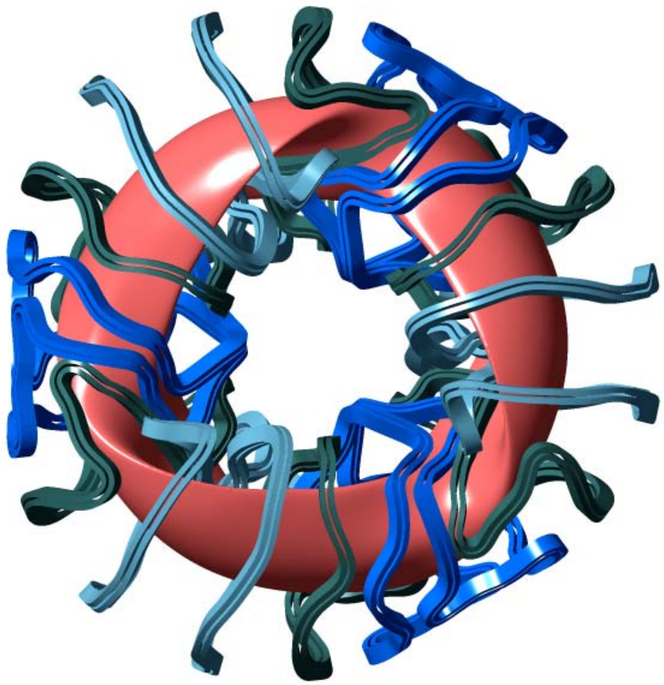
The National Compact Stellarator Experiment: Overview

Don Rej

NCSX Project Manager

NCSX Mission and Requirements

NCSX
National Compact Stellarator Experiment



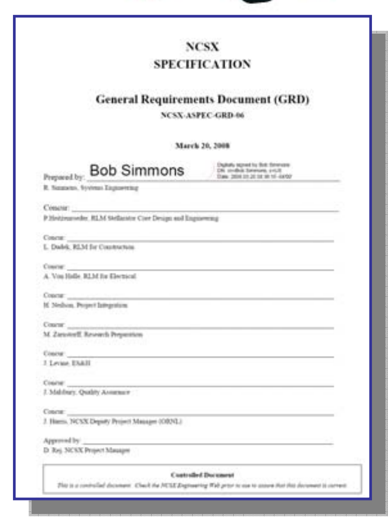
Mission: Acquire the physics data needed to assess the attractiveness of compact stellarators; advance understanding of 3D fusion science.

Understand…

- Plasma confinement and stability in an optimized 3D quasi-axisymmetric magnetic field
- Plasma pressure limits and limiting mechanisms
- Stabilization of disruptions
- 3D power and particle exhaust methods

Demonstrate: High-β, disruption-free operation, good confinement, compatible with steady state.

NCSX Design and General Requirements (GRD) were determined by the needs of this mission and understanding of previous experiments. →



NCSX
SPECIFICATION

General Requirements Document (GRD)
NCSX-ASPEC-GRD-06

March 20, 2008

Prepared by: Bob Simmons
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Concur:
P. Heitzenroeder, RLM Stellarator Core Design and Engineering

Concur:
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Concur:
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Concur:
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Concur:
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Concur:
J. Levine, ES&H

Concur:
J. Malsbury, Quality Assurance

Concur:
J. Harris, NCSX Deputy Project Manager (ORNL)

Approved by:
D. Rej, NCSX Project Manager

Controlled Document
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NCSX in the US Compact Stellarator Program

NCSX National Compact Stellarator Experiment

- **Integrated Program Elements:**

  NCSX: integrated high-pressure, low collisionality, quasi-axial symmetry

  HSX (Wisc.): 1st test of quasi-symmetry in 3D (quasi-helical)

  CTH (Auburn) : stability with ohmic current drive

  QPS (ORNL): very compact, quasi-poloidal symmetry

  Theory & Modeling

  ARIES Reactor Studies

  International Collaborations, via IEA agreement

- **NCSX Research guided by an International Program Advisory Committee**
  - **Has provided advice and perspective starting before project approval**
- **NCSX Research will be conducted by a National/International collaboration**
  - **First research forum held in Dec. 2006 with prospective collaborators**
  - **Collaboration discussions actively proceeding**

1 Fusion Energy 2002 IAEA-CN-94/IC-1

Physics Considerations in the Design of NCSX*

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Abstract. Compact stellarators have the potential to make steady-state, disruption-free magnetic fusion systems with β ~ 5% and relatively low aspect ratio (R/⟨a⟩ < 4.5) compared to most drift-optimized stellarators. Magnetic quasi-symmetry can be used to reduce orbit losses. The National Compact Stellarator Experiment (NCSX) is

PHYSICS OF PLASMAS 12, 102512 (2005)

Comparison of microinstability properties for stellarator magnetic geometries

G. Rewoldt,[a)] L.-P. Ku, and W. M. Tang
Princeton Plasma Physics Laboratory, Princeton University, Princeton, New Jersey 08543-0451

(Received 15 June 2005; accepted 6 September 2005; published online 17 October 2005)

The microinstability properties of nine distinct magnetic geometries corresponding to different operating and planned stellarators with differing symmetry properties are compared. Specifically, the kinetic stability properties (linear growth rates and real frequencies) of toroidal microinstabilities (driven by ion temperature gradients and trapped-electron dynamics) are compared, as parameters are varied. The familiar ballooning representation is used to enable efficient treatment of the spatial variations along the equilibrium magnetic field lines. These studies provide useful insights for understanding the differences in the relative strengths of the instabilities caused by the differing localizations of good and bad magnetic curvature and of the presence of trapped particles. The associated differences in growth rates due to magnetic geometry are large for small values of the temperature gradient parameter $\eta \equiv d \ln T / d \ln n$, whereas for large values of η, the mode is strongly unstable for all of the different magnetic geometries. © 2005 American Institute of Physics. [DOI: 10.1063/1.2089247]

I. INTRODUCTION

eighth case (NCSX-TOK) is the same as the NCSX-SYM case, except that the parallel current profile has been

FUSION SCIENCE AND TECHNOLOGY VOL. 51 FEB. 2007

ASSESSMENT OF TRANSPORT IN NCSX

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Received February 16, 2006
Accepted for Publication March 30, 2006

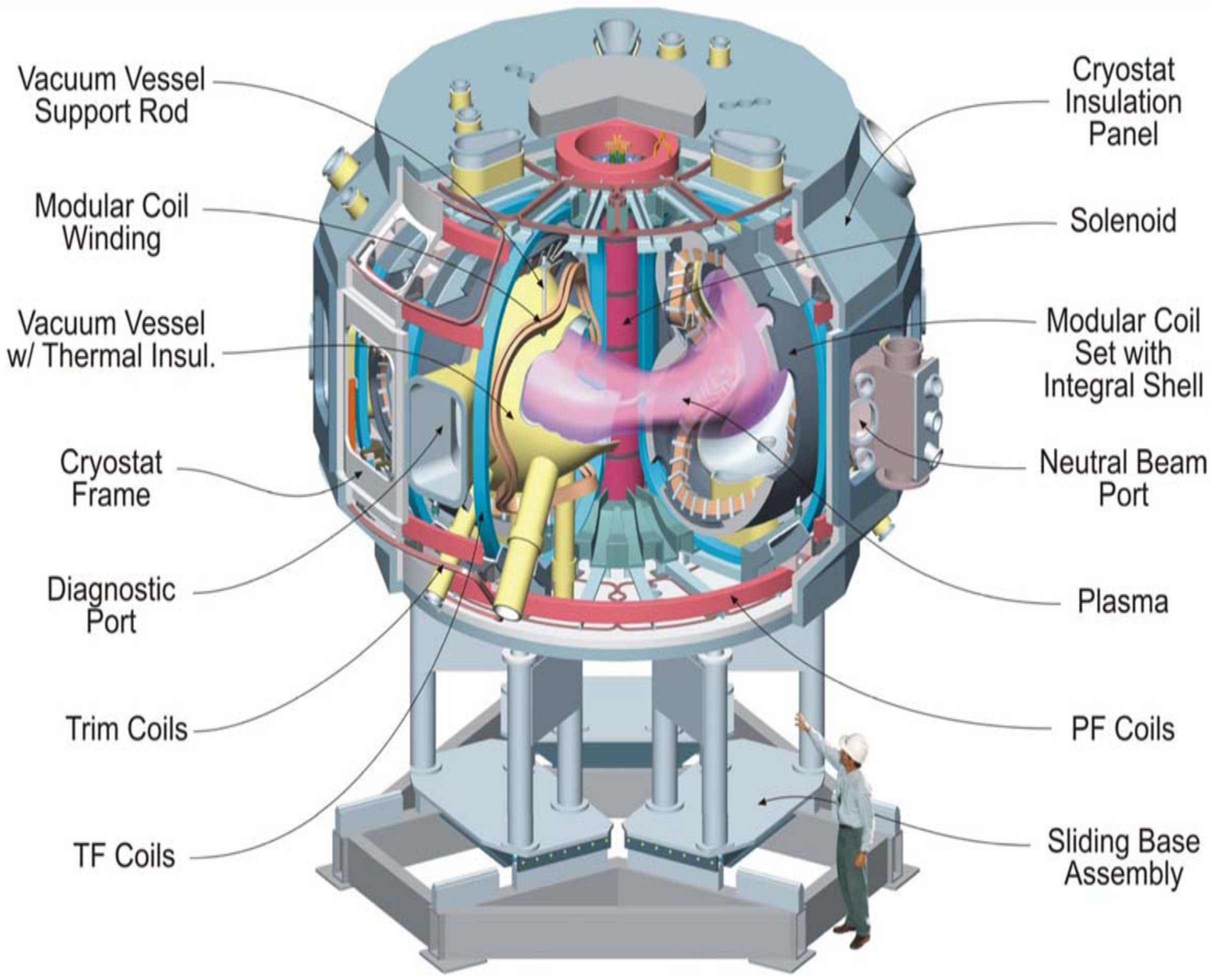
We explore whether the energy confinement and planned heating in the National Compact Stellarator Experiment (NCSX) are sufficient to test magnetohydro-

I. INTRODUCTION

There are three major transport questions that impact the National Compact Stellarator Experiment (NCSX) design.[1] First, is the energy confinement (with the avail-

