

# The path to NHTX and CTF



*Charles Skinner, PPPL*

## Where are we heading ?

1. NHTX & CTF heat loads.
2. ITER situation.
3. FDF Proposal.
4. DIII-D December 06 workshop.
5. PFC material choices.

## How do we get there ?

- Divertor Diagnostic upgrades.
- Test technologies to spread heat load.
- Advanced material studies.
  - Divertor material transporter system

# Goldston PPPLAC Presentation

22 June 2006

National High-power advanced Torus eXperiment  
would Provide Unique and Critical Data

Device	R (m)	a (m)	R/a	P (MW)	P/R (MW/m)	Pulse (sec)	Ip (MA)	Species	Comments
<b>Planned Long-Pulse Experiments</b>									
EAST	1.70	0.40	4.25	7	4	1000	1.0	H	Initial heating
JT-60SA	3.01	1.14	2.64	41	14	100	3.0	D	JA-EU Collaboration
KSTAR	1.80	0.50	3.60	28	15	300	2.0	H	Maximum heating
LHD	3.90	0.60	6.50	10	3	10,000	-	H	With upgrades
SST-1	1.10	0.20	5.50	3	3	1000	0.2	H	Initial heating
W7-X	5.50	0.53	10.38	10	2	1800	-	D	30MW for 10sec
<b>NHTX</b>	<b>0.95</b>	<b>0.53</b>	<b>1.80</b>	<b>38</b>	<b>40</b>	<b>60</b>	<b>4.2</b>	<b>D</b>	<b>Vary concentration, Rdiv</b>
ITER	6.20	2.00	3.10	150	24	400-3000	15.0	DT	Not for divertor testing
<b>Component Test Facility</b>									
<b>CTF (Low A)</b>	<b>1.20</b>	<b>0.80</b>	<b>1.50</b>	<b>58</b>	<b>48</b>	<b>Steady</b>	<b>12.3</b>	<b>DT</b>	<b>2 MW/m<sup>2</sup> neutron flux</b>
<b>Demonstration Power Plant Designs</b>									
ARIES-RS	5.52	1.38	4.00	514	93	Steady	11.3	DT	US Advanced Tokamak
ARIES-AT	5.20	1.30	4.00	387	74	Steady	12.8	DT	US Advanced Technology
ARIES-ST	3.20	2.00	1.60	624	195	Steady	29.0	DT	US Spherical Torus
ARIES-CS	7.75	1.70	4.56	471	61	Steady	3.2	DT	US Compact Stellarator
ITER-like	6.20	2.00	3.10	600	97	Steady	15.0	DT	ITER @ higher power
EU A	9.55	3.18	3.00	1246	130	Steady	30.0	DT	EU "modest extrapolation"
EU B	8.60	2.87	3.00	990	115	Steady	28.0	DT	EU
EU C	7.50	2.50	3.00	794	106	Steady	20.1	DT	EU
EU D	6.10	2.03	3.00	577	95	Steady	14.1	DT	EU Advanced
SlimCS	5.50	2.12	2.60	650	118	Steady	16.7	DT	JA
CREST	7.30	2.15	3.40	692	95	Steady	12.0	DT	JA

**Mastery of plasma-boundary interface science would give the U.S. leadership in an area where experience is critical.**

# ITER situation:

*Cambell's talk at DIII-D PAC 29 Jan 2007*

## “Urgent R&D Needs

- **Several issues stand out as requiring particular emphasis in the partners' R&D programmes**
  - These impact on ITER's operational reliability
  - They require near-term system design specification
- **Principal R&D issues are:**
  - Disruption avoidance and mitigation
  - Tritium retention and removal, and dust characterization and diagnosis
  - ELM control
  - RWM control
- **We would like to see these issues emphasized in partners' research programmes in near to medium term”**

