Summary of Innovative Concepts

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Fusion Power Associates Meeting
Washington DC, December 2010

OUTLINE

_____Innovative Confinement Concepts (ICC)
ICC workshop and proceedings summary
FESAC TAP and MFE and HED Renew planning
--> ICC Solicitation notice
Results of the ICC call: funded projects and non-renewals
The future for ICCs?

_____Innovation at Woodruff Scientific Inc (WSI)
WSI Progress
P&S
Proposed work

2010 Innovative Confinement Concepts (ICC) Workshop hosted by Princeton Plasma Physics Laboratory, NJ.

In total there were 38 invited talks, and 103 posters representing most of the CE level devices that are funded and in operation in the US, some from abroad, and some new ideas that were presented in a 'New Concept'* session.

Contributions were organized by session:

- Mirrors: gas dynamic traps and rotating; Dipole
- Magnetized Target Fusion
- New Concepts
- FRC
- Spheromak
- RFP
- Stellarators and Helical systems
- Spherical torus

Program information: http://www.iccworkshops.org

First time for anonymous peer review of contributions:

THANK YOU!

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Guest Editor: Simon Woodruff

Further articles can be found at www.springerlink.com

Indexed/abstracted in *Academic OneFile, Chemical Abstracts Service (CAS), CSA/Proquest, Current Contents/Engineering, Computing and Technology, EI-Compendex, Gale, Google Scholar, INIS Atomindex, Inspec, Journal Citation Reports/Science Edition, OCLC, PASCAL, Science Citation Index Expanded (SciSearch), SCOPUS, Summon by Serial Solutions, VINITI - Russian Academy of Science*

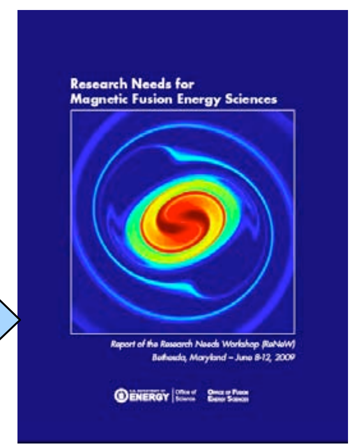
Instructions for Authors for *J Fusion Energ* are available at www.springer.com/10894

Renew for MFE (and also HED)

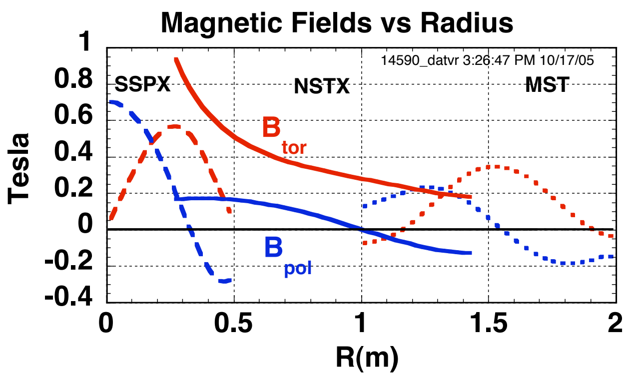
- **Arrangements** — Al Opdenaker
- **Workshop leadership** — Richard Hazeltine (C), David Hill (VC), Hutch Neilson (OFES)
- **Web support** — James DeKock, Emily Hooks

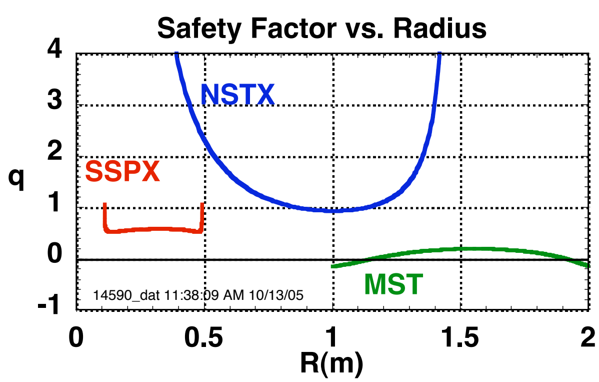
- **Burning plasma in ITER** — Jim Van Dam (C), Mickey Wade (VC), John Mandrekas (OFES)
- **High-performance steady state** — Amanda Hubbard (C), Chuck Greenfield (VC), Mark Foster (OFES)
  - Control
  - Measurement
  - Off-normal events
- Burning plasma in ITER:
  - Alpha particles
  - Reactor conditions
  - Self-heating
- High-performance steady state:
  - Integration
  - Modeling
  - Magnets
  - Auxiliary systems
- **Plasma material interface** — Mike Ulrickson (C), Rajesh Maingi (VC), Rostom Dagazian (OFES)
  - Plasma-wall
  - PFC
  - Internal
- **Fusion power** — Wayne Meier (C), Rene Raffray(VC), Barry Sullivan (OFES)
  - Fuel cycle
  - Power extraction
  - Materials
  - Safety and environment
  - RAMI
- **Magnetic configuration** — John Sarff (C), Mike Zarnstorff (VC), Sam Barish (OFES)
  - Stellarator
  - ST
  - RFP
  - CT

