NCSX Machine Assembly

E. D. Perry

Machine Assembly

- Requirements
  - Test Cell Preparation
  - Perform final installation / assembly of stellarator core using the Field Period Assemblies (FPAs) delivered from Station 5 and components from other WBS elements
  - Installation of power and other services from the boundary of the Test Cell up to the stellarator core
- Interfaces
  - Interfaces included in existing 3D CAD model … includes input from:
    - All WBS elements which have items to install
    - Safety, operations and maintenance personnel
  - Details being adjusted in the model are just those for conventional services
    - Cable and piping runs now being cleaned up

Machine Assembly Plan

- Design status
  - Detailed assembly plan has been developed
    - Plan includes specific metrology steps to assure that tolerance goals are met
  - Machine Assembly will be performed with detailed procedures
    - Procedures will cover safety issues as specific steps
      - Installation of platforms to assure safe access to work
      - Use of safety watches
      - Rotating workers when repetitive motion or awkward position tasks are involved
    - Procedures will include specific metrology steps called out in assembly plan
    - Procedures will include repeating operations until tolerance goals are met

Procurements for Machine Assembly

- Procurement Status
  - Machine Assembly only includes procurements of routine off-the-shelf items
  - All complex or one of a kind procurements are done by other WBS elements prior to Machine Assembly

Cost and Schedule

- The cost and schedule estimates are based on the detailed assembly plan
  - The mitigation of credible risks is included in the estimates
  - Multiple fit-ups/iterations are included in the estimates

- All tooling will be tested before it is needed

Staffing

- For each task in the assembly plan:
  - Determined crew size based on prior experience performing a similar task
    - on the PDX, TFTR, NSTX and NCSX devices
    - related to assembly issues and plans form Wendelstein-7
    - on the Advanced Toroidal Facility (ATF) stellarator at ORNL
  - Determined number of shifts to complete
  - Determined the amount of support staff and supervision required for each task
  - Metrology crew requirements were specified for each task
  - Support from the engineers who designed and fabricated each component were specified for each task when this support is needed

Level of Detail in Estimates

NCSX WBS 7 Rebaseline		rev 8 changes in red													
	Station 6 (Final Machine Assembly)														
					Manhours										
Step	Assembly Step	Crew Size	Qty Shifts	2nd Shift possible	EM (engr supervision budgeted as LOE. Shown here for est basis only))	SM (tech supervision budgeted as LOE. Shown here for est basis only))	SB (design)	EM (cog engr sprt)	SM (technical oversite)	TB	EA EM (dimensional control/back office budgetd as LOE. Shown here for ref only)	Metrology	M&S	Pre-Req	N
	totals =				2720	6958	990	996	498	31394	740	3348	524.3		
					man-hours	man-hours				man-hours	man-hours	man-hours	$K		
4.00	FPA-1 installation and assembly test														
4.01	Obtain a set of Period 1 alignment fiducial positions to use in locating the period.				1										
4.01a	Exercise assembly structure with FPA-1 before start of assembly		40	no	80	320				640		320		receive FPA-1	
4.02	Move FPA 1 support fixture to the assembly position and lock in place. Prepare corner position adjustors located on the period platform to accept the period.	3	1		3	6				24				4.01a	
4.03	Using laser at Period 1 support pole, establish a global coordinate system based on monuments on the walls and on the FPA support fixture.	2	2	no							4	16		4.02	
4.04	Position Period 1 on the period support stand and engage the corner positioning device, retaining the load on the crane.	3	0.5		2	3				12				4.03	

Summary of Costs

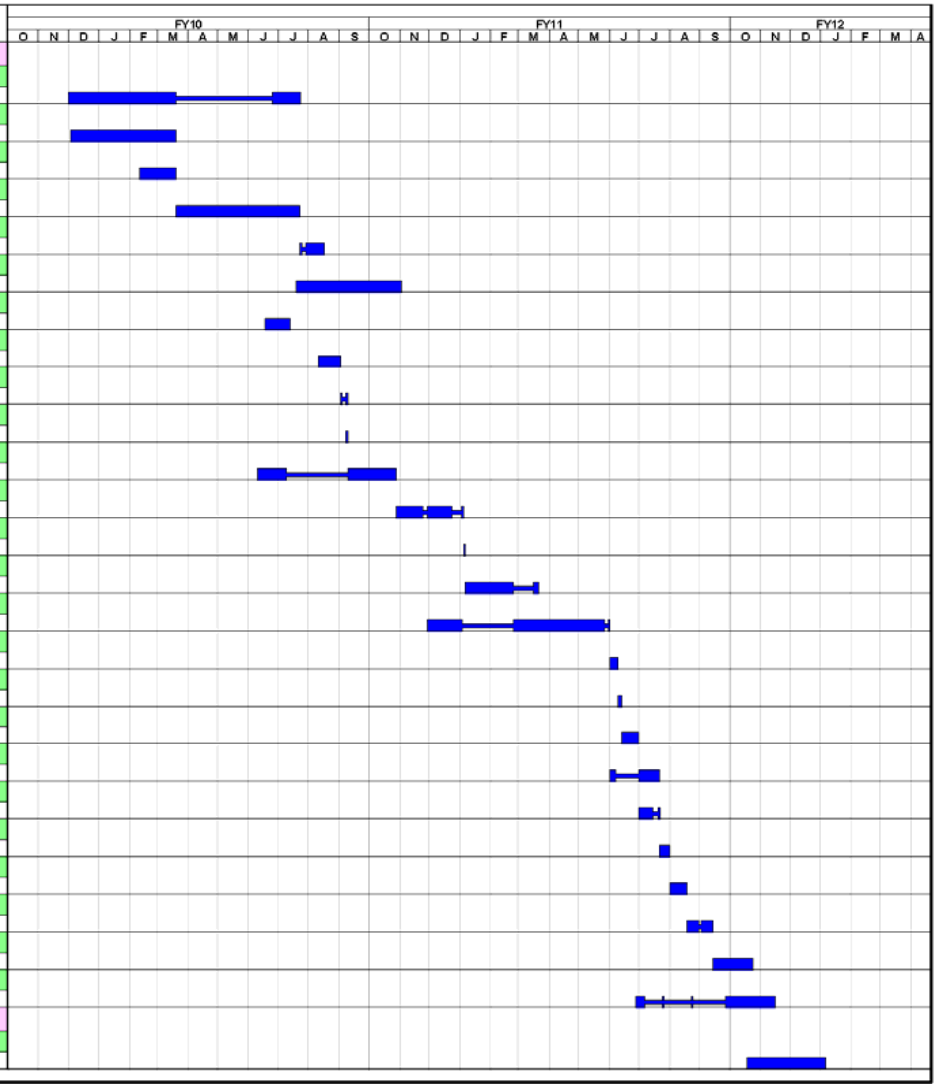
NCSX National Compact Stellarator Experiment

