Supported by

NSTX

NSTX Status and Plan

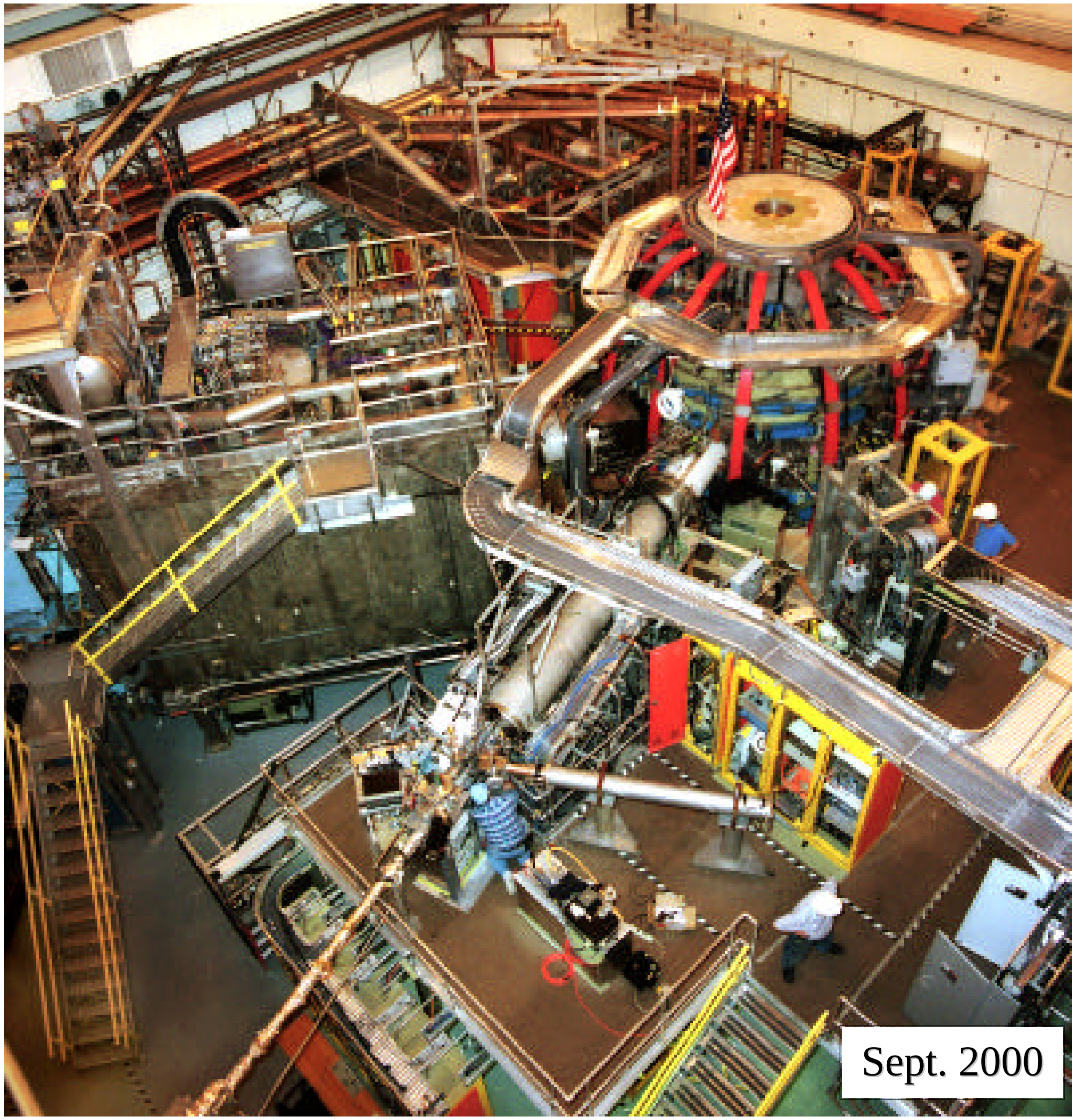
Masayuki Ono

For the National Spherical Torus Experiment Team

NSTX PAC-10, PPPL, Feb. 8 - 9, 2001

Facility is ramping up rapidly!

NSTX



Sept. 2000

Baseline Parameters
(Achieved)

Major Radius 0.85 m

Minor Radius 0.68 m

Elongation ≤ 2.2 (2.5)

Triangularity ≤ 0.6 (0.5)

Plasma Current
1 MA (1.07 MA)

Toroidal Field
0.3 to 0.6 T (≤ 0.6 T)

Heating and CD
5 MW NBI (4 MW)
6 MW HHFW (4.2 MW)
0.5 MA CHI (0.26 MA)
Pulse Length
≤ 5 sec (0.5 sec)

