Diagnostics needs on 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

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Device	R (m)	a (m)	R/a	P (MW)	P/R (MW/m)	Pulse (sec)	Ip (MA)	Species	Comments
Planned Long-Pulse Experiments									
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
NHTX	**0.95**	**0.53**	**1.80**	**38**	**40**	**60**	**4.2**	**D**	**Vary concentration, Rdi**
ITER	6.20	2.00	3.10	150	24	400-3000	15.0	DT	Not for divertor testing
Component Test Facility									
CTF (Low A)	**1.20**	**0.80**	**1.50**	**58**	**48**	**Steady**	**12.3**	**DT**	**2 MW/m^2 neutron flu**
Demonstration Power Plant Designs									
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
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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.

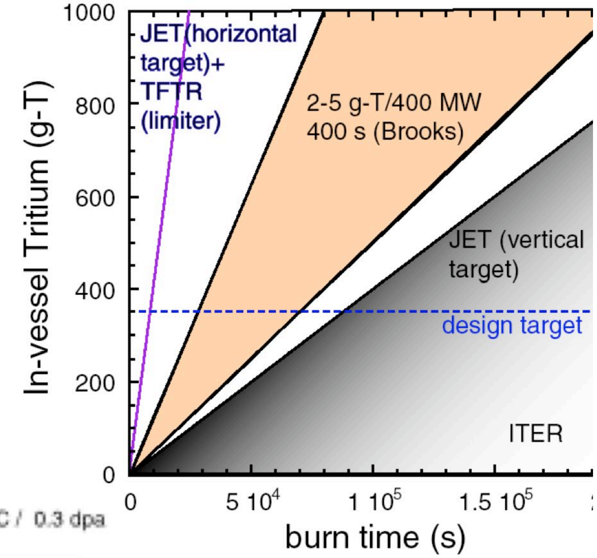
- *JET:* The EU has already recognized this with the ITER-like wall project on JET (60 million EU), 100% W on Asdex and edge ergodization on TEXTOR.

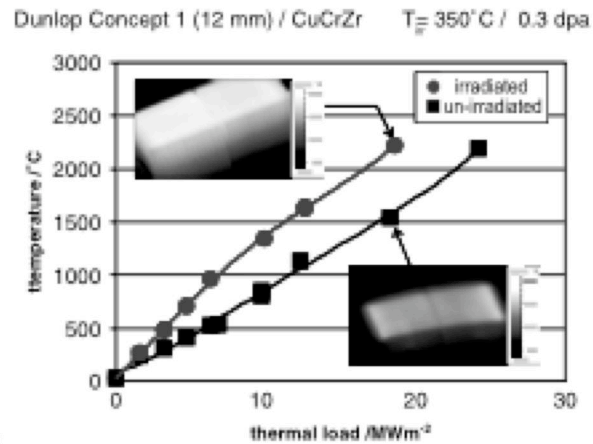
- *DIII-D* Dec 12th 2006 boundary workshop emphasized heat flux issues:
  - Petri: Heat Flux Reduction in High Performance Scenarios:Overview
  - Schaeffer: AC Excitation of I- and C-coils for Divertor Heat Flux Reduction
  - Schaeffer: Test Under-Floor Axisymmetric Kotschenreuther Divertor Coil in DIII-D
  - 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.

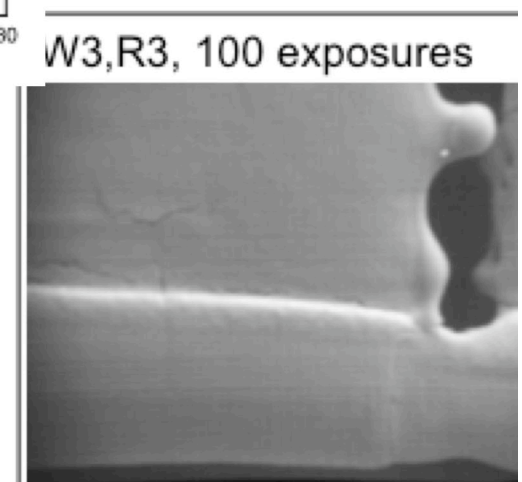
Cambell DIII-D
PAC presentation
29 Jan 2007





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

1 MJ/m2 0.5 ms



Zhitlukhin et al., PSI-17

NHTX mission correctly identifies most critical area for magnetic fusion

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.