RLM	JOB	BUDGET to COMPLETE (from May 1,2007)	LOE $	LOE %	NON-LOE $	NON-LOE %	ETC (bottoms-up) from 2/1/08	Bottoms up EAC (from May 1,2007)	increase
Don Rej	Job: 8101 - Project Management &Control-REJ	3,843	4,160	100%	-	0%	4,160	4,646	**803**
	Job: 8102 - NCSX MIE Management ORNL-HARRIS	499	654	100%	-	0%	654	821	**322**
	Job: 8998 - Allocations-STRYKOWSKY	1,453	1,928	100%	-	0%	1,928	2,300	**847**
	Total Don Rej	5,795	6,742	100%	-	0%	6,742	7,767	1,972
Larry Dudek	Job: 1204 - VV Sys Procurements (nonVVSA)-DUDEK	408		-	221	100%	220.6	462	54
	Job: 1250 - Vacuum Vessel Fabrication**CLOSED**	(252)					0	(252)	0
	Job: 1260 NB Transition Ducts- GORANSON		26	5%	541	95%	566.73	567	**567**
	Job: 1270 - Heater Control System-GORANSON			0%	642	100%	641.66	**642**	**642**
	Job: 1408 - MC Winding Supplies-CHRZANOWSKI	350	89	72%	34	28%	123.92	269	(81)
	Job: 1431 - Mod. Coil Interface Hardware-DUDEK	1,039	119	11%	955	89%	1074.03	1,545	506
	Job: 1451 - Mod Coil Winding-CHRZANOWSKI	2,867	355	39%	554	61%	909.14	2,604	(263)
	Job: 1459 - Mod Coil Fabr.Punch List-CHRZANOWSKI	501	32	11%	251	89%	282.75	710	209
	Job: 1802 - FP Assy Oversight&Support-VIOLA	1,989	3,845	100%	(19)	0%	3825.83	4,346	**2,357**
	Job: 1803/1805- FPA Tooling/Constr-BROWN/DUDEK	522		0%	994	100%	993.97	1,277	**755**
	Job:1810-Field Period Assy -Station 1 2 3 VIOLA	5,745	2,167	30%	5,176	70%	7343.14	8,605	**2,860**
	Job: 1815 - Field Period Assy Station 5	1,334		0%	1,888	100%	1888.31	1,888	**554**
	Job: 2101 - Fueling Systems-BLANCHARD	69	7	2%	332	98%	338.23	338	**269**
	Job: 2201 - Vacuum Pumping Systems-BLANCHARD	172	21	3%	659	97%	679.36	679	**507**
	Job: 3101 - Magnetic Diagnostics-STRATTON	291	94	23%	317	77%	411.26	553	262
	Job: 3601 - Edge Divertor Diagnostics-STRATTON	31		0%	30	100%	30.12	30	(1)
	Job: 3801 - Electron Beam Mapping-STRATTON	263		0%	258	100%	258.06	258	(5)
	Job: 3901 - Diagnostics sys Integration-STRATTON	132	112	100%	(0)	0%	111.52	146	14
	Job: 6101 - Water Systems-DUDEK	46		0%	112	100%	112.25	112	**66**
	Job: 6201 - Cryogenic Syst-RAFTOPOLOUS	655	50	3%	1,518	97%	1567.72	1,568	913
	Job: 6301 - Utility Systems-DUDEK	105		0%	109	100%	109.44	109	4
	Job: 6401 - PFC/VV Htng/Cooling(bakeout) -KALISH	573		0%	634	100%	633.78	634	61
	Job: 7301 - Platform Design &	204		0%	213	100%	212.67	213	9
	Job: 7401 - TC Prep & Mach Assy Planning-PERRY	1,417	2,324	100%	(2)	0%	2322.89	2,068	**651**
	Job: 7501 - Construction Support Crew-PERRY	1,407	1,325	100%	(0)	0%	1325.21	1,325	**(82)**
	Job: 7503 - Machine Assembly (station 6)-PERRY	4,511		0%	4,317	100%	4317.43	4,317	**(194)**
	Job: 7601 - Tooling Design & Fabrication-PERRY	412		0%	399	100%	398.69	399	(13)
	Total Larry Dudek	24,791	10,566	34%	20,132	66%	30,699	35,412	10,621

Machine Assembly Schedule

NCSX National Compact Stellarator Experiment

	Forecast Start	Forecast Finish
Job: 7503 - Machine Assembly (station 6)-PERRY		
+ 1.0 - Component Preparation	01DEC09	23JUL10
+ 2.0 - Test Cell Metrology set-up/deflection test	03DEC09	18MAR10
+ 3.0 - Pre-installation set-up and test	11FEB10	18MAR10
+ 4.0 - FPA-1 Installation and Assembly Test	19MAR10	22JUL10
+ 5.0 - Spool piece installation test	23JUL10	16AUG10
+ 6.0 - Spool piece flange machining	20JUL10	02NOV10
+ 7.0 - FPA-2 Installation	18JUN10	12JUL10
+ 8.0 - FPA-3 Installation	11AUG10	01SEP10
+ 9.0 - Measure Type-C MC Flanges	02SEP10	09SEP10
+ 10.0 - Type-C Shim Sizing/Prep	08SEP10	09SEP10
+ 11.0 - Type-C Inboard Shim Installation Check	11JUN10	28OCT10
+ 12.0 - Install Remaining TF Coils	29OCT10	04JAN11
+ 13.0 - Install PF-4 Lwr & Solenoid suprt column	05JAN11	05JAN11
+ 14.0 - Move all Periods to installed position	06JAN11	21MAR11
+ 15.0 - Move VV Period to final position and Weld	29NOV10	01JUN11
+ 16.0 - Move TF Coils to final position	01JUN11	09JUN11
+ 17.0 - Install Lower PF Colis	10JUN11	13JUN11
+ 18.0 - Transfer Weight to Final Machine Supports	14JUN11	30JUN11
+ 19.0 - Vacuum Pump System	01JUN11	20JUL11
+ 20.0 - MC/VVSA Annulus insulation fill	01JUL11	22JUL11
+ 21.0 - Instl Remaining Trim Coils & Mag struct	21JUL11	01AUG11
+ 22.0 - Install solenoid & Remaining PF Coils	02AUG11	17AUG11
+ 23.0 - Instl/Route Mag Leads to Transition Box	18AUG11	14SEP11
+ 24.0 - Install LN2 and I&C Services	15SEP11	24OCT11
+ 25.0 thru 35.0 - Cryostat,NB duct & I&C Routing	28JUN11	14NOV11
Job: 8501 - Integrated Systems Testing-GENTILE		
+ Start-up	18OCT11	05JAN12

