web page: http://w3.pppl.gov/~zakharov

Thermodynamics, science and religion in fusion[1]

Leonid E. Zakharov

[1] *Princeton Plasma Physics Laboratory, MS-27 P.O. Box 451, Princeton NJ 08543-0451*

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Abstract

Exclusiveness of Spherical tokamaks for developing a magnetic fusion power reactor is explained once again.

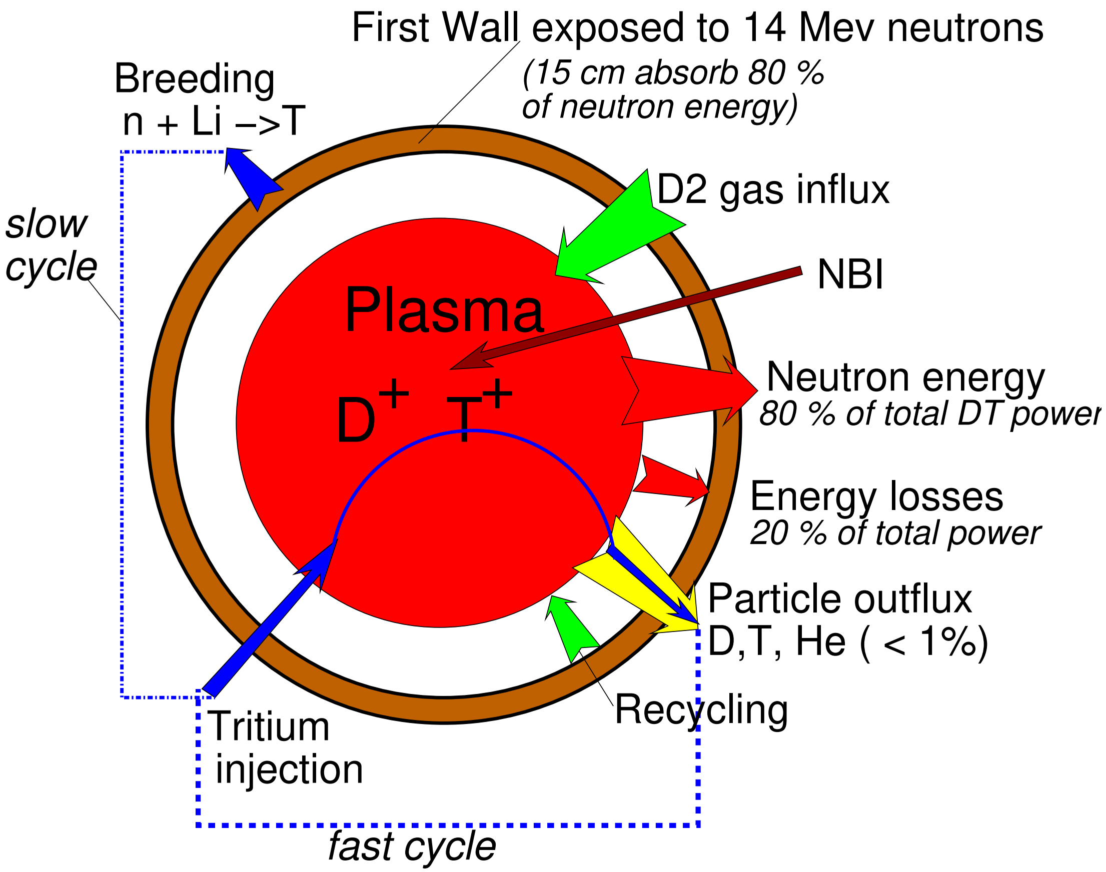
The talk also touches typically avoided, but perfectly relevant to physics in general, topic on why $\simeq$*1.5B spent on fusion during the last 7 years produced no progress toward the reactor (except an outstanding discovery of a stable Quiescent H Mode regime in DIII-D).*

It is noticed that it is a fundamental law of physics that any multi-parameter system (of many particles, of control parameters in complicated numerical codes, or of fusion scientists) with no "long range correlations" unavoidably goes into the "thermal depth" state. Correlations in a complicated programs, like fusion, should be provided by scientific leaders, which were lost in late 80s (when ITER failed in addressing the nuclear aspects of fusion).

As a result, the fusion program is now hopelessly fragmented. It is the same physics law that there is no way back from such a situation. Pouring the government money into such state is the same as boiling water with the green light laser. Much more efficient is to start a new, separate program for reactor development with a self-consistent, based on IST, vision of the goal and with understanding how the second law of thermodynamics works in the scientific society in order to not repeat the mistakes.

