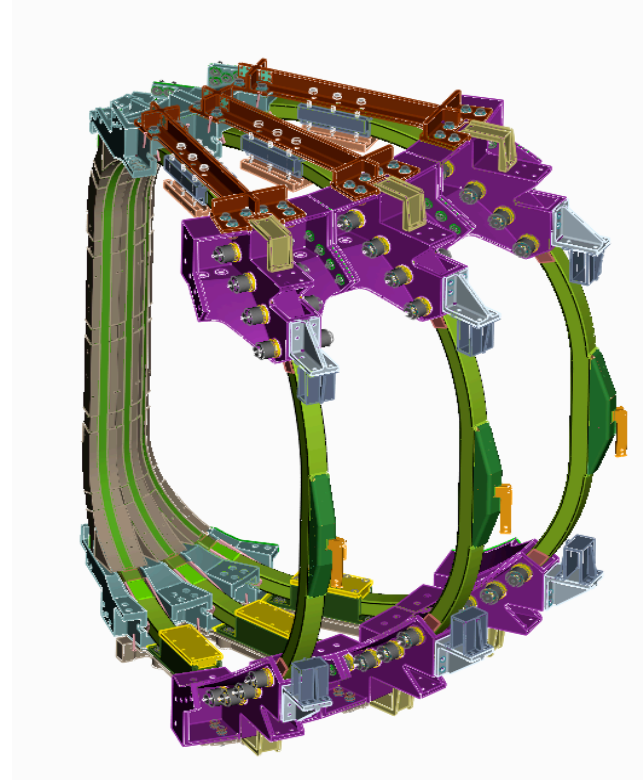
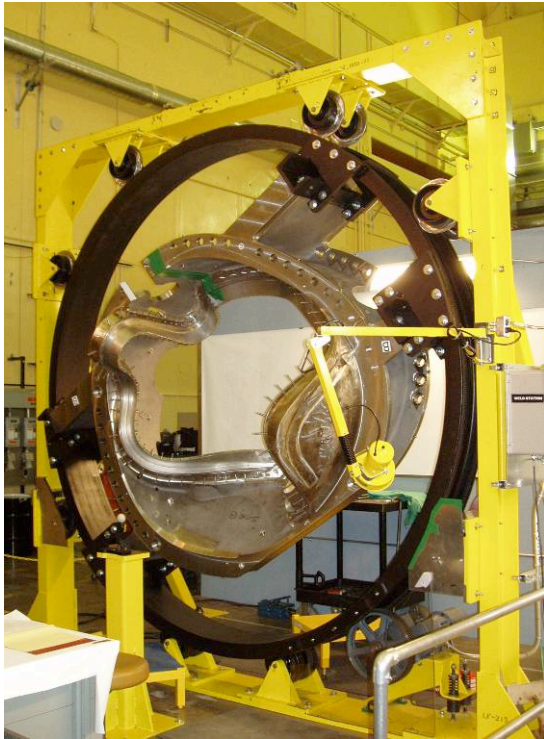