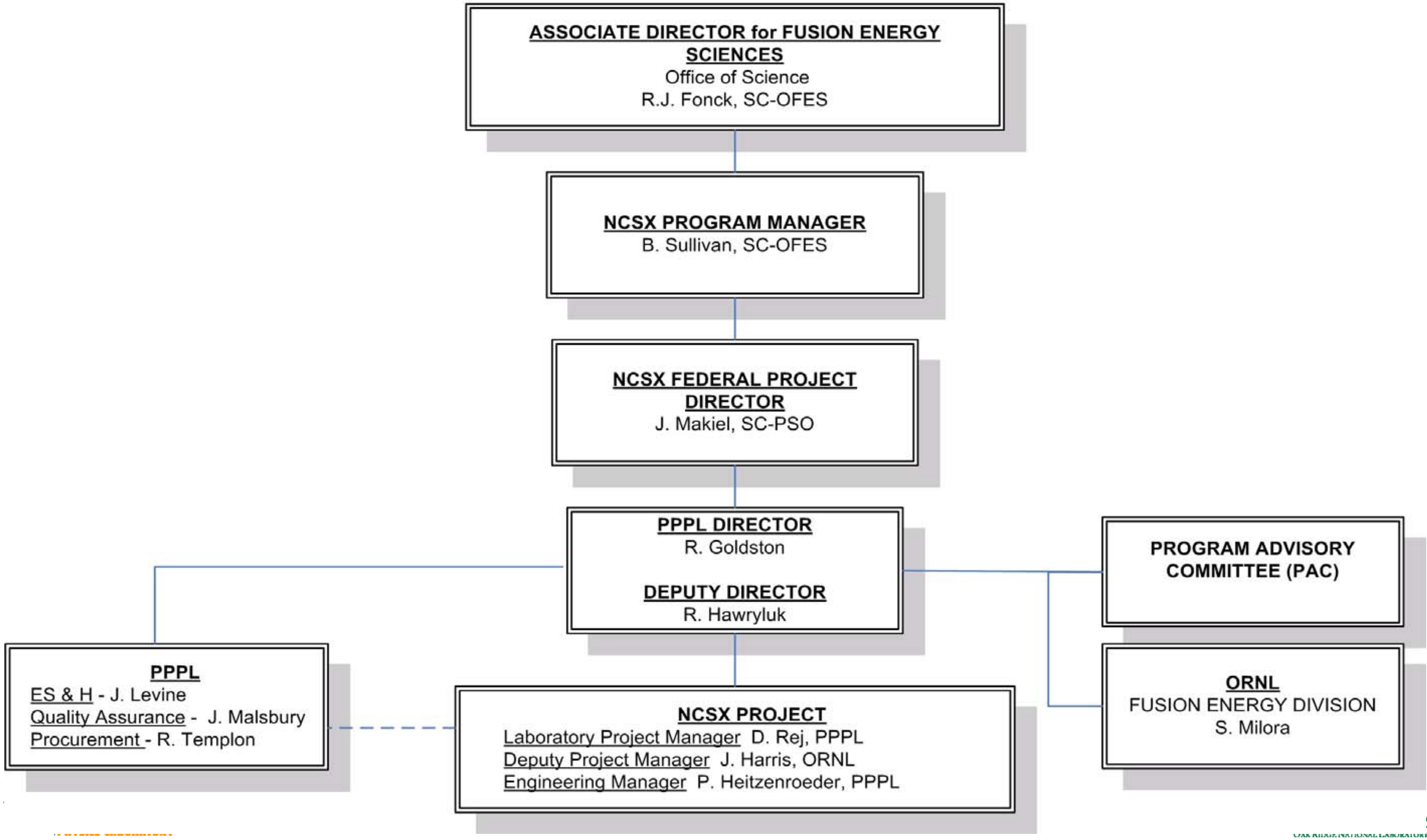
The National Compact Stellarator Experiment

- Construction Major Item of Equipment
  - CD-0: May 01
  - CD-1: Nov 02
  - CD-2: Feb 04
  - CD-3: Sep 04
- CD-4 scope definition, defined in 2005 baseline, will be met (Neilson)
  - First Plasma
  - Coils & Power Supply Performance
  - Magnet System Rating & Accuracy
  - Vacuum Vessel System Rating, Pressure & Pumping
  - Controls
  - Neutral Beam Preps
- Upgrades planned to extend performance



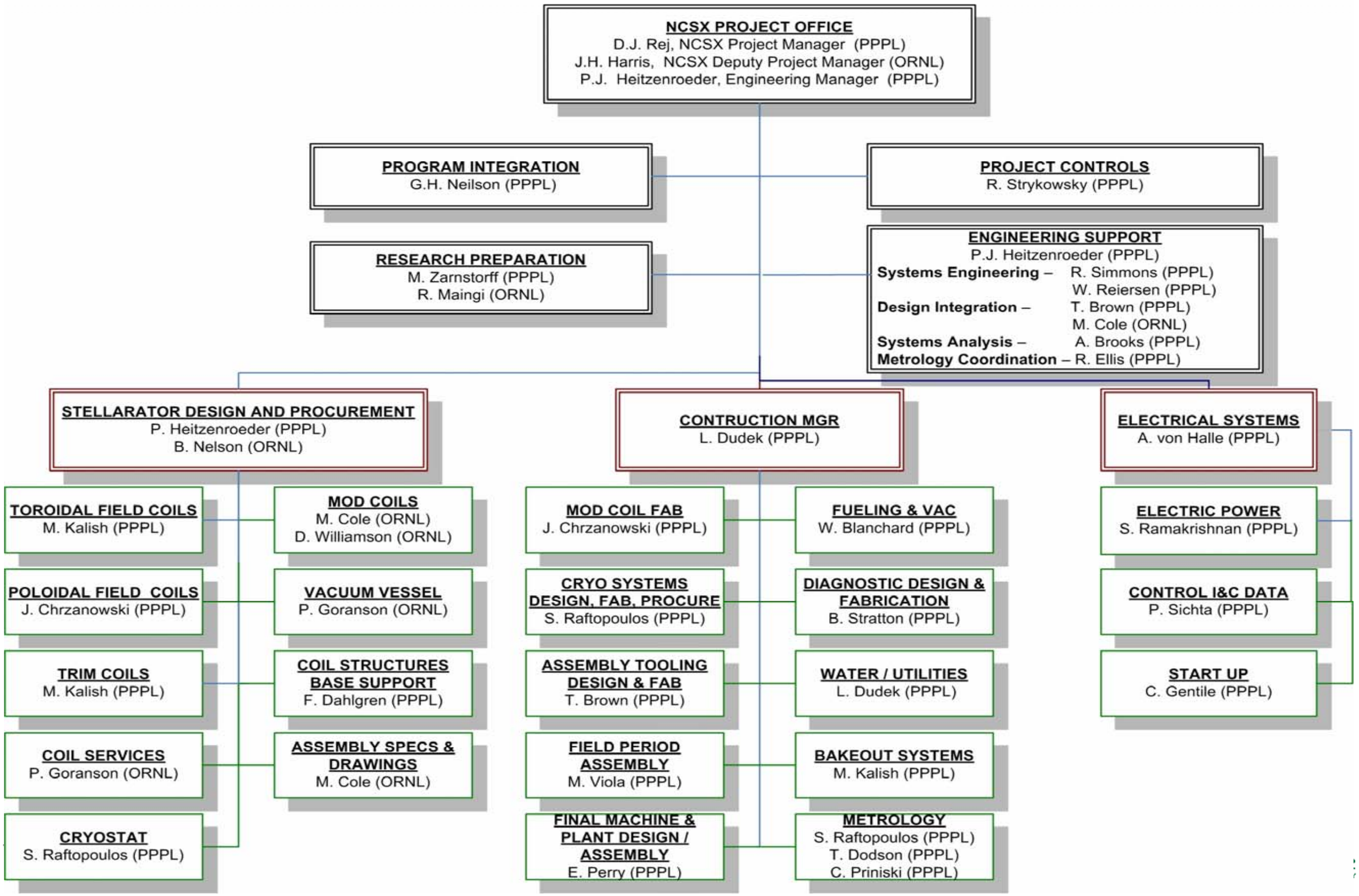
NCSX National Organization

March 2008



NCSX Project

April 2008



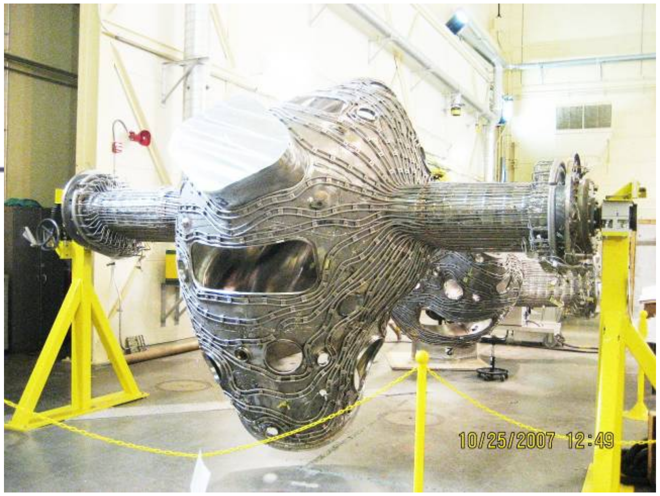
Project Status

- Project has costed $76.4M
  - R&D is 98% complete
  - Design is 68% complete
  - Procurements are 66% complete
  - Fabrication & Assembly is 42%
  - Overall project is 55% complete
- ES&H performance is excellent
  - 429,000 hours without an away from work injury (zero for project to date)
    - Project recipient of NJ Commissioner of Labor & Workforce Development Award for working 3 consecutive years without away-from-work lost time injury/illness case
    - 1 Total Recordable Incident
    - 0 Days Away/Restricted Work/Job Transfer (DART) Incidents

NCSX Construction Progress: Design & Manufacturing

NCSX
National Compact Stellarator Experiment

- Vacuum Vessel Sub-Assemblies & Modular Coil Winding Forms complete
  - Vacuum vessel sector component installation (magnetic loops, heating/cooling hoses, heater tapes, thermocouples) completed except for final tests
- Modular coil production nearing completion
  - 16 (of 18) coils completed
  - Remaining coil fabrication underway and will be completed in FY08
- Toroidal field coils fabrication
  - 10 (of 18) coils completed
  - Remaining coils in production and to be delivered before Nov 08
- Modular coil field period assembly underway



