NCSX Field Period Assembly

NCSX
National Compact Stellarator Experiment

August 15, 2007

Mike Viola
Field Period Assembly Manager

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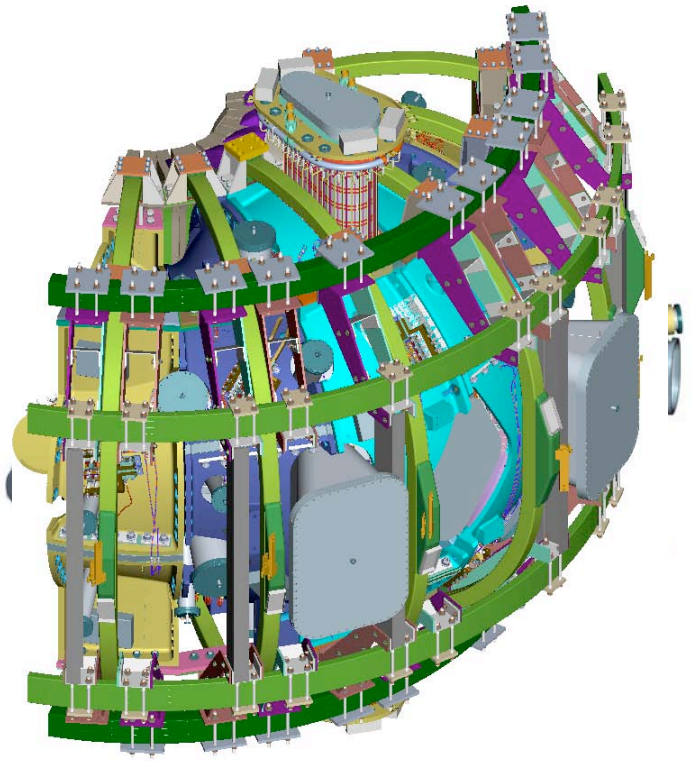
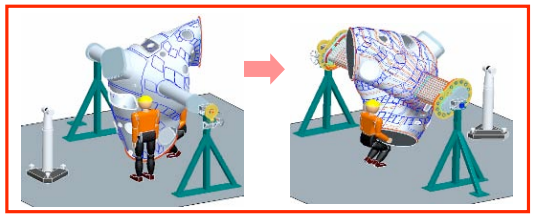
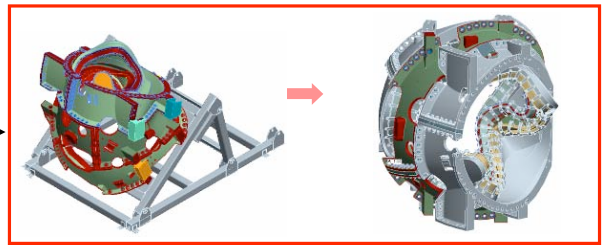


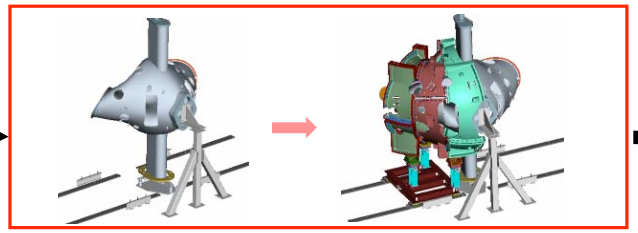
FPA is Accomplished in Four Stages



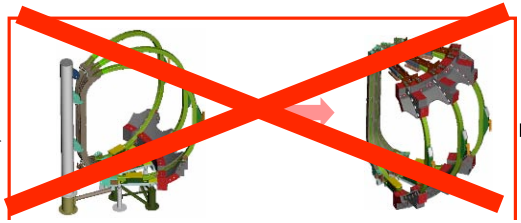
Station 1 - VV Prep



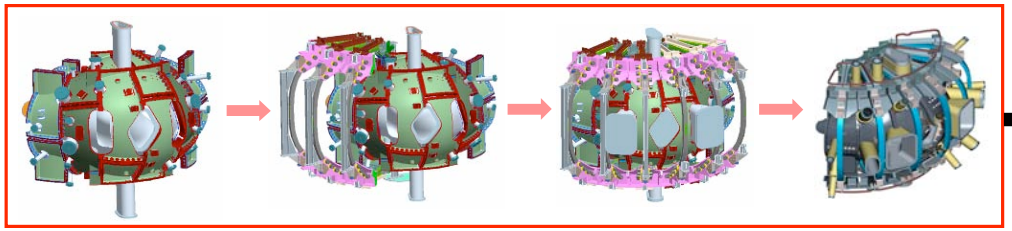
Station 2 - MC Half Period Assembly



Station 3 - MCHP installation over VV Period



Station 4 – TF alignment activities performed during Station 5



Station 5 - Final Assembly in NCSX Test Cell

Station 6 - Machine Assembly

"SAFELY SAFELY SAFELY"