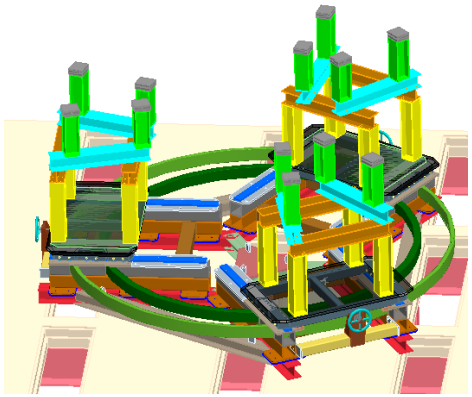


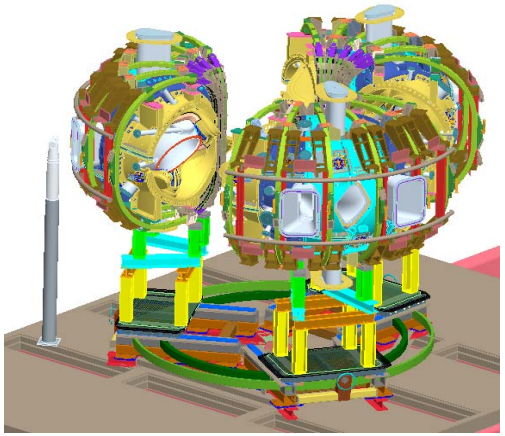
PPPL Princeton Plasma Physics Laboratory

ornl Oak Ridge National Laboratory

Machine Assembly

- Machine assembly will be performed with detailed procedures
  - Will be based on the detailed assembly plan
  - Will include specific metrology steps
  - Will assure that tolerance goals are met





Machine Assembly

- Component preparations

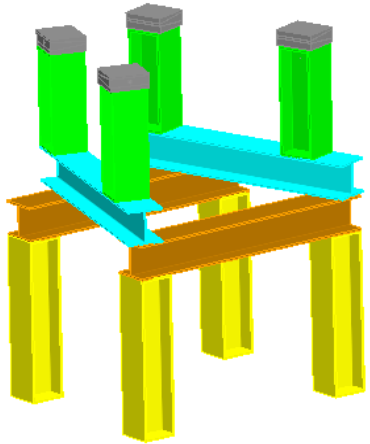


Fig 1a) Period support stand

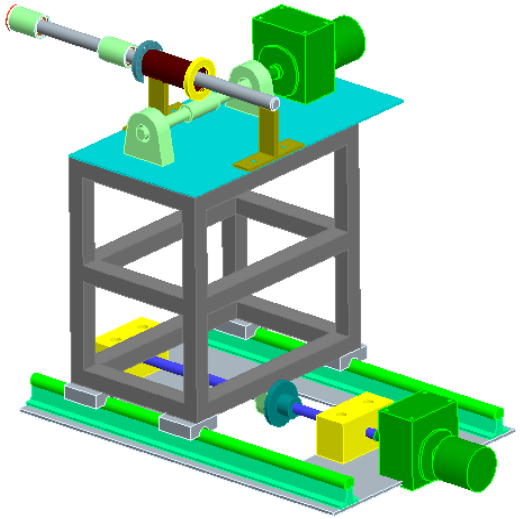


Fig 1b) Spool support stand

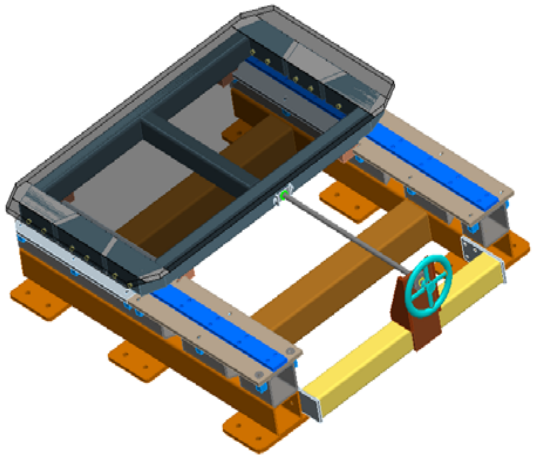


Fig 1c) FPA assembly cart

Machine Assembly

- Test cell metrology set-up

- Pre-installation set-up and test
  - All tooling will be tested before it is needed

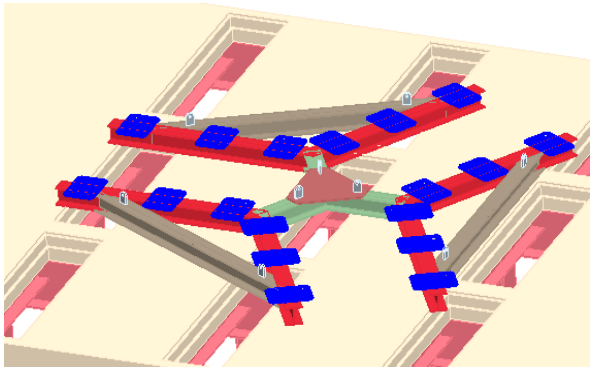


Fig. 2a) Machine base support structure

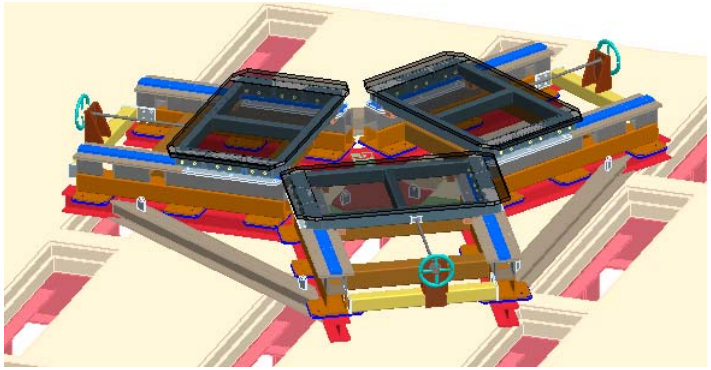


Fig. 2b) FPA assembly carts installed

Machine Assembly

- Temporary assembly structure used for increased positioning accuracy
  - Involves assembling field periods on one set of structures that have radial motion capability and then transferring to permanent supports
  - Positioning will be within 0.030”
  - Multiple fit-ups/iterations are included in the costs and schedules

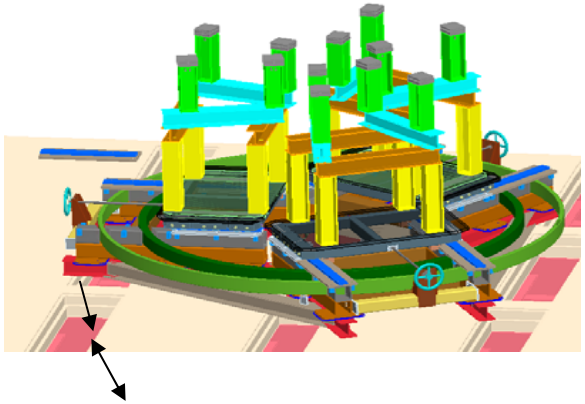


Fig. 2c) Lower coils positioned within the cart rail groves.