*Top level recognition that highest R&D priorities involve PSI area*

# Fusion Development Facility.....

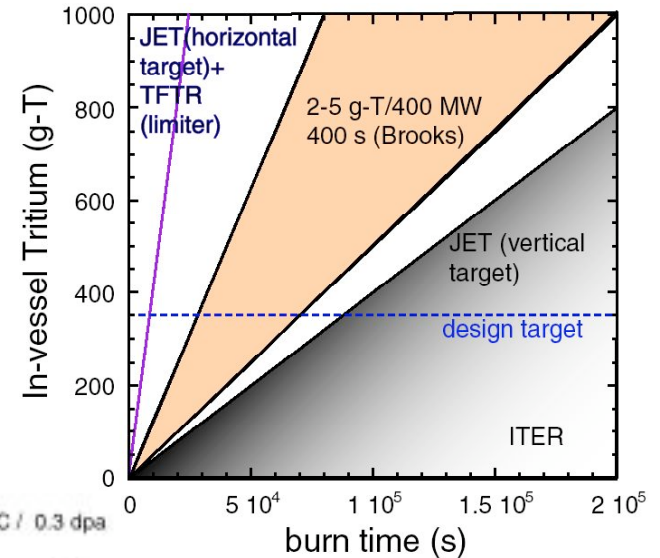
- *Stambaugh's FTF talk Jan 11th, 2007:*  
Striking contrast between the detailed predictions of the AT physics in FDF (H-ITER98Y2 of 1.59 (2nd decimal place) and lack of knowledge on T retention, erosion, - choices and associated compromises for plasma facing materials.
- *JET:* The EU has already recognized this with the ITER-like wall project on JET (60 million EU), 100% W on Asdex and edge ergodization on TEXTOR.
- *DIII-D* Dec 12th 2006 boundary workshop emphasized heat flux issues:
  - Petri: Heat Flux Reduction in High Performance Scenarios:Overview
  - Schaeffer: AC Excitation of I- and C-coils for Divertor Heat Flux Reduction
  - Schaeffer: Test Under-Floor Axisymmetric Kotschenreuther Divertor Coil in DIII-D
  - Tanabe: Tritium retention in plasma facing wall tiles, tile gaps and dusts in DIII-D
  - Whyte: Heat flux control & scaling: Is P/R correct? Or  $q_{||}/B$ ? Or?
  - Whyte: ELM mitigation: The PFC point-of-view

# PFCs for burning plasmas

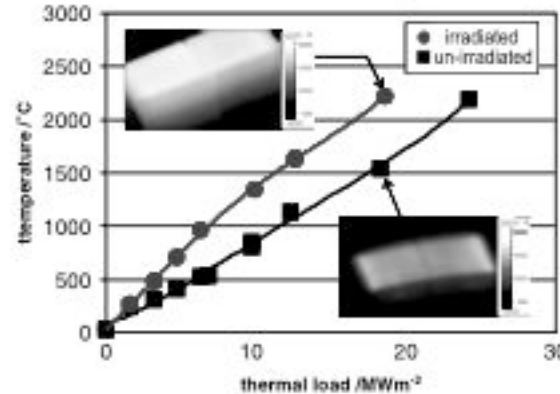
## - no proven solutions

- Carbon ? but
  - T retention (< 0.1% retention needed for CTF).
  - 2 cm erosion in 2-week burn
  - Neutron damage - loss of thermal conductivity
- Tungsten ? but D diffusion into Mo at C-mod (could be worse with neutron damage).
- Tungsten melt layer motion ?
- Be ? too much erosion - poor heat handling, mixed materials effects uncertain.
- Li ? but MHD effects uncertain.

