF WITH water
cooling



Drawings are completed and signed, ready for fabrication

Features of the New Center Stack

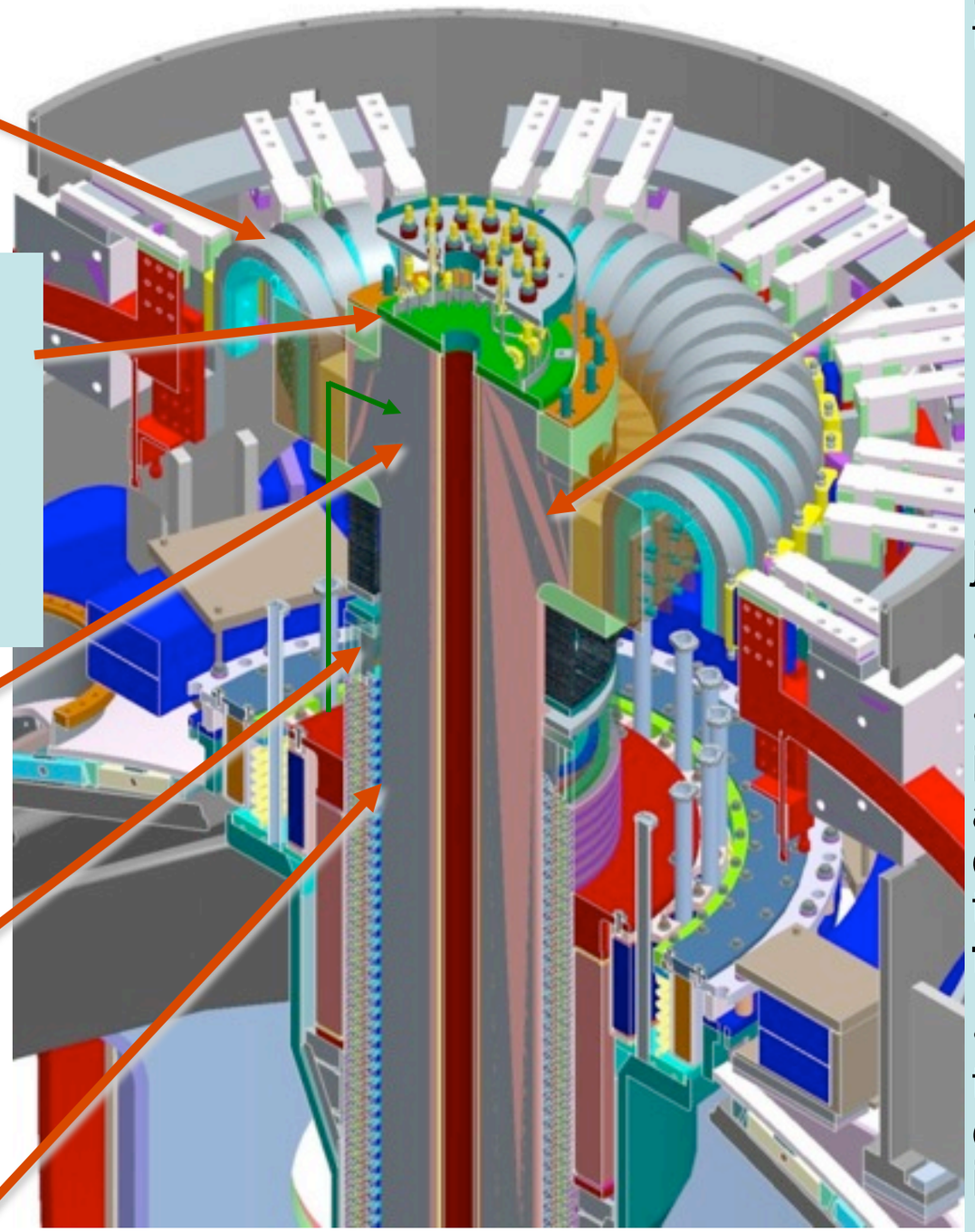
Cu alloy flex wire EDM from plate – tested to 300,000 cycles

Hysol 3561/2039 and S2 Glas torque reaction disc keyed directly into turns for direct torque restraint path.

