Interim Report
FESAC Panel on Priorities

Charles C. Baker, Panel Chair

DOE FESAC Meeting
26 July 2004

For further information, please access FESAC Priorities Panel website at:

http://www.mfescience.org/fesac/index.html

FESAC Program Priorities Panel

Chair: **Charles Baker, *University of California, San Diego***
Vice-Chair: **Stewart Prager, *University of Wisconsin at Madison***

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University of California, Los Angeles

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Princeton Plasma Physics Laboratory

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Oak Ridge National Laboratory

FESAC Charge on Priorities
from Dr. Ray Orbach

- **It is now time to focus the program in a more complete and fundamental way than we have done before.**
- **I would like FESAC to identify the major science and technology issues that need to be addressed, recommend how to organize campaigns to address those issues, and recommend the priority order for these campaigns.**
- **You will need to assemble a balanced domestic program that takes account of fusion programs abroad and that includes ITER as an integrated part of the whole. In each case, please recommend the relative priority of activities to pursue at any given time.**
- **It should be assumed that funding for ITER construction is provided in addition to (base program) funds.**
- **I would like FESAC to include Inertial Fusion and relevant aspects of High Energy Density Physics…**
- **Please look at the program through 2014, the year ITER operation is expected to begin.**

Program Goals and Overarching Themes

- **FESAC Priorities Panel started with a nearly diagonal transformation of the three program goals of the 1996 restructuring…**

  - **Advance plasma science in pursuit of national science and technology goals.**
  - **Develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program.**
  - **Pursue fusion energy science and technology as a partner in the international effort.**

- **Into three “overarching themes”:**

  - **O1. Understand the dynamics of matter and fields in the high temperature plasma state.**
  - **O2. Create and understand a controlled, self-heated, burning starfire on earth.**
  - **O3. Make fusion power practical.**

Lessons from Prioritization of Scientific Programs

- **Examples from other areas of science have been examined.**
  - **“Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century”**
  - **Astronomy’s and astrophysics’ decadal surveys**
    - **The Decade of Discovery in Astronomy and Astrophysics (1991)**
    - **Astronomy and Astrophysics in the New Millennium (2001)**
  - **High energy physics’ “The Science Ahead, The Way to Discovery”**
  - **NASA Astrobiology’s roadmaps**

- **In recent years, several areas of physical sciences have emphasized deep scientific questions as the basis for their planning and prioritizations.**
  - **Focus on questions leads to topical research programs.**
  - **Facilities are to be treated as means to address questions, rather than ends in themselves.**

- **FESAC has been charged by DOE/SC to prioritize all of our activities (i.e., not just the new scopes) for the next 10 years on the basis of questions and campaigns to address the questions.**

Topical Questions

Macroscopic Plasma Behavior

T1. How does magnetic structure affect fusion plasma confinement?

- **The properties of all magnetized plasma depend sensitively on the structure of the magnetic field.**
- **The field’s curvature twist, spatial symmetries, strength, and topology determine the existence of plasma equilibrium and strongly affect plasma flows and transport.**
- **Understanding their influence provides the basis to design configurations most favorable to fusion energy.**

T2. What limits the maximum plasma pressure that can be achieved in the laboratory?

- **For all magnetic field configurations used to confine plasma in the laboratory, there is an upper limit to the plasma pressure.**
- **Understanding of the cause of the pressure limit and optimizing the confinement configuration to achieve high pressure is an essential question.**

T3. How can external control and plasma self-organization be used to improve fusion performance?

- **Magnetically confined plasmas exhibit complex nonlinear interactions that govern their dynamical properties and potential for fusion energy production.**
- **Understanding self-organization plasma phenomena and the improvements in plasma behavior that can result from external control through complex linkages are major fusion research questions.**

Topical Questions (cont'd)

Multi-Scale Transport Behavior

T4. How does turbulence cause heat, particles, and momentum to escape from plasmas?