More from Heitzenroeder & Dudek

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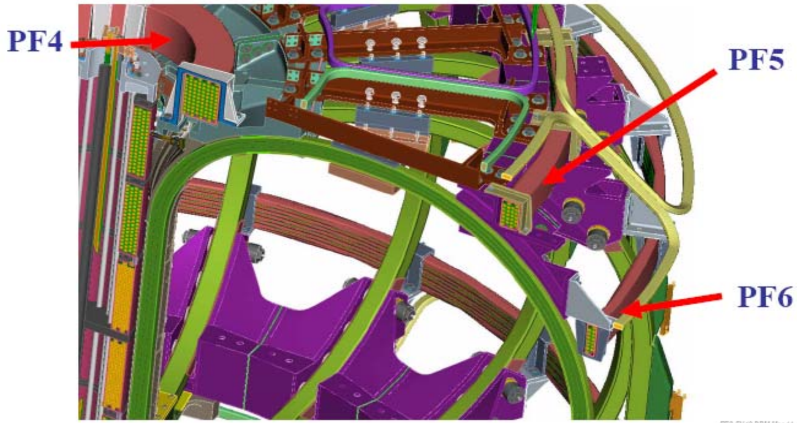
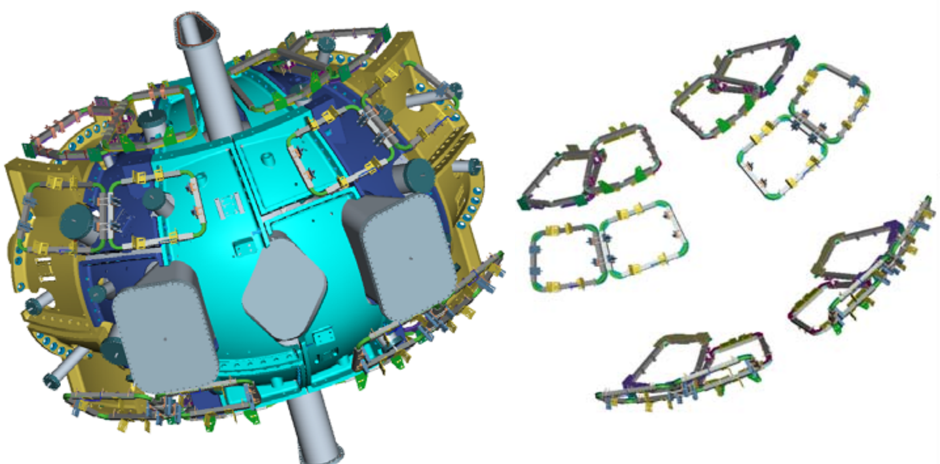
Substantial Design Progress Occurring in FY08

NCSX National Compact Stellarator Experiment



Poloidal Field Coils



Trim Coils

WBS	Scope	Job Mgr.	CDR	PDR	FDR	Free Float (days)	Start fab. / Award
NCSX Design Status Summary 4/3/08							
Inner Core (Stellarator Core out to MC Shell & VV port flanges)							
12	Vacuum Vessel	Goranson					
14	Modular Coil Assemblies	Williamson					
14	MC AA, AB, BC Interface	Williamson / Cole				0	
14	MC CC Interface	Williamson / Cole				0	
18	FPA Tooling:						
18	Station 3 stands and lift fixtures	Brown				147	5/29/2008
18	Station 3 module alignment system	Brown				147	5/29/2008
82	Assembly Sequence Plan Maturity		Assessmen	Envisioned future changes			
82	Station 2	Brown	99%	probably none			
82	Station 3	Brown	90%	module alignment system			
Outer Core (Stellarator Core Beyond MC Shell & VV port flanges)							
12	NB Transition Ducts	Goranson		9/30/2008	1/12/2009	318	3/9/2009
13	TF Coils	Kalish					
13	PF Coils	Chrzanowski				303	5/30/2008
13	Trim Coils	Kalish			4/28/2008	218	6/10/2008
15	TF/PF Coil Structures	Dahlgren			6/16/2008	188	9/2/2008
15	Central Solenoid Structure	Dahlgren				188	9/2/2008
16	LN2 Manifolds	Goranson		6/3/2008	9/5/2008	197	10/10/2008
16	Electrical Leads	Goranson		8/22/2008	3/27/2009	337	9/30/2009
17	Base Structure	Dahlgren			4/30/2008	147	9/30/2008
17	Cryostat	Raftopoulos	10/1/2008	7/6/2009	2/12/2010	115	8/17/2010
18	Assembly Tooling:						
18	Station 5	Brown			4/21/2008	200	8/14/2008
18	Station 6 module supports ("sleds"	Brown		6/10/2008	7/8/2008	255	9/30/2008
18	Station 6 spool piece support	Brown		6/10/2008	8/5/2008	439	9/30/2008
82	Assembly Sequence Plan Maturity		Assessmen	Envisioned future changes			
82	Station 5	Brown	90%	coil support details, cryostat supports, lifting features			
82	Station 6	Brown	75%	cryostat details, carts-base integration,			
Ancillary Systems (Facility Beyond Stellarator Core)							
12	Heater control sys	Gernhardt		5/1/2009	8/4/2009	107	8/31/2010
2	Fueling	Blanchard		4/29/2009	6/29/2009	318	1/13/2010
2	Vacuum Pumping System	Blanchard		2/6/2009	6/2/2009	361	2/12/2010
3	Diagnostics:						
3	VV spacer flux loops	Stratton		N/A	10/2/2008	426	10/20/2008
3	Visible camera system	Stratton		10/1/2009	11/25/2009	309	3/10/2010
3	Electron beam mapping sys.	Stratton		4/27/2009	6/24/2009	372	10/1/2010
4	Coil Protection System	Ramakrishnan		9/22/2008			
4	Power Systems	Ramakrishnan		9/22/2008	10/27/2009	305	FY-10
5	Central I&C	Sichta		FY-09	FY-10		FY-10
62	Cryogenic Systems (LN2)	Raftopoulos	12/23/2008	10/27/2009	3/12/2010	132	3/29/2010
62	Cryogenic Systems (GN2/Cryostat)	Raftopoulos	12/23/2008	7/6/2009	2/12/2010	115	6/1/2010
63	Utility Systems	Dudek		10/29/2010	11/15/2010	134	11/16/2010
64	VV heating and cooling system	Kalish		2/4/2010	5/14/2010	221	10/1/2010
85	Startup	Gentile	Starting safety docs. &				

Legend

- (black) Completed prior to FY-08
- (green) Completed in FY-08
- xx/xx/xx (yellow) Baseline early finish in FY08
- xx/xx/xx Baseline early finish beyond FY08

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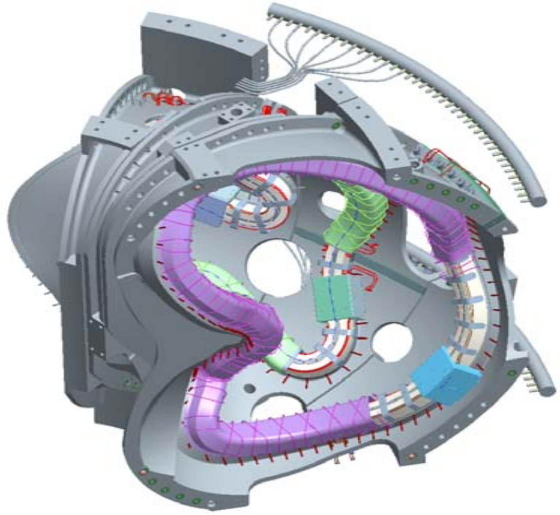
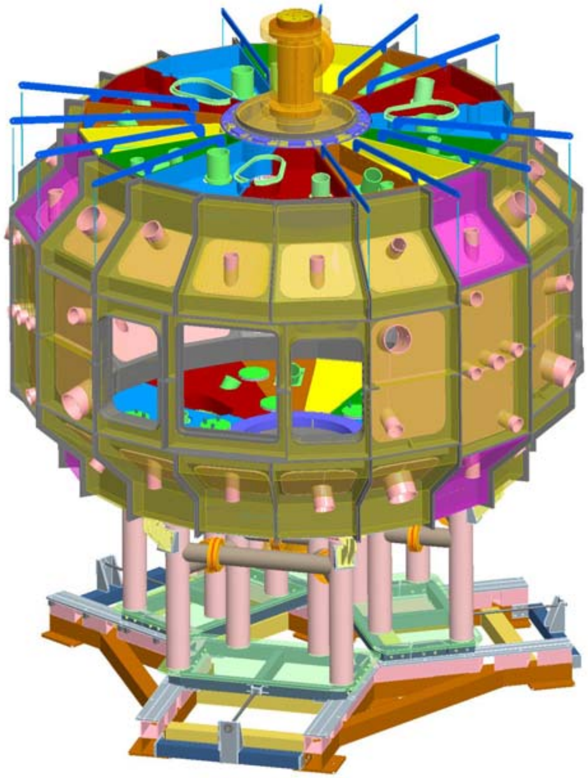
More from Heitzenroeder & Kalish

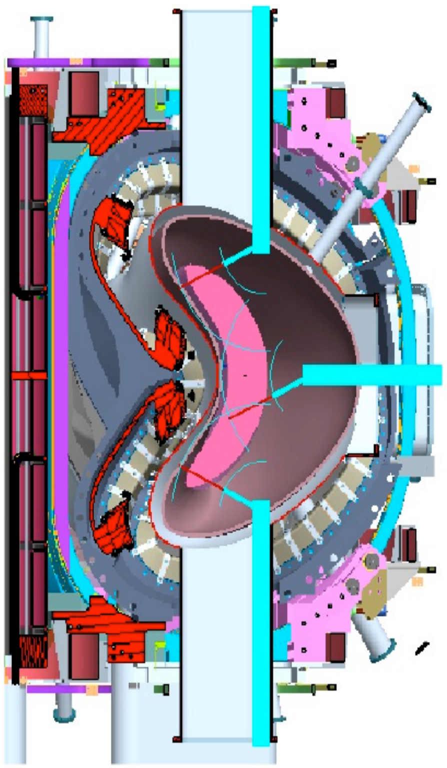
Stellarator Core Design Continues Into FY09



Coil Services



Cryostat



Diagnostics

Electrical Power System

More from Goranson, Raftopoulos, Ramakrishnan, & Stratton

Draft Baseline Change Proposal (BCP) Submitted to DOE in March 2008

NCSX National Compact Stellarator Experiment

- In FY07, Project determined that it could not meet the approved FY05 baseline and submitted a revised cost and schedule estimate
- Series of reviews (cost & schedule, scientific mission, engineering) held in Aug-Oct '07 to inform DOE decisions on the future of project
- In Jan '08, Department directed Project to submit a baseline change proposal (BCP) for decision this Summer
- Draft BCP prepared, submitted, & undergoing a series of reviews:
  - Princeton University External Independent Review - Mar 13-14
  - Office of Science Review - April 8-10
  - OECM External Independent Review - May 20-22