Contents

The problems of the First Wall and Tritium Cycle are specific for DT fusion



Two loops of tritium cycle are present. First wall is being damaged by 14 Mev neutrons

Three mutually linked objectives of magnetic fusion are

1. ***Development of the high power density Operational Power Reactor Regime, $\simeq$ 10 MW/m^3 (0.5 MW/m^3 in ITER, 1000 MW/m^3 in a fission sub-critical cell),***
2. ***Development of the "First Wall" (FW), i.e., first 15 cms of the structure faced by 14 MeV neutrons,***
3. ***Tritium Cycle***

It is impossible to separate these 3 objectives

Conventional fusion is trying to substitute them by a "step by step" approach.

The FW is the most challenging part of the fusion reactor

Neutron fluence $\simeq$15-20 MW·year/m^2 in necessary for destruction as well as for designing the First Wall of the reactor

15 MW·year/m^2 corresponds to consumption of 1 kg/m^2 of tritium.

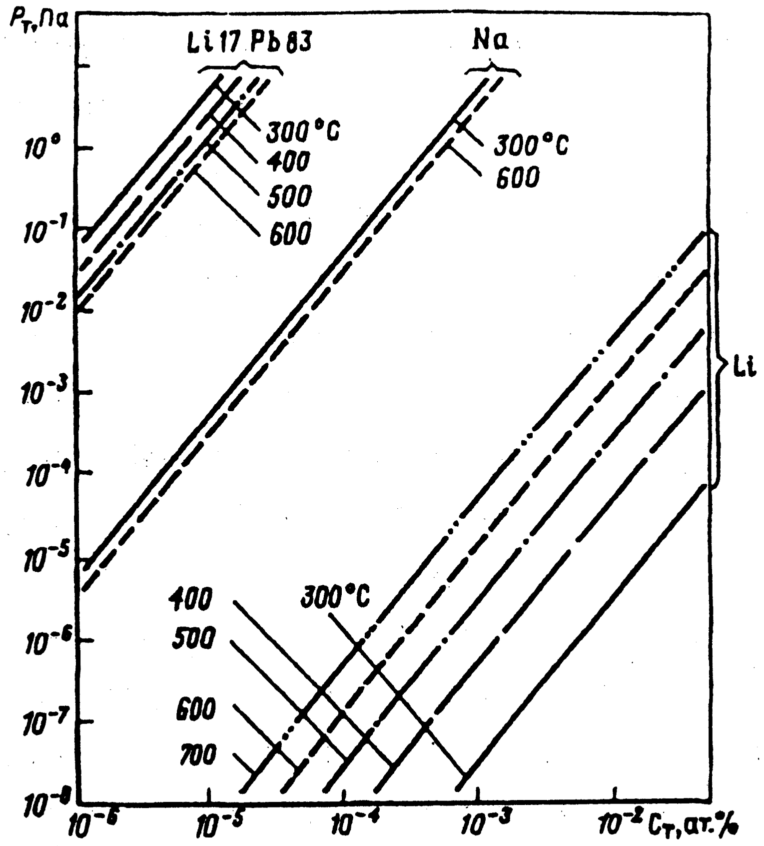
Frequently referred as an "inexhaustible" energy source, in fact,

Fusion has NO tritium fuel even for designing the reactor

E.g., with ITER wall surface $\simeq$ 650 m^2 650 kg of T should be consumed just for designing the First Wall.

The FW cannot be developed based on the present approach to fusion

Tritium Cycle is an untouched challenge



Li-, LiPb-, Na-T vapor pressure [Pa].