Cambell DIII-D  
PAC presentation  
29 Jan 2007



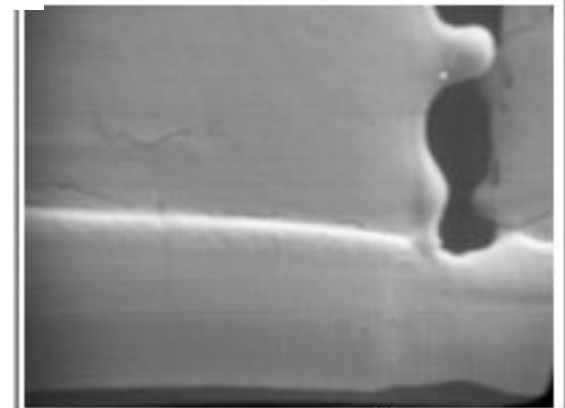
Dunlop Concept 1 (12 mm) / CuCrZr  $T_p = 350^\circ\text{C}$  / 0.3 dpa



Linke  
Phys. Scr. **T123** (2006) 45:53

1 MJ/m<sup>2</sup> 0.5 ms

W3,R3, 100 exposures



Zhitlukhin et al.,  
PSI-17

## NHTX mission correctly identifies most critical area for magnetic fusion

NSTX 5 year plan boundary physics meeting Monday, Feb. 12 2007

# How do we get there ?

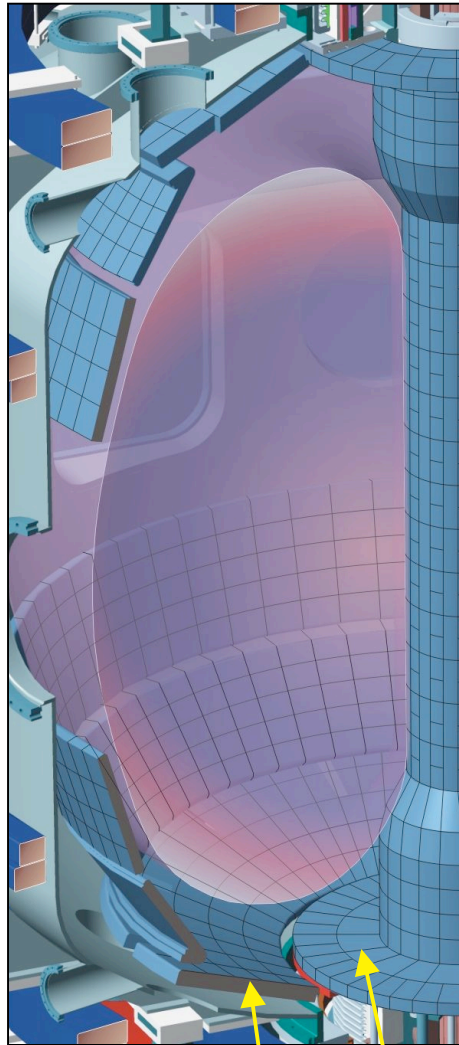
- How can NSTX lay foundation for NHTX and show leadership ?
- NSTX already stressed with 'mission creep':
  - Fusion science + ITER, and insufficient run time.

Build on strong credits in both ST and Li experience.

Three elements:

1. Divertor diagnostic upgrades - essential to understand divertor physics (separate workshop).
  - Divertor MPTS
  - Divertor bolometry (Paul...)
  - Divertor fast IR thermography (Maingi...)
  - Dust and deposition studies on-going (Skinner, Roquemore, Pigarov).
2. Test technologies to spread heat load (Evans, Cohen, Menard et al...)
3. Test advanced materials e.g. Liquid Lithium Divertor (Kugel...)

