Fusion Energy Research at PPPL

Presentation to
Walter Polansky, MICS
Buff Miner, MICS
Arnold Kritz, OFES

Professor Robert Goldston, Director
DOE Princeton University Plasma Physics Laboratory
August 28, 2002

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The Future of Energy on Earth is the Energy of the Stars — Fusion Energy

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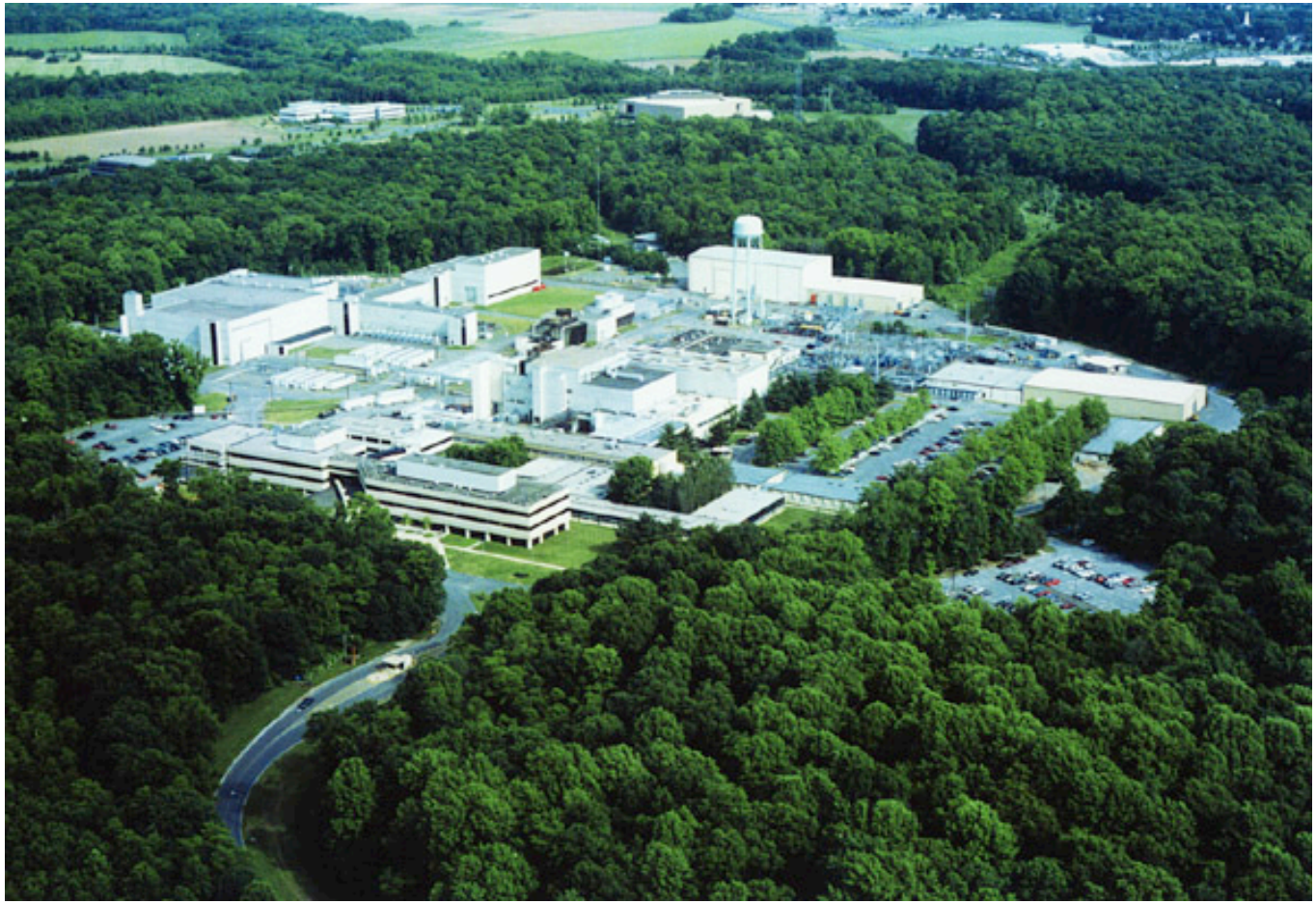
DOE Princeton University
Plasma Physics Laboratory



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Fusion Energy

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PPPL's Mission is Plasma Physics & Fusion Energy

The DOE Princeton Plasma Physics Laboratory is *a Collaborative National Center* for plasma and fusion science. Our primary mission is to develop *the scientific understanding and the key innovations* which will lead to an *attractive new energy source*.

"Science and Innovation for Practical Fusion Energy"

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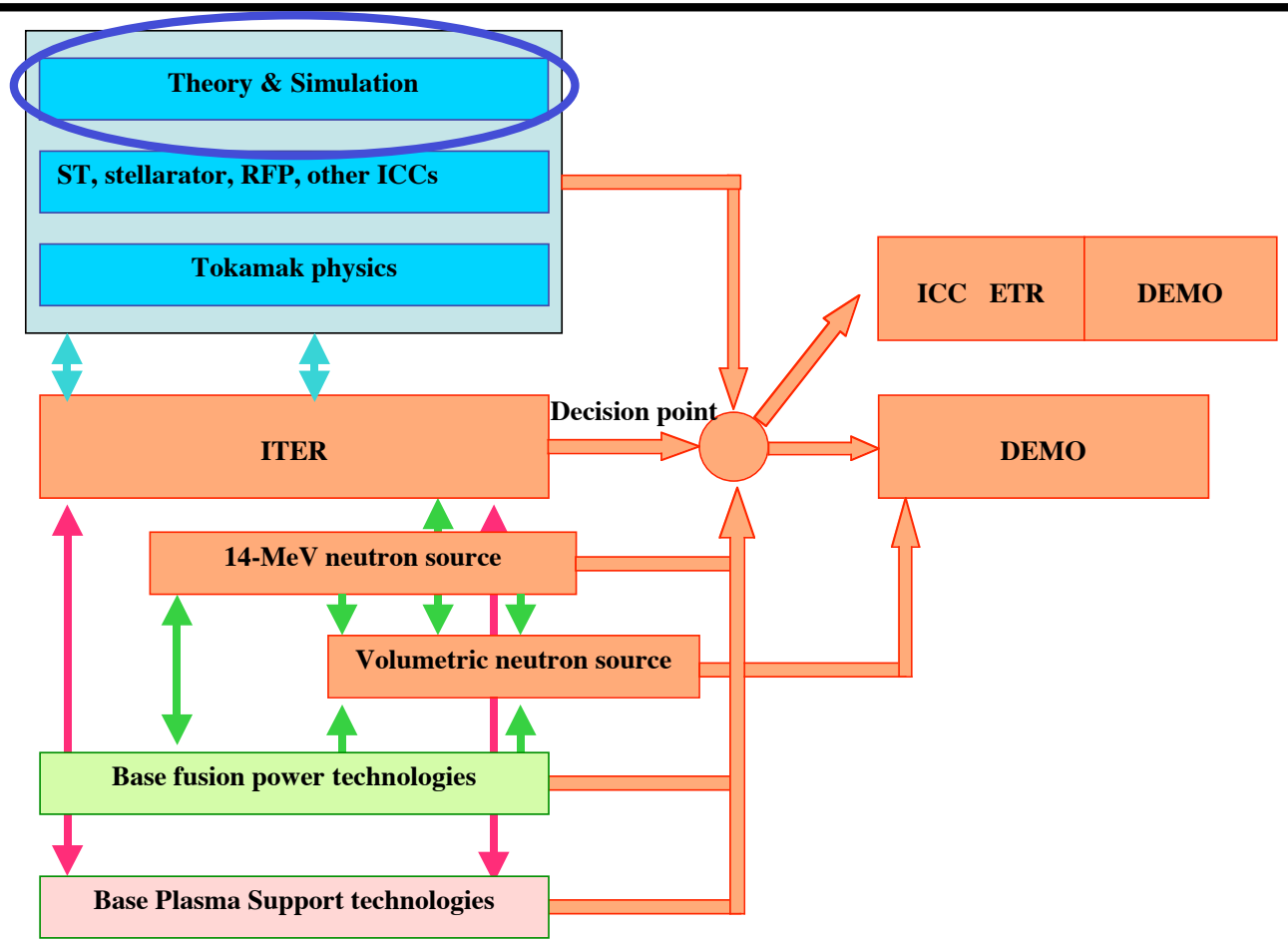
Snowmass Defined a Development Path for Fusion Energy



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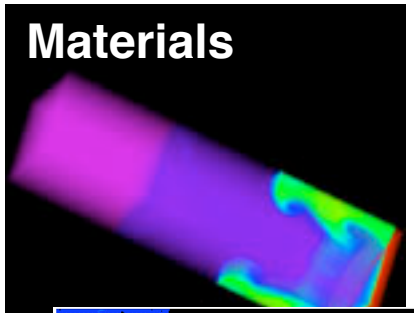
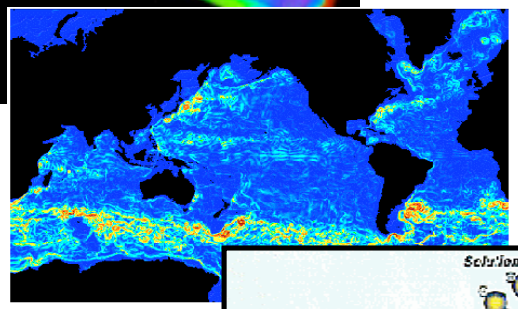
Advanced Computing

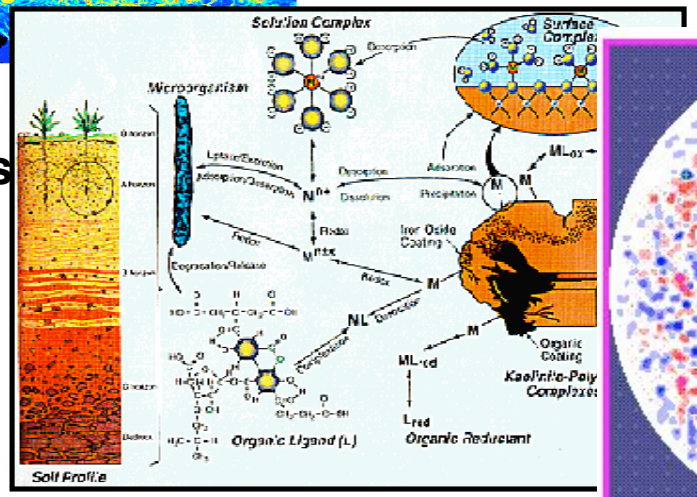
is Critical to Discovery in Many Scientific Disciplines

DOE Science Programs Need Dramatic Advances in Simulation Capabilities To Meet Their Mission Goals

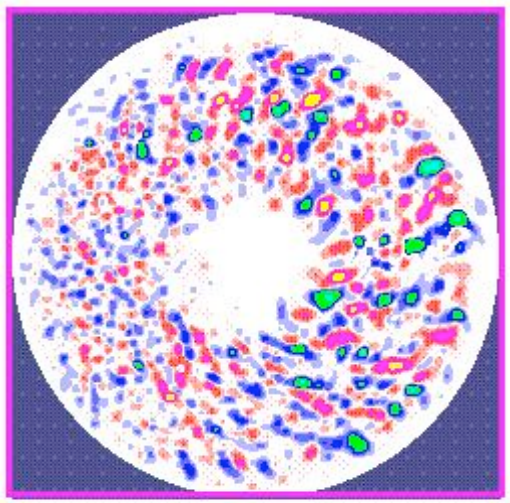




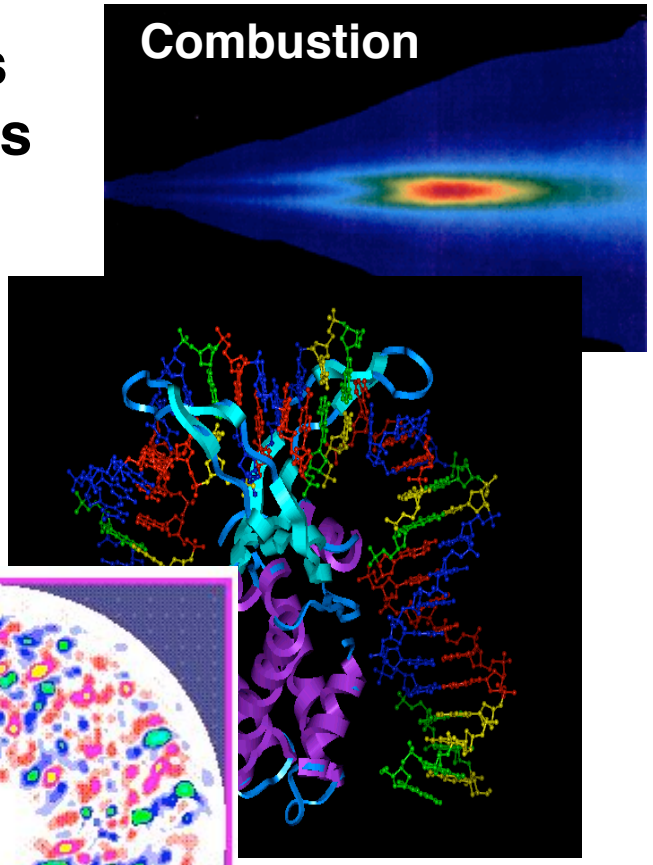
Global Systems



Subsurface Transport



Fusion Energy



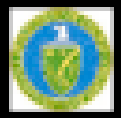
Health Effects, Bioremediation

Simulation of Microwave Reflection From Plasma Turbulence

Z. Lin, GTC simulation

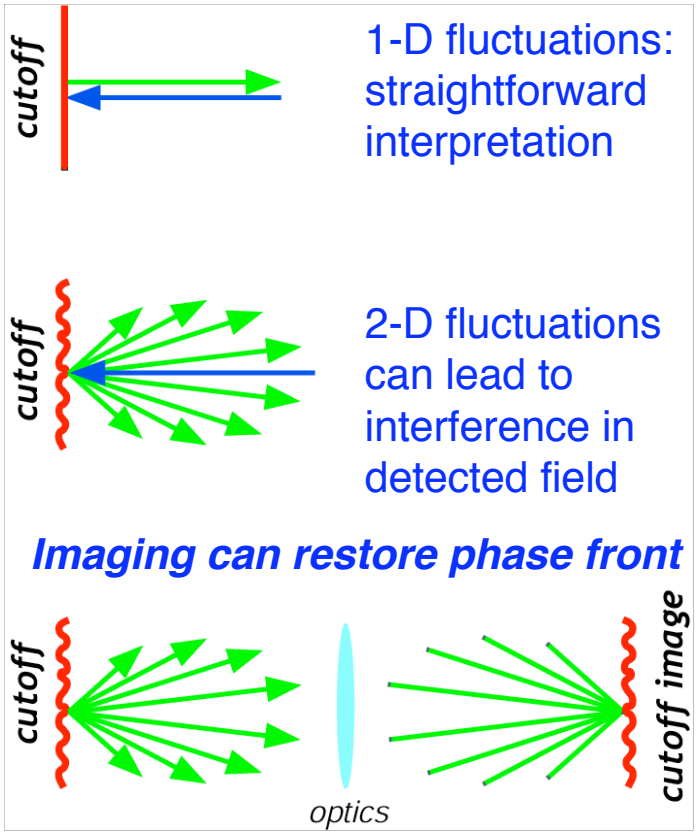
G.J. Kramer, E. Valeo, R. Nazikian, Full Wave simulation

S. Klasky, I. Zatz, Visualization

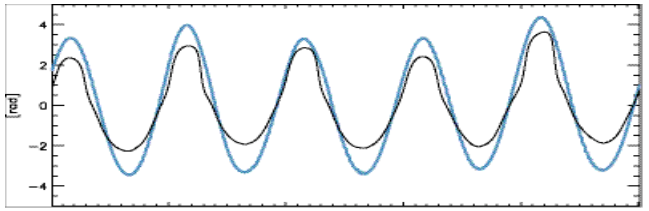


Microwave Imaging Reflectometry

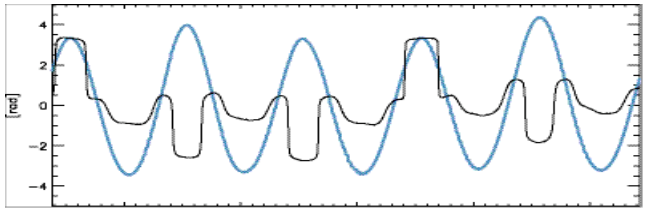
Laboratory tests of corrugated targets demonstrate limitations of 1-D reflectometry and improvements with MIR



