

# Next Step Options Program Advisory Committee Report

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

Dr. Roger Bangerter, Chair  
VLT Program Advisory Committee

From Dr. Tony Taylor, Chair  
NSO Program Advisory Committee

Date: January 4, 2002

## **Date and Place:**

The Next Step Options Program Advisory Committee (NSO-PAC) met Thursday and Friday, November 29 and November 30, 2001, at the Lawrence Livermore National Laboratory, in Livermore, California. This was the PAC's fourth meeting (PAC-4).

The next NSO-PAC meeting is tentatively scheduled to be held at the University of Texas in Austin, Texas. The date of the next PAC meeting is still to be determined, but is planned for about the first week of December 2002. The 2002 Snowmass meeting will be held in July 2002. There will be no summer PAC meeting as a consequence of the Snowmass meeting, and we thought it appropriate to give the FIRE team some time to respond to the outcome of the Snowmass meeting and the FESAC "Action Panel" prior to the next NSO-PAC meeting.

## **PAC Members in Attendance:**

Prof. Raymond Fonck

Dr. Earl Marmor

Dr. A. Rene Raffray

Dr. David Gates

Prof. Gerald Navratil

Dr. Tony Taylor

Dr. David Hill

Dr. Raffi Nazikian

Dr. James Van Dam

Dr. Wayne Houlberg

Dr. Craig Petty

Prof. Tom Jarboe

Dr. Kurt Schoenberg

## **PAC Members not in Attendance**

Dr. David Gates, Dr. Paul Thomas, and Dr. Mitsuru Kikuchi

## **Rotation of NSO-PAC Membership:**

At the PAC's inception, it was decided that the membership of the NSO-PAC would change, so that there would be overlap of new and old members. At our first meeting, we drew lots for the length of service. Seven members drew lots for 2 years, and this meeting completes their 2 years on the PAC. These members are: Prof. Raymond Fonck, Dr. David Hill, Prof. Gerald Navratil, Dr. Craig Petty, Dr. A. Rene Raffray, Dr. Kurt Schoenberg, and Dr. James Van Dam. We appreciate their conscientious service.

## **OBJECTIVES OF MEETING**

- 1) Provide feedback to FIRE Project on
  - a) Recent progress
  - b) Preparation for Snowmass meeting
- 2) Provide feedback and advice to NSO on uniform technical assessment activities in preparation for Snowmass

## **PROGRESS ON FIRE PROJECT**

### **Previous Findings and Recommendations**

The FIRE Project has made good progress on responding to many of the recommendations that we have given in our previous reports. However, there remain a number of issues not yet addressed. These issues remain important, but we will not reiterate them below except where we deem they are of very high priority.

### **1. NBI for FIRE**

**Finding 1:** At our previous meeting we reported in Finding 9.0 that recent tokamak experiments have shown the importance of plasma rotation, driven by tangentially injected neutral beams, on MHD mode control and that the incorporation of tangential access in the FIRE design could benefit several important diagnostic techniques. Where direct comparisons have been made (e.g. on JET) ICRF is found to be just as effective as beams for plasma heating. Nevertheless, since relatively little of the high performance data in the world tokamak data base comes from purely RF heated plasmas, the reliance of FIRE

on only RF heating increases the extrapolation from present experiments and hence the level of uncertainty in the extrapolation.

**Recommendation 1:** When the FIRE team works with the Snowmass Working Groups to prepare for the Snowmass 2002 meeting, the possibility of adding tangential access to the design, and using NBI as part of the baseline (or upgrade) heating set on FIRE should be included to strengthen its case to the community.

## **2. DND vs. SND**

**Finding 2:** The FIRE design team has selected a double-null divertor configuration, but has not documented) why it made this decision. Because FIRE is unique in this respect compared to the other proposed Next-Step devices (ITER and IGNITOR) and because this adds cost and complexity to the device, we believe that the project will be asked at Snowmass to explain the reasons for making this design choice.

**Recommendation 2:** Prior to Snowmass, the FIRE team should articulate the physics basis for choosing a double-null divertor configuration.

## **3. Nuclear heating of VV**

**Finding 3:** The pulse lengths for high performance AT plasma scenarios in FIRE are expected to be limited by nuclear heating of the vacuum vessel. Depending on the precise scenario models, pulse-length to skin-time ratios in the range from 1.3 to 2.8 are expected. Since the limit is due to the stresses, which result from differential expansion, it might be possible to extend the pulse length through modification of the double-walled vessel design.

