Compact Stellarator Experiments: NCSX and QOS

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Compact Stellarator Proof-of-Principle Program

(May, 1998 Proposal)

Compact Stellarators (CS): a hybrid combining 3-D plasma shaping and bootstrap current to obtain the best of two successful concepts:

- Stellarators (disruption immunity, low recirculating power)
- Tokamaks (high beta and good confinement at low aspect ratio)

3-D shaping offers advantages

- Reverse-shear all the way to the edge (neoclassical tearing stability).
- Kink-stable without a nearby conducting wall.

Two approaches to high-beta CS plasma configurations will be tested

- Quasi-axisymmetry (QA):
  advanced-tokamak-like bootstrap current and physics.
- Quasi-omnigeneity (QO):
  high iota, low current, advanced-stellarator-like physics.

The CS Program Includes Two New Experiments Having Complementary Missions

NCSX Proof-of-Principle experiment (QA approach)

High-beta, disruption-free operation.

Transport reduction and control.

Beta limits and limiting mechanisms.

QOS Concept Exploration experiment (QO approach)

Reduction of neoclassical transport and bootstrap currents.

Plan for FY-2000-01: Establish technical, cost, and schedule baselines for NCSX and QOS and move both into construction.

Preparation of the Compact Stellarator Experimental Elements is Progressing Well

NCSX National Design Activity- Progress Toward Key Milestones

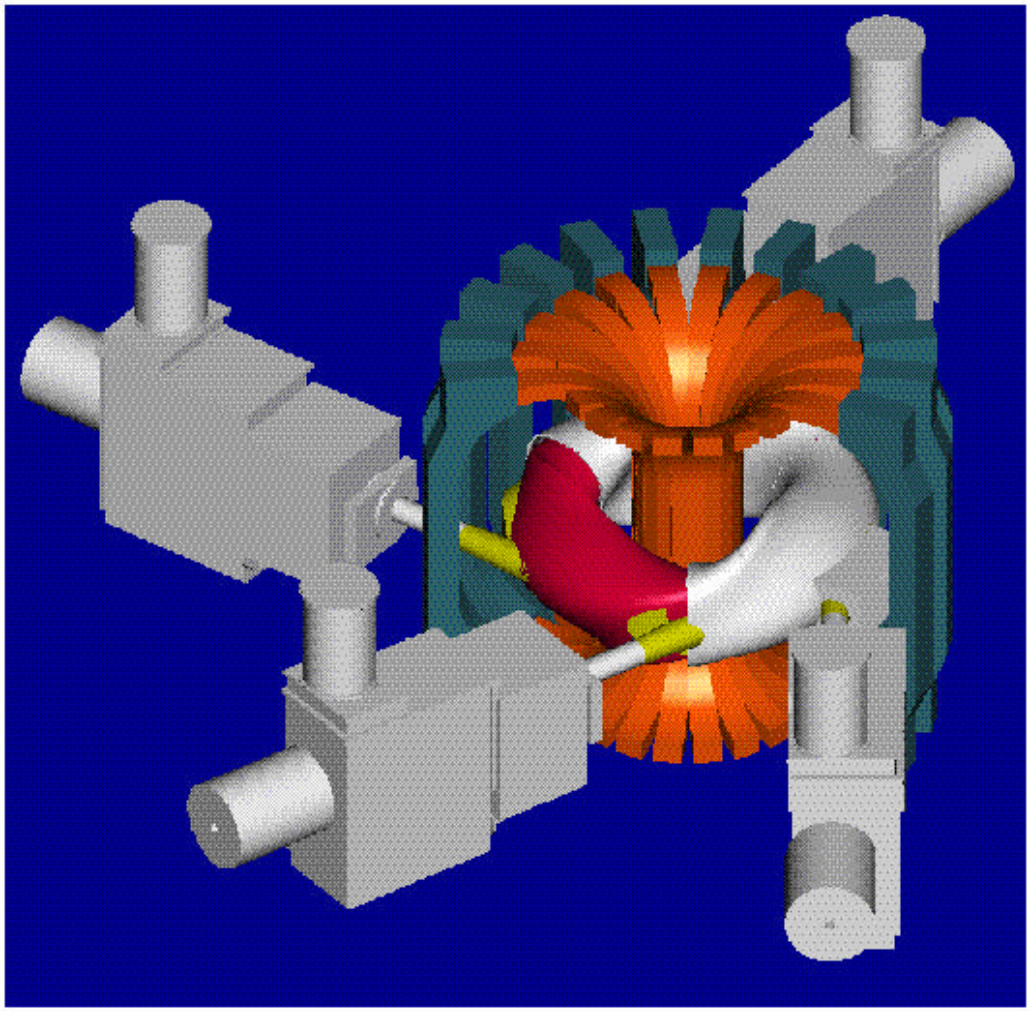
- Physics design basis is advancing (plasma and coil optimization, stability, transport, and energetic particle analyses). ⇒*A potent new U.S. capability, building on imported and U.S.-developed theoretical / computational tools.*

- Key project decisions have been made:
  - Cost-effective machine concept has been identified.
  - Reference plasma configuration satisfies performance criteria.
  - Practical saddle coil designs reconstruct reference plasma.