Turns bonded to create integral hubs

OH preload mechanism

OH coil wound in place



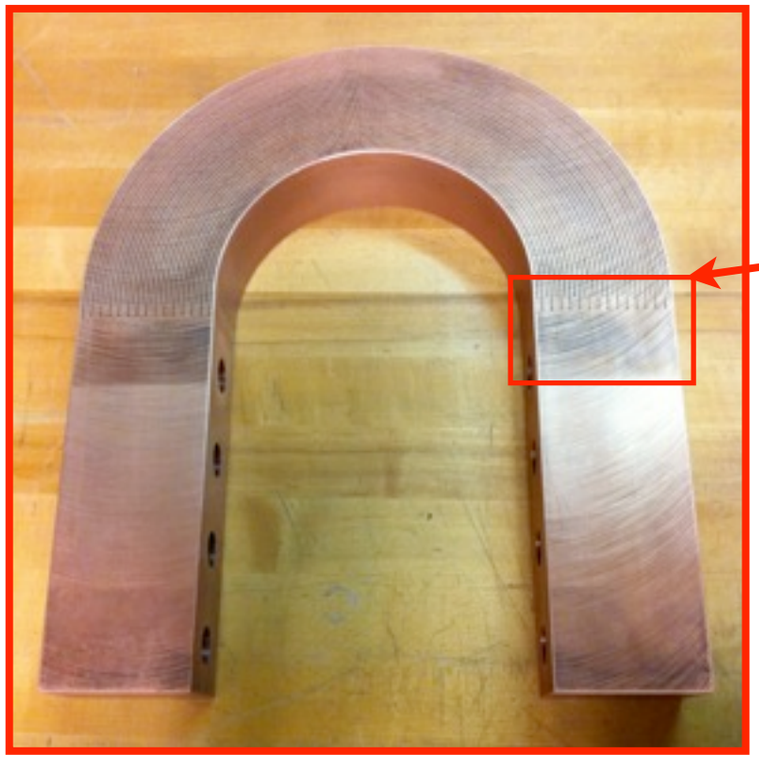
Original CS uses a hub assembly to collect the EM forces and to transfer them to the TF Bundle through the electrical joint bolts

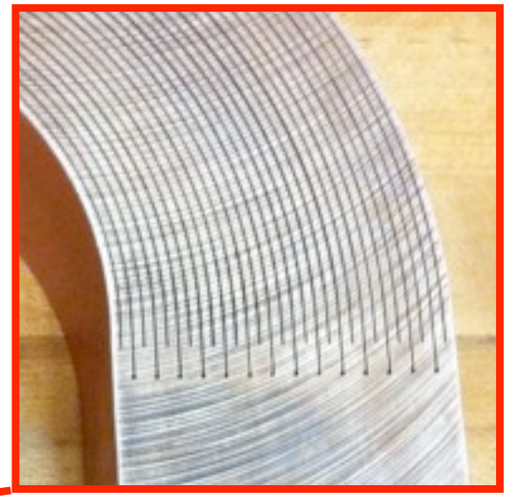
Features of design:

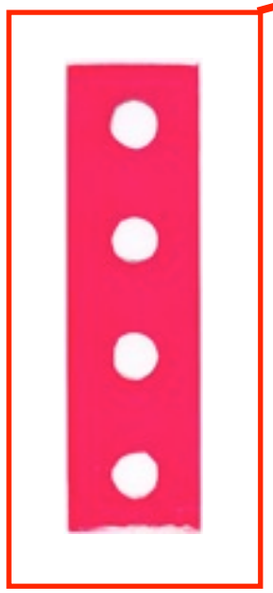
- Welded extensions of C18150 to TF conductors provides joint-free regions for current streamlines to transition from vertical to horizontal.
  - Hot spot where current hugs the corner does not affect the elec. Joint.
  - HS alloy permits Inconel studs & Supenuts to preload the joints to 5.1 ksi. Maintains 2.0 ksi under full load.
- Original B*R is 0.51; field at TF joint is 5.2T at r=0.098 m.
- Upgrade B*R=0.934
- This design moves bolted joint interface from 4.7 T region (r=0.2 m) at TF sfc. to 3.3 T (r=.28m.) region on bottom, and to 2.22 (r=.42m) at top. (**37 and 58% reduction in fields at joints**)
- Increases contact areas for joints to 12.6 sq. in. (vs 3.4 sq.in for existing) ($J=10.2$ kA/in^2 vs 21.3 kA/in^2 for existing).
- Joint resistance is reduced by factor of ~4