Machine Assembly

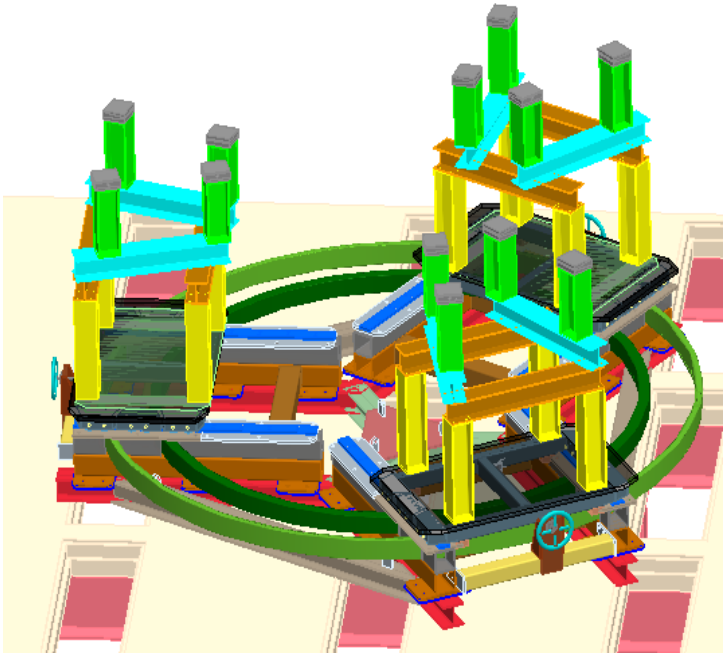


Fig. 2d) FPA cart moved to retracted position.

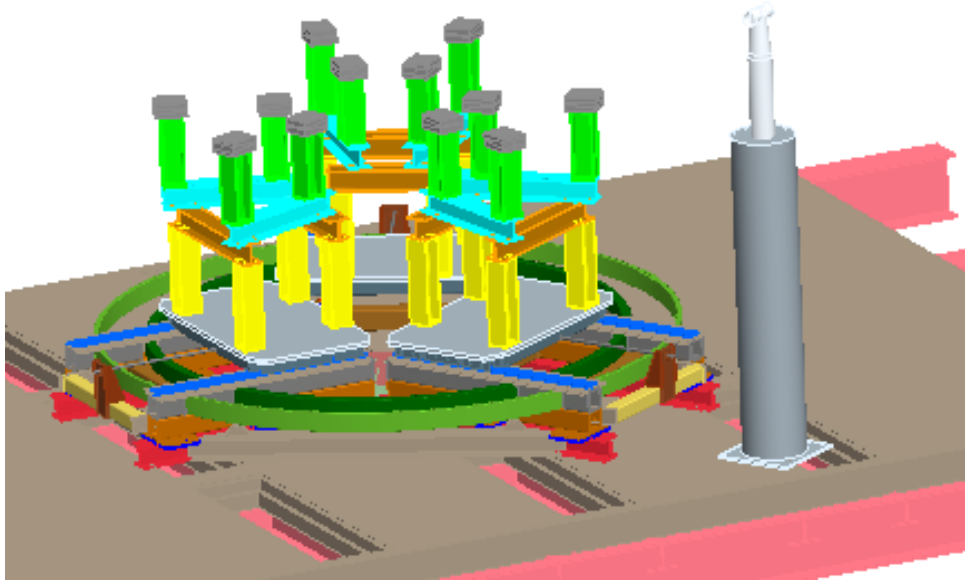


Fig. 3a) Laser support base and pole installed.

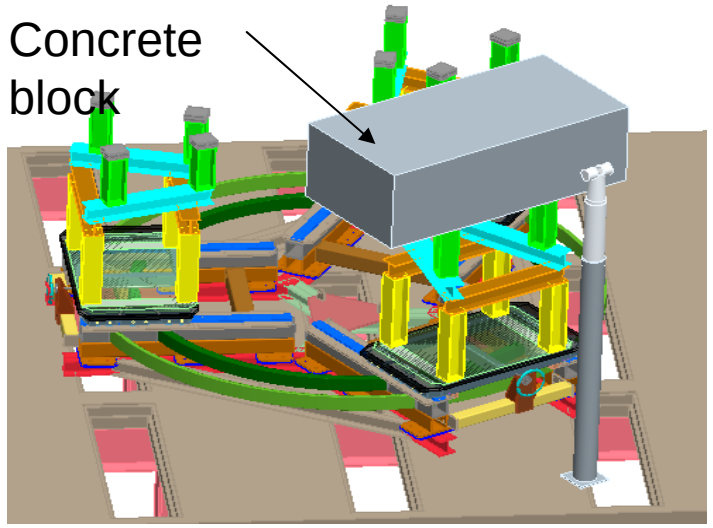
Risks and Risk Mitigation

- Risk: Assembly sled not stiff enough or does not have repeatable motion

- Mitigation: Sled will be designed with adequate stiffness and then evaluated with concrete blocks in plenty of time to make design modifications
  - Cost and schedule for this mitigation is in the base plan

