Burning Plasma Physics and the U. S. Strategic Plan for Magnetic Fusion Energy

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Burning Plasma Science should be defined in the context of the charge to the committee – namely "economical fusion energy within the next several decades is a U.S. strategic interest." Therefore, the scope for burning plasma science is defined by the needs for "economical fusion energy."

The long term vision for the U. S. magnetic fusion program has traditionally been commercially attractive fusion power plants (1985 Plan, ERAB-1986, FPAC (1990), EPRI (1994). The U. S. systems studies such as ARIES (1990 -2005) have concluded that high-Gain ($Q \approx 30$-45) steady-state fusion plasmas are a requirement for an economical magnetic fusion power plant. The recent 2015 ARIES-ACT study showed that large (9.75 m major radius) tokamak with a gain of 25 is likely not an attractive power plant in the U. S.

Burning Plasma Technical Issues for Economical Magnetic Fusion Energy

Burning Plasma issues have been described in a number of reports: MFAC XIV(1986), ERAB (1987), TPA(1987), NAS 1999, Snowmass 1999 & 2002, NAS 2004, etc. A summary of the burning plasma issues and the fusion gain requirements to address these issues is shown in Figure 1. The issues can be separated into three categories:

1. Weakly Burning Plasmas addressable at $Q \sim 1$: TFTR (1993-1997) and JET (1997)
2. Moderately Burning Plasmas addressable at $Q \sim 10$: FIRE 2005, ITER 2017
3. Strongly Burning Plasmas at $Q >\sim 30$: attractive MFE power plant DEMO