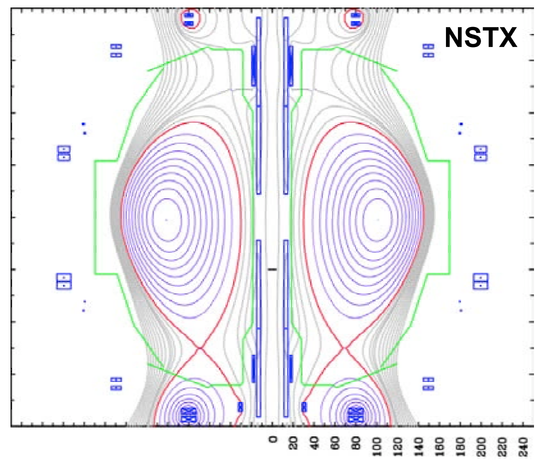
ICCs now organized by scientific overlap, not by concept per se.



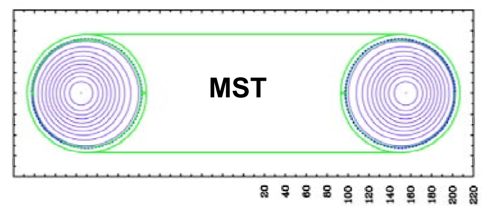
MFE Renew
Organization by Magnetic Configuration



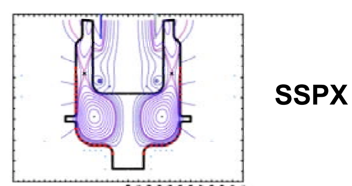




ST



RFP



Spheromak

MFE Renew
Common issues

NI startup and sustainment

Exhaust and power handling (divertors)

Confinement in symmetric systems

Control of profiles

Solicitation notice: DE-FOA-0000286

"The ICC program explores improved pathways to practical fusion power by addressing **critical problems that hinder the tokamak** concept, such as plasma disruption, heat load on internal components, and operational and maintenance complexity."

"Overall, support of research that can best help deepen the scientific foundations of understanding and **improve the tokamak concept is an important focus area of this Announcement**".

The results: funded

Auburn University, Stephen Knowlton MHD Stability and Equilibrium in a Current-Driven Stellarator-Tokamak Hybrid
California Institute of Technology, Paul Bellan Enhancing Fundamental Understanding of Magnetic Confinement
Columbia University, Gerald Navratil High Beta Tokamak Research
Swarthmore College/ NRL, Michael Brown/Vyacheslav Lukin Relaxation of 3D Magnetic Structures: SSX Experiments and Experimentally-Validated Simulations
UC Davis/SNL (CA), Hwang/ Buchenauer Multiple Applications of Accelerated Compact Toroids in Magnetic Fusion Devices
University of Texas at Austin, Kenneth Gentle Turbulence, Turbulence Suppression, and Controlled Fluid Flows in the Helimak
University of Washington, Thomas Jarboe The Helicity Injected Torus (HIT) Current Drive Program
UWashington/UWisconsin/Utah State University/NRL, Thomas Jarboe/Carl Sovinec/Eric Held/Vyacheslav Lukin The Plasma Science and Innovation (PSI) Center at Washington, Wisconsin, Utah State, and NRL
University of Wisconsin, David Anderson HSX: A Helically-Symmetric Toroidal Experiment
University of Wisconsin, Raymond Fonck Non-Solenoidal Startup and Stability Limits at Near-Unity Aspect Ratio
University of Wisconsin, Chris Hegna Targeted Optimization of Quasi-symmetric Stellarators
Oak Ridge National Laboratory (ORNL), Jeffrey Harris ELMs and ELM-free Regimes in Stellarators and Tokamaks
ORNL, Rajesh Maingi A Collaborative Program on the Lithium Tokamak Experiment
PPPL, Elena Belova Advanced Simulation Studies of ICCs
PPPL, Samuel Cohen Energy Confinement and Ion Heating in FRCs Generated by Odd-Parity Rotating Magnetic Fields
PPPL, Philip Efthimion Off-Site University Research Support
PPPL, Richard Majeski The Lithium Tokamak Experiment
PPPL/ORNL/LANL, George Neilson/Jeffrey Harris/Glen Wurden Control of 3D Diverted Plasmas: A Partnership with Wendelstein 7-X