Talk Outline

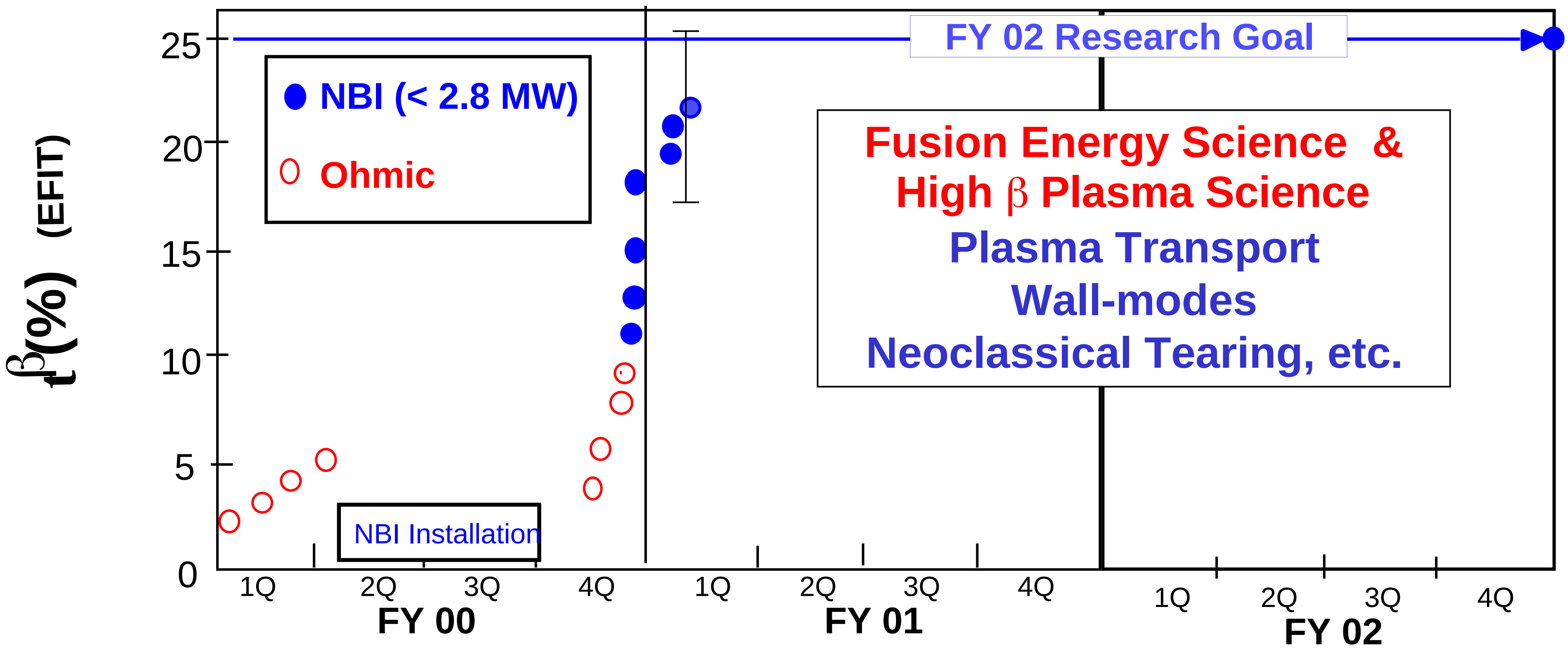
NSTX

- Project Highlights
- FY 00 Program Execution Agreement Status
- FY 01-03 Facility Plan
- Second Center Stack
- Incremental Plan
- EBW Plan
- Budget & Issues
- Summary

NSTX made excellent progress since PAC9!

- TMB Boronization an outstanding success.
- Plasma Operations exceeded in FY 00 target by about 2 weeks
- NBI started ahead of schedule. High beta / high confinement regimes accessed. Three sources now at 80 kV.
- HHFW now working in the full configuration (12 antenna - 6 transmitter). 4 MW milestone achieved in Oct. 2000.
- Excellent experimental results [Ed Synakowsi]
- Many new diagnostics [Mike Bell]
- Many new analyses tools [Stan Kaye]
- B_{TF} tested up to 6 kG and operated up to 4.5 kG.

NSTX Produced High Temperature - High β Plasmas Ahead of Schedule



(From magnetic reconstruction)

FY 00 Program Execution Agreement Completed

NSTX

• Machine Start-up and Testing	July 00 (Completed - July)
• NBI Vacuum System Operational	July 00 (Completed - July)
• 3 NBI Sources Tested	July 00 (Completed - July)
• Complete CHERS Design*	July 00 (Completed - Oct.)
• VIPS/SPRED Detectors	July 00 (Completed - Nov.)
• Complete MPTS System Installation	July 00 (Completed - July)
• Begin NBI Conditioning	Aug. 00 (Completed - Aug.)
• Science goals were all achieved:	
– 500 kA for 500 msec	Sept. 00 (Completed - Sept.)
– 200 kA for CHI	Sept. 00 (Completed - Sept.)
– 4 MW for HHFW	Sept. 00 (Completed – Oct.)

* 20 Channel System was implemented with TFTR components. Full CHERS system will be implemented along with the MSE to be completed in 2002.

NSTX Device Status

* After ≈ 2 years of plasma operations, the device successfully reached (even exceeded) design parameters.

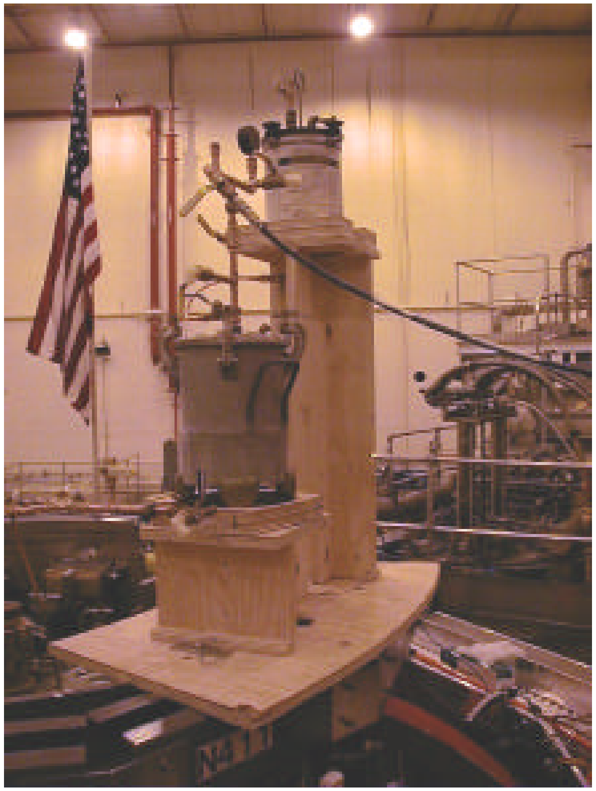
* But during the last month of operations in Dec. 2000, we experienced some problems with TF cooling water leak and OH insulation.

* To be on a positive site, the problems occurred toward the end of the run and they were identified during the low power test (not during the high power operations.)

We presently do not expect significant schedule and budget impact.

NSTX Toroidal Field Coil Water Leak

- An inspection showed that the TF water leak is likely to be related to the manufacturing problem (damage to tube surface looks like chisel marks.)



• During Jan. the TF water leaks (one large and one small) were successfully sealed by an epoxy technique developed on TFTR. This technique can be used in-situ within about one week if needed in the future.

