NSTX

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Li-PFCs for NSTX-U divertor ?

(PAC-31, 5-year plan preparations)

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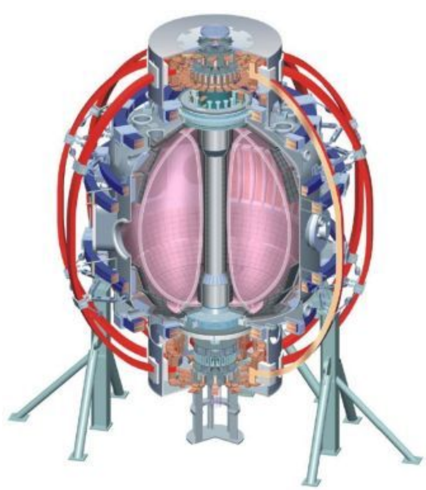
LRTSG meeting
PPPL B318
9:30 February 23, 2012



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Draft outline format for PAC presentations from TSGs: ~25 minutes > ~17 content slides (JM)

- Overview – goals and/or milestones for your TSG – 1 slide
- FY2011-12 research highlights/progress from your research area (newest/most important/ best since last PAC in Jan 2011) – 6 slides
- Collaboration plans (NSTX team wide) in your respective research area for 2012-2013 – 1-2 slides
- Outline of plans for first 1-2 years of research on NSTX-U (FY2014-2015) – 2 slides
- Discuss linkages between collaboration and first 1-2 years of NSTX-U operation – 1 slides
- Discussion of key diagnostics and facility upgrades needed to achieve FY2014-15 research goals – 2 slides

- Brief overview of research goals for 2016-2018 (last 3 years of 5 year plan) – 1-2 slides

- Brief overview of major diagnostics and facility upgrades needed to support research goals for 2016-2018 – 1-2 slides

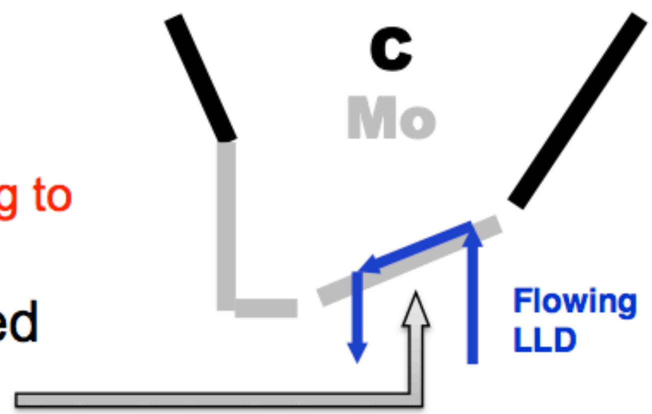
Flowing LLD development should be studied as alternative means of particle and power exhaust, access to low recycling

- LLD, LTX → liquid Li required to achieve pumping persistence
  - Flowing Li required to remove by-products of reactions with background gases
- Substantial R&D needed for flowing Li
- Need to identify optimal choice of concept for pumping, power handling:
  - Slow-flowing thin film (FLiLi)
  - Capillary porous system (CPS)
  - Lithium infused trenches (LiMIT)

  All systems above require active cooling to mitigate highest heat fluxes of NSTX-U
- Elimination of C from divertor needed for "clean" test of LLD D pumping
  - May need to remove all C PFCs?