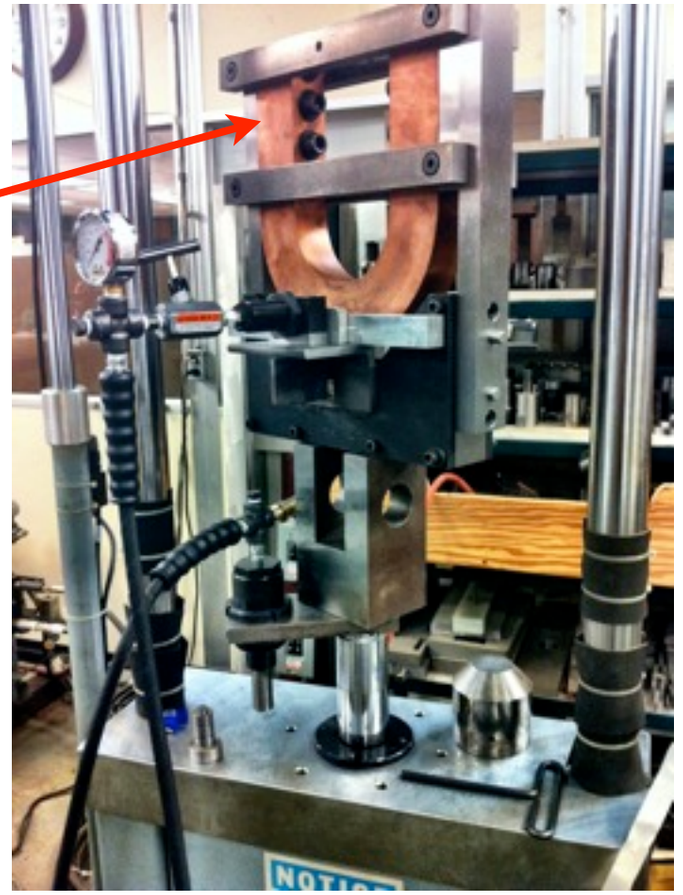
Centerstack R&D - TF Flex Connector

Successfully tested to 300,000 full stroke cycles
Design Requirement = 60,000 cycles