- **Variations in pressure or density across plasma generate electrostatic and electromagnetic waves and may result in plasma turbulence that drives the loss of heat, particles, or momentum.**
- **Because of the development of massively parallel simulation tools and the installation of new detectors to resolve details of turbulence in experiments, fusion scientists are now poised to answer fundamental physics questions.**

T5. How are electromagnetic fields and mass flows generated in plasmas?

- **Plasmas possess a remarkable tendency to generate spontaneously-ordered, large-scale electrical currents and mass flows.**
- **Complex mass flow patterns in the core and boundary of fusion plasmas can also play a dominant role in plasma dynamics and the interface of hot plasma to material walls.**

T6. How do magnetic fields in plasmas rearrange and dissipate their energy?

- **Magnetic fields in laboratory and astrophysical plasmas tend to spontaneously rearrange to create a new magnetic topology, through the fundamental plasma process called "magnetic reconnection."**
- **A fundamental theory for magnetic reconnection, applicable to the wide variety of venues, is not yet in hand.**

Topical Questions (cont'd)

High-Energy Density Implosion Physics

T7. How can high energy density fusion plasmas be assembled and ignited in the laboratory?

- **To achieve high energy densities, ignition and energy gain in inertial fusion implosions, a hollow shell of thermonuclear fuel must be compressed to densities that are as much as 10 times higher than the density found at the center of the sun.**
- **To achieve this, the physics of the absorption and the generation of pressure by the driver must be understood precisely.**

T8. How do hydrodynamic instabilities affect implosions to high energy density?

- **Understanding how to predict and control the Rayleigh-Taylor instability is a key question to the understanding of high energy density plasma and to the success of inertial fusion energy.**

Plasma Boundary Interfaces

T9. How can we interface a 100 million degree burning plasma to its room temperature surroundings?

- **A key recent result of plasma experiments, theory and modeling has been that the plasma near the edge sets boundary conditions that strongly influence transport in the hot core.**
- **Understanding and predicting these conditions, which are set by a complex interaction of turbulence, stability limits, atomic physics, and plasma-surface effects, is an unanswered yet crucial question.**

Topical Questions (cont'd)

Waves and Energetic Particles

T10. How can heavy ion beams be compressed to the high intensities required for creating high energy density matter and fusion ignition conditions?

- **A basic understanding of the collective processes and nonlinear dynamics of intense, high-brightness, heavy ion beams, and a determination of how best to create, accelerate, transport, compress and focus these beams to a small spot size are critical.**

T11. How do electromagetic waves interact with plasma?

- **Many types of electromagnetic wave excitations are unique to the plasma state of matter.**
- **Understanding the propagation of waves and their nonlinear interactions with plasmas will lead to new techniques to control plasma behavior, and will be key to optimizing the conditions for burning of the fusion fuel.**

T12. How do high-energy particles interact with plasma?

- **The interaction of the energetic particle population with the background plasma is a complex process, and a basic understanding of this interaction is critical to practical applications of fusion.**
- **Laser-induced energetic electron physics is essential to the understanding of the fast ignition concept.**

Topical Questions (cont'd)

Fusion Engineering Science

T13. How does the challenging fusion environment affect plasma chamber systems?

- **New phenomena occur within the fusion components closest to an energy producing, burning plasma.**
- **Advances in nuclear physics, chemistry, thermodynamics, magnetohydrodynamics, and other engineering sciences will result from addressing important technical challenges.**
- **Inertial fusion systems present related scientific issues pertaining to the interaction between a fusion target with surrounding chamber and components.**

T14. What are the operating limits for materials in the harsh fusion environment?

- **A key feasibility issue for fusion energy is the development of materials for the plasma chamber systems that will provide acceptably high performance and reliability, and exhibit favorable safety and environmental features.**
- **The design of fusion materials must utilize revolutionary advances in computational and experimental methods to control at the nanoscale the structural stability of the material.**

Topical Questions (cont'd)

Fusion Engineering Science (cont'd)

T15. How can systems be engineered to heat, fuel, pump, and confine steady-state or repetitively pulsed burning plasmas?