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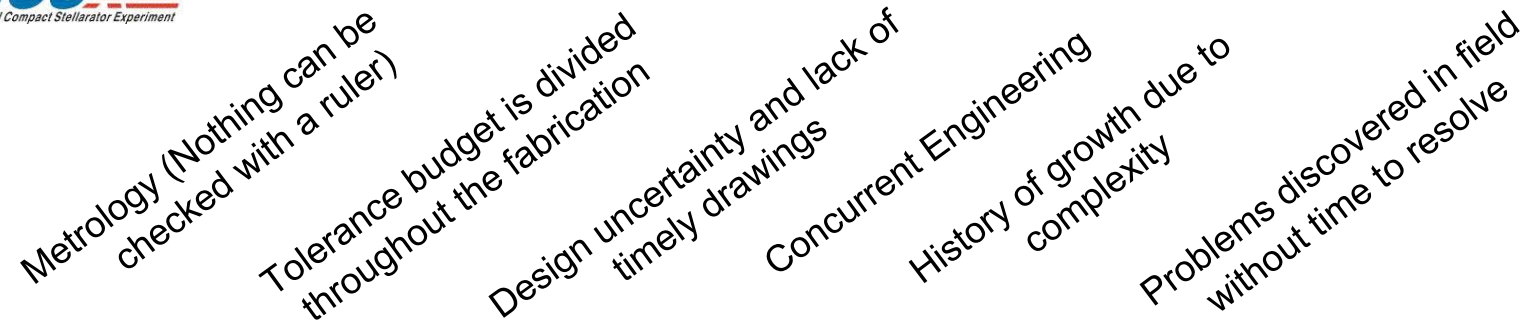
- Documentation and Integrated Safety Management (ISM) Work Plans
  - Manufacturing Facility Operation Plan (MFOP) completed for overall facility conduct using ISM as its basis.
  - Job Hazards Analysis (JHA) developed for FPA activity
    - Main hazard: components must be lifted by crane – many lifts will occur in several orientations. Lift procedures with individual lift data sheets are developed for each type of lift
  - Activities Certification Committee (ACC) independently reviews each station setup, operations, and plans before station is activated.
    - Station 1 review complete and declared operational
    - Station 2 trials review **complete**

FPA Process Definitions

- FPA Manufacturing, Inspection, Test, Quality Assurance Plan (MIT/QA) Complete
  - Input (Station specific):
    - Dimensional Control Plan (Art Brooks)
    - FPA Assembly Sequence Plan (Tom Brown)
    - FPA Specification and Assembly Drawings (Mike Cole)
  - MIT/QA Plan provides basis for individual procedures to perform tasks then revised to include developed improvements.
- FPA Procedures
  - FPA station 1 procedure complete and active
  - FPA station 2 trials are providing input to procedure development

- **ADDED DAILY ACTIVITY REVIEW MEETING**
  - **Report day's progress**
  - **provide clear guidance for next day**
  - **Obtain instant feedback from ORNL design team**

FPA Cost and Schedule Drivers



- We have changed the project structure and have put in place a schedule, system, and people that enable us to detect our problems in advance and develop resolutions and implement them in a timely manner.
  - Measure all modular coils in advance of assembly
    - developed new alignment techniques
  - Complete designs earlier to minimize configuration changes
    - not rely on concurrent engineering as much during assembly phase
  - Augmented metrology team and back office support
    - two additional engineers each.
  - Augmented trials to discover problems BEFORE the critical path.
    - Added stud tension, bushing, nose weld trials
- We have an active system in-place to deal with the problems that lie ahead.
  - Daily review of field progress and facilitation of needs (Viola)
  - Weekly review of project needs (Anderson)
- **We have a re-vitalized system that has produced these results with clear evidence of this successful transition (next slide)**

