U.S. DEPARTMENT OF ENERGY | Office of Science

FES update: activities, comments on budget, and on vision

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This is an extraordinary time for fusion and the sciences in the U.S.

- We are on the cusp of gaining scientific access to burning plasmas in the laboratory: ITER project transformation has been extraordinary. The opportunity for U.S. leadership in this new era is high

- Technical gaps for fusion demand some topical shifts in this decade. We must reach across national boundaries and lever our domestic resources in response to some of these needs

- There is uncertainty. Budgetary pressures are tremendous. But a 10 year vision describes an exciting destination. With this in mind, the place for the best university-based research in fusion and plasma science this decade and beyond can and should be strong.

Intersecting forces and overarching considerations include…

- A compelling scientific story you are writing, and its potential for enormous impact
- Extraordinary support of Office of Science leadership for ITER and FES
- Strong Administration support for U.S. science and the Office of Science
- A transformation in the international ITER project: this is translating to the ability of the US to respond effectively to technical challenges, working with the IO and the 6 other Members
- Enormous downward budget pressure throughout the government
- Administration emphasis on energy research with a near-term payoff

In what follows: FES activities and direction

- **The local**: FES updates
  - Important changes
  - Solicitations
  - Office business

- **The wider view:** towards a topically oriented, scientific approach for FES and the community

- **The vision:** where we need to be in 10 years

The FES Office has gone through significant changes… consider this past year alone – (1)

It's a pleasure to welcome Jim Van Dam on board to FES as Research Division Director

- He brings tremendous virtues to the table: scientific excellence, demonstrated community leadership, and a commitment to carrying forward a thoughtful, informed approach to federal service

The FES Office has gone through significant changes… consider this past year alone – (2)

- Staff retirement

  Erol Oktay (end of Feb 2011): He received DOE Distinguished Career Service Award, and also Special Award from FPA

- Departure: Mark Koepke (WVU), after IPA completed. including Acting Research Division Director service.
  - DOE recognition from Office of Science leadership for his leadership and service
  - Elected APS-DPP vice chair

The fusion community owes them a great debt of gratitude

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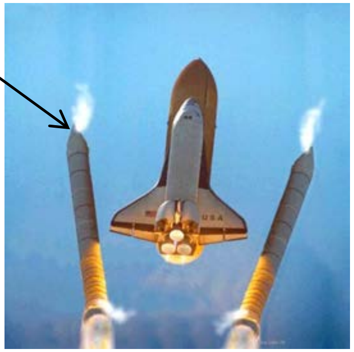
The FES Office has gone through significant changes… consider this past year alone – (3)

- New staff additions during the past year
  - Ann Satsangi (from NNSA): HEDLP and General Plasma Science

  - Sean Finnegan (from LANL): HEDLP and Theory

  - Pete Pappano (from ORNL): Materials

  - Ed Stevens (from NASA): Projects and Enabling Technologies



  - Pam Miller (from SC-HR): Budget

FES is undergoing a reorganization, and the way we interact with you will evolve

- Official FES structure will have two divisions:
  - Research Division
  - Facilities, Operations, and Projects Division (FOP)
  - Recall the present structure contains a RD and the "ITER and International Research" division
- SES-level FOP Division Director search will begin soon, pending completion of the reorg and availability of program direction funds
- Within this structure, the Division Directors will launch a Team-oriented approach to interface with the community in setting goals and metrics for fusion's development

Please consider contributing to your program’s success as an IPA

- IPA = Intergovernmental Personnel Act

- We are considering creating an IPA slot to help craft our international research endeavors, including with working with the Research Division Director to develop programs that optimize leverage with the domestic program along scientific, topical lines. Developing an approaches for university engagement with labs in such a program will be critical.

- Program support funding for an IPA is presently frozen, given federal budget uncertainties, but when there is some thawing we may pursue this

- Examples of recent IPA successes: Mark Koepke (WVU), and Hutch Neilson (PPPL)

There are many FES solicitations in the works

Solicitation	Date issued	Proposals due	$ anticipated, as stated in announcement - Pending available funds
Theoretical Research in Magnetic Fusion Energy Science	Mar 21, 2011	May 26, 2011	$3.3M
NSF/DOE Partnership in Basic Plasma Science and Engineering	Oct 6, 2010	Oct 7, 2011	$2M – jointly with NSF
National Spherical Torus Experiment: Diagnostic Measurements of Spherical Torus Plasmas	Aug 1, 2011	Oct 18, 2011	$2M.
Scientific Discovery through Advanced Computing: Scientific Computation Application Partnerships in Fusion Energy Science	Aug 3, 2011	Oct 26, 2011	$6.6M, FES & ASCR
High Energy Density Laboratory Plasmas	Sept 8, 2011	Nov 3, 2011	$14M annually
Materials Solicitation with Focus on Structural Materials, Blanket First Walls, and Divertor Plasma Facing Components	Oct 17, 2011	Dec 23, 2011	$2.6M

Details on Awards for fellowship and Early Career programs

- Office of Science Graduate Fellowship Program: call issued Nov. 19, 2011: **proposals due January 3, 2012**
  - Three-year award, $50.5K per year (FES → SC since 2008)
  - Annual SCGF Research Conference at a DOE laboratory (Argonne in 2010)
  - FES awards: FY10 = 8 + 2 interdisciplinary with BES & ASCR (of 70 total); FY11 = no appropriation

- FES Postdoctoral Fellowship Program – no new starts for FY'12 due to larger-than-normal number in FY'11
  - Two-year award, $61K per year
  - Awards: FY09 = 3; FY10 = 2; FY11 = 5

- Office of Science Early Career Research Program: Call issued July 19, 2011; **proposals due Nov 29, 2011**
  - For tenure-track junior faculty at universities (≥$150K/yr summer) and permanent junior research scientists at national labs (≥$500K/yr)
  - FES → SC since 2009
  - FES awards: FY10 = 4 univ + 2 lab (of 69 total); FY11 = 4 univ + 2 lab (of 67 total)

There are plans for upcoming solicitations

- Diagnostics
  - Last full solicitation was held in FY 2008
  - Existing awards were given two-year extensions for FY 2011 and 2012
  - New solicitation being planned for FY 2013 funding

- International collaborations
  - FESAC panel input to be taken into account. Scientifically topical, less facility-centric. Opportunity for university/lab teaming

- General Plasma Science (for laboratories)
  - Last full solicitation was held for FY 2006
  - Existing grants were given three-year extensions
  - Competitive review being planned for FY 2013 funding

- FES Postdoctoral Fellowship Program
  - No solicitation in FY12 (because funded larger-than-normal number in FY11). Will return in FY13.

