Status and Plans: The Fusion Simulation Project

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Chair, DOE Fusion Simulation Project Steering Committee

(D. Batchelor—ORNL, R. Bramley—U. of Indiana,
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PASCI meeting, Princeton, NJ

In 2002, US Fusion Community proposed a "Fusion Simulation Project"

- In 2002, FESAC and DOE proposed a "Fusion Simulation Project"
- Ramp up to $20 M per year in 3 to 4 years, begin with $4M in FY05

Fusion Simulation Project, Integrated Simulation and Optimization of Fusion Systems

Jill Dahlburg, *General Atomics (Chair)*
James Corones, *Krell Institute, (Vice-Chair)*
Donald Batchelor, *Oak Ridge National Laboratory*
Randall Bramley, *Indiana University*
Martin Greenwald*, Massachusetts Institute of Technology*
Stephen Jardin, *Princeton Plasma Physics Laboratory*
Sergei Krasheninnikov, *University of California - San Diego*
Alan Laub, *University of California - Davis*
Jean-Noel Leboeuf, *University of California - Los Angeles*
John Lindl, *Lawrence Livermore National Laboratory*
William Lokke, *Lawrence Livermore National Laboratory*
Marshall Rosenbluth, *University of California - San Diego*
David Ross, *University of Texas - Austin*
Dalton Schnack, *Science Applications International Corporation*

It's time for the FSP!

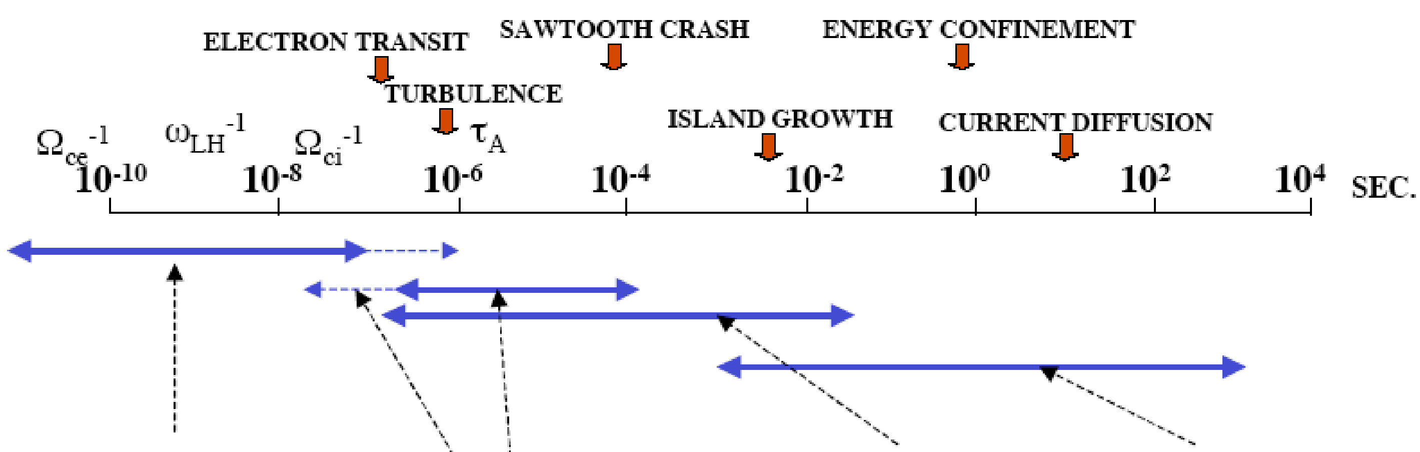
- ITER is a very important, ambitious and expensive experiment
- It's essential that the US and the international fusion program do all they can to ensure that ITER is successful
- The FSP can help the US and world fusion program maximize the benefits of ITER
- The FSP will allow the US to play a key role in helping ITER to succeed and maximize the benefits of ITER to the US
  - Optimize the Design
  - Achieve plasma performance goals
  - Avoid operational limits—avoid machine damage
  - Develop and Capture physics knowledge for use for DEMO and the future
- The FSP is enabled by:
  - Continued exponential growth of computing power
  - Technical progress in fusion (e.g. SciDac, US fusion program, tokamak experimental progress, international fusion theory program,…)
- FSP strongly leveraged by base fusion program, international program

Fusion Simulation is challenging!

- Basis of prediction is solution of conservation equations on a grid
  - Can we obtain accurate solutions for:
  - Particle transport—anomalous transport, MHD?
  - Momentum transport—MHD, viscosity due to anomalous transport?
  - Energy—Neo-classical and anomalous transport?
- Multi-physics—interaction of different complex effects, couple different time and distance scales
- Sources and rates—
  - NBI, RF, neutrals, external fields, atomic physics—reasonable confidence
  - MHD—medium confidence
  - Anomalous transport—low confidence
- Progress is being made (base program, SciDac,…), but the challenge is large.
- Strong focused research program needed

Multiple times are a challenge.