Evidence of this successful PROACTIVE transition

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- Station 2 FPA trials enhanced and well in progress:
  - Gross fit individual mating coils
    - found minor interferences that are all understood and straightforwardly resolved in a few days.
  - Joint design trials
    - Stud tension, shim fit, bushing fit, nose weld
- Remaining trials for Station 2 (useful for Station 3 also):
  - Install and torque bolts – assess accessibility **COMPLETE**
    - **Incorporated into coil punchlist activity**
  - Develop shim technique **COMPLETE**
    - **Incorporated into shim design**
  - Install holes and studs for nose
    - **NEW WELDED DESIGN trials in process**
  - Pillow shims **TRIALS SUCCESSFUL**
  - Install Alumina coated metal shims
    - Shims on order
  - Install shims and bolt bushings in vertical orientation
- Preliminary design level for Station 3 and 5

FPA Activity and Risk Resolution – Station 1

RISKS RESOLVED AND ACTIVITY AHEAD OF SCHEDULE

- Station 1 (Install vacuum vessel external components diagnostic coils, cooling tubes, thermocouples using Leica laser tracker)
  - All three VVSA's were received by 9/21/06
  - All work performed on station 1 fixture (2 "rotisserie" stations) with laser tracker & 2 men; augmented with 3 technicians when needed
  - Risks are identified – Installation Progressing
    - ✓ Technique developed to locate diagnostic loop templates
    - ✓ Technique developed to adjust interferences (cooling tube studs and thermocouples)
    - ✓ Technique developed to install diagnostic templates
    - ✓ Technique developed to wind diagnostic loops
    - ✓ Technique to hold heating tapes in place on vertical ports.
    - ✓ Technique to connect cooling hoses to vertical risers

NCSX Vacuum Vessel Station 1

90% Complete

- VV #1 and VV #2 95% Completed
- VV #3 80% Complete
- Diagnostic loop termination, cooling tube testing and final scans remain

VV #1

VVSA with ports welded

VV #3 completing diagnostic loops

VV #2

Station 1 Activity nearly complete – Metrology all the way

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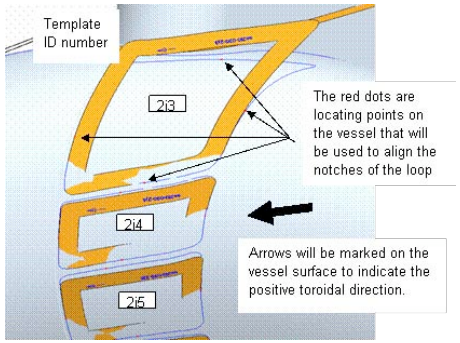
Much was learned from VVSA fabrication

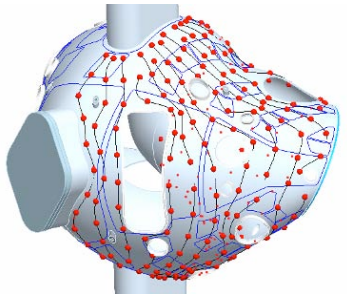
Laser tracker using Verisurf® Station 1 steps:

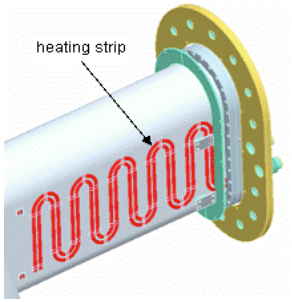
- ✓ **Install VVSAs in Station 1 Rotating Fixture COMPLETE**
- ✓ **Best fit Scan performed – confirmed MTM scans!! COMPLETE**
- ✓ **Mark Flux Loop Templates COMPLETE**
- ✓ **Mark Heating Coolant Stud Locations COMPLETE**
- ✓ **Shoot studs – vacuum vessel #1&2 COMPLETE**
- ✓ **Vertical Port Component Installation**
  - Install heating cooling manifolds **COMPLETE**
  - Install 29 thermocouple mounting plates on port 12's and vacuum vessel. **COMPLETE**
  - Install heater tapes **COMPLETE**
  - Install risers **2 of 3 COMPLETE**
- ✓ **Install of Magnetic Flux Loop COMPLETE**
- ✓ **Install Thermocouples COMPLETE**
- • **Install H/C lines 2 of 3 COMPLETE**
- • **Final Loop Routing and Measurement 1 of 3 COMPLETE**
- • **Perform final testing and scans**

