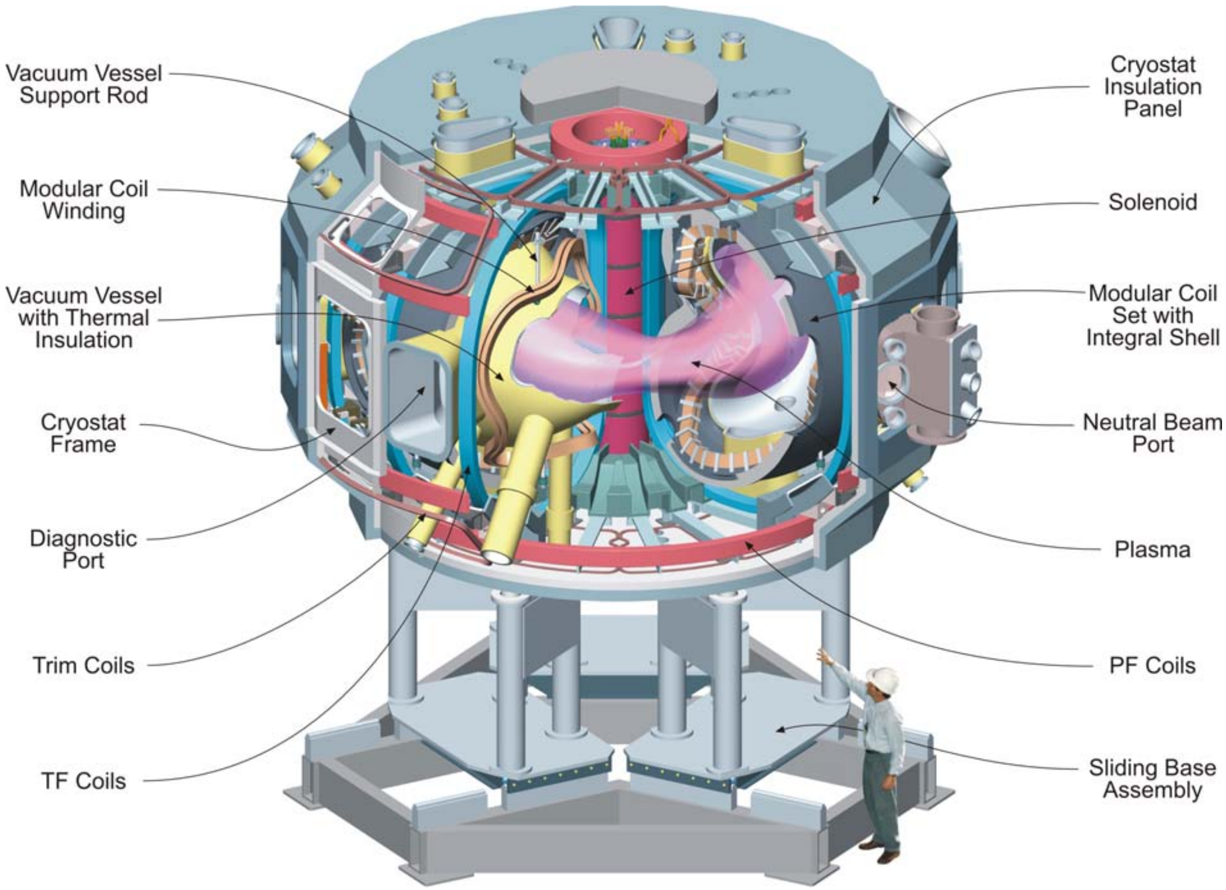
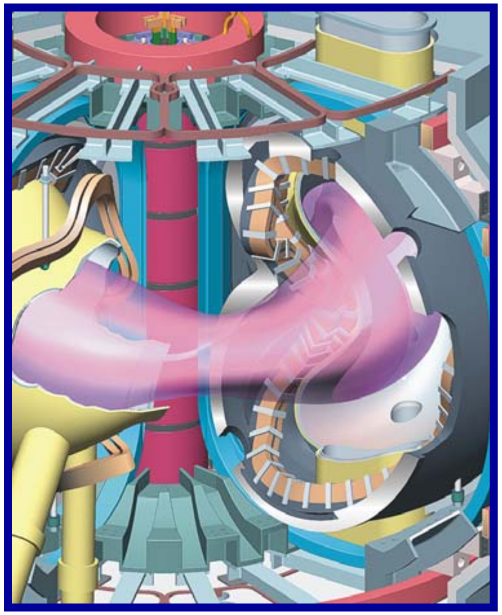
Recent Progress in the Design, R&D, and Fabrication of NCSX

