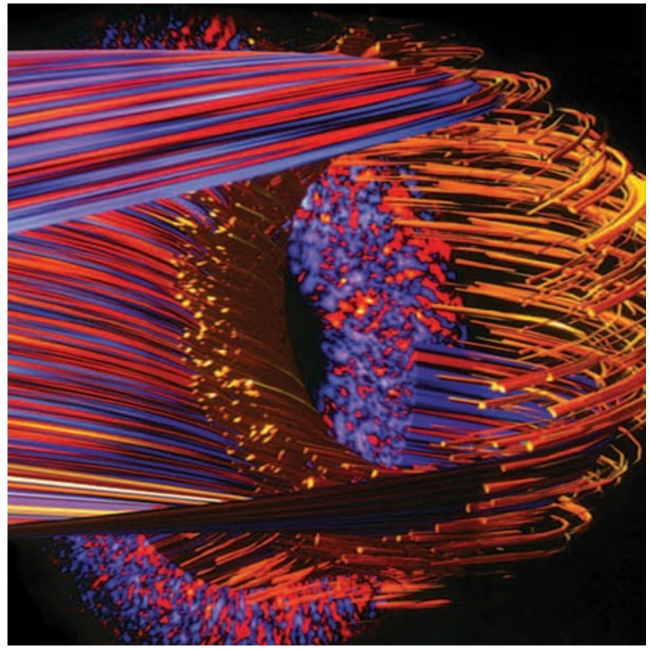
WHITE PAPER: Fusion Simulation Program (FSP)



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FESAC SUBCOMMITTEE MEETING

Bethesda, Maryland

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FUSION SIMULATION PROGRAM (FSP)

Outline

I. Situation Analysis
II. Motivation, Mission, & Goals for FSP
III. Science Challenges & Opportunities for FES
IV. FSP Program Elements
V. Concluding Comments

CURRENT SITUATION ANALYSIS

- Current ITER Fiscal Issues ➔ Critical importance of *cost mitigation* for MFE
  - *Modern HPC-enabled validated simulation & modeling capabilities is key*

- Potential cost benefits include:
  - Optimization of operation with possible *in situ* guidance for long-pulse ITER experiments
  - Efficient data collection, analysis, and dissemination of results from ITER burning plasmas
  - Risk mitigation by rapid proto-typing and exploring alternative designs and approaches

- Challenges:

  --- ITER represents significant departure from conventional duration/pulse lengths of discharges and in energy exhausted to plasma periphery

  --- each ITER discharge cost expected to exceed $1M

  --- current projections of ITER performance based on extrapolation from simple models