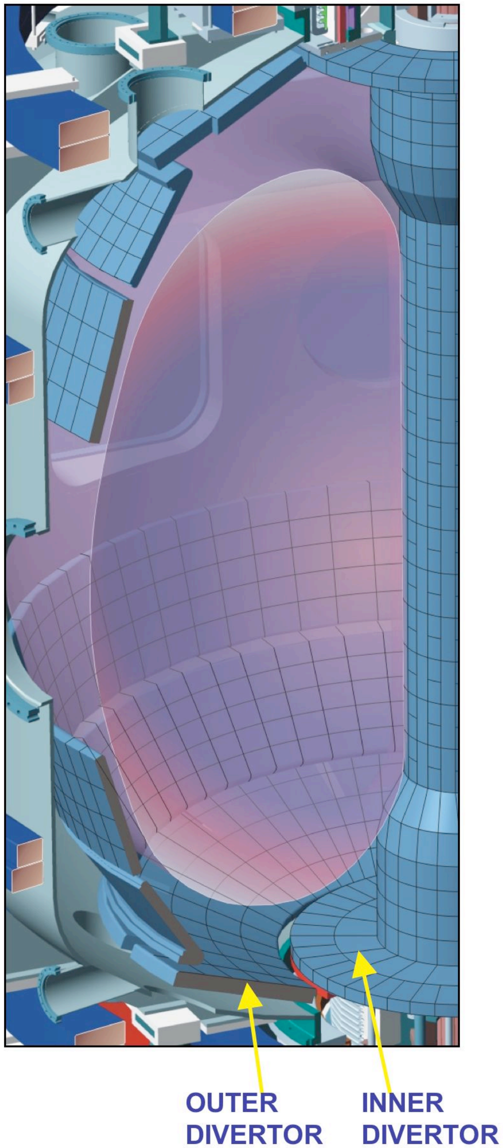
Build on strong credits in both ST and Li experience.

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…)

Kugel DPP APS06:

Future Plans



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

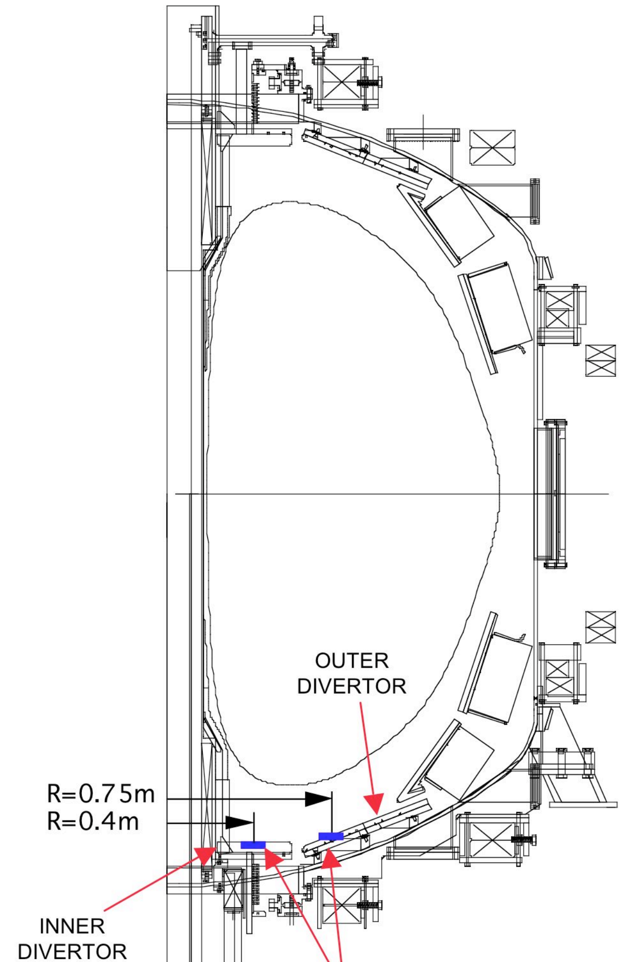
I. Lithium Pellet Injector (2005)

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)

Retractible 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.)
- TFTR Bay D Probe

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.*

DTS is 'stepping stone' on path to LLD

Many issues that DTS could provide key information on (from Li wkshp 2/27/07 at PPPL):

1. Impurity influx from Mo tray ? (recall experience with Cu passive plates)
2. Horizontal or tilted geometry ?
3. SS mesh or porous Mo ?
4. Meniscus effects due to gravity ?
5. Effect of lithium carbide or lithium carbonate (not addressed in CDX) ?
6. Temperature needed to melt slag ?
7. MHD effects in ST geometry ?
8. Choice of heaters / leads ?
9. Support failure mode analysis ?
10. Controls ?
11. Info on supplying Li to mesh ?
12. ….. ?