The NCSX Project Team

ANS Topical Meeting on the Technologies of Fusion Energy
Madison, Wisconsin
September 14-16, 2004

The NCSX Configuration



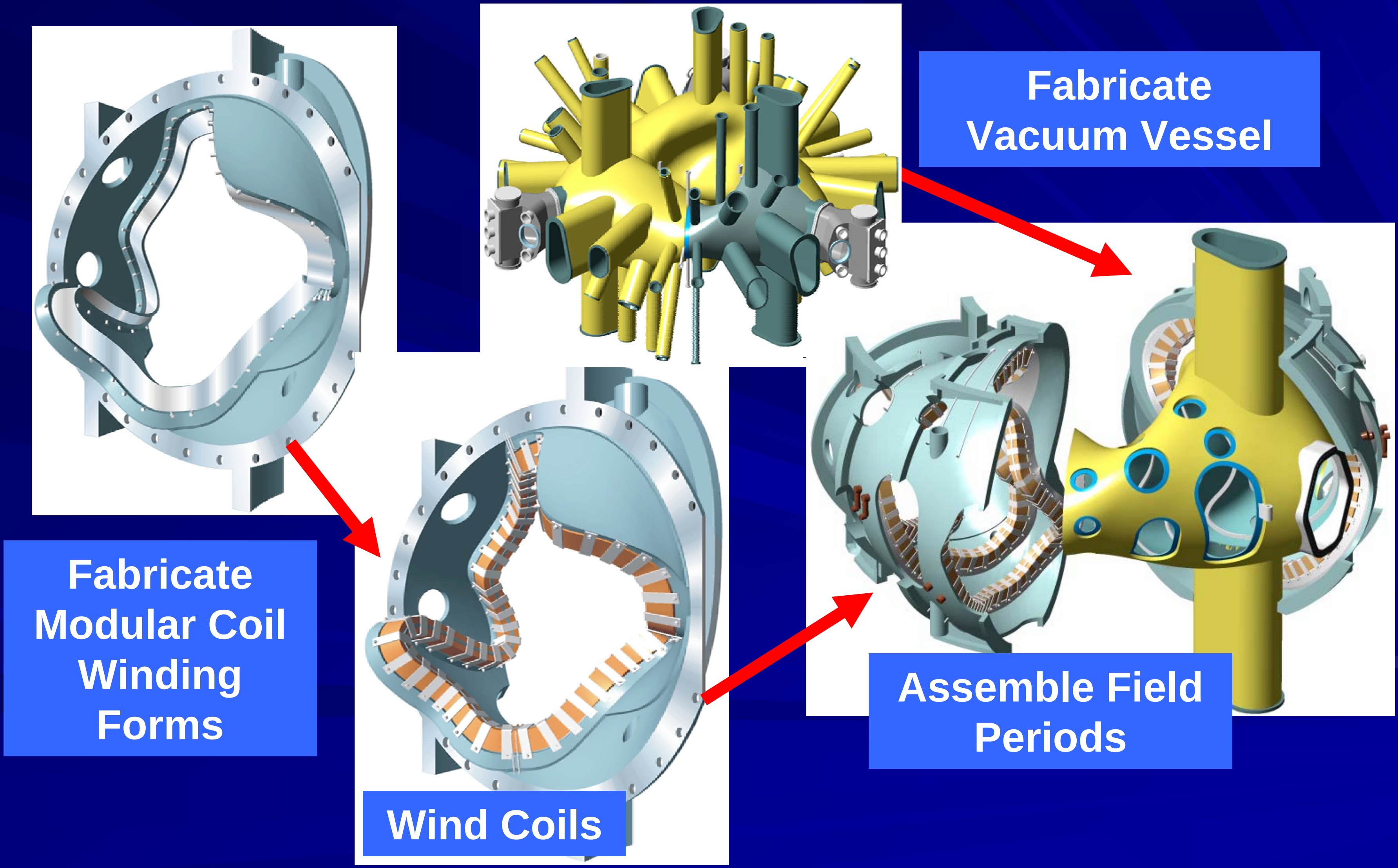


Why build a compact stellarator?

- Compact stellarators have tremendous promise, combining the best features of tokamaks and stellarators:
  - High beta (>4%) stability
  - Excellent confinement
  - No tokamak-like disruptions (no VDEs, much smaller plasma current)
  - No current drive required for steady state operation
  - No conducting wall or feedback system required to provide vertical stability or to stabilize external kink modes
  - Low aspect ratio resulting in high power density and improved economics

- Compact stellarators require 3-D shaping of the last closed magnetic flux surface, and a small bootstrap current to provide a fraction of the rotational transform.