The results: not renewed

University of Washington, Uri Shumlak ZAP flow pinch
University of Washington, Alan Hoffman TCSU FRC
University of Maryland, Adil **Hassam** Maryland Centrifugal Experiment
MIT, Jay Kesner Levitated Dipole Experiment
…list not complete.

CE devices were only meant to run for 3-5 years (if properly funded at ~5M/year).

At 5 years, reviewed and either shut down or evolved to the next development level.

The future?

Toroidal CEs now organized by scientific area, generally supporting larger systems.

What is missing though?

→the opportunity to talk up cheaper, faster routes to fusion (suggestion: seriously try it).

→a fusion ‘Skunkworks’. (well, Lockheed might complain)

→CE and POP level devices investigated in their own right.

→Whole devices that younger scientists can manage (design expts for, session lead, build and maintain).

The future?

What if one of the CE level devices showed promise?

--How would we know it? (Better performance than T3?)

--How to convince others of it? (Excellent publication?)

--How to develop it? (<20 years, < $1Bn = private sector?)

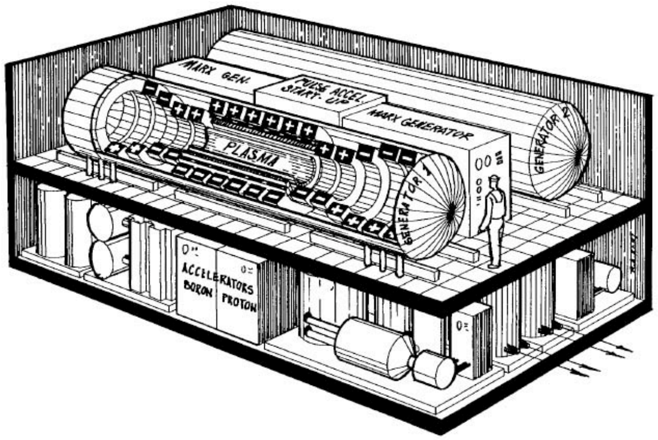
Suggestion for the future:

--manage CEs at one or maybe two institutions to offset fear of downselecting

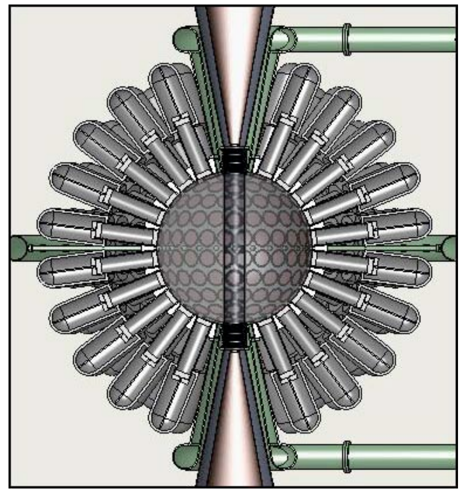
--set clear guidelines for participating in the program

--fund properly, and prioritize next steps (roll-back planning).