- **Fusion burning plasmas require a variety of plasma support systems that will lead to broad advancements in our technical capabilities.**
- **In inertial fusion energy concepts, the repetition rate will be several times per second. Realizing these goals will require advanced science and technology development in laser physics, optics, materials, and pulsed power.**

Working Group Input

- **Context of theme area and relationship to overarching themes.**
- **For each question:**

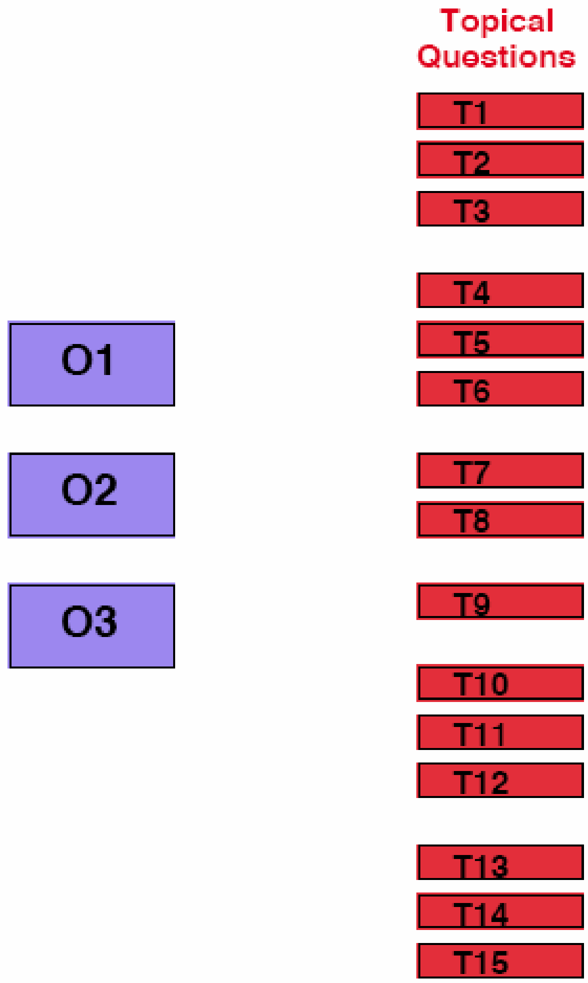
→ **summarize key issues**

→ **define a research approach including two to three research thrusts.**

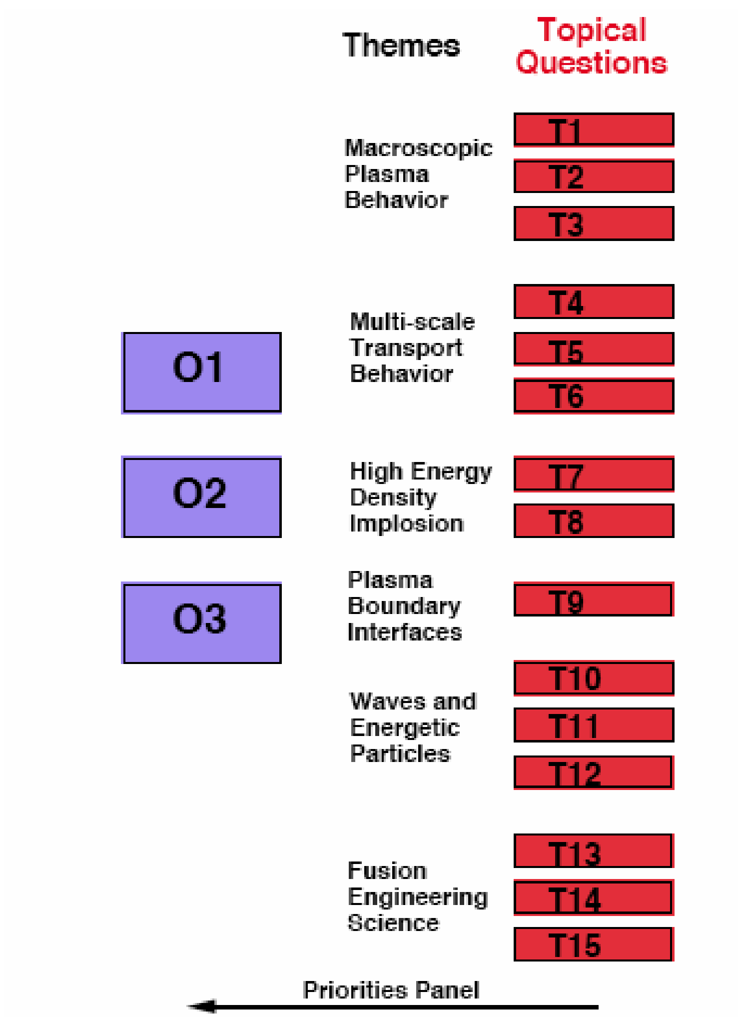
By limiting proposed research thrusts,

some degree of priority setting has already occurred.

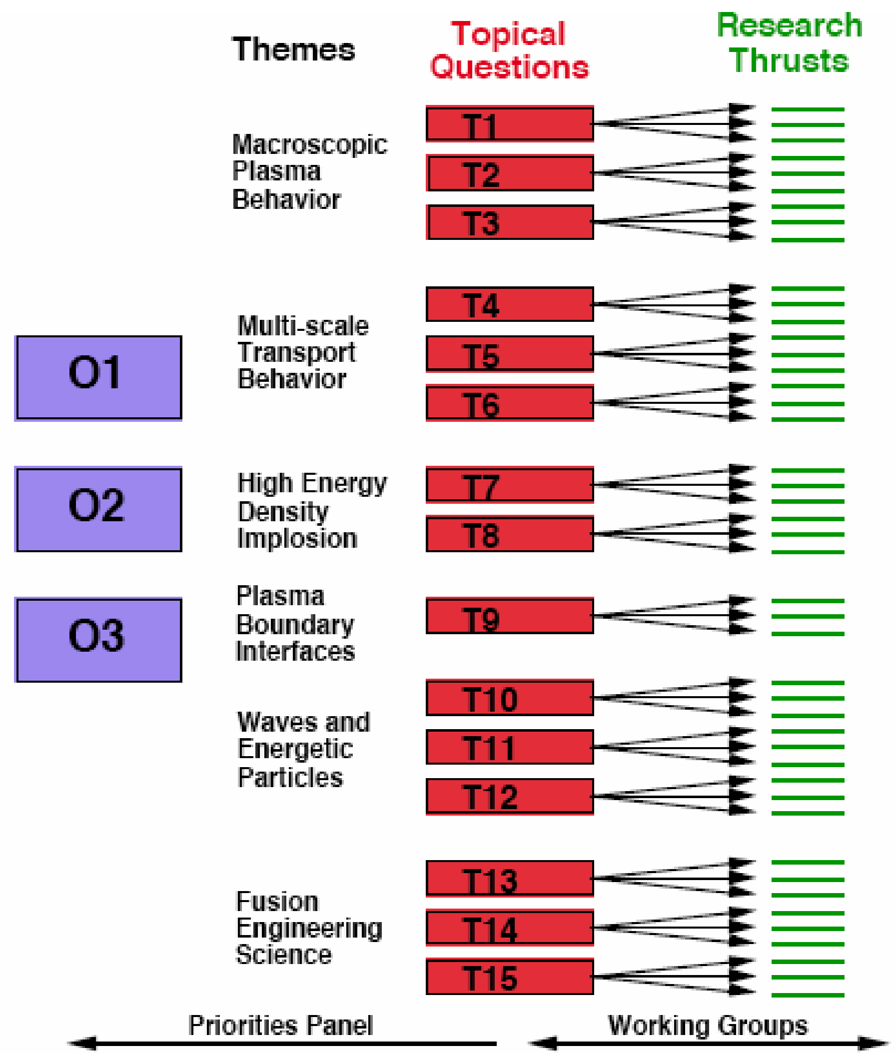
Expand Fusion Research Into 15 Topical Questions:



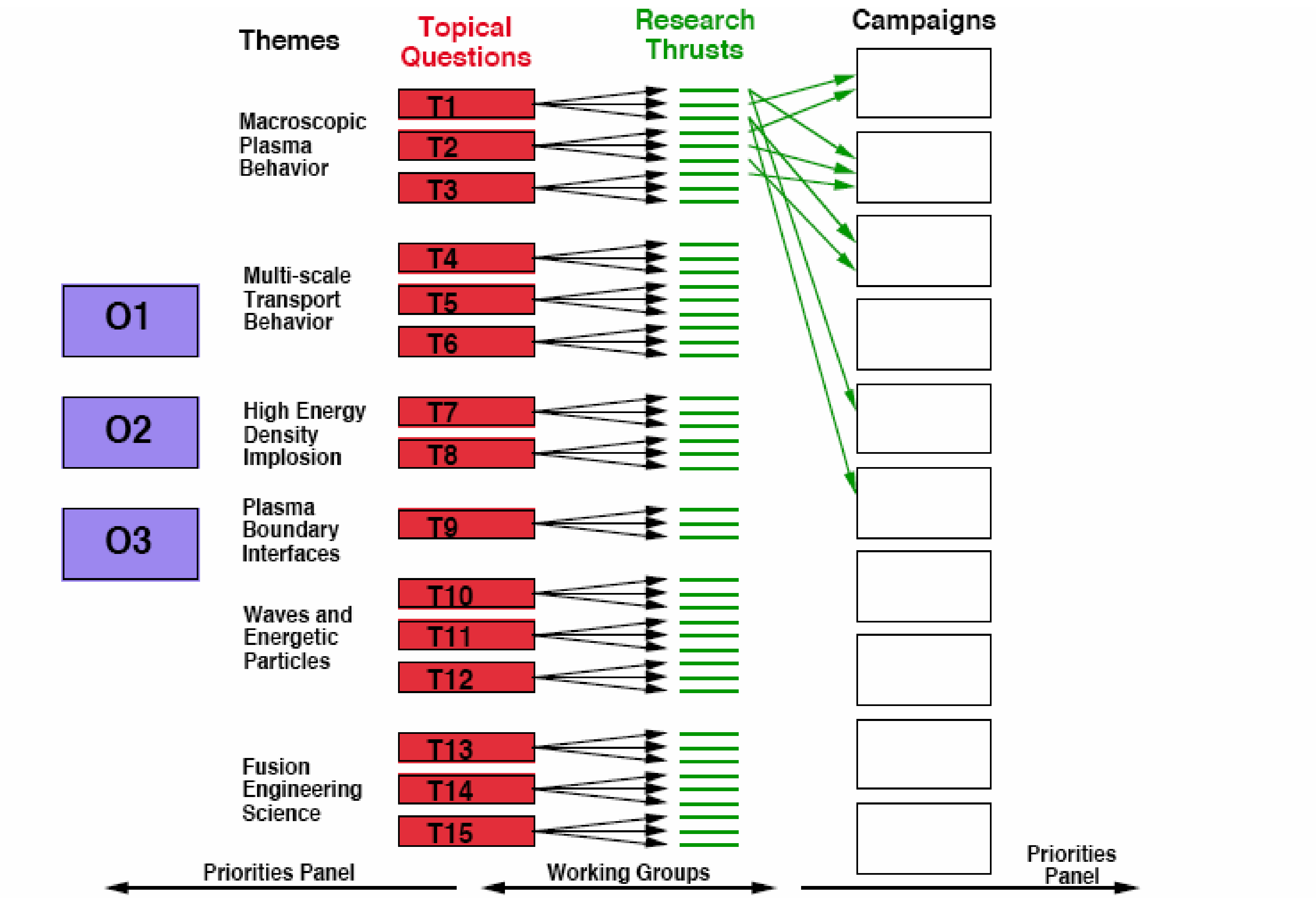
Group Into Six "Themes," each assigned to a WG:



WG Charged to Identify ≤3 Research Thrusts per Topical Question:



Priorities Panel Plans to Organize Research Thrusts into about 10 Campaigns:



Panel Approach to Inertial Fusion

The charge to the panel includes both magnetic and inertial fusion topics. All aspects of magnetic fusion research are contained within DOE's Office of Fusion Energy Sciences (OFES), but inertial fusion research is conducted both in DOE's National Nuclear Security Administration (NNSA) and OFES. All aspects of inertial fusion research will be included when describing research challenges, but we consider only those inertial fusion topics currently funded by OFES when considering future priorities.

The ITER Situation

- The charge letter says to include "ITER as an integrated part of the whole."
- Yet the future of ITER is unclear.
- The panel's work to date has not been greatly impeded by this uncertainty.
- However, the panel's forthcoming work on priorities will be impacted by what happens to ITER.
- The panel's dilemma — what to do?!

Panel Next Steps

- **July 27-28 at Marriott Gaithersburg**
  - **definition of campaigns and priority setting process.**
- **Sept. 13-15 at Madison**
  - **initial cut at priorities.**
- **Continued use of panel website and briefings by panel members at home institutions.**
- **Tuesday, Nov. 16 at Savannah**
  - **evening town meeting at the APS/DPP meeting.**
- **Final report to FESAC in December.**

7/15/04

Interim Report of the Panel

on

Program Priorities

for the

Fusion Energy Sciences Advisory Committee

July 2004

C. Baker, UCSD (Chair)
S. Prager, U.Wisconsin (Vice-Chair)
M. Abdou, UCLA
R. Betti, U. Rochester
D. Craig, U.Wisconsin
R. Davidson, PPPL
R. Hawryluk, PPPL
A. Hubbard, MIT
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K. McCarthy, INEEL
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G. Wurden, LANL
S. Zinkle, ORNL
L. Berry, ORNL
V. Chan, GA
J. Dahlburg, NRL
J. Drake, U. Maryland
D. Hill, LLNL
G. Logan, LBNL
M. Mauel, Columbia U.
S. Parker, U. Colorado
R. Stambaugh, GA
J. Van Dam, U. Texas
M. Zarnstorff, PPPL

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Working Group Chairs, Co-Chairs, Vice-Chairs

Macroscopic Plasma Behavior

Chair:	Gerald Navratil	Columbia University
Vice-Chair:	Michael Zarnstorff	Princeton Plasma Physics Lab

Multi-scale Transport Behavior

Chair:	Paul Terry	University of Wisconsin
Vice-Chair:	Earl Marmar	Massachusetts Inst. of Technology

High-energy Density Implosion Physics

Chair:	Max Tabak	Lawrence Livermore Nat'l Lab
Vice-Chair:	Riccardo Betti	University of Rochester

Plasma Boundary Interfaces

Chair:	Steven Allen	Lawrence Livermore Nat'l Lab
Vice-Chair:	Michael Ulrickson	Sandia National Labs

Waves and Energetic Particles

Chair:	Ernest Valeo	Princeton Plasma Physics Lab
Vice-Chair:	Grant Logan	Lawrence Berkeley National Lab

Fusion Engineering Science

Group A: Materials and Chamber Technology

Co-Chair:	Mohamed Abdou	University of California, Los Angeles
Co-Chair:	Steve Zinkle	Oak Ridge National Laboratory

Group B: Plasma and IFE Technology

Chair:	Stan Milora	Oak Ridge National Laboratory
Vice-Chair:	Wayne Meier	Lawrence Livermore National Lab