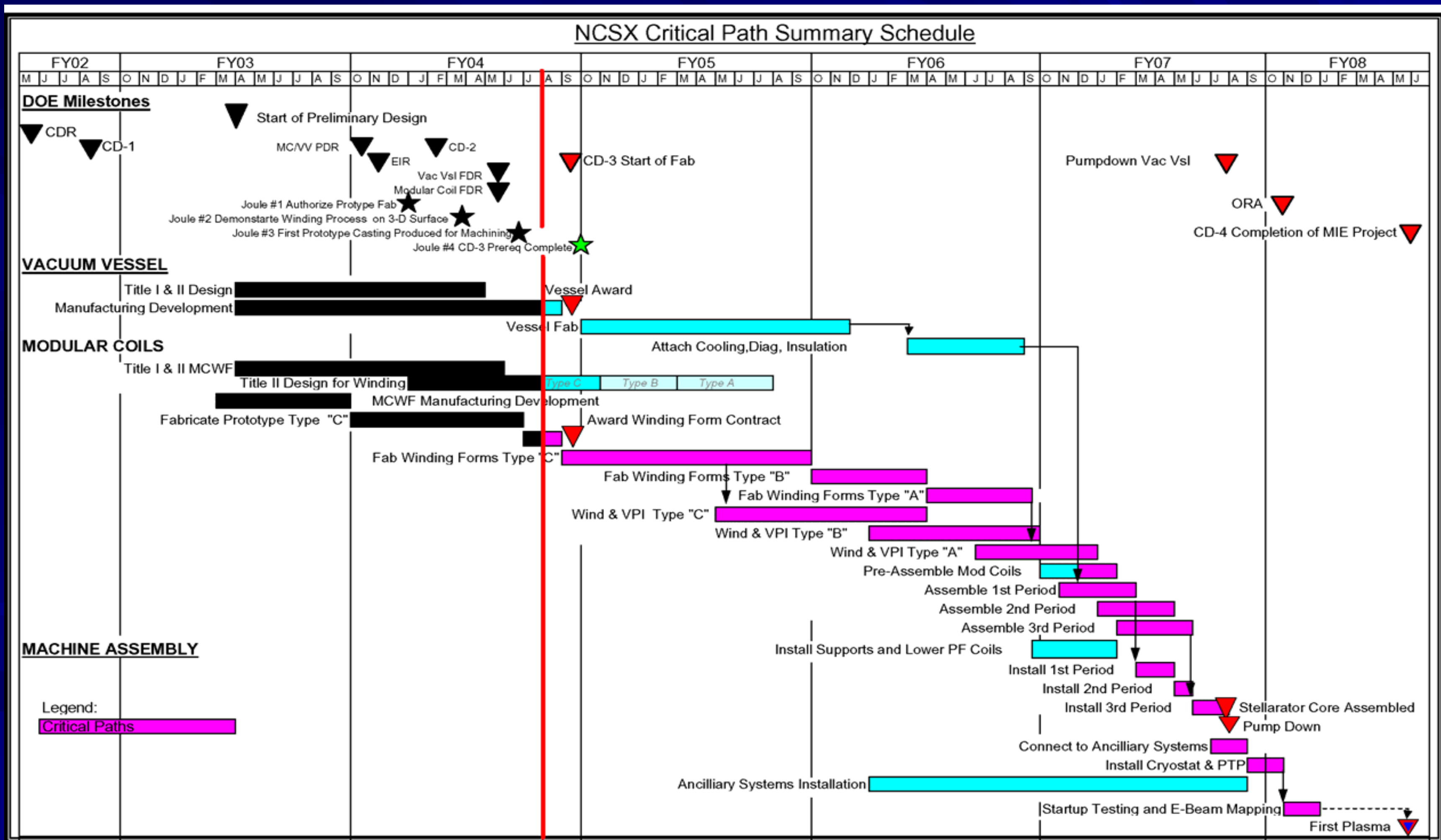
The Basic NCSX Device Concept is Robust



Excellent Project Progress Made

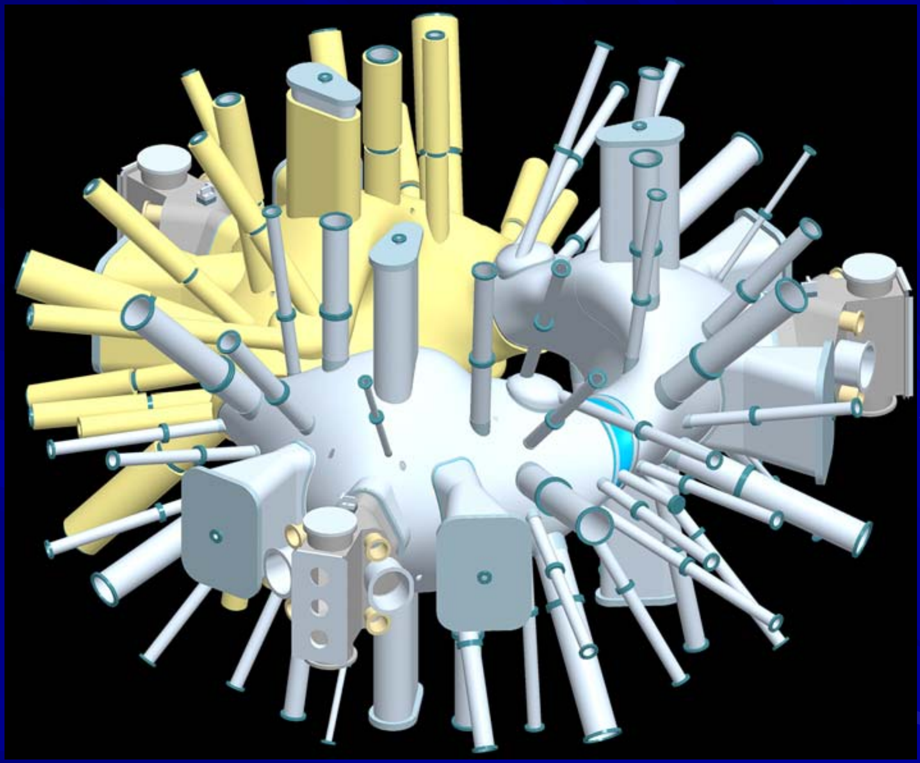
- Project base line established in February
  - TEC $86.3M
  - First Plasma May 2008
- Final design reviews of modular coil winding forms and vacuum vessel completed In May
  - Prototypes for both received and resolved technological issues associated with manufacture
  - In process of final negotiations on production contracts for both major procurements
- OFES review of project completed at beginning of this month and project is awaiting authorization to proceed with start of construction

Schedule is Sound and Provides ~ 5 Months of Schedule Contingency



Vacuum Vessel Design Is Robust and Supported by R&D and Analyses

- **Design improvements**
  - Added 50% more ports to improve diagnostic access (ensures capability to accommodate all required upgrade diagnostics) and provides for inboard RF
  - Added 350° C bakeout capability
- **Analyses confirmed robustness of the design**
- **Design issues resolved via extensive R&D and manufacturing development activities**
- **Final negotiations underway to award production contract**
  - Prototype fully meet project technical requirements