Plans and Risk Mitigation- Coil Winding



**J. H. Chrzanowski for the NCSX Project
November 2-3, 2005**

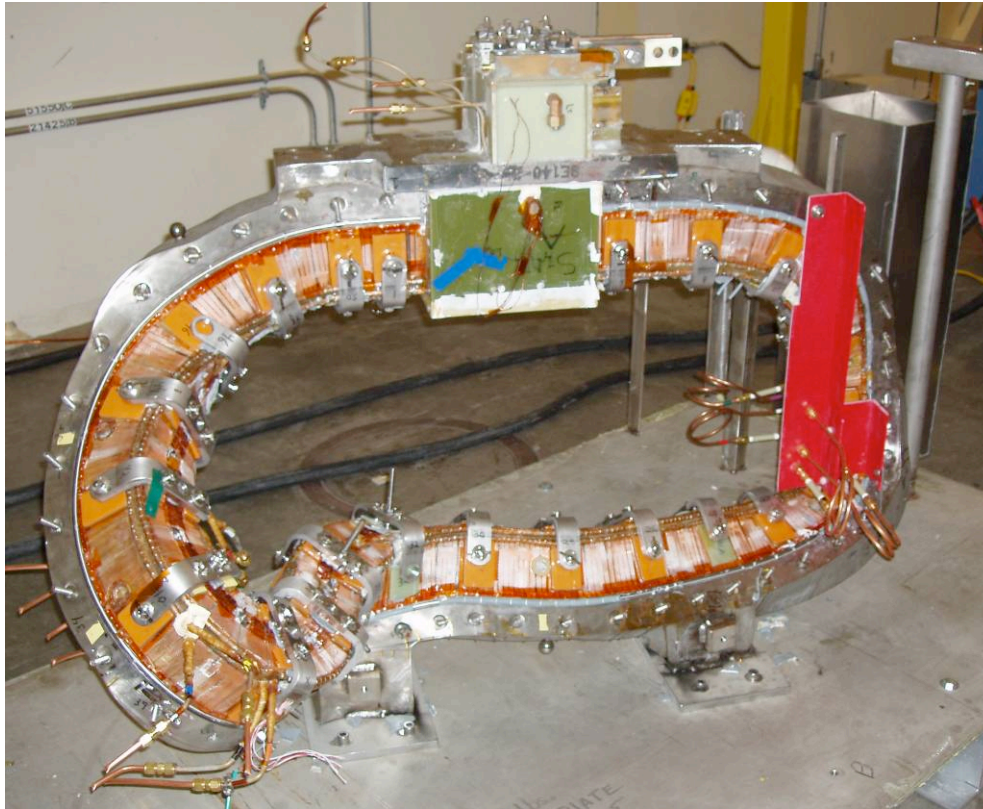
Modular Coils



- **The modular coils have introduced unique and challenging technical requirements.**
 - Complex geometry
 - Use of compacted copper rope conductor
 - Extremely tight tolerance controls
 - Unique manufacturing processes and use of equipment
- **To address these issues, a number of R&D activities were completed including a demonstration coil “Twisted Racetrack Coil” [TRC] which was fabricated and successfully tested. [\[Risk mitigation\]](#)**

Twisted Racetrack (TRC)

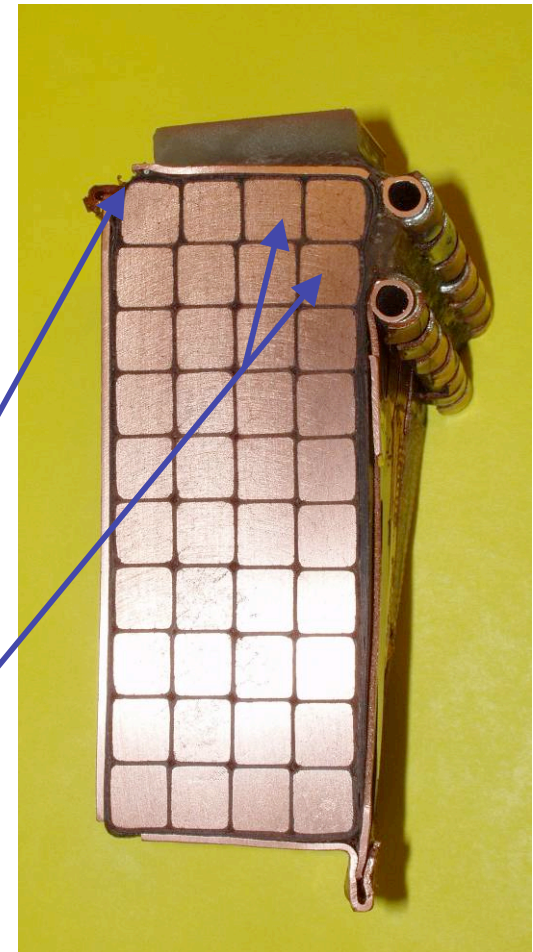
Accomplishments [Risk Mitigation]