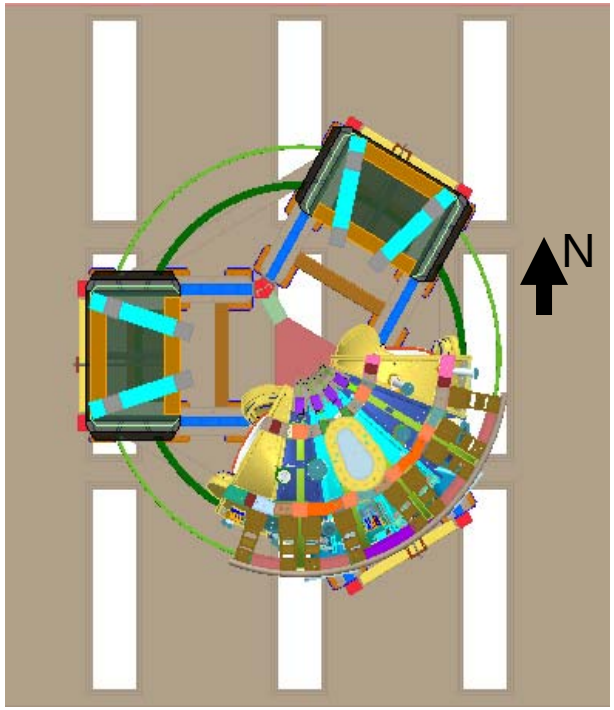
Machine Assembly

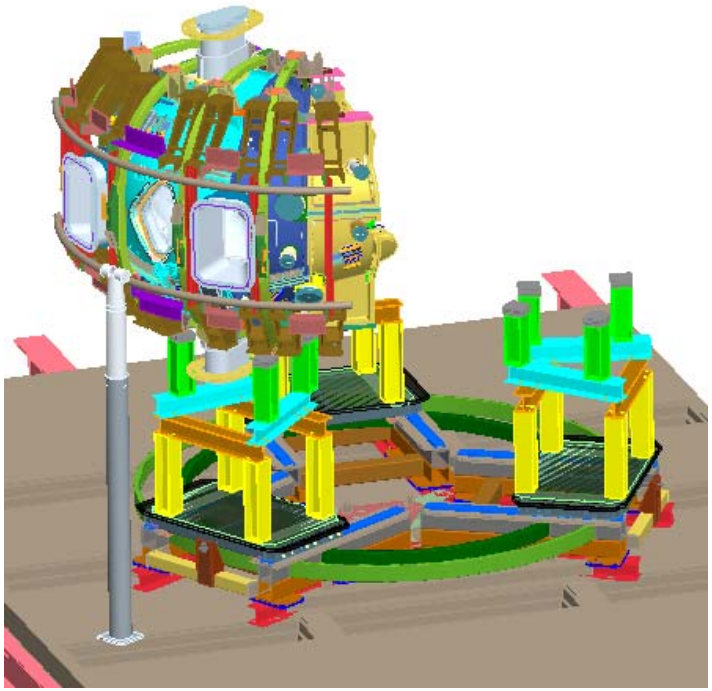
- Metrology/assembly testing of each assembly sled with a dummy load
  - Metrology is 1/3 of the total field work, as has been the experience on coil winding and vacuum vessel assembly
- Then testing each FPA on it's sled prior to final assembly
  - Per experience of Wendelstein 7-X



Machine Assembly

- Field Period Assembly (FPA) installation and assembly test





Risks and Risk Mitigation

- Risk: Field Period Assembly (FPA) alignment not within tolerances
- Testing: Metrology check of position
- Mitigation: Use assembly carts to reposition FPA
  - Cost and schedule for this mitigation is in the base plan

Machine Assembly

- Spool piece installation test

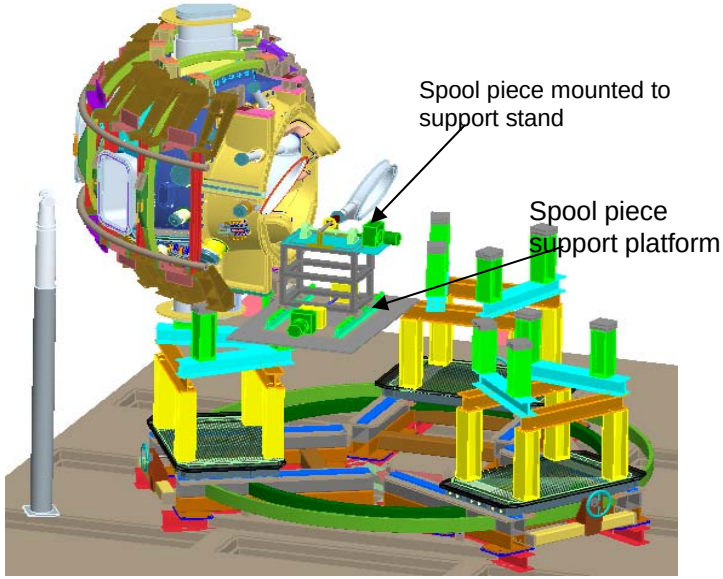


Fig. 5a) Period 1 retracted with spool and support stand installed

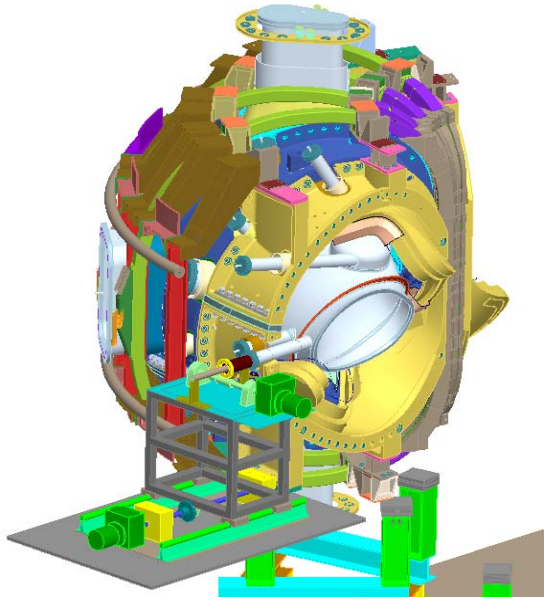


Fig. 5b) Period 1 and spool shown at installed position

Risks and Risk Mitigation

- Risk: Vacuum vessel sectors not in perfect position
- Testing: Measure gap between sectors
- Mitigation: Final machining of vessel spool piece after actual gap is measured
  - Cost and schedule for this mitigation is in the base plan