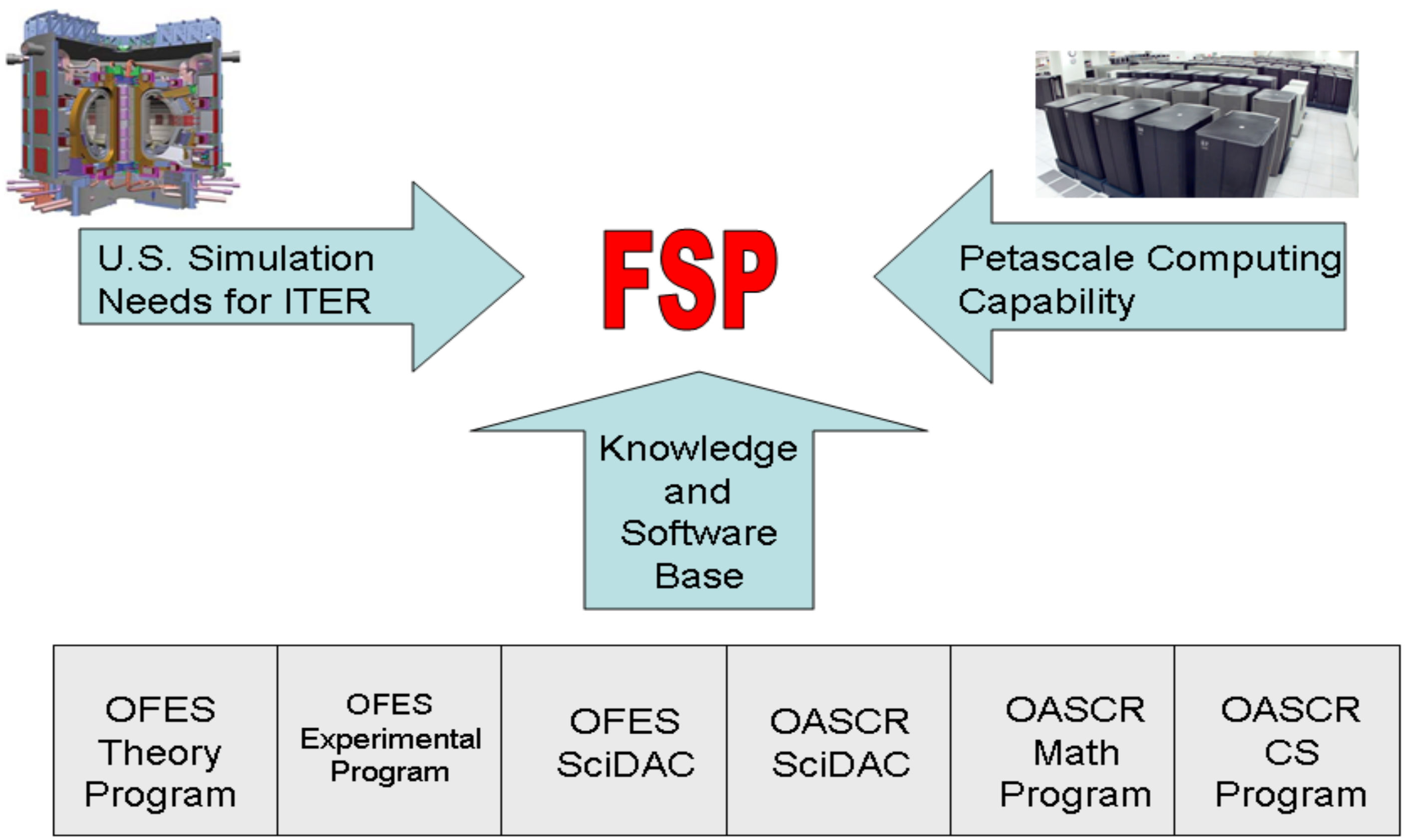
- Approach: Enable reliable operation & efficient experimentation by *deployment of validated HPC models of integrated physics in ITER*

Motivation: Opportunity to Cost-Effectively Accelerate Scientific Progress in FES

• Predictive simulation capability needed for planning & harvesting scientific results from experiments worldwide, including *participation in ITER* & reducing risks in plans for future devices

• Powerful ("Leadership Class") Computational Facilities worldwide moving rapidly beyond the petascale *(10^{15} floating point operations per second)*

• Interdisciplinary *collaborative experience*, knowledge, & software assembled ~ past decade under SciDAC plus ongoing FES and ASCR base programs



FSP MISSION & VISION

MISSION: develop, validate, and apply state-of-art simulation models to address key scientific questions with urgent practical impact on development of magnetically-confined plasmas as clean & sustainable energy source

GOAL: provide capability to confidently predict toroidal magnetic confinement fusion device behavior with comprehensive and targeted science-based simulations of nonlinearly-coupled phenomena in the core plasma, edge plasma, and wall region on time and space scales required for fusion energy production.

➔ *FSP National Website:* [http//www.pppl.gov/fsp]

SUMMARY: FUSION SIMULATION PROGRAM (FSP)

- Intended as a 15 year national program funded jointly by FES & ASCR at ~ $25M/year
  -- FSP Plan: start @ ~$12M & ramping up as work-scope grows over 5 years to ~$22M/year effort

- 2-year national effort producing FSP Plan, involving ~ 6 national labs, 9 universities, & 2 companies
  -- strong national engagement of leading scientists from both FES (theory & experiment) and ASCR (applied math & computer science) communities