# Future Plans



OUTER DIVERTOR INNER DIVERTOR

- The 3 Phase NSTX 5-Year Lithium Plan for Particle Control and Power Handling is moving aggressively toward the 3rd Phase:

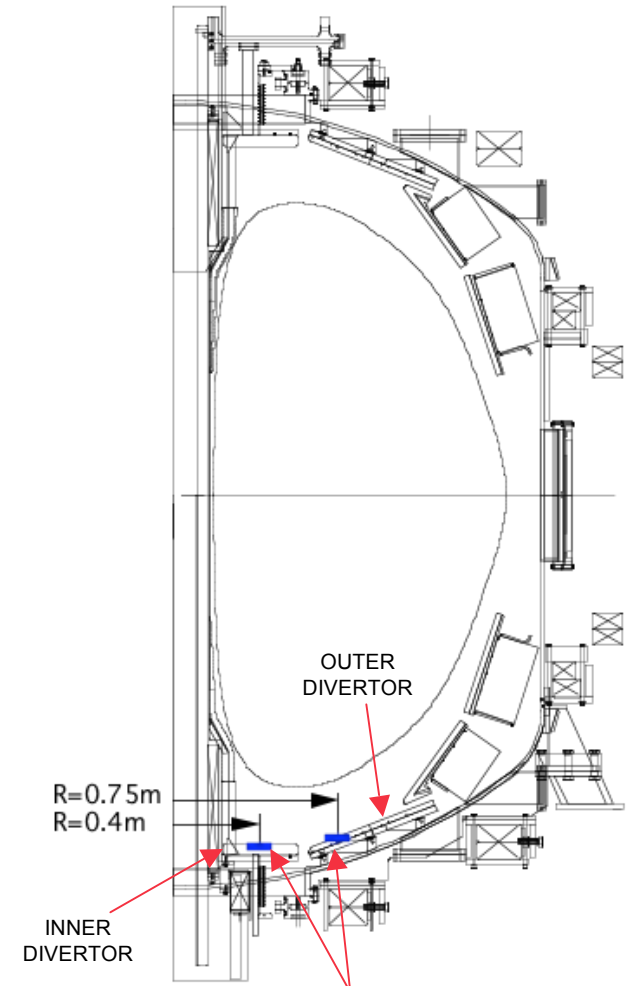
- I. Lithium Pellet Injector (2005)

- II. Lithium Evaporator (2006)

- III. Liquid Lithium Divertor (2008)*

- Phase III will benefit from much previous international lithium work.

- 2007 Experimental Proposals will investigate open questions using Li Pellet Injector and Li Evaporator.



- Two candidate locations for a toroidal, Liquid Lithium Divertor at lower outer strike-point

# Proposal for Divertor Transport System (DTS)

Retractable materials probe exist in:

- DIII-D -DiMES (already contributed to Li studies)
- TEXTOR - materials probe
- Asdex-U - midplane manipulator
- Asdex-U - divertor manipulator (recent ITER relevant results on deposition in tile gaps and first mirrors.)

NSTX probe proposed in 2002 by Clement Wong (but not funded).

Could speed liquid lithium divertor development by factor of year/week at lower risk.