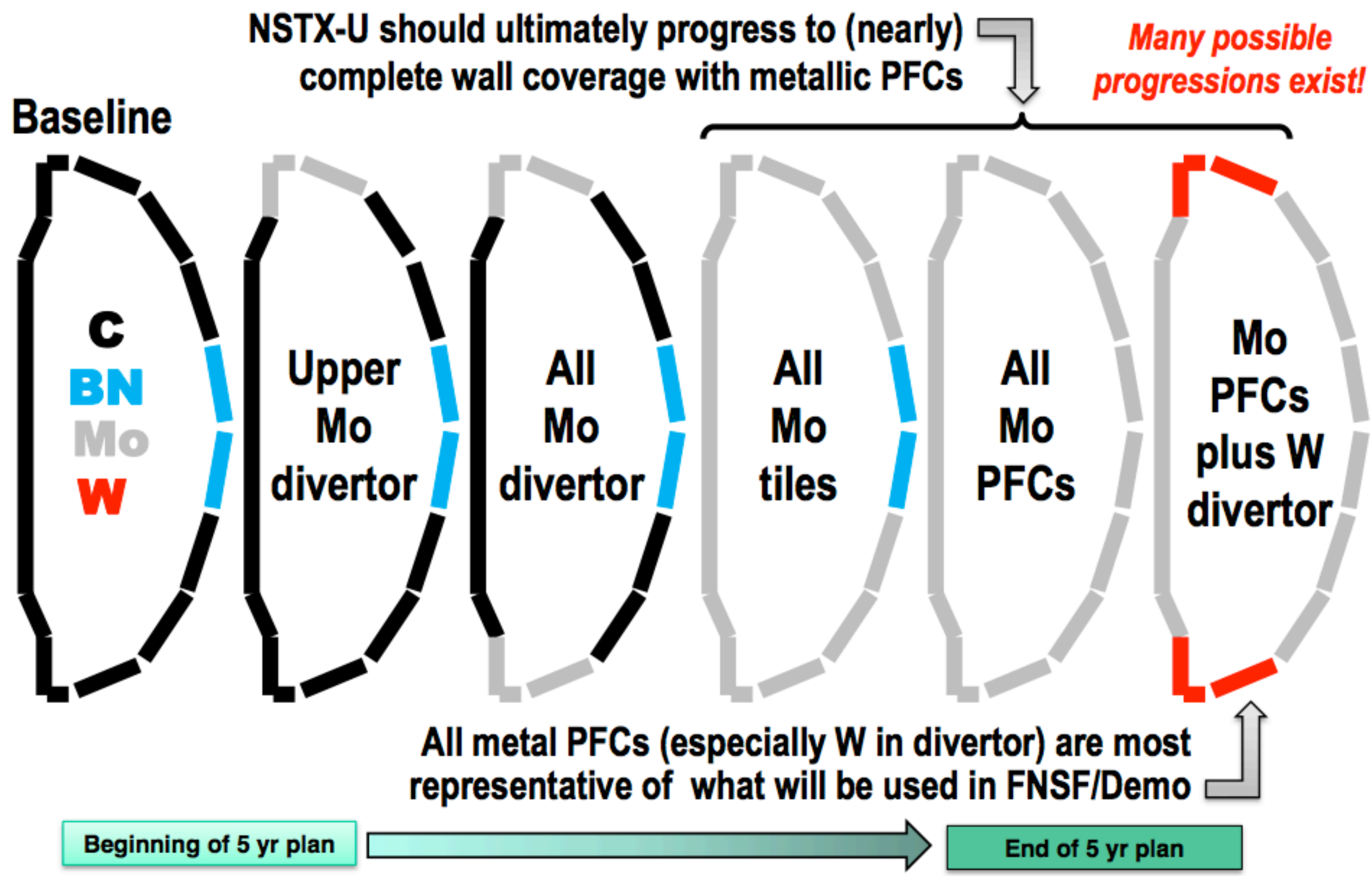
Possible approach:

- Dedicate 1-2 toroidal sectors (30-60˚ each) to LLD testing (and/or integrate with RDM?)
- Test several concepts simultaneously
- Full toroidal coverage after best concept is identified

