

Development-Path Issues and Options for the Reversed-Field Pinch (RFP)

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New FESAC Charge(s)

- DOE Under Secretary for Science, Ray Orbach, has issued [a new Charge asking FESAC](#) to 1) identify and prioritize the broad scientific and technical questions to be answered prior to a DEMO; 2) assess available means (inventory), including all existing and planned facilities around the world, as well as theory and modeling, to address these questions and 3) identify research gaps and how they may be addressed through new facility concepts, theory and modeling. A second charge will be issued asking FESAC to develop a long-term strategic plan including a specific pathway to DEMO as well as other program elements needed in a comprehensive strategic plan for fusion research. The new charge will be discussed at the [next FESAC meeting March 1-2](#) in Gaithersberg **[sic]**, MD.
[Source: fire.pppl.gov 2/8/2007](#)

Sidebar

- “The tokamak is not the only way to confine a plasma. Physicists are actively pursuing other schemes, such as stellarators and reverse-field pinch machines. But the tokamak is the most successful design so far and forms the basis of ITER and, most likely, the commercial power reactors that will come after it.” -Daniel Clery, “ITER’s \$12 Billion Gamble,” *Science*, Vol. 314, (13 Oct. 2006) 238-242.

FESAC *Status Quo**

- Does the present state of RFP research** justify it's promotion along the PoP– PE rungs of the ICC ladder on a timely basis?
- Does the Snowmass Development-Path consensus*** preclude any ICC as a VNS/CTF candidate?
- What does it take to make the cut as a viable DEMO candidate when the time comes?

*(March 2003).

**e.g., S. Prager, FPA Annual Meeting (Sep. 2006).

***F. Najmabadi, Snowmass Summer Study (July 2002).

What is a DEMO?

- ‘Same’ physics and technology as first commercial power plant to avoid surprise.
- Close in scale [$>75\%$ per ARIES Team Utility Advisory Committee (UAC) advice (mid 1990s)].
 - perhaps same with more design margin
 - inhibition to large plant size & output to limit DEMO risk
- Lower availability, longer construction lead time, first of a kind (FOAK) contingency, absence of learning-curve credits, *etc.* leads to higher projected COE.
- Shared public/private financial arrangements.

Portfolio Considerations

- A robust portfolio contains options with differing characteristics as a strategy for risk mitigation.
- Justification for continuation of options will receive intense scrutiny in times of tight budgets.
- An agile approach should do well.

RFP Power-Plant Options

- High plasma density and modest energy confinement time of the TITAN* conceptual designs (c1990) lead to a high-power-density, high first-wall 14-MeV-neutron wall load (10-18 MW/m²), compact system.
- Improved energy confinement times recently seen in the MST experiment probably extrapolate to a more modest neutron wall load (4-5 MW/m²) and a fusion power core size similar to that of an advanced tokamak design (e.g., ARIES-RS) or compact stellarator (e.g., ARIES-CS), recalling early RFP pulsed configurations (c1980).

*F. Najmabadi, *et al.*, “The TITAN Reversed-Field-Pinch Fusion Reactor Study—Final Report,” UCLA-PPG-1200 (1990).

High Neutron Wall Load Option

- Requires active emergency cooling of afterheat (LSA = 4)* and long neutron fluence lifetimes ($\sim 20 \text{ MW a/m}^2$)
- Is consistent with compact, high-power-density operation and 'single-piece maintenance'.

**cf.* ESECOM (1989).

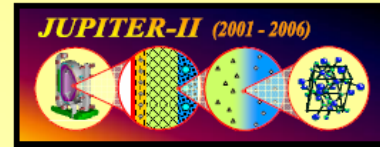
Modest Neutron Wall Load Option

- ESECOM* suggested incentives for low-activation materials choices and passive-safety cost credits as manifested in later ARIES Studies.
- Is consistent with modern blanket R&D.

*J. P. Holdren, *et al.*, “Report of the Senior Committee on Environment, Safety, and Economic Aspects of Magnetic Fusion Energy,” Lawrence Livermore National Laboratory report UCRL-53766 (Sep. 1989).

Blanket R&D Supports Modest Neutron Wall Loads

Advanced Blanket Systems and Integration Issues



System	Vanadium Alloys/Li	SiC/SiC Composite/He	Ferritic Steel etc / FLiBe
Candidate Structural Material	V-4Cr-4Ti V-4Cr-4Ti-Si, Al, Y	SiCf/SiC	JLF-1, ODS Vanadium Alloy
Coolant	Liquid Li	He	FLiBe (He)
Breeding Materials	Li	Li ₂ O etc	FLiBe
Typical Blanket Design	ARIES-RS Liquid Blanket	DREAM Gas Cooled Blanket	FFHR Liquid Blanket
Activation	Low	Very Low	Medium Low
Inlet / Outlet Temperature & Heat Flux	330-610°C High	500-800°C Medium	450-550(700)°C Medium
Thermal Efficiency	45%	50%	37%
Issues for Power Reactor	Li Technology MHD Drop	H, He Production Thermal Conductivity	FLiBe Technology
Materials System Issues	Ceramic Coating	Hermeticity	Corrosion Coating

Steady-State Operation

- RFP Studies invoked Oscillating Field Current Drive (OFCD).
- If OFCD compromises energy confinement, as has been suggested*, it may have to be dropped or modified.
- OFCD may play a part in hybrid operational modes (OFCD ramp-up sequenced with PPCD ramp-down).
- RFCD or NBCD may be applicable; depending on consequences for performance, penetrations, and recirculating power.