NSTX OH Solenoid Insulation Problem

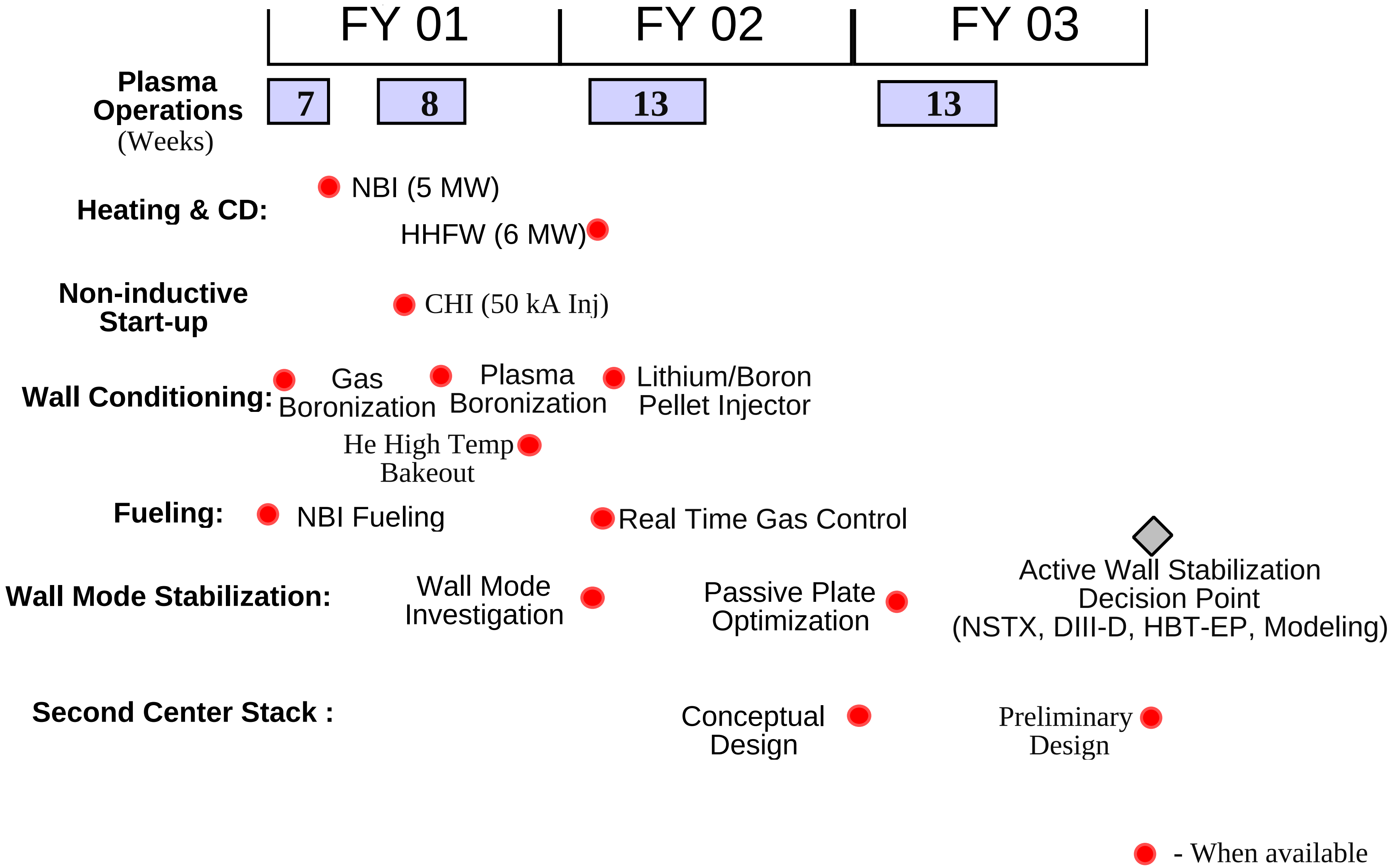
- A hi-pot test was conducted on Dec. 13 at 9 kV and a failure occurred after about 15 sec. To pass the test, 1 min at 9 keV is required.

- Measurements indicate that the OH leakage is <u>between the outer-most layer of the OH solenoid to the ground plane</u> painted on the OH solenoid surface located at about the 30% down from the top of the OH coil. No obvious explanation but moisture from TF waster leak may have played a role.

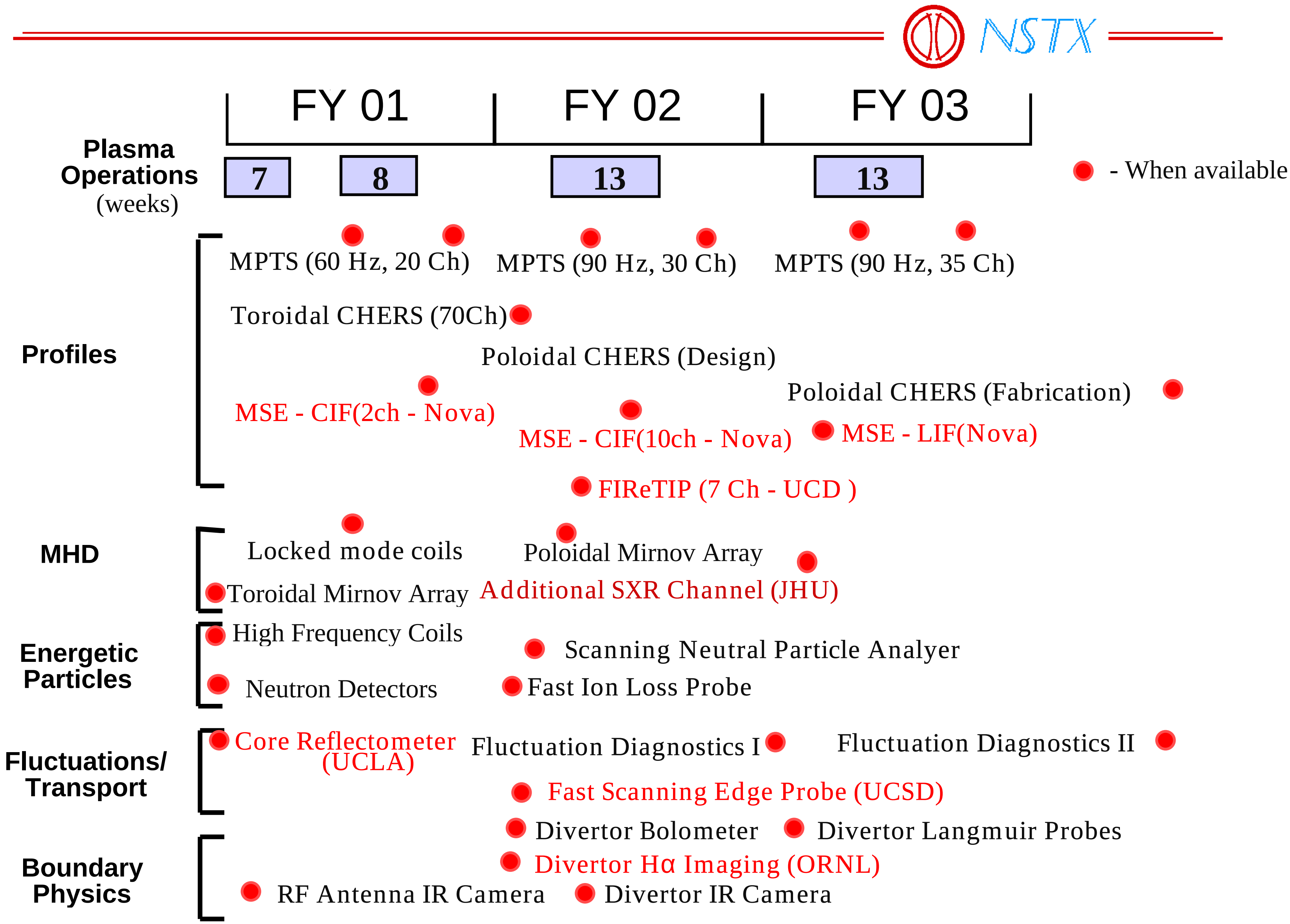
- The affected area is not accessible. The OH +TF bundle will be lifted out of machine without breaking vacuum during the week of Feb. 12. The present schedule calls for returning to plasma operation in early May to complete the remaining 8 week run in FY 01.