- Integrated science topics include:
  -- Plasma Edge (including Pedestal & Boundary Physics)
  -- Whole Device Modeling (including Disruption Avoidance)
  -- Disruption Dynamics (including mitigation if disruptions are not successfully avoided)
  -- Core Profiles (including 3D effects, meso-scale physics, & integration with plasma edge)
  -- Energetic Particles/Wave Physics (including non-thermal distributions from fusion reactions, RF & Neutral Beam Injection heating, MHD activity, & turbulence)

- Large-scale High Performance Computing (HPC) crucially needed to support ITER mission
  -- clearly articulated in reports from FESAC, ASCAC, & DoE-SC strategic planning documents

- "FSP Pause" for FY'12 to carry out assessment of FSP Plan

- ***With the FSP established, the US would be the world leader for the coming decades in validated integrated fusion simulation***

PRIORITIZATION METRICS

1. **A clear need for multi-scale, multi-physics integration**:
   - proposed FSP topics should be outside focus area of current modeling programs
   - solving/delivering significant advances on targeted problem would demonstrate FSP "is more than the sum of its parts"

2. **Importance and urgency**:
   - solve problems integral to creation of knowledge base needed for FES mission leading to "an economically and environmentally attractive fusion energy source"
   - urgency is related to schedules, dependencies and critical paths for program elements that FSP would support

3. **Readiness and Tractability:**
   - The underlying physics base (with applied math, CS, and computing platforms), should be sufficient to begin work at outset of FSP
   - Need for FSP to impact ongoing research at an early date
   - Need for clear "living roadmap" for substantive progress on each FSP research topic

4. **Opportunity for New Lines of Research:**
   - Associated R&D offer opportunities for delivering new insights or potential breakthroughs, particularly those not accessible by other means

1st SET OF TARGETED FSP ACTIVITIES

Prioritization leads to: First Set of FSP Activities

(i) Whole Device Modeling + Disruption Avoidance:

=> *Indispensable part of discharge optimization and prediction, especially the avoidance of disruptions*

(ii) Edge Physics: Boundary + Pedestal:

=> *Heat and particle loads with associated impact on Plasma-Material Interactions (PMI) and including the nature and impact of Edge Localized Modes (ELM's)*

→ ***natural complement to new fusion material science studies***

Accountability: substantive achievements in initial scope needed to drive evolution & growth to additional areas of integration

- ***NL interactions of plasma with control actuators TOO COMPLEX to investigate via empirical methods alone ➔ need modeling to guide exploration coupled with strong experimental validation***

- ***Successful FSP enhances return of investments in experimental facilities /ITER via harvesting of scientific insights from burning plasma experiment***
  --- Enabling of new modes of operation improving performance needed for future systems such as FNSF and DEMO

FSP Alliance with U.S. Experimental Facilities

- **FSP/U.S. Experimental Facilities Collaboration Document:**

  -- affirms need for partnerships and mutual interactions -- institutionalized through formal agreements, regular participation in planning and reporting activities, and cross-membership in planning groups as appropriate

- **Key Elements include:**

  - ***Proposed <u>mechanisms for short-term and long-term planning</u>***
  - ***<u>Roles & Responsibilities</u> for the FSP and for experimental teams in their collaboration***
  - ***<u>Lessons learned</u> from the major experimental facilities that are useful in planning the FSP R&D program– e.g. <u>open annual community research forums</u>***

- *Prominent presence of FSP involvement in 5 year plans presented and endorsed at 2011 PAC meetings for DIII-D, C-MOD, and NSTX*

*** ***Note: This <u>will help guide future planning of FSP collaborations with international facilities and ITER</u>***

FSP ELEMENTS

- **Collaborations with FES Base Theory Program for basic research providing foundations for realistic integrated modeling & with DoE's SciDAC Program**

- **Tasks:** *(i) application of modern Verification, Validation, and Uncertainty Quantification (VV&UQ); (ii) efficient integration of best physics components & common interfaces & data structures guided by appropriate set of standards; & (iii) production of FSP-standardized , well-documented tool sets for data preparation, code input validation, data analysis, and visualization.*