Smaller experiments are also progressing

- HSX construction nearing completion; CAT modifications are under way.
- QOS scoping studies have found candidate concepts that meet physics criteria.

The NCSX Construction Cost Will Be Reduced By Re-Using PBX-M Magnets and Neutral Beams



Machine Parameters

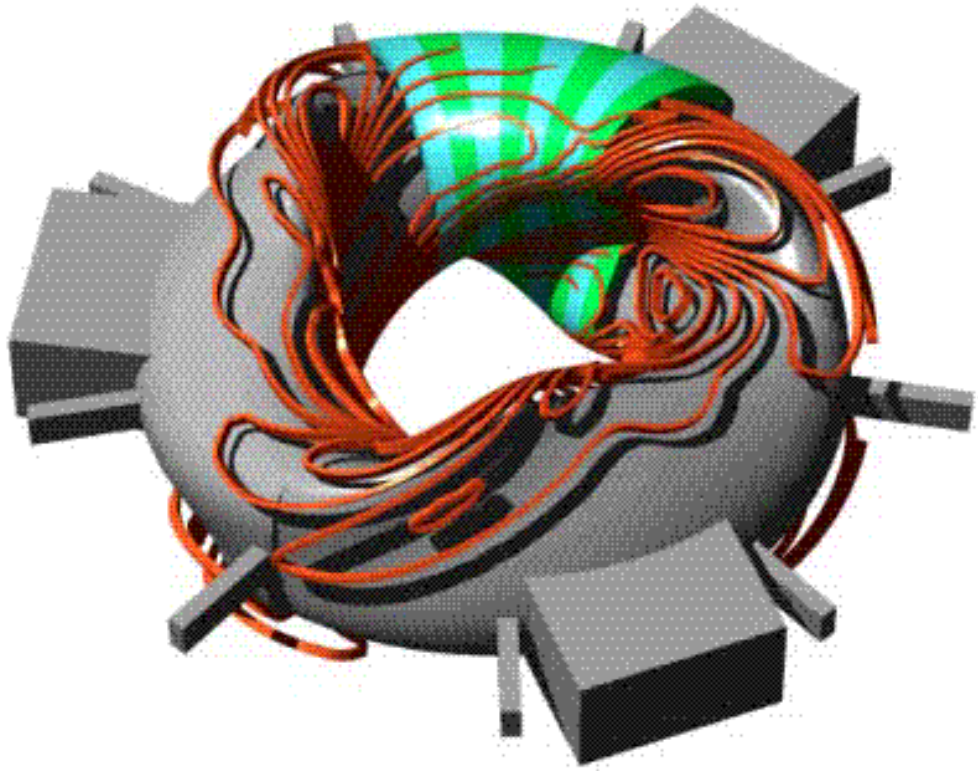
- R=1.45 m, a =0.42 m
- B≤2 T / ~0.5 s
- I ≤ 330 kA

Plasma Heating:

- NBI: 6 MW
- ICRF: 6 MW available

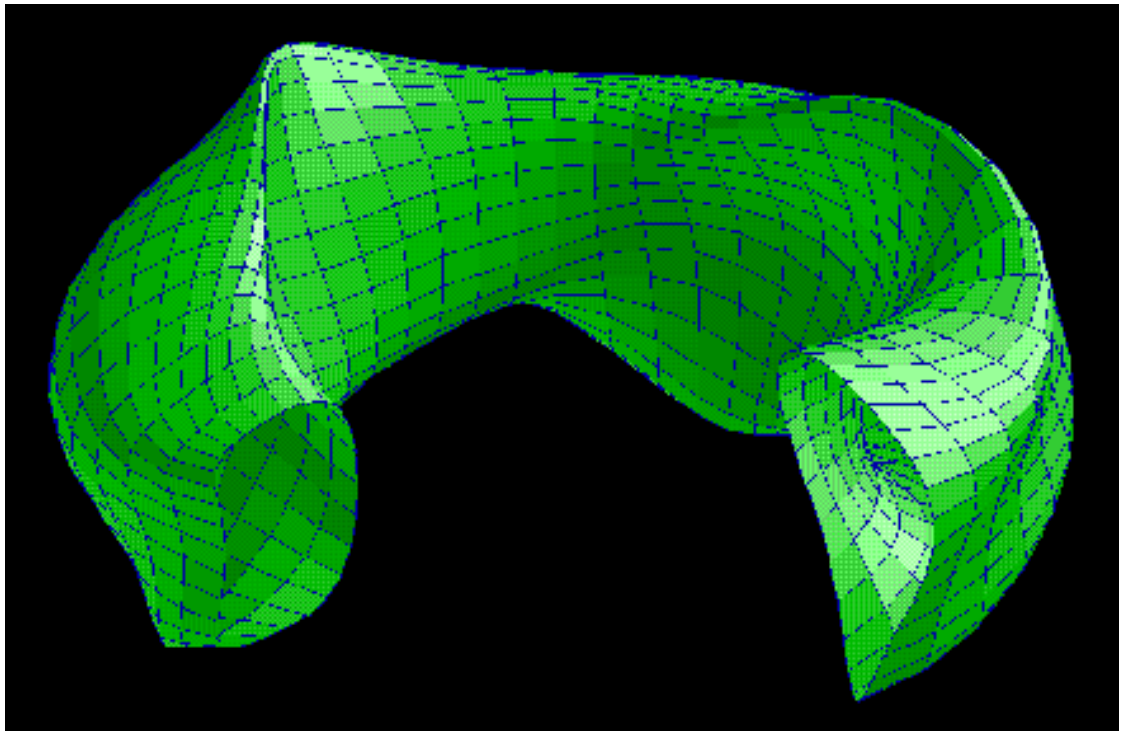
- Also re-use existing diagnostics, power supplies, C-site infrastructure at PPPL.

3D Shaping Fields Will Be Provided by Cryogenically Cooled Saddle Coils Wound on Structural Shell



- NCSX Stellarator Core Assembly (shown) will be pre-assembled and installed in PBX-M axisymmetric magnet set.
- Cost-effective for PoP using existing TF magnets, but not reactor prototypical.

NCSX Plasma Configuration Stable at $\langle\beta\rangle$=4%



- 3 field periods
- Aspect ratio 3.4 (fits in PBX-M)
- Bootstrap current ~200 kA @B=1 T
- Bootstrap-consistent current profile
- Ballooning and kink stable at β=4% without nearby conducting structures.
- Stellarator shear ($\frac{dq}{dr} < 0$) for neoclassical tearing stablility

Confinement: predict β=4% reachable with 4 beams.

NCSX Design Plans

Remainder of FY-1999

- Document physics basis, design and cost at preconceptual level.
- Scope key reactor-extrapolation issues.
- Physics community discussions: Snowmass (July), International Stellarator Workshop (Sept.)
- **Physics Validation Review, Sept., 1999**

FY-2000

- Conceptual design to establish technical, cost, and schedule baseline.
- **Conceptual Design Review, March, 2000.**

  Key step to provide technical basis for full project funding request.

Next Steps (schedule depends on funding)

- R & D to validate design approaches.
- Preliminary and final design.
- Procurement.

R & D Is Planned To Solidify Technical Basis

Saddle coils and structure

- Behavior of braided conductor in slot during thermal and magnetic cycling.
- Insulating, winding and potting of conductor.
- Automated machining of grooves in shell structure.
- Assembly of shell structure around vacuum vessel.

Vacuum vessel

- Test automated formation of vacuum vessel sections.
- Test welding together of vessel sections within geometric and magnetic permeability tolerances.

Industry involvement will provide critical manufacturability input.