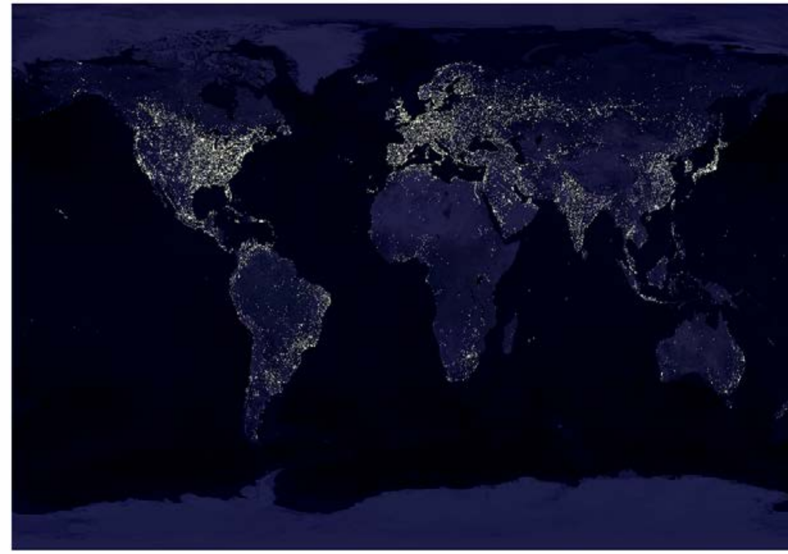
Other program news

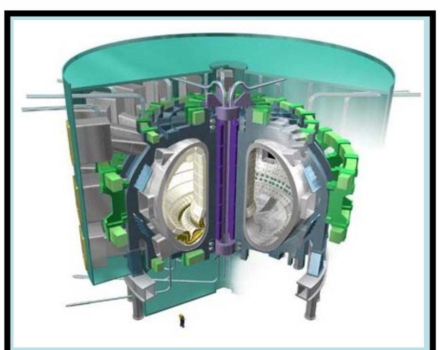
- New leadership for USBPO
  - Chuck Greenfield (Director): talk Tues evening at ITER Town Meeting
  - Amanda Hubbard (Deputy Director)
- SC Graduate Fellowship Program
  - Announcement just recently approved for release
  - Encourage applications from fusion energy sciences grad students [Note: In the last round, only 2.2% of the applications were from FES students; nevertheless, 10 students (7% of the total) were funded.]

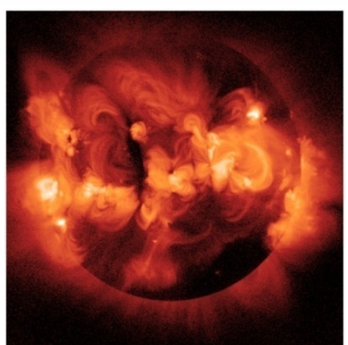
On the FES vision and path forward

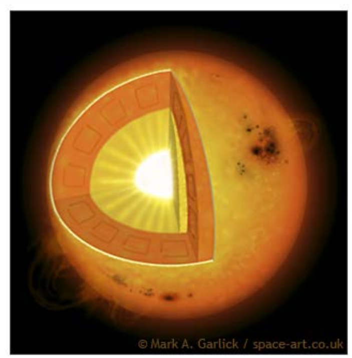
The science at the heart of fusion energy is far-reaching and is poised for a transformation

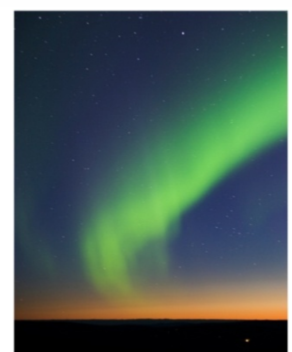
- *Stewarding plasma science as a broad enterprise is fully consistent with the leading ambition of powering the planet*









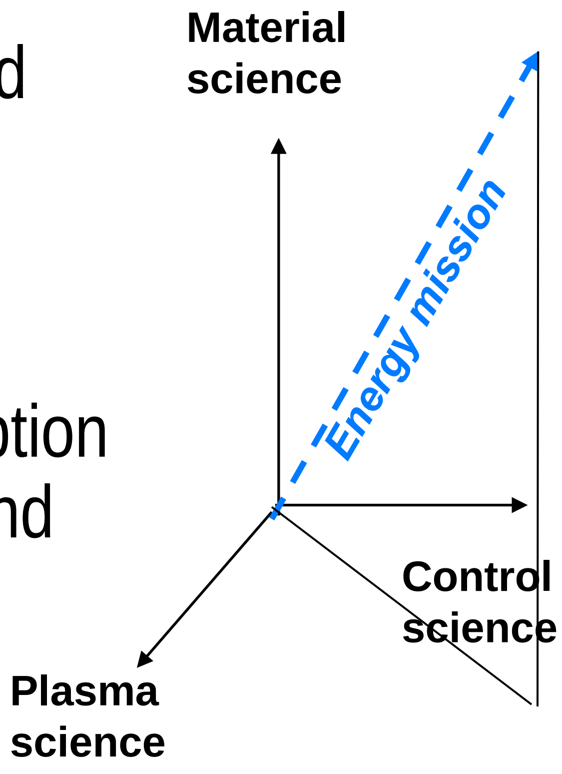


Much of the science we need to develop can be represented in a fairly simple scientific space

Imagine our scientific credibility to be represented by a vector

There are many "frames of reference" we could choose, but this seems fairly complete

Scientific credibility for fusion ➔ forming a complete enough basis set to enable a description of the requirements for energy development and the accompanying risks



We need to develop our path forward in a most challenging environment

- The U.S. budget challenge places enormous pressure on all of our scientific endeavors. There are large, not completely known moving parts that may collide as U.S. science budgets are developed and enacted. The outcome is not known; I cannot speak to any particulars

  ➔ very tough competition between science and energy with other national interests

  ➔ very tough competition within the Office of Science

- The scrutiny on fusion's budgets will increase sharply as the program becomes more conspicuous and ambitious, especially in such times

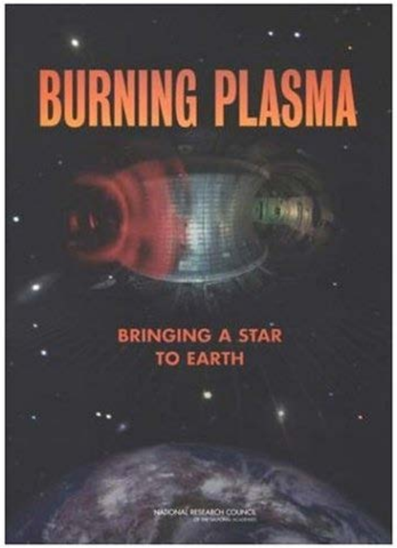
  ➔ the quality of fusion science has to be of the highest order in order to compete successfully

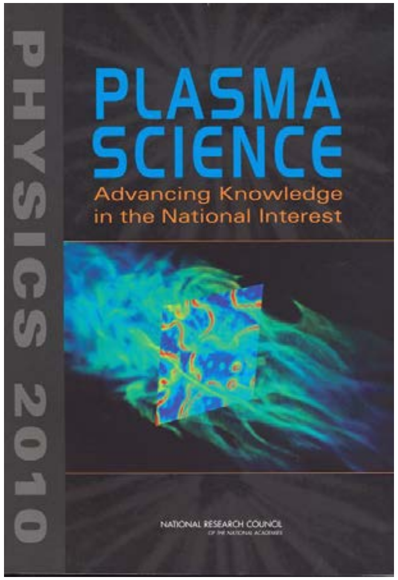
Where we need to be in ten years: overarching considerations

- This budget cycle may drive hard choices in the near term. The outcome is not known, but we know the destination

  - **The U.S. needs to lead in burning plasma science:** Essential for establishing fusion's credibility. ITER must succeed as a project. Complement ITER with science from our facilities, computation, and international opportunities
  - **Position the U.S.** to assert leadership in present gaps
  - **Steward the broader plasma sciences**: This is a leading obligation and opportunity

Overarching themes: utilize leverage between offices and agencies, create opportunities to execute the best fusion and plasma science in the world for our students and researchers





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Where we need to be in 10 years (1)

- A vision for 2021:
  - **ITER Research** - The U.S. has a strong research team hitting the ground on a completed ITER project in Cadarache. This team is capable of asserting world leadership in burning plasma science
  - **Fusion materials science** - The U.S. has made strides in fusion materials science and passed critical metrics in tokamak and ST operations with national research teams. It has assessed technical risks associated with moderate vs small aspect ratio and scope of mission, and is prepared to move beyond conceptual design of a fusion nuclear science facility
  - **Extend the reach of plasma control science and plasma-wall interactions-** U.S. fusion research has successfully levered new international research opportunities, including program leadership, in long pulse plasma control science and 3-D physics. Opportunities also include the plasma-wall interaction science made possible with long pulses.

