ST1, EAST1, ITER-100 - all exceeding ignition criterion

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1 Introduction

At present, **the problem fusion is in management***, rather than in physics of technology. The science based strategy of the program is absent. It relies on obsolete stuff.*

The last 10 years have been remarkable for observing how fiercely the management of PPPL tried to suppress any development of the LiWall Fusion (LiWF) concept, and how successful these foes of new fusion ideas were in getting the solidarity of the fusion science community in this. The solid science basis, consistence with crucial, although indirect, experiments on DIII-D (i.e., its discovery of the ELM-free QHM regime, RMP experiments), as well as the outstanding self-consistency of the LiWF concept did not matter at all. Instead, a "great" idea of 3D quasi-symmetric confinement at a single magnetic surface in compact stellarators was overblown out of proportion, resulted in wasting $ 0.1B of taxpayer money in direct costs, more than $ 1B due to the destruction of all capable tokamaks in the Lab. Stealing 10 years of our lifetime cannot be given a price.

Now, when initial Li experiments on NSTX at PPPL did confirmed the tendencies predicted by LiWF theory, i.e., enhancement in the energy confinement, in global and ELM stability, and when it is not longer possible to deny the basic validity of LiWF, the same guys, who lost the junk compact stellarator project, suddenly became positive about Li in fusion.

But by no means becoming positive about LiWF. The references on its fundamental results for fusion are essentially prohibited, and this is strictly obeyed by NSTX experimentalists. Even such an unambiguous prediction as ELM stabilization was ignored (i.e., Dr. R.Mangi and C^o) and experimental results were presented as independent discovery with a fabricated theory "explanation".

Now, PPPL presents NSTX Li experiments as a "logical" continuation of the excellent TFTR experience with Li. They forgot that it was just the negligence of TFTR leaders to understanding the fundamental character of the "kitchen effect" of Li on the plasma, their obsession with "bigger (I_{pl}, P_{NBI}), stronger (B_{tor}), higher l_i, more (runtime, $$), ..." was the real reason of the TFTR failure in Q factor. The catastrophic effect of this failure on fusion is unrecoverable.

After their failure with the compact stellarator the same people are preparing another failure with upgrade of NSTX, recently barely rescued from permanent shutdown, where Li is considered as a "tool" for improving their 1 keV plasma. Of course, the guiding idea is again the same, i.e., "bigger (I_{pl}, P_{NBI}), stronger (B_{tor}), higher, more (runtime, $$), ..." for NSTX-U. Several lessons of the past play no role, the same stupid approach persists for further waste of money and our lives.

As a result, still there was no single experiment implementing the LiWF concept and it is not expected in future. What does it mean for fusion can be seen from the following Table comparing the LiWF with the present "Bib$_{\rm b}$le of the 70s" (BBBL-70) concept, which is incapable to resolve a single fusion issue.

Issue	LiWF	BBBL-70 concept of "fusion"
The target	RDF, neutron source	Political "Burning" plasma
Reactor Issues:	$P_{NBI} = E/\tau_E$	ignition criterion $f_{pk} p \tau_E = 1$
Hot-α, 3.5 MeV	"let them go"	"confine them"
He ash, mixed with plasma	Nor existent	Expect that "it will go by itself"
$P_\alpha = 1/5 P_{DT}$	goes to walls, Li jets	dumped to SOL and plates
Power extraction from SOL	conventional technology	no idea except to "radiate 90 %"
Plasma heating	"hot-ion" mode: NBI $\longrightarrow i \longrightarrow e$	"hot-e mode": $\alpha \longrightarrow e \longrightarrow i$
Use of plasma volume	100 %	25-30 %
Tritium control	pumping by Li	tritium in all channels and in dust
Plasma contamination	no Z^2 thermo-force drive, core fueling	junk from walls goes to the plasma
He pumping	as ionized gas, $p_{in} < p_{out}$	gasdynamic, $p_{in} > p_{out}$
Fusion producing β_{DT}	$\beta_{DT} > 0.5\beta$	diluted: $\beta_{DT} < 0.5\beta$
Fusion power control	existing NBI technology	no idea
Physics:		
Confinement	diffusive, RTM$\equiv \chi_{=}\chi_e = D = \chi_i^{neo}$	turbulent thermo-conduction
Anomalous electrons	play no role	YES for 40 years and ahead
Transport database	scalable by RTM (Reference Transp. Model)	not scalable to "hot e"-mode
Sawteeth, IREs	absent	unpredictable
ELMs, $n_{Greenwald}$-limit	absent	intrinsic for low T_{edge}
p'_{edge} control	by RMP through n_{edge}	through $T_{edge} \rightarrow$ low performance
Fueling	existing NBI technology	unresolvable
Current drive	Consistent with low n_e, high T_e regime	inconsistent
Stationary plasma	Straightforward external control	unresolvable
Tangible RDF time scale:	$\Delta t \simeq 15$ years	$\partial_t(progress) \simeq 0$, $\Delta t \simeq \infty$
Cost:	\$2-2.5 B for RDF program	$\simeq$ \$20 B with no RDF strategy
Scientific status:	Consistent with physics and technology	Everything is Upside-Down

2 "Laser" beam versus "flashlight"

The present fusion program can be compared with endless "improvement" of the flashlight. In contrast, the LiWF introduces new physics, suggesting a transition to the "laser beam" development.