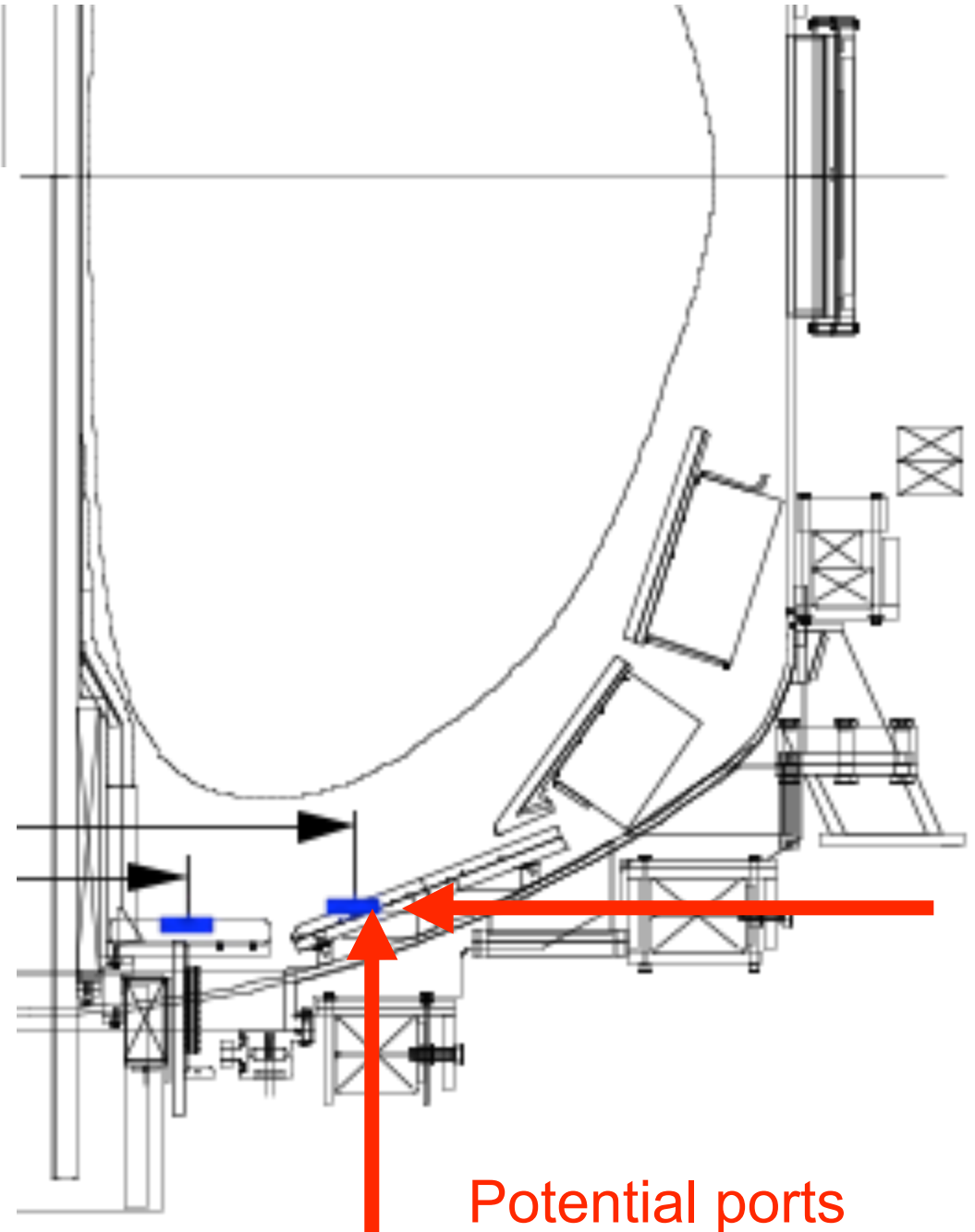
*From Wong 2002 proposal:*

- Provide data on surface material erosion and tritium (deuterium) up-take
- Provide data on the effect on the core plasma from eroded material transport
- Evaluate surface effects from NSTX wall conditioning methods
- Provide the data for the selection of divertor plasma facing solid or liquid materials for NSTX, DTST and ST-VNS
- Support development of edge physics diagnostics
- *Provide engineering for future, higher power NSTX operation, DTST and ST-VNS.*



## Hardware location:

- Can insert candidate Li tiles from lower vertical or horizontal ports
  - Porous metal 'sponge'
  - Stainless mesh
  - Other concepts ...
- Change on daily basis
- Only risk one-day's run at a time if major problems
- Use proven 'best' design for liquid lithium divertor
- General purpose tool for PSI material studies.
- To feed into Li divertor schedule need to install summer 2007.
- Next step is conceptual design study



# Conclusions:

- PSI issues critical to operation of ITER, NHTX, CTF, FDF and any burning plasma.
- NHTX correctly identifies this as research priority
- NSTX should lay foundation for NHTX and demonstrate leadership in tackling PSI issues.
- Divertor transporter system a key tool in liquid lithium divertor development. Would greatly speed up progress and lower risk.
- Conceptual design needed.
- Installation in summer 2007 desirable.