Where we need to be in 10 years (2)

- A vision for 2021:(continued)
  - **Validated predictive capability**- The U.S. is a world leader in integrated computation, validated by experiments at universities and labs. Such computation should be transformational, as it must reduce the risks associated with fusion development steps
  - **IFE science** - FES has a leadership role in establishing the scientific basis of IFE through HEDLP and synergy with MFE in materials science
  - **Plasma science for discovery** - The U.S. is the world leader in plasma science for discovery. Leverage has been successfully applied across agencies in Discovery Science with NNSA and NSF, and overseas

In every one of the items on these two slides, universities have an opportunity to make contributions of the highest order

Burning plasma science: ITER

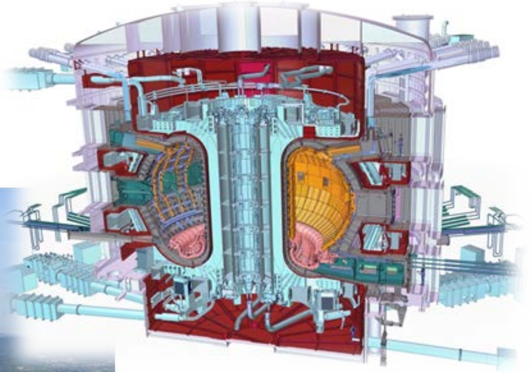
ITER progress is dramatic and important

- The stakes surrounding ITER’s success for fusion overall could not be higher.
- The IO has made significant technical and managerial strides
- The Member states are committed and have worked hard under the DG to minimize schedule delays following the Japan disasters

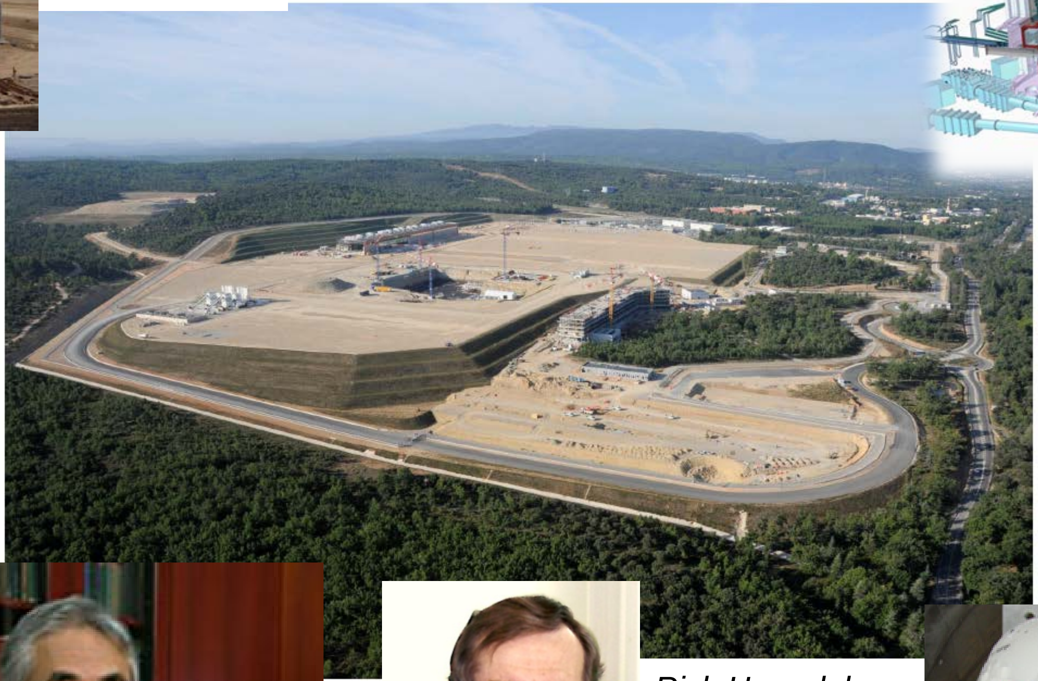
There has been important progress in constructing ITER

Poloidal winding building construction

The ITER Device



Site construction ***is underway***



New project leadership

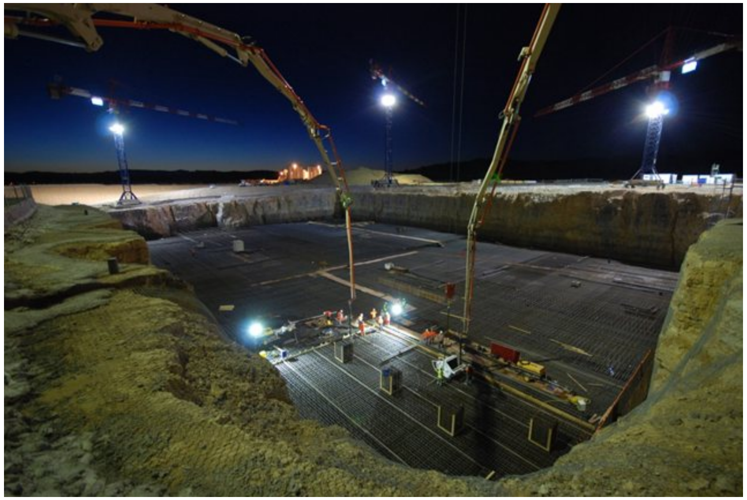
Director General Motojima

Rich Hawryluk (U.S., from PPPL); new ***Deputy Director General*** *for Administration*

Rem Haange (Netherlands), new ***Deputy Director General*** *for ITER Construction*

The future ITER headquarters will be completed before the 2012 November ITER Council meeting.

Facing the main entrance to the ITER site, the ITER Headquarters building will be the window to the ITER project for the world, Sept 2011.



At 5:00 a.m. on Tuesday, 9 August, operations began to create the lower basemat of the Tokamak Complex

Steel reinforcement bars—each one weighing nearly 100 kilos—are built up to 1.5 meters on the floor of the Seismic Pit. In the distance, the future ITER Headquarters buildings rises above the platform. (August 2011).

Sitting atop the lower basemat, 500 of these 1.8 metre concrete columns will support the seismic pads. These, in turn, will support the upper basemat of the Tokamak Complex—the actual "floor" of the installation (August 2011).

Work advances rapidly on the Poloidal Field Coils Winding Facility in August 2011: the cladding is nearly finished, the three-floor office building is in place.