- **Collaborations with DoE's SciDAC Program & associated alliance with OASCR for deployment of modern Applied Math (AM) & computer science(CS) technologies**
  → enables rapid sharing of new tools & approaches between applications in world-leading nationally coordinated program
  → notable enthusiasm & interest from AM &CS communities at FSP workshops (documented on FSP national web-site)

- **Coordinated national staff dedicated for software infrastructure, developer support, production computing, & user support**
  → improvement over current practice of diffuse development & support of individual applications

FSP ELEMENTS

• **Benefits of Larger Scale:** ***"economy of scale" to enable targeted FSP capabilities***

- ***Set new standards for V&V&UQ with more rigor & efficiency via strong coordination with experimental facilities (national & international)***

  → includes streamlined construction of *synthetic diagnostics* through common data structures for representing diagnostics, code geometry, phase-space sampling, and physics kernels

- ***Training of new generation of "analysts" with breadth of multi-disciplinary skills – involving strong coupling to university participation in FSP***

• **Community "Buy-In" & Vetting of FSP:**

• Development & initiation of FSP strongly supported over past decade by numerous major community workshops & strongly endorsed by FESAC & ASCAC Panels

• Consistent with key priorities from ITER organization (IO), FES Research Needs Worksnop (ReNeW) document, & recent FESAC reports on *international collaboration opportunities* (e.g., in Asia with long-pulse experimental capabilities not available in US facilities)

→ ***If the FSP is established now, the US would be the world leader for the coming decades in validated integrated fusion simulation***

- **U.S. Energy Secretary** *Steven Chu:*

27 September 2010 – "All Hands Meeting" at PPPL, Princeton, NJ

"The world's energy challenge requires a strong continued commitment to plasma and fusion science."

"Progress in fusion has to be grounded in validated predictive understanding: the DoE is clearly interested in your planning and progress for a strong Fusion Simulation Program (FSP)."

- **U. S. Energy Undersecretary** *Steven Koonin:*

18 March 2011 *-- House Sub-Committee on Energy & Water Testimony, DC*

"With respect to US investment in ITER … need to make sure our program is best positioned to take advantage of that … so we'll ***put a lot of money into diagnostics, simulation, and the human capability*** *… Executing simulation is in part about the hardware but it's also about the software and the expertise to meld experiments and observations together with the codes .. and there the U.S. is second to none."*

US Senate Appropriations Subcommittee 2012 Report: (*current language, page 97, Sept. 2012*):

"The Committee also encourages the fusion energy program take advantage of high performance computing to address scientific and technical challenges on the path to fusion energy. <u>The Committee supports the Fusion Simulation Program to provide experimentally validated predictive simulation capabilities that are critical for ITER and other current and planned toroidal fusion devices</u>. *Given current and future budget constraints, the Committee views this initiative as critical to maintain U.S. world leadership in fusion energy in* ***a cost-effective manner****."*

"FSPAC Strongly Endorses both Concept & Potential of FSP"

Executive Summary (May 8, 2011)

Douglass Post, Chair (DoD), Allen Boozer (Columbia U), Leslie Greengard (NYU), Brian Gross (GFDL), Greg Hammett (PPPL), Wayne Houlberg (ITER), Earl Marmar (MIT), Dan Meiron (CalTech), Jon Menard (PPPL), Mike Norman (UCSD), Rick Stevens (ANL).Carl Sovinec (U Wisc), Tony Taylor (GA), Jim Van Dam (U Texas)

Based on the demonstrated progress, the Fusion Simulation Program (FSP) planning team has made toward developing a plan for the FSP, the Fusion Simulation Program Advisory Committee (FSPAC) ***strongly endorses both the concept and the potential of the Fusion Simulation Program***.

The FSPAC judges that:

1) the FSP will enable *significant advances in fusion science*,

2) the FSP will substantially *increase the value of ITER to the US*,

3) the FSP will make major contributions to build the *knowledge base required for DEMO*,

4) the FSP provides one of the few opportunities available for the US to provide *recognized leadership in the international fusion science community*, and

5) *a Fusion Simulation Program of the type proposed by the FSP team provides the most credible path forward for the integrated whole device model that will be highly important for the realization of fusion energy.*