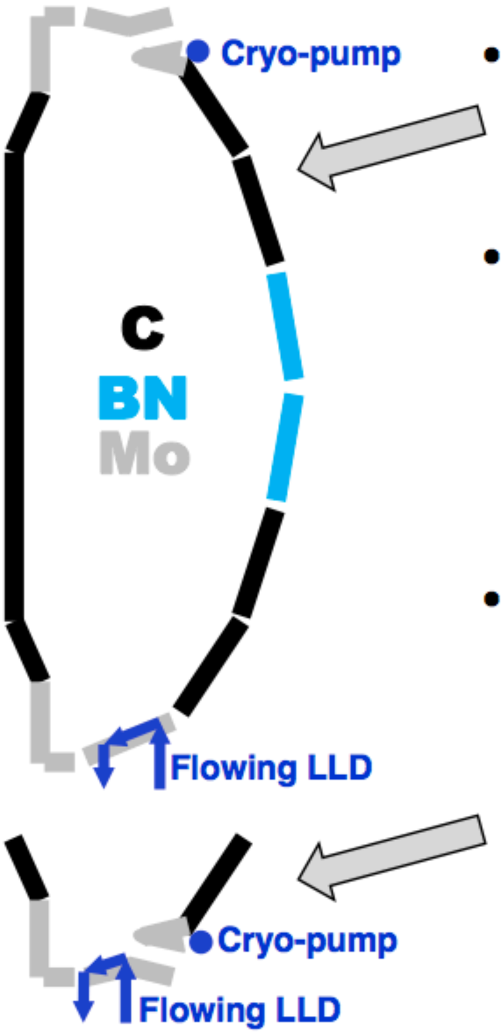


PAC draft: Brief overview of research goals for 2016-2018 (last 3 years of 5 year plan)
Menard NSTX-U_PMI_Discussion 1/30/12

Possible progression of PFC materials in NSTX-U



Direct comparison of particle control from cryo-pumping and flowing LLD would greatly aid development of FNSF divertor



- Could dedicate upper divertor to cryo-pumping and lower divertor to flowing Li
- IF this is the preferred long-term approach, it argues for converting lower divertor to Mo tiles first to avoid re-doing upper divertor PFCs for cryo.
- If flowing LLD region is sufficiently narrow radially, it could (maybe) be combined with cryo-pumping in the same divertor:
  - Utilize cryo for D pumping?
  - Utilize flowing Li + evaporative and/or radiative cooling for power exhaust?
  - Can Li pump D while taking power exhaust?

Li inventory and safety

- The current lithium inventory limit in NSTX is 2 kg.
- Any increase in this inventory would have to be predicated on a subsequent safety analysis and review that proves that this amount of lithium can be safely handled under all routine and abnormal conditions. (Levine)
- The biggest challenge is how do we handle a vessel opening and entry after such a large quantity of lithium has been introduced.
- Opening the vessel to air will NOT be effective in passivating the majority of the lithium in those cases. (Slavin)
- Lithium won't drain by itself ! (Majeski)
- See p. 8-12 of NSTXSAD_LITER_DRAFT_11MAY2011r0 .doc by Henry K. for NSTX info.

NSTX-U Li-PFC concept issues

- Is primary goal D uptake or heat flux removal or impurity control ?
- What are Li-flow requirements:
- How does this concept fit with an RDM or a toroidal quadrant? (Edges, etc.)
- How does this concept fit with a cryopump
- What is development / testing path; (LDRD, OFES $, HT7, ….)
- What performance criteria qualify PFC for NSTX-U
- What D uptake or MW/m^2 is estimated ?
- Is Li inventory > 2 kg ?
  If so, how to address safety.

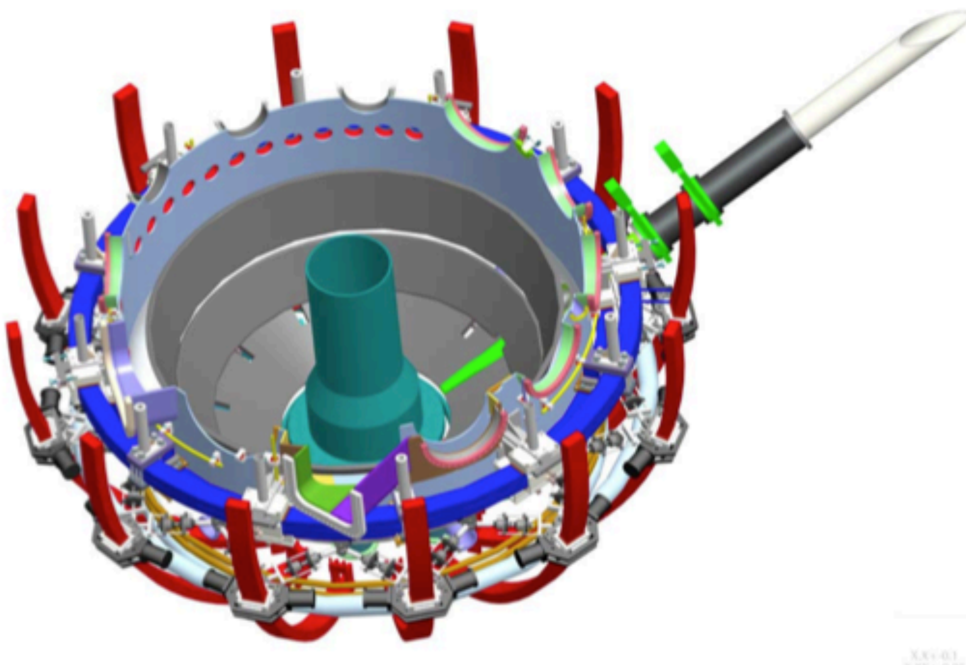
Menard NF table 1
Projected peak heat flux and pulse duration allowed before reaching a divertor graphite PFC surface temperature of 1200◦C