We must support ITER at this extraordinary time

- Our engagement in ITER is essential to the future of U.S. fusion and plasma science
- There have been important, positive, dramatic shifts on both the technical and political fronts
- The case is being made aggressively that scientific success for ITER requires a strong domestic program

Fusion nuclear science and the plasma-material interface

On the scope of this area…

- *Building on the Greenwald Report (FESAC) and the MFE ReNeW, a leading challenge for fusion, and an opportunity for the U.S., pertains to understanding and controlling*
  - the processes beyond the last closed flux surface, including the open field line plasma physics, the plasma/material science governing the plasma-surface interactions, and how these processes couple to define the close flux surface boundary, and
  - the nuclear science related to structural evolution, integrity, and harnessing fusion power
  - the coupling of these non-nuclear and nuclear elements
- The materials science per se represents the most urgent need, but the open field line science/divertor issues are quite urgent

Overall, this represents a major, leading challenge for the field, an opportunity for U.S. leadership, and a significant responsibility

There is a FESAC charge on materials research being addressed

"What areas of research in materials science and technology provide compelling opportunities for U.S. researchers in the near term and in the ITER era? Please focus on research needed to fill gaps in order to create the basis for a DEMO, and specify technical requirements in greater detail than provided in the MFE ReNeW (Research Needs Workshop) report. Also, your assessment of the risks associated with research paths with different degrees of experimental study vs. computation as a proxy to experiment will be of value."

Consider near- and long-term (~0-5; 5-15; 15+ years); what can be done with existing facilities, new facilities, and emergent international facilities

Experiment & the role of computation: Identify 2-3 paths with varying emphases on massively parallel computing – what are the risks associated with each path?

Materials = nuclear (dpa's); non-nuclear (pmi); differential and integrated; harnessing fusion power

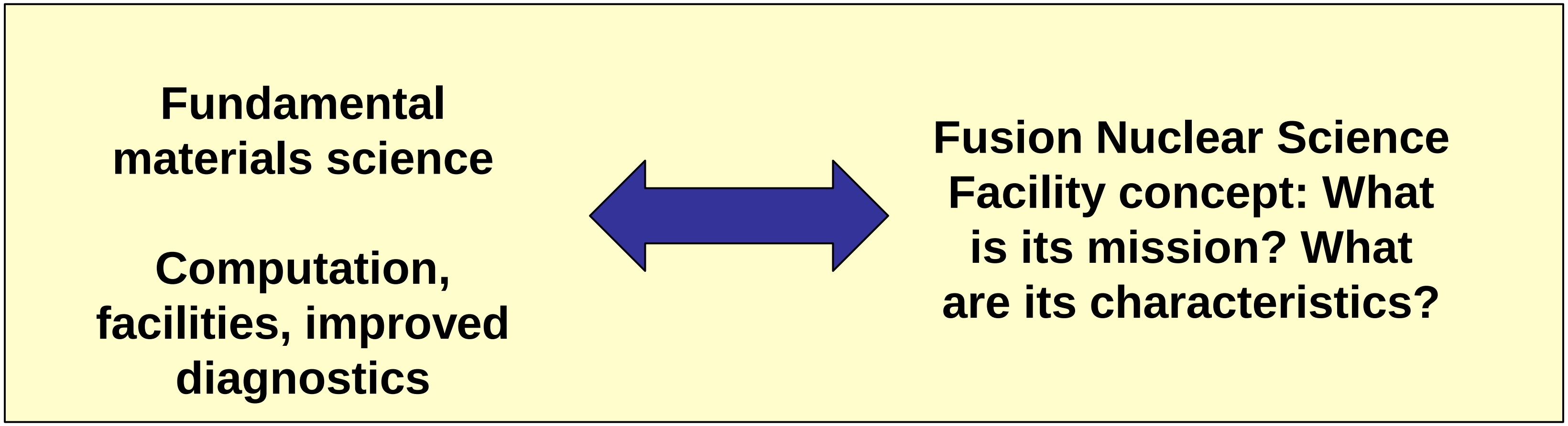
Our resources include…

- *In hand*
  - Non-nuclear: confinement facilities & diagnostics, low and moderate aspect ratio, test stand; computation
  - Nuclear: proxy with fission; computation
- *Nearly in hand*
  - Non-nuclear: international leverage on long-pulse, high heat flux facilities
  - Nuclear: fusion neutron proxy – spallation source
  - Increased effort in computation (SciDAC)
- *Building towards*
  - Strong experiment/theory/simulation program in materials, nuclear and non-nuclear
  - Fusion simulation coupling at disparate scales: physics of the plasma boundary
  - Sharpened metrics for deciding upon geometry of fusion nuclear science facility as anchor of program in 2020's

The materials challenge is enormous, both non-nuclear and nuclear, and the program needs to be carefully thought out

We need to construct a sensible program: deeply scientific as well as directed

➔What does a sensible program look like that advances materials science efficiently and effectively, towards a facility to investigate volume neutron effects on structures and materials and for harnessing fusion power?



"A tightening spiral of research and concept definition"

A spallation source may provide a cost-effective entrance to fusion nuclear science

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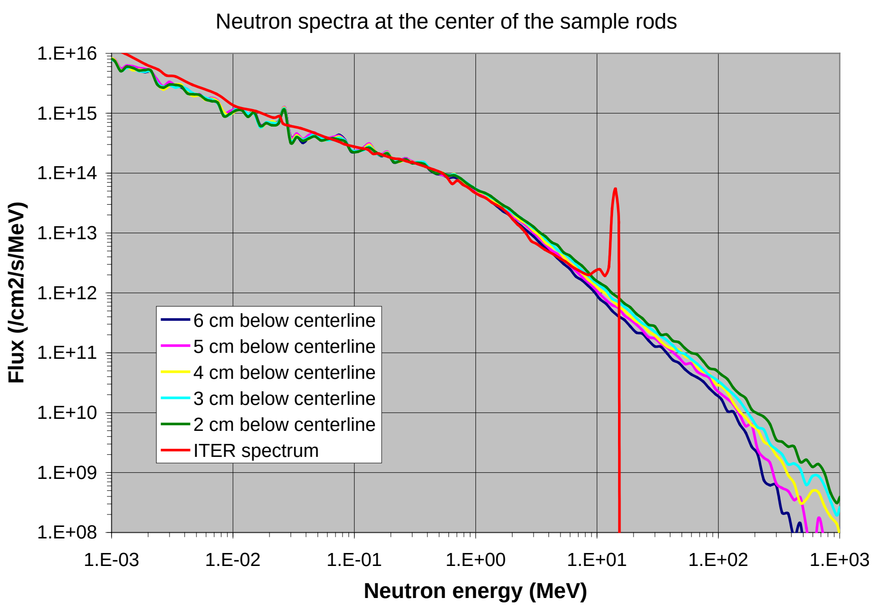
Great scientific question of practical import: Can massively parallel computing build a credible bridge regarding the materials effects of a pure fusion vs spallation neutron spectrum?



Location for sample tubes

Modified target regions

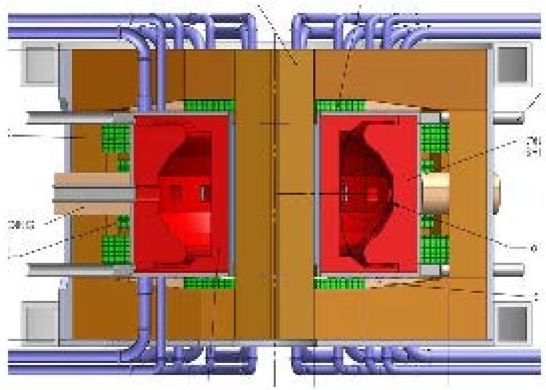
SNS SPALLATION NEUTRON SOURCE

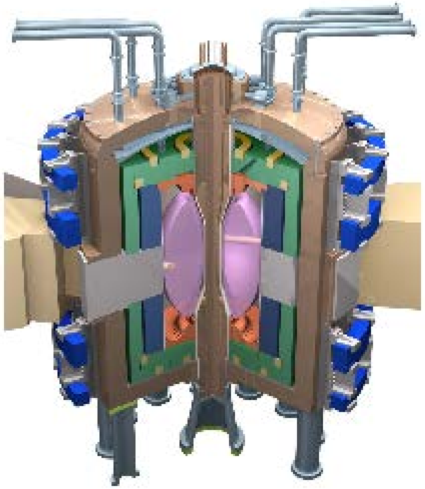
Towards a fusion nuclear science facility (FNSF)

Objective: Develop experimental data base for all fusion reactor internals and, in parallel with ITER, provide the basis for DEMO.