Typical Time Scales in a next step experiment with $B = 10$ T, $R = 2$ m, $n_e = 10^{14}$ cm^{-3}, $T = 10$ keV



Single frequency and prescribed plasma background	Neglect displacement current, average over gyroangle, (some) with electrons	Neglect displacement current, integrate over velocity space, neglect electron inertia	Neglect displacement current, integrate over velocity space, average over surfaces, neglect ion & electron inertia
RF Codes	Gyrokinetics Codes	Extended MHD Codes	Transport Codes
wave-heating and current-drive	turbulent transport	device scale stability	discharge time-scale

FSP will advance fusion science.

- FSP will address the overarching question in the DOE Office of Science Strategic Plan: "How can we create and stably control a high-performance fusion plasma?"
- In particular many of the major outstanding scientific questions of vital importance to the future of the program:
  1. What are the conditions under which a sequence of nonlinear magnetohydrodynamic (MHD) events lead to a catastrophic disruption of the fusion plasma?
  2. What is the physics of the plasma edge whose structure critically affects global confinement of heat and particles?
  3. What is the physics of fine scale turbulence on global transport length and time scales?
  4. How do we best use heat, particle, and current sources to control plasmas to achieve high levels of fusion power?

FSP is a big project with tremendous challenges and tremendous opportunities.

- $20M/year ~ 60 staff
- 5 to 10 (or more) non-collocated institutions
- Very little large code project experience in fusion community
- Many disciplines involved: physics, computational mathematics, computer science, document writers, managers,…
- Technical challenge greater than most computational endeavors
  - Probably the most technically ambitious computational physics project being contemplated
- Only a project with a new focus will be able to attract a significant level of new funding

Fusion Simulation Project Steering Committee task is to "design" project

- 2002 FESAC ISOFS report left two major issues on the table
  - Vision and Definition for a definite product
    - Specific Roadmap for producing the product
  - Governance structure/project organization
- In November, 2003, DOE formed the Fusion Simulation Project Steering Committee to address these issues so that we take the next step to make the project a real project
  - Douglass Post, chair, Los Alamos National Laboratory
  - Donald Batchelor, Oak Ridge National Laboratory
  - Randall Bramley, University of Indiana
  - John Cary, University of Colorado
  - Ronald Cohen, Lawrence Livermore National Laboratory
  - Phillip Colella, Lawrence Berkeley National Laboratory
  - Steven Jardin, Princeton Plasma Physics Laboratory

Fusion Simulation Project Steering Committee task is to "design" project

- Report due to DOE in later summer, 2004
- Resource guidelines: roughly $20M/year for 15 years
- Multi-institutional with "project" structure ("like an experimental project") and governance
- Recommend:
  - Project goals
  - Project structure
    - What kind of modules, codes, etc.?
  - Committee charged to recommend a governance structure similar to the structure of an experimental project
  - Project organization/governance/management structure
- Provide basis for "Request for Proposal" to be issued in late 2004
- Project to begin in 2005 with award of contract
  - Multi-institutional—labs, universities, industry
  - Multi-disciplinary—plasma physics, computer science, computational mathematics
  - Supported by DOE Office of Fusion Energy Sciences and DOE Office of Advanced Scientific Computing Research

FSP priority is to support ITER

- Ray Orbach, head, DOE Office of Science
  - “ITER is the number 1 priority project for the US DOE Office of Science.
  - Simulation is the number 2 priority for the US DOE Office of Science.”
- Our logic: The Fusion Simulation Project is the number 2 priority supporting the number 1 priority
- Develop “predictive capability” for ITER

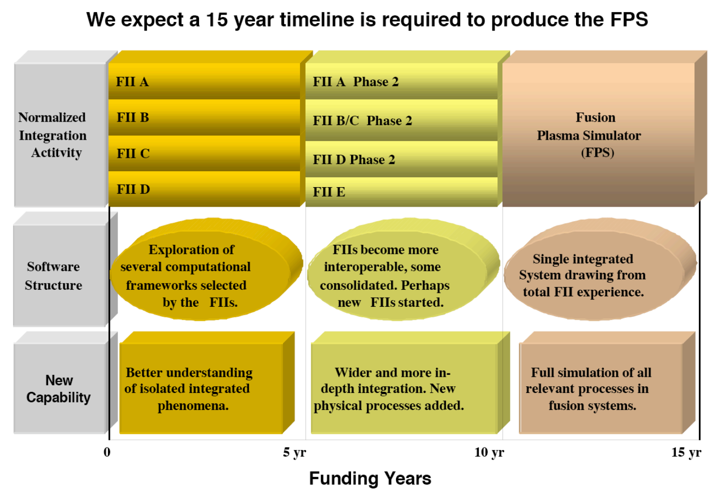
ITER (N. Sauthoff) defined 5 Major Potential ITER Contributions

