FIRE Project Action Plan

in Response to

Next Step Options
Program Advisory Committee Report (PAC1)

FIRE Mission:

Finding F1-1: PAC-1 felt that the FIRE mission statement, "Attain, explore, understand and optimize alpha-dominated plasmas to provide knowledge for the design of attractive MFE systems.", 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.

Recommendation R1-1: 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.

Action A1-1: The project proposes to add a Vision Statement above the Mission Statement. The Vision Statement would be developed to convey the excitement and breadth of the science to a broader audience. The project has incorporated the PAC suggestion of replacing alpha-dominated with fusion dominated in the technical mission statement. The project is reviewing the Mission Statements and justifications other Large Science Initiatives such as the Very Large Hadron Collider, the Next Linear Collider, the Next Generation Space Telescope, etc. The project will also solicit input from the science community outside fusion.

Finding F1-2: 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.

Recommendation R1-2: 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.

Action A1-2: The project concurs with Finding F1-2 and Recommendation R1-2 and will focus on burning plasma physics in a fusion-dominated plasma, and the coupling between burning plasma physics and advanced tokamak physics. This dual thrust is central to the FIRE Mission and the development of an attractive magnetic fusion reactor. FIRE will increase the effort to define possible AT modes and the device capabilities needed to explore these modes. The emphasis will be on operational scenarios involving strongly burning plasmas in an AT configuration for a duration of 1 to 3 current redistribution times. The long-pulse non-burning capabilities for AT studies at much lower fields (e.g., 2 MA, 4T for 200s) will not be emphasized.

Finding F1-3: 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.

Action A1-3: The project strongly agrees with this sentiment and believes that it is essential for the success of FIRE. The project is just finalizing a cost estimate of the baseline, and the "Greenfield Cost" cost is in the range of $1.2B(FY99) with about $300M for the tokamak. Reducing costs by finding a site with ~$200 M of site credits seems feasible. The project will develop provisional AT operational modes to serve as a basis for discussing affordability issues. The project will look into staging the implementation of advanced tokamak auxiliary systems and a report will be given at the January NSO-PAC meeting.

Finding F1-4: 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.

Action A1-4: The project concurs and believes that the science mission has the highest priority. The project will continue discussions with the community on how to best articulate the science mission. The UFA Burning Plasma Workshop on December 11-13 will be a good opportunity for additional discussion and feedback. This will be reported on at the January NSO-PAC meeting.

Recommendation R1-5: 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.

Action A1-5: FIRE concurs. A one pager will then be developed for discussion at the UFA Workshop and the next NSO-PAC meeting.

FIRE Design Point:

Recommendation R1-6: 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.

Action A1-6: FIRE concurs. A section of the physics basis document will be developed to address this recommendation. The FIRE paper at the APS began to address this issue, A one pager will then be developed for discussion at the UFA Workshop and the next NSO-PAC meeting.

Recommendation R1-7: 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.

Action A1-7: FIRE agrees that the mission statement of fusion-dominated (alpha-dominated) translates to alpha heating fractions (f_α) ≥ 50%. A study is underway to survey the sensitivity of performance (f_α), pulse length, engineering stress and cost trends to variations of size, field and aspect ratio. The first physics analyses were presented as part of the FIRE IAEA paper. The FIRESALE system code, developed at MIT, is being used to assess variations in aspect ratio, size and cost subject to constraints on fusion performance, pulse length and coil stresses.

Recommendation R1-8: 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.

Action A1-8: A common set of physics design criteria was used to compare FIRE, ITER-RC, JET Upgrade and a 10 MA D-T ST on the Q versus HH98 VG, and to compare FIRE, JT-60SC, JET Upgrade, ITER-FEAT, M2S/C, … and ARIES-AT in the Tokamak Table handed out at the PAC meeting. FIRE agrees that this area can be improved by using the latest version of the confinement data base DB3v9, and by constraining the projections to n/nGW and density profile peaking values relevant to the device under consideration. FIRE has obtained a copy of the most recent confinement data base and has used these data in the most recent FIRE performance projections described in the IAEA and ANS papers. FIRE also presented this methodology at the International Confinement Data Base Workshop at Frascati.

Recommendation R1-9: The PAC recommends delineating the design implications and quantifying the potential savings as one of the major engineering design efforts for the coming year.

Action A1-9: An engineering plan is being developed by Thome and Heitzenroeder and was reviewed at the ANS meeting in October. Status report will be given at the January NSO-PAC meeting.

Recommendation R1-10: 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.

Action A1-10: A list of diagnostics needed for FIRE and related diagnostic R&D issues will be prepared by Ken Young. It will be discussed at the UFA workshop and reported to the NSO-PAC in January. The issue of plasma control and the impact of low repetition rate will be discussed at the UFA workshop in preparation for the next NSO-PAC meeting.

Recommendation R1-11: We also recommend that the performance margin needed to meet the science objectives be discussed at a future meeting.

Action A1-11: The FIRE IAEA paper discussed this issue as did the APS poster. This will also be discussed at the UFA Workshop with a report at the January NSO-PAC meeting.

Appendix

The following is a tabulation of comments made during NSO-PAC-1. Most of these were addressed directly or indirectly in the main Findings and Recommendations of the PAC Report. They are retained in the appendix for completeness

Additional Specific Comments concerning the FIRE mission:

- 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, $\alpha-$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?

Additional Specific Comments concerning the FIRE design point:

- 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.
- Run transport simulations for the design point.
- Identify potential upgrades. The base design should at least support exploration of AT plasmas.
- 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.
- Evaluate helium ash accumulation issues, especially for advanced modes
- Examine the existing database for double-null divertor tokamaks concerning up-down/in-out power asymmetries during disruptions.
- Develop a better characterization of disruptions, vertical disruption events (VDE), electromagnetic loads, and other effects, as well as their consequences on the design point.

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

- 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.

- Consider providing tangential port access.

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