- Our programs must be smartly directed to inform critical decisions:
  - Determine the FNSF Geometry.
  - Determine the materials the FNSF will be made from and should test
- International Collaborations with Asian tokamaks will inform physics data base for non-nuclear plasma-wall science and operational scenarios.
- We need to sharpen our understanding of the metrics we must meet in order to justifiably advance into this class of research.

FDF: standard aspect ratio





CTF: lower aspect ratio

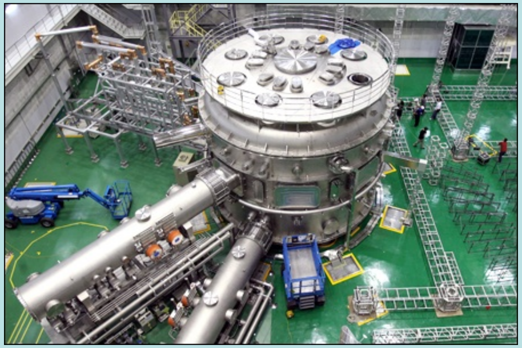
Extend the reach of plasma control and plasma-material interactions science:

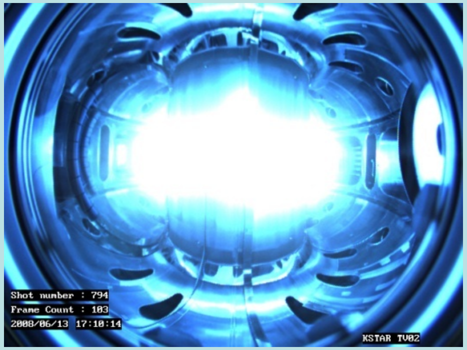
Levering domestic and international research

There have been large investments in the steady-state tokamak arena

Opportunities in both plasma control science and high heat flux, long pulse plasma-materials interactions. . .

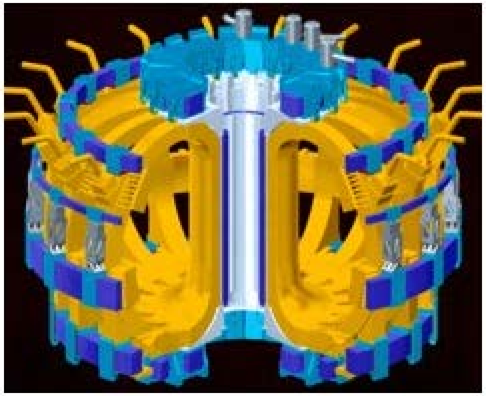
KSTAR
Daejon, S. Korea
Goal: 300 s pulse
2 MA



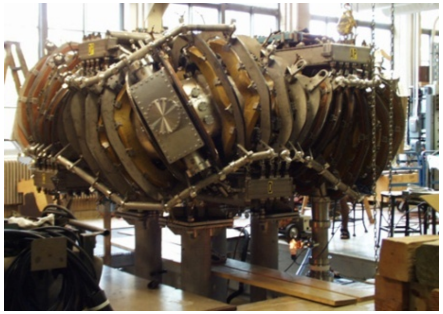


EAST
Hefei, China
Goal: 1000 s
1 MA

… and, between tokamaks and stellarators, a wide range of 3D B perturbations is spanned



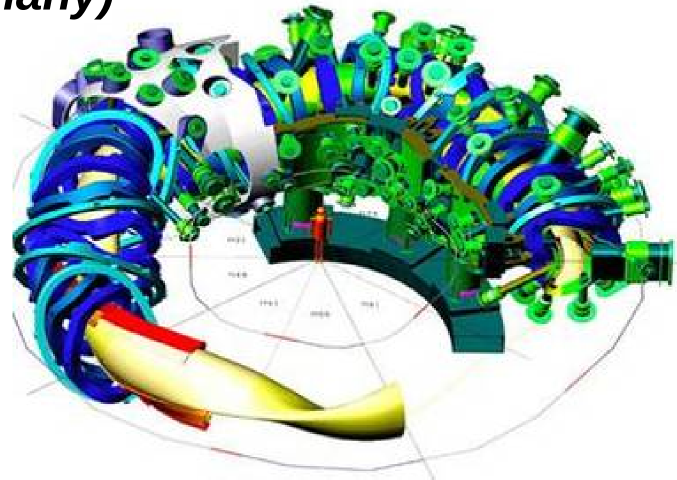
ITER: ELM coils considered - 3D B a small perturbation



HSX - fully 3D B – (UWisc)

LHD - fully 3D B (Japan)

W7-X fully 3D B (Germany)



Point of view*: range of 3D **B** perturbations presents a scientific opportunity to develop fundamental understanding of this class of physics: benefits understanding of ELM control, required device complexity, and disruptions*

➔ ***Facilities worldwide are an experimental test bed*** *for validating simulation, enabling optimizing between physics complexity and engineering complexity*

There are FESAC charges on international collaboration opportunities being addressed

"What areas of research on new international facilities provide compelling scientific opportunities for U.S. researchers over the next 10 – 20 years? Look at opportunities in long-pulse, steady-state research in superconducting advanced tokamaks and stellarators; in steady-state plasma confinement and control science; and in plasma-wall interactions."

- The explicit aim is to focus on the superconducting facilities in Asia and Europe, both existing and emergent

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There are FESAC charges on international collaboration opportunities being addressed

"What research modes would best facilitate international research collaborations in plasma and fusion sciences? Consider modes already used by these communities as well as those used by other research communities that have significant international collaborations."

- What lessons can we learn from other scientific fields, e.g. high energy physics, nuclear physics, others, that have had to undergo a transition and take on off-shore research significantly or nearly entirely
- FESAC is encouraged to engage members of those fields and representatives from universities where international research efforts are successful, as well as where transitions to an off-shore emphasis have failed
- Observations about national lab/university partnerships in new international collaborations will be highly valued. Again, what can other fields teach us?

Aim: *Construct domestic/international programs that address great science questions*

- The reason for reaching internationally: obtain access to new frontiers in plasma control and materials
  - levering our domestic facilities and computation, launch research centers

- Create Topical Centers: possible topics include
  - Plasma-wall interactions: domestic & superconducting long-pulse tokamaks as experimental focal points
  - Long-pulse, high beta plasma control
  - 2D-3D physics: domestic ELM coil experiments and stellarators (domestic and international)

These are notional, but the intent is to use any particular facility as a means to a scientific end, rather than a demonstration of performance

Validated predictive capability: *mitigating risks in fusion development, and promoting scientific discovery*