QOS Scoping Studies Have Prepared the Foundation for Machine Design

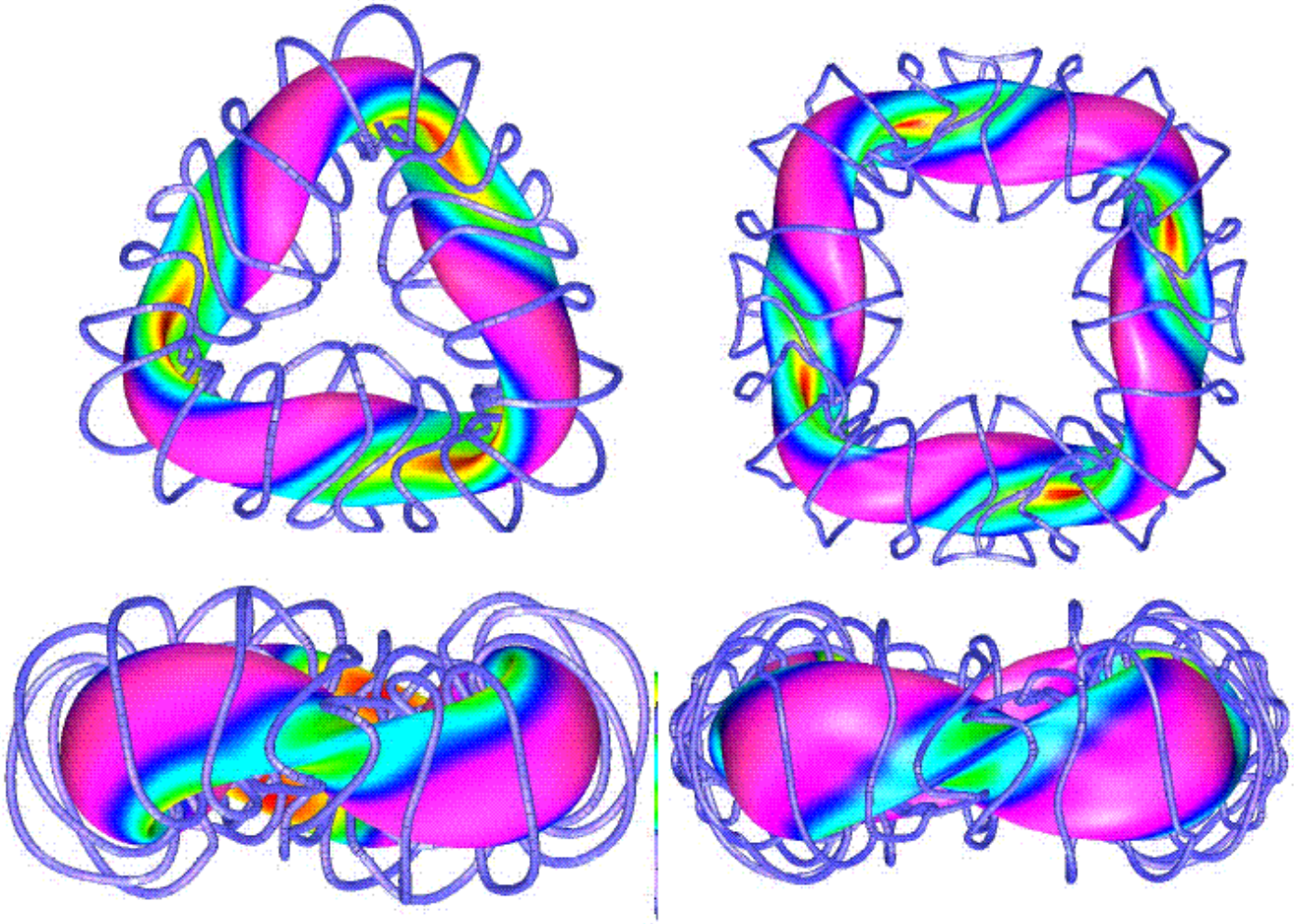
(ORNL-UTA partnership; PPPL collaborating)