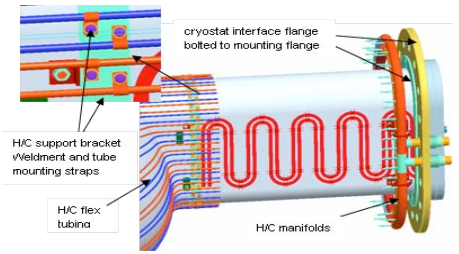
Schedule to complete

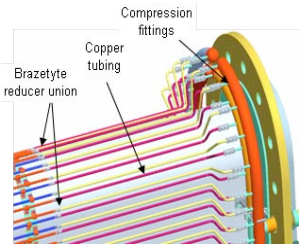
- • **#1 May '07 95% COMPLETE**
- • **#2 Aug '07 95% COMPLETE**
- • **#3 Jan '08 80% COMPLETE**









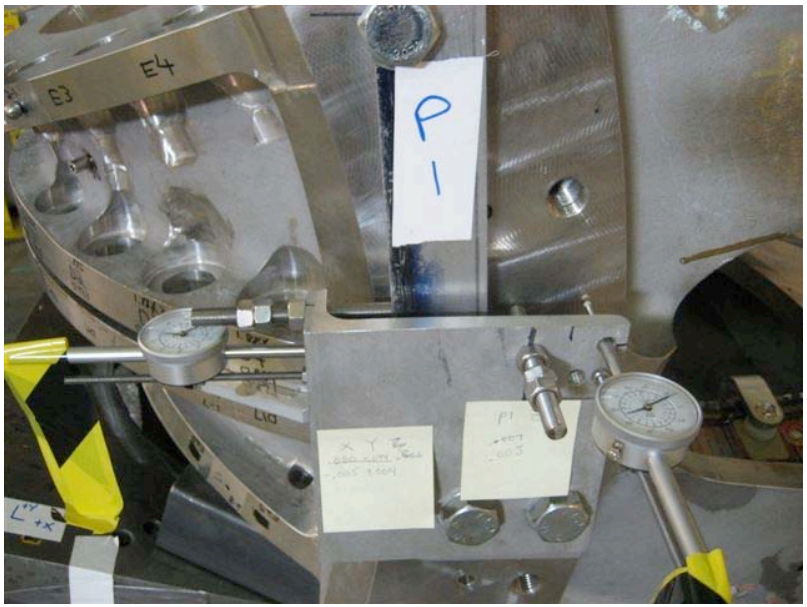


FPA Station 2 Activity

- Station 2 (3 coil preassembly – scan, align, shim, **weld,** and assembly using laser tracker)
- Activity has begun:
  - A1, B1, and C1 have all been gross fit to each other
    - found minor interferences that are all understood and straightforwardly resolved in a few days.
  - Measurements started – new technique for reproducing original scans shows great promise.
    - Discovered that coils deform from nominal shape by up to 0.020”
    - Major Tool dogged coils onto a fixture and then performed machining
    - PPPL takes that coil and fixes it into a winding ring and then performs scans referenced to newly installed conical seat fiducials
    - After coils are wound they are removed from the ring which allows flexure
    - Coils are mounted onto flat wedges and “racked” using adjustable wedges to reproduce conical seat alignments - 0.005” is required
      - Originally achieved ~0.014” RMS scan: unacceptable
      - New racking technique achieves 0.005” RMS scan

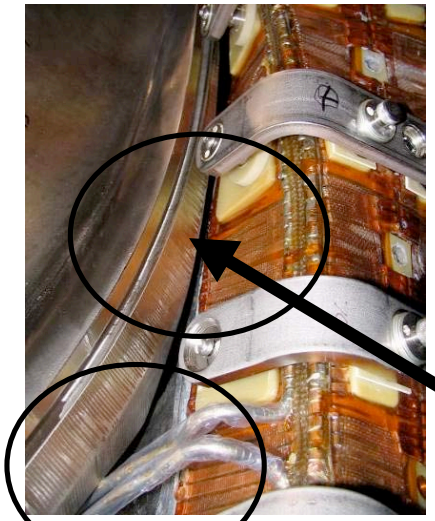
FPA Station 2 Risk Management –Developed alignment technique