Machine Assembly

- FPA-2 installation

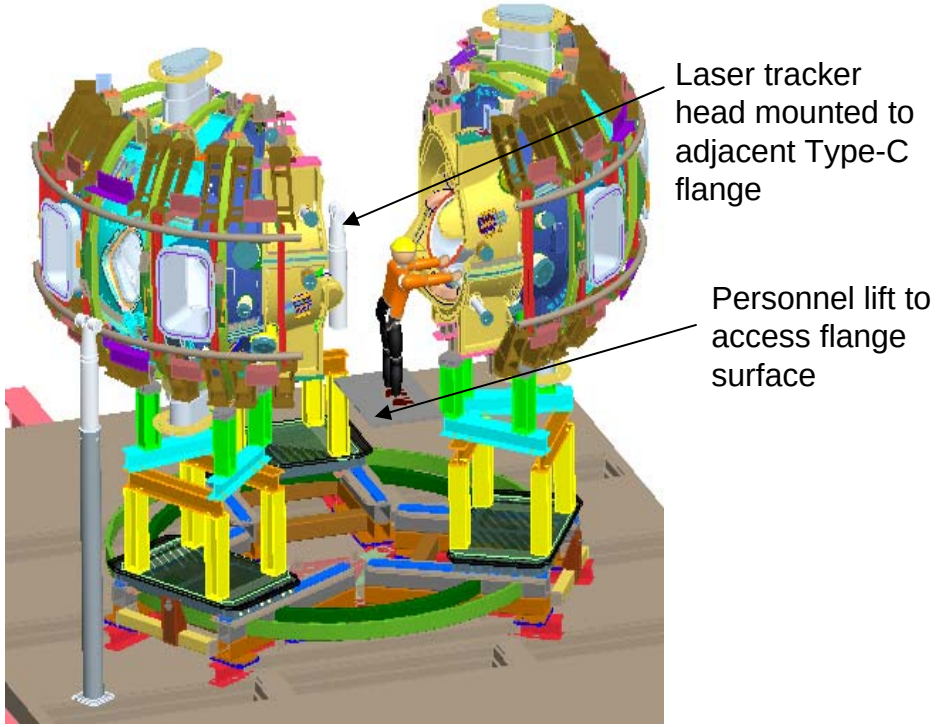


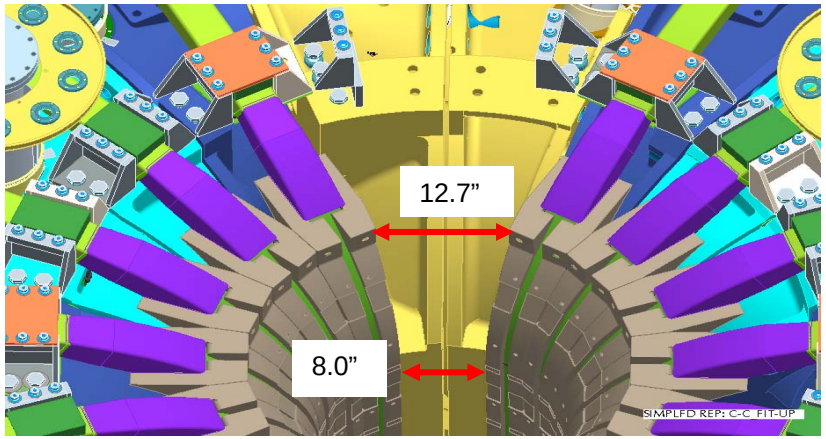
Fig. 6a) Type-C flange measurement

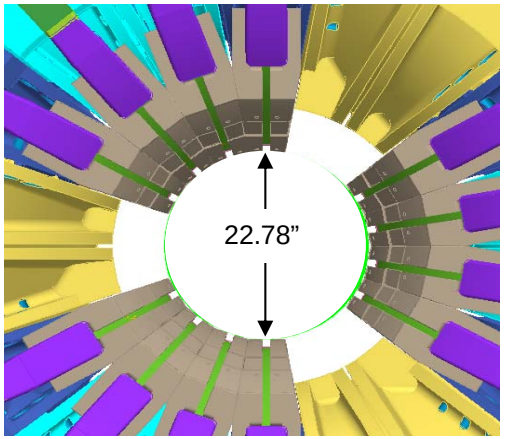
Risks and Risk Mitigation

- Risk: Space between modular coils on adjacent FPAs not perfect
- Testing: Metrology to determine actual gap between Type C coils
- Mitigation: Custom shims
  - Cost and schedule for this mitigation is in the base plan

Machine Assembly

- FPA-3 installation
- Measure remaining Type-C modular coil flanges
- Type-C inboard shim installation check
  - Very limited space – platform needed for technician





Machine Assembly

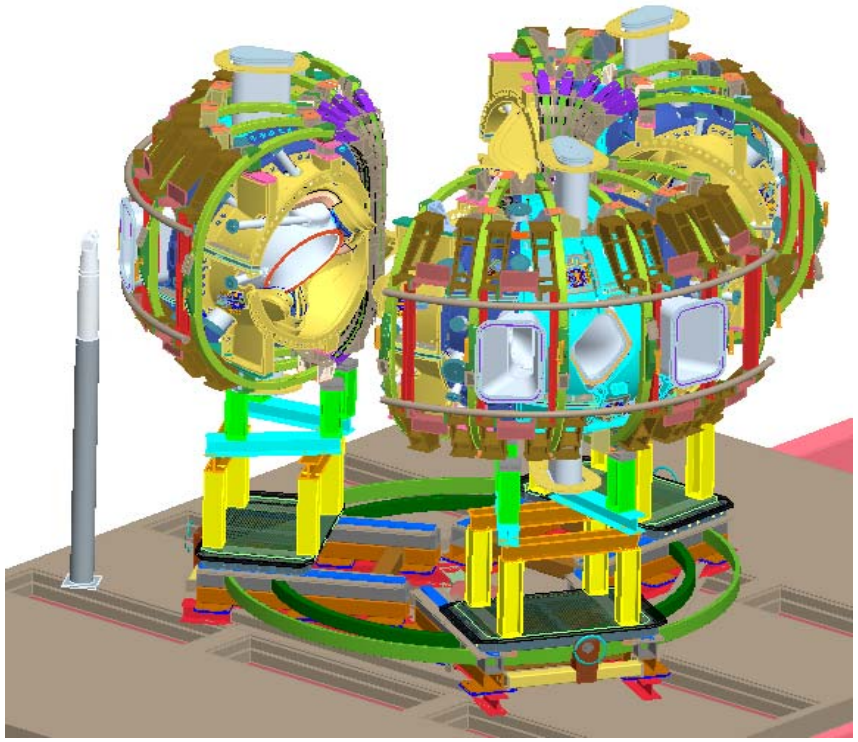
- Type-C inboard shim check / installation
  - Temporarily attach a set of outboard shims (top/bottom) and all inboard shims on one Type-C flange of each of the three FPAs
  - Move all FPAs to their installed position
  - Install studs and supernuts at the shimmed locations; torque to 50% of final value
  - Do a hand “wiggle” test for all shims to make sure they are tight
    - If a loose shim is found, back off on sufficient adjacent bolts to allow a replacement shim to be inserted – tighten bolts and repeat

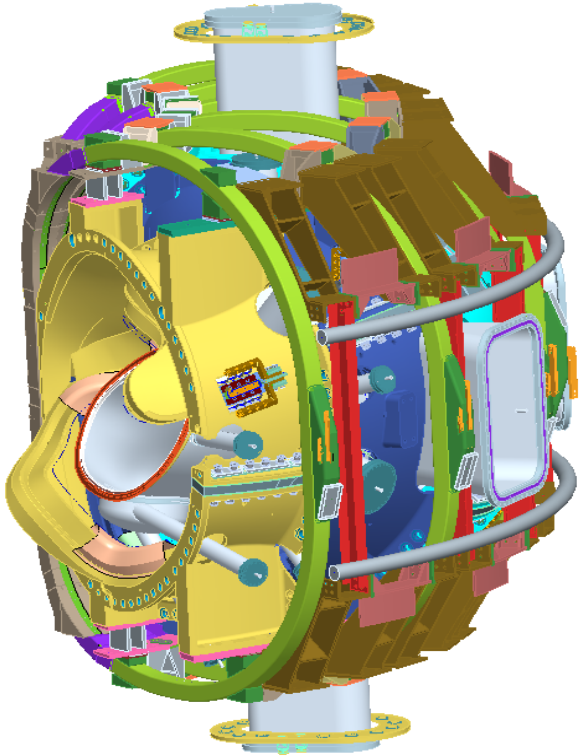
Machine Assembly

- Type-C inboard shim check / installation cont
  - Measure a minimum of eight tooling balls on each FPA
    - The maximum deviation should be 0.020” or less
  - If deviation exceeds 0.020”, “back office” input is needed on which new shims should be used
  - Loosen hardware, install new shims and repeat
  - With successful metrology measurements, remove all hardware and return each FPA to its retracted position
  - Permanently secure in place all inboard shims. Retain in place all initial alignment outboard shims

