

Public Comment on Draft FESAC-SP Report  
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The FESAC Panel has done a remarkable job making significant progress on addressing the Charge despite constraints imposed by DOE that made this a nearly impossible task. The Panel's recognition of the program's critical needs including a significant paradigm shift toward fusion energy is an important change in direction. However, it is clear that more interaction between the Panel/FESAC and the fusion community, similar to that in other Office of Science programs (Nuclear Physics, 2011-2012) and High Energy Physics, 2012-2014), is needed to develop a strategic plan that is both technically sound at the detailed level and has the support of the fusion community.

### **General Aspects of a Strategic Plan**

The Panel's report is not a strategic plan- it is constrained to being a limited response to a narrowly focused charge from the Office of Science. The report is a plan for prioritization of resources under four constrained budget scenarios for the domestic program. This report is missing many of the essential elements needed for a U. S. Magnetic Fusion Strategic Plan. Where is the analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT)? The draft panel report says nothing about the overall strategic issues of the overall fusion program; especially those associated with ITER, the biggest driver for the U. S. fusion program.

***Recommendation – Change the title of the FESAC Report transmitted to DOE to reflect its content e.g., Priorities Assessment of the U. S. Domestic Fusion Program for Congressional Budget Scenarios.***

It is my understanding that this FESAC Panel Report will be sent to the Fusion Energy Sciences Office where it will be used as input to develop a Strategic Plan for the U. S. Fusion Energy Program. It will be essential for the Fusion Energy Sciences Office to interact with the U. S. Fusion Community during the development of the Strategic Plan for the U. S. Fusion Energy Program.

***Recommendation: The development of the Strategic Plan for fusion might occur in two stages. The first stage high level plan in the very near term to satisfy the Congressional request in the 2014 Omnibus Bill, followed by a second stage with a more detailed technical plan, at the same level of detail as the EU Fusion Road Map, developed interactively with the fusion community.***

### **General Comments on 10 Year Program**

Increasing the emphasis on resolving science issues directly related to fusion energy is a welcome change in direction for the U. S. fusion program, and is consistent with the

direction of the international fusion community. It is important to set out a plan to accomplish the stated goals with specific easily understood milestones and decision points that can be used to guide the program, and provide a basis for Congress to track our progress. In addition, the goals, milestones, and decision points need to be described in more exciting terms and a sense of urgency that will make this a more compelling plan.

***Recommendation – Add a section in the beginning of the report that conveys the importance of fusion as an energy source to combat the challenges of the future, and that also conveys the tremendous progress that was made during the decades when fusion research was more strongly supported, and describes the challenging scientific/technical issues that need to be attacked with a sense of urgency. The addition of several figures would help communicate the technical challenges and excitement. (Review the Nuclear Physics and High Energy Physics reports for examples)***

### **Resources needed for the stated 10 Year Vision are inadequate**

The goals set out for the next decade provide a basis for rejuvenating the U. S. fusion program. For the past 20 years the U. S. fusion program has been living off the investments that were made in the late 1970s and early 1980s. This enabled the U. S. to have a leadership position through the mid-1990s. However, the US fusion program has not recovered from the disastrous budget cuts of FY 1996, and has steadily lost its position among the leaders in international fusion research. This loss of position is clear when one considers the new confinement and fusion technology facilities that have been built and are under construction in Europe and Asia, while the US doesn't even have the resources to effectively operate its aging facilities.

Even if one of the three major facilities is terminated and all remaining resources are focused immediately on only FNSF/ITER tasks, the remaining facilities will not have the resources to make the required modernization upgrades, and operate at full availability. The recommendations for a large-scale migration of U. S. experimental research to foreign facilities is an admission that U. S. facilities are not world leading at the present time.

Under the most optimistic budget scenario, the U. S. fusion base program (non-ITER construction) will have ~\$3.5B available over the next decade. Detailed budget breakouts are not available in the Panel Report to support the Panel recommendations. As a result, I expect that the resources needed to accomplish the goals described in the Panel Report far exceed the budgets foreseen in any of the budget scenarios. For comparison, the EU Commission (Horizon 2020 extended to 2025) plus the budget of the National Associations would have ~ \$7B available for Non-ITER construction activities from 2015 to 2025. It is unrealistic to expect the U. S. to remain among the leaders in Magnetic fusion energy under these conditions.