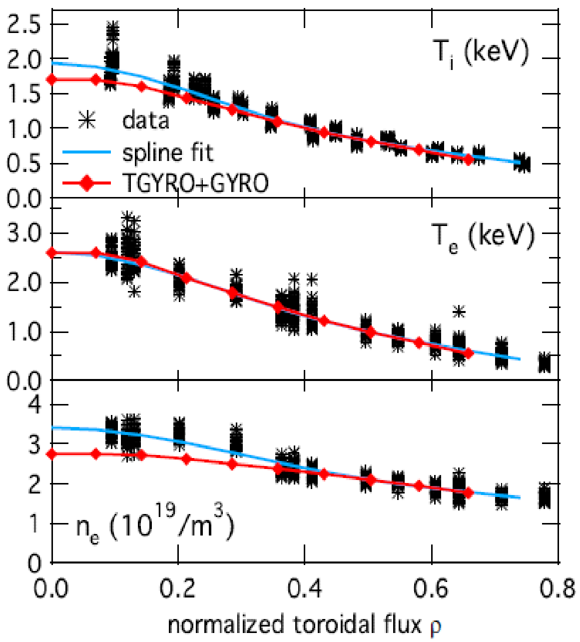
Massively parallel computing is critical to our predictive science effort, but it is only part of it

- Fusion simulation will only be as good as the physics models that go into it
- Our reliance on validated prediction to fill gaps will demand a kind of confidence we don't yet appreciate
- Plan: grow our emphasis on validation of physics models that are incorporated in fusion simulation

The continuing strong contributions of universities will be critical for success in this arena on the computational front, and can grow with respect to experimental validation

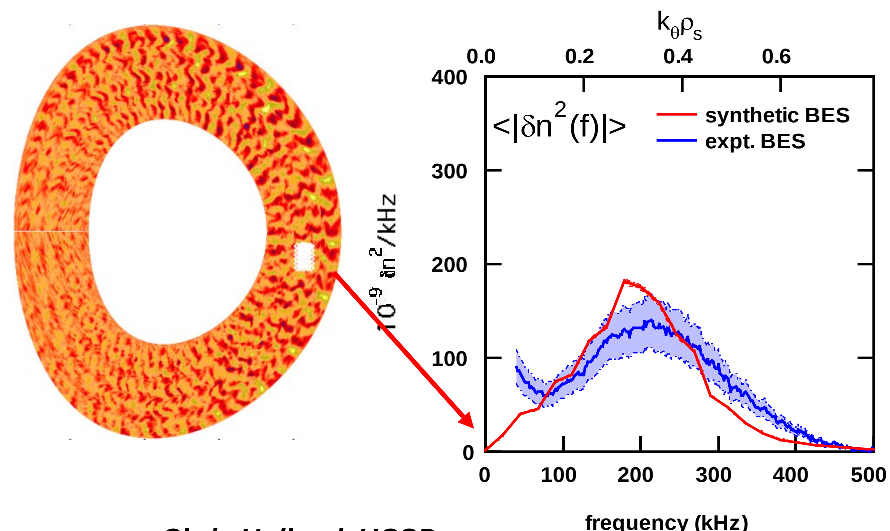
Predictions of the plasma profiles based on detailed understanding of non-linear physical processes are emerging

Predicted and measured temperatures and densities…



Simulation results (red) versus experimental data (blue) for ion temperature (top), electron temperature (middle) and electron density (bottom) and electron (right) for DIII-D L-mode discharge 128913. The TGYRO solutions in red represent a steady-state scenario in which measured input power and particle source balances the neoclassical and turbulent fluxes.

… based on validated understanding of the detailed processes



Chris Holland, UCSD

Visualization of turbulent density fluctuations from a first-principles gyrokinetic simulation of plasma turbulence and predicted fluctuation spectra

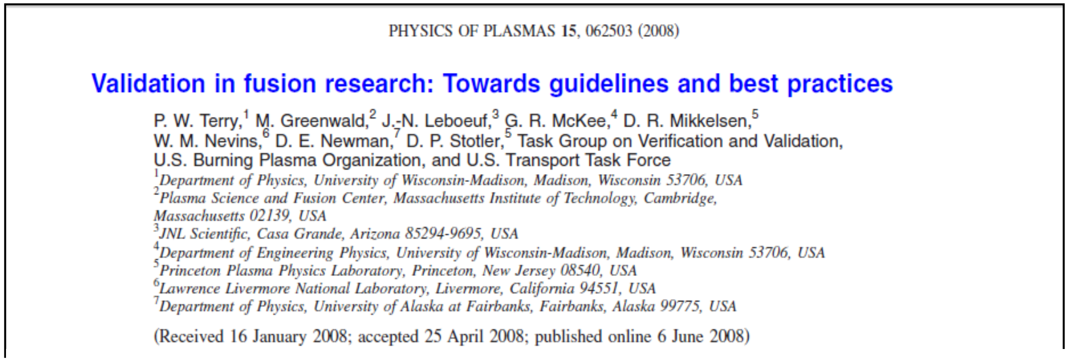
- These kinds of measurements are made on all three major devices in complementary physics regimes. FES also has dedicated experiments designed for isolated physics studies of particular phenomena, and seeks to grow these

University-scale research is well-suited for critical tests of fundamental physics and discovery

- Plasma Science Centers
  - Predictive Control of Plasma Kinetics: Multi-phase and bounded systems (U. Michigan)
  - Momentum Transport and Flow Self-organization in Plasma (UCSD)
  - Bridging the PSI Knowledge Gaps - A Multiscale Approach (MIT)
  - Also a joint Frontier Science Center with NSF: Magnetic Self-Organization (U. Wisconsin)

- Basic Plasma Science Facility (UCLA) (with NSF)
  - User facility for Alfven-wave physics and plasma-current dynamics, relevant to geospace plasmas, fusion and astrophysics.

What is the potential role of universities for testing physics models in an expanded materials science program for fusion?



PHYSICS OF PLASMAS **15**, 062503 (2008)

Validation in fusion research: Towards guidelines and best practices

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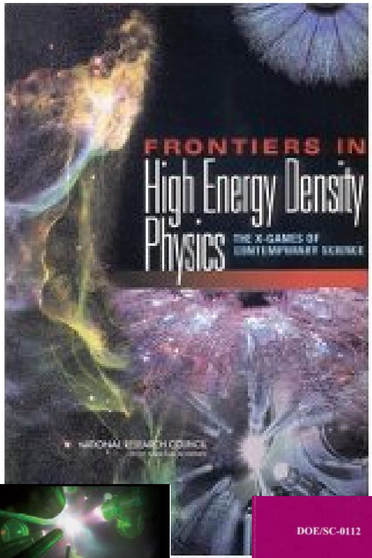
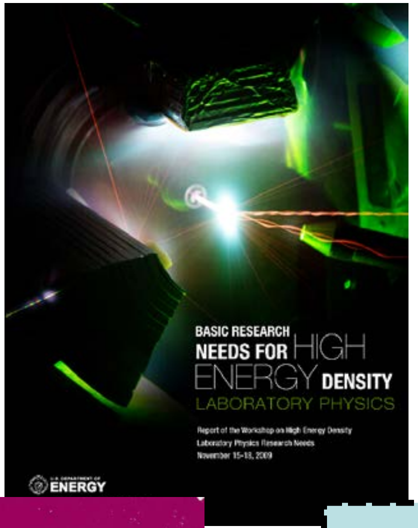
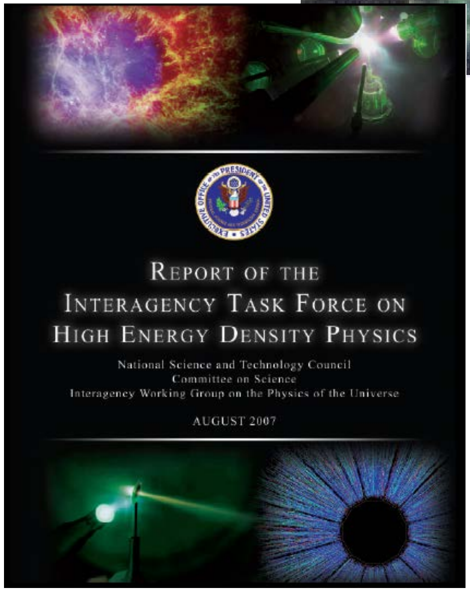
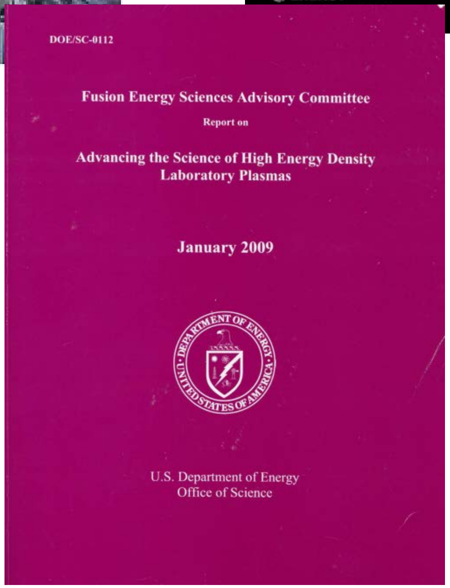
IFE science, high energy density laboratory plasma physics, and general plasma science for discovery

