Li Walls and Betatrons of the Fusion Reactor Strategy

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There is an obvious inconsistency between necessity in an ecologically compatible and powerful energy source and our promises to deliver such a clean and inexhaustible energy source.

Instead of learning the lessons of termination of TFTR program and rejection of (big) ITER, the premise has been invented that just our propaganda of fusion is not sufficient and that public has to be more educated.

Public ignorance of fusion as a potential energy source resulted in a series of failures with the next step in magnetic fusion.

... eroded support of fusion.

... growth in neutron production by fusion.

... claims on "tremendous progress in fusion (referring to exponential growth in neutron production by fusion)"

... necessity in an ecologically compatible and powerful energy source
The next step in fusion is the first step into reactor physics.
The next step requires the reactor relevant strategy with emphasis on

1. Necessity in the reactor oriented strategy (cont.)

The strategy.

There are several layers of the reactor physics which should determine

bigger and bigger scales.

The same strategy should have a clear research path, when the prob-

reliability in the reactor control

low activation

simplicity

efficiency

lems are gradually solved along the way instead of piling them up at the

The next step requires the reactor relevant strategy with emphasize on
The ignition criterion is both the major scientific milestone and the basic requirement for the reactor operation. It looks as 3-dimensional (in the parameter space $n, T, f$), thus suggesting many routes toward the fusion reactor. The big ITER was expected to pass the ignition margin in a long lasting discharge (1000 sec), while the present (smaller) version meets its 60% (and with some luck 100%) margin on a shorter time scale. Everything looks OK at this level of consideration for both ITERs.

\[ \left( \frac{m_3}{K e^2 \cdot \text{sec}} \right) T_\text{sec} < \frac{5 \cdot 10^2}{n \cdot T \cdot f} \]

The ignition criterion is both the major scientific milestone and the basic requirement for the reactor operation.
This creates inconsistency with the reactor physics at the most fundamental level.

With low $f$, the magnetic fusion is essentially trapped at the one lane with the only parameter left for magnetic fusion is $T_F$.

\[ (2.2) \]

\[ B^2 \cdot \frac{1}{T_F} \cdot \frac{\dot{\theta}}{T_F} < 4 \]

\[ B^2 \cdot \frac{1}{T_F} \]

The same criterion

\[ (2.3) \]

\[ \theta \cdot 10^2 \]

After a substitution

2 Ignition, power and the cost of the reactor (cont.)
The power of the reactor which is practically predetermined at the level of the cost of the reactor and its control

\[ p \sim 2 - 3 \cdot \text{GW} \]
Lack of consistency with the reactor physics at the plasma physics level.

They would follow the same one true road.

which may work but will never "fly" as a power reactor.

"Steam engine" variant of the fusion reactor,

Based on low "$\beta$-high "$A$-"high "$W$-10B for 0 MW of the electric power.

The big ITER has put a numerical calibration on the present road of low "$\beta$-high "$A$-"high "$W$-10B for 0 MW of the electric power.

The conventional tokamak and, thus, the cheapest device in its class.
The fusion reactor strategy should target opening the high path $\theta$ configurations relevant to the non-recycling regime.

For the magnetic fusion reactor rather than ironing once more time a piece of the “dead end” road of good confinement.

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The fusion reactor strategy should target

2 Ignition, power and the cost of the reactor (cont.)
Ignition, power and the cost of the reactor (cont.)

The LiWall concept relies on a straightforward way of controlling plasma profiles relevant to the second stability regime, i.e., that of inverted temperature (consistent with the plasma edge physics). The conducting shell at the plasma boundary (consistent with the high-β path in the ignition parameter space for the magnetic fusion reactor).

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Fixed boundary plasma & flattened temperature profile results in a new core MHD regime: 

- LIWalls
- $\beta$-limits for Li Wall fixed boundary plasma
- $\beta = 0.2$
- $\beta = 0.4$
- $\beta = 0.6$
- $\beta = 1.2$
- $\beta = 1.45$

Non-recycling regime

- NSTX
- No sawtooth oscillations;
- No Troyon limit;
- No sawtooth oscillations;
- $\kappa = 1.6$, $\delta = 0.3$
- $\kappa = 2.45$ $q$
- $q = 1.45$

Core MHD regime:

- Fixed boundary plasma & flattened temperature profile results in a new
As a by-product, the LiiWall concept provides the most efficient way of solving the problem, i.e.,

1. Freeing the $T_E$ problem, i.e.,
2. Ignition, power and the cost of the reactor (cont.)
3 Power extraction. The problem of the „first wall“

The „first wall“, i.e., the first 10-15 cm of the plasma facing structures, is the concentration of the most challenging problems of fusion.

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The present approach based on divertor configuration and high-Z first wall structure, essentially, still far away from providing a reactor relevant conceptual solution to the „first wall“ problem.

- be consistent with low activation events
- withstanding possible abnormal thermal or electromagnetic plasma events
- withstanding deterioration of mechanical properties
- withstanding deterioration of neutron power into the high-temperature coolant
- tritium breeding
- conversion of the neutron power into the high-temperature coolant
- absorbing most of remaining 4/5 of the fusion power
- surface absorption of 1/5 of the fusion power flux

The concentration of the most challenging problems of fusion: surface absorption of 1/5 of the fusion power flux, tritium breeding, conversion of the neutron power into the high-temperature coolant, withstanding deterioration of mechanical properties, withstanding possible abnormal thermal or electromagnetic plasma events, be consistent with low activation events.
3. The "Yacht sail" approach for dynamically balanced design of the first wall.
2. Zinke Nelson FLiBe blanket.
1. Intense Lithium streams, and the "first wall" by inventing the LIWALL concept did the reconciliation of the basic plasma physics.