Proposed Baseline Changes

NCSX National Compact Stellarator Experiment

Item	Current Baseline	Proposed Baseline	Comment
Cost ($M)			
Cost through Jan. 31, 2008	76.4	76.4	
ETC from Feb. 1, 2008 (w/o contingency)	16.0	61.8	
EAC (w/o contingency)	92.4	138.2	
Contingency free balance at Feb. 1, 2008	–	22.4	36% of ETC
Total Estimated Cost (TEC)	**92.4**	**160.6**	**$68.2M increase**
Pre-CD1 planning & conceptual design	9.6	9.6	
Total Project Cost (TPC)	**102.0**	**170.2**	
Schedule			
ETC from Feb. 1, 2008 (w/o contingency)	18	48	
Early Finish	Jul. 2009	Jan. 2012	
Contingency (months)	–	19	40% of ETC
Project Completion (CD-4)	**Jul. 2009**	**Aug. 2013**	**49 months delay**

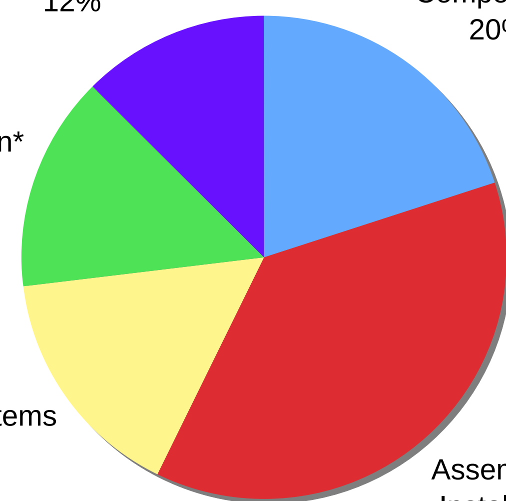
BCP Based on a Comprehensive Bottoms-Up Estimate to Complete (ETC)

NCSX National Compact Stellarator Experiment

Cost in $k	Estimate to Complete from 2/1/08	per cent of to-go work
Stellarator Components	**12,357**	**20%**
12 Vacuum Vessel	1,429	2%
13 Conventional Coils	4,256	7%
14 Modular Coils	2,563	4%
15 Coil Structures	1,528	2%
16 Coil Services	1,085	2%
17 Cryostat & Base Structure	1,497	2%
Assembly & Installation	**22,988**	**37%**
18 Field Period Assembly	14,412	23%
7 Test Cell Prep & Machine Assy.	8,577	14%
Ancillary Systems	**9,864**	**16%**
2 Fueling & Pumping	1,018	2%
3 Diagnostics	811	1%
4 Electrical Power Systems	2,719	4%
5 Central I&C/Data Aq.	2,099	3%
6 Facility Systems	2,423	4%
85 Integrated System Testing	795	1%
Integration*	**8,892**	**14%**
Management*	**7,713**	**12%**
Total Work	**61,815**	**100%**

***in WBS 19, 81, 82, 89**

Distribution of To-Go Work by Work Category



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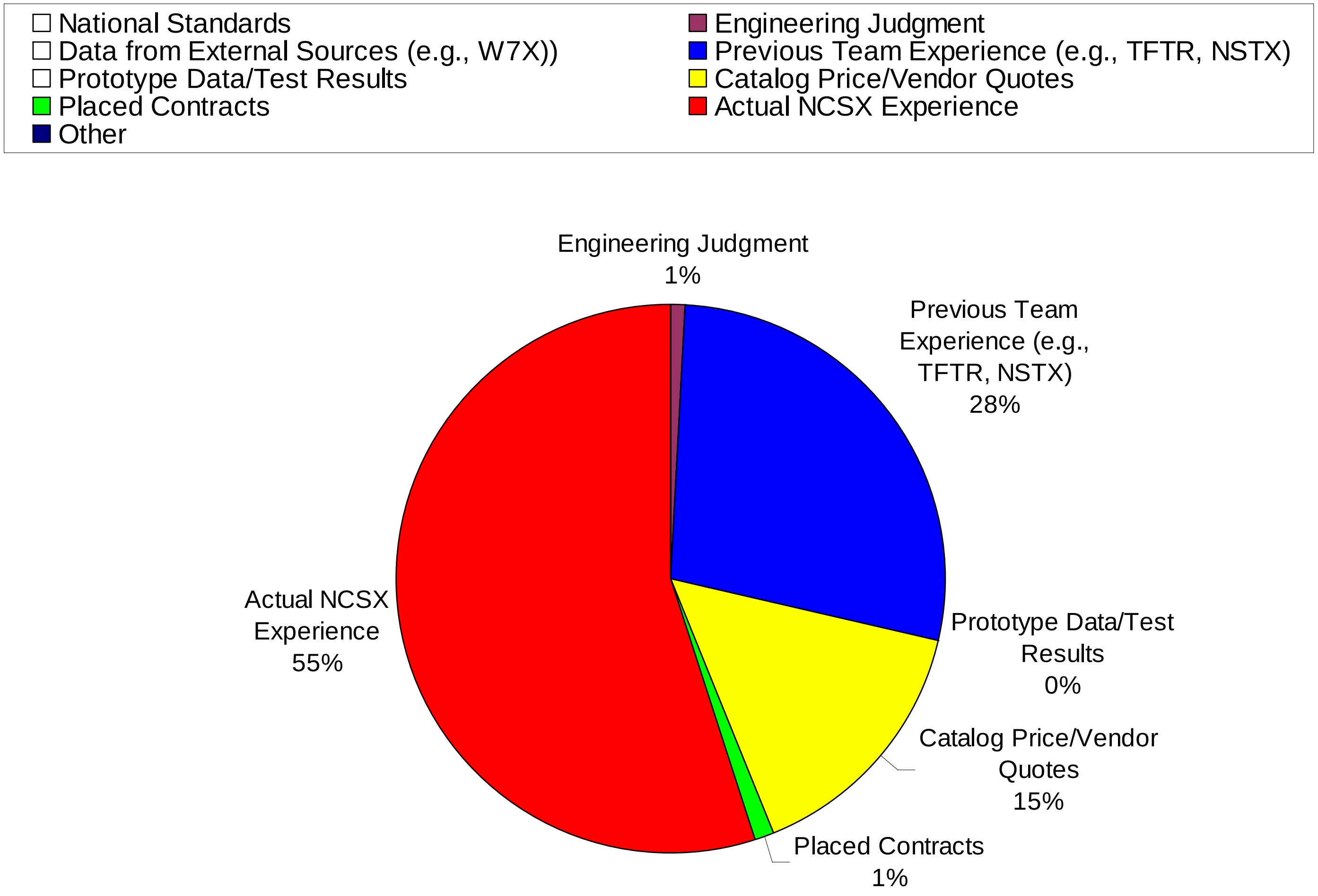
ETC Confidence Much Higher Because of Assembly Design Maturity & Actual Experience

- Modular coil half-period assembly (*i.e.,* three modular coils) design & development completed
  - Key tasks included the design of modular coil interface hardware and the development of procedures for accurate assembly
    - Design & process are consistent with tight tolerance requirements & large forces
    - Construction feasibility review (Nov 07) confirmed Project's technical approach to meeting tolerance requirements
- Assembly of half-period assemblies underway
  - Dimensional tolerances being met, to date

First Modular Field Coil Assembly is Underway

More from Dudek, Viola, Perry, Brown

ETC Basis of Estimate Categorization



Proposed Funding Profile is Consistent with DOE Guidance

NCSX National Compact Stellarator Experiment

FUNDING PROFILE

	2003-07	2008	2009	2010	2011	2012	2013
TOTAL PROGRAM		**16.6**	**20.3**	**20.8**	**38.7**	**52.3**	**52.8**
Research,Ops, & upgrades		**0.7**	**0.7**	**0.7**	**16.6**	**43.7**	**52.8**
MIE Project	**74.2**	**15.9**	**19.6**	**20.1**	**22.1**	**8.6**	**-**
MIE Project by Institution	***72.5***	***15.9***	***19.6***	***20.1***	***22.1***	***8.6***	**-**
(contingency included in PPPL, ORNL lines)		-	***2.7***	***3.0***	***10.1***	***6.5***	
PPPL	*1.6*	*14.1*	*18.1*	*19.1*	*21.2*	*8.3*	-
ORNL	*0.2*	*1.8*	*1.5*	*1.0*	*0.9*	*0.3*	
	carryover						

- Low contingency in FY08-10 offset by increased schedule float in non-critical path activities
- Final BCP to redistribute work between PPPL & ORNL

More from Strykowsky

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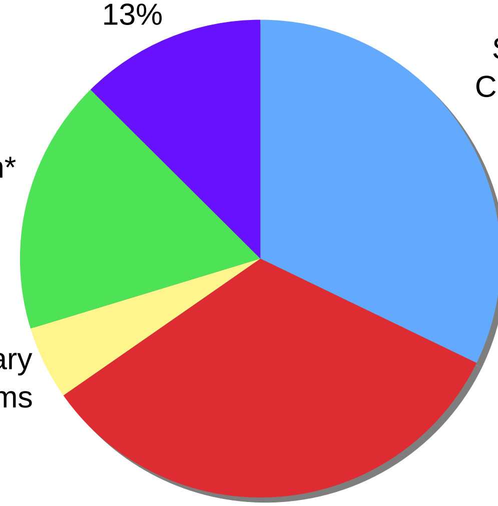
Reconciliation of BCP with the 2005 Baseline: What Happened?

Cost in $k (w/o contingency)	EAC Change from FY05 Baseline	% of To-go Work
Stellarator Components	**18,811**	**32%**
12 Vacuum Vessel	1,641	3%
13 Conventional Coils	3,298	6%
14 Modular Coils	12,639	22%
15 Coil Structures	661	1%
16 Coil Services	(53)	0%
17 Cryostat & Base Structure	626	1%
Assembly & Installation	**19,405**	**33%**
18 Field Period Assembly	14,532	25%
7 Test Cell Prep & Machine Assy.	4,873	8%
Ancillary Systems	**2,855**	**5%**
2 Fueling & Pumping	581	1%
3 Diagnostics	798	1%
4 Electrical Power Systems	32	0%
5 Central I&C/Data Aq.	82	0%
6 Facility Systems	1,756	3%
85 Integrated System Testing	(394)	-1%
Integration*	**10,062**	**17%**
Management*	**7,378**	**13%**
Total Work	**58,512**	**100%**