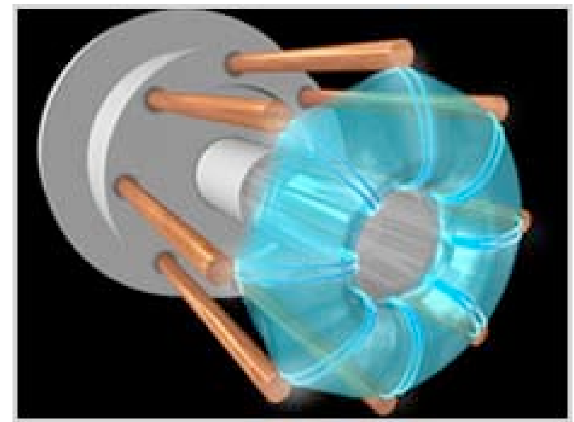
Some are exploring fusion development in the private sector



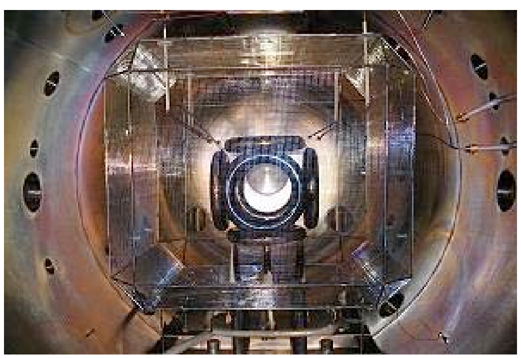
Tri-Alpha Energy ($100M)



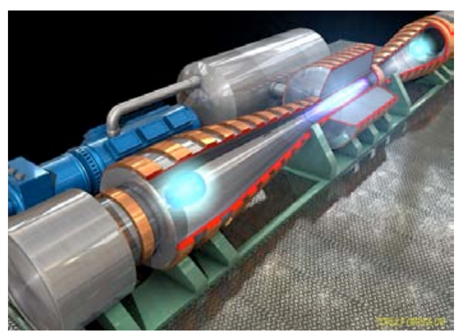
General Fusion ($20M)



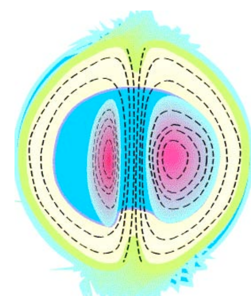
Lawrenceville ($1.2M)



EMC2 ($9M)



MSNW



PLASMAK

…

Woodruff Scientific Inc is also exploring fusion in the private sector

WSI has made huge strides in the last year.

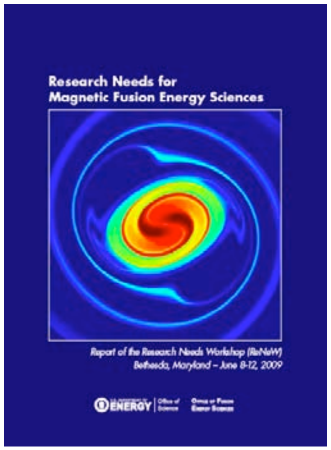
Defined specialty

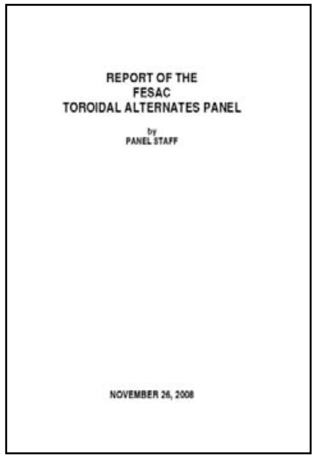
Defined business plan: products and services are finding customers.

Wide collaboration base.

Ready for growth: charting the path to success with much help.

WSI focus on compact tori





REPORT OF THE
FESAC
TOROIDAL ALTERNATES PANEL
by
PANEL STAFF

NOVEMBER 26, 2008

J Fusion Energ
DOI 10.1007/s10894-010-9303-1

ORIGINAL RESEARCH

Why Compact Tori for Fusion?

S. Woodruff · M. Brown · E. B. Hooper · R. Milroy · M. Schaffer

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Abstract A compact torus (CT) has a toroidal magnetic and plasma geometry, but is contained within a simply-connected vacuum vessel such as a cylinder. Spheromaks and field-reversed configurations fall into this category. Compact tori are translatable and have a high engineering beta. The primary benefit of CTs for fusion is the absence of toroidal field and Ohmic Heating coils and the many problems brought on by them. Studying fusion-relevant plasma in simply-connected geometries affords the world fusion program both physics and technology opportunities not found in other configurations. This paper outlines the technology and physics opportunities of compact tori, and presents a cost model based on geometry for comparison with less compact configurations.

