August 18, 2000

Next Step Options
Program Advisory Committee Report

To: Dr. Charles Baker, Director
Virtual Laboratory for Technology

Prof. Stewart Prager, Chair
VLT Program Advisory Committee

From: Dr. Tony Taylor, Chair
NSO Program Advisory Committee

The Next Step Options Program Advisory Committee (NSO PAC) met Thursday, July 20, and Friday, July 21, at General Atomics in San Diego, CA. This was the PAC's first meeting (PAC-1). The next NSO PAC meeting will be held at MIT, Wednesday and Thursday, January 17 and 18, 2001.

PAC Members in Attendance

Dr. David Gates (3)
Dr. Wayne Houlberg (3)
Prof. Tom Jarboe (3)
Dr. Mitsuru Kikuchi (3)
Dr. Earl Marmar (3)
Dr. Raffi Nazikian (3)
Dr. Tony Taylor (3)
Dr. Paul Thomas (3)
Prof. Raymond Fonck (2)
Dr. David Hill (2)
Prof. Gerald Navratil (2)
Dr. Craig Petty (2)
Dr. A. Rene Raffray (2)
Dr. Kurt Schoenberg (2)
Dr. James Van Dam (2)

Each PAC member's term of membership in years is indicated in the parentheses next to his name. It was decided that the international members would each serve for 3 years. The terms for the U.S. members were chosen by random drawing.

Charges for this meeting:

The NSO-PAC was asked to consider four main charges during this meeting:
1) What is the scientific value of a burning-plasma physics experiment?
2) What is the scientific readiness to proceed with such an experiment?
3) Is the FIRE mission scientifically appropriate?
4) Is the initial FIRE design point optimal?

The PAC decided that the first two of these charges are long-range tasks and would be addressed in subsequent PAC meetings. The US fusion community will also be considering these two issues, and the NSO PAC will participate and assist in that effort. In particular, the NSO PAC will assist in the upcoming workshop on the scientific value and scientific readiness of burning plasmas that is being organized by the University Fusion Association, to be held in Austin, TX, in December 2000.

NSO PAC-1 did consider in some detail charges 3 and 4, and our responses are delineated separately below. First, we address those issues that we considered most important and offer our recommendations. Then we include a broader list of important issues that were raised. The PAC recognizes the broader list of issues can not all be addressed in the near term, but deemed them important to include.

FIRE mission:

The mission statement of the FIRE experiment was presented to us as: "Attain, explore, understand and optimize alpha-dominated plasmas to provide knowledge for the design of attractive MFE systems." PAC-1 felt that the FIRE mission statement, as presented, correctly states the scientific direction and objectives of the FIRE program, but that the mission statement does not adequately communicate the excitement and depth of fusion science and burning plasma science. The content of the mission is appropriate, but the articulation should be improved. The Committee recommends that the FIRE project review its mission statement with the goal of strengthening and communicating the excitement of the science of self-heated fusion-dominated plasmas. The project should review other mission statements from the Office of Science in order to understand better how to articulate the depth of the science and the excitement of the science to the broader scientific community and to the public. The PAC will review improvements in the mission statement at its next meeting.

The Committee discussed the issue of the focus of the FIRE project. This issue was presented to us in the context of the extent to which the experiment should focus on burning plasmas or self-heated fusion-dominated plasma, versus the extent to which such an experiment should focus on advanced toroidal physics or optimization of tokamak physics. By a large majority, the Committee agreed that the science of self-heated fusion-dominated plasmas should be the primary objective of the FIRE project and that advanced toroidal physics should be pursued without sacrificing the primary objective. Although this sentiment was clear, a number of Committee members felt quite strongly that the FIRE facility should be capable of addressing Advanced Tokamak (AT) physics issues—both in the context that improved physics would enhance the ability to pursue self-heated fusion dominated plasmas, and also in the context that FIRE should, as much as possible, be able to explore the regimes that lead to an attractive reactor. The Committee also endorses the project's focus on "affordability.'' How to maintain a focus on the science of self-heated fusion-dominated plasmas and include advanced toroidal issues while keeping the project affordable was, however, not resolved.

The Committee thought that it is important for FIRE to have a single well-articulated mission. The mission statement and the discussion of the mission should avoid conflicts between a performance (or energy) and a science goal. The Committee recommends that the project enumerate what would be gained from achieving the mission, especially in terms of the knowledge (science) gained, as well as outstanding issues that will not be addressed within this mission.