***in WBS 19, 81, 82, 89**

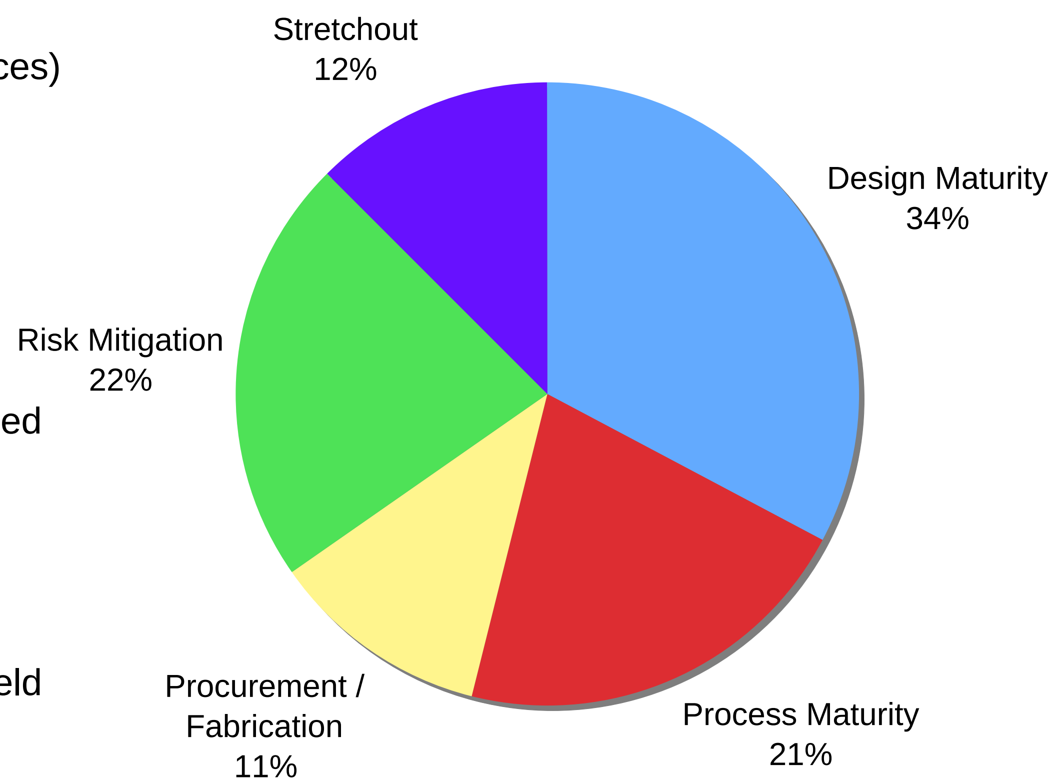
Distribution of Cost Growth by Work Category



Reconciliation of BCP with the 2005 Baseline
Why did it happen?

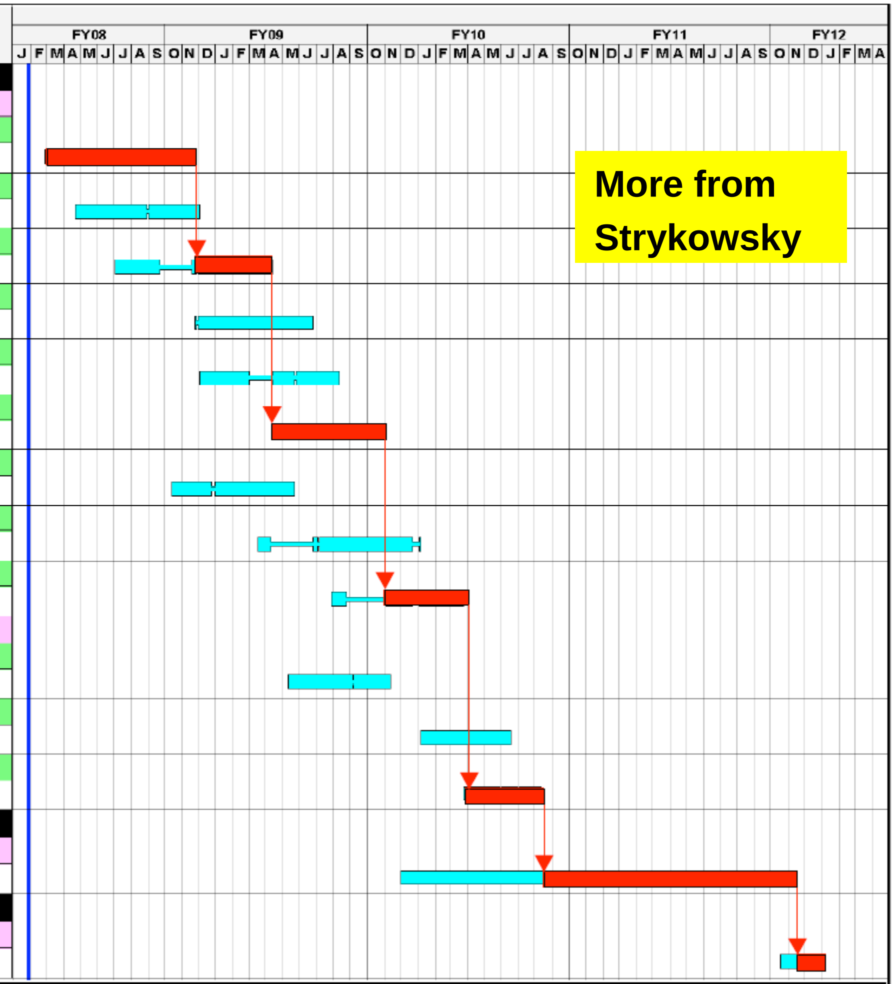
- We know more now
  - Design Maturity
    - Modular coil design (including interfaces) completed
  - Process Maturity
    - Field period assembly underway
  - Procurement & Fabrication
    - Modular coil fabrication nearly complete
    - Toroidal field (TF) coil contract awarded
    - Magnetic flux loops fabricated and installed
- Risk Mitigation Investments
    - Trim coil relocated within TF coils
    - Systems engineering support (e.g., field engineering, analysis, dimensional control) correctly resourced
    - Concerted focus on project management, integration, value engineering
- Critical Path Stretch-out

Causes of Growth in Work Estimates



Critical Path is Driven by Assembly & Testing

Activity ID	MILE-STONE LEVEL	Activity Description	Forecast Start	Forecast Finish
18 - Field Period Assembly				
Job: 1810 - Field Period AssyStation 1,2,3 VIOLA				
+ Station 2 MC subassy A1B1C1				
			27FEB08	18NOV08
+ Station 2 MC subassy A2B2C2				
			24APR08	01DEC08
+ Station 2 MC subassy A3B3C3				
			02JUL08	13APR09
+ Station 2 MC subassy A4B4C4				
			24NOV08	24JUN09
+ Station 2 MC subassy A5B5C5				
			02DEC08	12AUG09
+ Station 2 MC subassy A6B6C6				
			14APR09	03NOV09
+ Station 3-Assemble Mod Coils and VVSA-FP#1				
			15OCT08	22MAY09
+ Station 3-Assemble Mod Coils and VVSA-FP#2				
			17MAR09	05JAN10
+ Station 3-Assemble Mod Coils and VVSA-FP#3				
			30JUL09	24MAR10
Job: 1815 - Field Period Assy -Station 5-VIOLA				
+ Station 5- Final FP Assy -FP#1 (in NCSX TC)				
			12MAY09	12NOV09
+ Station 5- Final FP Assy -FP#2 (in NCSX TC)				
			06JAN10	18JUN10
+ Station 5- Final FP Assy -FP#3 (in NCSX TC)				
			25MAR10	11AUG10
75 - Test Cell and Basement Assembly Operations				
+ Job: 7503 - Machine Assembly (station 6)-PERRY				
			01DEC09	14NOV11
85 - Integrated Systems Testing				
+ Job: 8501 - Integrated Systems Testing-GENTILE				
			18OCT11	05JAN12



RB08

NCSX Project
Critical Path Summary

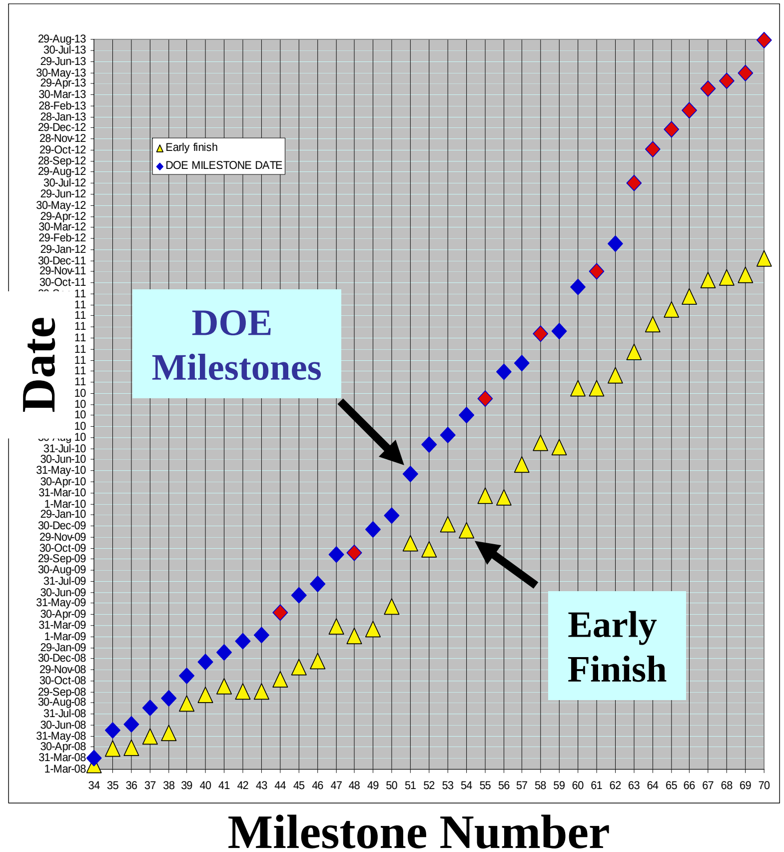
Remaining Project Duration: 48 months (early finish without contingency)