1. Facility design (2004 through construction)
   – Continued support of ITER design and construction
2. Plasma scenario development (~2008 through operation)
   – Planning for ITER Operation
3. Control system design and tuning (prototype through operation)
   – Support control system development
4. Experimental shot design (~2012 through operation)
   – Provide capability for ITER Physics team to design experimental shots
5. Data analysis (~2008 through operation)
   – Provide tools to support data analysis

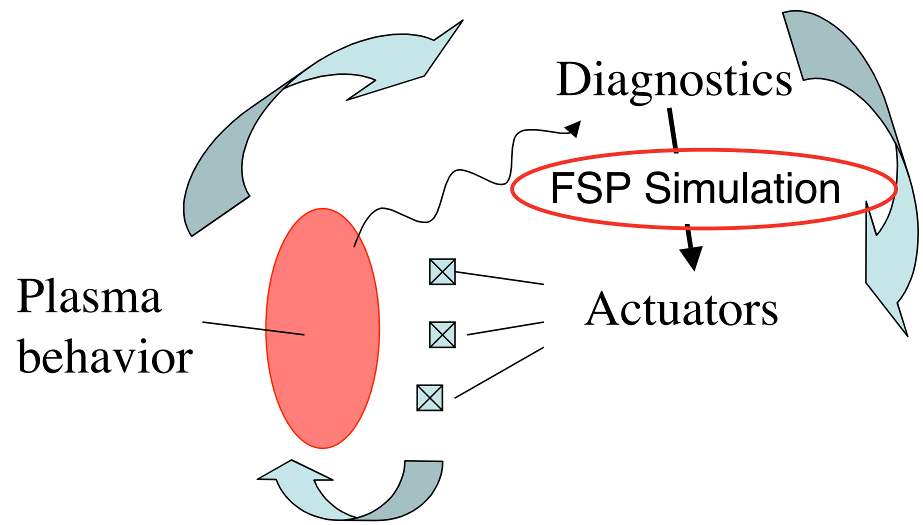
- DEMO design
- Capability to be available to international ITER physics team, multi-institutional, non-collocated

One—among many—candidate vision: ITER plasma control

- ITER Physics Team has requested that real-time control of the burning plasma will be essential to meet ITER performance goals (e.g. long pulse ignited burn) and to avoid operational limits such as disruptions



- ITER team vision: Use predictive simulation running in real time to extrapolate from measured plasma conditions to optimum plasma parameters
- With proper extensions, such a capability can bring together the disparate simulation efforts in the US
- Collaborations with EU and Japanese simulations potentially valuable as well



Committee has continued development of FSP concept.

- To attract new funding, the FSP will need to address major scientific problems with exciting innovations that can solve the problems
- Committee has continued discussion and development of a more concrete vision for the FSP
  - 7 Conference calls
  - 1 day and 3 day planning workshops, Dec. 2, 2003, May 18-20,2004
  - Assessed Japanese program—participated in Japanese workshop Dec. 2003
  - Assessed European program—participated in EU workshop in Feb. 2004, visited Culham and JET May 30 and June 1, 2004
  - Visited ITER Physics team and ITER leadership in Naka and Garching
  - Informally Canvassed fusion community at 2003 APS and many other venues
- Very challenging to get everyone together
  - Very busy people, job is demanding, but people have worked pretty hard
- General conclusion is that design of a software project of this magnitude is real work, will take people who can spend half to all of their time on it and who have the authority to make decisions and can speak with authority

U.S. Department of Energy

Office of Science

US Losing Leadership in FSP Activities

European and Japanese FSP activities proceeding based on US FESAC ISOFS Subcommittee report of 2002

- **In European FSP Task force 80 professionals already involved with 14 laboratories participating http://www.efda-taskforce-itm.org/**
- Target is a complete European modelling structure for ITER, and any other fusion device, meeting the reliability standards required by the operation of a nuclear device
- JET: Project to integrate Transport and MHD codes into a unified system, linked with JET and ITER databases

Japanese TASK: Burning Plasma Simulation Initiative

- Collaboration among Universities (including Kyoto, Kyushu, Tokyo,Yamaguchi), NIFS and JAERI