- **Manufacturing lessons learned:**
 - Tolerance control
 - Manufacturing procedures
 - Tool development
 - Verification of the VPI plan
 - Training of key personnel
- **Testing results: [Exceeded insulation design requirements]**
 - Verification of thermal performance [single phase liquid nitrogen -81 °K]
 - Operating current at 31.5 KA
 - Verified integrity of electrical insulation:
 - >10 KV groundwall
 - >5 kV turn to turn

TRC- Observations from Dissection

- **Observations from dissection:**
 - Overall good epoxy impregnation **P**
 - Demonstrated Bag Mold and VPI procedure **P**
 - No change in conductor height- [1st row vs. 10th] **P**
 - Minimal “Keystoning” observed **P**
 - Some dry areas near top clamps due to bag installation [will be corrected] **P**
 - Cladding tight to tee except in upper clamp region [probably due to bag mold- will be corrected] **P**
 - Top two rows are shifted from tee- R&D activities following manufacturing of TRC will address this issue **P**



Dimensional Control & Metrology



- *To ensure stellarator symmetry, the current centroids of all modular coils shall be within $[\pm 0.020 \text{ inch}]$*
- A coordinate measuring machine [CMM] is being used to verify the position of the coil bundle.
- To accommodate any out of tolerance's on the winding forms, it was determined that the coil bundles [centroids] can be repositioned after winding
- Pre-positioned glass tape lacing bands are to control the position of the turns during installation of Groundwrap, chill plates and bag mold.



Modular Coil Manufacturing Estimates



- The present estimates for manufacturing the modular coils are based upon the lessons learned from the R&D activities including the manufacturing of the Twisted Racetrack coil.
- Design changes, additional manufacturing tasks plus real time fabrication times are included in the new estimates.
- The next series of slides identifies the tasks required to manufacture the modular coils.
- The durations are identified in shifts with manpower and hours included per task.
 - Tasks and hours in **blue** identify new tasks added since last review
 - Tasks in **red** identify changes with most significant impact
 - Totals in bold are for the 1st. coil operations. Coils 2-18 are identified in italics

Engineering and Oversight

TASK DESCRIPTION	EAEM	EAEM	EMSM
	Chrz.	Raft.	Meighan
	hours	hours	hours
Engineering and Oversight	70%	40%	70%
LOE FY06 (October thru September)	1208	690	1208
LOE FY07 (October thru September)	1208	690	1208
LOE FY08 (October thru December)	324	175	0

-Field oversight will be provided throughout the manufacturing operation

-Second shift oversight- coverage will be provided through half of 2nd. Shift, ton call for balance of shift. No additional engineering required.

-Critical 2nd. Shift activities will have full oversight coverage



Modular Coil Casting Preparation



TASK DESCRIPTION	Total Shifts	No. of Tech./Shift	Hrs per Shift	personhrs /coil
Station No. 1- Casting Preparation	25	Total Shifts per Coil		
Drill (4) holes at Poloidal Break for cooling tubes-Total Shifts (1)	1	2	8	16
Electrical test poloidal break-Total Shifts (1)	1	1	8	8
Position & mount casting to support ring- Total Shifts (5)				
1st. of each type coil	5	4	10	200
Remaining coils [2-6 of each type]	3	3	8	72
Install coil in station 1b turning fixture- Total Shifts (1)	1	3	8	24
Weld monuments, stud adapters & lead nuts-Total Shifts (2)	2	2	8	32
Inspect casting -Total Shifts (3)				
[Label, Inspect surfaces, & magnetic permeability]				
Measure casting using metrology equipment				
1st. of each type coil	3	2	8	48
Remaining coils [2-6 of each type]	2	2	8	32
Install studs for winding clamps- Total Shifts (3)				
Position and weld studs for winding clamps	3	3	8	72
Clean casting- Total Shifts (1)				
Clean casting using acceptable solvents	1	2	8	16
Inspect and clean all threaded holes				
Fitup Lead blocks and terminals [Remove lead blocks]- Total Shifts (2)	2	2	8	32
Install inner cladding plates- Total Shifts (6)				
Position and secure copper cladding plates	6	4	8	192