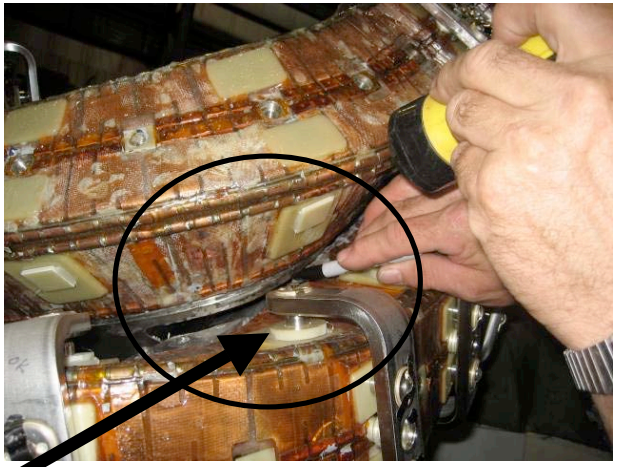
- Learned that positioning and leveling is simpler than expected
  - Simple corner plates with dial indicators
- Achieved
  - X-Y +/-0.002”
  - Z +/- 0.001”



FPA Station 2 Risk Management –

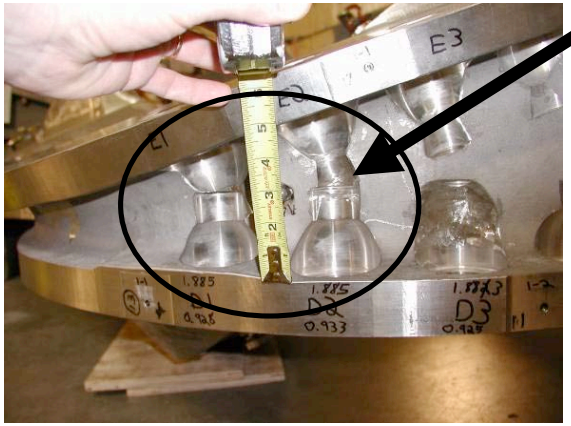
Gross fit-up finds problems in advance of critical path!

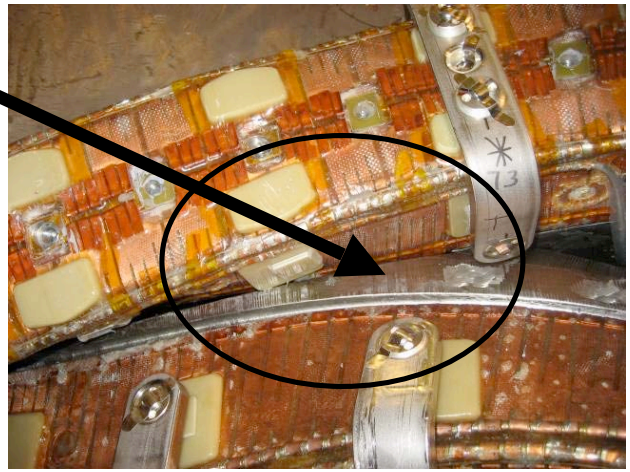




A1 B1 Fitup

Overcast





B1 C1 Fitup

FPA Station 2 Risk Management – Developed shim fit requirements

- Shims need to fit properly to work in shear
  - Accurate thickness
  - Sufficient surface contact

Effects of varied tension and film range

Varied single shim by 0.001”

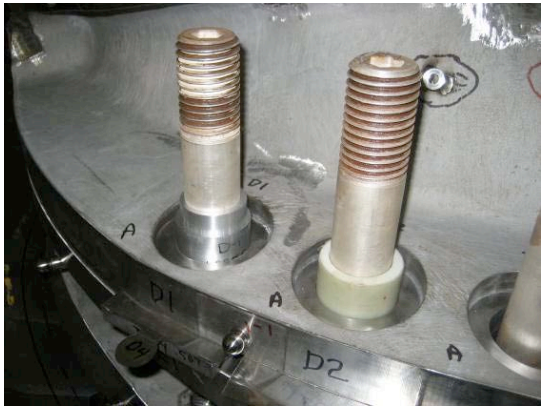
FPA Station 2 Risk Management – trials are invaluable

Utilize every opportunity

Assembly techniques tried in parallel with interface design development trials

- New technique for reproducing original alignments shows great promise
- Alignment technique developed
  - Achieved X-Y +/-0.002" Z +/- 0.001"
- Gross fit-ups identified potential interferences
- Bushing design and fit trials offered opportunity to save 7 of 10 days on critical path
- Ultrasonic tension meter accurately confirms tension
  - Can be checked over the life of the machine
- Assigned engineer to managing coil punchlist job and Station 2 preparation
  - Coils will arrive completely ready to assemble
- Joint task force lead by Phil Heitzenroeder is resolving the welded nose and joint issues.