Machine Assembly

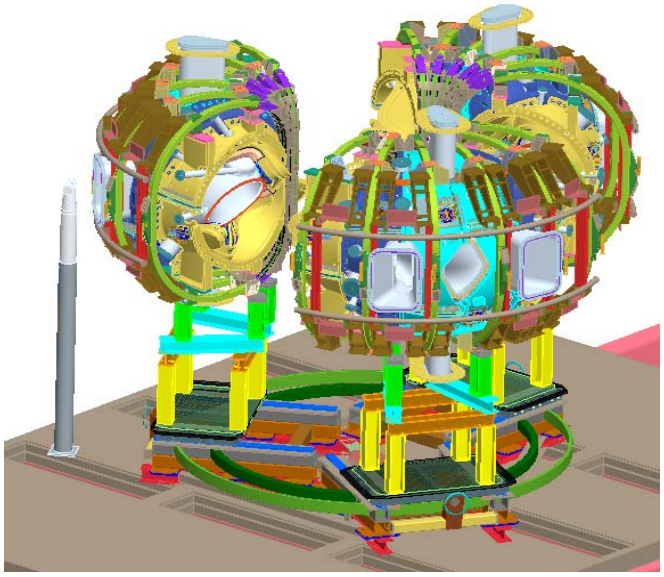
- Install remaining TF coils





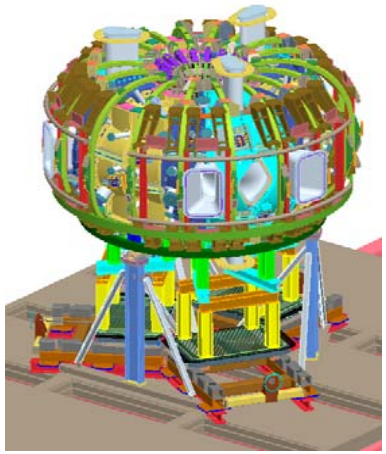
Machine Assembly

- Position lower PF4 coil and solenoid support
- Move all FPAs to installed position
- Install outboard C-C shims and remaining studs, bushings and supernuts
- Move each vacuum vessel section to its final position and secure



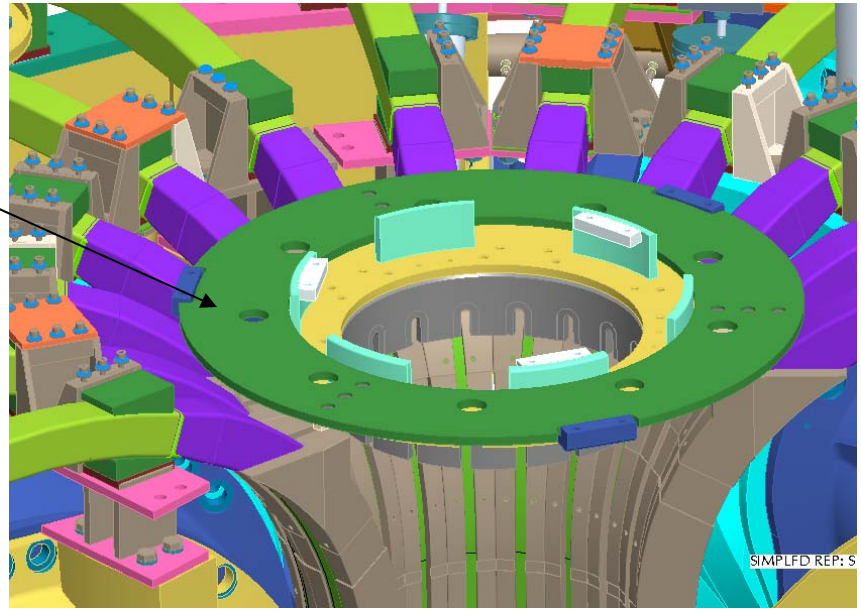
Machine Assembly

- Position each vacuum vessel spool piece
  - Lock in place with clips to vacuum vessel
- Weld all spool pieces to vacuum vessel
  - Weld inspections and leak checks on second shift
- Weld on port 4s



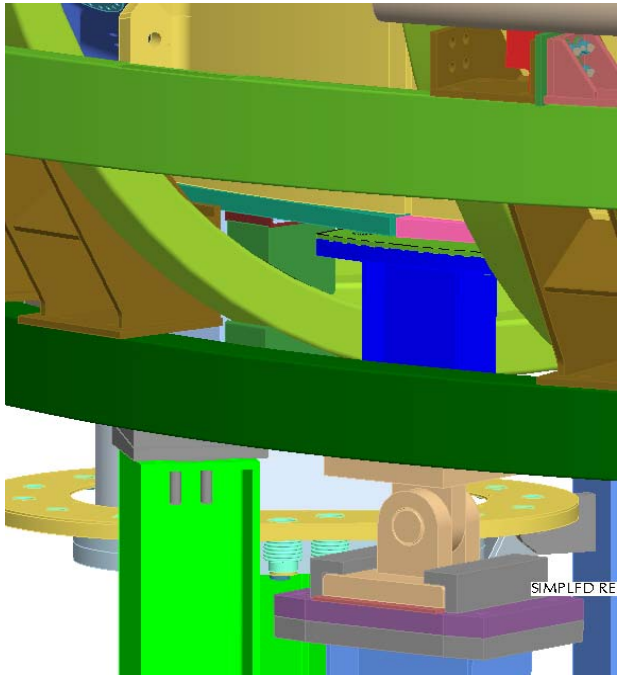
Machine Assembly

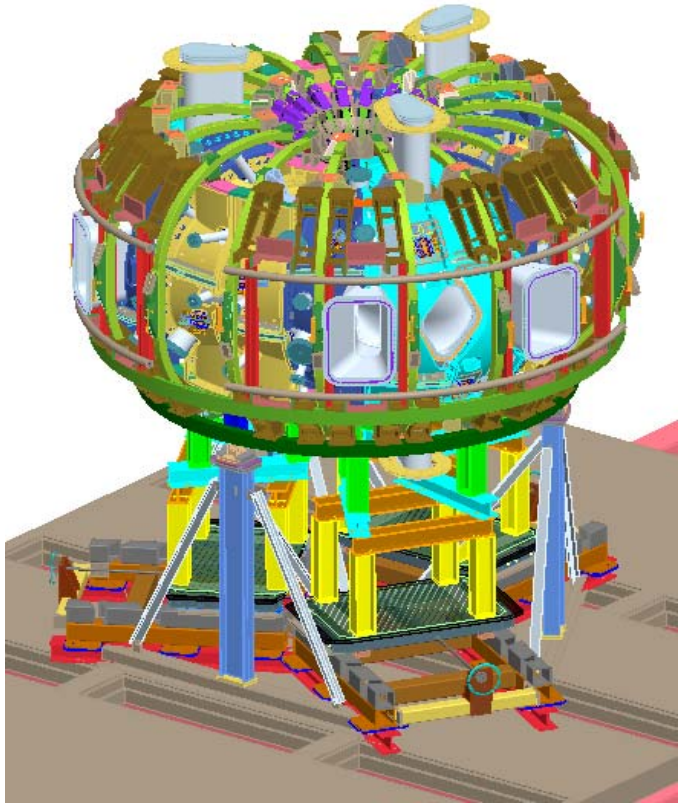
- Move TF coils to wedged position
- Install lower PF coils