Candidate Design Concepts Meet Criteria for Testing QO Principles

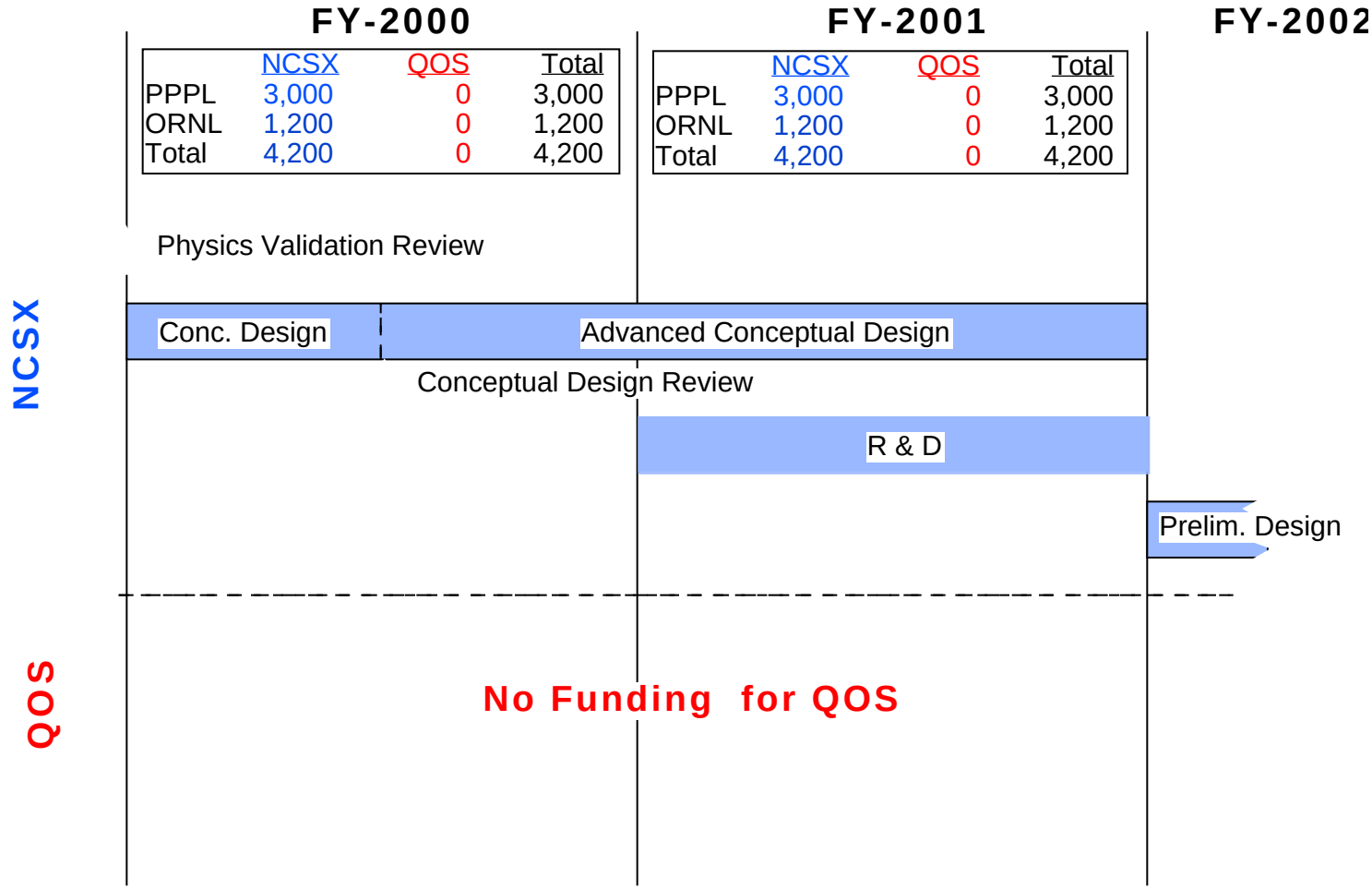
- 3-period plasma configurations at different aspect ratios; stable β~4%
  - Good confinement of thermal and energetic trapped ions.
  - Reduced neoclassical transport: test enhanced confinement, QO optimization.
  - Low bootstrap current: test configuration insensitivity to beta.
- Machine characteristics for CE mission (transport, bootstrap reduction)
  - R~1 m, a ~0.3 m, B~1 T, P_{ECH}~0.5 MW, P_{ICRF}~1.5 MW.
  - Modular coils that accurately recreate desired flux surfaces
  - New device construction, cost-effectively re-using ATF auxiliary systems and infrastructure at ORNL.

The Design Effort Needs to Start in FY-2000 in Order to Establish the Technical Basis for QOS Experiment Construction.

Candidate QOS Plasma and Coil Configurations



Flat Budgets in FY-2000-01 Will Delay Program Implementation By At Least a Year



	NCSX	QOS	Total
PPPL	3,000	0	3,000
ORNL	1,200	0	1,200
Total	4,200	0	4,200

	NCSX	QOS	Total
PPPL	3,000	0	3,000
ORNL	1,200	0	1,200
Total	4,200	0	4,200

- Focus on design and R&D efforts essential to solidifying NCSX baselines.

A $1.3M Increment in FY-2000 Would Position Both NCSX and QOS for Construction Funding in FY-2001

The $3.9M fund identified for PoP programs would strengthen the national PoP portfolio- a vital element of the restructured program.

Consider a case in which equal amounts ($1.3M) are provided for each of the three new PoP programs.

A $1.3M increment for Compact Stellarators in FY-2000 will accelerate design and R&D activities critical to solidifying the technical basis:

- NCSX (+$650k)
  Start project R&D tasks in FY-2000 instead of 2001.
- QOS (+$650k)
  Start the design effort and complete Physics Validation Review in FY-2000.

Increments of $1.3M in FY-2000 and $11.5M in FY-2001 Would Keep Program Moving Forward.