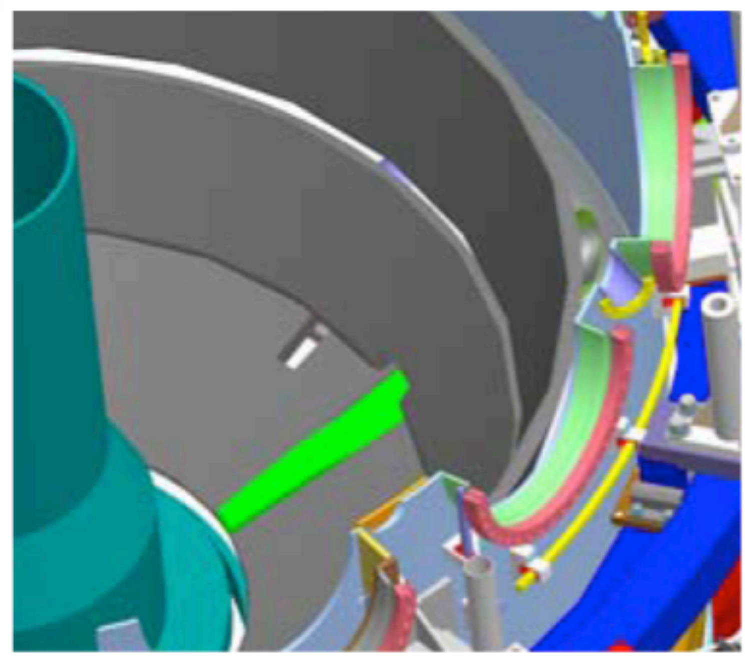
NSTX Upgrade Scenarios

	NSTX-U 100% NICD		NSTX-U Long-pulse		NSTX-U Max I_p		NSTX-U Max I_p, P_{heat}		NSTX-U 100% NICD		NSTX-U Max I_p		NSTX-U High f_{BS}	
Power fraction to divertor	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
$R_{strike\text{-}point}$ [m]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
SOL heat-flux width [mm]	7.9	8.9	10.9	10.9	3.0	3.0	3.0	3.0	4.8	5.0	3.0	3.0	7.8	7.3
Poloidal flux expansion	22	22	22	22	62	62	62	62	22	22	38	38	22	22
Peak heat flux [MW/m^2]	9.1	8.1	3.4	3.4	8.7	8.8	16.2	16.2	9.0	8.6	8.4	8.6	3.7	4.0
Time to T_{PFC} = 1200°C [s]	6.1	7.6	44	44	6.7	6.5	1.9	1.9	6.1	6.7	7.1	6.8	36	31
Fraction of T_{PFC} limit	**0.96**	**0.76**	**0.24**	**0.24**	**0.97**	**1.00**	**0.94**	**0.95**	**1.00**	**0.91**	**0.92**	**0.96**	**0.16**	**0.19**

Removable Divertor Module (Zweben)

- Small divertor segment replaced during run using bellows, for testing new PFCs, e.g. CPS or flowing liquid metal, or for new diagnostics, e.g. probes or surface samples





Agenda:

See http://nstx.pppl.gov/DragNDrop/Five_Year_Plans/2014_2018/facility_brainstorming/

GoogleDocs: https://docs.google.com/a/pppl.gov/spreadsheet/ccc?key=0ApOCxE3zjciwdGJHMG1WYmhUYlRveTRfanU5aGMzT3c

- Goldston (CPS + active cooling)
- Jaworski/Ruzic (LiMIT- lithium-metal infused trenches + TE-MHD effect)
- Ji (fast flowing thicker layer)
- Majeski (static thin? pool stirred with e-beam, and maybe this is only for pumping?)
- Ono (slow thin film + active cooling? + Mo tile protection?)
- Zakharov (slow thin film + active cooling)

CPS + active cooling (Goldston)

Pre-tokamak R&D essential to accelerate & reduce risk of advanced PFCs

If DOE Proposal is funded, NSTX-U should begin design of large-area CPS divertor to be installed in 2016.