The LiWF concept is transparent: (a) core fueling of the plasma by Neutral Beam Injection (NBI), and (b) pumping plasma by Li plasma facing surfaces. There is no plasma physics present, except the simple MHD.

The plasma temperature is automatically flat (even with imperfect pumping or walls, as soon as the incoming gas supply does not exceed the NBI source). There is no ITG or ETG turbulence, which is a topic of $\simeq 50\%$ of studies in fusion. There is no tendency of current density peaking, which would lead to disruptions, no ELMs, no sensitivity to anomalous electron thermo-conduction. The expected confinement time (based on the ion neo-classics) is huge, and there is no need for the $\alpha-$particle heating. Automatically, the heat flux to the divertor plate is very limited, thus solving the unresolvable for BBBL-70 problem of the PFC materials. Crucial fact for the long term stationary plasma is that in the collisionless SOL, there is no thermo-force driving impurities to the plasma. The list of breakthroughs by LiWF is endless (see the Table).

Besides this, in all its predictions of tokamak experiments, the LiWF never failed so far.

Of course, this is neither impressive nor interesting to the fusion community and its leaders. The goal is

not to understand and contribute. The goal is to find something "bad" in the concept to order to discredit the new concept.

One of the "bad" things they are able to invent is the Trapped Electron Modes (TEM) in the regime with a density gradient. Nobody yet identified the "danger" in experiments, but the idea is to present the LiWF regime as a replacement of one turbulence with another. In fact, even with TEM, nothing crucial will happen in the LiWF regime. It will be the same temperature profile, same density, same insensitivity to anomalous electrons, same stability, same NBI energy. Just might be that the NBI current should be enhanced. It might be not good, but not anywhere near as "bad" as the disastrous situation in the BBBL-70.

Another "bad" thing is the issue with He pumping from the plasma-wall gap. The answer is that it is necessary to switch from the present hydro-dynamic pumping concept to pumping He as the ionized gas.

Finally, the third "bad" thing is the secondary-electron emission, which could cool down the edge electrons. This could be a problem as far as the appropriate answer is not given. But it does exist in LiWF.

All other "bad" things about LiWF, which attemted to confront the LiWF during its 10 year story of suppression, do not deserve consideration in the context of the white paper.

The LiW concept is presented in details at the web-site http://w3.pppl.gov/~zakharov/ accessible by typing Leonid Zakharov in Google. In my view, its scientific, technical or technology basis cannot be shaken. Of course, this is not sufficient to resolve the major problem of fusion, specified in Introduction.

3 ST1, EAST1, and ITER-100 for three missions of fusion

Two machines and the ITER-100 regime are proposed for 3 purposes for the next 10-15 years.

1. The development of "clean" fusion, where the major physics and technology problem is the First Wall (FW), which is first ≃15 cm on the way of 14 MeV neutrons, should go through a Reactor Development Facility (RDF). The crucial requirement for RDF is providing the 15 MW·year/m^2 fluence of neutrons.

   Only Spherical Tokamaks in the LiWall regime are suitable for the mission of RDF. So called CTFs, based on conventional plasma regimes, have no plasma physics basis.

   The spherical DD tokamak ST1 is the first step (out of three) toward RDF. With $B = 1.5$ T, $R_{outer} = 1.65$ m, I_{pl}=2-4 MA, $R/a \simeq 5/3$, $\kappa = 2$, $\beta = 0.2$, it can achieve in DD plasma $P_{DT}^{equiv} \simeq 10 - 15$ MW, and based on RTM model calculations $Q_{DT}^{equiv} > 5$, thus exceeding the ignition criterion $p\tau_E > 1$.

2. The stationary super-conducting DT EAST1 tokamak has sufficient space for a 50 cm thick nuclear blanket and addresses the fission-fusion development. With $B = 5$ T, $R/R_{outer} = 2.4/3$ m, I_{pl}=4 MA, $R/a = 4$, $\beta = 0.033$, it can achieve $P_{DT} \simeq 30$ MW, $Q_{DT} > 20$, $p\tau_E > 4$.

3. The ITER-100 regime is defines as a safe hydrogen regime $I_{pl} = 8$ MA, $\beta = 0.01$, capable of demonstrating $P_{DT}^{equiv} \simeq 100$ MW and according to RTM modeling $Q_{DT}^{equiv} > 25$ and $p\tau_E > 5$, 5 fold exceeding the ignition criterion. Development of the ITER-100 regime and demonstration (with or without tritium) of ignition plasma parameters and the reference power (100 MW) for fission-fusion applications at the early stage of ITER would be crucial for both fusion and fission-fusion programs of its participants.

All of these machines and are in the LIWF regime and need less than 5 MW of NBI power

Nothing of this can be done without focusing the NSTX facility in PPPL on the development of the LiWF regime, as it is defined by the science, with a clear milestone in reproducing the CDX-U achievement in 4 fold enhancing confinement.