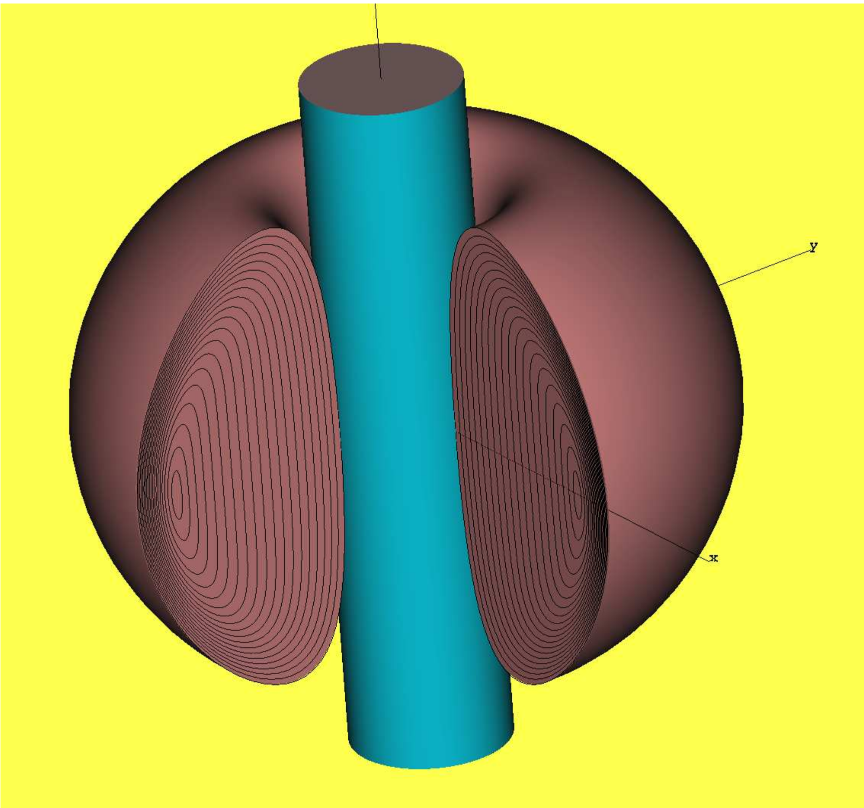
1. ***In the fast loop 97 % left from injected T should be recycled. Lithium based PFC can do the job in the best way. Conventional way is extremely inefficient.***
2. ***In the breeding loop every neutron should be converted into tritium.***

   Then tritium should be extracted from Lithium at concentration of 0.0001 atomic %.

   In the case of Li blanket, tritium cycle needs 480 MW of power for a reactor unit. *"Lithium in thermonuclear and space energetics",B.N.Mikhailov et al, Moscow, Energoizdat, 1999*

Tritium cycle development is out of reach for conventional approach

The simple number 1 kg/m^2 of T, rather than teraflop computers, uniquely specifies the fusion strategy for reactor R&D



ISTs are the only candidate:

1. ***Volume $\simeq$30 m^3.***
2. ***Surface area 50-60 m^2.***
3. ***DT power $\simeq$ 0.5 GW.***
4. ***Neutron coverage fraction of the central pole is only 10 %.***

The possibility to have a bare copper central pole, exposed to neutrons, is a decisive factor in favor of IST as the reactor R&D tool

No one of 3 objectives of magnetic fusion can be addressed by the conventional approach

The question is

Why 7 years were wasted $^{(*)}$ when not only a new concept was formulated but new tokamak regimes (DIII-D) were discovered and demonstrated

(*) "wasted" is not accurate, the time was used rather productively to destroy PLT, PBX, TFTR and get rid from TEXT, thus, eliminating the very possibility of the experimental base for new ideas.

2 How science is converted into a religion

Typical for programming is the problem of matching your understanding of the code with its control parameters

#	Control parameters user has in mind	FORTRAN namelist
0	promotion to AL	`igrid`
1	promotion to group leader	`rleft`
2	major monetary award	`rright`
3	promotion within the rank	`zbotto`
	...	`ifcoil`
	...	`iecoil`
	...	...
	...	`af2`
	...	`fcturn`
95	minor disciplinary actions	`he`
96	suspension for a week	`ecid`
97	layoff	`vsid`
98	torture	`rvs`
99	electric chair	`zvs`

In science we match what was encoded by the nature with our knowledge

The total number N_0 of possible sporadic matches of n items is

$$N_0 = n! \quad (e.g.,\ 100\,!) \tag{2.1}$$

with entropy

$$\boxed{S_0 \equiv \ln N_0 \simeq n(\ln n - 1) + \frac{1}{2}\ln(2\pi n)}$$

Suppose both sides subdivide each set on n/k mutually consistent sections with k elements in each.