FY 01-03 Base Facility and Diagnostic Plan

FY 01- 03 Base Budget Facility Plan



FY 01- 03 New Diagnostic Base Plan



Second Center Stack

Based on the past two years of operational experience and exciting experimental results, we believe that a second center stack is a cost effective way to address the FESAC 5- 10 year objectives and to provide significant improvement in plasma performance and device flexibility.

Second Center Stack Specifications

NSTX

Initial survey points to a design point which is about 2.5 x in TF and OH capability with 60% increase in the center stack radius while keeping the stress ≤ the present center stack.

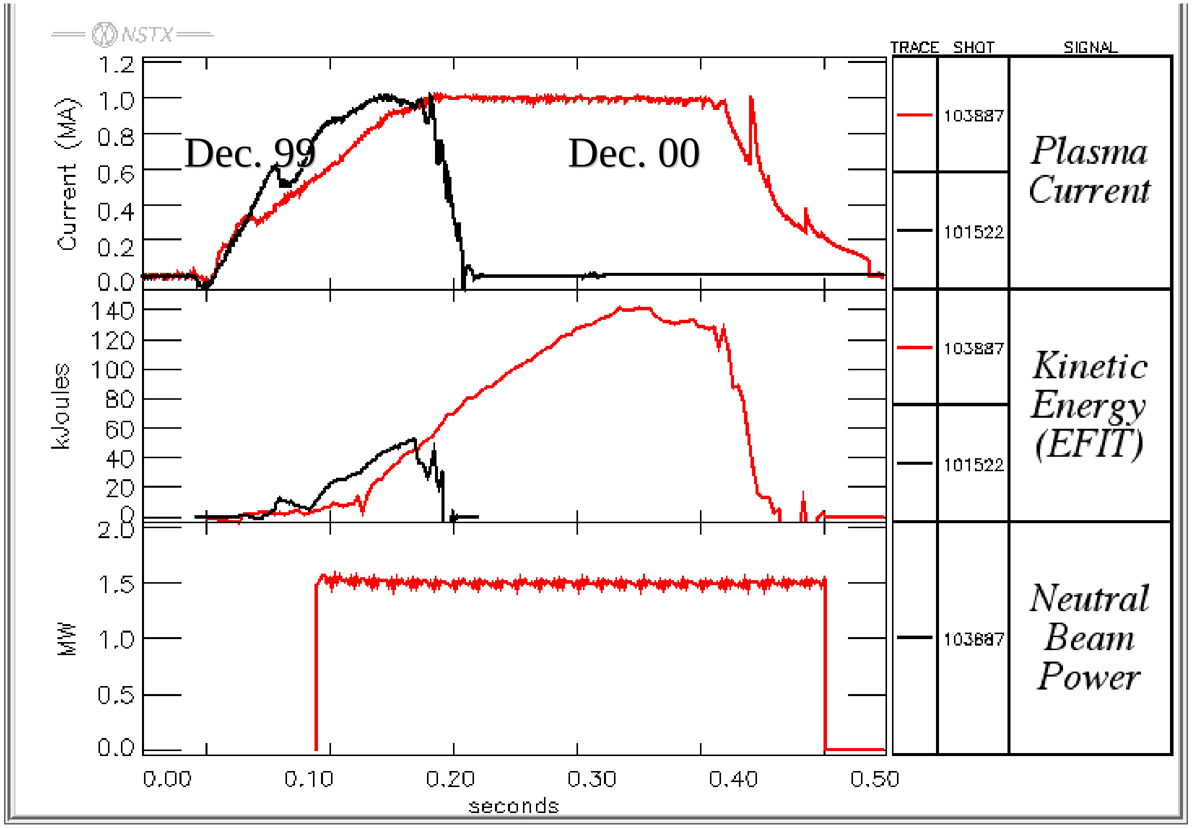
	First Center Stack	Second Center Stack *
Nominal R (m)	0.84	0.91
Nominal a(m)	0.67	0.6
Nominal A (R/a)	1.26	1.5
Elongation	2	2.5**
Triangularity	0.4	0.6**
Ip (MA) (maximum)	1.2 MA	3 MA
OH Flux	0.6 V-S	1.5 V-S
Long Pulse	5 sec at 3 kG	15 sec at 4.5 kG
High Performance Pulse	1 sec at 6 kG	3 sec at 9 kG
CHI	0.5 MA	1MA***

* 2nd C-S is about half way toward next step ST ($\kappa=3$, R/a ≈ 1.6)

** Improved PF coil set as well as sensors

*** Improved absorber arc control and ceramic insulator design.

Can we get 3 MA with 2.5 x OH Flux? Yes!