- **As part of the rebaseline we have changed our plan to allow design changes and interferences to be discovered in advance of the critical path!**

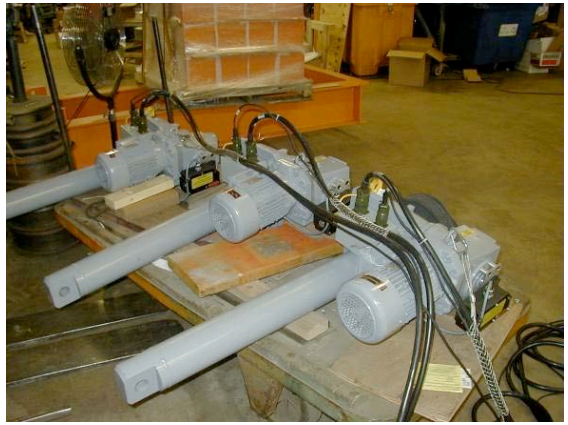


FPA Station 2 Issues

- Most Previous Concerns **RETIRED**
- Joint is still complex (welded nose shims and tight fitting bushings) but we have gained great confidence through trials.
  - Welded nose
    - **Trials Promising**
  - Bushing OD custom fit in advance
    - **Critical path activity reduced to 3 days from 10!**
- Rebaselined Schedule
  - **As part of the rebaseline we went from ½ page of sequence steps to 7 pages incorporating new found respect for metrology and stringent sheer design requirements**.

FPA Station 3 Activity

- Station 3 (install coils onto vacuum vessel using laser tracker)
  - Alignment and assembly trials are being developed at station 2
  - Actuators received for 3 legged manipulation of coils over vacuum vessel
    - Positioning demonstrated to be easily achievable using simple lasers with tracks
    - Each leg capable of full load plus 3:1 design factor



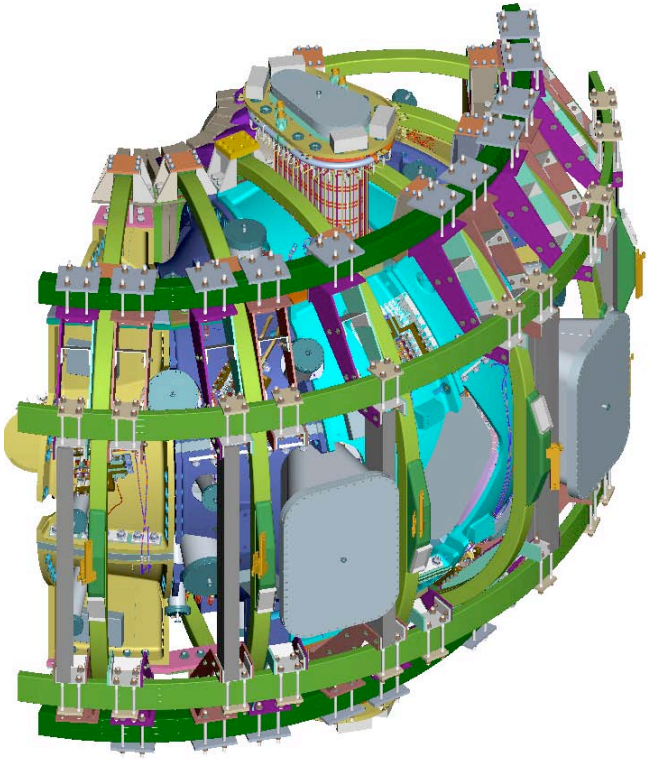
FPA Station 3 Issues

Station 3 (install coils onto vacuum vessel using laser tracker)

- Resolved Issues
  - Alignment and assembly trials are being developed at station 2
  - Trial with 25,000 lb. block resolved main concern of installing coils onto vacuum vessel
  - Complex installation mechanism replaced with simple 3 legged actuator system
- Concerns (Although low risk)
  - Out of tolerance conditions may cause interferences between coil and vessel (We have learned that CAD space is not real world)
    - Trials are included in the new schedule to discover potential problems
  - Potential problems associated with vertical alignment
    - Again trials are included in the new schedule to discover potential problems