DOE Milestones Support an August 2013 Finish

NCSX
National Compact Stellarator Experiment

Milestone Number	P3 id	Activity description	Early finish	DOE MILESTONE DATE
34	TRIM-101	** Trim Coil PDR **	12-Mar-08	Mar-08
35	TRIM-221	** Trim Coil + Structure FDR **	28-Apr-08	Jun-08
36	1702-525M	Base Support Structure FDR	30-Apr-08	Jul-08
37	141-036	PF Coils Awarded	30-May-08	Aug-08
38	TRIM-250	AWARD TRIM COIL PROCUREMENT	10-Jun-08	Sep-08
39	P3-171VM	COMPLETE VPI OF 18th MOD COIL	28-Aug-08	Nov-08
40	451-2-3	Power system - PDR	22-Sep-08	Dec-08
41	1351-195X	ALL TF COILS DELIVERED	15-Oct-08	Jan-09
42	162-036.9	Award Coil Support Structure	2-Oct-08	Feb-09
43	1803-605M	Station 6 Specification & Assy Drawings Complete	2-Oct-08	Mar-09
44	S21-11.07M	Complete 1st MCHP Assy (Sta 2)	4-Nov-08	May-09
45	TRIM-270M	Trim Coils for FPA #1 Delivered	8-Dec-08	Jun-09
46	1701-100M	Cryostat- CDR	23-Dec-08	Jul-09
47	2-3-11.09M	Complete 3rd MCHP Assy (Sta.2)	30-Mar-09	Oct-09
48	162-037M	Deliver Coil Structure components	4-Mar-09	Oct-09
49	1352-145M	PF 5&6 Lower Delivered	23-Mar-09	Dec-09
50	S31-10.02M	Complete 1st MC-VV Assy (Sta 3)	22-May-09	Jan-10
51	S51-14.03M	Complete 1st Field Period Assy (Sat. 5)	12-Nov-09	May-10
52	451-202.2	Power systems C-Site - FDR	27-Oct-09	Aug-10
53	S32-10.02M	Complete 2nd MC-VV Assy (Sta 3)	5-Jan-10	Sep-10
54	1701-141	Cryostat- FDR	18-Dec-09	Oct-10
55	S33-10.02M	Complete 3rd MC-VV Assy (Sta 3)	24-Mar-10	Dec-10
56	7501-10.4M	Complete Base Support Structure Assembly	18-Mar-10	Feb-11
57	S52-14.03M	Complete 2nd Field Period Assy. (Sta.5)	18-Jun-10	Mar-11
58	7503-150	FPA-3 Installed on sleds	16-Aug-10	Jun-11
59	431-275M	C-site DC Systems Installed	3-Aug-10	Jun-11
60	380-135M	E-beam mapping apparatus ready for Installation	12-Jan-11	Oct-11
61	7503-412M	Move FPA's & spacers together/chk fitup complete	12-Jan-11	Nov-11
62	R56-70M	Compl Central Safety&Interlock Sys Pre-ops Tests	17-Feb-11	Feb-12
63	S-6-15.04M	Vacuum Vessel Welding complete (3 FP's)	22-Apr-11	Jul-12
64	7503-250	Begin Vac Vsl Pumpdown	8-Jul-11	Oct-12
65	S-6-22.11M	ALL PF Coils Installed	17-Aug-11	Dec-12
66	7503-330	Begin Cryostat Installation	23-Sep-11	Feb-13
67	730.125	PSO Operational Readiness Assessment	7-Nov-11	Apr-13
68	8501-304	Begin Start-up Testing	14-Nov-11	May-13
69	730.8200M	Cooldown of Machine	21-Nov-11	May-13
70	8501-110	NCSX Startup Complete	5-Jan-12	Aug-13

- Level-2 milestones distributed to provide a good metric of schedule progress



More from Strykowsky

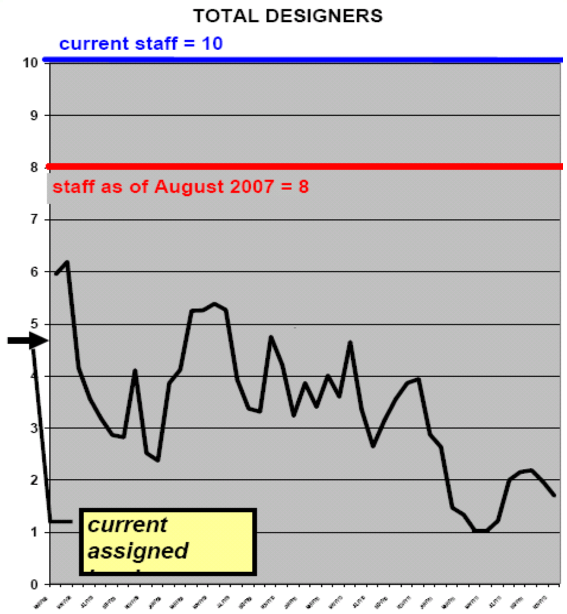
PPPL PRINCETON PLASMA PHYSICS LABORATORY

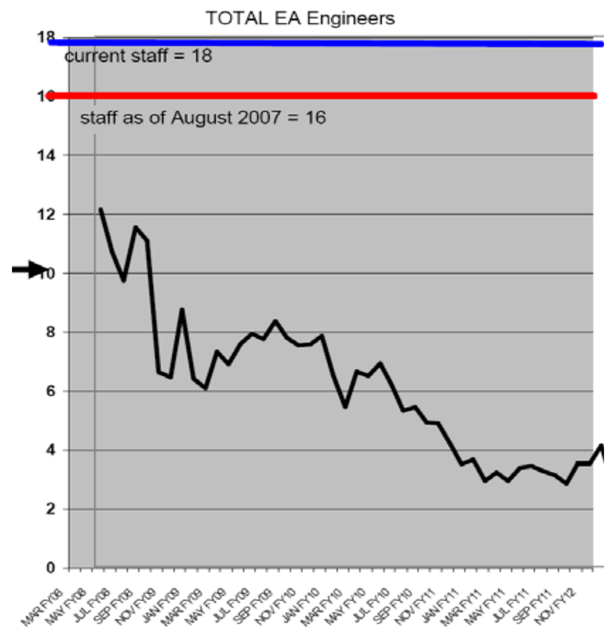
ORNL OAK RIDGE NATIONAL LABORATORY

Resource-loaded schedule staffing plan is at the individual level

NCSX National Compact Stellarator Experiment

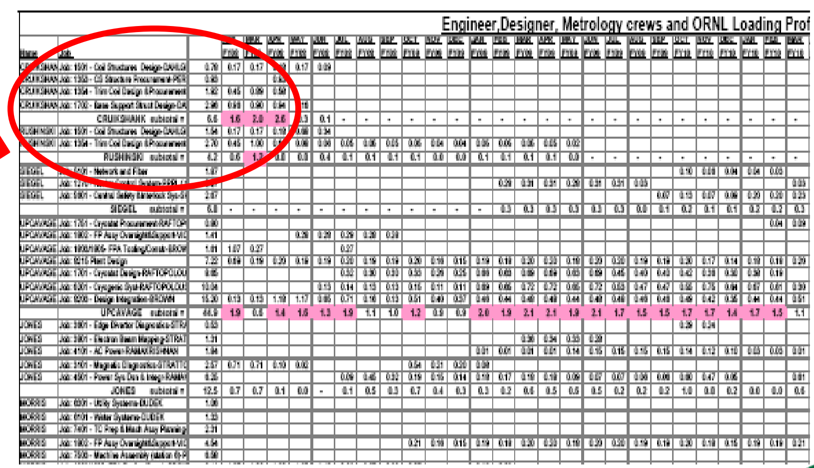
- Enables:
  - Load leveling
  - Meeting other Institutional commitments
  - Recruiting (regular, term, contract, consultant)
  - Career & capability development
  - Retention
  - Succession planning
  - Glide paths off Project





More from Strykowsky

Name	Job		FEB FY08	MAR FY08	APR FY08
CRUIKSHAN	Job: 1501 - Coil Structures Design-DAHLGI	0.78	0.17	0.17	0.18
CRUIKSHAN	Job: 1353 - CS Structure Procurement-PERI	0.93			0.93
CRUIKSHAN	Job: 1354 - Trim Coil Design &Procurement-	1.92	0.45	0.89	0.58
CRUIKSHAN	Job: 1702 - Base Support Struct Design-DAI	2.96	0.96	0.90	0.94
	CRUIKSHANK subtotal =	**6.6**	**1.6**	**2.0**	**2.6**
RUSHINSKI	Job: 1501 - Coil Structures Design-DAHLGI	1.54	0.17	0.17	0.18
RUSHINSKI	Job: 1354 - Trim Coil Design &Procurement-	2.70	0.45	1.00	0.61
	RUSHINSKI subtotal =	**4.2**	**0.6**	**1.2**	**0.8**



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Contingency is supported by and consistent with appropriate project-wide risk analysis

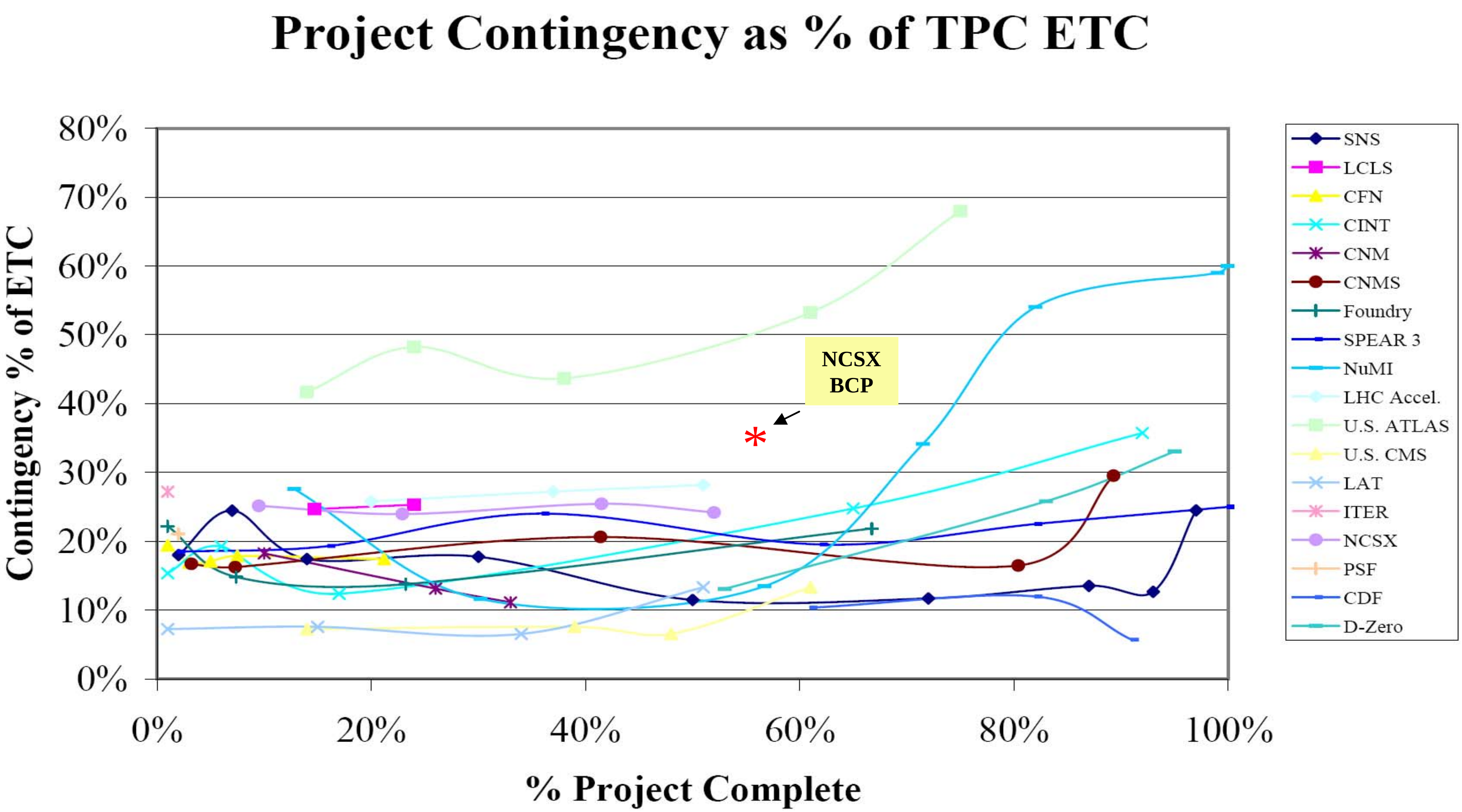
- Analysis based on the use of a comprehensive Risk Registry
  - Owners & retirement dates identified
  - Mitigation plans developed
  - Opportunities to recover schedule and reduce cost also identified & managed same way as risks
- Uncertainty due to design maturity & complexity assessed
- Monte Carlo model used to estimate cost & schedule contingency for desired confidence level
  - Consider 80, 90, 95% Confidence Levels
  - Cost contingency: $20.0M – $24.4M (32-39%)
  - Schedule contingency: 16.3 - 21.1 mo. (34%-44%)