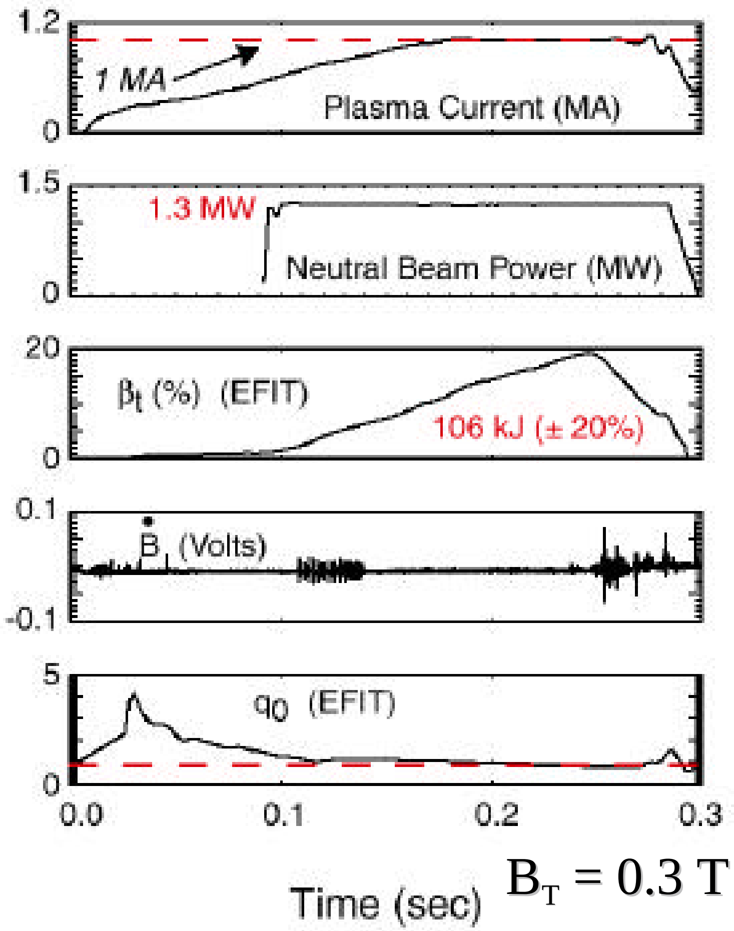


- Based on the recent data (high flux utilization and benign wall-halo currents):
  - 3 MA with 2.5 x OH achievable
  - 1.5 MA with half-swing OH also achievable.

High-β_t & High Confinement Obtained with NBI

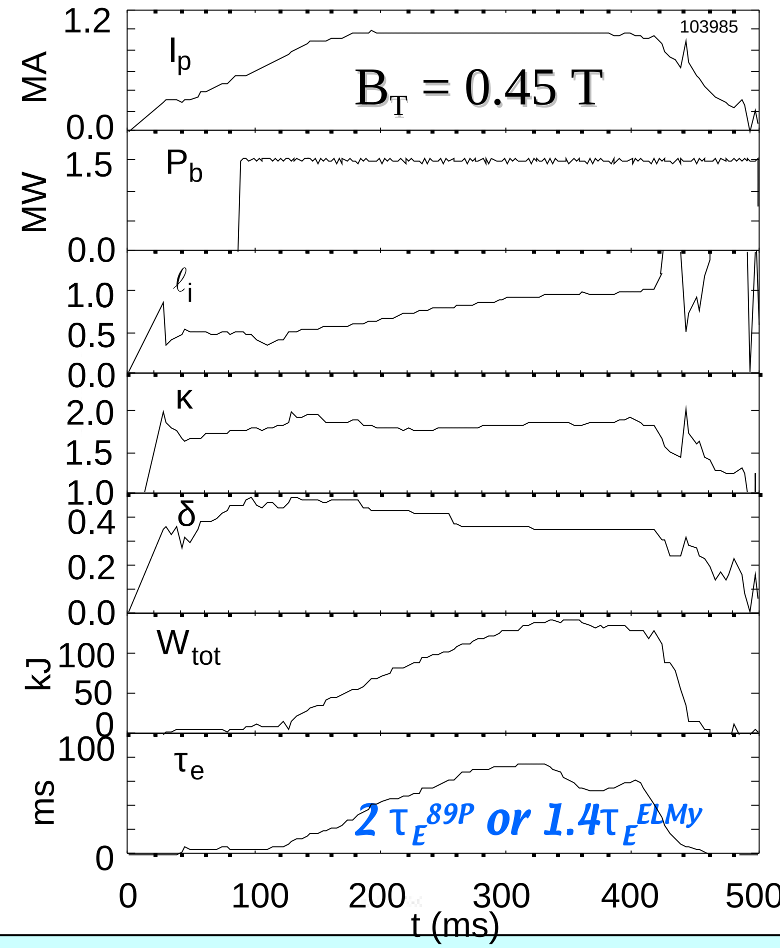
NSTX

High Toroidal β Regime



B_T = 0.3 T

High Confinement Regime



Importance of high confinement@ high β_T results: Additional flexibility to our approach to high β_T and high performance ST regimes without additional heating power.

Recent confinement trend suggests that operating point can be extended to higher B_T and I_p without additional heating power

Comparison of Present Center Stack and 2nd Center Stack

	Present Center Stack			2nd Center Stack	
	NSTX-3kG	ISTX-4.5KG	Adv. ST	Adv. ST	BP
Heating Power (MW)	**2.5**	**2.5**	**11**	**11**	**11**
Toroidal Magnetic Field (kG)	**3 kG**	**4.5 kG**	**3 kG**	**4.5 kG**	**9 kG**
Aspect Ratio	1.35	1.35	1.35	1.55	1.55
Plasma Major Radius (m)	0.85	0.85	0.85	0.9	0.9
Plasma Minor Radius (M)	0.63	0.63	0.63	0.58	0.58
Plasma Volume (m3)	11.97	11.97	11.97	14.93	14.93
Plasma Current (MA)	**1.00**	**1.00**	**1.00**	**1.5**	**3**
Elongation (κ95)	1.80	1.80	1.80	2.5	2.5
Average Triangularity (δ95)	0.40	0.40	0.40	0.6	0.6
Greenwald Density (1014cm-3)	0.80	0.80	0.80	1.42	2.84
Volume Average Density (1014cm-3)	0.40	0.40	0.50	0.95	1.4
Average Temperature (keV)	0.58	0.65	0.90	1.05	1.75
toroidal Beta (%)	**20.62**	**10.27**	**40.00**	**39.41**	**24.20**
Beta-N	**3.90**	**2.91**	**7.56**	**6.86**	**4.21**
Stored Thermal Energy(MJ)	**0.13**	**0.15**	**0.26**	**0.71**	**1.76**
tau-E (sec)	**0.053**	**0.060**	**0.024**	**0.065**	**0.160**
H-factor(x IPB91)	**1.4**	**1.4**	**1.4**	**1.4**	**1.4**

Achieved Results

2nd Center Stack for FESAC 5-10 Year Goal:

Demonstrate attractiveness of ST for τ–pulse >> τ–skin

NSTX

• To pursue FESAC 5-10 year goal of current maintenance, we need to have 1-1.5 MA current capability with OH half-swing.