Modular Coil Winding Operations



TASK DESCRIPTION	Total Shifts	No. of Tech./Shift	Hrs per Shift	personhrs /coil
Coil Winding Station 2 and 4	61	Total shifts per coil		
Prepare coil for winding -Total Shifts (17)				
Install coil in turning fixture	1	3	8	24
Install/set winding clamps sides A & B	3	2.5	8	60
Position inner groundwrap insulation onto winding form (sides A & B)	9	2.5	10	225
Position lacing strips sides A & B [Metrology require't]	2	2.5	10	50
Dimensional measure surface [First coil] [Metrology require't]	2	2	10	40
Dimensional measure surface [Coils 2-18] [Metrology require't]	1	2	10	20
Wind Side "A" -Total Shifts (15)				
Position & secure 1st. coil lead set [inc. brazing]	2	2.5	10	50
Type C-Wind layer #1 - [10] turns of conductors (4-in-hand)	11	2.5	10	275
Types A & B-Wind layer #1 - [11] turns of conductors(4-in-hand)	12	2.5	10	300
Position & secure 2nd. coil lead set [inc. brazing]	2	2.5	10	50
Prepare station for Side "B" -Total Shifts (1)				
Reposition coil from side A to side B	1	3	8	24
Wind Side "B" -Total Shifts (15)				
Position & secure 1st. coil lead set [inc. brazing]	2	2.5	8	40
Type C-Wind layer #1 - [10] turns of conductors (4-in-hand)	11	2.5	10	275
Types A & B-Wind layer #1 - [11] turns of conductors casting (4-in-hand)	12	2.5	10	300
Position & secure 2nd. coil lead set [inc. brazing]	2	2.5	10	50
Final coil winding activities -Total Shifts (13)				
Reposition coil bundle [sides A & B] [Metrology require't]	4	2	10	80
Secure Lacing [Metrology require't]	2	2	10	40
Remeasure after lacing is secured [Metrology require't]	1	2	8	16
Complete groundwrap installation	6	2.5	10	150

Mold Installation and VPI Activities



TASK DESCRIPTION	Total Shifts	No. of Tech./Shift	Hrs per Shift	personhrs /coil
Final coil prep & Mold Application (Station 2 & 4)	23	Total shifts per coil		
Install outer Diagnostic loops -Total Shifts (2)	2	2	8	32
Install chill plates & Tubing -Total Shifts (12)	12	2.5	10	300
Perform pre-VPI elect. & press. tests-Total Shifts (1)				
Pressure test cryo lines& perform prelim. [pre-vpi] electrical tests	1	2	8	16
Install bag mold around modular coil- Total Shifts (8)				
Install silicone bag & sprues	4	2.5	8	80
Vacuum pumpdown & leak repair	2	2.5	8	40
Install epoxy shell	2	2.5	8	40
VPI Activities (Station 5)	16	Total Shifts per Coil		
Transfer modular coil to Autoclave -Total Shifts (1)	1	3	8	24
Prepare modular coil for VPI -Total Shifts (3)				
(Connect fill lines, manifolds, hookup thermocouples & leak check)	3	3	8	72
VPI modular coil -Total Shifts (12)				
Vacuum pumpdown & preheat mold and autoclave	2	3	8	48
Epoxy fill coil	2	3	8	48
Temperature rampup and Cure	3	2	8	48
Temperature rampup and Post cure	2	2	8	32
Temperature rampdown	1	1	8	8
Cleanup & ready autoclave	2	3	8	48