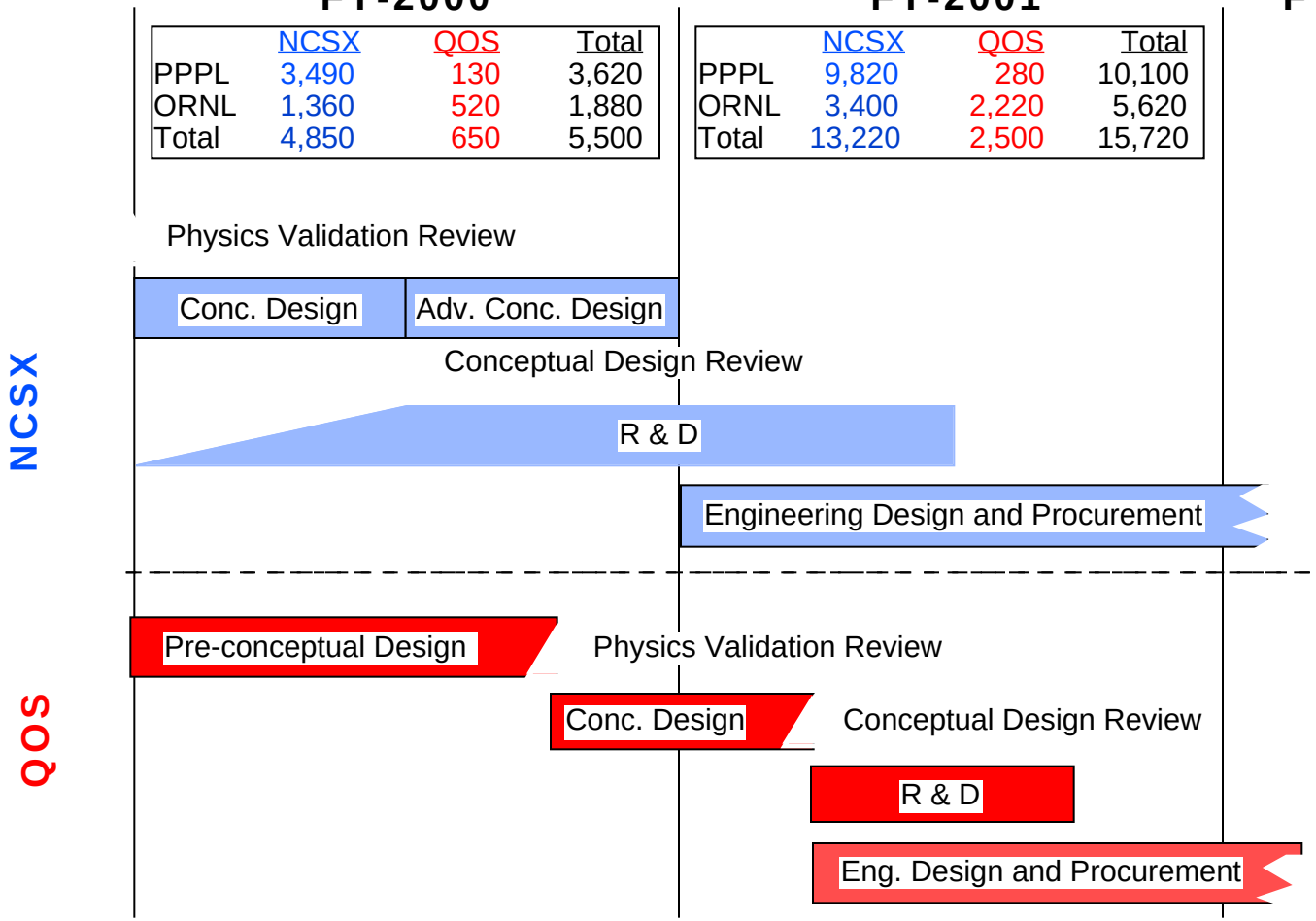
FY-2000

	NCSX	QOS	Total
PPPL	3,490	130	3,620
ORNL	1,360	520	1,880
Total	4,850	650	5,500

FY-2001

	NCSX	QOS	Total
PPPL	9,820	280	10,100
ORNL	3,400	2,220	5,620
Total	13,220	2,500	15,720

FY-2002



NCSX and QOS Title I design start in FY-2001

Construction-Funded Activities Could Start in FY-2001 or in FY-2000 as Originally Proposed.

	Guidance		+$1.3M in 2000; Constr. In 2001		+$5.9M in 2000; Constr. In 2000	
	2000	**2001**	**2000**	**2001**	**2000**	**2001**
NCSX	4,200	4,200	4,850	13,220	8,830	13,220
QOS	0	0	650	2,500	1,300	2,500
Total	4,200	4,200	5,500	15,720	10,130	15,720
NCSX Milestones						
Physics Validation Review	Sep., 1999		Sep., 1999		Sep., 1999	
Conceptual Design Review	Mar., 2000		Mar., 2000		Mar., 2000	
Start R&D	Oct., 2000		Apr., 2000		Apr., 2000	
Start Preliminary Design	Oct., 2001		Oct., 2000		Apr., 2000	
Start Final Design			Mar., 2001		Oct., 2000	
Start Procurement			Jun.,2001		Jan., 2001	
Complete Final Design					Sep., 2001	
QOS Milestones						
Physics Validation Review			Jun., 2000		Apr., 2000	
Conceptual Design Review			Dec., 2000		Sep., 2000	
Start Final Design			Jun., 2001		Mar., 2001	
Start Procurement			Aug.,2001		May, 2001	

The Compact Stellarator Community Is Working Together Effectively

- A national project organization for NCSX is in place (PPPL, ORNL, UTA, Columbia, Auburn). Integrated physics and engineering teams have been functioning productively since mid-1998.
- Completed PPPL-ORNL Memorandum of Understanding delineates responsibilities and organization. Both laboratories are committed to NCSX and QOS moving forward together.
- Sound advice from informal Program Advisory Committee (members from U.S. and abroad) has influenced NCSX technical directions.
- National Stellarator Program Planning Committee (members from 10 institutions) has resolved key program issues and produced deliverables (1998 white paper, 2-pagers).