Office of Fusion Energy Sciences

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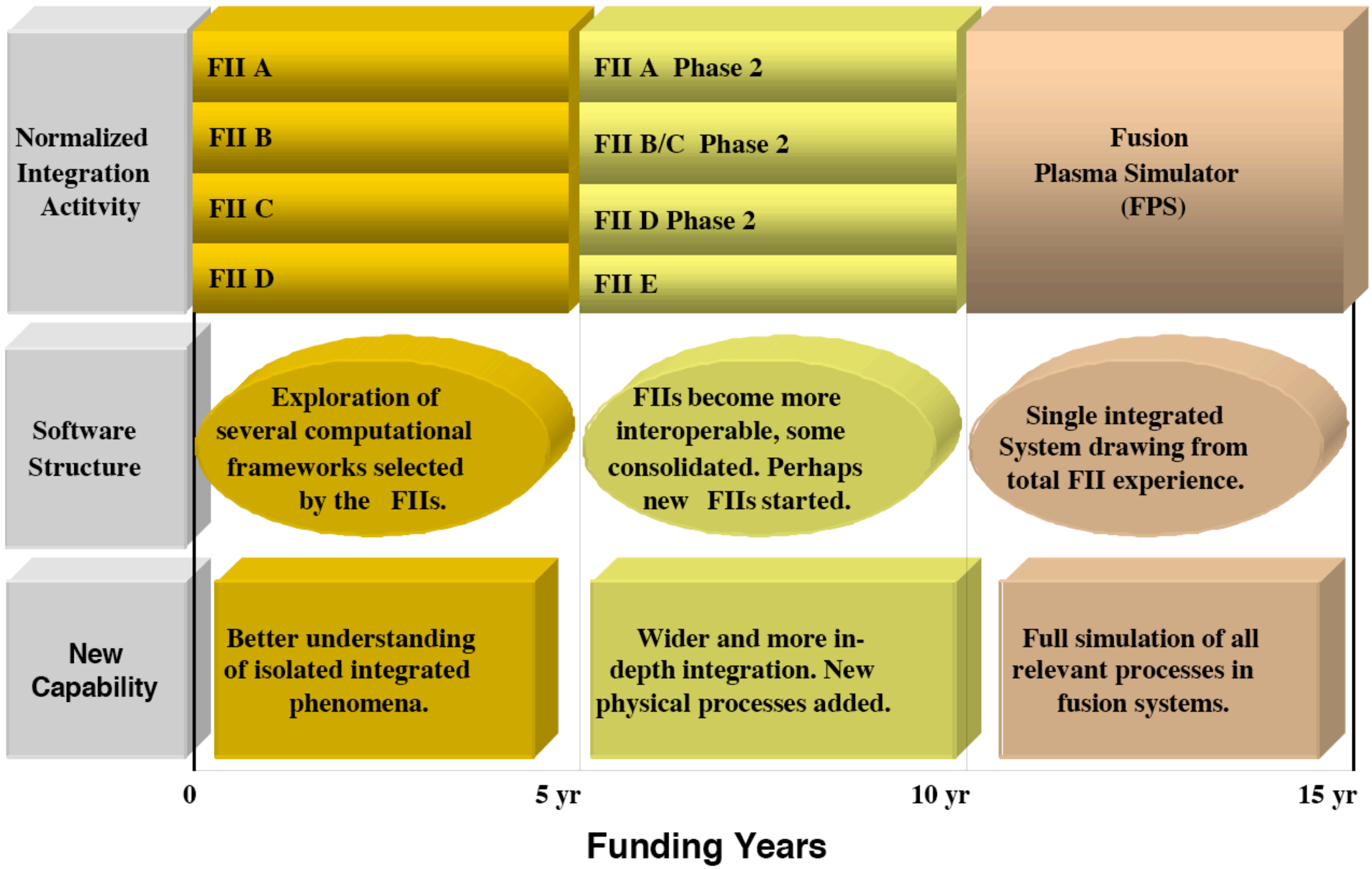
Strategy is to build up to full predictive capability in stages.

- Start with Focused Integration Initiatives (FIIs)
  - Develop practical algorithms for single physics effects
  - Couple single physics effects together to explore integration issues
  - Physics/math integration
  - Gain experience and develop techniques for frameworks

10 years for FIIs then integrate.

We expect a 15 year timeline is required to produce the FPS



Fusion Simulation Project Challenges

- **Fusion Program has much successful experience with small size code projects (1 to 4 staff), but little experience with larger projects.**
- **Key physics elements not well understood enough for prediction (e.g. ion and electron energy transport,…)**
- **Wide range of distance and time scales in problem**
- **Many different concepts and magnetic configurations**
- **Project vision is for "virtual projects", with widely dispersed development teams at different institutions**
- **Computer platforms and platform architectures not clearly identified**
- **Must have tightly focused projects to deliver a useful product**

Organizing the FSP has challenges.

- Tension among project organization, research goals, Community-wide involvement (fusion, math, computer science)
- Need different type of project organization- Knowledge-based projects
- Need to ensure accountability but preserve research creativity
  - Program—general goals, advance knowledge, science, program is a collection of projects
  - Project—requirements and deliverables, schedule, resources, need structure to ensure accountability

Any governance scheme will need to ensure that these issues are met.