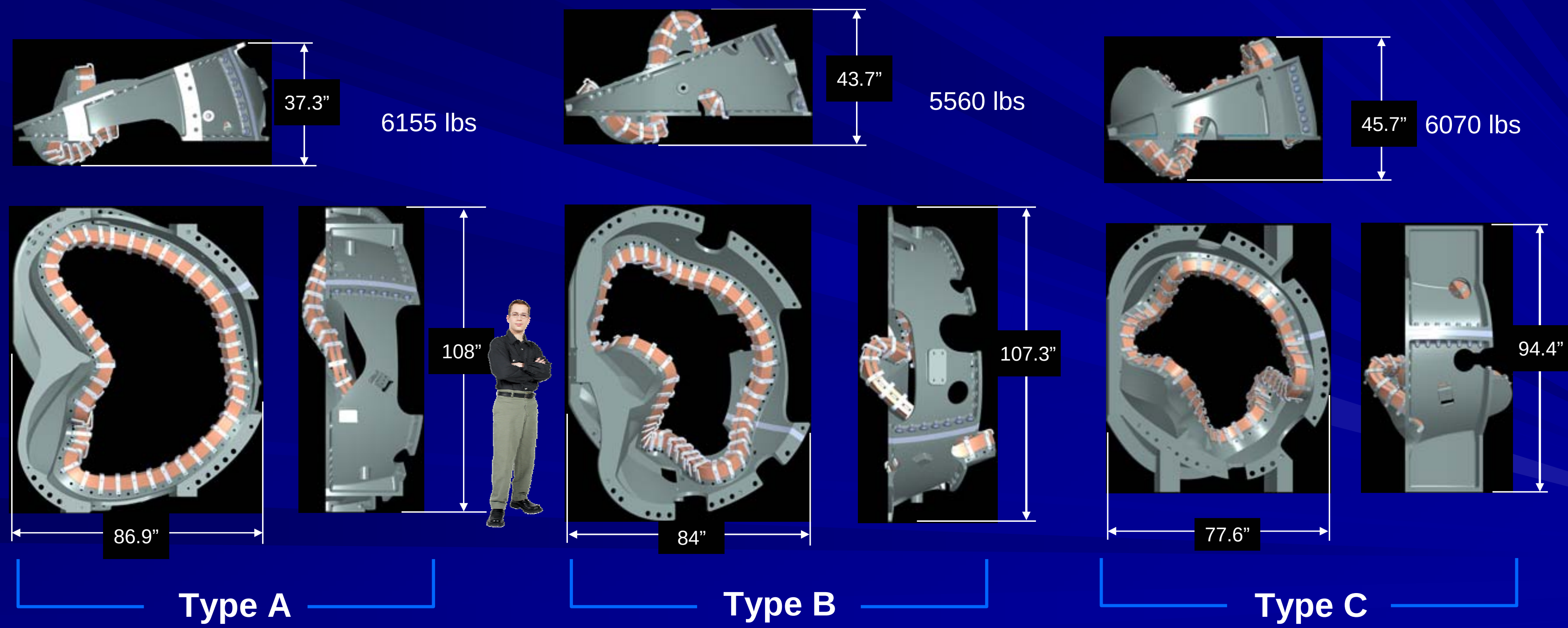


Vacuum Vessel Prototypes Settled Manufacturing Issues

- Full scale prototype on display here at TOFE
- Proved that Inconel vessel could be press formed with tight tolerance, vacuum, and surface finish requirements
- Demonstrated ability to handle CAD data

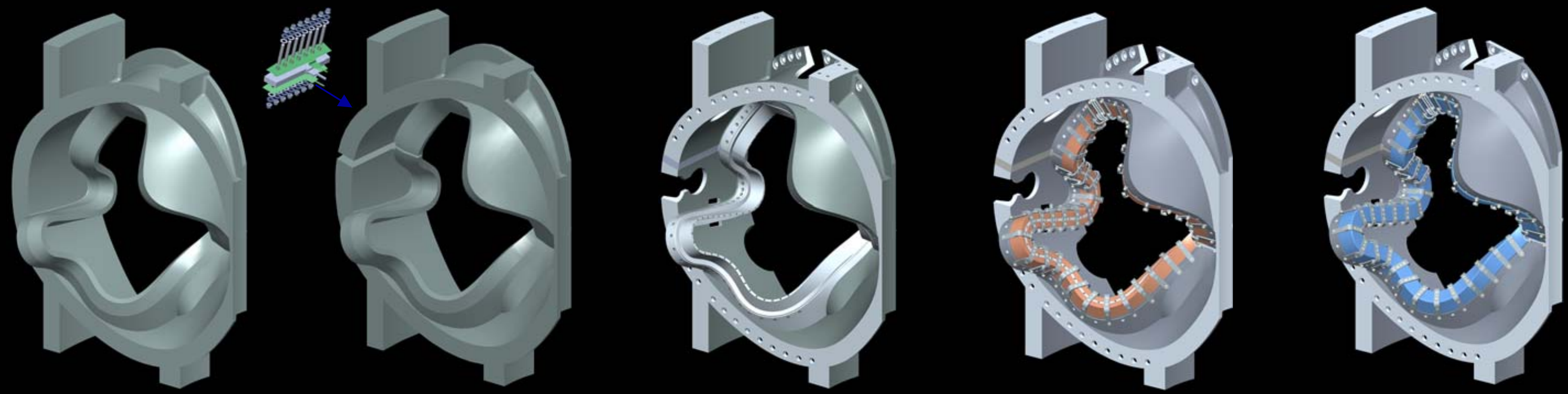
Modular Coil Winding Form Design Is Also Robust and Supported by R&D and Analysis

- **Final design completed**
  - Design issues resolved via extensive R&D and manufacturing development activities
  - Custom alloy optimized for both manufacture and NCSX performance
  - Analyses confirm design
- Three unique coil types :



Modular Coils Designed for Strength and Accuracy

- Continuous support for strength and accuracy of winding
- Single machined part provides winding form and assembly features
- Winding never removed from coil form



Casting:

- Casting poured
- Casting removed from mold and upgraded

Poloidal Break:

- Poloidal break cut
- Poloidal break hardware is installed,

Machining:

- All machining is completed
- Port openings cut

Winding:

- Studs attached
- Conductor wound
- Chill plates & coolant tubing installed

VPI and Testing:

- VPI
- Cryogenic and electrical tests
- Final geometry measurement

The Winding Forms Are Made of a Custom and Robust Stainless Steel Alloy

- The alloy is a variant of CF8M (316L)
- Mechanical properties guaranteed by vendor