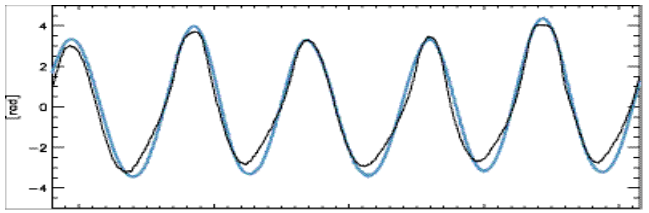
1-D System *d=10 cm*



1-D System *d=30 cm*



MIR System *d=235 cm* ***(at focus)***



Black curves are 1-D/MIR data
Blue curve is measured reference

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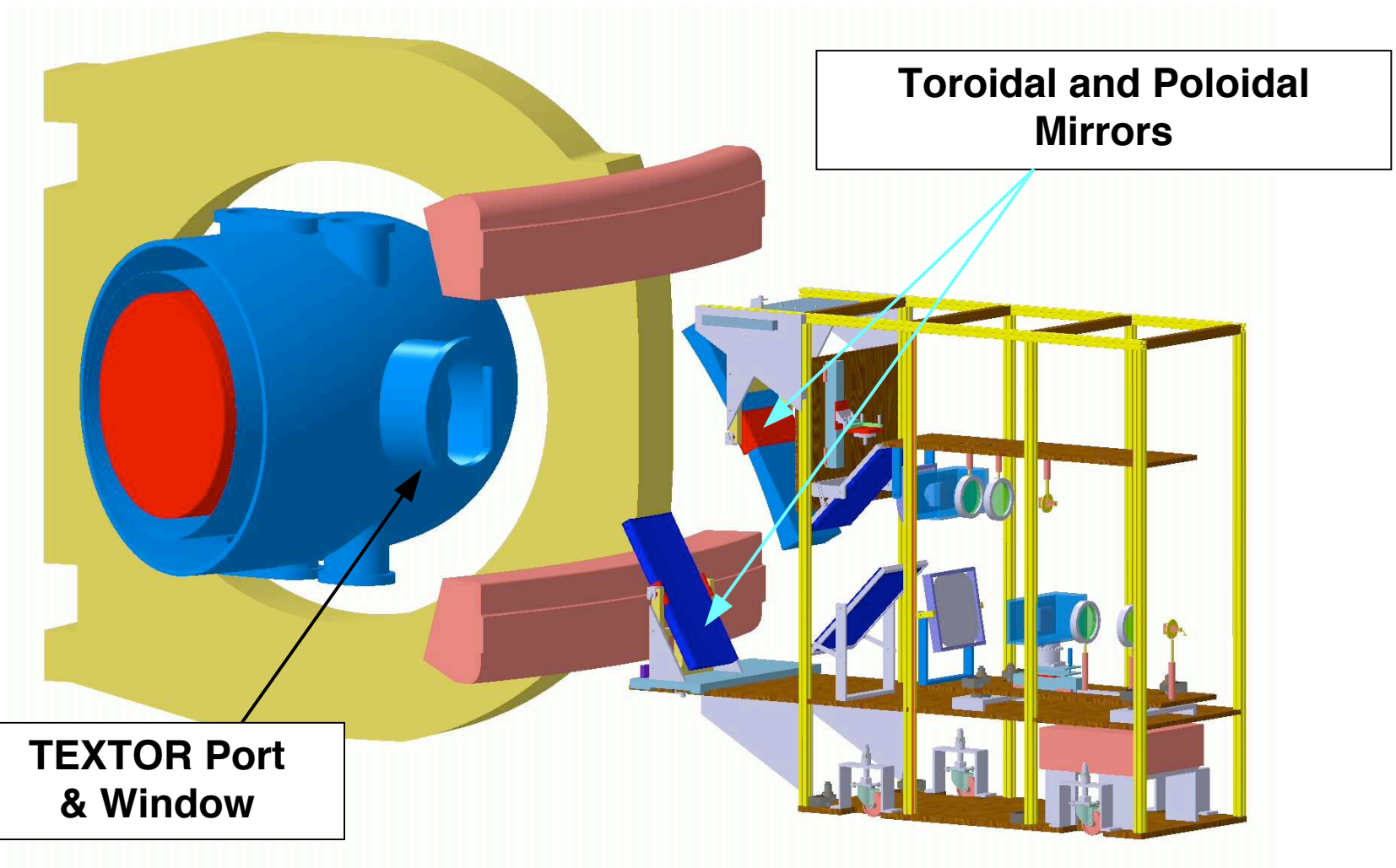
Reflectometry Imaging System



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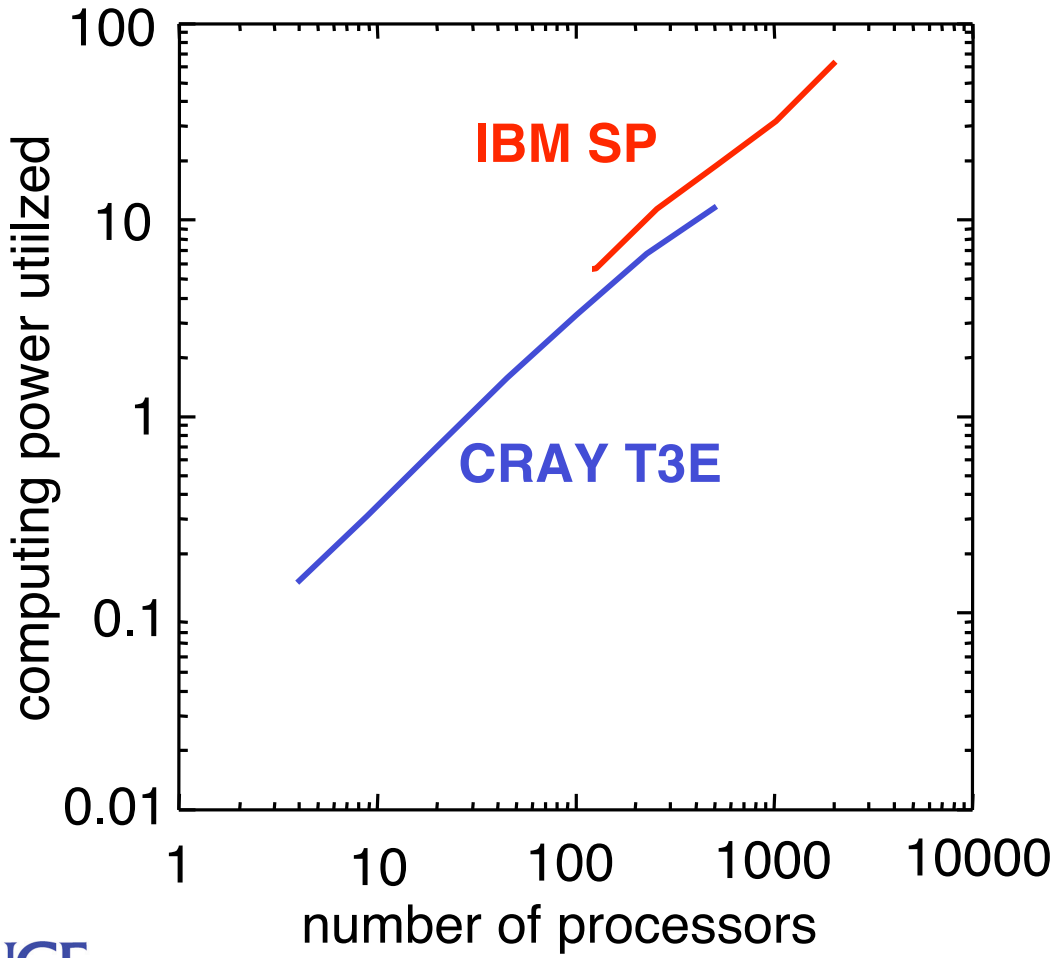
PPPL Fusion Codes have Delivered Results on the Most Powerful Computers at DOE-SC



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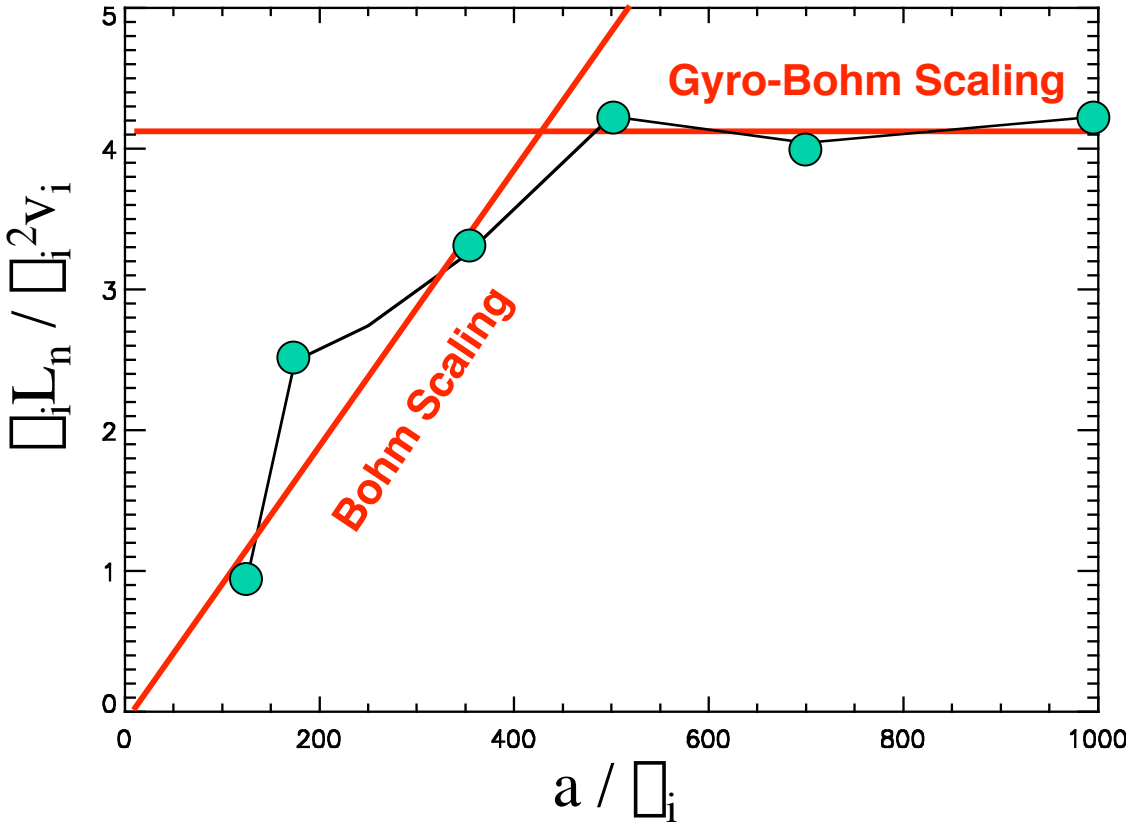
Simulations of Turbulent Losses vs. Size are Favorable for ITER



The largest simulation used 1 billion particles and 125 million zones.

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PPPL / GFDL / Princeton are Exploring a Joint Computing Proposal

- **Geophysical Fluid Dynamics Lab**
  - Lead for NOAA scenario calculations
- **Princeton University**
  - Leader in computational astrophysics
  - Leader in geophysical computation
- **PPPL**
  - Leader in fusion computation
- **May be opportunity for DOE to partner with NOAA and Princeton.**
  - Building on new Fusion Prototype Topical Computing Facility (Thank-you!)

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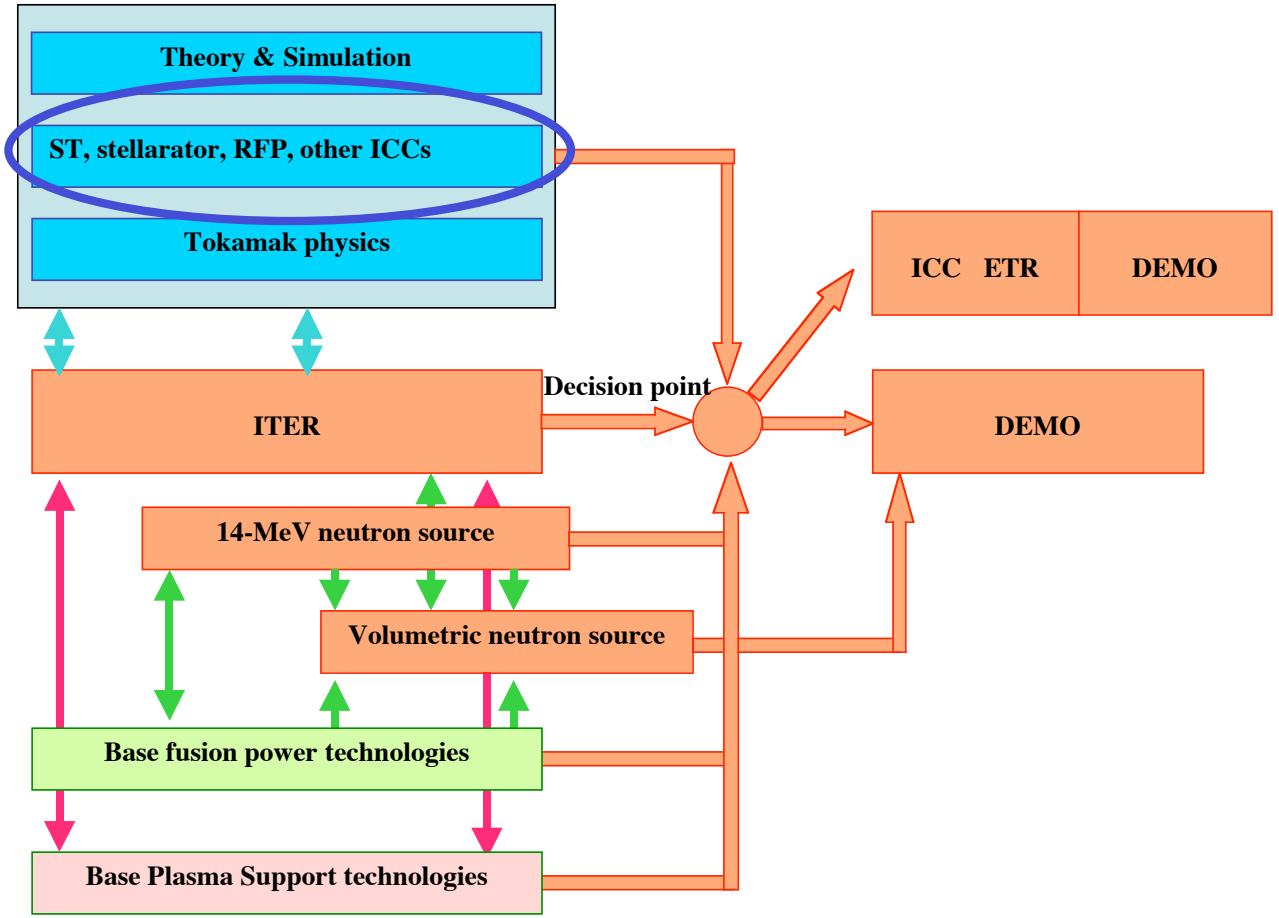
Snowmass Defined a Development Path for Fusion Energy



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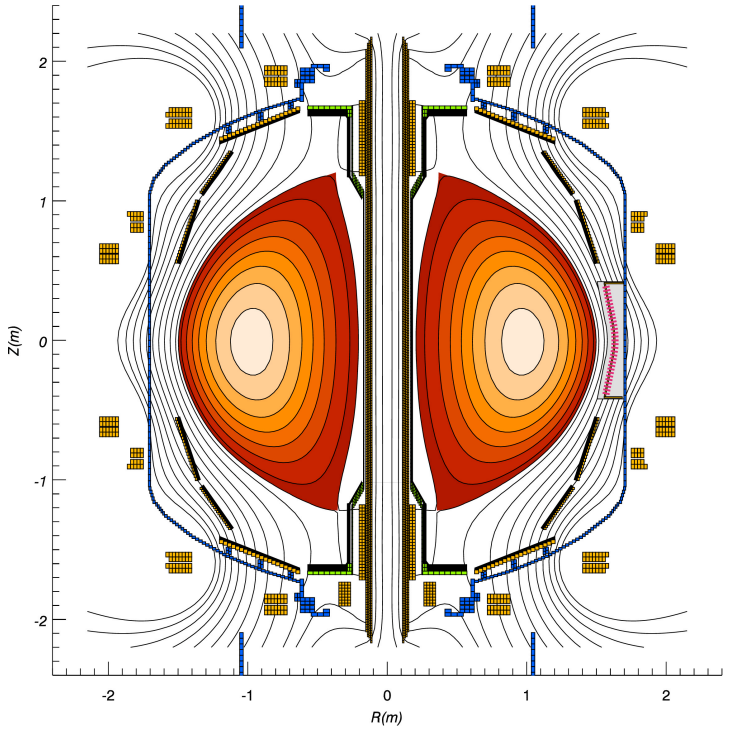
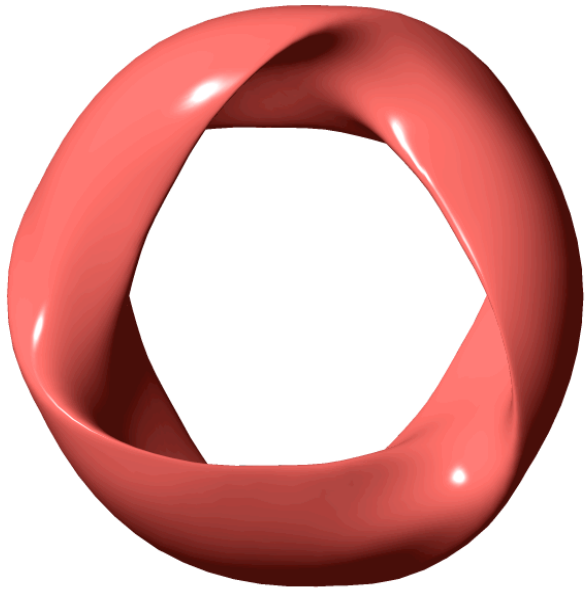
New Toroidal Plasma Configurations Address Key Issues for Fusion



Spherical Torus offers high fusion power density at low magnetic field.



Compact Stellarator design optimizes plasma stability and steady-state properties.