Table 7
Contingency Analysis Results

Base Schedule	**48.0**	months
Schedule Uncertainty Contingency at 90%	7.2	
Risk Schedule Contingency at 90%	11.8	
Total Schedule Contingency (90%)	**19.0**	**months**
Base ETC	**61,794**	
Contingency at 90% (Std Uncertainty)	9,350	15%
Cost of Schedule Uncertainty Contingency	3,780	6%
Cost of Schedule Risk Mitigation	270	0%
Total Uncertainty Contingency - 90% Confidence	13,400	22%
Risk Cost Contingency (from Risk Model) at 90%	2,840	5%
Risk Schedule Contingency (cost of stretch) - 90%	6,170	10%
Total Risk Contingency - 90% Confidence	9,010	15%
Total Cost Contingency (90%)	**22,410**	**36%**
ETC with Contingency (@90%)	***84,204***	

More from Gruber

Comparison with Project Contingency Survey From DOE Office of Science (June 2006)



Key Aug 2007 Review Recommendations Addressed

Cost & Schedule

- "Expedite design engineering and reviews whenever possible"

  Completed: Incorporated into the proposed baseline change

- "Improve the data analyses that form the basis of the baseline estimates"

  Completed: A consistent basis of estimate categorization implemented; all work reviewed by responsible line managers and PPPL AD for Engineering

- "With new guidance from the Program Office, develop an alternate cost/schedule baseline based on an "optimum" funding profile"

  Completed: Analyses completed & submitted to DOE in Nov 07 and funding profile received; DOE FY09 Budget Request to Congress consistent with this profile

Management

- "Ensure that the full project work scope as approved in the FY 2005 baseline and the new proposed baseline are consistent"

  Completed: Scope meets equivalent level of machine performance from FY05 baseline

- "Provide strong leadership in the systems engineering and integration area"

  Completed: Project organization revised to ensure adequate integration

Lessons Learned Study Conducted

- Magnitude of the proposed BCP calls for changes in how the NCSX project is managed if the new baseline is approved.
- Lessons learned study conducted by Princeton U and PPPL to better understand issues that led to cost and schedule variances and to establish corrective actions to prevent reoccurrence of similar problems in future projects.
- Issues:
  - Premature definition of the project cost and schedule when the project baseline was established at CD-2.
  - Underestimate of the implications of meeting the tolerance requirements of a complex three-dimensional structure
  - Lack of independent internal review of cost and schedule
  - Inadequate Princeton University and PPPL Oversight of the NCSX Project
  - Inadequate communication with DOE
  - Lack of appreciation of the high risks associated with the application of cutting edge technologies.
  - Insufficient management and project execution.

Key Lessons Learned

- Prior to establishing a baseline, R&D and design needs to be completed sufficiently to establish a sound technical basis for the estimates.
- Formal risk assessment techniques based on a risk register and analysis of the tasks at the job level is required to establish the need for cost and schedule contingency.
- When reporting estimates, it is important to realistically assess the uncertainties, their sources, and the prospects for reducing them. Subjective characterizations of “confidence” should be avoided.
- Projects need to use care when planning to use high technology tools at or near their upper limits.
- Project Teams needs to develop stronger ties with external communities.
- One can never over communicate! Confront problems early before they get out of control. Get “bad news” and mitigation/recovery plans out to stakeholders fast.

Corrective Actions from Lessons Learned

- ✓ Bolster implementation of risk management plan
- ✓ Revise all NCSX job estimates to incorporate new analyses and lessons learned, *e.g.,* metrology and Title III engineering
- Conduct bottom-up ETC semi-annually and management ETC monthly
- ✓ Increase formality of the development of the job estimates
- Implement training on high technology tools before their use is required
- ✓ Develop stronger ties with external fusion labs and other communities for peer review and advice on new technology
- ✓ PPPL Director to conduct monthly project review, with results communicates through PU Dean for Research to the University President and Provost
- Strengthen project management at PPPL.
- ✓ Propose greater, direct access to key members in the Office of Science and improve communication both about the Project successes and issues.
- ✓ Establish PU external review committee to assess project progress and plans semi-annually

New NCSX Project Manager's assessment after 2 months on the job

- PPPL-ORNL team has good track record in solving problems & maintaining high quality - no show stoppers to date. Impressed by quality of individual team members. They *can* do the job
- Challenge is to develop confident cost & schedule estimates, recognizing project complexity and design maturity, and managing to them
- Design is much more mature than in Aug 07, but not complete. Assembly sequence plan is incomplete until we finish design
- Peer review has strengthened confidence and ability to successfully complete project
- Cost & schedule estimates are now more rigorous with a defensible basis of estimate
- Institutional sponsorship from PPPL, Princeton U, and ORNL is strong
- PPPL Lessons Learned and Corrective Actions are appropriate
- There've been good investments to improve project management; further work needed to:
  - **Drive schedule** while maintaining safety & quality excellence
  - **Instill** a culture of **accountability**
  - **Enhance float** by accelerating remaining design and R&D ahead of construction
  - **Provide transparency** with customer & stakeholders

Concluding Remarks

- Historical Perspective – Our concluding remark at Aug 15, 2007 SC Review:
  - "NCSX, with current technical scope, can be completed within cost and on schedule to proposed Cost Estimate and Resource Loaded Schedule"
- So, why should you believe us now?
- I believe that our BCP is credible and markedly improved over previous ETCs because:
  - Highest risk, first-of-a-kind modular coil design is now complete & assembly is underway
  - Risk management now taken to a new level (*e.g.,* registry, mitigation plan execution, pursuit of key alternatives, & contingency determination)
  - Viable staffing plan at the individual level now developed and supported by PPPL & ORNL through assignment priorities and new hires
  - Aggressive external outreach now strengthening our peer reviews, and providing exposures to improved and alternative technologies and methods
  - Lessons learned study conducted, and most of the corrective actions implemented
  - Concerted effort underway to drive schedule while maintaining safety & quality excellence

Supplemental Backup Slides

NCSX Program Advisory Committee is Composed of the International Leaders in Stellarator Science

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Project WBS Incorporates All Remaining Work

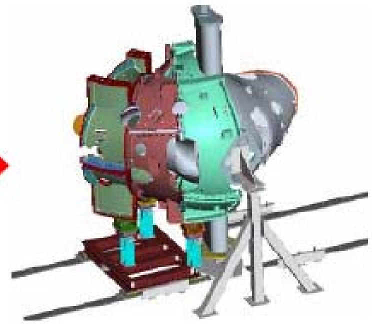
NCSX WBS DICTIONARY (2007 Rebaseline)	
WBS Listing (Revision 4)	
WBS 1 - Stellarator Core Systems • Revision 5 - *Approved 8/3/2007*	WBS 2 - Auxiliary Systems • Revision 2 - *Approved 6/22/2007*
WBS 3 - Diagnostic Systems • Revision 2 - *Approved 6/22/2007*	WBS 4 - Electrical Power Systems • Revision 3 - *Approved 4/12/2007*
WBS 5 - Central Controls and Computing Systems • Revision 2 - *Approved 7/5/2007*	WBS 6 - Facility Systems • Revision 4 - *Approved 7/9/2007*
WBS 7- Test Cell Preparation & Machine Assembly • Revision 3 - *Approved 7/16/2007*	WBS 8 - Project Oversight and Support • Revision 3 - *Approved 7/10/2007*

Assembly Sequence

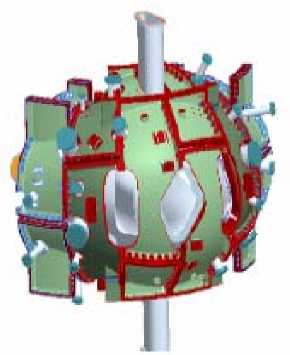
NCSX National Compact Stellarator Experiment

Assemble 3 coils for half field period

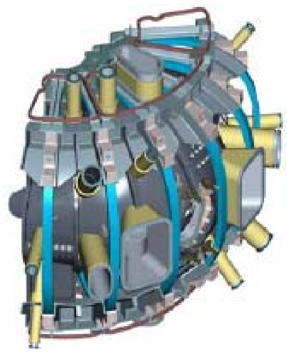
Now Underway!