•Take advantage of previous design work for NSTX LiTER2 probe.

•Take advantage of CDX radial Li limiter (hardware + experience).

•Aim for installation in NSTX in summer of 2007 to support LLD design at SNL.

Bottom line:

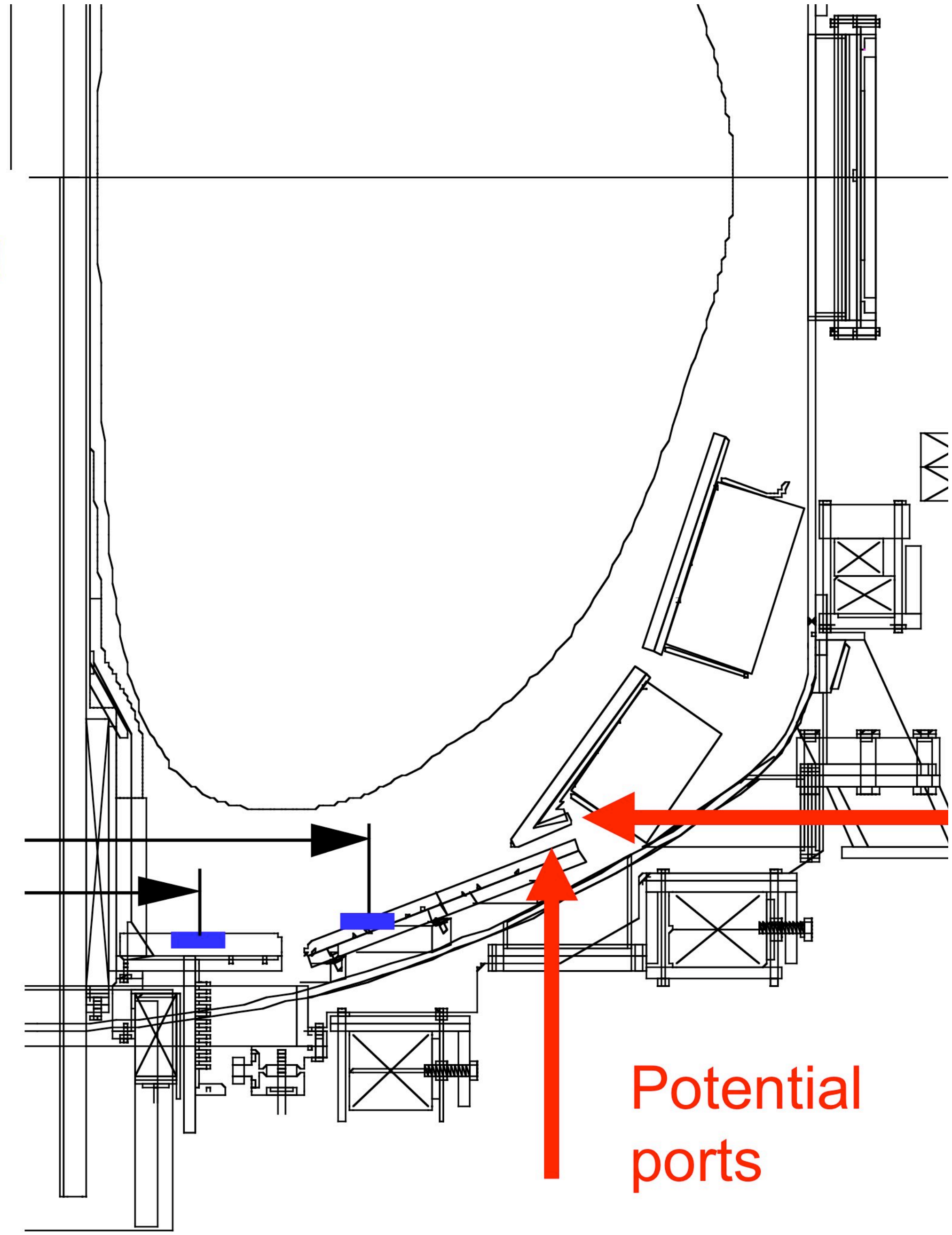
Minimises technical uncertainties

Supports design decisions.

Reduced risk and faster LLD development.

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 needed.