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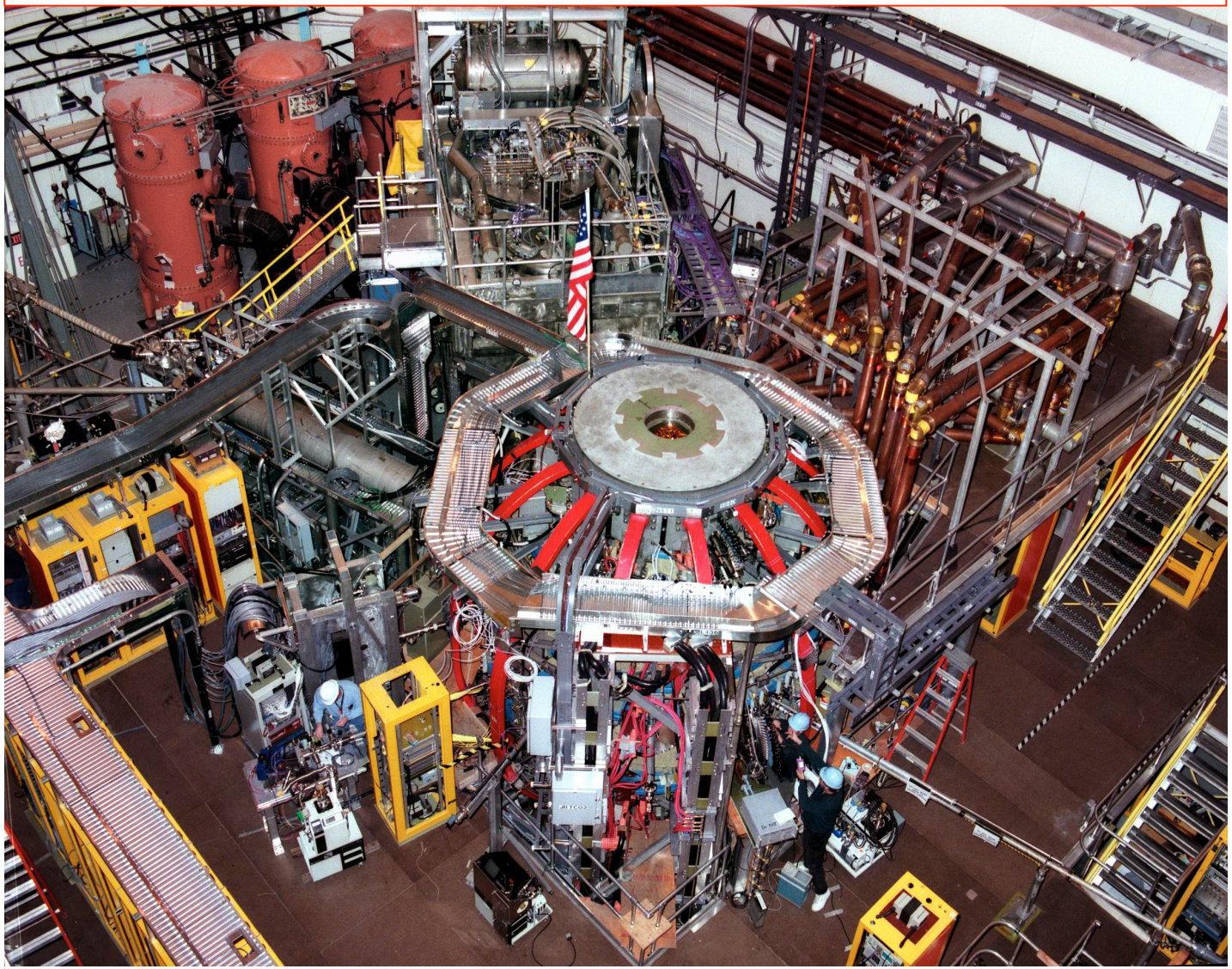
National Spherical Torus Experiment



Los Alamos NATIONAL LABORATORY
NOVA PHOTONICS
ornl
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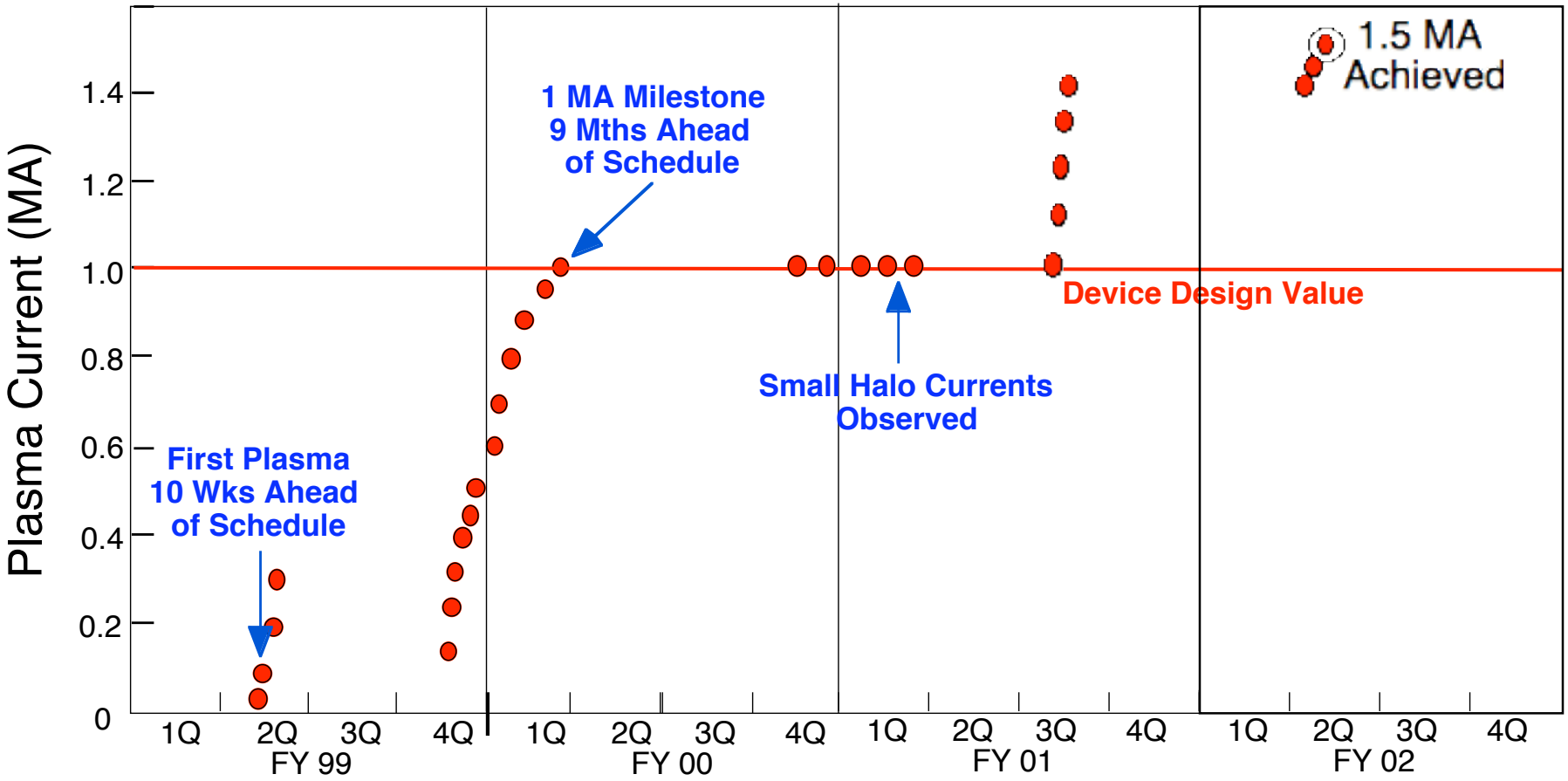
Sandia National Laboratories
UCLA
UCSD
UW

NSTX Delivered Design Value Current 9 Months Ahead of Schedule – then Exceeded its Goal by 50%



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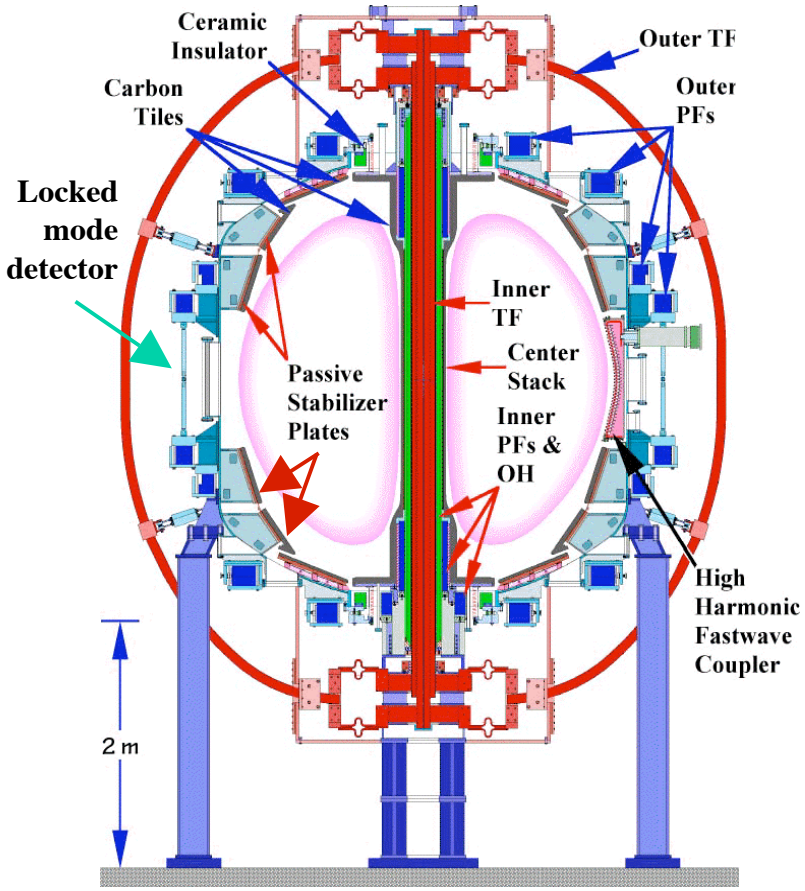
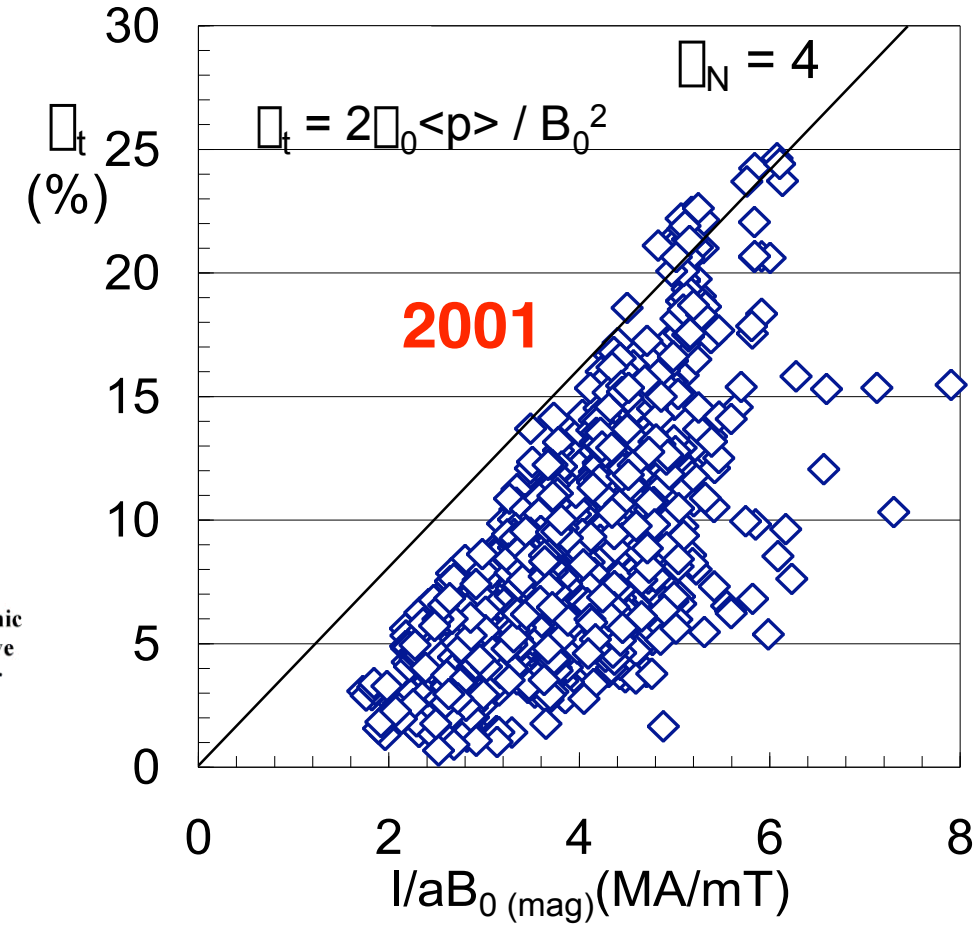
NSTX Reached β_t = 25% in FY 2001 – Its Goal for FY 2002 !





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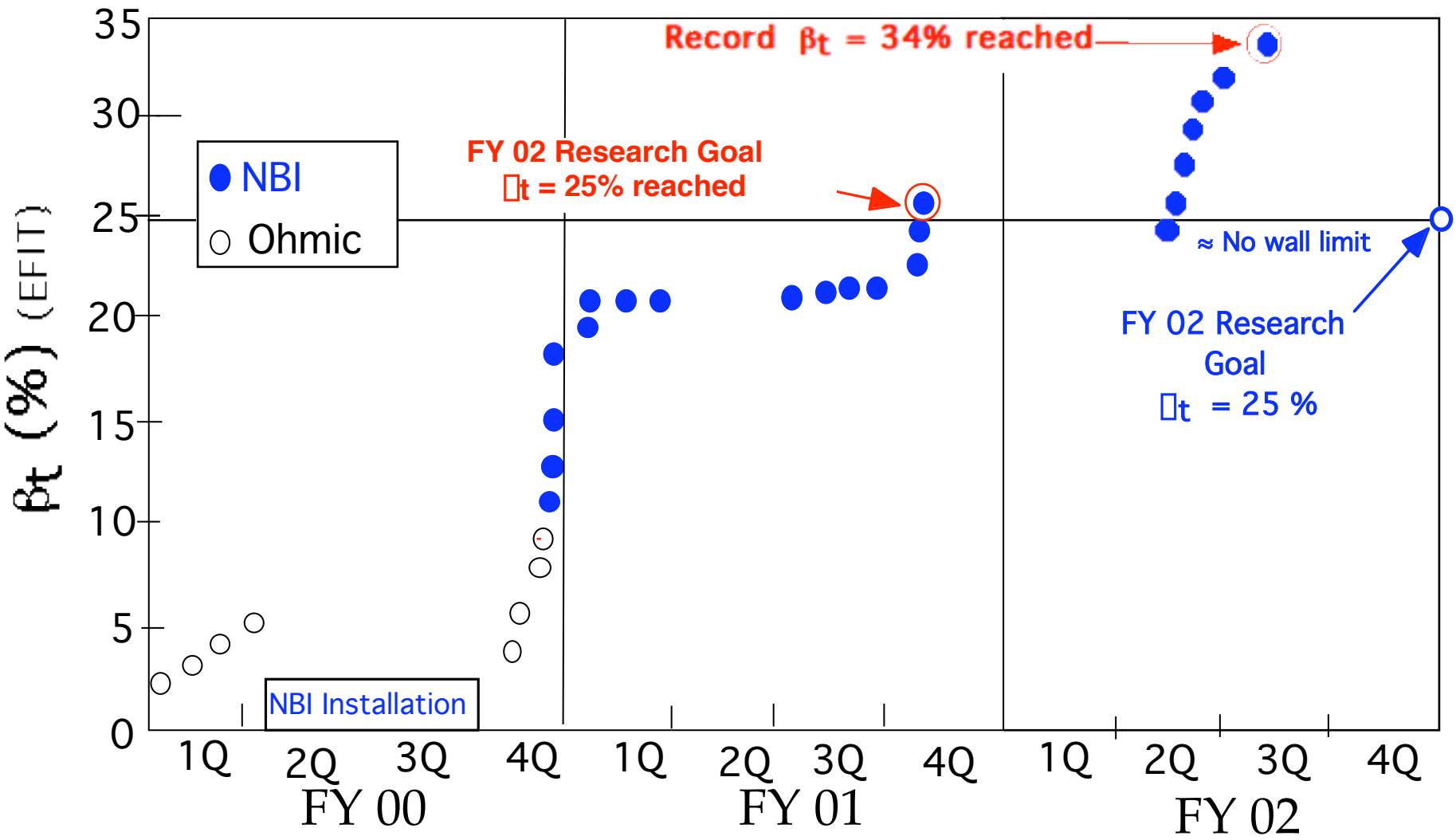
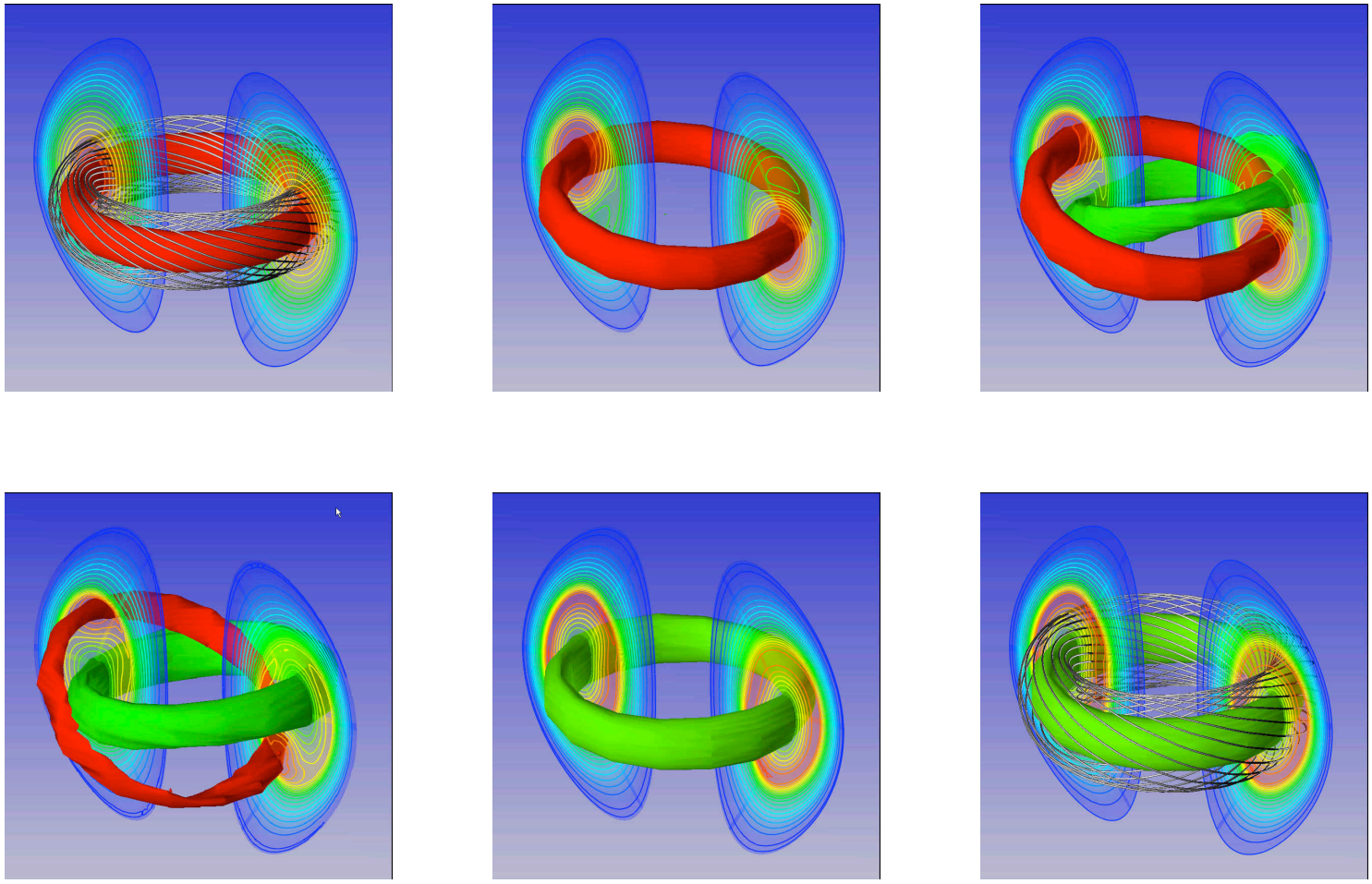
High Beta Research on NSTX Delivered Ahead of Schedule – and Beyond FY2002 Goal