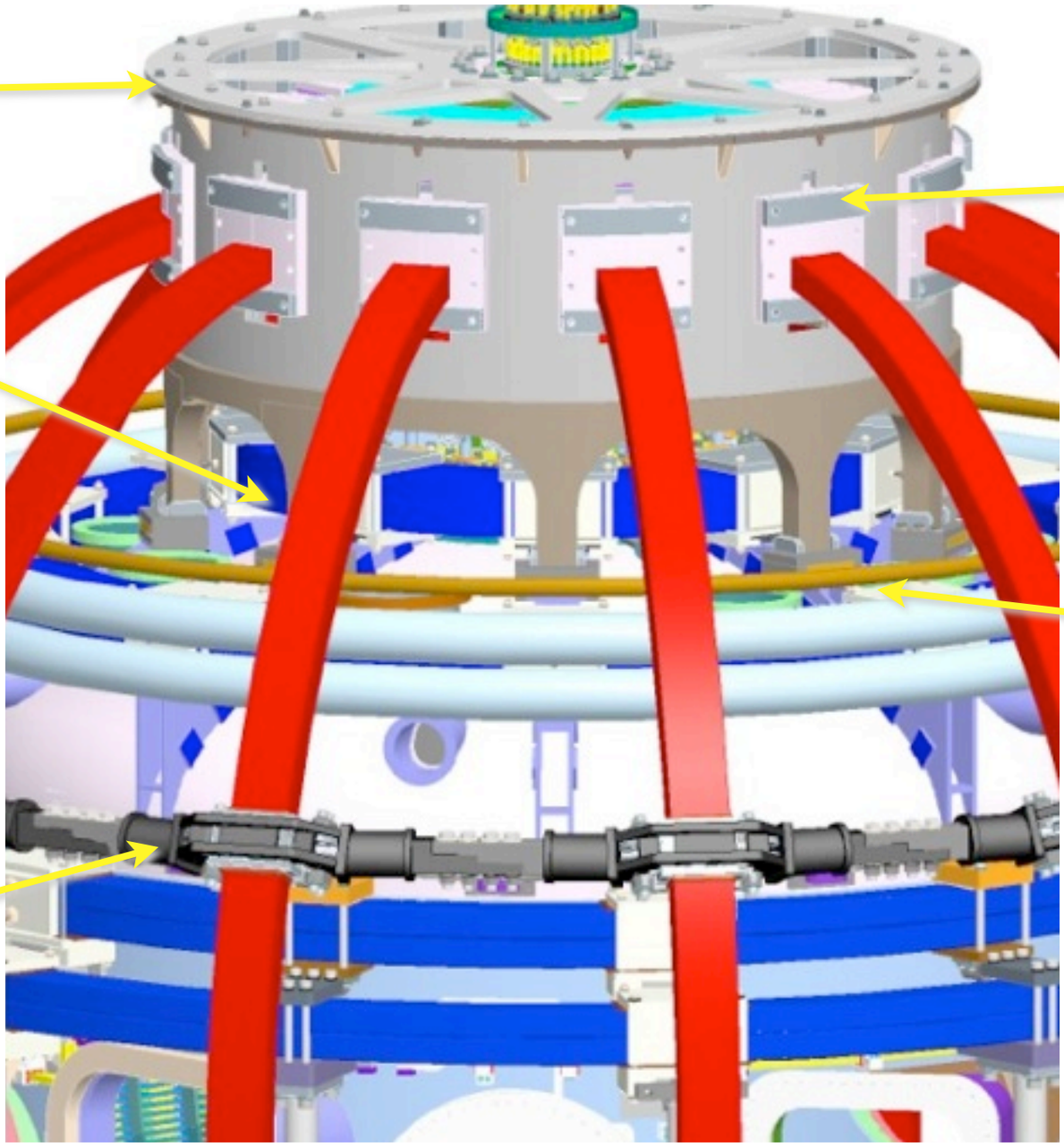






Fuji Paper pressure tests indicate >1500 psi over the entire joint surface

Structural Reinforcements (Smith)



Drawings are completed

Structural Support Modifications

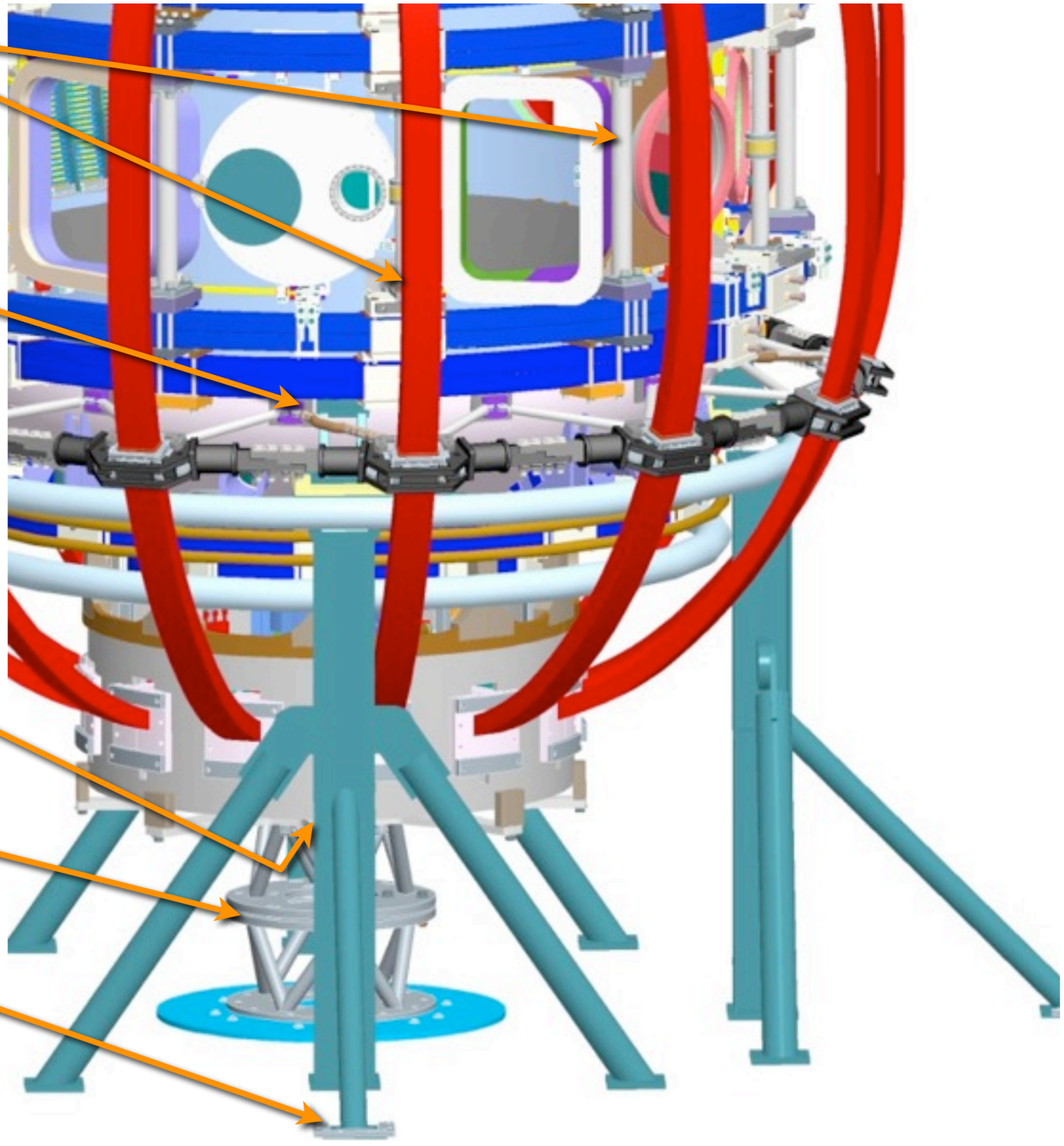
Additional PF4/5 supports & Reinforcement to existing