**Recommendation 3:** The project should consider whether vessel design changes could be accommodated in order to reduce these stresses, so that the pulse length could be lengthened to match the TF-coil heating limits.

## **4. Auxiliary Heating/Current Drive Systems**

**Finding 4:** The design of the auxiliary heating systems, ICRH for high-Q experiments and LHCD for AT experiments, lags the other conceptual design efforts. A credible design of the auxiliary heating/current drive systems in regard to both power density and plasma facing components is critical to a realistic assessment of FIRE.

**Recommendation 4:** A more detailed design of the auxiliary heating/CD systems, subject to an expert review, needs to be done before Snowmass.

## 5. Off-normal events

**Finding 5:** Off-normal events, including disruptions, VDEs and ELMs, can result in substantial localized energy deposition and electromagnetic loads on plasma facing components. The magnitude and frequency of such events would directly impact the thermo-mechanical performance and erosion lifetime of these components.

**Recommendation 5:** It is recommended that a table be developed to characterize off-normal events for FIRE and the corresponding design requirements on the PFCs. For each off-normal event, this table should include location, frequency, energy, time scale, and affected area. The corresponding temperature, thermal stress, and erosion associated with these events should be analyzed in the future.

## 6. Confinement Scaling Studies

**Finding 6.1:** We find that good progress has been made in incorporating results of non-dimensional scaling experiments into the design projections and optimization. Some progress also has been made into looking at how robust is the projected operating point is to variations in the choice of scaling relations.

**Recommendation 6.1:** We recommend that the project complete their proposed work on non-dimensional scaling (i.e., Q vs. H for Electrostatic GyroBohm). Work should be continued on the sensitivity of various confinement scaling relations to the FIRE operating point and to FIRE's choice of triangularity, double null, high edge density, etc.

**Finding 6.2:** We find that good progress has been made in using theory-based transport modeling for the AT scenario development. However, pedestal physics have yet to be included in the theory-based modeling, necessitating a normalization of the transport to a global scaling relation.

**Recommendation 6.2:** We recommend that the project work to incorporate pedestal physics into the theory-based modeling, possibly in consultation with the ITPA, and eliminate the normalization to global scaling relations. This should be viewed as a longer-range effort and only preliminary results are expected prior to Snowmass.

## 7. AT physics

**Finding 7:** The FIRE team presented an initial analysis of accessibility to an advanced tokamak operation regime using the base facility, plus some additional tools specific to exploring AT physics in a burning plasma environment. The target AT regime is characterized by  $N(0)/\langle N \rangle > 1.5$ ,  $P(0)/\langle P \rangle = 2.5 - 4.0$ , H

$> 1.2$ ,  $0.6 < N/N_{gw} < 0.95$ , and  $1.3 < t\text{-Pulse}/t_{skin} < 2.8$ . The committee endorses this target parameter regime for exploration of AT physics in FIRE.

**Recommendation 7.1:** The FIRE team should better define the flexibility needed in profile control for AT regime studies. This includes the requirements and capabilities for current profile and pressure profile modifications.

**Recommendation 7.2:** More effort is required to identify viable diagnostic concepts for detailed current and pressure profile measurements in AT regimes. (presumably done in concert with and support from the SnowMass working groups)

### **8. Engage the divertor physics community**

**Finding 8:** The FIRE divertor design operates at significantly higher heat flux than present-day tokamaks and has pulse lengths, that force the use of actively cooled surfaces. In addition, the design requires that the divertor provide helium ash removal and sufficient pumping to produce peaked density profiles [ $n(0)/\langle n \rangle > 1.5$ ] in low-density AT plasmas. Further unique features of the FIRE divertor include a double-null configuration, the use of high-Z targets, and an inertially cooled private region baffle. Because the ITER project has focused international attention on the divertor and devoted considerable resources to its divertor design, the FIRE team undoubtedly will be asked to show how its divertor design will allow the device to accomplish its mission. So far, the project has focused more on the technology of its solution rather than its physics.