M3D Code has Uncovered New Stabilization Effects in NSTX



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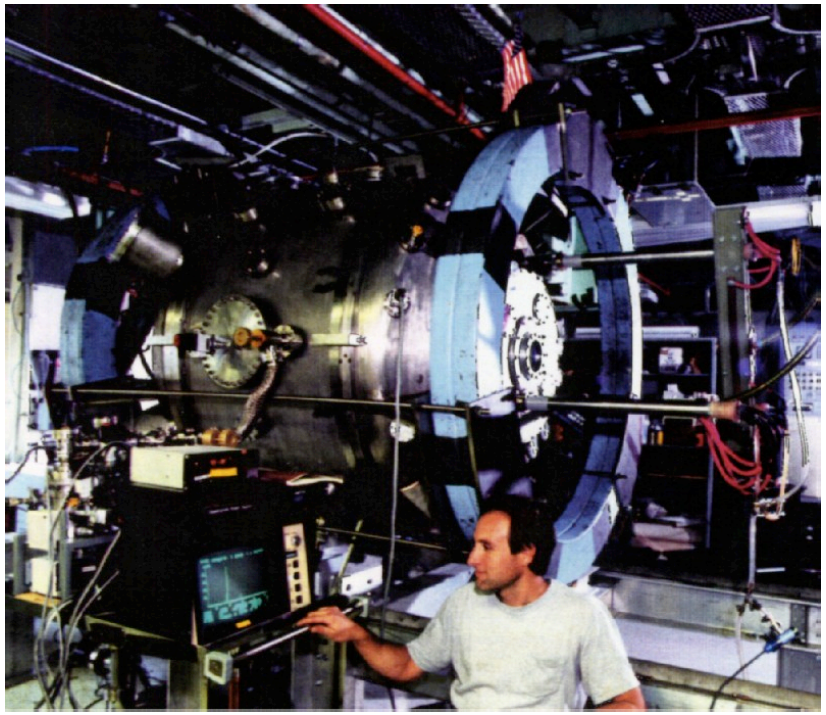
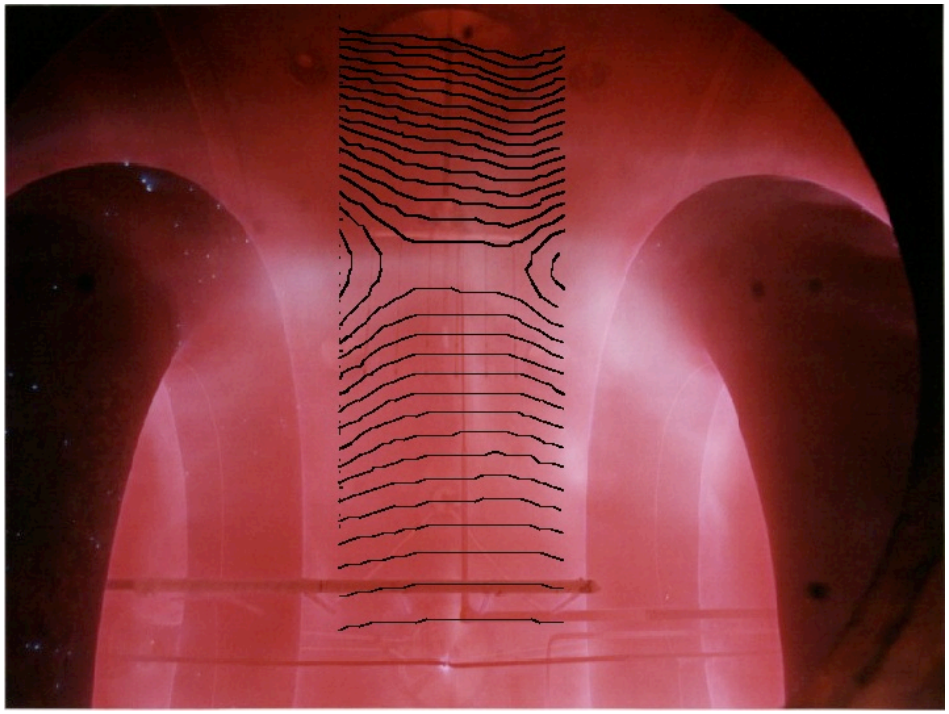
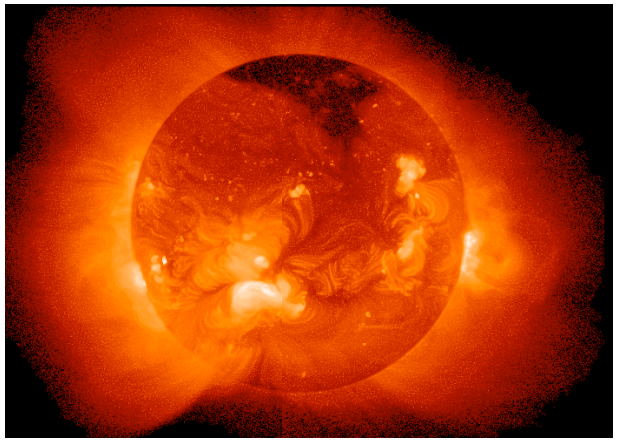
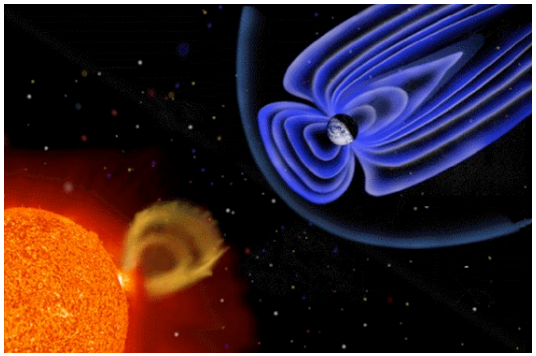
Magnetic Reconnection Experiment

Winner of 2002 Excellence in Plasma Physics Award









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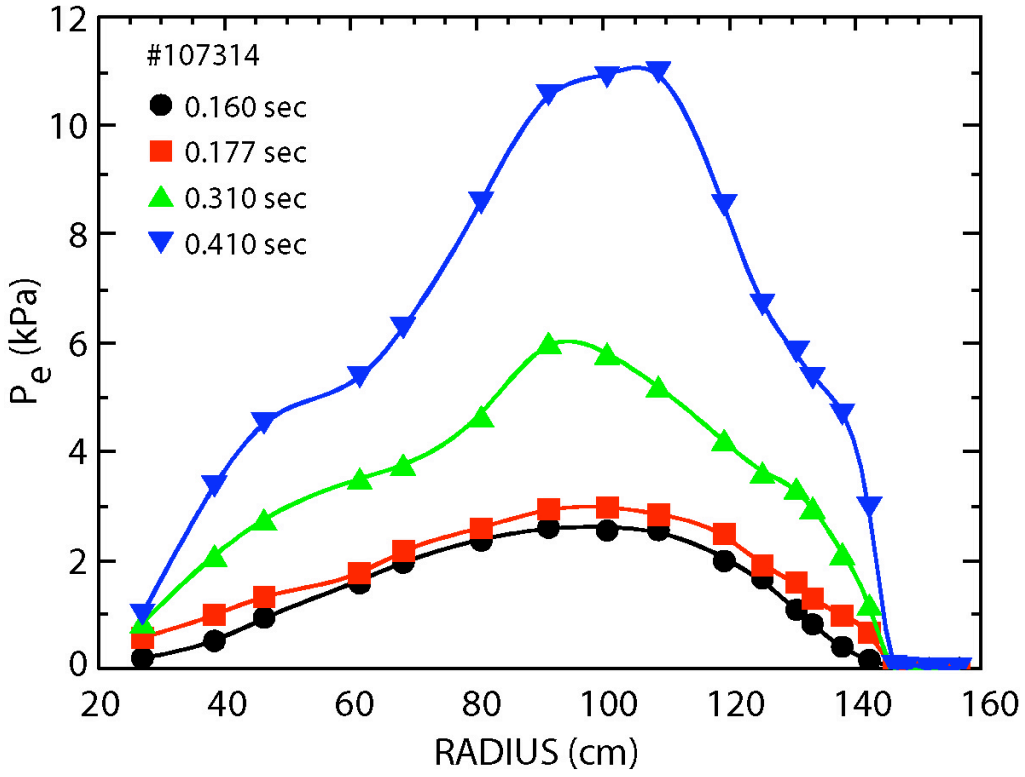
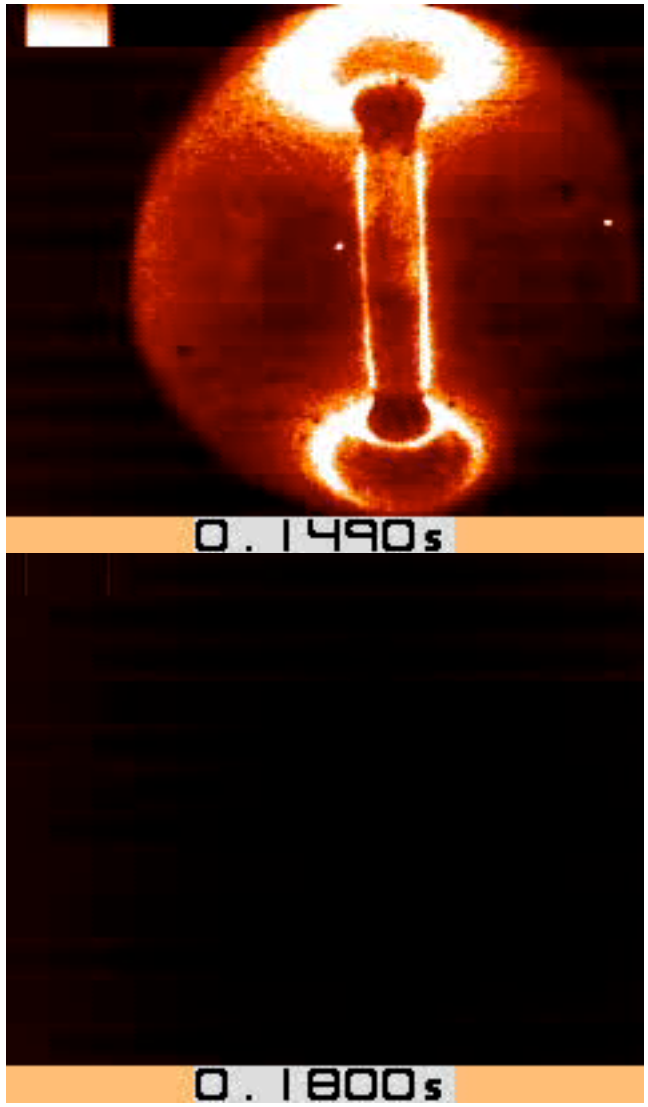
Very Steep Pressure Gradients are Observed near Edge of Plasma in H-mode





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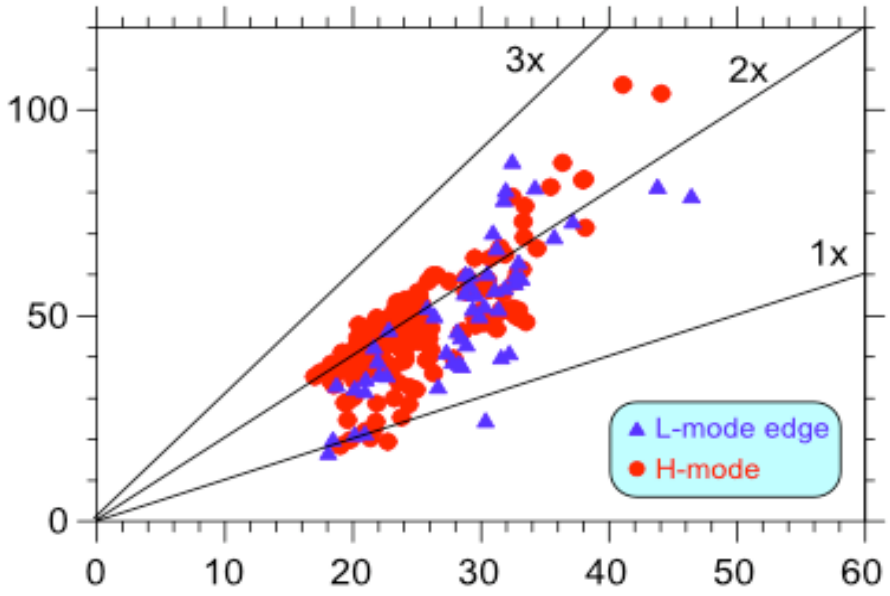
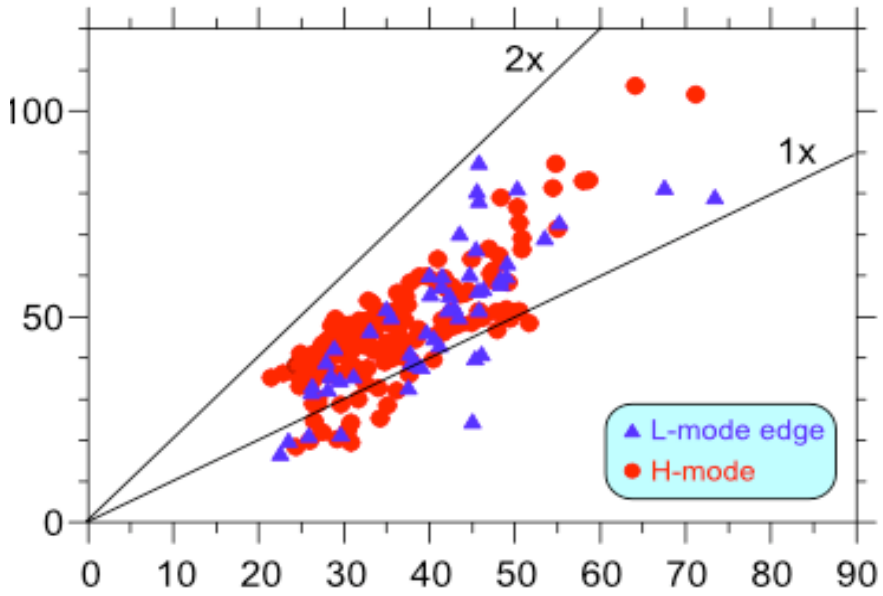
Recent NSTX Results Show Large Confinement Improvement Over Conventional Expectations



L-mode scaling (msec)



H-mode scaling (msec)

Improved confinement was predicted theoretically for NSTX!

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Compact Stellarator offers Passive Stability and Steady-State Operation

Goal:
Stable, steady-state operation with excellent plasma confinement and low power for plasma sustainment and control.

Technique:
Use massively parallel computing to optimize 3-dimensional shaping.

Cost: $73.5M as spent
PPPL - ORNL construction project.
In President's FY2003 budget.