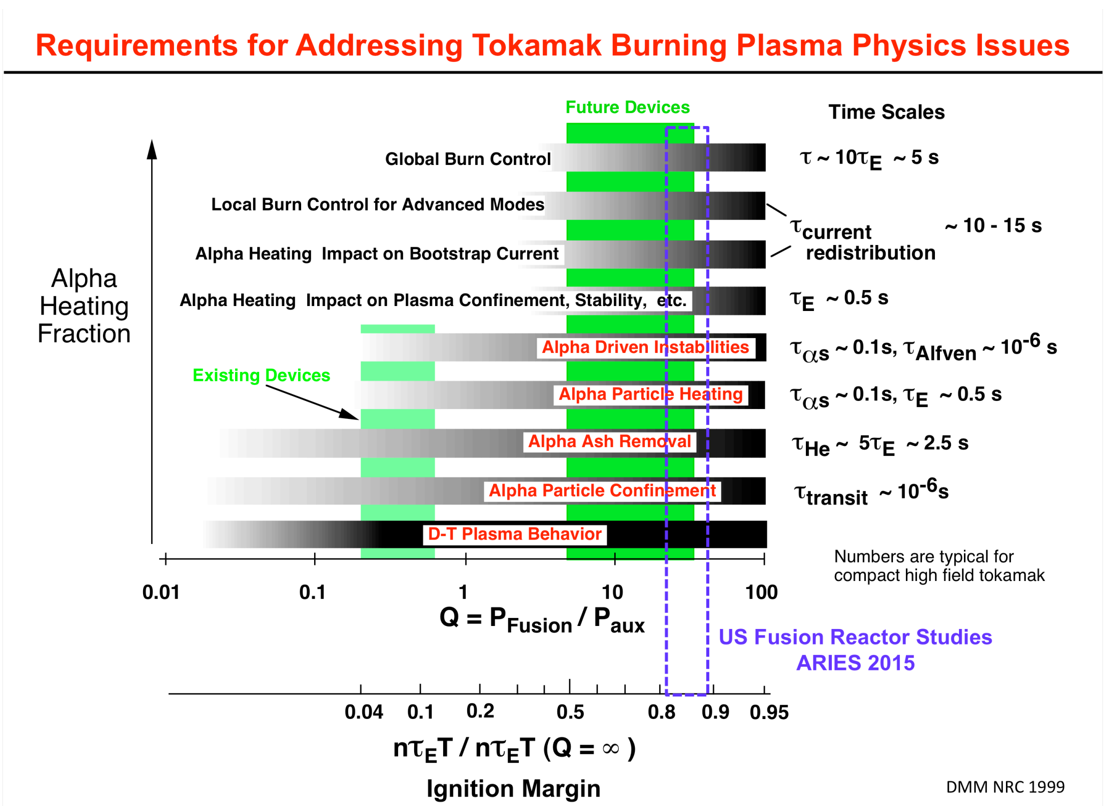

Figure 1. Burning Plasma Physics, D. Meade , Nat'l Academy Panel Input May 1999

TFTR and JET, with weakly burning Q~ 1 plasmas, explored aspects of the first five issues in Figure 1: DT plasma confinement (isotope effect), alpha confinement, alpha ash removal and indications of alpha heating and alpha driven instabilities. (last reference, p.3)

A strongly burning plasma in a tokamak is a very unique highly self-organized system where the self-heating and local transport properties determine the pressure profile which in turn produces a large self-driven bootstrap current to confine the plasma. All this must be done with minimal external heating or current drive in order to produce a high gain.

Table 1. The control of a tokamak burning plasma becomes increasingly more difficult as Q increases.

Q Gain	Alpha heating Power %	Control Power %
10	67	33
20	80	20
30	86	14

Can such a highly organized burning plasma state exist in a tokamak, or any other magnetic configuration? Such highly organized burning plasma states do exist in nature. Consider the sun, the delicate balance of a self-heated burning plasma core that produces outward radiation pressure at the radiation zone that balances the inward gravitation pressure. Amazingly, this complex highly self-organized equilibrium is globally stable and there are billions of examples of this state in the universe. This should give some hope that such a state could exist in the laboratory. This is the crucial question and the highest priority should be given to determining the conditions required to do this in magnetic fusion energy.

Burning Plasma Implications for Magnetic Fusion Energy Strategic Plan

During the 1980s and early 1990s, U. S. fusion program discussions focused on the burning plasma issues for a fusion power plant, while the more recent discussions have focused almost exclusively on burning plasma issues expected to be problematic for ITER.

Even if all goes as planned, successful completion of the >$50B ITER program will not provide all the burning plasma physics information needed to build the DEMO for an attractive magnetic fusion power plant. It is missing the crucial information on attaining and controlling a Q ≥30 burning plasma! This crucial physics step will have to be done on the DEMO!

The present strategy is backwards, and leads to a very risky and expensive development path. The crucial burning plasma physics experiments should be done before a DEMO is constructed. This is another example of the trend in the U. S. fusion program to "Make ITER Work" instead of to "Make Magnetic Fusion Energy Work." The U. S. should be following the U. S. MFE strategies of the 1980s (ERAB 1987) and that recommended by the 2012 NAS Committee on the potential of IFE that found: “The appropriate time for the establishment of a national, coordinated, broad-based inertial fusion energy program within DOE would be when ignition is achieved. (Conclusion 4-13)”

Recommendation: the goal of the burning plasma science program for U. S. magnetic fusion energy should be to attain, understand and control high-gain steady-state fusion plasmas required for economical fusion energy.

References:

US MFE Plan 1985 (http://fire.pppl.gov/us_mfe_plan1985.pdf)

MFAC Panel XIV Report 1986 (http://fire.pppl.gov/MFAC14_Burn_Plasma.pdf)

MFE ERAB 1986 (http://fire.pppl.gov/mfe_erab_1986.pdf)

FPAC 1990 (http://fire.pppl.gov/fpac_1990.pdf)

EPRI Criteria for Fusion 1994 (http://fire.pppl.gov/EPRI_Fusion_Criteria_1994.pdf)

ARIES Documents – Bibliography (1988-2012)
(http://aries.ucsd.edu/ARIES/DOCS/bib.shtml)

Fusion Energy Studies at Snowmass 1999 and 2002
(http://fire.pppl.gov/snowmass02.html)

Burning Plasma Physics, D. Meade Input at National Academy Fusion Panel Meeting –May 1999 (http://fire.pppl.gov/NRC_BP-Physics_May1999.pdf)

September 13, 2017
March 1, 2018 Table 1. revised