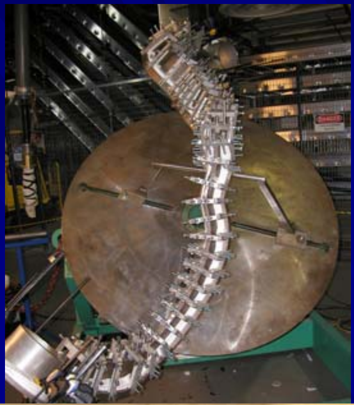
Minimums Guaranteed	@ 77K	@293K
Elastic Modulus	21 Msi (144.8 GPa)	20 Msi (137.9 GPa)
0.2% Yield Strength	72 ksi (496.4 GPa)	34 ksi (234.4 GPa)
Tensile Strength	95 ksi (655 GPa)	78 ksi (537.8 GPa)
Elongation	32%	36%
Charpy V-Notch Energy	45 ft-lbs (61 J)	60 ft-lbs 81.3 J)

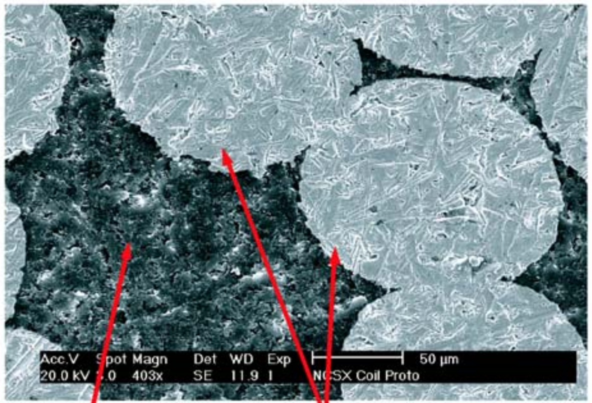
Modular Coil Winding Form Manufacturing Capability Demonstrated by Prototypes

- Two teams each produced a full scale prototype winding form casting.
- Computer-optimized casting process and pour capacity with ample margin demonstrated
- Poloidal break made on one; very little movement resulted

Conductor Configuration and Characterization Successful

- Final conductor configuration decided
- Conductor properties characterized by extensive R&D (modulus, strength, keystoning, etc.)
- Winding and VPI trials successful
  - "Inch worm" coil used to develop winding techniques
  - "Twisted Racetrack" coil will be fully prototypical and will be used to qualify the design and manufacturing process
  - VPI tests resulted in essentially no voids