Auburn U., Columbia U., LLNL, NYU, ORNL, PPPL, SNL-A, U. Texas, UCSD, U. Wisconsin

Australia, Austria, Japan, Germany, Russia, Switzerland, Ukraine

FESAC Strongly Endorsed the National Compact Stellarator Experiment

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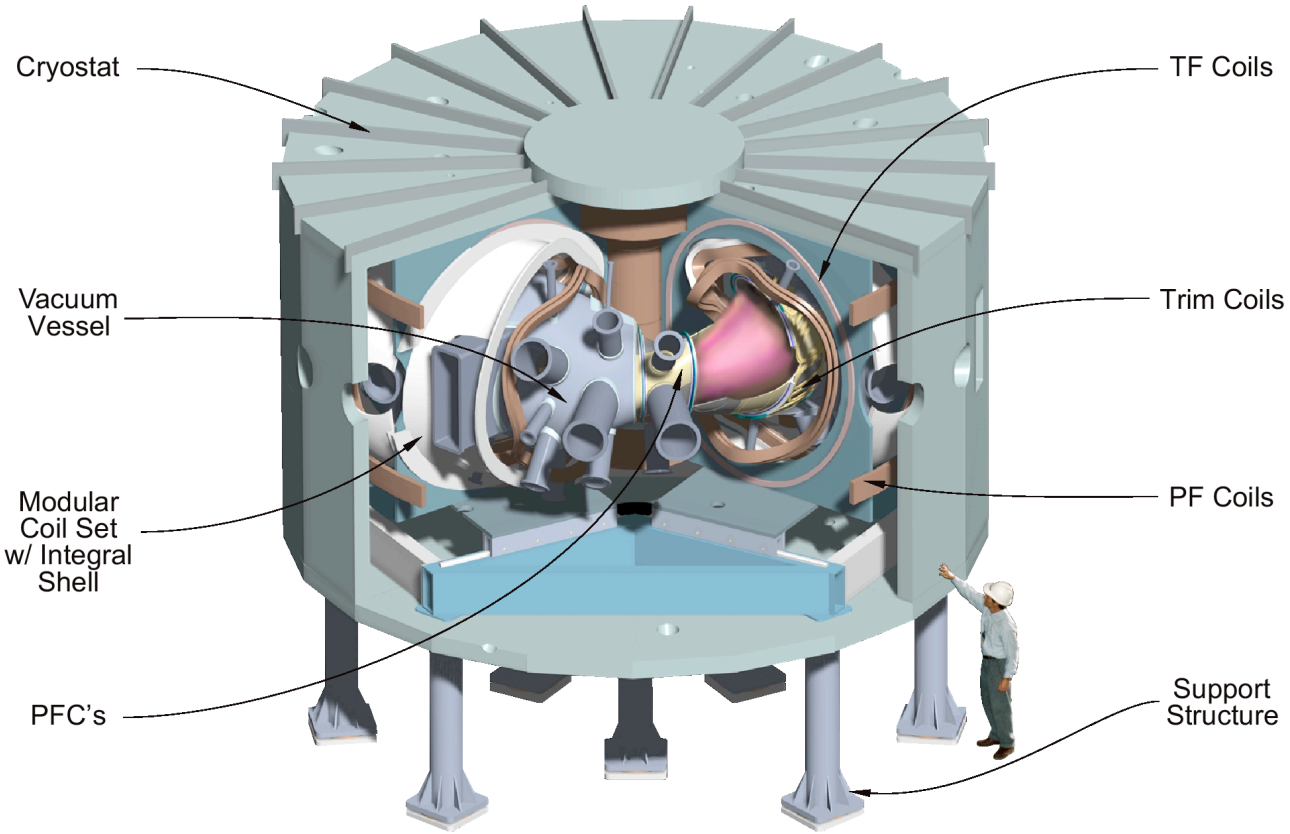
"The NCSX program offers an exciting opportunity in fusion research for several reasons.

- ***First**, a plausible case has been made (for example, at the NCSX Physics Validation Review) that a fusion power system based on a compact stellarator may resolve two significant issues for fusion power systems: **reduction or elimination of plasma disruptions, and provision for steady-state operation**. **These gains earn for the compact stellarator an important place in the portfolio of confinement concepts being pursued by the US Fusion Energy Sciences program.***

- ***Second**, the NCSX would **complement research now underway on the advanced tokamak,** which addresses closely related issues by different methods. It also **complements stellarator research outside the US**, which has emphasized different geometries and plasma regimes.*

- ***Finally**, understanding the behavior of magnetized plasmas in **three-dimensional configurations is an important scientific frontier area**, which the NCSX program would advance and strengthen."*

NCSX Design has Come Together



Passed DOE-SC Lehman Review, May 2002, with flying colors!

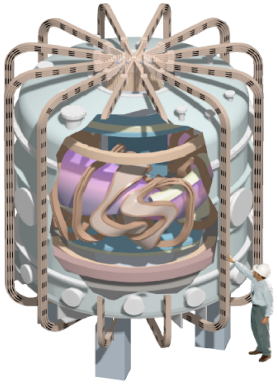
Project Execution Plan Signed.

NCSX Design has Come Together

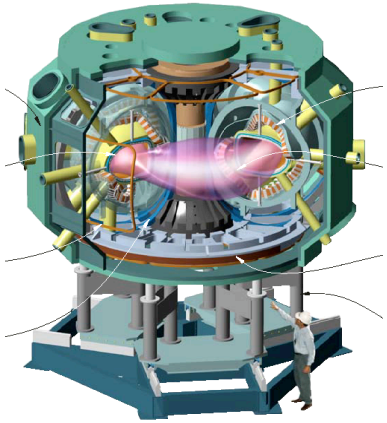
NCSX
Stellarator Core
Assembly Sequence

Passed DOE-SC Lehman Review, May 2002, with flying colors!
Project Execution Plan Signed.

U.S. Program Aims at a Compact Stellarator Design



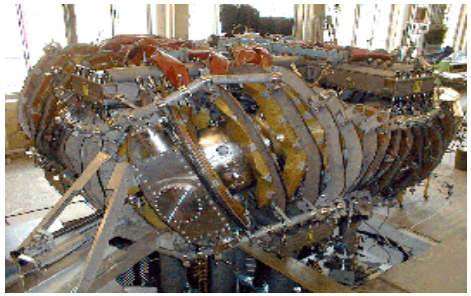
QPS (ORNL) - in design
Compactness limits



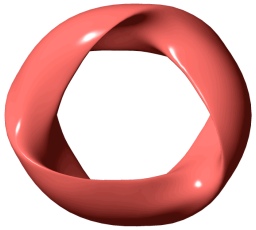
NCSX

Integrated test of compact stellarator physics

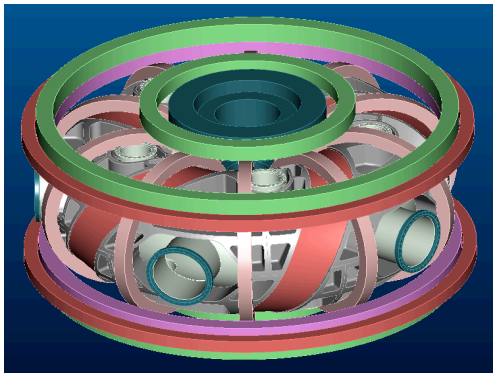
- How high can the plasma pressure be?
- What is the optimum 3D shape?
- How compact can we make it?



HSX (U. Wisconsin)
First test of quasi-symmetry



Theory & Computation
Optimized Design
Predictive Capability



CTH (Auburn U.) - Ops. in 2003
Stability Physics

What is the best design for a fusion reactor?

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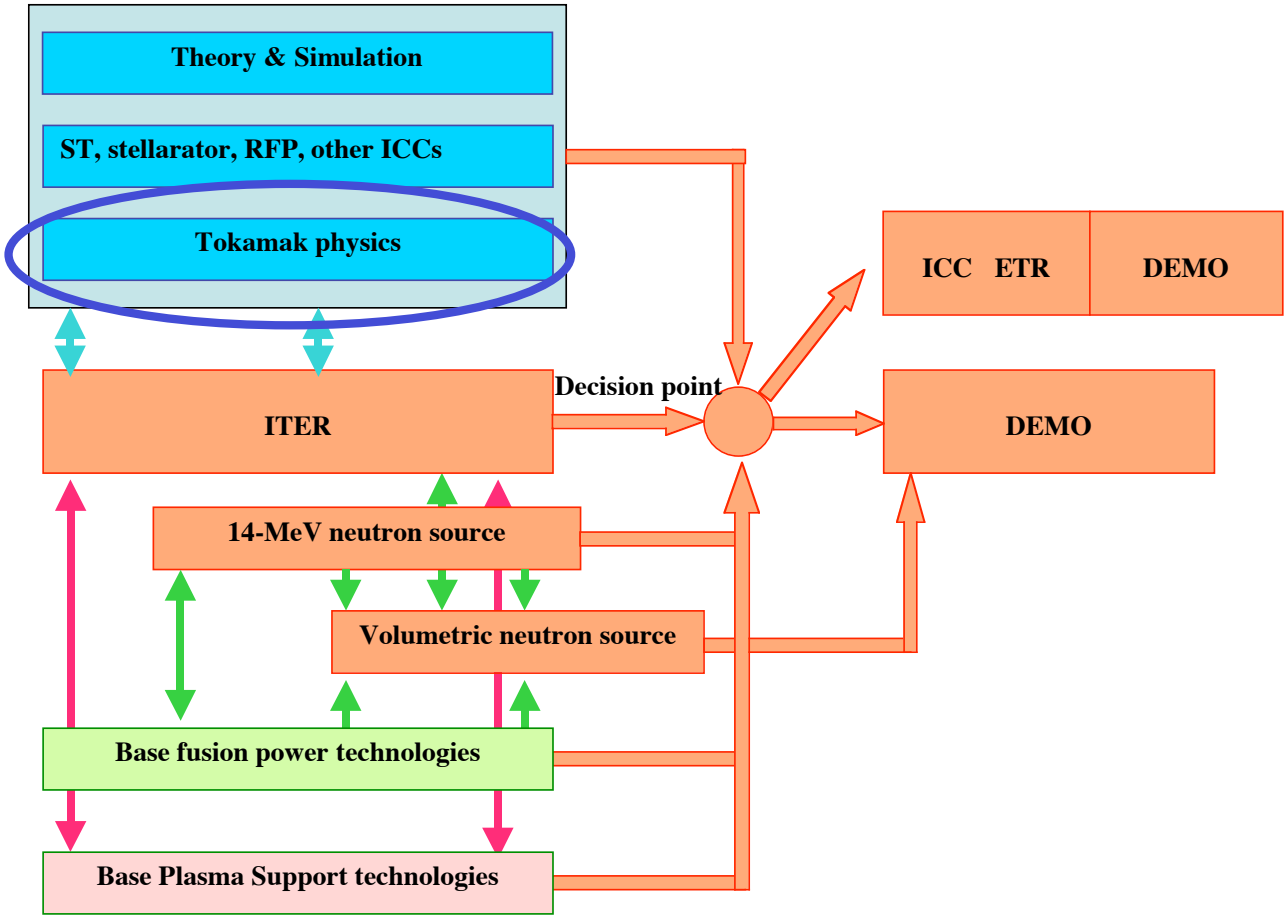

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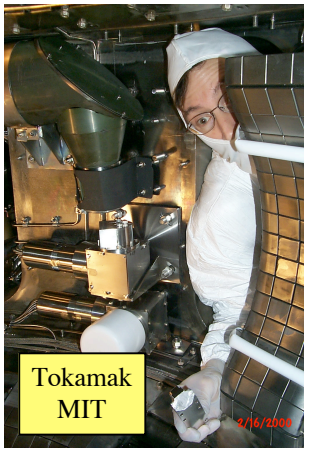
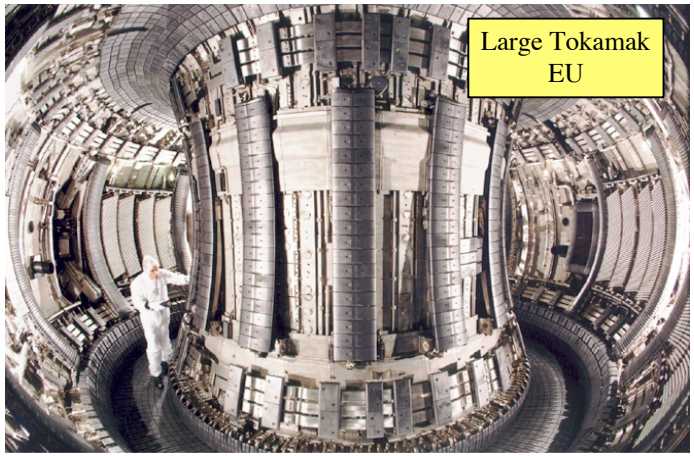
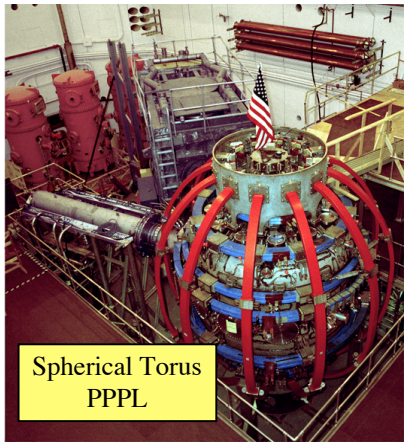
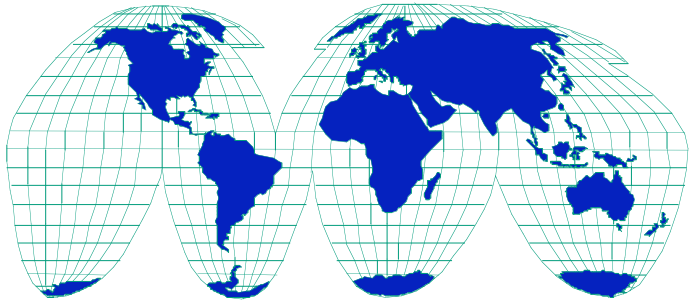
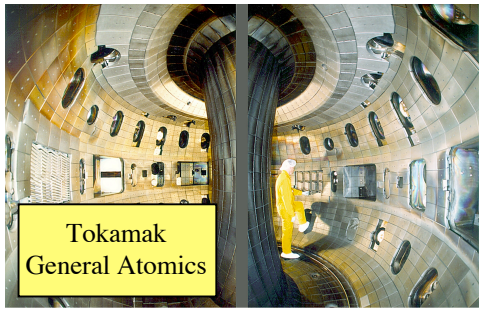
PPPL has Collaborative Research Programs Worldwide

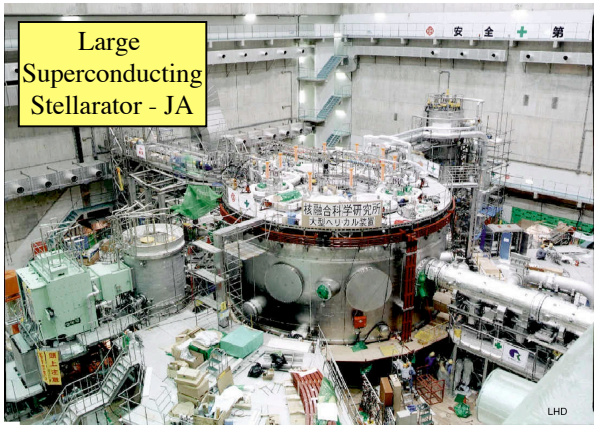


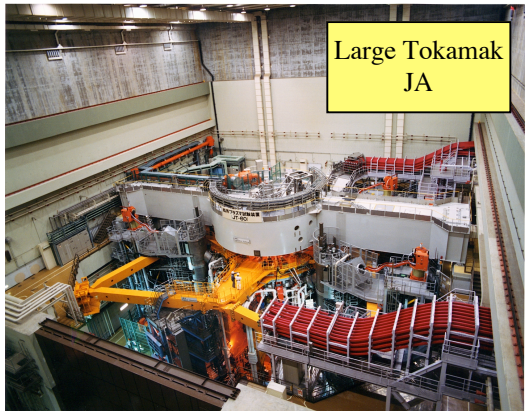






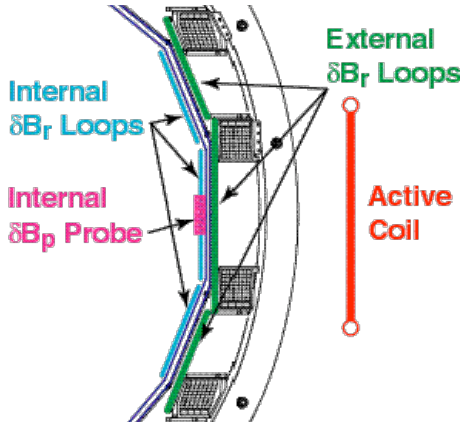




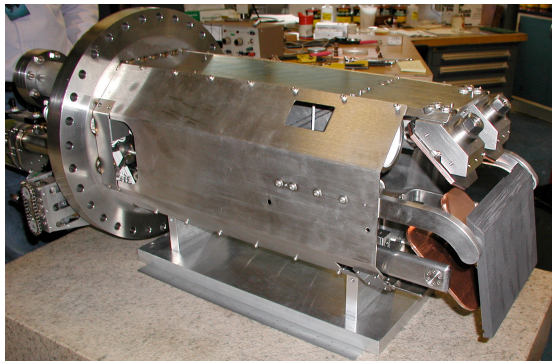


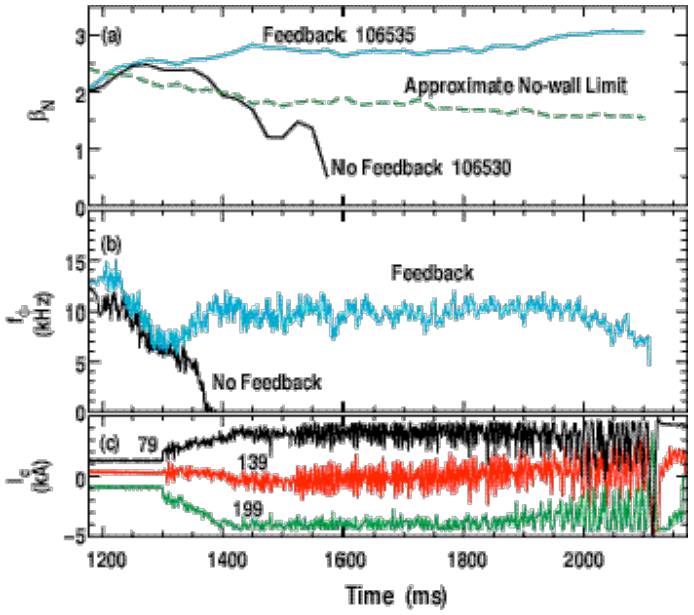
PPPL@DIII-D: Active Control of Instabilities