- Tension between:
  - Sufficient freedom to innovate and do research to develop methods to solve new problems we can't yet solve
  - Sufficient structure and accountability to ensure that a useful product is delivered on time and on budget
- In particular:
  - Sufficient local authority within the project elements to innovate and develop the new methods and physics understanding essential for success

  And

  - Sufficient central authority to make binding decisions on technical merit rather then political considerations
  - Sufficient structure and authority to ensure adequate coordination among the various collocated and non-collocated project elements.
  - Sufficient structure that the project sponsors (DOE and the fusion community) can hold the project and the project team members accountable

The FSP project will need to follow the ASCI *"Lessons Learned"*

The Successful ASCI projects emphasize:

- Building on successful code development history and prototypes
- Highly competent and motivated people in a good team
  - **Appropriate skill mix (~half physicists, half computer science and project support)**
- Risk identification, management and mitigation
- Software Project Management: Run the code project like a project
- Determine the Schedule and resources from the requirements
- Customer focus
  - For code teams and for stakeholder support
- Better physics and computational mathematics is much more important than better "computer science"
- The use of modern but proven Computer Science techniques,
  - Don't make the code project a Computer Science research project
- Develop the team
- Software Quality Engineering: Best Practices rather than Processes
- Validation and Verification

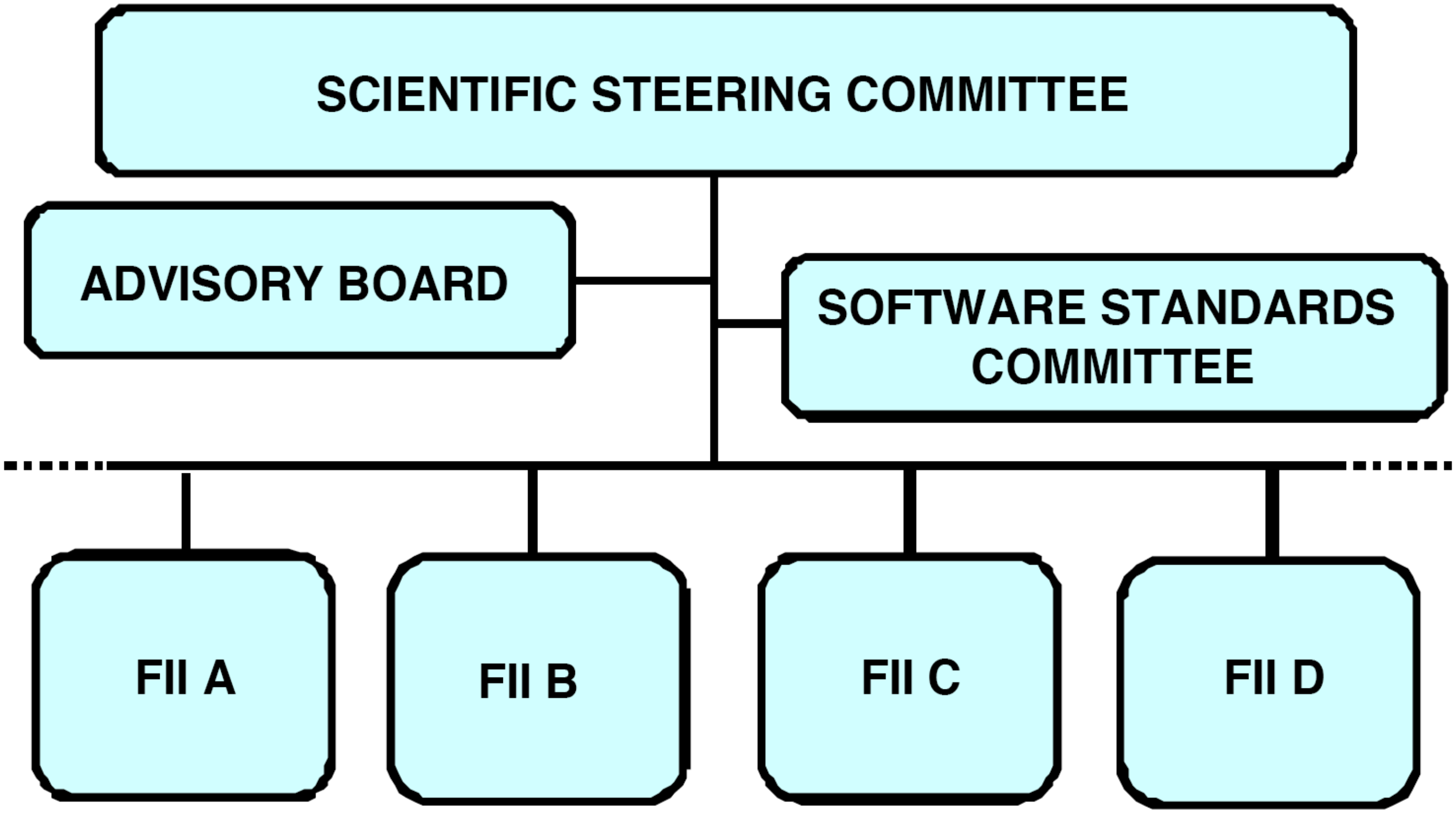
The Unsuccessful ASCI projects didn't emphasize these!

The FSP project organization will need to be consistent with all of these elements.

—D.E.Post and R.P.Kendall, "Lessons Learned from ASCI", The International Journal of High Performance Computing Applications, (in press this Fall) 2004.