Keywords Compact tori · Spheromak · Field reversed configuration

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Introduction

In the next 5–15 years, two devices (NIF and ITER) will produce ignited plasmas, the next steps from which will be demo (power-producing) reactors. As we enter the era of NIF and ITER, several concepts are being developed in parallel that offer opportunities for resolving well known critical issues. Within magnetic fusion, the concepts known as 'Compact Tori' are researched: plasma toroids that have no material linking the plasma. Removing the need for toroidal field (TF) coils means that the resulting configuration can be compact and highly modular, lowering cost and providing easier maintenance. Without an externally imposed toroidal field, compact torus (CT) plasmas are stabilized either by appropriately tailoring the profile of currents flowing in the plasma or by the presence of a population of highly kinetic ions, allowing operation at high beta. Formation and current drive are achieved by a variety of novel techniques involving magnetic reconnection that now are finding application for non-inductive start-up in larger machines. CTs therefore offer many unique opportunities for resolving critical issues relating to both technology and plasma physics, and serve as valuable test-beds for the development of new ideas.

The ideas presented here form a distillation of thoughts relating to CTs from two recent DOE planning activities: Fusion Energy Sciences Advisory Committee (FESAC) Toroidal Alternates Panel (TAP) [1] and The Burning Plasma Organization Research Needs Workshops (ReNeW) [2]. The FESAC TAP report defines the Compact Torus concepts in great detail, and states the ITER era goal: "To demonstrate that a CT with simply connected vessel can achieve stable, sustained or long pulsed plasmas at kilovolt temperatures, with favorable confinement scaling to proceed to a pre-burning CT plasma experiment." In the report,

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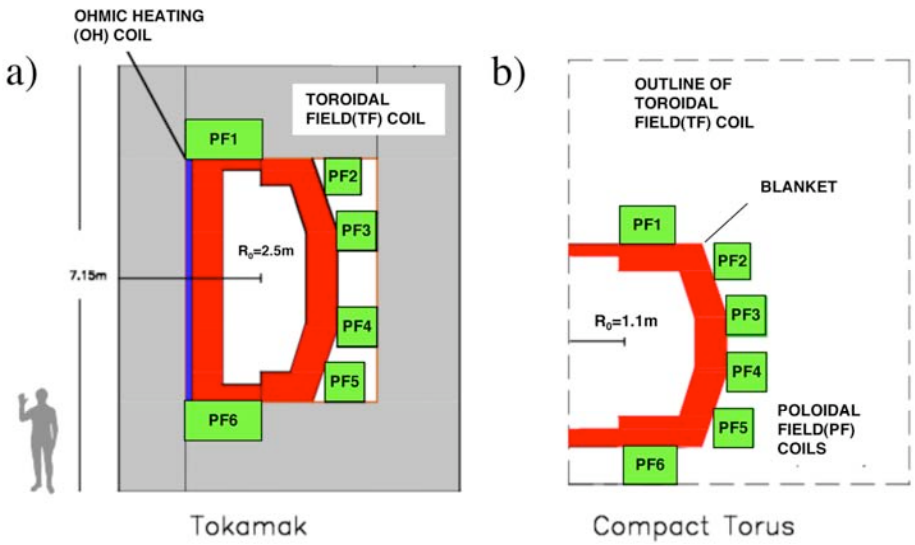
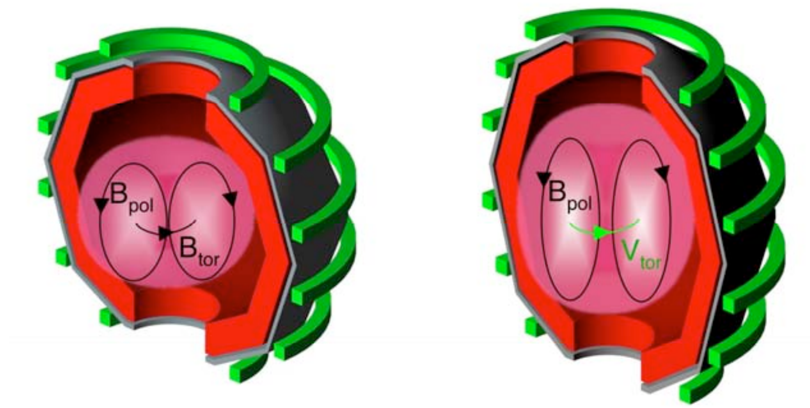
We contributed to the discussion of spheromaks in both FESAC TAP and BPO Renew.

July 2010 paper appeared in JFE outlining opportunities for Compact Torus Research.