*R. W. Moses, R. A. Gerwin, and K. F. Schoenberg, "Transport Implications of Current Drive by Magnetic Helicity Injection," *Physics of Plasmas*, 8, 11 (Nov. 2001) 4839.

Thick-Liquid-Wall Option*

- May rescue the compact, high power density option with additional savings in the component replacement cost.
 - no neutron fluence limit on protected structures.
 - higher availability
- Supports pulsed operation independent of high-power-density option.
- May substitute for divertor or have other implications for plasma boundary layer.

*R. W. Moir, R. H. Bulmer, K. Gulec, P. Fogarty, B. Nelson, M. Ohnishi, M. Resnick, T. D. Rognlien, J. F. Santarius, and D. K. Sze, "Thick Liquid-Walled, Field-Reversed Configuration Magnetic Fusion Power Plant," *Fusion Technology*, 2, 2, Part 2 (March 2001) 758.

Burning-Plasma RFP

- Conceptual design* would have to be revisited and updated.
- May require PoP/PE precursor.
- Can it compete with ST-based NHTX?
- Might be first phase of later VNS/CTF device.

*C. G. Bathke, R. A. Krakowski, R. L. Miller and K. A. Werley, "ZTI: An Ignition Class Reversed-Field Pinch," *Fusion Technology 1990*, [In Proceedings of the 16th Symposium on Fusion Technology (SOFT), London, UK, Sept. 1990], **2**, 1297.

VNS/CTF RFP

- Conceptual design* would have to be revisited and updated.
- Can such a machine generate results for conventional FW/blanket options and still serve as a step toward a RFP DEMO with thick liquid walls?

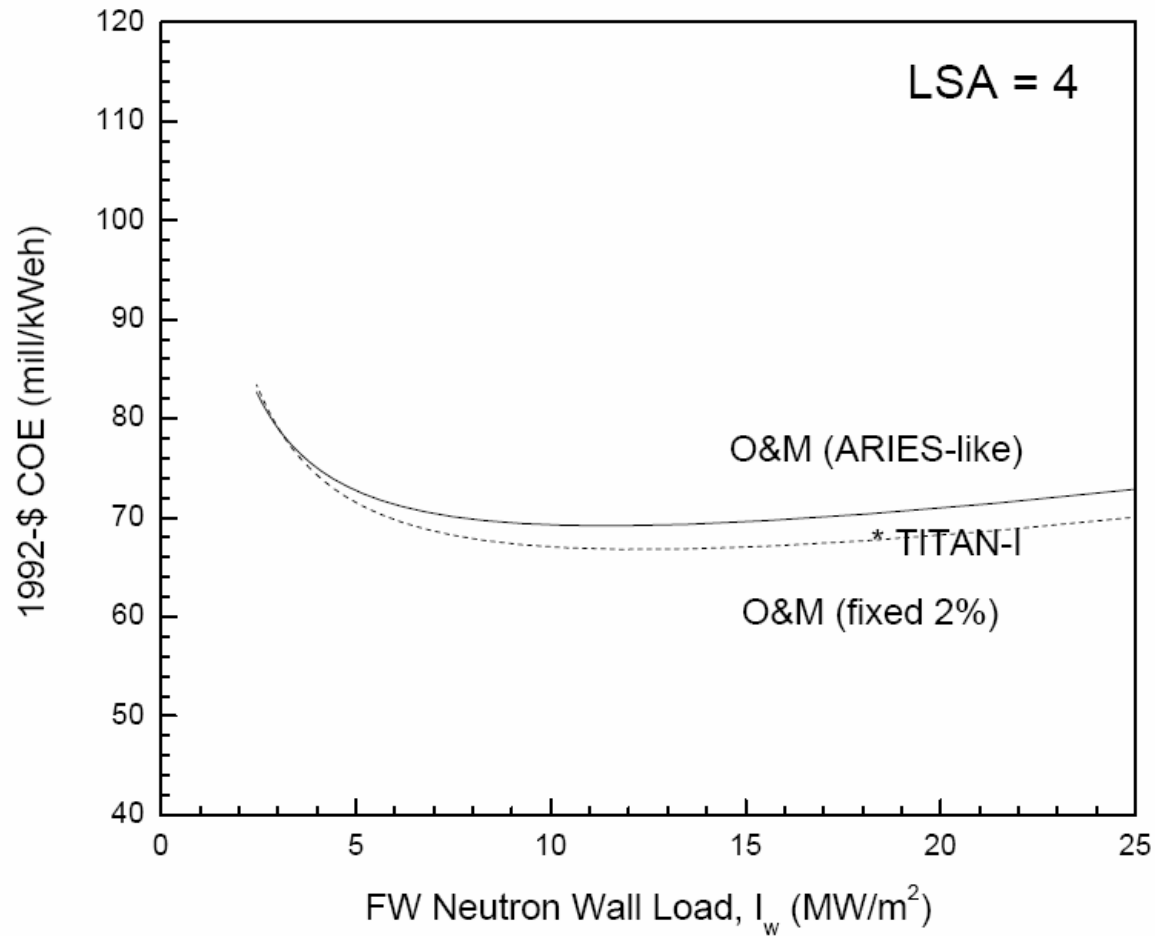
*C. G. Bathke, R. A. Krakowski, R. G. Manzanares, R. L. Miller, and K. A. Werley, "Conceptual Design of a Reversed-Field Pinch Fusion Neutron Source," *Fusion Engineering and Design*, 10 (1989) 39-45.