New Clevis and Connecting Rods

New Lower Umbrella Lid

New Pedestal

New leg foot reinforcement



Drawings are completed

Electrical, Controls and Diagnostics

- Power Feed Upgrades (Ramakrishnan)
  - Upgrade TF power supply to support full field capability of ~1T. (At ~1T, ~2.5s flattop every 20 min and up to ~5 s every 40 min)
    - Existing cables will be reconnected for TF use. Thus there will be a total of 8 cables per pole for TF.
    - Requires procurement, installation and commissioning of some additional components (CLR's, DCCTs, etc)
  - Drawings are complete
- Controls (Sichta)
  - ~3.5x longer Pulse Length drives real-time control, data acquisition, analysis, networking, and storage.
- Diagnostics (Kaita, Labik)
  - Relocation of Centerstack Magnetic diagnostics to new home
    - Rogowski Coils
    - Mirnov Coils
    - Flux Loops
    - Langmuir Probes
    - Thermocouples
  - Designs use existing drawings
  - Relocation of MPTS to account for eclipsed view of new CS (new)
    - Upgrade project scope includes the VV interface which recently passed PDR, FDR is planned for August
    - VV port design is complete and is now being optimized for RWM impact

Auxiliary Systems

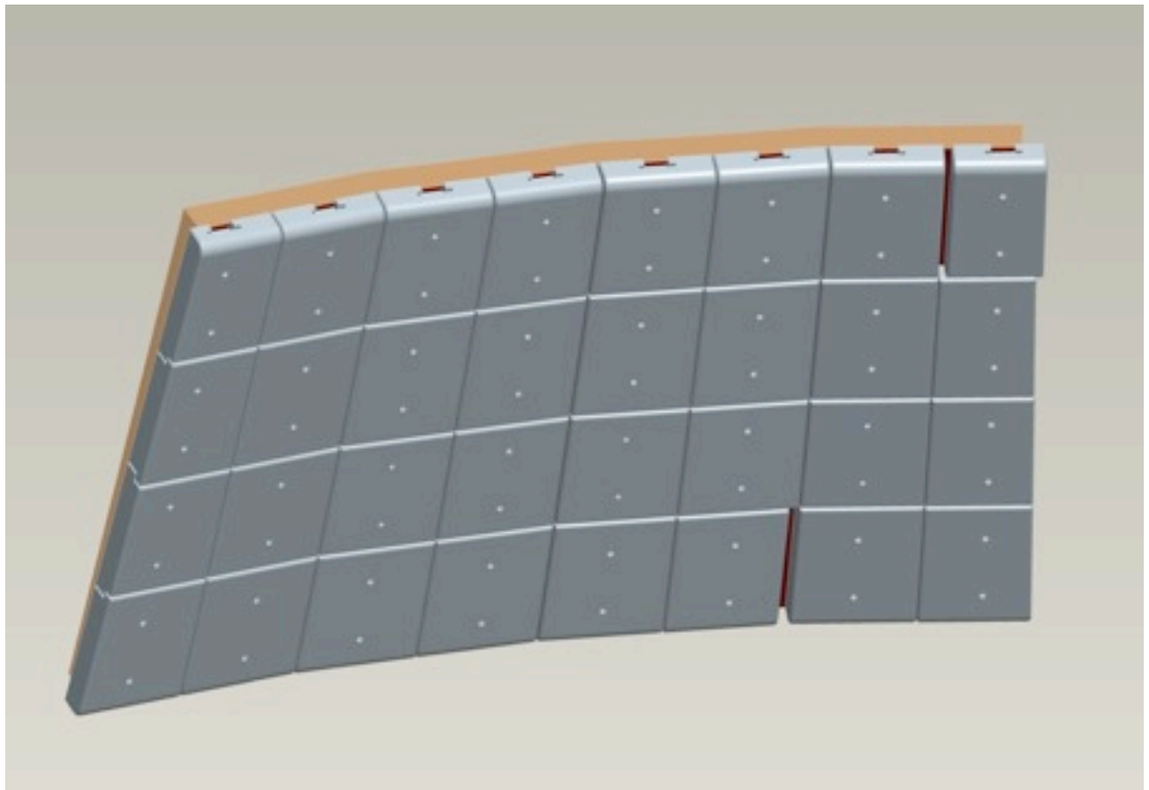
- Gas Injection Systems (Blanchard)
  - Relocate existing center stack gas injection system to the new center stack
  - Design is complete
- Coil Cooling water modifications (Denault)
  - Restoring of cooling to the outer TF legs for upgraded TF.
  - Reconnect cooling to the TF inner legs, OH and PF coils
  - Provide cooling for the coil buswork