• Second Center Stack with 1.5 MA current capability with OH half-swing will permit the research team to move on to the current maintenance research without waiting for the non-inductive start-up techniques.

• Non-inductive start-up techniques such as CHI / EBW / Bootstrap Over-drive will be pursued in parallel to be available for the future VNS-like long pulse ST experiments.

Additional Benefits of Second Center Stack

- Facilitate longer range non-inductive start-up research for VNS:

  - Improved CHI performance: e.g., in-board ceramic, better arc prevention, absorber field null control.

  - Long TF pulse length will permit for example rf and bootstrap - current “overdrive” current ramp of investigation (EBW/HHFW/NBI).

- Extend high performance regime for shorter pulse.

  - Expand ST plasma data base toward reactor relevant 10 keV range.

  - Facilitate ST-Tokamak science collaboration (e.g. NSTX/DIII-D)

Budget and Issues

NSTX Budget Summary ($M)

	FY 01	FY 02		FY 03	
Facility (Run weeks)	(15)	**Base** (**13)**	**Inc.** (7)	**Base** (13)	**Inc.** (7)
Facility Op.	12.11	11.31	0.63	12.01	0.79
NBI Op.	2.14	2.25	0.1	2.49	0.1
D-site				0.43	
Wall-mode Stab.			0.2	0.2	0.3
ECH Upgrade	0.05		0.15		0.5
CS Upgrade		0.2	0.8	0.25	2.12
Facility Total	14.3	13.76	1.88	15.38	3.81

Science					
PPPL Research	5.86	6.67	0.55	6.45	0.99
PPPL Diag.	1.55	1.34	0.77	0.90	1.05
Diag. Interface	0.5	0.66	0.2	0.63	0.2
PPPL Sci. Total	7.91	8.67	1.52	7.98	2.24
Collaboration	4.48	4.48	0.76	4.48	1.12

Grand Total -PPPL	**26.69**	**26.91**	**4.16**	**27.84**	**7.17**

Incremental Funding Activities

NSTX

- Accelerate NSTX Research Program through additional run weeks and diagnostic tools.

- Develop in-depth science understanding (per NRC) in particular to develop predictive capabilities.

- Accelerate 2nd Center Stack to meet FESAC 5-10 year goal.

- Start EBW/ECH non-inductive start-up research.

Incremental Funding to Enhance Science For the NSTX National Research Team

- Increase the NSTX run weeks by 50% (from 13 to 20 run weeks).

- Accelerate local transport research by one year.
  - Full MPTS system (99 Hz, 40 Ch) to FY03 from FY 04
  - Poloidal CHERS to FY 03 from FY 04
  - Acceleration of key fluctuation diagnostics
  - Enhance collaboration (including diagnostics) activities

- Enhance analyses/modeling capability

- Accelerate wall-mode investigation

Incremental Funding Greatly Accelerate and Enhance Science Output

NSTX

_ 4 months/year (30%) improvement in the research goal schedule

_ More in-depth research investigation for improving predictive capabilities (per NRC and FESAC 5 yr. goal).

_ In particular, in view of the recent exciting confinement results, the incremental funding will facilitate in-depth understanding and predictive capability of plasma transport by the FESAC 5 year check point.

Incremental Funding Will Permit a Timely Start of the NSTX 5 - 10 Year Research

NSTX

Cost in $M: Total Cost - $6.42 *

Fiscal Year	Base Funding Profile	Base + Incremental
02	0.2	0.2 + 0.8 = 1.0
03	0.25	0.25 + 2.22 = 2.47
04	1.06	1.06 + 1.14 = 2.2
05	1.66	0.75 Start of Experiment
06	2.58	
07	Start of Experiment	

* The cost and schedule estimate is based on the bottom-up estimate by engineering using the first center stack design and construction data.

Incremental Funding will permit EBW Start-up Research

NSTX

Objective: ECH/EBW upgrade to achieve rf-only non-inductive start-up method.

Note: Due to over dense condition, EBW is needed to access higher density plasma core.

ECH/EBW 100 - 200 kA ST formation (1.2 MW) + HHFW (6MW) heating and current ramp up could lead to an rf-only non-inductive current start-up method.

Proposed plan:

-Establish ECH/EBW physics feasibility in FY 01 (combination of EBW emission + low power coupling study + modeling by MIT, ORNL, GA, Wisconsin, PPPL)

-Engineering design / fabrication using existing ECH supplies at ORNL in FY 02-04 (Incremental) (PPPL-ORNL Joint Project with Enabling Technology)

Issues

- Number of personnel which can be covered on NSTX base budget declines both in FY 02 and FY 03.

- Adding significant diagnostic capability in FY01-03 but staff is reduced to operate diagnostics and analyze results.

- FY 03 is a particularly challenging year due to increased D-site responsibility and G&A rates both due to the completion of the D&D project. Impact to NSTX is about $2 M.

- The M&S fund for upgrades / spare parts is decreasing and essentially vanishes in FY 03.