Post VPI Activities

TASK DESCRIPTION	Total Shifts	No. of Tech./Shift	Hrs per Shift	personhrs /coil
Post VPI Activities (Station 1)	9	Total Shifts per Coil		
Transfer MC from Autoclave to Station #1- Total Shifts (1)	1	3	8	24
Remove sprues & structural shell & studs- Total Shifts	2	2	8	32
Finalize coil & install final clamps (40-50 clamps/per coil)-Total Shifts (3)	3	2	8	48
Perform (RT) electrical & Pressure Tests-Total Shifts (1)	1	2	8	16
Remove coil from ring assembly- Total shifts (2)	2	2	8	32

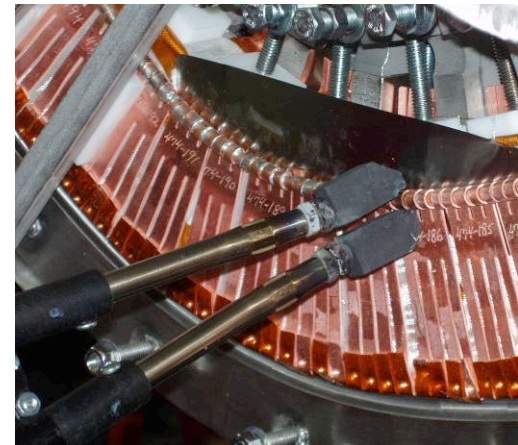
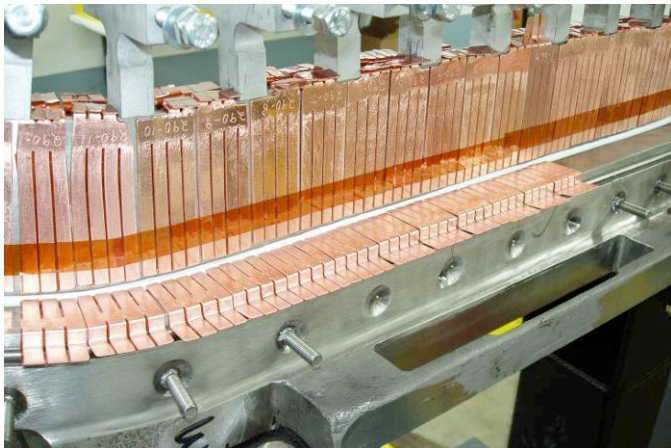


FY06 Modular Coil Manufacturing Plans- Complete Winding (7) and VPI (6)

Cost and Schedule Impacts



- Three tasks have been identified with the most cost and schedule impact to the manufacturing of the modular coils. These are all labor intensive activities.
 - Installation of inner cladding and outer chill plates [492 person hours/coil vs. 196 person hours]
 - Installation of groundwrap insulation [375 person hours/coil vs. 96 person hours]
 - Additional Metrology and measurement requirements [226 person hours/coil] NEW



Risk Mitigation- Modular Coils



- **A great number of technical issues associated with manufacturing the modular coils have been addressed**
 - **Tolerance control** [Positioning of coil centroid]
 - **Cooling plates** [cladding & chill plates] -though time consuming to install, low technical risk
 - **Winding method** [equipment, clamps and procedures]
 - **“Whisker Detector”**- designed for detecting copper strands that could cause T/T shorts
 - **Mold design** [Bag mold has designed and tested]
 - **Vacuum Pressure Impregnation (VPI)**- epoxy system tested
 - **Lead brazing techniques developed**
- **The greatest risk is not due to technical issues, but instead due to manufacturing times. Continual efforts will be made to reduce/streamline these times**