**Recommendation 8:** The project should engage the US divertor physics community to validate and improve the articulation of the physics basis for its design choices. The experience of the DIII-D divertor group with double-null pumped divertor operation in AT plasmas should be particularly valuable, as would be the high-field RF-heated experience of the C-Mod team. We recommend that the project sponsor a short workshop on divertor physics as the best way to engage the community on this subject.

### **9. Physics Validation Review: Schedule**

**Finding 9:** Completion of the uniform technical assessment of FIRE as part of the preparation for and discussions at Snowmass 2002, should result in a reasonably complete pre-conceptual design of FIRE. This will also position the FIRE project to complete a DOE Physics Validation Review following the conclusion of the Snowmass meeting.

## FIRE PROJECT PREPARATION FOR SNOWMASS

### 10. Continuing FIRE Effort

**Finding 10:** We are please to note that NSO effort on the FIRE project was maintained at a nearly level effort (FY 2002 wrt FY 2001) and that additional resources were provided by DOE for the NSO uniform technical assessment in preparation for Snowmass.

### 11. Maturity of Physics Program in Comparison with the Facility

**Finding 11:** Much of the FIRE work so far has, of necessity, been concerned with design of the facility. In comparison, the articulation of the planned physics program is less mature. This imbalance is reflected in the list of twelve FIRE action items in preparation for Snowmass, only one of which is concerned with physics issues. However, scientific goals and assessment will be important at Snowmass (note that the physics working groups are slated to receive 75% of the NSO Snowmass funding). Furthermore, the view of FIRE by the community will depend on its perceived ability and operational flexibility as an instrument for doing science.

**Recommendation 11.1:** FIRE should begin to outline an operational plan for its physics program (6 years, 500 full-power shots per year).

**Recommendation 11.2:** FIRE should articulate what types of physics could be done on this facility, relative to other next step burning plasma facilities, highlighting the use of the facility as a scientific instrument. This work should be carried out with the cooperation of the uniform technical assessment effort

**Recommendation 11.3:** The NSO PAC recommends that the FIRE group become proactive in the Snowmass process. The Snowmass organizing committee should identify, in particular, specific project people to work with each of the Snowmass sub-groups.

### 12. Other Physics Action Items for FIRE:

**Recommendation 12.1** In preparation for Snowmass, consider the interaction of RF with alpha particles.

**Recommendation 12. 2** Construct popcon diagrams with more detailed alpha particle stability input.

### 13. Range of Operational Space

**Finding 13:** The extent of the operating space is not sufficiently characterized in relation to the range of parameters required to carry out the physics program.

**Recommendation 13:** For each major physics issue relevant to the mission of the experiment, the relevant physics parameters should be identified and the range of parameters accessible to the experiment should be discussed. This work should be carried out in conjunction with the “uniform assessment” activity for Snowmass.

#### **14 Roadmaps with FIRE**

**Finding 14:** The realization of fusion energy will require significant advances in burning plasma science and related technologies. An important discriminator among the various approaches to burning plasma experiments is the flexibility to examine these challenges and to define a fusion development path or “roadmap”. The FIRE project has made a good start at articulating a development path with FIRE as one of the central elements.

**Recommendation 14:** In preparation for the Snowmass activity, FIRE should propose a fusion development path consistent with its expected performance and scientific/technology mission. The development path should include its role in addressing the key fusion science/technology issues, a brief overview of its base experimental program, what follow-on or complementary experiments are required, and a brief summary of advantages and disadvantages of a multi-machine vs. a single-step to demo development strategy.

### **NSO PLANS FOR UNIFORM TECHNICAL ASSESSMENT**

#### **15. Support for Students and University Researchers**

**Finding 15:** The committee notes that the initial allocation of Snowmass-specific resources supports mainly individuals in the national labs. It is also important to encourage the widest possible community attendance, including younger community members such as senior graduate students and early-career scientists based in academic institutions. Some funding has been set aside to support attendance of university-based fusion researchers.

**Recommendation 15:** Support for travel to all relevant Snowmass-related activities (including preparatory meetings as well as Snowmass itself) should be made available for early career scientists, post-docs, and senior graduate students.

## **16. International participation**

**Finding 16:** The PAC recognizes that in certain instances experts from overseas are necessary in order to perform critical tasks in the physics assessment of the burning plasma options. The PAC further recognizes that the participation of these key individuals will be unlikely without some token level of support in the form of travel funds.