Elements of a path forward in HEDLP and IFE science are being informed by many high-level panel and community assessments









National Academies Study on IFE

underway

FES can assume a leading role in IFE science

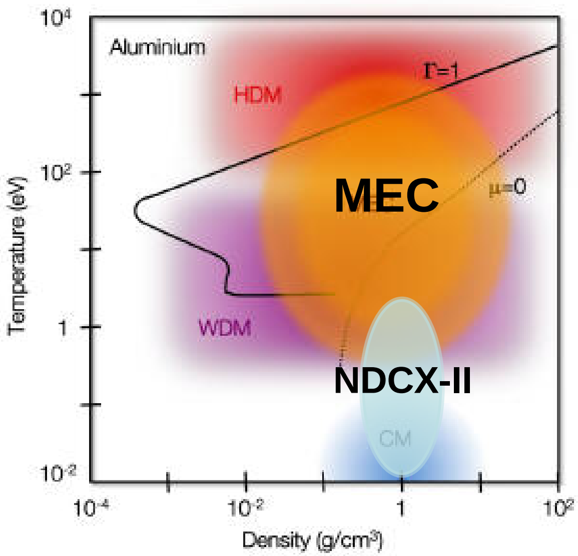
What I've told the National Academies:

- **Credibility** is the key issue for fusion. For IFE, NIF ignition will be a critical part of establishing this, but the challenge is deeper. Both the science and technology need to be advanced in concert for IFE to establish needed credibility
- **Science ⇔ technology:** A future IFE program needs to be deeply scientific as well as technologically aggressive. Technological development (e.g. in drivers or advanced ignition scenarios, for example) will require a strong scientific basis to create attractive innovation pathways.
- Fusion can help itself by recognizing and **levering common interests between MFE, IFE, and advanced fission.** This will be of value scientifically and for program stability and growth.

FES can assume a leading role in IFE science

- Necessary ingredients
  - Scientific chops in FES - ✓
  - Effective collaboration and cooperation with NNSA - ✓
  - Budget authority - ?

High Energy Density Laboratory Plasmas



Funding Opportunities

HEDLP solicitation:

Science on MEC and NDCX-II

Community Development Activities:

Concept Development Initiative to strengthen and support science on HED facilities, HEDLP facility user groups ,and conference support

Achieving an Annual Solicitation:

Stability: provide confidence for investments in HEDLP: people, departments, reapplication opportunities

Flexibility: ability to respond to scientific and technological changes

Growth: provide opportunity for emerging faculty and students each year

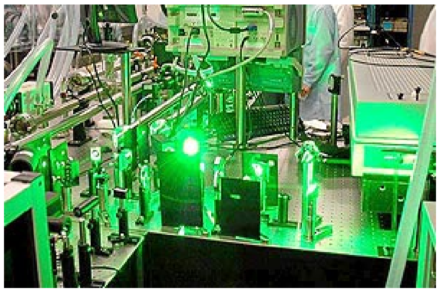
Facility Operations

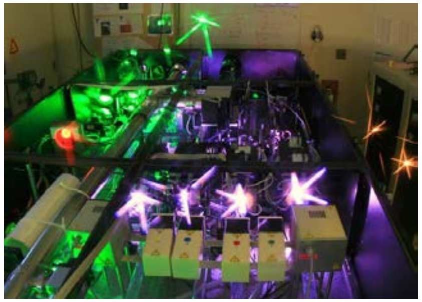
Matter in Extreme Conditions (MEC) at LCLS - Projected Completion Date: January, 2013
First Users in FY2012 (overlap 2nd laser installation)

Neutralized Drift Compression Experiment (NDCX-II) - Projected Completion Date: October, 2011 First Users in FY 2012

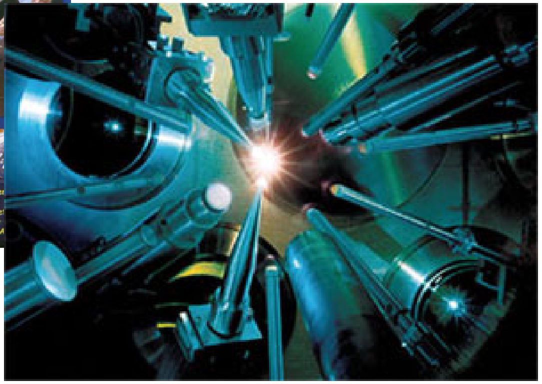
Range of facilities on the NNSA side is impressive: scientific leverage opportunity

e.g. Petawatt lasers at Texas, LLNL, Michigan, Rochester…





Omega-EP (Rochester) has a well-run Users Group



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In plasma science, all aspects have a unifying theme

- The leading challenge of plasma science is understanding the physics of the plasma distribution function and using laboratory control of this for the benefit of mankind and for discovery

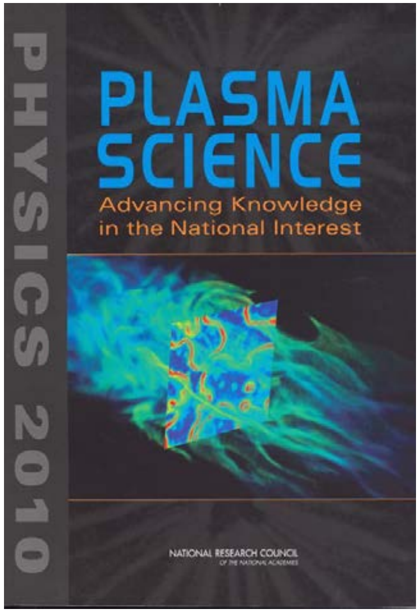
- Every aspect of plasma science has this as its leading goal: magnetic fusion, inertial fusion, industrial applications, plasma astrophysics

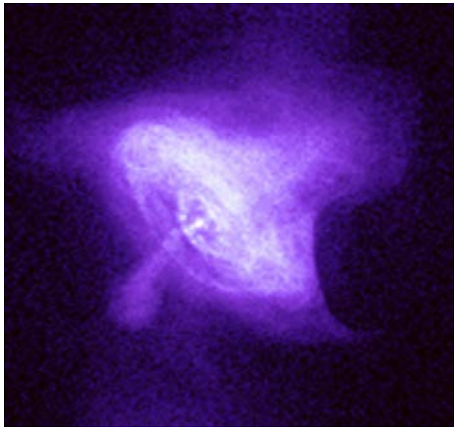
Promoting this as an overarching charge and mission of FES is a leading priority: It is in the spirit of National Academies' recommendations, and is consonant with the Office of Science mission

Deepening credibility of plasma science as a discipline demands nurturing the field broadly

Principal Recommendation: To fully realize the opportunities in plasma research, a unified approach is required. Therefore, the Department of Energy's Office of Science should reorient its research programs to incorporate magnetic and inertial fusion energy sciences; basic plasma science; non-mission-driven, high-energy-density plasma science; and low-temperature plasma science and engineering.