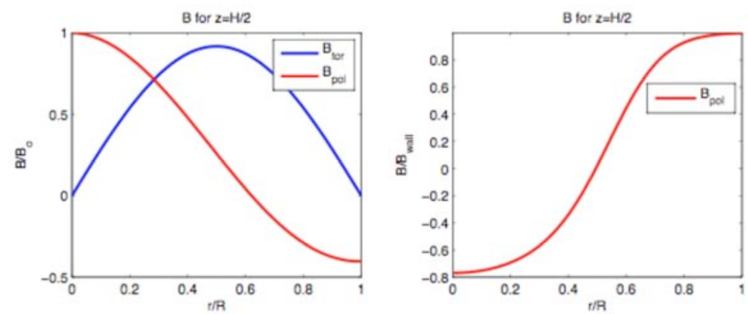
Compact tori



Two kinds:



Spheromak FRC



Omit TF leg:

Possibly more compact, lower cost, modular power cores.

Code validation, small experiments.

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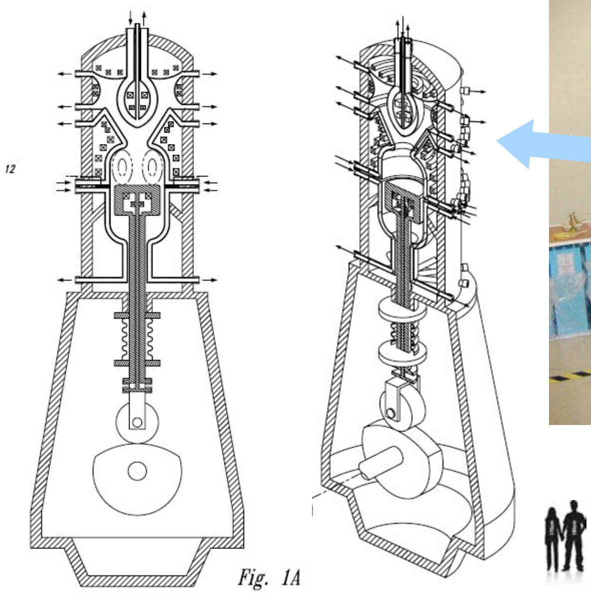
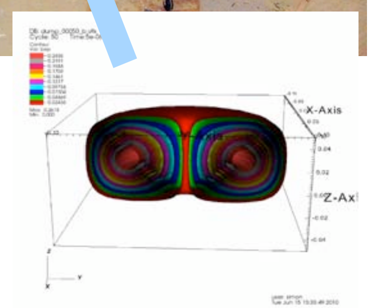
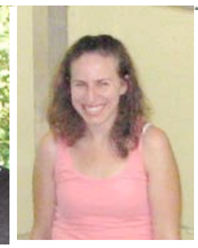


US PATENT PENDING U.S. Serial No. 12/706,963



WSI Team

Woodruff



Baerny

Marston

Stoulil

Interns!

Johansson
Bean
Sondee
Krizan
Kakos
Whitford

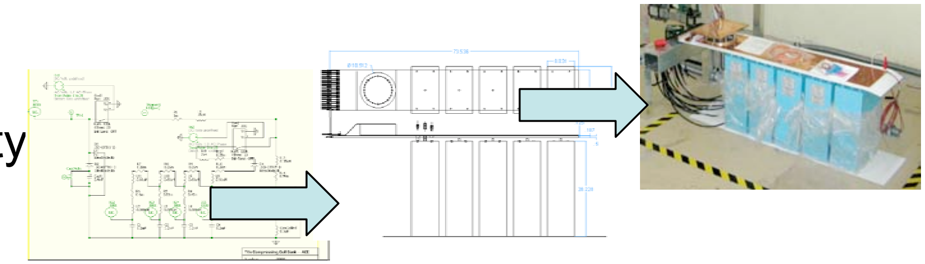
Scientific Advisory Board

University of Washington · Swarthmore · UT · University of Wisconsin–Madison · University of Maryland · PPPL Princeton Plasma Physics Laboratory · Lawrence Livermore National Laboratory