Summary

- The Compact Stellarator program has made excellent progress and is ready to move toward construction of its needed new experimental facilities.
  - NCSX: Key project decisions have been made.
  - QOS: Scoping studies have prepared the foundations for machine design.

- It is important to expedite the design and R&D work needed to establish technical, cost, and schedule baselines.
  - NCSX: Physics Validation Review in Sept., 1999
    Conceptual Design Review in March, 2000
    R&D Starting in FY-2000.
  - QOS: Physics Validation Review in FY-2000.

- Incremental funding in FY-2000 ($1.3M) and in FY-2001 ($11.5M) would put program implementation on a good schedule.

With Incremental Funding in 2000 and 2001 NCSX Could Proceed As Called For in PoP Program Proposal

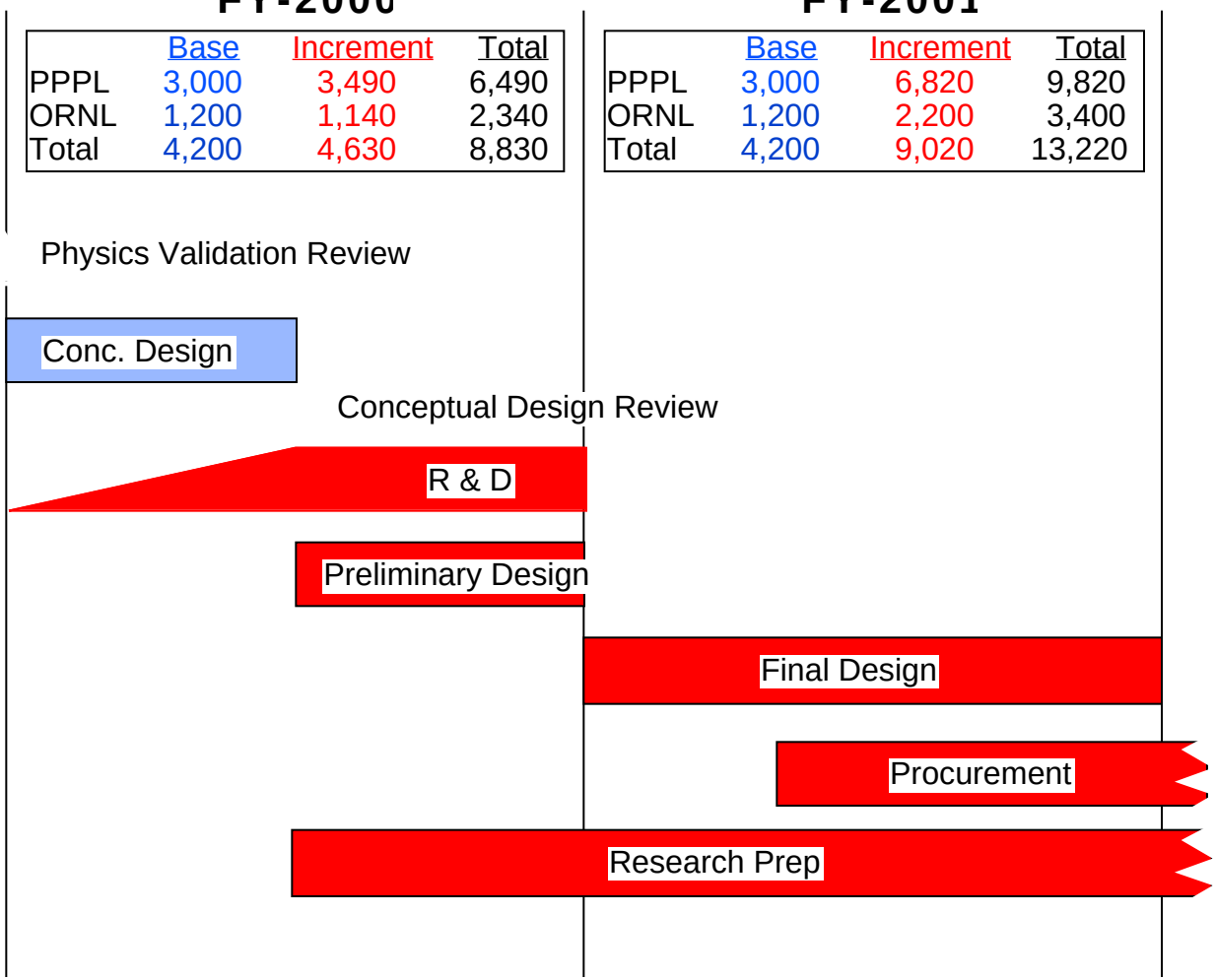
FY-2000

	Base	Increment	Total
PPPL	3,000	3,490	6,490
ORNL	1,200	1,140	2,340
Total	4,200	4,630	8,830