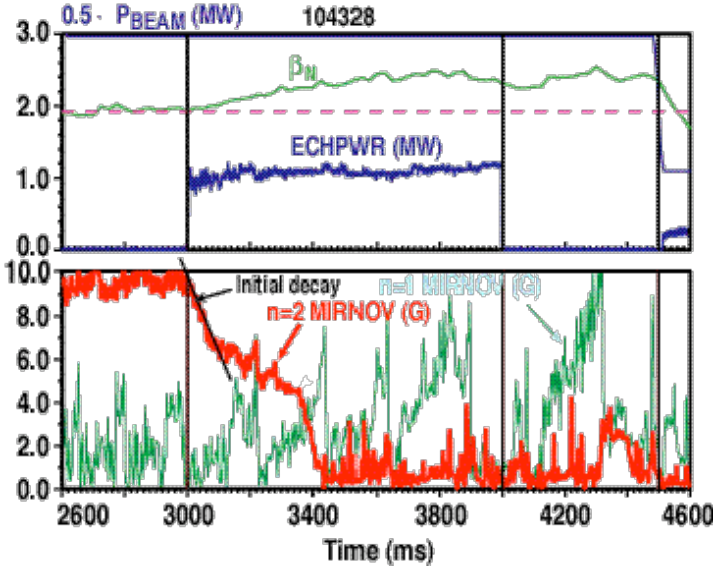
Active magnetic feedback using PPPL sensors and power supplies stabilizes Resistive Wall Modes

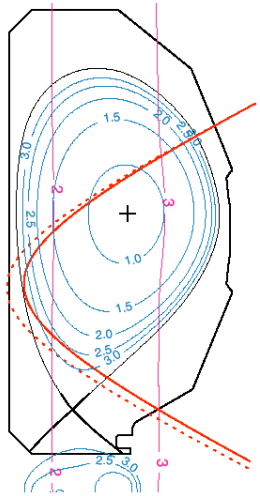


Steerable PPPL ECH launcher allows stabilization of Neoclassical Tearing Modes









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Experience for ITER

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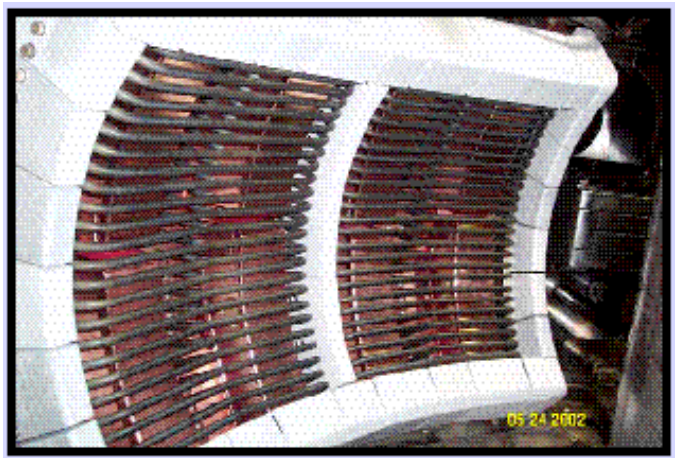
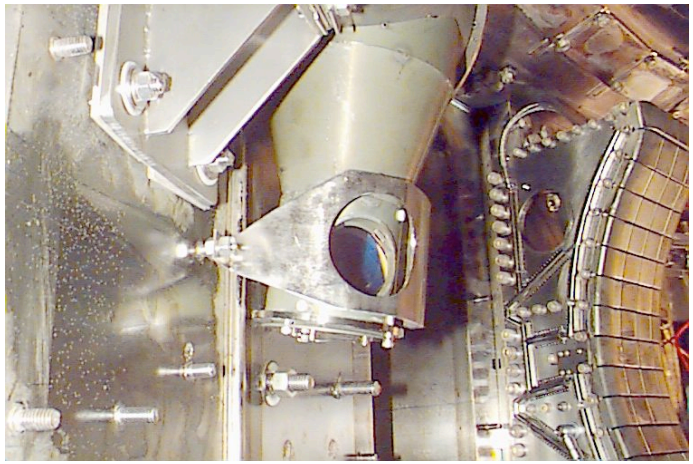
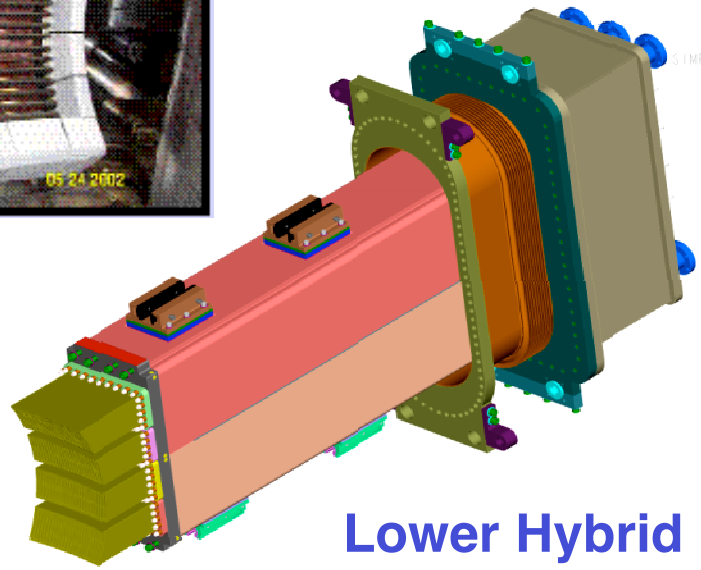
PPPL @ C-MOD: Providing Heating, Diagnostics and Current Drive Systems

Ion Cyclotron Launcher



Motional Stark Effect Diagnotic





Lower Hybrid Launcher

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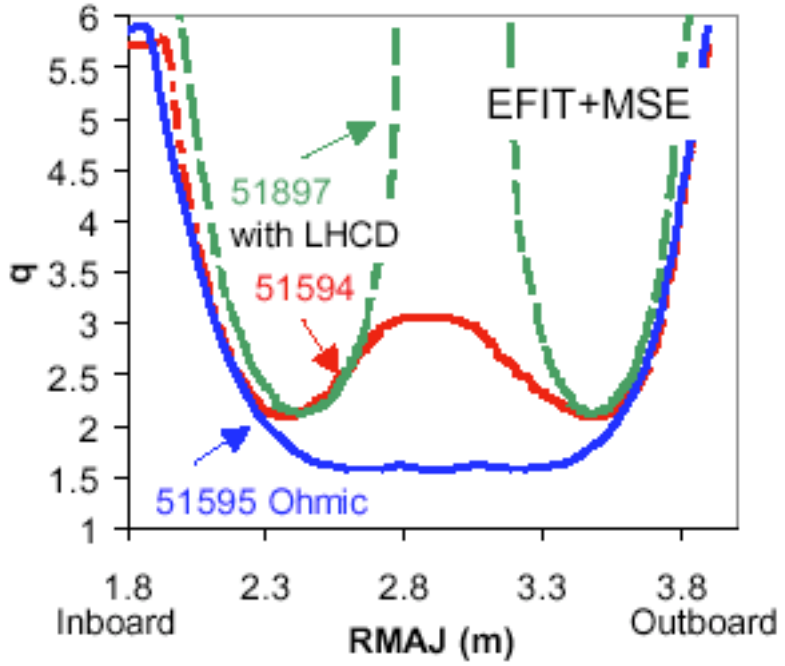
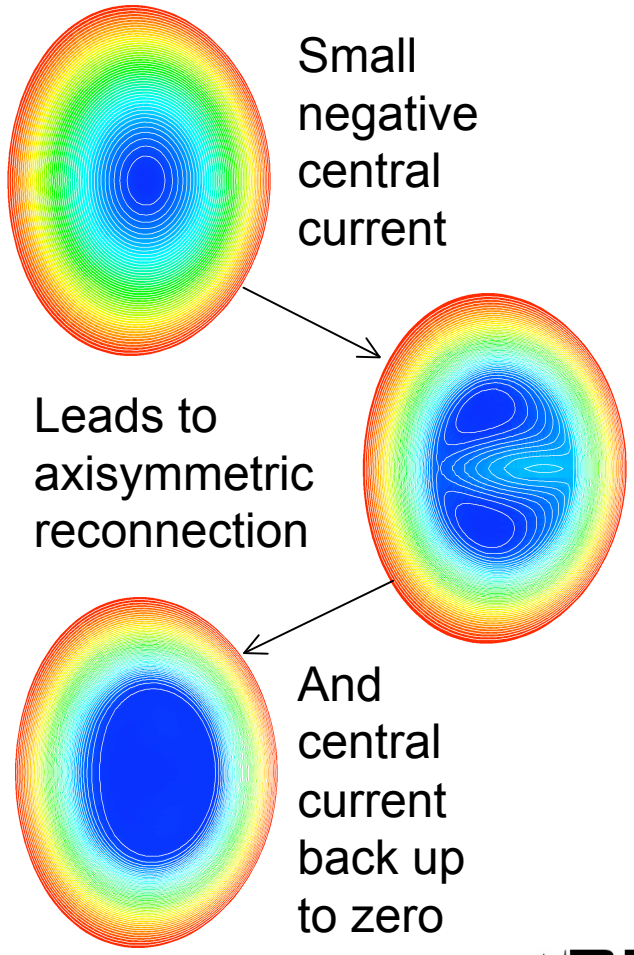
PPPL Diagnostics @ JET: On-axis current does not go negative during strong off-axis current drive





Experience for ITER

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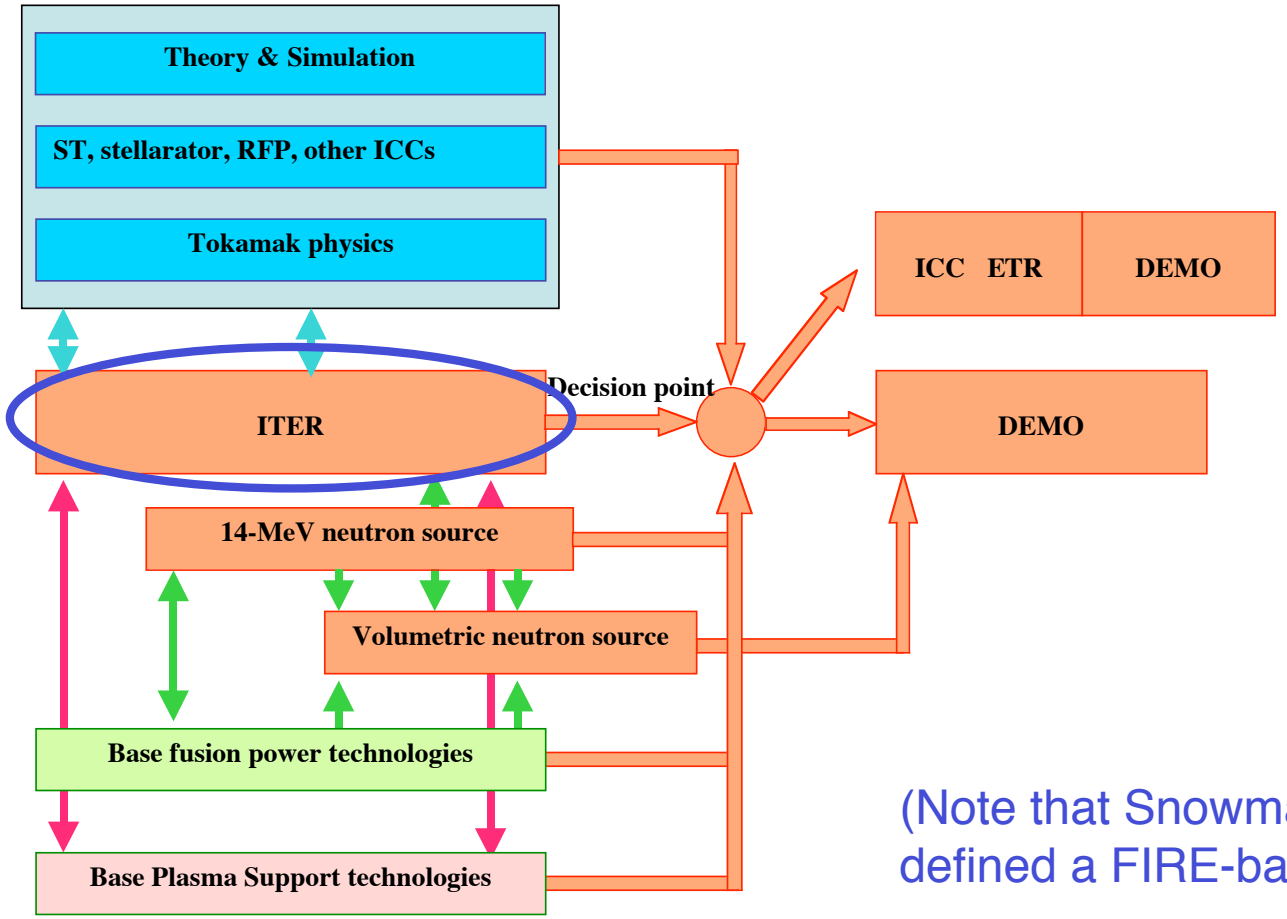
Snowmass Defined a Development Path for Fusion Energy



(Note that Snowmass also defined a FIRE-based path.)

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The Future of Energy on Earth is the Energy of the Stars — Fusion Energy

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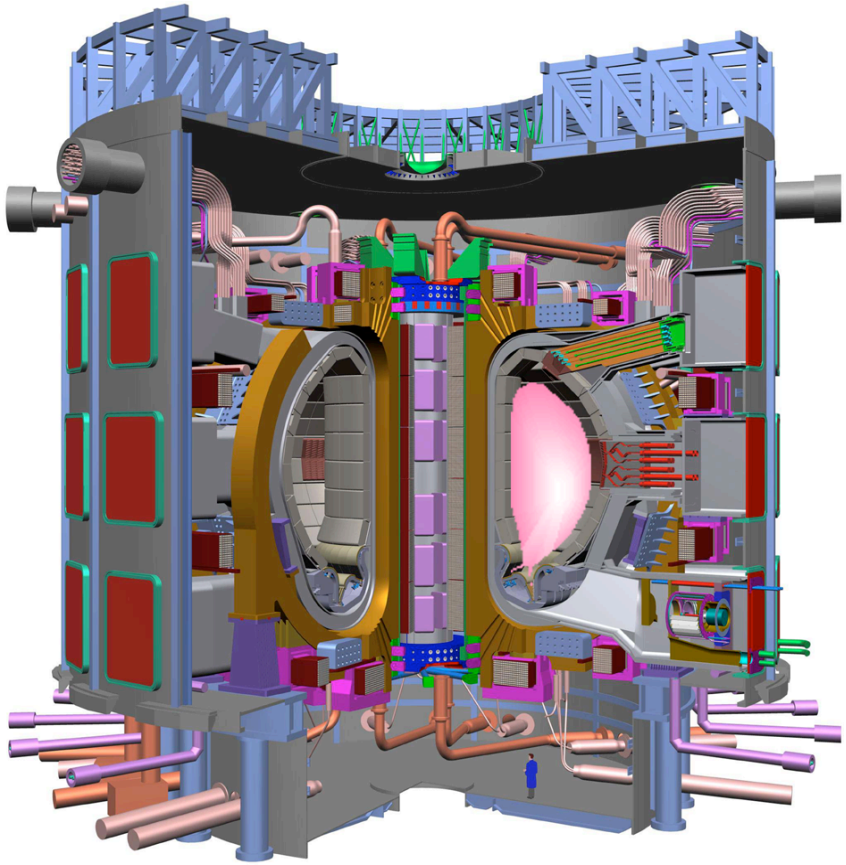
ITER Provides a Collaborative Opportunity to Create a Sun on Earth



Fusion Science Benefits:
Extends fusion science to larger size, burning (self-heated) plasmas – for very long pulses.

Technology Benefits:
Fusion-relevant technologies.
High duty-factor operation.

Contributes to Spherical Torus & Compact Stellarator as well as Advanced Tokamak development.