Machine Assembly

- Transfer weight to final machine support structure





Risks and Risk Mitigation

- Risk: FPA position shifts when load is transferred to permanent supports
- Testing: Metrology determines shift
- Mitigation: Transfer load back to temporary carts, re-set permanent supports to compensate, and repeat
  - Cost and schedule for this mitigation is in the base plan

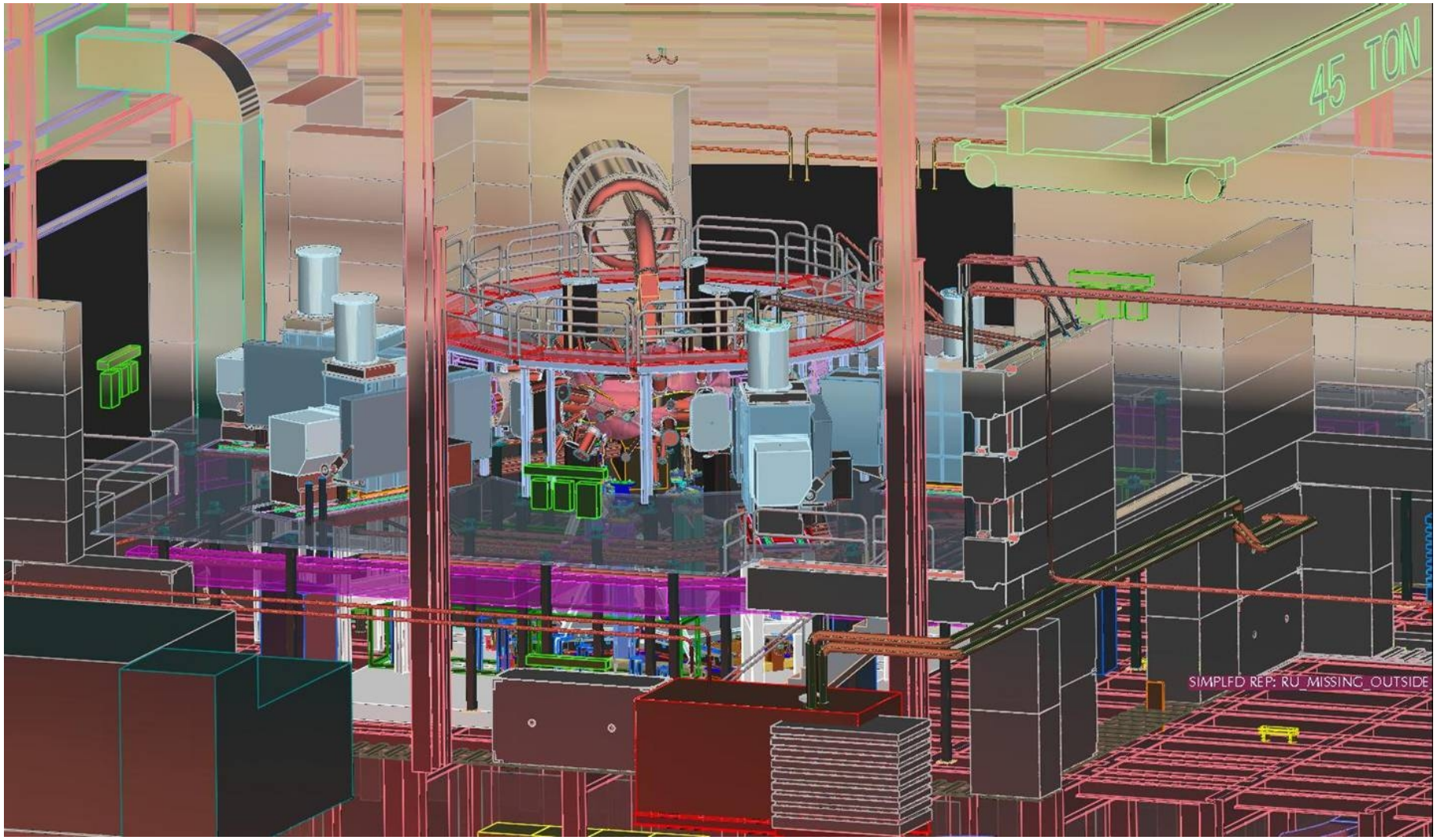
Machine Assembly

- Install vacuum pumping system on period #1
- Pumpdown and leak check vacuum vessel
- Insulation fill in annulus between modular coils and vacuum vessel
- Install remaining trim coils and magnet structures
- Install center solenoid and remaining PF coils
- Install and route all magnet leads to temperature transition box

Installations Outside Stellerator Core

- Install LN2 distribution system
- Install I&C cables to stellarator core
  - Includes general use cable tray installation
- Install the cryostat
- Connect bakeout system
- Install remaining test cell platforms

3 D Model of Test Cell



Tolerance Goals

- Tolerance Goals can be achieved
  - Procedures and tooling, including metrology, are being designed to be consistent with tolerance requirements of within 0.030”
  - Procedures and tooling have been developed for Field Period Assembly which can be carried over to Final Assembly tasks

Tolerance Goals cont

- Final machine assembly planning is consistent with requirements
  - Assembly access for C-C inboard bolted joint has been studied using CAD modeling and a physical mockup
  - Mitigation measures are being budgeted, planned and implemented for risks that are still outstanding

Summary

- The level of detail for the Machine Assembly has increased significantly in the last 18 months
  - Assembly Sequence Plan was developed
  - Task by task estimates were made
  - Assembly risks were identified
  - Mitigation of the risks were developed and incorporated into the base plan

- Although designs affecting the assembly are at a conceptual level in some cases, conservative estimates which allow for multiple fit-ups, along with experience from the assembly of other devices* as well as the metrology experience gained from the Field Period Assembly, will assure the assembly of NCSX within the tolerance requirements

  * (PDX, TFTR, NSTX, NCSX so far, ATF and W-7)