The new stewardship role for the Office of Science would extend well beyond the present mission and purview of the Office of Fusion Energy Sciences (OFES). It would include a broader portfolio of plasma science as well as the research OFES currently supports. Two of the thrusts in this portfolio would be new: (1) a non-mission-driven, high-energy-density plasma science program and (2) a low-temperature plasma science and engineering program. The stewardship framework would not replace or duplicate the plasma science programs in other agencies; rather, it would enable a science-based focal point for federal efforts in plasma-based research. These changes would be more evolutionary than revolutionary, starting modestly and growing with the expanding science opportunities.





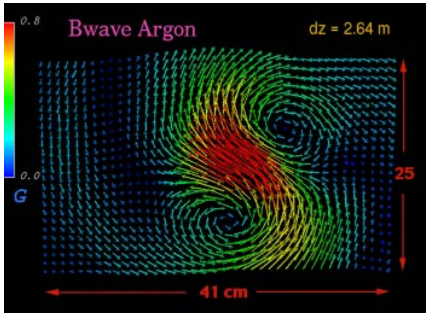
FES should be the federal home for plasma science broadly.

The project's theory is supported in part under the NSF/DOE Partnership in Basic Plasma Science and Engineering

General Plasma Science Program

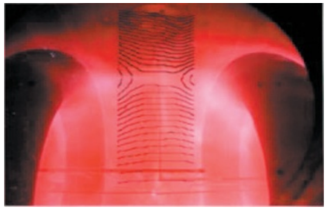
Plasma Science Centers

Predictive Control of Plasma Kinetics @ U. Michigan
Bridging the PSI Knowledge Gaps @ MIT
Momentum Transport and Flow Self-Organization @ UCSD



NSF/DOE Partnership

Annual joint solicitation in Basic Plasma Science and Engineering
43 projects currently (FY11) supported by DOE awarded through joint solicitation
Center for Magnetic Self-Organization, U. Wisconsin - joint Frontier Science Center
Basic Plasma Science Facility (BaPSF), UCLA – jointly funded user facility



Magnetic Reconnection Experiment, PPPL

Laboratory Basic Plasma Science

FY2013 competitive review of Lab programs
Opportunities for international collaboration

Fusion must take on new classes of challenges; we need to be prepared

Our opportunity and charge is to establish fusion's scientific credibility

- Plasma control science and materials science are the broad categories we need to pursue: supported by National Academies studies and FESAC
- Our future program proposals need to be carefully thought out.
- A leading challenge: validated, predictive capability
- Leverage is key: cross-agency, new international partnerships

There is risk at this time, but the science programs that succeed will have a few things in common

- With ITER growth and downward financial pressure overall in Washington, the discussions are vigorous and impactful. However, DOE commitment to Science within the Administration has been impressive.

- The quality, richness, and relevance of our science is our best asset.

- Successful science programs will be prepared: they will have identified the critical science problems. They will have capitalized on leverage opportunities – cross-agency, internationally

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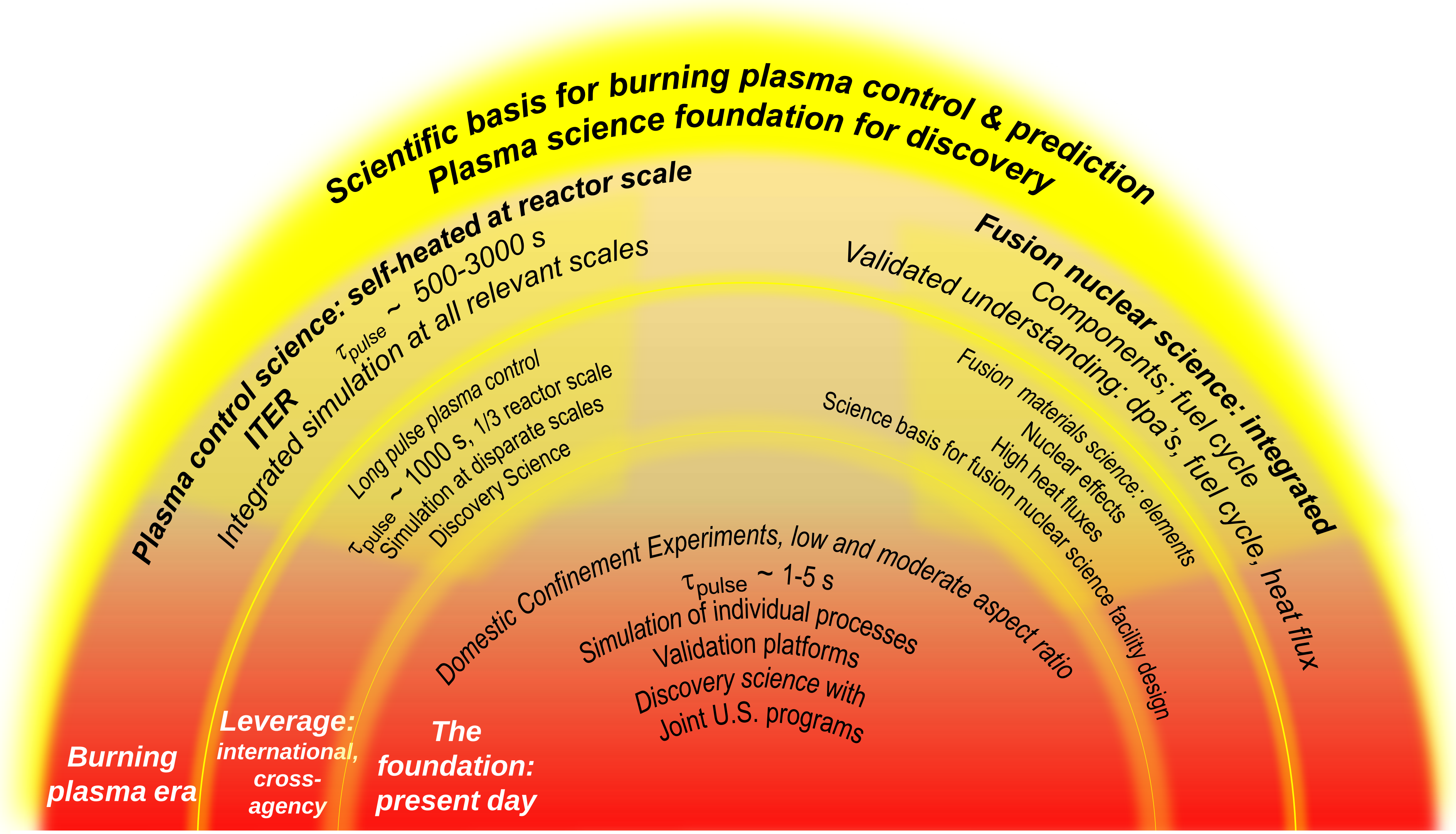
Establishing the scientific basis for fusion requires strong domestic research and leverage across national and institutional boundaries



Thank you