FY-2001

	Base	Increment	Total
PPPL	3,000	6,820	9,820
ORNL	1,200	2,200	3,400
Total	4,200	9,020	13,220

FY-2002

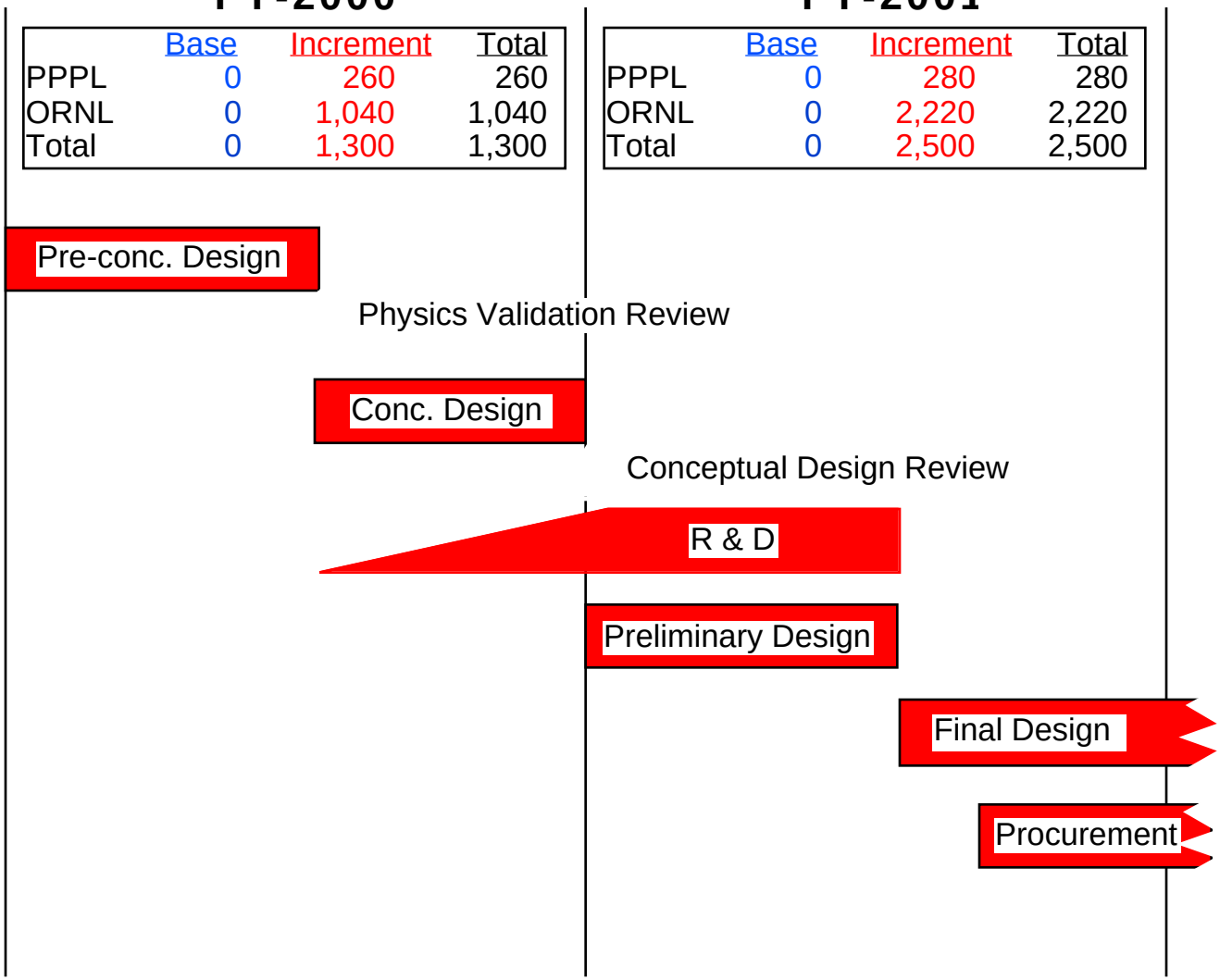


With Incremental Funding in 2000 and 2001 QOS Could Proceed As Called For in PoP Program Proposal

FY-2000

	Base	Increment	Total
PPPL	0	260	260
ORNL	0	1,040	1,040
Total	0	1,300	1,300

FY-2001

	Base	Increment	Total
PPPL	0	280	280
ORNL	0	2,220	2,220
Total	0	2,500	2,500

FY-2002