US has had major impact on device design
500 – 700 MW thermal fusion power
400sec – 1 hr pulse length, duty factor ~25%

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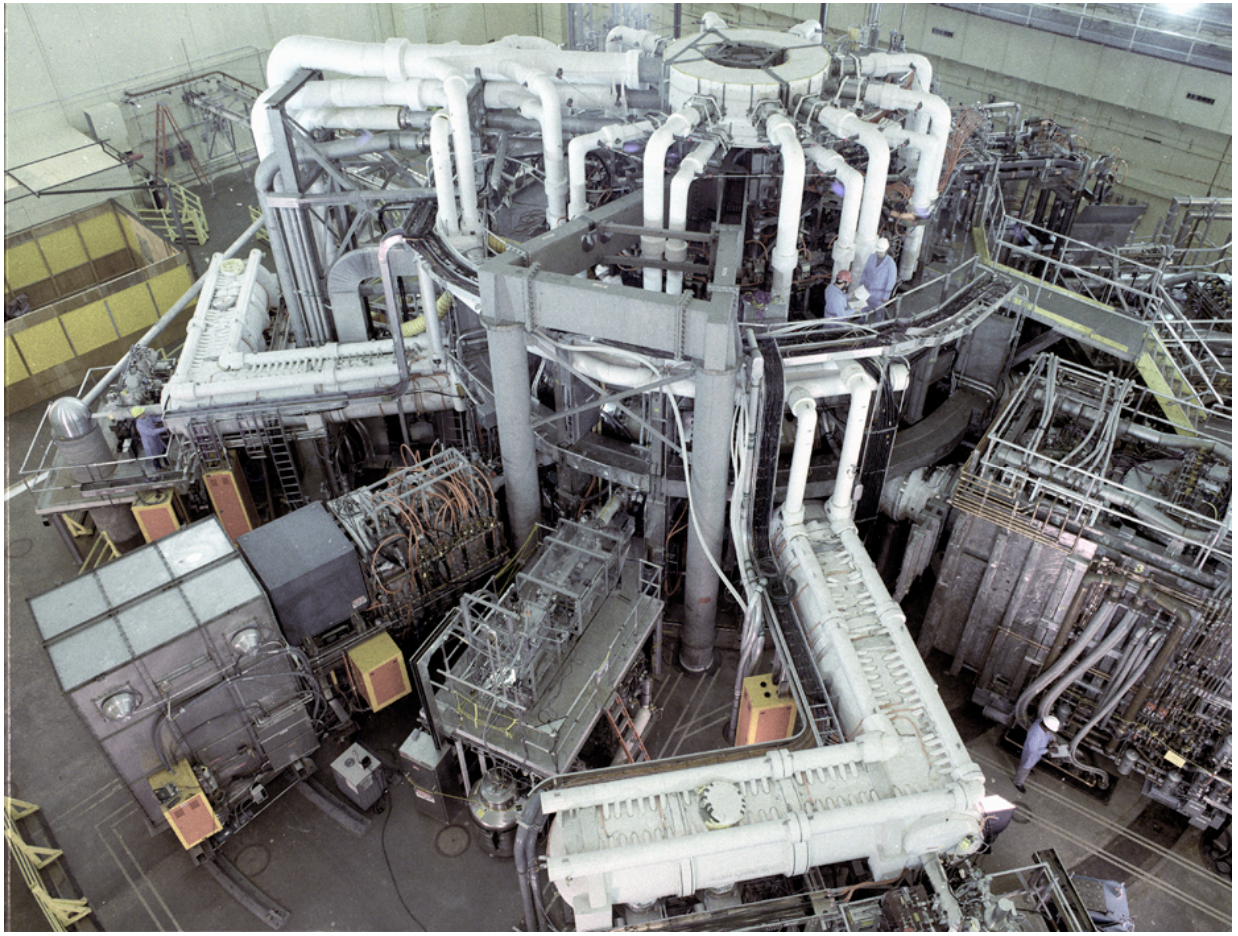
PPPL PRINCETON PLASMA PHYSICS LABORATORY

Experience with Large Facilities and Tritium Positions the U.S. to Contribute to ITER



Over a million curies of tritium safely processed on TFTR.

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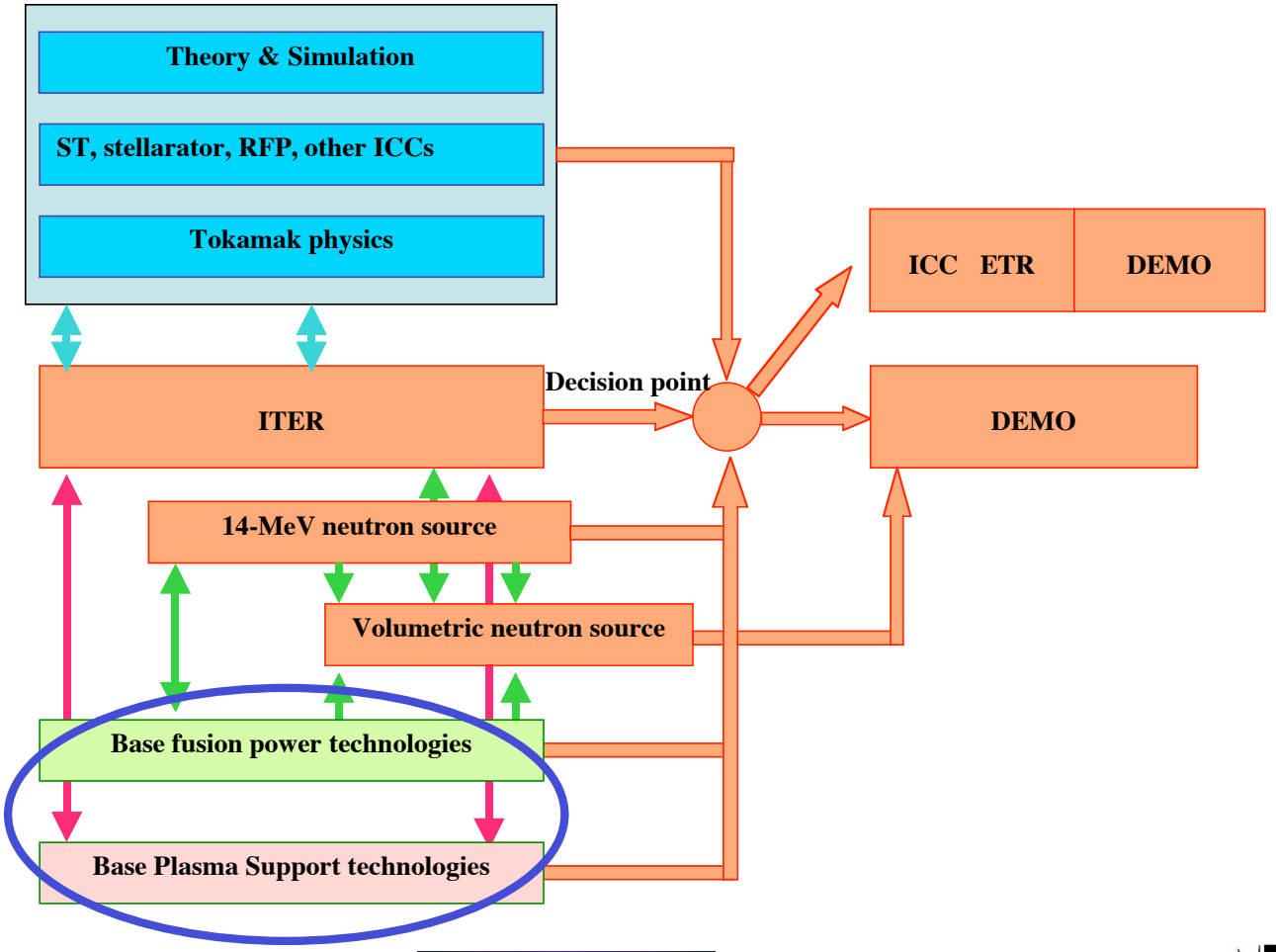
Snowmass Defined a Development Path for Fusion Energy



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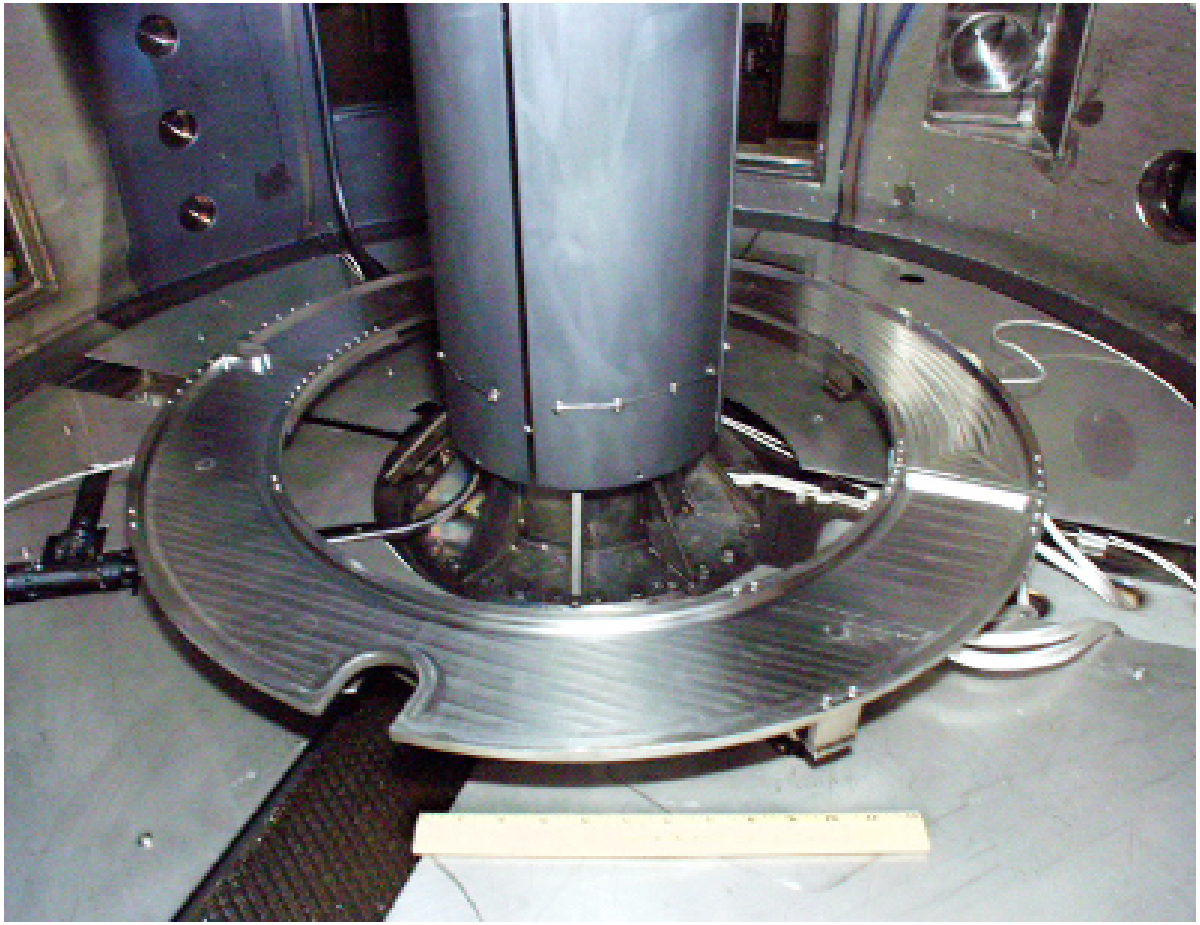
Experiments with Liquid Lithium Plasma Facing Components are Promising on CDX-U



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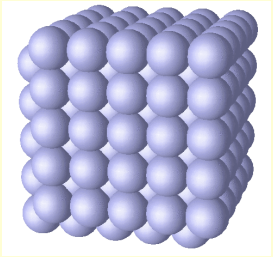
Multiscale nanoscience simulation of materials for fusion

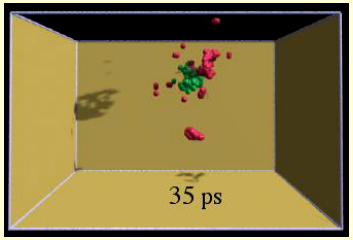
First-principles

(<200 atoms,<10ps)



- Accurate energetics of point defects and defect clusters

Molecular dynamics (< million atoms,<ns)



- Initial defect distribution
- Migration after cascade

Kinetic Monte-Carlo (<□m,<ms)

Microstructure evolution of defects
- Size distribution
- Volume fraction

PRINCETON UNIVERSITY PMI Princeton Materials Institute

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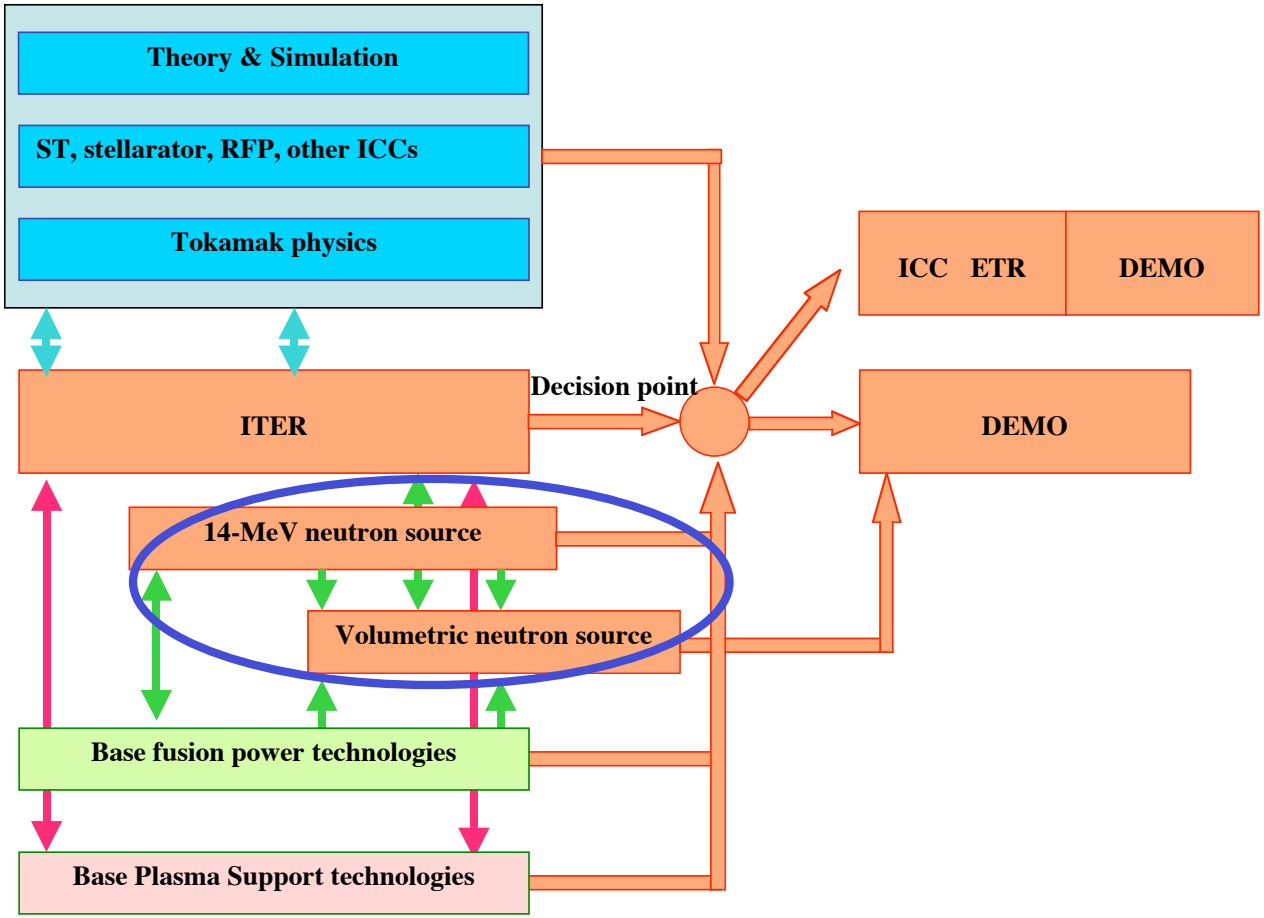
Snowmass Defined a Development Path for Fusion Energy



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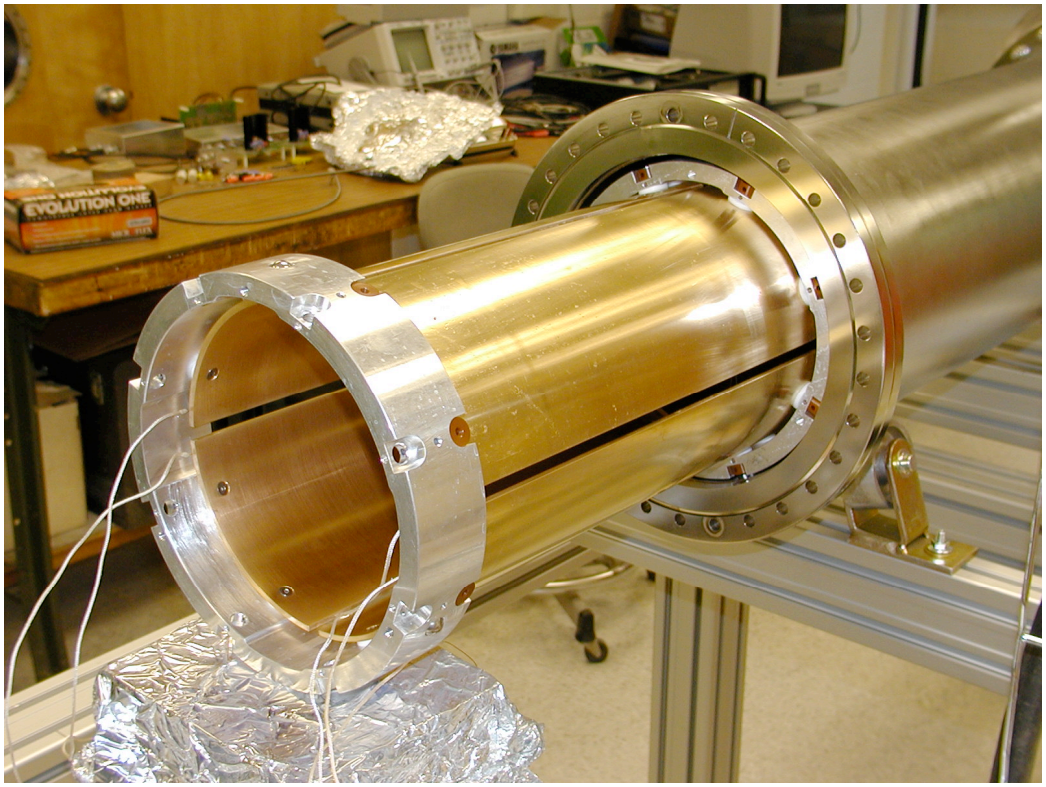
PPPL Contributes to Inertial Fusion Energy via the LBNL/LLNL/PPPL VNL for Heavy Ion Fusion