DCPS and Analysis

- Digital Coil Protection System (Hatcher)
  - System protects the coils and supports from EM load combinations that were not employed in the design (vs Power Supply limits)
  - Completed a successful CDR Mar 2011
  - PDR held in June 2011, FDR to follow in 2012
- Analysis (Titus)
  - A 136 page executive summary is being provided covering the design calculations performed to support the Final Design
  - Supports the design, based on operational limits
  - Operational Limits
    - Original GRD required the use of the power supply (designed for TFTR) limits as the design criteria
    - Early on it was realized it was impractical, therefore the GRD requirements were reduced to a set of 96 operating scenarios described in the Design Point Spreadsheet.

Passive Plates

- Passive Plate Upgrade (Realized risk)
  - Disruption analysis identified a weakness in the Cu Passive Plates during one of the disruption scenarios - ~ 2x allowable stress (A check by another analyst indicates the max stresses are ~50% allowables)
  - Now in the process of reconciling the differences (Skin effects, fields in model, modeling detail, 3d vs 2d Opera)
  - Several concepts have been considered, simplest and least invasive to the machine would be to increase the plate thickness (up to 2x current thickness, 0.5” > 1”)
  - Between the FDR and Lehman review the differences will be reconciled
  - Cost impact would be ~ $1,200K
  - Schedule impact for the overall outage = nil
  - The cost and schedule are being added as a planning package



FDR Risks

Owner	Number	Affected Job	Job Title	Risk Description	Mitigation Plan (& job where budgeted)	Current Status
Tresemer	1001e	1001	Centerstack Plasma Facing Components	May be able to use ATJ on CS VS instead of 2D CFC. Depends on fastening needs		**Retired - Adopted ATJ for cost savings**
Titus	8200e	8200		Passive Plate Tiles/hardware need upgrading: Possibly ~3500 tiles, 70000 in^3, replacing with 2D CFC	Finalize disruption and thermal load analysis by FDR.	**Retired - Estimate for oversize plates is being added to project**
Titus	1000a	1000	Centerstack Analytical Support	Analysis indicates a significant component needs upgrade that previously hasn't been identified	Maintain upgrades of the model and keep ahead of the scenario changes	**Will be closed at completion of FDR**
Titus	1000b	1000	Centerstack Analytical Support	Analysis indicates a minor component needs upgrade that previously hasn't been identified - weld details, details that are inconsistent with the Pro-E model	Identify these areas early with site surveys and as-builts	**Will be closed at completion of FDR**
Titus	1002a	1002	Passive Plate Analysis	Halo and New/other disruption loads are beyond the capacity of the present **hardware**	Size modifications based on calculations and implement	**Estimate added to project**
Titus	2300a	2300	Miscellaneous small appendage reinforcements on vessel	Upgrade may increase EM loads to small items on vessel that may need reinforcement, e.g. shutters, ECH, brackets,diagnostic supports.	Design reinforcements as problem areas are identified.	**Will be closed at completion of FDR**
Sichta	6100c	6100	Data Acquisition rate	Data acquisition takes too long	Upgrade additional data acq systems and/or networks, revise software	**Retired - Design meets requirements**

Chits: Power System

Comment or Concern	Owner	Response / Status
Conduct a design review of the Digital Coil Protection system with external reviewers to include consideration of the coil current combinations, analysis of the loads and overall system design including software and reliability requirements for all components and instrumentation prior to the Final Design Review in 2011	Raki	CLOSED: This is getting addressed in the FDR of the Digital Coil Protection by Ron Hatcher.
Include contingency quantities for components or equipment that are long lead, critical for the first plasma milestone, critical for subsequent operation on, and/or are one-of-a kind.	Raki	CLOSED: The DC CLR for OH will be ordered giving sufficient time for delivery.
Permit Power System installation as soon as possible to minimize interferences, escalation of cost of materials, escalation of cost of labor.	Raki	Agree in principle. Will schedule within schedule priority and available funding allowing ample free float. Project Manager is requested to allow installation activities to begin six months earlier than currently planned.