***Finding: The Panel Report does not provide a description and quantification of the resources needed to carryout the stated program, or those needed for the U. S. program to be world leading. The EU developed a Technical Road Map for what needed***

*to be done, including the required budgets, and this is now serving as a basis for budget discussions with the government funding agencies.*

*Recommendation: Add a section to the report that describes in quantitative terms the present U. S. facility capability and compares that with the front line research facilities that exist and those under construction in Europe and Asia.*

*Add a section to the Panel Report that compares the present funding and projections for the total European Program (EU Commission plus National Associations) funding with the budget cases analyzed by the FESAC Panel. The EU Road Map for Fusion provides the data for EU Commission funding and facilities. For China and Japan, a comparison of funding is problematic, but a comparison of the existing facilities and those under construction is sufficient to reach a similar conclusion.*

## **Analysis of Initiatives**

There are some serious technical inconsistencies between the highest priority initiatives and the recommended research program to address those initiatives.

The four highest priority Initiatives identified by the 2014 FESAC Strategy Panel, categorized in two tiers, are:

Tier 1:

- Control of deleterious transient events (Transients)
- Taming the plasma-material interface (Interface)

Tier 2:

- Experimentally Validated Integrated Predictive Capabilities (Predictive)
- Fusion nuclear science (FNS)

## **Implementation of a Program to Address Tier 1 Initiatives**

It is well known that the plasma facing component material has a very strong impact on plasma performance (confinement, MHD, disruptions, etc), and over the period 1976 to 2010 nearly all of the plasma confinement experiments gravitated to using carbon plasma facing components (PFC). Unfortunately, there is a strong consensus among the materials scientists and fusion facility designers that carbon PFCs are not relevant for use in the fusion power environment. The previous Nuclear Science Pathway Assessment (2011) also concluded that carbon PFCs were irrelevant to an FNSF and that high-Z high-temperature PFCs would have to be developed for an FNSF and DEMO. The leading candidate for PFC material for an FNSF and fusion DEMO is a tungsten based metal operating at temperatures over 500°C according to the FESAC Fusion Materials and Technology Panel Report 2012.

The previous trend toward carbon PFCs has now reversed in the international fusion community as they move forward with a fusion energy emphasis. ITER has decided to go with an all metal (W/Be) PFC system from the beginning of operation due to tritium retention and safety requirements. The EU has now transitioned its major confinement

facilities (JET, ASDEX, Tore Supra/WEST) to all metal PFCs. EAST is partway through a transition to W PFCs with the upper divertor W and the lower divertor carbon. Eventually, EAST and WEST will have all W PFC systems operating at relevant (~500°C) temperatures. However, the major U. S. plasma confinement facilities propose to continue using room temperature carbon PFCs on DIII-D and NSTX-U for at least the next five years, while only C-Mod has all high-Z PFCs and a proposal to convert to a high temperature W divertor on hold by DOE since 2012.

The experience on ASDEX and JET-ILW has demonstrated that the plasma behavior is different and more challenging with plasma performance degraded relative to experiments with carbon-based PFCs. The JET ILW experiments also demonstrated that changing the PFC material from carbon to tungsten also changes the behavior of transients – disruptions and ELMs. The **integration of a high performance plasma core with a relevant plasma wall interface** has been and will continue to be one of the most vexing challenges for fusion confinement experiments, and the near term U. S. Program should be focused on addressing this critical issue.

***Finding: the PFC material has a significant effect on both Tier 1 Initiatives – Transients and Plasma Materials Interface through the close coupling of confinement physics and the plasma material interface. In addition, the implications for the very long pulse lengths in a FNSF are critical.***

If the US BP Foundations and BP Long Pulse sub programs are going to **focus on supporting ITER and FNSF**, then the operating regimes of the operating experiments need to access conditions relevant to ITER and FNSF. The Panel recommendation to immediately cease operation of C-Mod with a relevant PFC system under all budget scenarios, and continue operating DIII-D and NSTX-U for the next five years or more with an irrelevant PFC material is difficult to justify technically. I don't believe that a **virtual integration** of plasma confinement results from carbon based PFC tokamaks plus PMI results from a high power linear device with metal PFCs that are input to a Fusion Plasma simulation code will provide the data to achieve the 2025 Vision goals.

***Recommendation: The Strategy Panel and FESAC should reconsider their logic and resulting recommendations regarding the appropriate materials/facilities for pursuing the Tier 1 Initiatives - Control of deleterious transient events, and Taming the plasma-material interface. A detailed technical analysis should be done to compare the requirements needed to address the issues with the capabilities of the facilities along with a timeline for accomplishing this task. High priority should be given to near term operation under fusion relevant PMI conditions.***

### **Divertors for Controlling the Plasma Material Interaction (PMI)**

The classic poloidal divertor (1972-1982) is a concept for effectively removing the plasma exhaust heat while providing a low temperature plasma interaction at the divertor target material and allowing for a higher temperature plasma at the confined plasma edge.