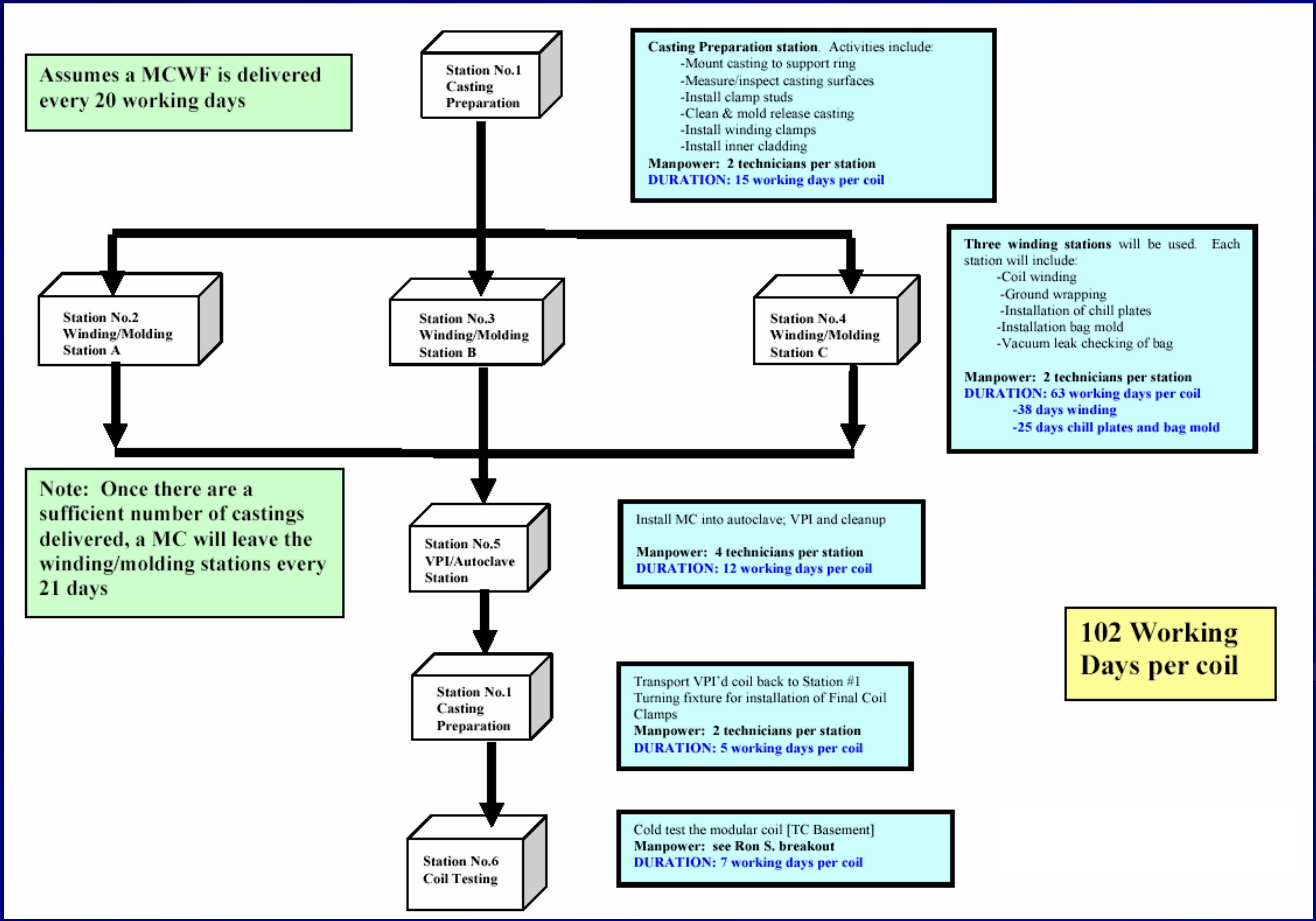




Epoxy visible in virtually
ll gaps as in this example

Copper Strands

Modular Coil Winding Process Defined in Detail



Modular Coil Winding Facility Already Constructed in TFTR Test Cell Area

One of the Modular Coil Mounting Fixtures at Stations 2-4

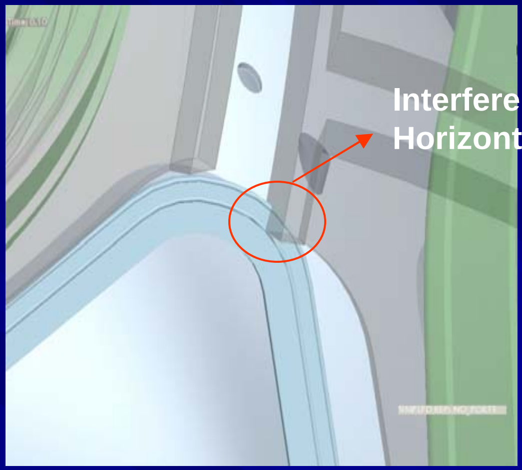
Autoclave at Station 5

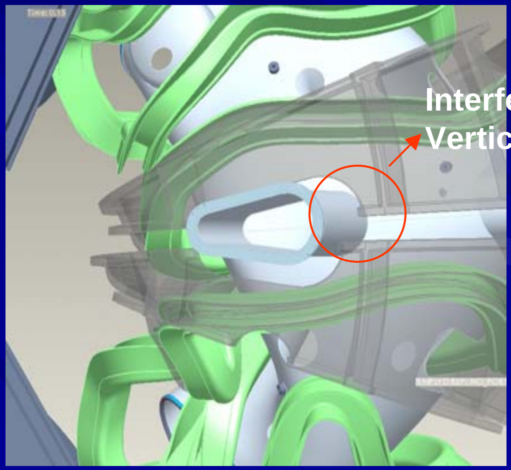
Modular Coil Test Facility will Ensure that all Coils will Work

- Accommodates full size modular coil
  - Station 6 already constructed in TFTR Test Cell basement
- Designed for full power/duty cycle testing
- All coils will be tested at cryogenic temperatures prior to installation