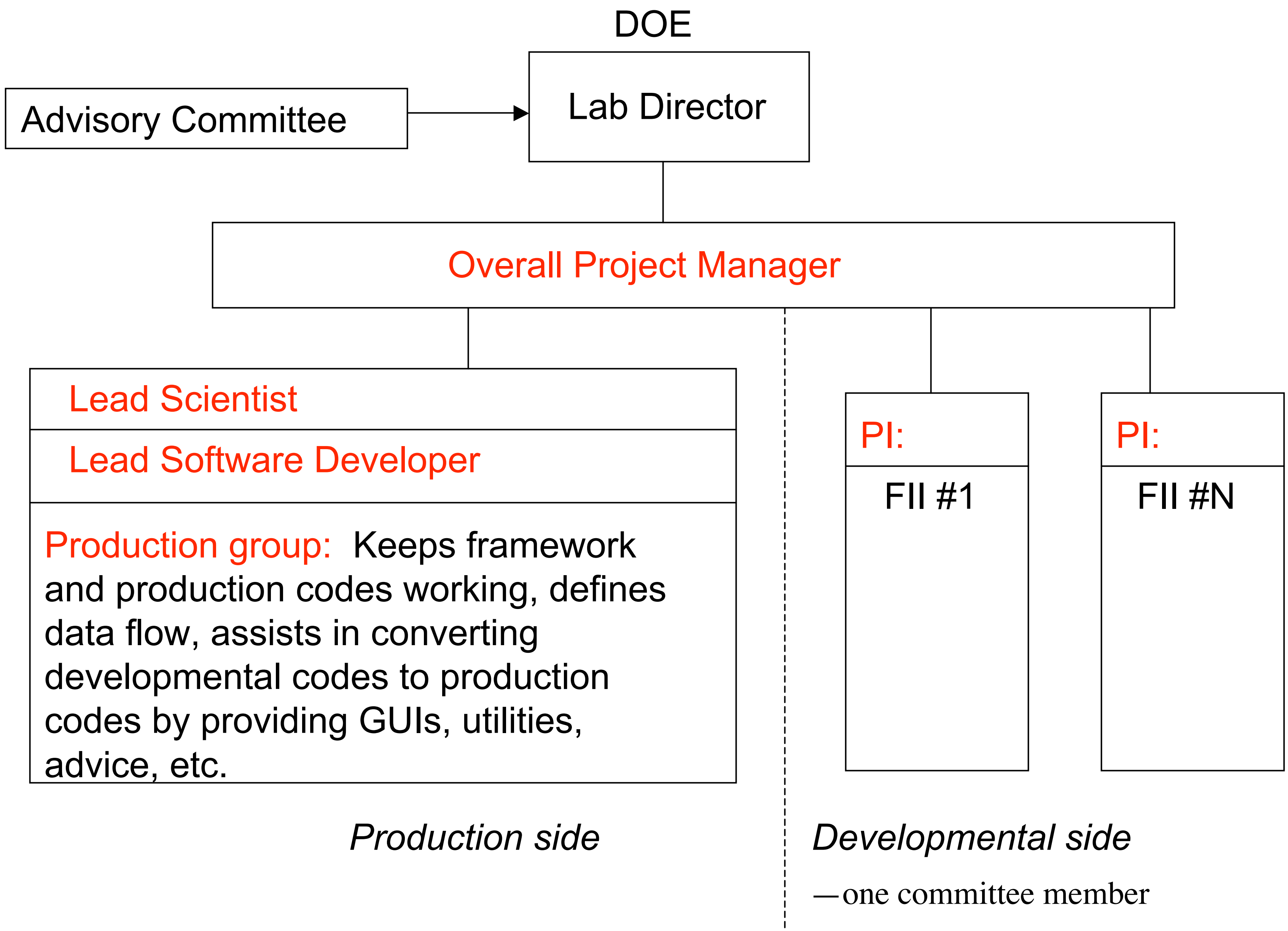
Governance is a key issue.