The LIWALL concept did the reconciliation of the basic plasma physics.
plasma
nuclonic coupling with the
with still good electromagnet-
tected by the FLiBe layer
feedback plates are pro-

ium breeding
-Z-N blanket provides the tri-
temperature FLiBe colant
neutron power into high-
-Z-N blanket converts the

the neutron fusion power
FLiBe layer absorbs most of

FLiBe capability of excessive power extraction
intense lithium streams have

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be corrected on the fly

deformations of the wall can

neutron zone;
activation is minimum in the

winding plasma control
magnetic plasma events and pro-
ing abnormal electromag-
ing best approach for withstand-
conducting blanket is the
wire rope structure + non-

reactor

and mechanisms of the fusion

beryllium ropes are consis-
flux;

withstanding the high neutron
wire mesh guide wall can

3 Power extraction. The problem of the „first wall” (cont.)
Inconsistency with the reactor requirements of the "first wall" becomes insensitive to thermal deformations in consistency with the reactor requirements.

Thus, the LiWALL concept has eliminated the necessity of the stationary regime of tokamaks (and, thus, downgraded the relative importance of stellarators as the reactor concept).

The problem of the "first wall" (cont.)
Electric power production

In fact, this is the entire complex of technology of extracting the power from the fusion reactor, which is the real indicator of maturity of the fusion reactor strategy as the energy source.

By relying on FLiBe as a perfect coolant for the fusion reactor, the ITER project at its early stage has been canceled from the ITER project essentially.

This issue of the primary importance of the reactor strategy is being essentially not addressed by the conventional approach.

Well addresses the problems in a way consistent with the power reactor requirements.

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Same property simplifies the 3-D design of the FLiBe blanket.

Neutron heat at \( 800 \, ^\circ \text{C} \) with negligible losses (4-5 %). The thermo-conduction FLiBe is so small that it can transport the entire neutron (neutron) heat source and \( J \) in the FLiBe channel.
Reactor control and scalability

This is the issue of learning how to control the reactor using smaller facilities.

The reactor relevant plasma physics concept should be able to resolve the plasma control problems at the sub $\alpha$ level of experiments.

The reactor development step should be provided with sufficient stability margins to be focused on the reactor specific problems.
There is no scalability in the conventional approach:

1. Plasma temperature profile has the tendency of peaking, resulting in lower excitation of sawtooth or minor disruption.

2. Stability of the free boundary is sensitive to the boundary conditions.

3. Stability is essentially marginal.

4. The divertor physics is marginal (even in the "steam engine" variant).

5. The divertor physics is very complicated to be scaled.

6. ...
In the LiWall concept

1. There is no tendencies of peaking the plasma temperature.
2. Stability of the fixed plasma boundary is scalable from smaller scale machines (conducting wall + feedback).
3. Operational point can have large stability margins (about 50%).
4. Power extraction capabilities are excessive.
5. There is no tendencies of peaking the plasma temperature.
6. The "first wall" structure is consistent with the plasma control.

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5 Reactor control and scalability (cont.)
Research path should provide the solving problems rather than piling them at larger scales.

The research path should provide the solving problems rather than piling them at larger scales.

Regarding the plasma physics, the Li wall concept relies on circular machines with the Li coated copper shell, which may provide extension of TFTR Li pellets and DOLTOLP experience, as well as control of the Li surface temperature in full range of required parameters. For the same ∇θ = 2000 °C, the time of exposure is determined by the expression in the full range of required parameters:

\[
\text{time} \approx \frac{n_{\text{wall}} B}{\sqrt{\frac{\text{MW}}{\text{m}^2}}} \times 3.5 \text{ sec}
\]

5 times greater than in ITER.

giving, e.g., 1-4 minutes for the thermal flux \( B \) giving, e.g., 1-4 minutes for the thermal flux.
6 Research Path (cont.)

- Reactor relevant stability control by the conducting shell + feedback system
- Low-recycling, high-β regimes
- Reactor relevant particle control

With the success in Li/Cu shell experiments (up to ignition regimes), most of the plasma physics can be applicable to the reactor in a straightforward manner.
Regarding the technology, the LiWALL concept is focused on full utilization of advantages of

1. Liquid wall/blanket elements
2. Low-Z structural wall/blanket materials
3. FLiBe coolant

and emphasizes the Liquid Lithium MHD aspects with their studies, separated from the tokamaks.

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At the "beta\(\tau\)" level of the reactor strategy, the enhancement of the \(A\)-factor is the primary target, which can reshape the whole approach to the reactor design.

In contrast, the Li\(W\)all concept demonstrates that there is nothing fundamentally contradictory between the tokamak physics and the reactor physics and technology, and there is nothing fun.

The conventional approach of mimicking the plasma physics and the power plant, created a miriad of problems in all other aspects.

The Li\(W\)all concept demonstrates that there is nothing fundamentally contradictory between the tokamak physics and the reactor physics and technology, and there is nothing fun.

At the "beta\(\tau\)" level of the reactor strategy, the enhancement of the \(A\)-factor is the primary target, which can reshape the whole approach to the reactor design.