Station 5 FPA Activity – Job 1815 in NCSX test cell

- Station 5 (weld ports, install TF coils, leak check, final metrology)
  - final assembly in NCSX test cell
  - Leak check moved to final assembly
  - Now at Preliminary design level
    - Design simplified but still strong dependency on metrology and alignment
  - Trials to be developed



FPA Station 5 Issues

- Resolved Issues
  - Port weld preps are acceptable
- Previous concerns are being mitigated
  - Previously concerned that there could be excessive distortion during to welding on ports
    - Can be monitored and equalized in-situ
  - Previously concerned that the TF/PF Structure would be complex and hard to align.
    - Preliminary design review of new design indicates a more reasonable design
- Station 5 design is much more mature and the sequence plan has been significantly enhanced with far more detail.

Risk Register

NCSX Risk Register

No.	Job	Risk Description	Mitigation Plan	L O
8	1810 7503	"Back office" support for FPA and final assembly becomes a chronic bottleneck, stretching out the time required to complete assembly operations	Additional support budgeted for Brown, Brooks, and Ellis providing "2 deep" back office support. Should be available to mitigate peak demands once training in key skills is completed.	
9	1810	Modular coil damaged during assembly requiring significant rework to coil	Equipment will be handled during FPA using carefully constructed procedures to minimize likelihood	
10	1810	VV surface component (coolant tube, flux loop, or TC) damaged during FPA requiring significant rework	Equipment will be handled during FPA using carefully constructed procedures to minimize likelihood	

2 New "blue" lift beams designed and built.

Risk Register

11	1810	Unacceptable distortion in a field period when welding modular coil shims requiring	Likelihood of occurrence is very unlikely as a result of extensive welding R&D and careful monitoring during welding.
12	1810	Field period damaged during loading, transport, or unloading from TFTR TC to NCSX TC	Extreme care will be taken when transporting a field period. Additional reviews including external reviewers will be performed.
13	1815	Multiple vacuum leaks during initial pumpdown	Welds will be leak checked during FPA when leaks can be addressed without significantly impacting the critical path. Likelihood of many leaks appearing during initial pumpdown is considered extremely unlikely with this mitigation plan.

Ports will be individually tested as they are welded on.