*C. G. Bathke, R. A. Krakowski, R. L. Miller, and K. A. Werley, "The Reversed-Field-Pinch (RFP) Fusion Neutron Source: A Conceptual Design," *Journal of Fusion Energy*, 8, 3/4 (1989) 249-268.

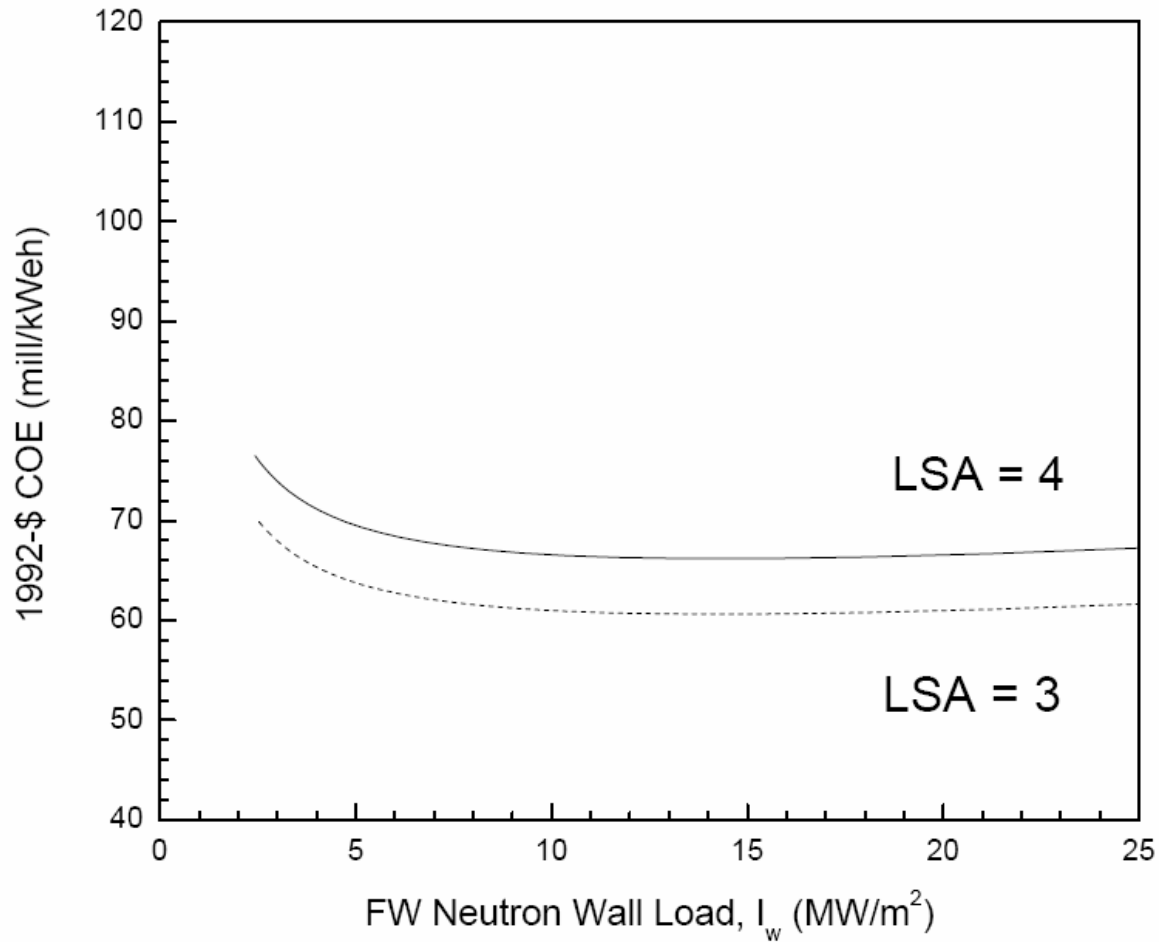
DEMO/Power-Plant Design

- If these embodiments are in fact to be the same machine, this consideration should be explicit.
- Multi-mode optimizations can be performed.
- Performance differences can be accounted for.
- For the RFP, the TITAN systems code has been reactivated and 'validated'.

TITAN-I Revisited



TITAN-II Revisited



Summary

- The stage is set for a reconsideration of fusion strategic plans in general and ‘specific pathways to DEMO’.
- New information from generic and RFP-specific R&D must be considered in updating the rationale for new RFP devices along this pathway.