- PPPL Deputy Director
- Strong theory team (Contributions to SNS, future: IFMIF)
- Growing experimental group:
  - Plasma neutralizer
  - Neg. Ion beams
  - Multi-ionization
  - PTSX

PTSX: Simulation of long ion accelerators with oscillating E field

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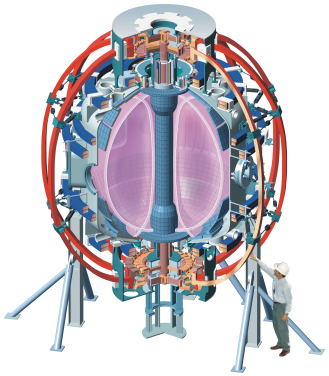
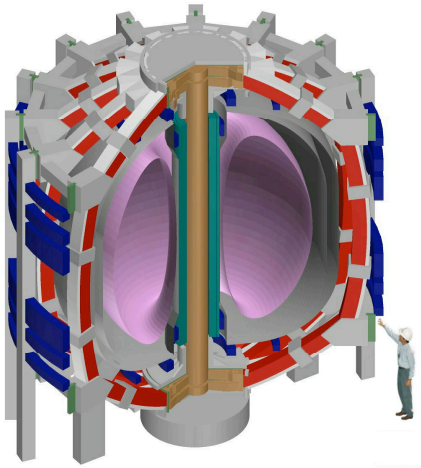
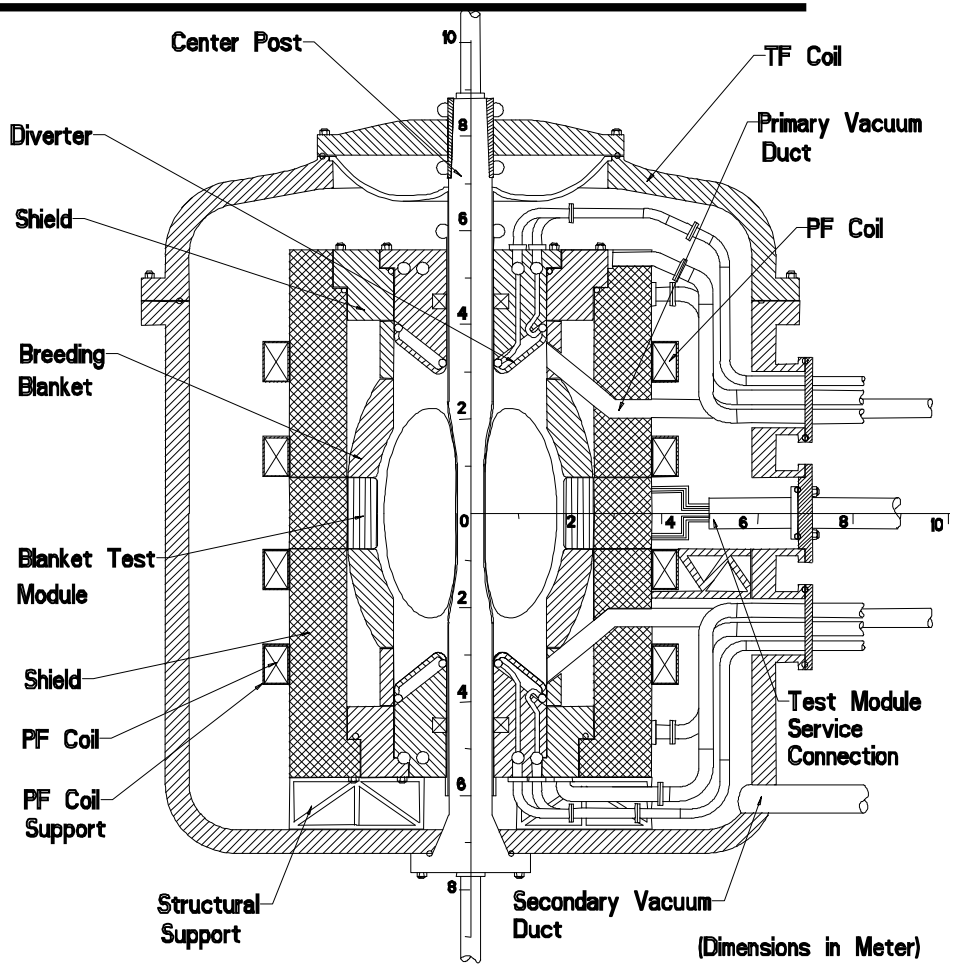
The Spherical Torus is Well-Suited for a Component Test Facility



NSTX



Next-Step ST



CTF

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The Future of Energy on Earth is the Energy of the Stars — Fusion Energy

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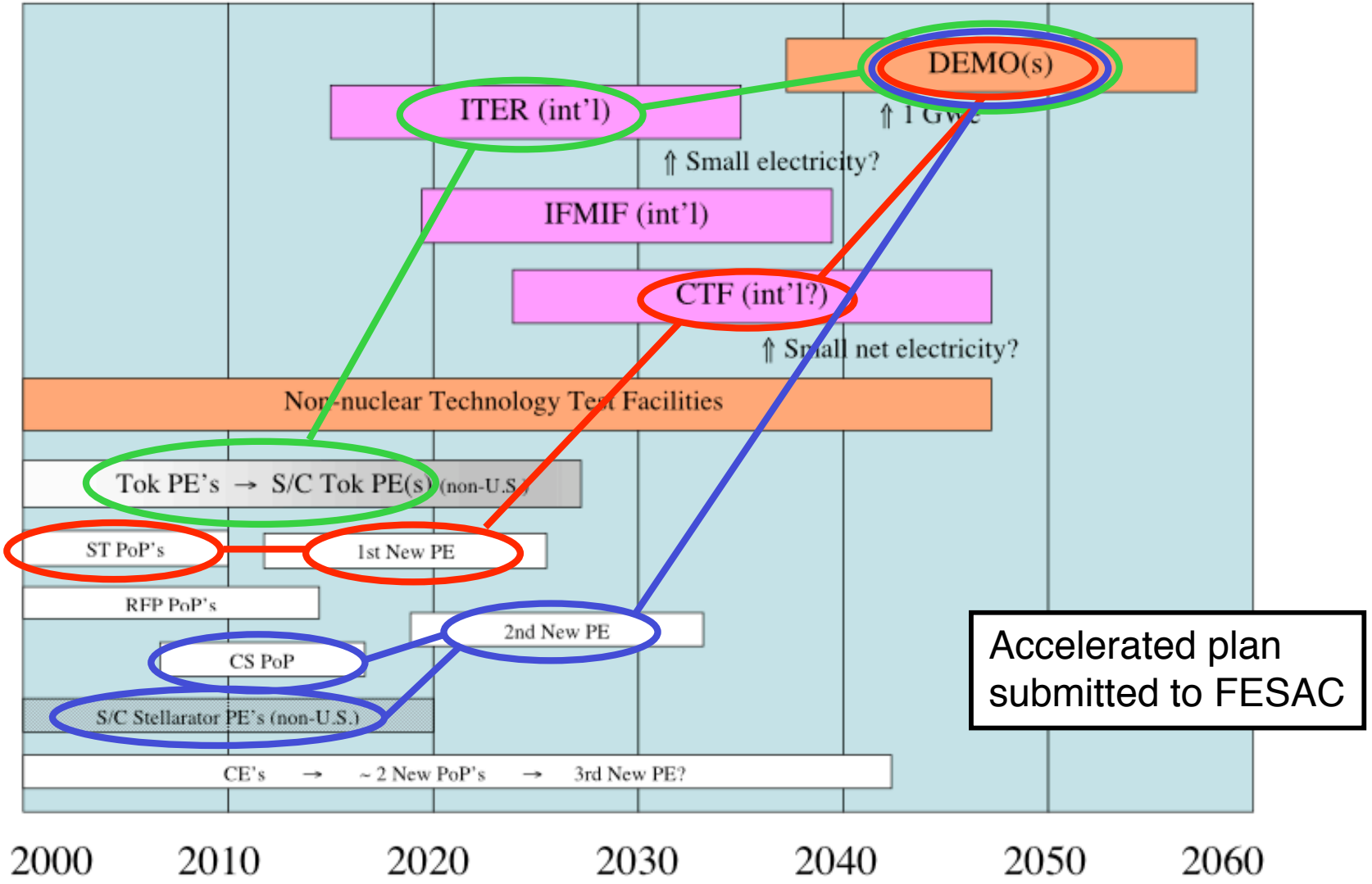
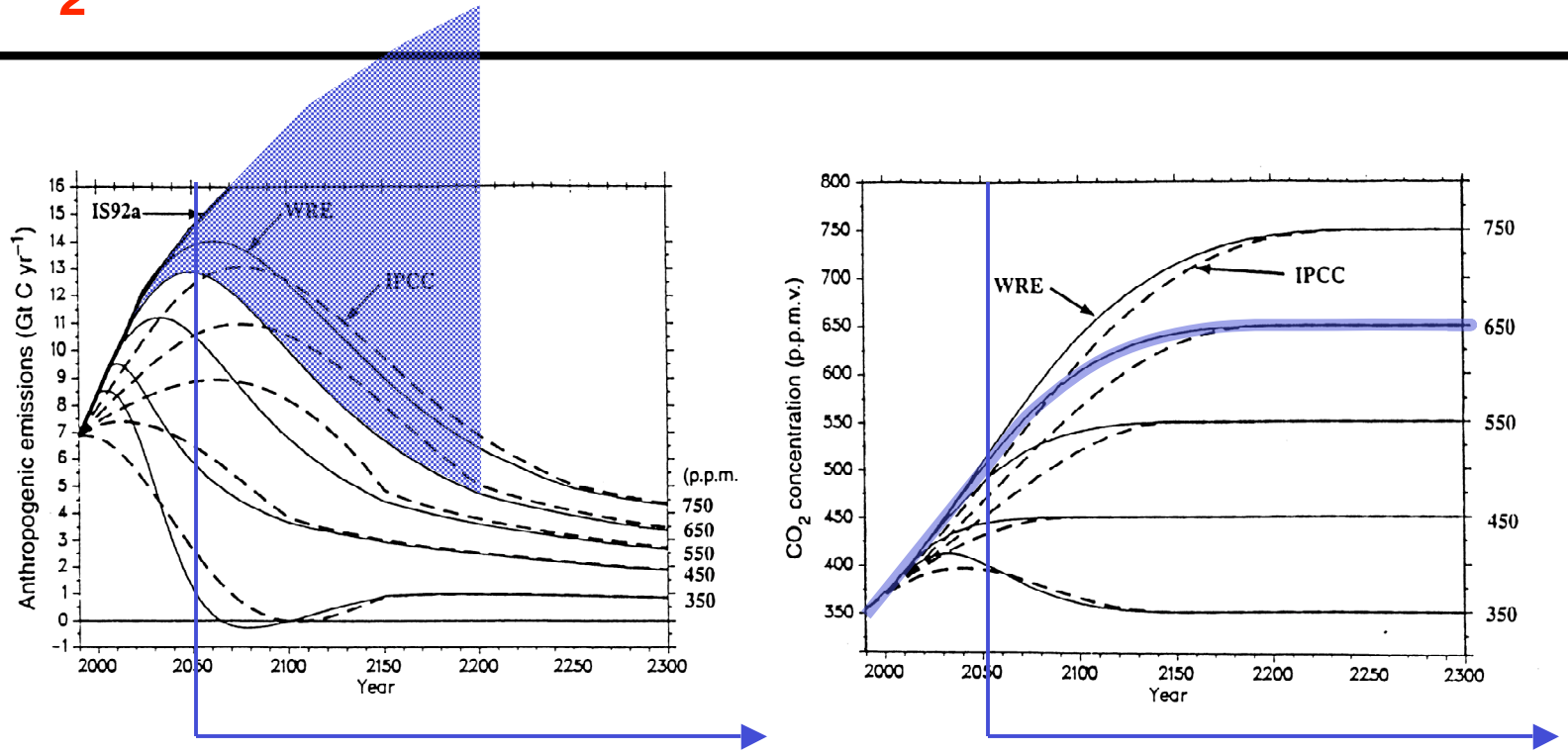
The Accelerated Plan is Focused on Delivering a Timely & Attractive Fusion DEMO



Accelerated plan submitted to FESAC

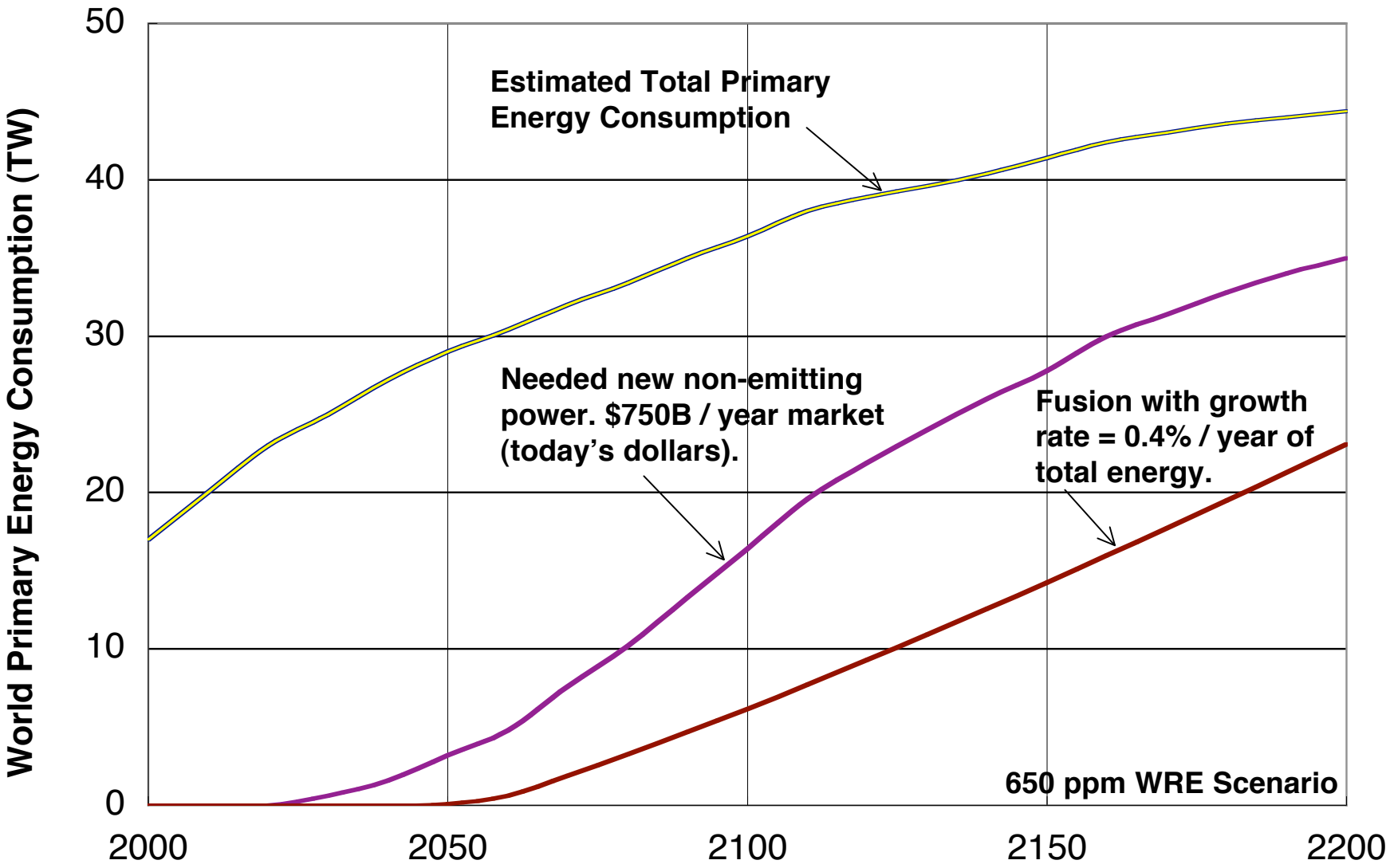
CO_2 Accumulation is a 100 to 200 Year Process



"When confronting long-run challenges – and the environment is certainly one of these – investments in the research and development of new technologies, with actual applications decades in the future, are far more cost-effective than trying to act with existing technologies."

Lawrence Lindsey, Assistant to the President for Economic Policy, May 2001

Fusion will Contribute on a Timely Basis



World population growth will be in cities and "megacities," requiring large new power stations.

PPPL is a Key Resource for Fusion Energy Development

- PPPL is deeply engaged in theory and advanced computing.
- We are world leaders in configuration optimization.
- PPPL's experience running TFTR, and providing heating, current drive and diagnostic systems on tokamaks world-wide positions us to contribute to ITER.
- We are newly engaged in fusion technology; the Spherical Torus may be the best basis for a Component Test Facility on the path to DEMO.

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The Future of Energy on Earth is the Energy of the Stars — Fusion Energy

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