$$\begin{aligned}
&\underbrace{\cdots\cdots\cdots\cdots\cdots}_{n\ of\ a\ physics\ program} = \underbrace{\underbrace{\cdots}_{k}\ \underbrace{\cdots}_{k}\ \underbrace{\cdots}_{k}\ \cdots\ \underbrace{\cdots}_{k}}_{n/k}, \qquad e.g.,\ k = 10\\
&\underbrace{\cdots\cdots\cdots\cdots\cdots}_{n\ of\ nature} = \underbrace{\underbrace{\cdots}_{k}\ \underbrace{\cdots}_{k}\ \underbrace{\cdots}_{k}\ \cdots\ \underbrace{\cdots}_{k}}_{n/k}
\end{aligned} \tag{2.2}$$

$\boxed{\textit{The job is reduced to matching } k \textit{ parameters inside each group.}}$

Organizing the job can be made in two ways, corresponding to logical '|' ('or') and '&' ('and') relations

Uncorrelated permutations ('|' choice) inside each section is the easiest way. The total number of actions N_1 in this case

$$
\begin{aligned}
N_1 &= \underbrace{k!\ k!\ k!\ \ldots\ k!}_{n/k\ times} = (k!)^{\frac{n}{k}}, \\
S_1 &= \ln N_1 \simeq \frac{n}{k}(k\ln k - k) = n(\ln k - 1) \quad \simeq \quad n(\ln n - 1)
\end{aligned}
\tag{2.3}
$$

Simple grouping of physicists (with no management control of the job) has a little effect on entropy of the system,

while being deceptively "efficient" for small n, k

As a rule, k and n rise in time (with n/k fixed) and initial "effect" disappears

$$
S_1 = n\left(\ln n - \ln\frac{n}{k} - 1\right) \quad \rightarrow \quad n(\ln n - 1) \tag{2.4}
$$

"Organizing" job as uncorrelated "parallel" processes is a typical mistake in management

Imposing strong correlations ('&' type) is crucial for reducing entropy

Matching sections in sequence reduces the number N_2 to

$$\begin{aligned} N_2 &= \underbrace{k! + k! \ldots + k!}_{n/k \text{ times}} = (k!)\frac{n}{k}, \\ S_2 &= \ln N_2 \simeq (k-1)\ln(k-1) + \ln n \quad \ll \quad n(\ln n - 1) \end{aligned} \tag{2.5}$$

Any coherency in action results in dramatic reduction in entropy for any n.

```
{ Step0;
  { Step1;
    { Step10;
    }
    { Step11;
    }
  }
  { Step2;
  }
}
```

Coherency requires a rigorous control. Mistake at the top may cost a lot.

The types '&' and '|' of job organization have different properties

The type '|' ('or')

1. Is inefficient
2. Is stable
3. Results in further fragmentation of the job, rather than solving the problems
4. Has tendency to go out of control into "activity trap"

The type '&' ('and')

1. Efficient in reaching the goal.
2. Is metastable. Stability is provided by the competence and creativity of leaders.
3. Is prone to self-destruction as soon as unresolvable problem is faced.
4. Requires external control (inclusion into another type '&' structure).

An optimal mixture of a hierarchical structure with parallel groups can provide both stability and efficiency

"Two" legs structural principle may serve as an example

```
Box0;
  Box0a; /*necessary*/                                   |  Box0b; /*possible*/
    Box0aa; /*necessary*/  |  Box0ab; /*possible*/
    ...                       ...
```

Here, every level contains two parallel categories of jobs: necessary and possible.

The "strategically necessary" vertical line provides coherence. High priority

The "what is possible" line provides stability

Management structure can be mapped to a C-code structure like

```
Box0{
  BIGLEADER b0,b1,b2,b3; /* list of control parameters*/
  JobBox0();
   Box1{
    MIDDLELEADER a0,a1,a2;
    JobBox1();
    ------------------------------------------------------------
     Lab0[                 |     Lab1[                 |     Lab2[
      LEADER h0,h1,h2;|     LEADER h0,h1,h2; |     LEADER h0,h1,h2;
      JobLab0();           |     JobLab1();            |     JobLab2();
    ]                      |   ]                       |   ]
   -------------------------------------------------------------
    Box2{
      .......
    }
  }
}
```

The entire structure and its functionality should be transparent

Functional position of control parameters (or leaders) inside the structure is crucial

The typical structural a single element can be shown as

$$\begin{array}{l} \{ \\ \quad \mathtt{LEADER}\ \ \mathtt{L0,L2,L3;}\quad \text{/* providing correlations across the parallel sections */} \\ \quad [\,\mathtt{CX}_0\,]\ |\ [\,\mathtt{CX}_1\,]\ |\ [\,\mathtt{CX}_2\,]\ |\ [\,\mathtt{CX}_3\,]\ |\ [\,\mathtt{CX}_4\,]\ |\ [\,\mathtt{CX}_5\,] \\ \quad \mathtt{MONITOR}\ \ \mathtt{M0,M2,M3;}\quad \text{/* monitoring and selling the output */} \\ \} \end{array} \qquad (2.6)$$

It includes both “leaders” and “monitoring” control parameters.