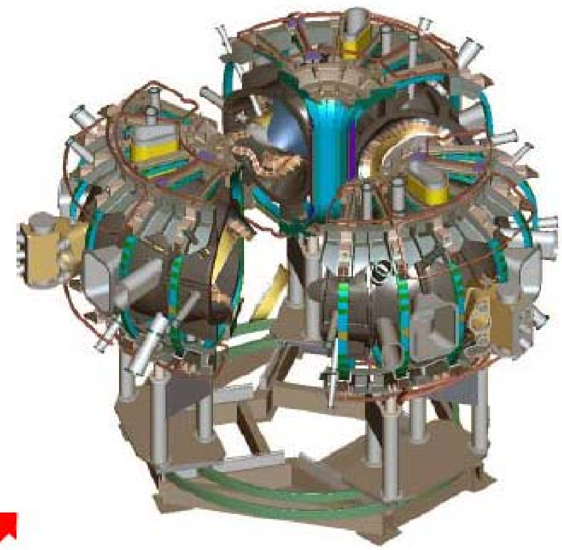
Install 3-coil set over vacuum vessel sector



Connect 2nd 3-coil set over vacuum vessel sector



Add ports & TF coils to complete a field period



Connect 3 field periods

Require coil current center accurate to ±1.5 mm

More from Dudek, Viola, Perry

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BCP Based on a Comprehensive Bottoms-Up Estimate to Complete (ETC)

NCSX National Compact Stellarator Experiment

Cost in $k	Actual 4/1/03 thru 1/31/08	Estimate to Complete from 2/1/08	EAC	per cent to-go
1 Stellarator Core	**60,647**	**29,023**	**89,670**	32%
12. Vacuum vessel	9,743	1,429	11,172	13%
13. Conventional Coils	3,832	4,256	8,088	53%
14. Modular Coils	38,168	2,563	40,731	6%
15. Coil Structures	545	1,528	2,073	74%
16. Coil Services	3	1,085	1,087	100%
17. Cryostat & Base Structure	489	1,497	1,986	75%
18. Field Period Assembly	5,550	14,412	19,962	72%
19. Stellarator Core Mgt. & Int.	2,317	2,255	4,572	49%
2 Auxiliary Systems	**348**	**1,018**	**1,365**	75%
3 Diagnostics	**1,130**	**811**	**1,941**	42%
4 Electrical Power Systems	**615**	**2,719**	**3,333**	82%
5 Central I&C/Data Aq.	**33**	**2,099**	**2,132**	98%
6 Facility Systems	**24**	**2,423**	**2,447**	99%
7 Test Cell Prep & Machine Assy.	**708**	**8,577**	**9,285**	92%
8 Project Mgt. & Integration	**12,784**	**15,145**	**27,930**	54%
81. Project management	4,029	4,814	8,843	54%
82. Engineering Mgt. & Integration	6,497	7,608	14,105	54%
84. Project Physics	470	-	470	0%
85. Integrated System Testing	-	795	795	100%
89. Allocations	1,788	1,928	3,716	52%
Total Work	**76,289**	**61,815**	**138,104**	**45%**
DCMA	75	-	*75*	0%
	-	-		
Contingency	**-**	**22,410**	**22,410**	
Total	**76,364**	**84,225**	**160,589**	

Schedule in Months				
Total Work	**58**	**48**	**106**	**45%**
(Early Finish)			**Jan-2012**	
Contingency		**19**	**19**	
Total	**58**	**67**	**125**	
CD-4			**Aug-2013**	

More from Strykowsky

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NCSX PROJECT ETC (by WBS and Fiscal Year)

WBS	FY03 - FY07	Actual FY08	ETC FY08 (from 2/1/08)	TOTAL FY08	FY09	FY10	FY11	FY12	TOTAL EAC
12 Vacuum Vessel	9,642	101	75	176	239	770	345	-	11,172
13 Conventional Coils	3,540	290	2,557	2,847	1,323	275	102	-	8,086
14 Modular Coils	36,693	1,479	2,350	3,829	184	28	-	-	40,734
15 Structures	517	33	319	352	1,209	-	-	-	2,077
16 Coil Services	3	-	280	280	319	486	-	-	1,088
17 Cryostat & Base Support Structure	436	53	222	275	672	405	197	-	1,986
18 Field Period Assembly	4,688	853	4,387	5,239	5,815	4,211	-	-	19,952
19 Stellarator Core Management & Integration	2,238	79	379	458	629	657	510	81	4,573
2 Auxiliary Systems	348	-	-	-	441	251	326	-	1,365
3 Diagnostics	1,096	35	275	310	336	113	88	-	1,942
4 Electrical Power Systems	615	-	130	130	367	1,223	999	-	3,334
5 I&C Systems	33	-	15	15	57	1,396	631	-	2,132
6 Facility Systems	24	-	77	77	507	744	1,095	-	2,447
7 Test Cell Preparation & Machine Assembly	681	27	169	196	181	2,557	4,730	940	9,284
81 Project Management	3,773	252	1,030	1,282	1,505	1,320	823	136	8,840
82 Project Engineering	5,968	532	1,283	1,815	2,358	2,073	1,632	263	14,109
84 Project Physics	470			-					470
85 Start-up	-	-	-	-	275	70	-	450	795
89 Allocations	1,616	176	287	462	460	489	514	178	3,720
	72,380	3,910	13,833	17,743	16,877	17,069	11,990	2,047	138,105
DCMA	75								75
Contingency					2,730	3,044	10,126	6,510	22,410
Total	72,455	3,910	13,833	17,743	19,607	20,113	22,116	8,557	160,590

More from Strykowsky

Project Completion Analysis

		Design	R&D	Procure	Fab & Assy	Mgt & Oversite (wbs 19 & 8)	TOTAL
12 Vacuum Vessel	Spent $k)	$1,641	$1,787	$6,325	$0		$9,753
	Total ($k)	$1,864	$1,787	$7,315	$216		$11,182
13 Conventional Coils	Spent $k)	$1,278	$0	$2,016	$536		$3,830
	Total ($k)	$1,665	$0	$5,670	$751		$8,086
14 Modular Coils	Spent $k)	$6,297	$5,454	$12,934	$13,483		$38,168
	Total ($k)	$6,463	$5,458	$13,979	$14,870		$40,770
15 Structures	Spent $k)	$550	$0	$0	$0		$550
	Total ($k)	$639	$0	$1,430	$12		$2,081
16 Coil Services	Spent $k)	$3	$0	$0	$0		$3
	Total ($k)	$392	$24	$496	$179		$1,091
17 Cryostat & Base Support Structure	Spent $k)	$489	$0	$0	$0		$489
	Total ($k)	$1,206	$0	$780	$0		$1,986
18 Field Period Assembly	Spent $k)	$1,439	$0	$7	$4,094		$5,540
	Total ($k)	$2,520	$0	$362	$17,096		$19,978
1 Stellarator Core	**Spent $k)**	**$11,697**	**$7,241**	**$21,282**	**$18,113**		**$58,333**
	Total ($k)	**$14,749**	**$7,269**	**$30,032**	**$33,124**		**$85,174**
		79%	*100%*	*71%*	*55%*		*68%*
2 Auxiliary Systems	**Spent $k)**	**$348**	**$0**	**$0**	**$0**		**$348**
	Total ($k)	**$784**	**$0**	**$215**	**$366**		**$1,365**
		44%	-	*0%*	*0%*		*25%*
3 Diagnostics	**Spent $k)**	**$565**	**$0**	**$0**	**$565**		**$1,130**
	Total ($k)	**$938**	**$0**	**$68**	**$934**		**$1,940**
		60%	-	*0%*	*60%*		*58%*
4 Electrical Power Systems	**Spent $k)**	**$615**	**$0**	**$0**	**$0**		**$615**
	Total ($k)	**$1,369**	**$0**	**$216**	**$1,749**		**$3,334**
		45%	-	*0%*	*0%*		*18%*
5 I&C Systems	**Spent $k)**	**$33**	**$0**	**$0**	**$0**		**$33**
	Total ($k)	**$818**	**$0**	**$624**	**$689**		**$2,131**
		4%	-	*0%*	*0%*		*2%*
6 Facility Systems	**Spent $k)**	**$24**	**$0**	**$0**	**$0**		**$24**
	Total ($k)	**$896**	**$104**	**$722**	**$726**		**$2,448**
		3%	*0%*	*0%*	*0%*		*1%*
7 Test Cell Preparation & Machine Assy	**Spent $k)**	**$0**	**$0**	**$0**	**$708**		**$708**
	Total ($k)	**$0**	**$0**	**$367**	**$8,919**		**$9,286**
		-	-	-	*8%*		*8%*
Sub-TOTAL	**Spent $k)**	**$13,282**	**$7,241**	**$21,282**	**$19,386**		**$61,191**
	Total ($k)	**$19,554**	**$7,373**	**$32,244**	**$46,507**		**$105,678**
	% complete	68%	98%	66%	42%		58%
19 Stellarator Core Management & Integratic	Spent $k)	$0	$0	$0	$0	$2,317	$2,317
	Total ($k)	$0	$0	$0	$0	$4,572	$4,572
8 Project management & Engineering	Spent $k)	$0	$0	$0	$0	$12,862	$12,862
	Total ($k)	$0	$0	$0	$0	$28,007	$28,007
Grand Total	Spent $k)	$13,282	$7,241	$21,282	$19,386	$15,179	$76,370
	Total ($k)	$19,554	$7,373	$32,244	$46,507	$32,579	$138,257
	% complete	68%	98%	66%	42%		55%
						contingency =	22410
							$160,667

More from Strykowsky

Major procurement of components as well as ancillary system have adequate schedule margin

National Compact Stellarator Experiment

Stellarator Core Critical Procurements Schedule Margin

job	Procurement	Estimated Fabr Lead Time	Months off critical path	schedule margin
1260	Neutral Beam Transition Ducts	12	8.3 +	69%
1361	TF Coils (10 left)	6.5	23.2	357%
1352	PF Coils	16	14.5	91%
1354	Trim Coils	6	12	200%
1353	Central Solenoid Support structure	6	7.3 +	122%
1550	Coil Support Structure	5	8.7 +	174%
1451	Last Modular Coil (3 reminaining)	5	4.4	88%
1601	Coil Services -Lead stubs & LN manifolds	4.3	11	256%
1601	Coil Services -Cables	6	16	267%
1752	Base Support Structure	8	8.4 +	105%
1751	Cryostat	13.8	5.5	40%
1803	Station 5 Fixtures	5	11.4	228%
1803	Station 6 Fixtures	7	9.3	133%

More from Strykowsky

BCP Cost & Schedule Contingency Set at 90% Confidence Level

Confidence Level	90%		80%		95%	
Base ETC	***$61,8 M***		***$61,8 M***		***$61,8 M***	
Contingency (Standard Uncertainty)	$9.4	15%	$8.7	14%	$10.0	16%
Cost of Schedule Uncertainty Contingency	$3.8	6%	$3.1	5%	$4.3	7%
Cost of Schedule Mitigation	$0.3	0%	$0.2	0%	$0.3	0%
Total Uncertainty Contingency	$13.4	22%	$12.0	19%	$14.6	24%
Risk Cost Contingency (from Risk Model)	$2.8	5%	$2.5	4%	$3.0	5%
Risk Schedule Contingency (stretch cost)	$6.2	10%	$5.5	9%	$6.8	11%
Total Risk Contingency	$9.0	15%	$8.0	13%	$9.8	16%
Total Cost Contingency	$22.4	36%	$20.0	32%	$24.4	39%
ETC with Contingency	***$84.2 M***		***$81.8 M***		***$86.2 M***	

More from Gruber

Schedule Contingency Analysis Results

- Remaining Project Duration 48 months
  (early finish without contingency)
  NCSX Critical Path
- 90% Confidence Contingency Requirement
  - Schedule Uncertainty 7.2 months
  - Risk Schedule Contingency 11.8 months
  - Total Schedule Contingency 19.0 months (40%)

- 80% Confidence Contingency 16.3 months (34%)
- 95% Confidence Contingency 21.1 months (44%)

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