- Information on wetting and contamination /decontamination of lithium CPS is scheduled to be available by January 2014.
- Could begin design to be confirmed by Magnum-PSI in 2014 (wetting) and 2015 (wetting + cooling).

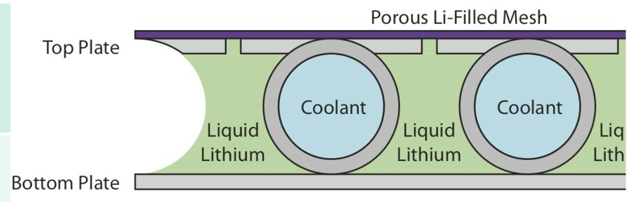
If DOE Proposal is not funded…

- Could do wetting and contamination/ decontamination studies with PPPL facilities, collaboration with Koel nominally “cost-free”.
- Magnum-PSI has separate funding, so perhaps some activity could proceed with NSTX support for PPPL activities.

Replaceable Divertor Module would provide valuable tests in either case.

- If no DOE funding, and no Magnum-PSI, RDM could play the role of Magnum PSI in 2014 – 2015, before we install large-area divertor in 2016.
- If DOE funding, RDM would provide valuable additional tests in 2014 – 2015, before installing large-area divertor in 2016.

	RDM	Full toroid	Notes
toroidal length (cm)	9.4	565	
radial width (cm)	10	10	
Effective thickness (cm)	0.33	0.33	
heat input (MW)	0.1 / 0.01	6/0.6	heat flux to divertor / heat flux conducted locally to coolant. Just outer lower.
Li velocity (cm/s)	0.29	0.29	Speed in CPS if no feed in strike area
Li flow (l/s)	0.00 09	.055	Flow is makeup for evaporation.
Li temp rise (C)	450	450	temperature for evap. rate less assumed T_0 = 300 C



LiMIT- lithium-metal infused trenches + TE-MHD effect (Jaworski/Ruzic)

- LIMIT concept exploits TEMHD pumping effect to self-pump lithium
- Thermoelectric (TE) current and toroidal field drives radial flow
- Cooling required on the back-side in steady-state to maintain gradients

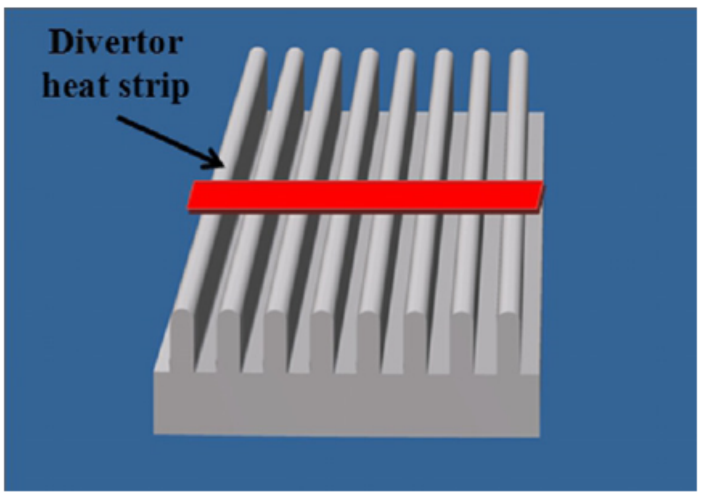


Figure 1. The LiMIT concept: metal tiles with radial trenches containing lithium. The trenches run in the radial (poloidal) direction such that they lie primarily perpendicular to the toroidal magnetic field and the divertor heat stripe.