In management “leaders” are the meta-stable “inverse” population.

Their conversion into a very “stable” population of monitors is a natural tendency.

After loss of leaders the structural element falls into “activity trap”

Thermodynamically, the activity trap is similar to a thermostat in physics

The thermostat is characterized by:

1. ***Large amount of total thermal energy with no "free" energy.***
2. ***Equipartition distribution.***
3. ***Destruction of any non-thermal fluctuation.***
4. ***Ability to dissolve to non-existence any externally injected negative entropy (information) or attempts to generate a coherence.***
5. ***Extreme stability: cannot be shaken, destroyed, can be only gradually deflated.***

Accordingly, in a thermostatic scientific community (no leaders left)

1. ***Equipartition distribution, rather than progress, is the goal.***
2. ***Only external achievements are recognized (e.g., spherical tokamaks, quasi-symmetry in 3-D), while internal ones are suppressed.***

The thermostat is incapable to generate anything coherent

Fusion program has lost its leaders approximately at the end of 80s

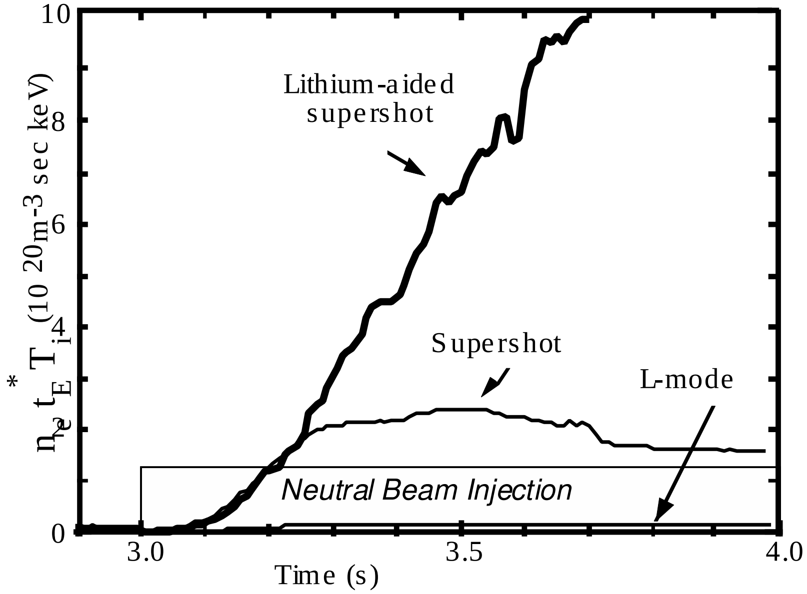
The milestone of redirecting fusion into activity trap was the failure of ITER project to address the nuclear aspects of the reactor.

After this, the real problems of fusion was put under the rug, and the scientific mentality were gradually converted into a sort of "religion".

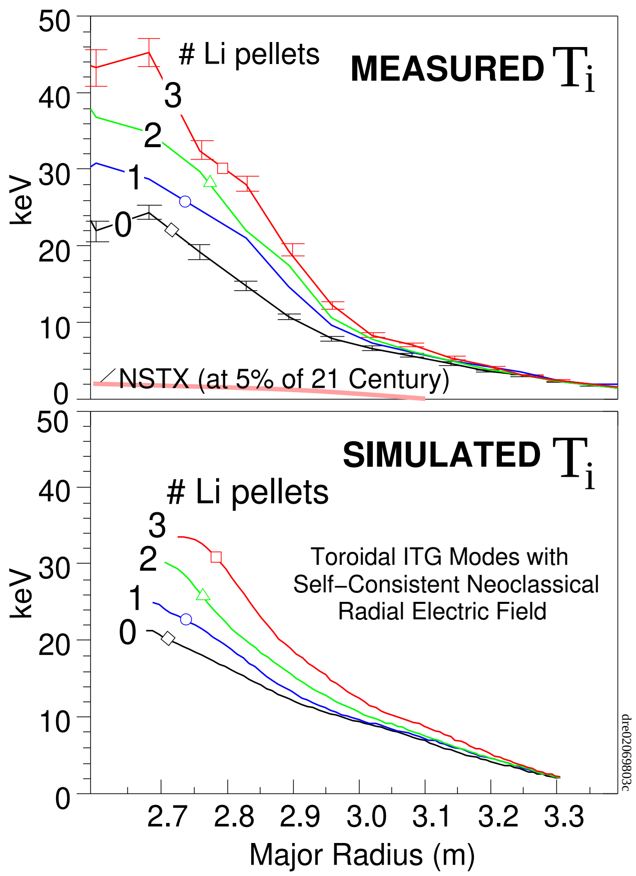
In the present fusion community:

1. ***Everybody is happy inside his own cell and avoids embracing the global picture.***
2. ***Everybody believes in contributing to a fusion power reactor.***
3. ***Illusion is created that "long range correlations" are provided by some "super-natural" force at the top of the program.***
4. ***"Inquisition" is in place for monitoring "rules of religious behavior" (preserving thermostatic happiness) and for protecting the layer of "middle men" who filled the gap between the "super-natural" force and the community.***
5. ***Scientific means of measuring progress are substituted by counting paper production (to match the only ability of monitors).***

Scientifically the "progress" of the last 7 years is rather obvious



(TFTR # 83546 D.Mansfield, C.Skinner)



Most of machines capable for new research were destroyed

In two approaches to fusion one is scientific and another is religious

Objectives	Religion	Science
Strategy	Old and neo- teachings "DEMO", "VNS", "CTF"	3 objectives of reactor R&D
τ_E	Believes in miracles in turbulence, bigger and bigger JET, donations from 6(+2) governments	New regimes, suppression of turbulence
β	Total mess with stability of sawteeth, ELMs, reliance on mysterious "profile control" at $\beta = 2.5$ %	Wall stabilization, stable separatrix limited plasma with high edge temperature at 10-40 % β
Power extraction	Localized of power deposition, mysterious conversion of particle energy to radiation	Distributed power deposition and extraction
Fueling, Helium ash	Mysterious replacement of He in the core by DT fuel from the edge.	Compact machines with core DT fueling

There is almost nothing in common between two approaches

Religion and science serve different purposes

Clerics and committees of the religion approach are incapable to organize the progress. They are only making impression of "long range correlations" in the program under their rule.

The goal of religion is to provide a broad happiness in the absence of the progress. Religion favors multiplication of problems.

The goal of science is to make progress and resolve the problems. This requires scientific leaders (not monitors) for providing coherence in research.

Science itself, being broad, is not yet the progress.

Scientific leaders, not the scientists, are who make the progress happen

Euphoria or amatorial enthusiasm about Li never existed

The conditions when Li can work were understood in the first month of LiWall concept.

The crucial plasma physics condition, which leads to flatten temperature inside the plasma, remains the same

$$\Gamma^{micro}_{edge\rightarrow wall} \simeq \Gamma^{convective} \tag{3.1}$$

The LiWall is not the same as low recycling regime. For two fluxes

$$\Gamma^{micro}_{edge\rightarrow wall} = \Gamma^{micro}_{ion} + \Gamma^{micro}_{electron} \tag{3.2}$$

two relations are required

$$\begin{aligned} &\Gamma^{micro}_{ion} \simeq \Gamma^{convective}_{ion} \quad (\equiv low\ recycling), \\ &\Gamma^{micro}_{electron} \simeq \Gamma^{convective}_{electron} \end{aligned} \tag{3.3}$$

Electron behavior is unpredictable (Harold Furth). Although much more should be understood

Quiescent H-Mode discovered on DIII-D gives a basis for optimism

Because of a sober approach to all Li issues the progress with LiWall concept was possible

On this way many problems (possibility of elimination of turbulence, robust stability of fixed- and free-boundary plasma, distributed power extraction from the plasma, helium and tritium control, self-sufficiency of bootstrap current, liquid lithium MHD in tokamaks, etc), have been conceptually resolved in a manner consistent with the power reactor development.

New divertor solutions, consistent with the ITER design baseline, were proposed.

The science based fusion strategy was formulated within LiWall concept

In conventional fusion (38 years old) conceptual integrity never existed.

There are all indications that the current fusion is in irrevesible situation.

It is a sober conclusion that reactor R&D needs a separate, science based program