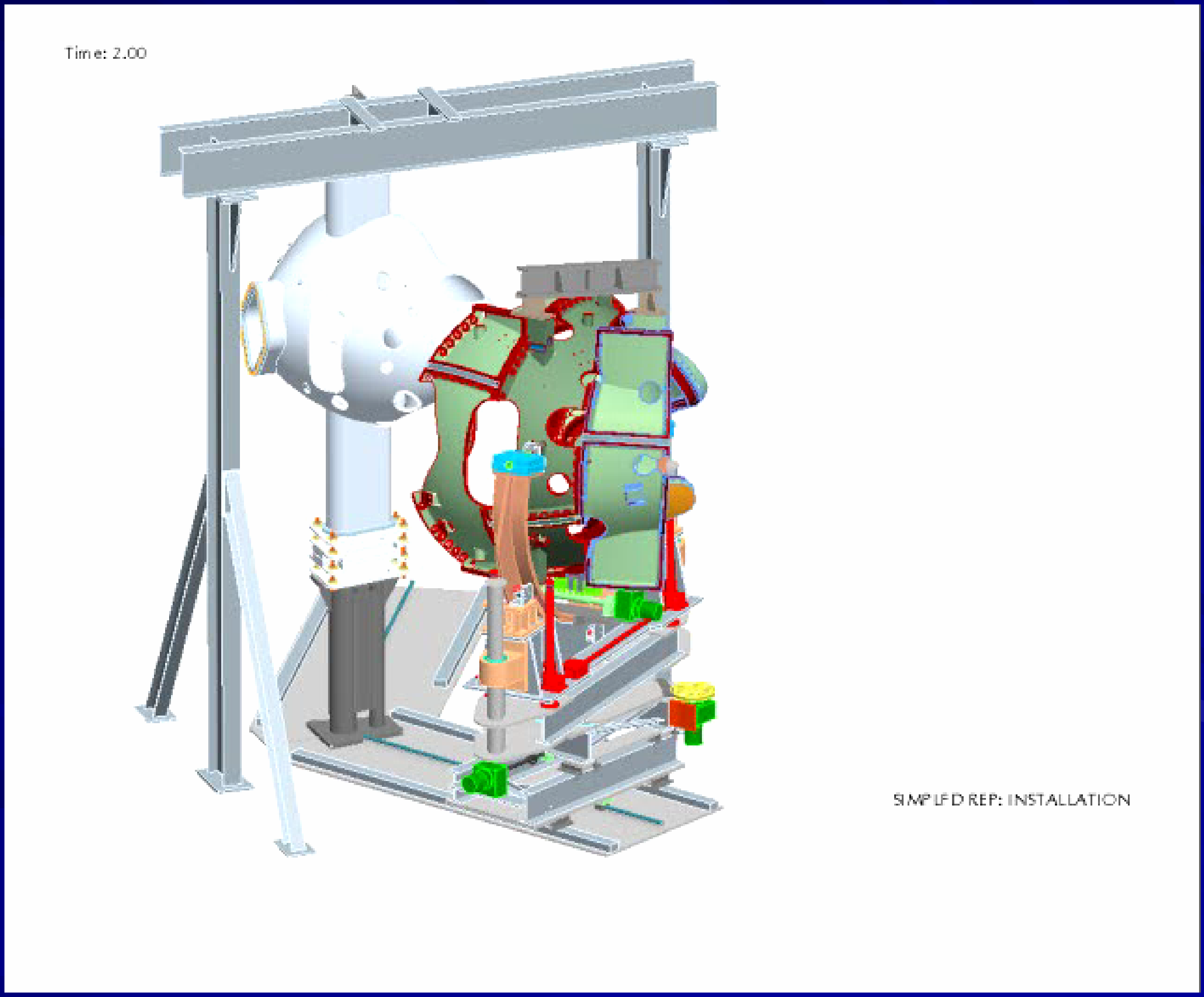
3D CAD Models Facilitated Resolution of Assembly Issues

- **The models are part of an integrated model of stellarator core**
  - Essential for establishing envelopes and avoiding interferences
  - Facilitates interface definition with other stellarator core components
- **Assembly fit-ups require following complex 3D trajectories**
  - MC-to-MC to form 3-coil modules
  - Sliding a 3-coil module over VV and into mating 3-coil module
  - Concurrent positioning of completed field period assemblies and spacers (6 pieces)
- **Many Interference Checks Completed and Problems Resolved**





Assembly Trajectory Developed that Avoids Interferences



Power System Update

- Use of C-site electrical systems deemed adequate for first plasma, field period mapping, and initial experimental operations
  - Enables NCSX construction and startup program not to interfere with on going NSTX operations
- Later experimental phases will require sharing of D-site power supplies with NSTX

Summary

- Significant progress made in the last year!
- Baseline costs and schedule maintained
  - Critical path has ~5 months of schedule contingency
- Major technical risks in the two most complex procurement areas (mod coils and vessel) have been retired
  - Proceeding with finalizing production contracts
- Project is ready to proceed with start of construction!
  - Plan is sound, credible, and reasonable
  - DOE review this month confirmed that project is ready to proceed with start of construction
  - Awaiting OFES authorization to proceed