FSP Report Proposal

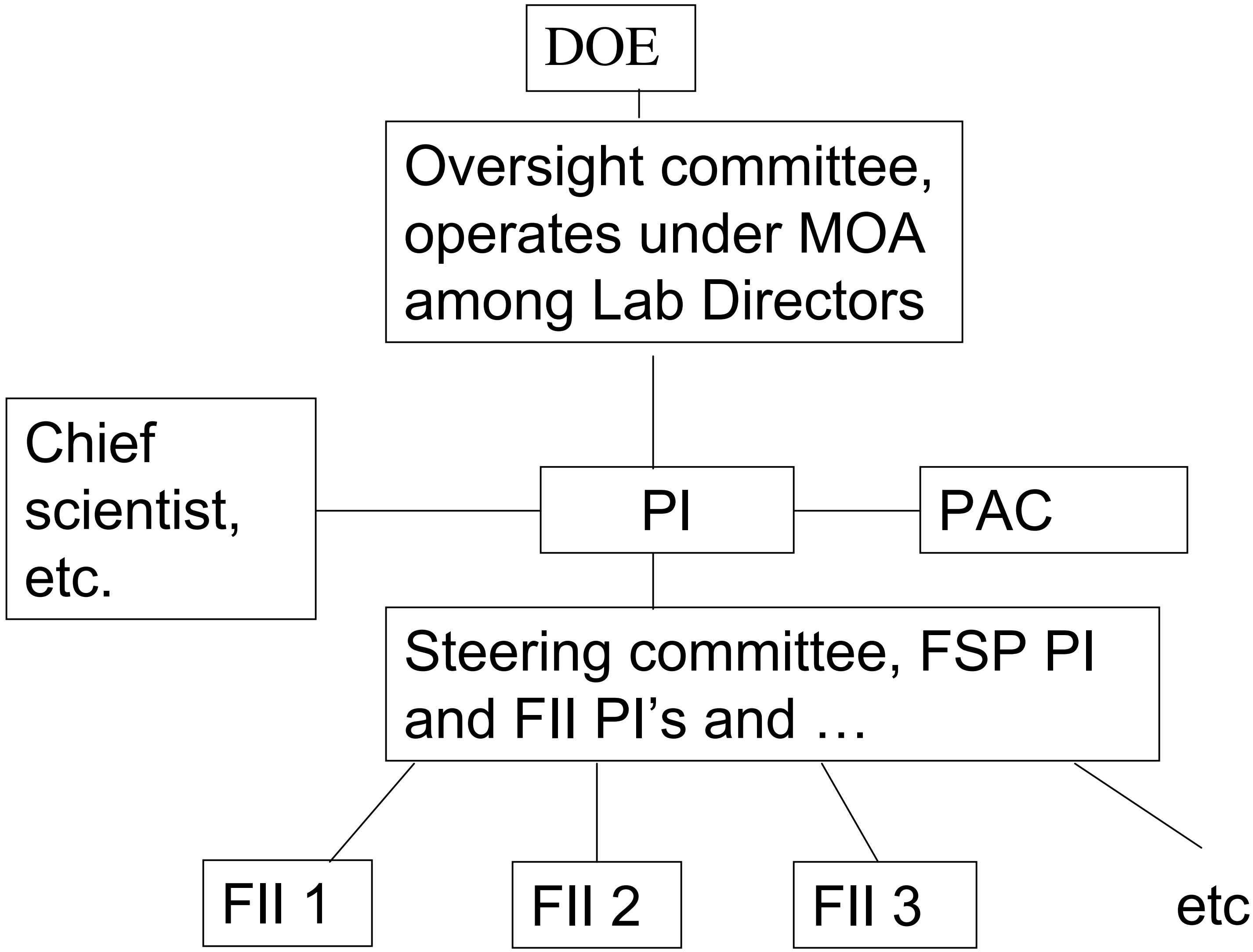


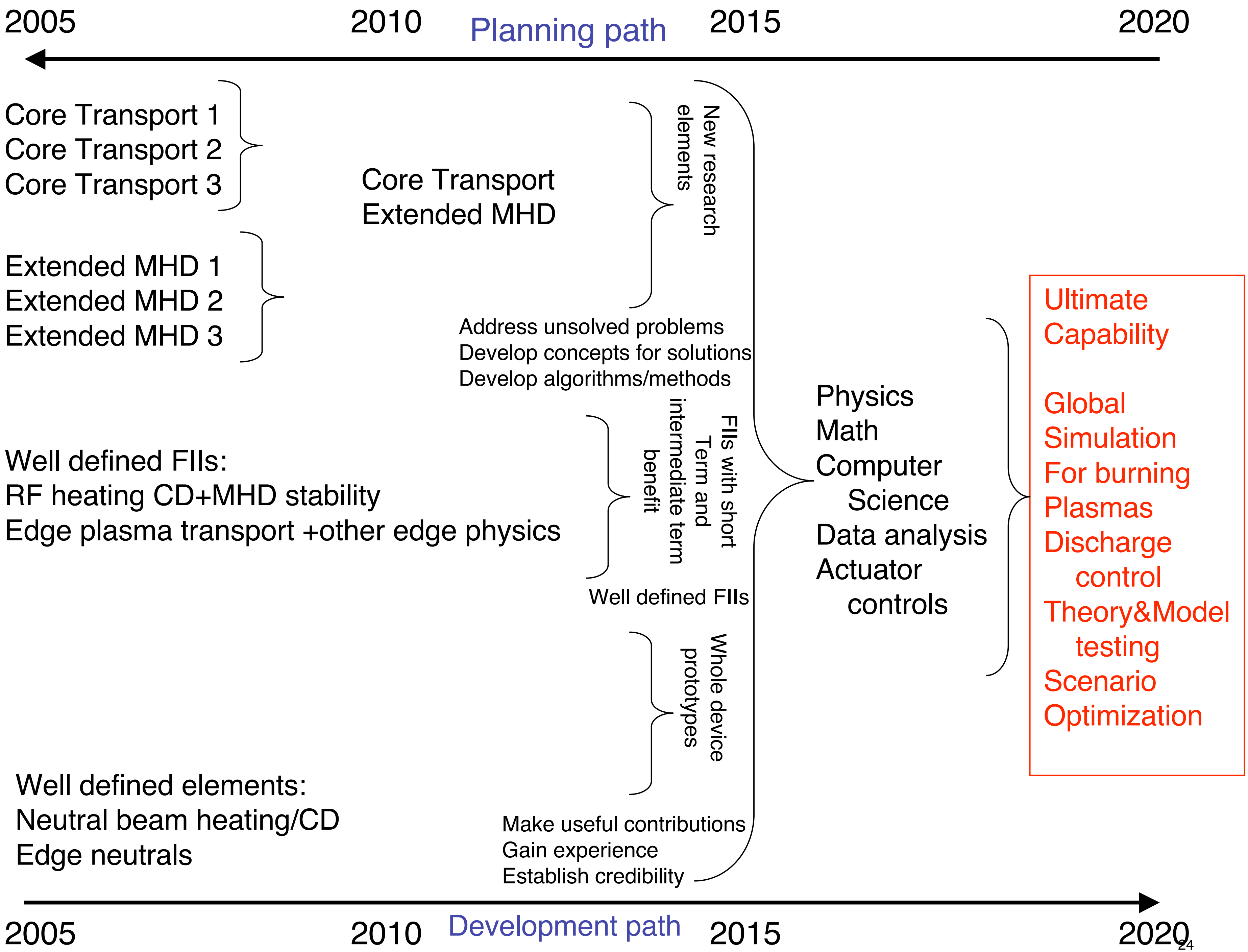
- Will this work? Like INTOR, good for exploration, but not doing. Committee debating other structures.

Possible management organization---with lead lab



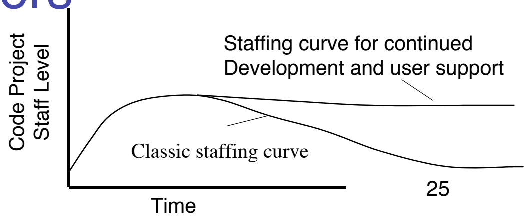
A “Virtual National Lab” model for managing the FSP




Planning path
2005
2010
2015
2020
Core Transport 1
Core Transport 2
Core Transport 3
Extended MHD 1
Extended MHD 2
Extended MHD 3
Core Transport
Extended MHD
New research elements
Address unsolved problems
Develop concepts for solutions
Develop algorithms/methods
Well defined FIIs:
RF heating CD+MHD stability
Edge plasma transport +other edge physics
FIIs with short Term and intermediate term benefit
Well defined FIIs
Physics
Math
Computer Science
Data analysis
Actuator controls
Ultimate Capability
Global Simulation For burning Plasmas
Discharge control
Theory&Model testing
Scenario Optimization
Whole device prototypes
Well defined elements:
Neutral beam heating/CD
Edge neutrals
Make useful contributions
Gain experience
Establish credibility
2005
2010
Development path
2015
2020

May 18-20 planning workshop focused on these issues.

- The FSP committee held a planning workshop May 18-20 that focused on these issues.
- Participation from FSP committee and DOE and experimentalists (S. Scott, D. Schissel, C. Kennel) and computer scientists (L. Frietag, A. Sanderson)
- What is (are) the deliverables?
  - Develop a vision for the project
- What should be the governance structure?
  - Lead lab, strong project manager?
  - Multiple lead labs, distributed authority?
  - Multiple groups, committee leadership?
- Not yet general agreement, but views are converging
- Strong agreement that we need pre-conceptual design team for the next year, design and plan project, start with ~$2M, grow to full size over 3 to 5 years, can't design project with committee of volunteers
- Standard project staffing plan ("Rayleigh curve")



Summary and Conclusions

- The FSP will make highly important contribution to ITER, allow the US to play an important role in ITER, and will provide us the capability to move from ITER to DEMO
- Advances in computer technology, computational physics and computational science, and the tokamak experimental program make the FSP a realistic goal
- US wants to start a fusion simulation project
  - Focus will be ITER, development of predictive capability
  - Resources of about $20M/year for 15 years
  - Project structure, with participation from multiple institutions
  - Accountable management structure
- Hoping for ~$2M next year, then $4M, then $8M, then ~ $20 M
  - The appropriate growth curve for a software project
- Launch pre-conceptual design phase next year with $2M
  - Must get a number of people working on this who are part of the project, can make decisions, can speak with authority and can begin to bring in the stakeholder communities
- Strong participation from the computational science community (OASCR ~ 1/3 of funds) is essential
- FSP should leverage and be embedded in the US fusion program