Chits: Analysis

Comment or Concern	Owner	Response / Status
Look at how many cycles have already been performed on components -> get accurate count. Then specify how many new/ extra cycles are needed. Is it 30,000 / 3,000 more or 60k?	Titus	IN PROGRESS: Fatigue qualification is based on analysis, and on in-service inspection. On new components for the upgrade we calculate fatigue life and check to make sure it complies with the NSTX structural criteria document. Analysis is also being done to qualify old components which are being added to a list. Parts will be monitored via a maintenance procedure
Write a design specification to collect and identify all design critical components which exceeded allowables that would guide DCPS design.	Titus	IN PROGRESS: Each detailed stress analysis section will outline the algorithm that will be incorporated into the DCPS. These will be listed by reference to the calculation in a design load specification which simply will be a list of algorithms and their calculation number sources. The calculations will be "living documents". A Protection and Algorithms document will be provided as a deliverable with the DCPS.
TF centre rod temperature close to flags is over 100C and may creep under stress. Consider shaping the wedge/flag area to reduce peak temperatures and stress.	Titus	CLOSED: A Cyanate Ester blend was chosen for the epoxy system. This resin system with shear and tensile stress allowables high enough that local high spots in the TF corner are no longer a problem. (Ref: CTD Cyanate Ester Tests)
Divertor surfaces could get quite hot. Need thermal analysis of temp. in o-ring region to ensure o-rings wont melt, or spec. cooling requirement	Brooks	CLOSED: Thermal analysis has been completed and it was determined that additional cooling will be required in that area to protect the o-rings. Plans to provide additional cooling have been added to the NSTXU design.

Chits: Center Stack Coils

Comment or Concern	Owner	Response / Status
Check strength and modulus of room temperature stycast (epoxy) for use on the TF castle (teeth).	JHC	Concur. The TF teeth/crown structure will be fabricated in-house with a wet layup process with glass positioned circumferentially in structure to provide maximum strength. Design was modified to reduce stresses on the epoxy composite. The glass layers are oriented for maximum strength. Stycast will not be used, will be using Hysol 3561/2039 and S2 Glas. Coupon will be performed.
Use of Superbolts on electrical connections is a new application. Concern is related to thermal cycling of joint and braze/solder creep under high load.	JHC	CLOSED:Tested by cycling a simulated joint equipped with Inconel Studs and SuperNuts - with no loss in pretension. The Supernuts tension tests completed using FUJI pressure sensitive paper
Solenoid conductor braze joints - Finalize the manufacturing process for the OH conductor.	JHC	IN PROGRESS - Once conductor length can be verified, braze joint process will be finalized. Will be completed during conductor procurement

Chits: Miscellaneous

Comment or Concern	Owner	Response / Status
All NSTX components, including passive plates, etc. must be compatible with the design point. Any modifications which may be necessary must be included in the cost. See GRD 2.1.2.a	Dudek	CLOSED: Risk was retired. The passive plate upgrade cost and schedule planning package is being added to the Center Stack upgrade plan.
Convene external peer reviews / verification of key aspects of the design and analysis, especially the TF joint electrical design and the algorithms to be used for the digital coil protection system, prior to the Final Design Review (FDR)	Dudek	CLOSED: External reviewers are included in the May 2011 peer review and the DCPS PDR to be held in June 2011.
Develop a plan for operating instrumentation to monitor selected displacements, temperatures and joint resistance, prior to the FDR.	Dudek	CLOSED: The cost to monitor the new TF flex connection is not warranted. The TF conductor flex joint design is much more robust than the existing joint on NSTX (>factor of 5). The flex connection was successfully tested to 300,000 full displacement and full load cycles and demonstrated excellent contact pressure using the super bolt fasteners. The joint will be inspected at regular maintenance intervals to monitor its performance under operating conditions