W. Xu and D.N. Ruzic

	RDM	Full toroid	Notes
toroidal length (cm)	10	2π	Inboard divertor used for toroid
radial width (cm)	10	18.1	In-board horizontal tile width
Effective thickness (cm)	~2	~2	
heat input (MW)	31kW Li	1.4MW Li	???
Li velocity (cm/s)	45	45	Calculations assume 1T field everywhere
Li flow (l/s)	0.17	5.8	
Li temp rise (ΔC)	162	223	Assumes 200C back surface

Fast flowing thicker layer (Ji)

- a) Establish fast liquid metal channel flow across magnetic field in divertor-like geometry
- b) Characterize heat transfer properties of free-surface liquid metal pool and flow
- c) Study electromagnetic effects of side walls channel flow•
- We can follow the development path of a), b), c), RDM to test and implement the idea of using flowing liquid metal to remove heat.

	RDM	Full toroid	Notes
toroidal length (cm)	10		
radial width (cm)	10	10	
Effective thickness (cm)	d	d	d~ 1 cm
heat input (MW)	25 MW/ m2	25 M W/m2	
Li velocity (cm/s)	50/d	50/d	
Li flow (l/s)	1.25	75	
Li temp rise (C)	100	100	

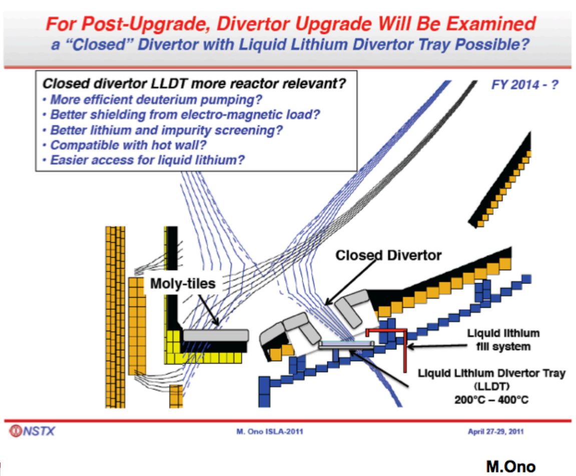
Static thin (?) pool stirred with e-beam (Majeski)

- bullets

	RDM	Full toroid	Notes
toroidal length (cm)			
radial width (cm)			
Effective thickness (cm)			
heat input (MW)			
Li velocity (cm/s)			
Li flow (l/s)			
Li temp rise (C)			

Slow thin film + active cooling? + Mo tile protection? (Ono)

1. Rely on lithium cooling - heating up, melting, evaporation, and radiative cooling.
2. Need to take into account thermo electric effects and other forces which could move the liquid lithium at least locally.
3. Lithium may need periodic purification cleaning which might be done between shots for NSTX-U.
4. The lithium drainage may be needed to keep the lithium inventory at acceptable level.



	RDM	Full toroid	Notes
toroidal length (cm)		565	
radial width (cm)		10	
Effective thickness (cm)		0.1-0.2	
heat input (MW)		5 MW/m2	
Li velocity (cm/s)			May not need any externally driven flow.
Li flow (l/s)		~0	
Li temp rise (C)			We could let the initial temperature to be cool then let it rise to about 400C to avoid excessive evaporation except in some local areas.

Slow thin film + active cooling (Zakharov)

1. FLiLi solves the problem of the Li surface contamination: open loop during machine operation, close loop overnight
2. Flow rate is under external control by pressure in the feeding pipes.
3. The system is scalable in both poloidal and toroidal direction, and from a laboratory test chamber to a real tokamak device.
4. Minimal in-vessel inventory of LiLi. LiLi is supplied from outside and is exhausted to outside the VV.
5. The bulk of LiLi is protected from plasma disruptions by the filter layer.
6. No side walls for LiLi flow, no leading edges.
7. Simple for maintenance, at the end of the campaign can be flushed out by argon and then by vinegar.
8. Is insensitive to yet unknown j × B forces.
9. Filter channel geometry and orientation is flexible.

	RDM	Full toroid	Notes
toroidal length (cm)			
radial width (cm)			
Effective thickness (cm)		0.01	
heat input (MW)		5 MW/m^2	
Li velocity (cm/s)			
Li flow (l/s)		0.001-0.002	
Li temp rise (C)		10