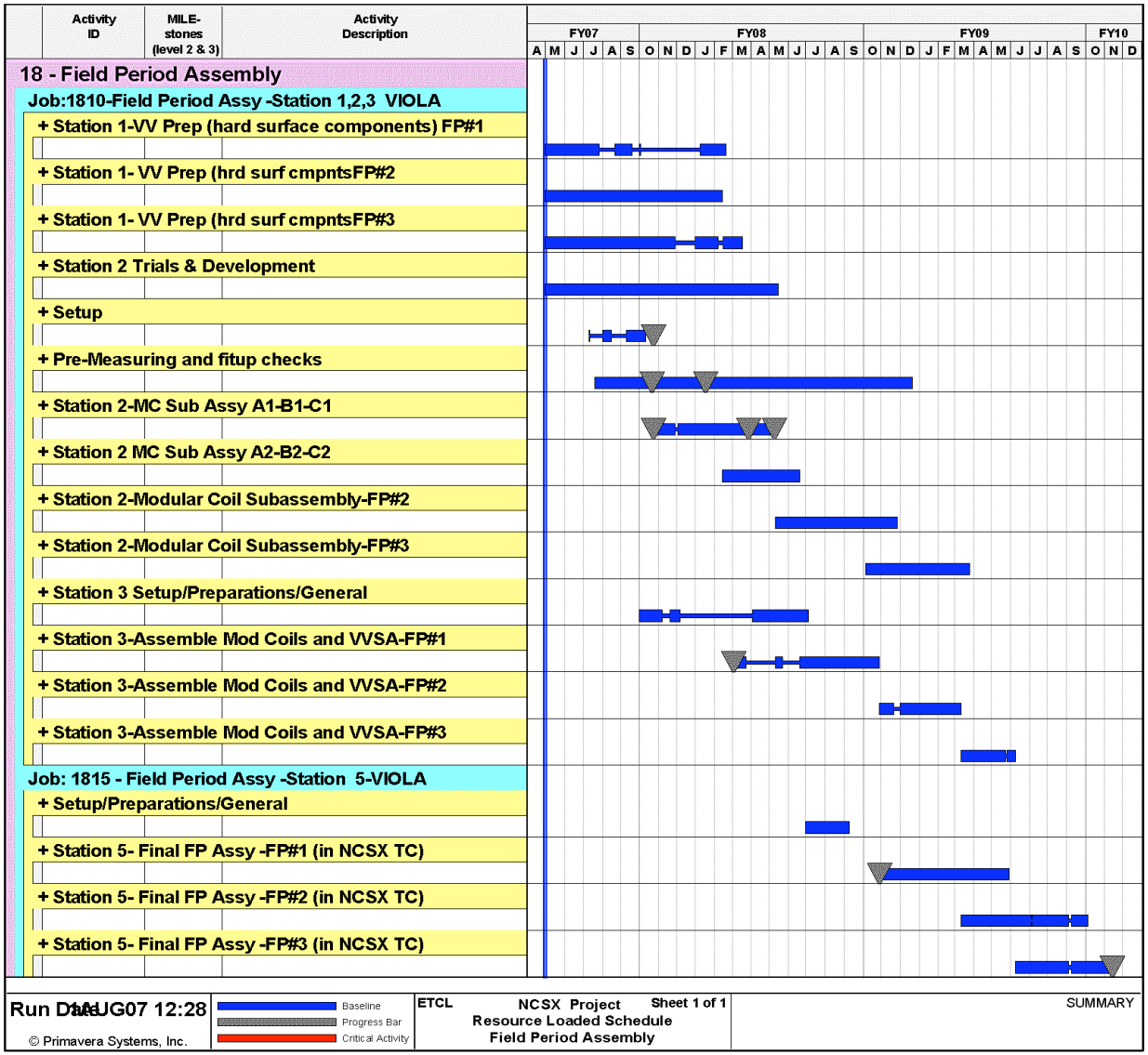
Cost and Schedule Increased

FPA increased 150% from 2 years ago. WHY?

- We have learned a great deal over the past two years.
  - We have learned from the Major Tool VVSA and Modular Coil contracts and PPPL Modular Coil winding experience that metrology and tight tolerances are a significant cost driver. Iterations between the field techs and the back office must be accounted for to understand the measurements and meet the tolerance requirements.
  - We have learned from Station 2 process development activities and have a better understanding of the steps required to handle, accurately position, and fasten the modular coils.
  - The design has matured, revealing complexities not previously appreciated.
- We have updated our estimates with input from field crews, design, and dimensional control to incorporate this understanding and include realistic allowances for problems.
  - The assembly detail significantly increased to allow for pre-measurements with laser trackers to accommodate the precision required and perform trials in advance of the actual assembly. For example, Station 2 alone went from ½ page of sequence steps to 7 pages. Station 3 and 5 have moved from a conceptual scheme to a detailed plan.
  - ALL done with metrology teams and back office support. Metrology accounts for $2.4M of the $9M for FPA.
  - Task durations account for impacts of complexity and tight positioning tolerances.
  - Measurements of as-built coils and rework of over-cast conditions are included in the estimate.
- **We have realistically assessed the activities required to complete field period assembly. We now have "center of the error bar" estimates that account for the extra time and cost to assemble the machine including the engineering and metrology oversight to achieve a successfully managed project.**

Rebaselined Schedule

- Station 1 is likely to complete ahead of schedule.
- Station 2 trials and Pre-measuring and fit-up checks have been revealing and provide a solid basis for realistic cost and schedule.
- Station 2 critical path activities have begun and are on track.
- Station 3 and 5 activities allow for early discovery.



Summary

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- We have changed the project structure and have put in place a schedule, system, and the people necessary to enable us to detect our problems in advance and develop resolutions and implement them in a timely manner.
- Added daily activity review meeting and weekly planning meetings
- Station 1 risks have all been resolved and activity ahead of schedule.
- Station 2 risks are being actively managed, budgeted in the rebaselined schedule, and the resolutions are promising.
- Station 3 and 5 designs are much more mature and their sequence plans have been developed in detail including the necessary metrology and trial elements.
- The new rebaseline has taken a realistic look at the challenges and incorporated sufficient time and resources to detect and mitigate problems.
- I have great confidence in successfully meeting the rebaselined schedule.