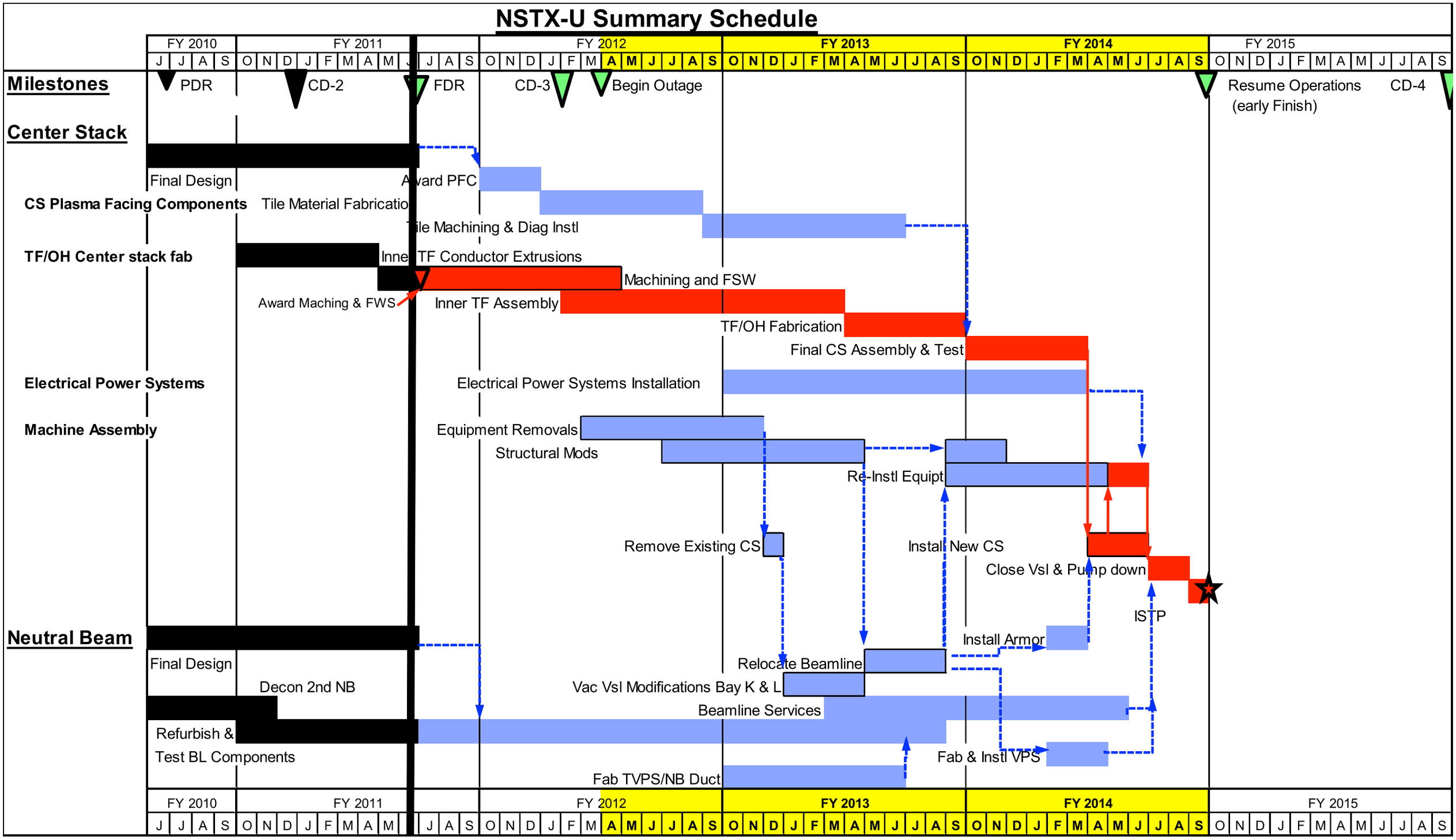
Chits From Peer Review

Comment or Concern	Owner	Response / Status
Review the flags required for bakeout of vessel	Chrzanowski	Bakeout current is being increased. Flags arrangement 3 flags at over 2 sq. in. which is adequate for the 6,000 amp power supply rating.
Need to incorporate lift points into the centerstack design.	Chrzanowski	Lifting is being accomplished in a manner consistent with the existing CS. Fixtures are being designed where needed for lifts.
A resolution of increased production, and the introduction of additional G-10 and new insulating materials, what is the activation profile and post pulse? Has analysis been performed to evaluate if we will stay below a Cat 3 nuclear facility during NSTX operations?	Dudek	CLOSED: The elements in the the new resin system are no different than the elements in CTD101K. Analysis by LP Ku early in the project determined that there is no problem for the existing hardware. Levine in the process of preparing a revised10CFR830 part B letter for distribution.
Ground the additional supports for the PF 4/5	Smith	This is being added to the design

Chits from Peer Review

Comment or Concern	Owner	Response / Status
The intent of this review was to focus on the technical design. However, prior to the FDR we should schedule an assembly review. Target week of May 23rd.	Perry	This was conducted. E. Perry is presenting the results today
Need to verify the reasonableness of the assumption that the inboard diverter tiles at the CHI gap will not see significant heating on both the horizontal and the vertical surfaces.	Bell	*The heat flux deposited on the PFCs will be controlled by the NSTX physics program (e.g., advanced divertor operations) and will be maintained within allowables based on the choice of materials, geometry, and cooling. Allowables resulting from the design will be provided.* (Ref. GRD para. 3.1.1)
CTD-425 is acceptable from the test data and calculations provided. For the FDR, this insulation performance should be described clearly.	Heitzenroeder	Titus is presenting the results today
Peak stress (slide #32) in FSW joint is 124 mPa. This is compared to which allowable? Consider methods to reduce this peak value.	Heitzenroeder	This is based on the weaker material CDA 107, based on tests

NSTX-U Summary Schedule



Conclusion

- The analysis performed to date supports the Final Design being presented today
- The Final Design is >90% complete.
- The project is ready to begin procurement, fabrication and Installation .