

Fusion (?) Energy (??) Science (???) and its gaps and integration

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1 Introduction. The theory of the failure of magnetic fusion

The guiding letter pretends that the FES program is a synchronized development with a realistic vision of long-term goals. It eventually assumes that the basic science components are mature and require only a timely integration. The community needs to advise the program management on new research opportunities in order to fill the (remaining) gaps in research.

This guidance would be appropriate for 1970s when near-term challenges and evident progress in new science obscured the importance of a distant vision of future.

Now, the former long term problems, which remain unresolved even conceptually, become a near-term headache. They began to affect magnetic fusion in a very tangible fashion. The ITER project, a product of a program with multiple “gaps” in fundamental issues, was forced to introduce tungsten as the plasma facing material. Since the 1970s it has been known that tungsten is the most efficient poison for the high temperature plasma. The real problem is that the present FES, as managed, is incapable to develop another option to tungsten - it would require a considerable redirection of research, not acceptable to the community.

The present FES program does not have either synchronization or a science based vision, which are the key conditions for technical development of “integrated simulation capabilities”. Two earlier attempts at relatively simple integration, (a) stability and equilibrium codes (1996), and (b) core transport and the plasma boundary (1998), were converted into pure programming exercises with no impact on “new opportunities”.

This is not an occasional failure. Its general theory was created in 2004 and reported to APS DPP-2007 (<http://w3.pppl.gov/~zakharov>, November 2007). It introduced two phases of any long-lasting unsuccessful program: (a) the “difficult” one, which in fusion ended in the mid 1980s, and (b) the following “complicated” phase, similar to “activity trap” in business.

The “difficult” phase has created the foundation of the fusion science. Progress was visible. This phase was essentially self-managed by well recognized leaders, capable of keeping track of the near-term problems all together. This phase was terminated by inability of leaders to address the incoming long term problems.

In fusion, the clear indication of transition to a complicated phase was a conversion of ITER, which was envisioned as a device for testing nuclear components of fusion reactor, into a “big-JET” plasma physics facility. The leaders disappeared, the realistic vision became impossible and the program was converted into an activity trap. The good experts, from times of the “difficult” phase, were continuing to develop their science. But uncorrelated achievements cannot move progress of the entire field. It has stagnated. The equi-partition distribution of resources became the leading approach of management, relying, in the absence of vision, on community inputs.

There is no reverse path from the complicated phase to progress. In contrast, my theory of the failure predicted its imminent transition to degradation and a final collapse. The unexpected observation was how short was the phase of uncorrelated science. Essentially degradation started in 2007, when the science was evidently neglected in VDE simulations by M3D, then, in the decision on tungsten for ITER, etc.

2 The science of FES

FES has no “fusion energy science” in the most fundamental areas. I comment on just 3 of them. At the same time both the community and OFES overslept the creation of a real “fusion energy science”, referred below as LiWall Fusion (LiWF), developed since Dec. 1998 as undesirable, essentially, “underground” activity. LiWF is already integrated and has a vision consistent with the fusion science and technology.

A. Energy confinement and power extraction.

Good energy confinement is the key to magnetic fusion. The biggest, root-level mistake, costing tens of \$B and decades of wasted research time, is the misrepresentation of the confinement problem as a “core transport” problem. Yes, it would be remarkably good if the turbulent thermal conduction coefficients were orders of magnitude smaller. No such luck, TFTR and JET proved this.

The entire program was misguided by this false interpretation of confinement and reliance on everything-BIG.

Regarding their own science, the TTF experts do not understand where the confinement zone in tokamak is, and why the toroidal plasma has two regions: the plasma core and the edge pedestal. Even the direct hints from the discovery of QHM and results of RMP experiments on DIII-D did not help them.

In contrast, LiWF suggests the best possible confinement regime in which energy losses are related exclusively to plasma diffusion. Unlike thermal conduction, it is determined by the best confined component, ions, which are essentially neo-classical. Thus, conventional NBI can be sufficient for plasma maintenance and core fueling. The puzzle, unsolvable for TTF, was explained by LiWF.

Very modest lithium flow ($\simeq 1$ g/s flow rate) is sufficient for suppressing recycling. But for this fusion community and OFES is impossible to accept the fact, that if the plasma edge is not cooled down by recycling, the plasma will be hot $T \simeq 1/5 E_{NBI}$ everywhere. Exactly as it is necessary for fusion. FES is blind to both straightforward science and Li experiments (not yet even approaching the LiWF conditions).

It is much more efficient to prevent the plasma edge cooling by suppressing recycling, rather than to rely on enhanced heating power in the presence of turbulence. **Good confinement of LiWF, rather than reliance on sole material improvements, is the key to solving the power extraction problem.**

B. Plasma edge.

The pedestal region, highly perturbed by SoL currents and located outside the confinement zone, is considered as perfect 2-D magnetic configuration with transport suppression. The amazingly informative direct RMP data from DIII-D, all puzzles for TTF of FES, were confronted by fantasies on “shear flow rotation”, “screening” magnetic perturbations, huge bootstrap current density, etc, still leaving puzzles unresolved. *This critical area for progress in magnetic fusion was converted by FES into a high performance industry of “cooking” science using the notion of the “edge transport barrier”.*

Instead, LiWF gave the basic understanding of the plasma edge and its pedestal. It determines the edge temperature as the ratio of the heating power to the particle flux from the edge to the wall.

C. Stability.

In the FES approach all natural tendencies of the tokamak plasma are bad for stability: (a) peaked temperature leads to sawtooth oscillations, (b) in turn, they trigger NTMs, (c) H-mode automatically leads to ELMs, (d) the plasma edge density is high and prone to high-density disruptions. Predictive understanding of this mess is impossible. The “flagship” codes of FES, the long multi-\$M investment in MHD simulations, are inconsistent with the basic plasma physics and incapable to simulate even the simplest VDE disruptions.

Stability of LiWF plasma is simple and predictable: (a) no sawteeth and NTM triggering, (b) no ELMs, (c) no density limit, (d) the entire plasma is stationary and externally controlled. It is the LiWF person, who developed the appropriate theory and model for MHD simulations.

3 The energy of FES

The FES “vision” of an inexhaustible energy source from the ocean water is a science fiction: *the direct relation between energy from DT fusion and the life time of the First Wall makes it impossible to cover its replacement by the value of electricity produced.*

In contrast, LiWF determines the limited realistic objective of magnetic fusion: a 100 MW DEMO facility ($R/b/a=4/1.6/1$, $I_{pl} = 5$ MA, $B_{tor} = 6$ T with $Q_{electric} > 1$) as potentially useful size for fusion-fission.

4 Fusion of FES

With science ignored, FES is going to a collapse with discrediting the fusion idea without demonstrating at full extend its potential, although limited. The decision on a tungsten divertor is the “death sentence” to ITER even as a plasma physics device. Also JET in the conventional regime is incapable to demonstrate $Q_{DT} > 1$ or even to repeat the mid 1990s results. The failure with DT can trigger the collapse. (The captains of the Center are already abandoning the ship. In fusion they are the first to do so).

In Oct. 2014 EAST demonstrated 3 hours of uninterrupted lithium flow with ${}^{24}_{7}\text{FLiLi}$ limiter but, thanks to FES intervention into Chinese program, we missed the time for demonstration of LiWF technology in advance in order to convince JET to use it for getting $Q_{DT} \simeq 5$ in the LiWF DT discharges.