Toroidal Field Coils- Make vs. Buy



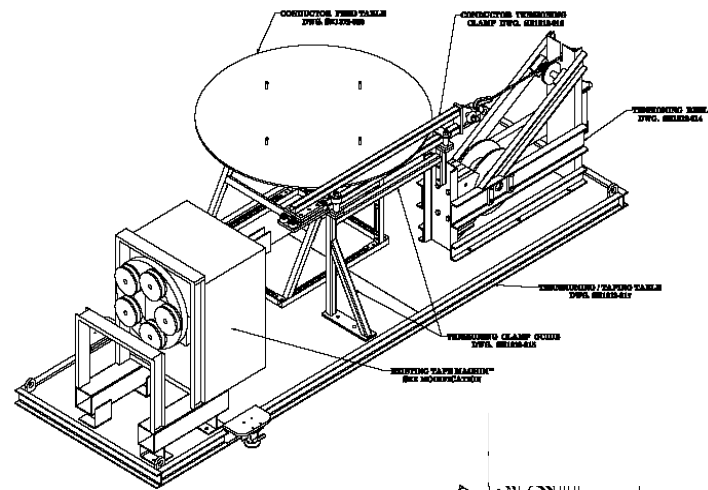
- The decision to manufacture the TF coils at PPPL was made based upon a “Make vs. Buy” study performed by the NCSX Project.
 - No cost difference when oversight costs, G&A plus vendor profit estimates were included in estimates
 - It was felt that higher quality was more achievable if fabricated in-house based on previous experiences with domestic coil vendors
 - Resources were optimized during gaps in modular coil VPI schedule.
 - Shared engineering oversight with the modular coil program



TF Coil Manufacturing Status



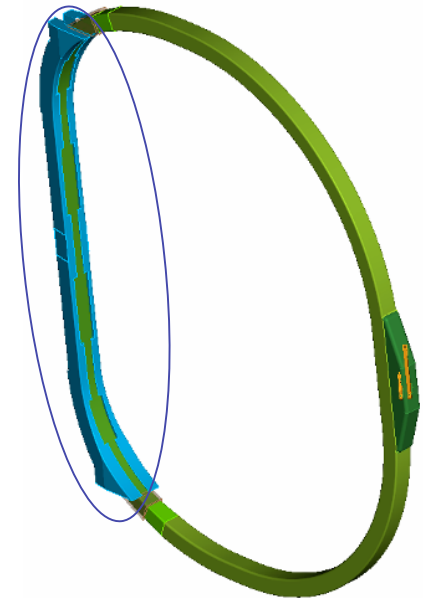
- All of the tooling for manufacturing the TF coils has been designed with the exception of the molds [50% complete]
- Majority of the tooling presently being manufactured in PPPL facilities
- The winding facility [clean room] has been completed
- Winding table has been modified and installed
- Manufacturing, Inspection, Test & QA Plan [MIT] has been approved
- Procedures and safety reviews need to be completed



TF Coil Status-Materials



- The extruded copper conductor has been procured
- G-11 lead fillers, insulation and copper plate for coil lead spurs (oxygen free silver bearing) has been procured
- Epoxy [CTD-101k]- Using same epoxy system as being used for Modular Coils [Contract already in place]
- **TF Wedge castings-** Only (1) response received. Quotation exceeded budget estimate
 - Investigating changes in tolerance and materials
 - Castings are not required until late FY06



TF Coil Wind & Ground Wrap



TASK DESCRIPTION	No. of Shifts	Hrs per Shift	No. Tech. per Shift	Person hrs per coil	No. of Shifts	Hrs per Shift	No. Tech. per Shift	Person hrs per coil
Station No. 4- Coil Winding	23	Total shifts 1st. coil			13	Total (avg) shifts coils 2 thru 18		
Prepare winding station	3			72	1			16
Install and prepare mandral	3	8	3	72	1	1	2	16
Wind TF coil	20			256	12			200
Position starting conductor & wind layer #1	4	8	2	64	1	1	2	16
Braze lead spur	2	8	2	32	1	1	2	16
Position 2nd. Conductor and braze layer 1 to 2	4	8	2	64	1	1	2	16
Wind layer #2 -	2	8	2	32	1	1	2	16
Position 3rd. Conductor & wind layer 3	1	8	2	16	1	1	2	16
Perform locking braze layers 2 to 3	1	8	2	16	1	1	2	16
Position 4nd. Conductor and braze layer 3 to 4	1	8	2	16	1	1	2	16
Wind layer #4	1	8	2	16	1	1	2	16
Braze lead spur	1	8	2	16	1	1	2	16
Fitup & modify fillers	2	8	2	32	2	1	2	32
Secure and transfer TF coil to station #3	1	8	3	24	1	1	3	24
Station No. 4b- Grd wrap & Mold	8	Total shifts 1st. coil			5	Total shifts coils 2 thru 18		
Ground wrap TF coil	4				3			
	4	8	2	64	3	8	2	48
Install TF coil in mold	4				2			
	4	8	3	96	2	8	2	32