FIRE design point:

The Committee recommends that the project clearly show the logic for how the mission statement leads to the design point. The size of the machine, the aspect ratio, the toroidal field, and other design considerations should be better explained on the basis of meeting the objectives of the device. In particular, the choice of aspect ratio and the size of the device should be further examined with respect to accessibility of physics regimes and the cost of the device. The PAC requests that the choice of the design point be further discussed at a future meeting.

To more clearly understand the cost/benefit tradeoffs in designing a lower cost machine for the investigation of self-heated fusion-dominated plasmas, the PAC recommends the examination of at least one variation of FIRE at somewhat larger size. The design point of the larger device could be an increase in the device size by 50% or an increase in the cost by 50% to reach Q=5, using the ITER Y2 scaling and flatter density profiles.

In defining baseline performance and in comparing the performance of FIRE to that of ITER and other devices, the PAC recommends that common design criteria (with respect to ITER) be used. We expect that this would involve the use of the best available confinement scaling, including ITER Y2, and also a range of density profiles, including flatter profiles with a peaking factors down to ~ 0.1. The PAC further recommends that the performance variation be examined as a function of the density. If performance projections are cited for FIRE based on assumptions that differ from those for ITER (or other comparison devices, *e.g.* Ignitor), these different assumptions should be made clear and justified.

The PAC was told that a significant cost reduction of the TF coil/power systems might be possible if OFHC copper is used on the inner TF legs. The PAC recommends delineating the design implications and quantifying the potential savings as one of the major engineering design efforts for the coming year.

Issues to address at future NSO PAC meetings:

The PAC identified two issues with respect to the FIRE design that we recommend should be addressed more fully at a future meeting. The first of these is the diagnostic capability, with respect to meeting the science objectives and the control requirements, with the proposed schedule and low pulse rep rate taken into account. We also recommend that the performance margin needed to meet the science objectives be discussed at a future meeting.

Additional issues concerning the FIRE mission:

- Common design criteria (with respect to ITER) should be used when performance expectations are compared.

- The scientific objectives need to be strengthened:

  — Simulations must be benchmarked against experiments to be reliable. Wholly new situations or regimes cannot be simulated.

  — The excitement of the science can be enhanced by showing the connection to theory, theory development and advanced computing

  — Study of the 1/1 mode in FIRE would be a benchmark for analysis using full kinetic, energetic particle drive, and 2-fluid effects.

  — What are the key parameters for alpha physics studies in FIRE— β_α/β, α-fraction, or other parameters? Does FIRE provide a significant advance in these parameters over present devices?

  — Can FIRE study ‘burn control’ issues?

  — Can FIRE study transport barriers?

  — The capability to study AT modes needs to be clarified, in terms of magnetic topology flexibility, current profile control, transport control, density control, rotation control, and so forth.

Additional issues concerning the FIRE design point:

- Define the impact on the design point of advanced modes and pursuing advanced toroidal physics. Assess the flexibility of the base design to support AT plasmas, and other advances in tokamak physics.

- Identify potential upgrades. The base design should at least support exploration of AT plasmas.

- Develop a table of key dimensionless parameters and their values expected in FIRE and compare them for existing experiments, proposed experiments, and the reactor goal.

- Define the range of operation needed to explore the physics of neoclassical tearing modes, alpha particle-driven instabilities (e.g., TAE), and other MHD issues.

- Assess runaway electron production during disruption in FIRE and develop mitigation plans if necessary.

- Develop a better characterization of disruptions, vertical disruption events (VDE), electromagnetic loads, and other effects, as well as their consequences on the design point.

- Examine the existing database for double-null divertor tokamaks concerning up-down/in-out power asymmetries during disruptions.

- Firm up the cost estimates of tritium systems. The current estimates (~$30 million) seems low relative to the cost of such systems on TFTR.

- Clarify the pumping requirements for FIRE. There is ambiguity in what was presented.

- Eliminate carbon first-wall components in FIRE in order to minimize tritium retention. The Committee supports this approach.

- Develop a plan for re-coating beryllium walls periodically in the event that migration of tungsten to the first-wall surfaces introduces unacceptable levels into the plasma.

- Analyze the effect of ELMs on the divertor plates.

- Plan for FIRE experimental operations, taking into account the relatively low rate of full-power shots. This may require a shift in experimental strategy toward the ICF paradigm, which involves more pre-operational simulation prior to each full-power, long-pulse shot and more complete single-shot diagnostic coverage.

- Clarify the trade-off between the lifetime limits on pulse number and pulse length.

- Include error field correction coils in the design, and assess if these could be used for n=1 feedback control.

- Determine the power supply requirements for n=0 control with the use of the specified passive and active control coils.

- Run transport simulations for the design point.

- Evaluate helium ash accumulation issues, especially for advanced modes

- Consider providing tangential port access.