- National Research Team budget needs to be enhanced

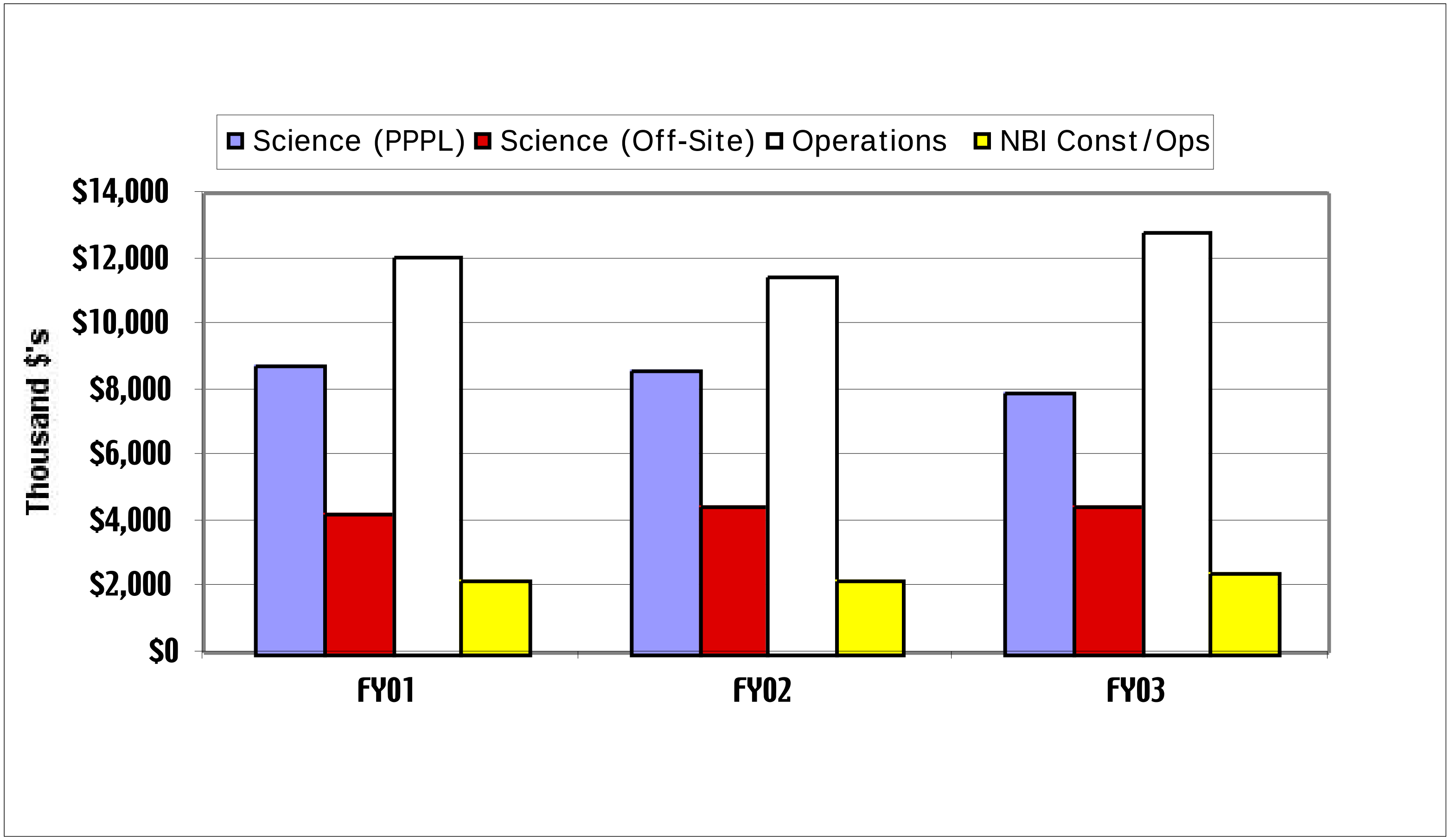
- Incremental funding will greatly enhance the productivity of the NSTX National Research Team.