Initial experiments on tokamaks, using coils internal to the TF coils and vacuum vessel, confirmed the basic features of scrape-off dynamics and power flow. Linear divertor simulators demonstrated (1980) detaching the plasma from the divertor target as proposed in the early (1970) reactor divertor concepts. However, this configuration with internal coils fell out of favor in the early 1980s, since the internal poloidal coils were considered to be irrelevant for a fusion environment due the difficulties of providing neutron shielding and cooling. In addition, the use of valuable space inside the TF coil bore was thought to reduce the reactor economics to unacceptable levels.

In the early 1980s, the discovery of the H-Mode demonstrated that a poloidal field X-point near the plasma surface was sufficient to provide an edge transport barrier, but did not provide divertor action. In the 1970s, this “X point” configuration would have been called a “magnetic limiter”, but the terminology evolved to labeling this a “divertor” even if it did not provide the classic divertor action. Over 40 years the divertor concept has now come full circle with extended divertor channels produced by PF coils trapped within the TF, and even vacuum vessel, but now described as an “advanced divertor.” One new variation has been introduced – a higher order multiple null produced by an even more complex set of coils trapped within the TF coil/Vacuum vessel. When the engineering requirements for neutron shielding, cooling and mechanical structure required for an FNSF or DEMO are imposed, the practical application of this concept becomes even more intractable than the classic divertor of the 1970s.

***Finding: It is appropriate to take another in depth look at finding a divertor configuration that would be feasible for implementation in the fusion environment.***

***Recommendation: The evaluation of experimental concepts/configurations/facilities for tests related to addressing Tier 1 initiatives must include an analysis of the direct relevance/feasibility for operation in the fusion environment of FNSF or DEMO.*** Note: If the fusion program is transitioning toward fusion energy, fusion compatibility should now be a general requirement for all aspects of the confinement configuration. The exploitation of liquid metal PFCs would be an example of a task that would benefit from a fusion power environment compatibility analysis. Another example, is whether the RWM coils similar to those being designed for ITER are compatible with a fusion power environment. In my view, the present design concept may not even be compatible with high availability ITER operation. This last example illustrates the importance of having a single integrated Fusion Strategic Plan, and not one Strategic Plan for the domestic program and another for the ITER construction activities. Design concepts with better maintainability and improved availability, or perhaps an entirely different strategy should be developed for avoiding transients.

### **Possible Alternate Approaches:**

The Nuclear Physics Priorities Panel 2011-2012 faced a similar challenge of what to do with three facilities (RHIC, CEBAF Upgrade and FRIB Construction) under similar budget scenarios. The report (p.91-94) describes in detail the scientific impact of closing each of the three facilities. The panel report (p. 95-96) described two options: one stopped RHIC

operation and the second stopped FRIB construction. They quantified the impact of each option, and after much debate NSAC indicated a slight preference for the first option.

***Recommendation: Structure the FESAC Panel description of the impact of restricted budgets on facilities along the lines of the NSAC report and NSAC Transmittal letter to Office of Science as suggested by Congressional language and the FESAC Charge.***

The FESAC panel report should have considered at least two facility options for proceeding.

Here is a possible option for discussion:

1. Assess what C-Mod could do in 3 years if dedicated to addressing only PMI issues.  
If compelling, continue C-Mod as a dedicated PMI facility for 3 years.
2. Assess immediately, upgrading either DIII-D or NSTX-U to relevant PFCs (ready to operate in 3 yrs)
  - a) if DIII-D is chosen to upgrade to W PFCs ASAP, then it's operation would be extended beyond 5 years to exploit the capability. NSTX-U would focus the next five years entirely on establishing the capability for non-inductive start-up and sustainment, which is essential for an ST FNSF.
  - b) this would be the reverse of a).
  - c) panel should assess the technical aspects a) versus b)

The likely conclusion is that the restrictive budget cases (with resources < 1/2 that of the EU) will have a severe negative impact on the US fusion research effort to be a world leader no matter which option is chosen, and the US will be relegated to being a follower in the world fusion effort. **The FESAC report should say this clearly as the NSAC report did.**

### **The FESAC Panel Process**

The FESAC panel process for a charge as important as responding to a Congressional directive on prioritization of fusion program priorities for the next decade should have had more interaction between the fusion community, the FESAC Panel and FESAC. The NSAC and HEPAP panels had much more interaction between the scientific community, the panel and the parent Advisory Committee.

The restriction that prohibited scientists from three of the four institutions with the largest fusion programs eliminated critical technical expertise and experience from the FESAC Strategy Panel. For example, expertise and experience with construction, operation and research on large fusion facilities was absent, yet the panel made key recommendations in this area.

The limited public interaction with the Panel took the form of a community wide solicitation for White Papers that resulted in nearly 100 10-minute presentations to the Panel that frequently seemed like a blizzard of mini proposals. **In the draft Panel report, there are recommendations for two specific proposals that appear to bypass the traditional independent peer review process. This should be clarified in the final report.**