A learning curve is built into the manufacturing estimates for the TF coils.

TF VPI/Test Activity

TASK DESCRIPTION	No. of Shifts	Hrs per Shift	No. Tech. per Shift	Person hrs per coil	No. of Items
Station No. 5- VPI TF Coil	16	Total shifts per coil			
Transfer TF coils to Autoclave	1				10
	1	8	4	32	
Prepare TF coil for VPI	2				
Connect fill lines, manifolds, hookup thermocouples & leak check	2	8	2	32	18
VPI TF coil	13				
Vacuum pumpdown mold and autoclave	1	8	3	24	10
Epoxy fill coil	2	8	3	48	10
Temperature rampup and Cure	3	8	2	48	10
[parallel activity] Station cleanup during cure	1	8	3	24	10
Temperature rampup and Post cure	2	8	1	16	10
Temperature rampdown	1	8	1	8	10
Cleanup & ready autoclave	2	8	2	32	10
Remove TF coil from mold/clean mold	2				18
	2	8	3	48	
Station No. 6- Electrical Test Station	2	Total shifts per coil			
Perform electrical & Pressure Tests	1				
Warm tests (room temperature) only	1	8	2	16	18

With the exception of the first (2) coils, the TF coils will be VPI'd in pairs which will help reduce the processing times

TF Coil Manufacturing Schedule



- The NCSX baseline schedule identifies the manufacturing of TF coils to begin by March 2006.
- The FY06 Project plan calls for the complete winding and VPI of only (1) TF coil- this could be improved if additional funding were available
- All of the Toroidal Field coils are scheduled to be completed by November 2007

Risk Mitigation- TF Coils



- **In-house** fabrication minimizes schedule and Quality Control concerns
- **Oversight**- Engineering supervision will be shared with Modular coil fabrication team
- **“Learning curve”**-Repetitive operations [18] times can be used to minimize manufacturing times
- Team will continue to make improvements on manufacturing processes

Safety is Integrated in All Aspects

- **Safety** has been integrated in all aspects of the coil manufacturing activities
- **Readiness:**
 - Modular coil manufacturing facility has successfully completed a safety review by the PPPL Activities Certification Committee (ACC)
 - Personnel have been trained
- **Communication:**
 - Shift turnover meetings are used to discuss work and safety related items associated with the manufacturing operations.
 - Station logs are used to document daily activities, issues, etc.
- **Safety Performance:**
 - There have been no time loss accidents associated with the Modular coil R&D or production activities

In Summary....



- The Modular coil winding activities have begun with the arrival of the 1st.modular coil winding form [C1]
- The manufacturing times, to date, associated with the C1 have been equal to or less than are identified in the present plan
- The manufacturing plans and tooling for the TF coils are nearing completion, with production to begin in March 2006.
- NCSX has a well trained qualified manufacturing team
- Ramp-up of staffing for full production capability is in process
- Safety will continue to be in the forefront of all planning and field activities
- The coil team will continue to strive for improvements in manufacturing processes that would result in improved schedule and reduction in costs
- ***The NCSX coil team is ready to begin the manufacturing of the Modular Coils and by March, the Toroidal Field Coils!!***