Products and services

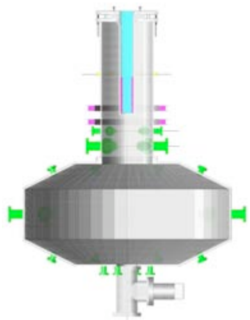
Pulsed power

--banks for pulsed power, controls, safety

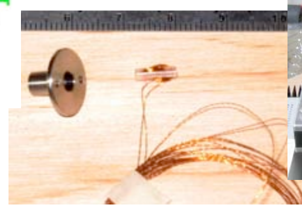


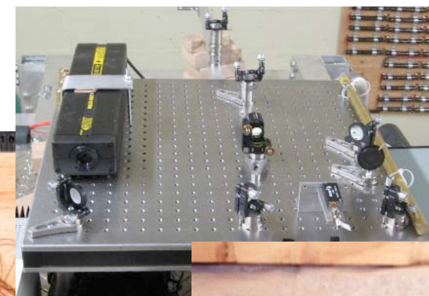
Vacuum

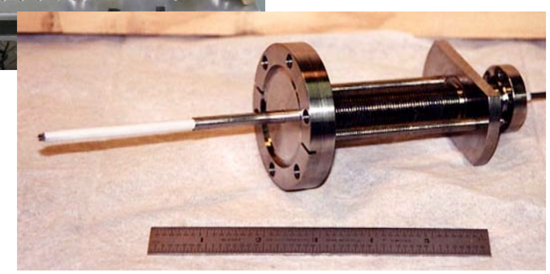
--design and fab, controls



Diagnostics



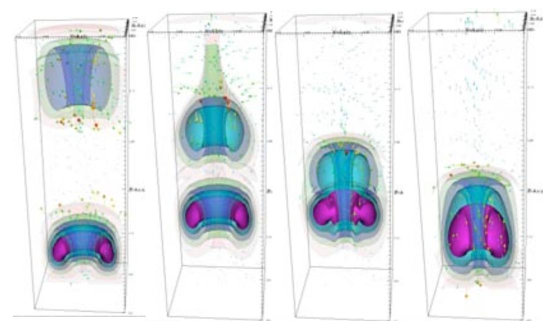




Integrated research systems

--Turn key systems (controls, banks, diagnostics, safety)

Computer simulations of key experimental results



Facilities

2 expt. labs

1 workshop

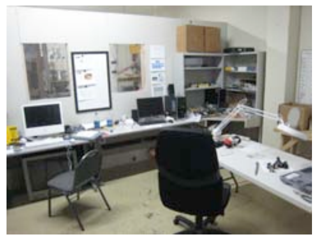
1 computer lab

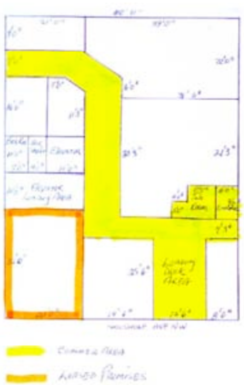
Clean room

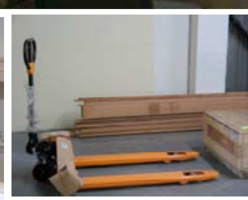
Offices

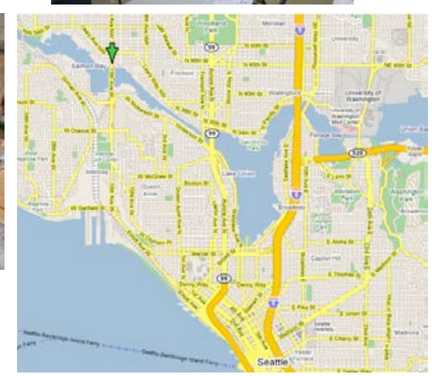
Loading bay

Lots more room to expand into!









Projects in the pipeline

DOE SBIR (submitted 2 weeks ago):

1. Laser endoscope for remote optical monitoring and ablation of Be and C deposition on ITER first mirrors
2. Prototyping and Design of a Universal Validation Tool
3. Modeling for Spheromak Performance Metrics and Development Milestones
4. Concept Design of an Ultra Compact Volumetric Neutron Source (UCVNS)

Upcoming:

Ion heating in NI startup by merging (multi-group proposal).

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Summary

After FESAC TAP and BPO Renew, ICC program redirected.

Some closures, some refocusing.

ICC workshop proceedings peer reviewed for the first time ~20 papers published.

WSI: working on growing company through P&S, contracting.

Focus is on issues relevant to larger systems (validation effort)

New work focuses on broader issues (inc. ITER).