Summarv

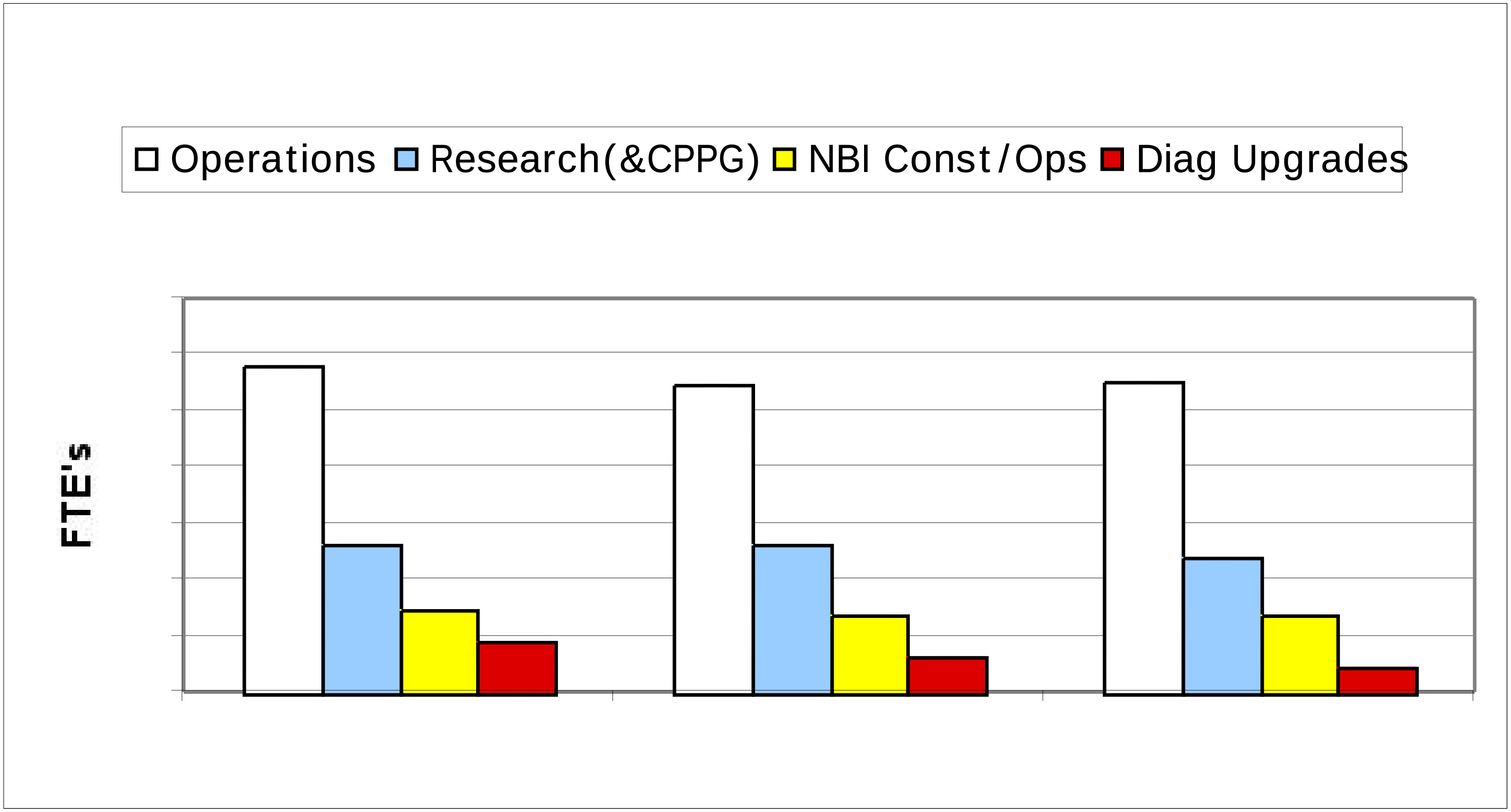
NSTX

- NSTX Team achieved major milestones on schedule.
- Facility achieved high level of availability and utilization for FY00 – FY 01.
- Research capability is rapidly increasing.
- Tantalizing high beta / high confinement results obtained.
- H-mode with good confinement observed.
- Good progress on HHFW and CHI tool development.
- Very exciting research run is coming up in May.
- FY 02-03 base budget allows 13 run weeks. FY 03 is a particularly challenging year due to the D&D completion.
- Incremental funding greatly enhances research productivity and longer term device / plasma capability.

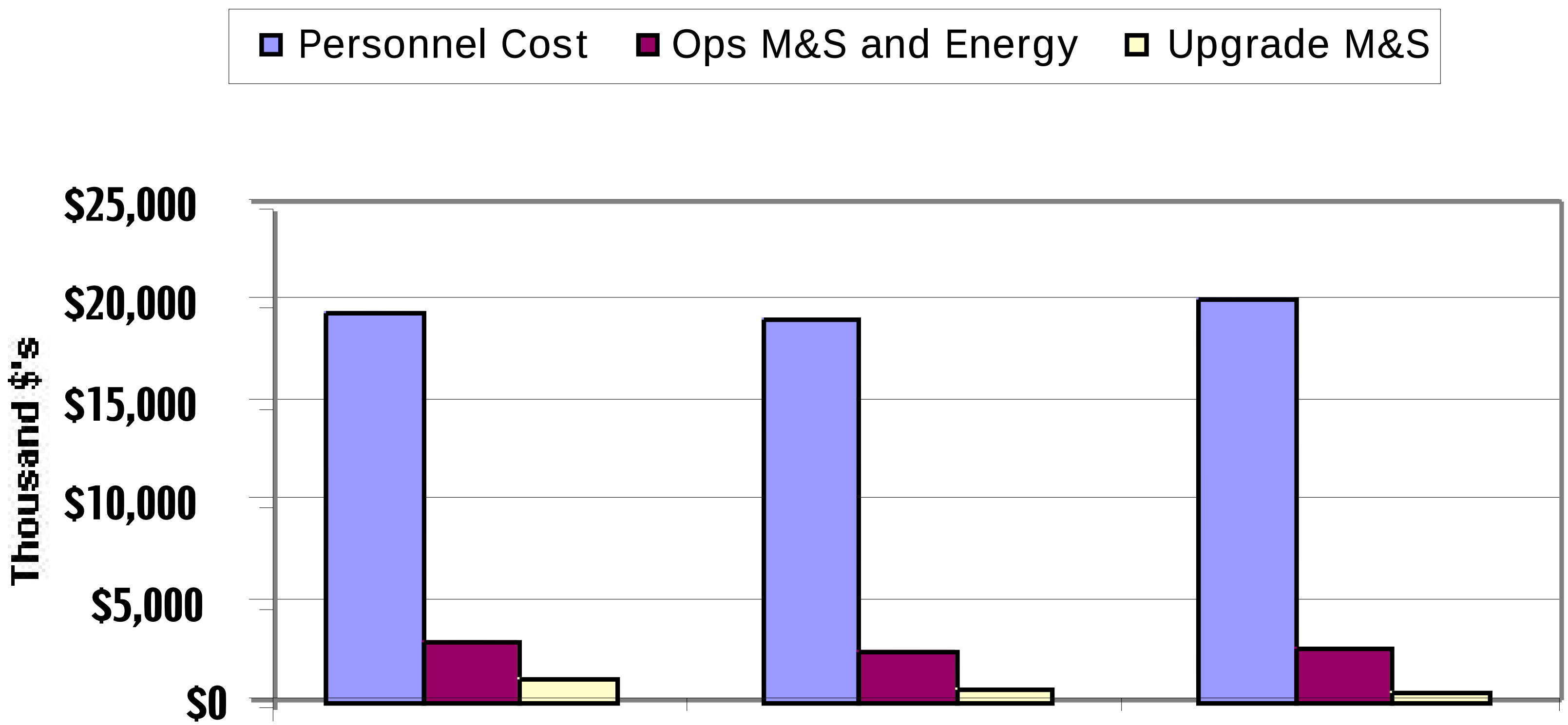
FY 2001- 2003 Budget Breakdown



NSTX PPPL Personnel Staffing



NSTX PPPL Personnel Staffing



Confinement Trend Suggests a Compact ST-BP!?

	NSTX-3kG	NSTX-9KG	UBPX-STI
Estimated Q (Fusion Gain)			10.0
Heating Power (MW)	2	11	16
Magnetic Field	0.3 T	0.9 T	3 T
Plasma Current	1 MA	3 MA	15 MA
Aspect Ratio	1.31	1.50	1.50
Plasma Major Radius (m)	0.85	0.90	1.20
Plasma Minor Radius (M)	0.65	0.60	0.80
Plasma Volume (m3)	12.75	15.97	45.43
Plasma Current (MA)	1.00	3.00	15.00
Field at Plasma Center (T)	0.30	0.90	3.00
Elongation (κ95)	1.80	2.50	3.00
Average Triangularity (δ95)	0.40	0.50	0.60
Greenwald Density (1014cm-3)	0.75	2.65	7.46
Volume Average Density (1014cm-3)	0.35	1.50	3.50
Average Temperature (keV)	0.68	1.50	6.50
toroidal Beta (estimate)	21.16	22.22	20.22
Beta-N	4.13	4.00	3.24
Stored Thermal Energy(MJ)	0.15	1.73	49.61
Fusion Power - MW			160.01
Required tau-E	0.073	0.157	1.034
H-factor	1.62	1.25	1.31
	(Best Data)		

Is this interesting?
Yes!

Is this credible?
Not yet.

But, the science advance on NSTX can make it credible!