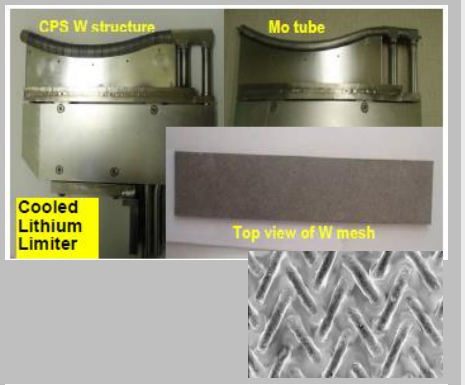

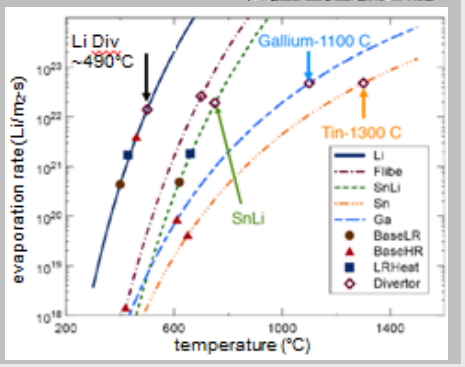

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Exceptional service in the national interest

LM PFCs

Evaporative Limits, CPS and other Concepts

with focus on materials issues

RE Nygren

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Why me?

- ALPS and APEX experience
- PMTF test (Ulrickson), Li jet flowing through B field
- work on Flibe properties
- Built hardware for NSTX Liquid Lithium Divertor
- Li fire at PMTF (my watch) ⇒ Li safety awareness
- Other - Li programs at PPPL, UCLA and Purdue
  - Critic of those who over promise
  - Concern with development path and deployment
  - *Recent PFMC paper on design integration of LM PFCs*
  - *Long invited paper, Part 1 of 2, on the potential of LM PFCs in Nuclear Materials & Energy in final review for publication*
  - *Paper on liquid metal embrittlement of (ferritic) mild steel by Li not yet submitted(old SOFT 2014 poster)*

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

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Consider the points below.

- Clever ideas emerging; many still “cartoons”.
- **Capillary Pore System or CPS** is more mature (1994) with several stages of development and many tests in labs and in tokamaks.
- Deployments (US units for EAST/HT-7) important; modules small.

We lack evidence that the schemes can be successfully integrated into the subsystems for an FNSF or a DEMO.

Convected power to solid FWs may require shaped walls.

Complex issue - Poloidal limiters would restrict breeding volume and complicate power injection.

Outline

- **LS PFCs applications**
- **CPS applications**
- **Integrated subsystems**

CPS

- delivery system for stable liquid surfaces
- architecture engineered for this purpose
- replenishing flow draws liquid from reservoir
- capillary forces - liquid wetting, pore size must be matched for the chosen liquid. *Tabares noted that pore size for supply flow differs from that retaining surface liquid.*

Consider the points below.

- Clever ideas emerging; many still “cartoons”.
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We lack evidence that the schemes can be successfully integrated into the subsystems for an FNSF or a DEMO.

Convected power to solid FWs may require shaped walls.

Complex issue - Poloidal limiters would restrict breeding volume and complicate power injection.

We need a credible vision of a path forward

Critical challenges: Tame plasma interface, harness fusion power

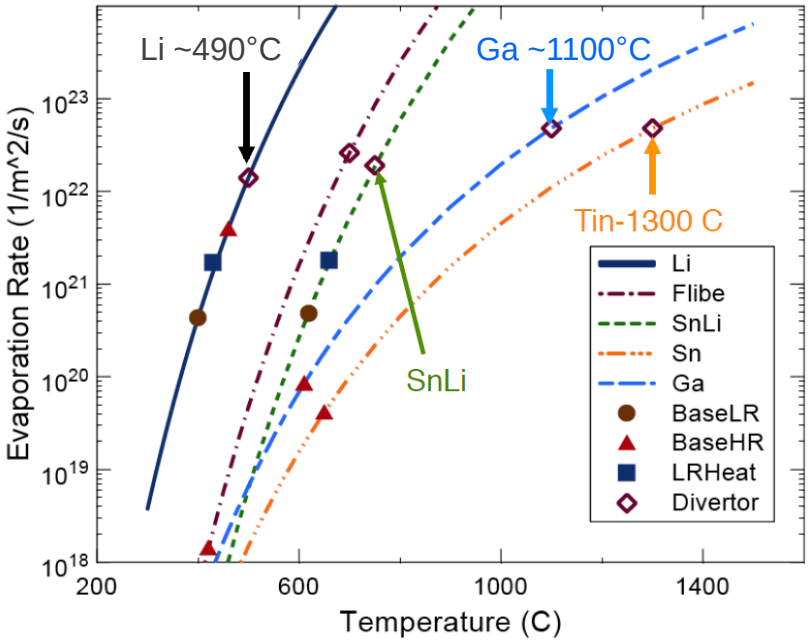
Developing at least one credible scheme to handle power is critical.

Showing that LS PFCs provide robust heat removal, renewable surfaces for any of the following would bolster the credibility of the program:

• divertors • wall protection (limiters/guards) • LS PFC-blankets

LS PFCs: Divertors AND FWs?

Evaporative limits, no shielding

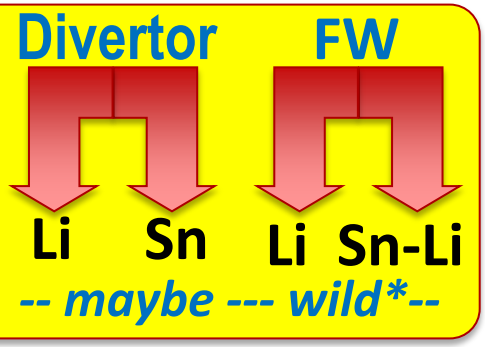


role(s) for vapor shielding

transient protection
- ELMs (ms)
- Hot spots (s)

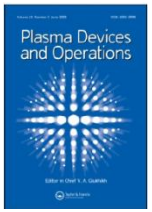
- Magnum-PSI
- Confinement tests

steady state protection
- Hot spots (h)
- PFC basis (h)



*Recent work in TJ-II and ISSTOK [FL Tabarés et al. 2016 Experimental tests of LiSn alloys as potential liquid metal for the Divertor target in a Fusion Reactor, (PSI2015) to be published in Physica Scripta] as well as lab experiments in Pilot-PSI [TW Morgan et al. 2014, Interaction of a tin-based capillary porous structure with ITER/ DEMO relevant plasma conditions, JNM in press; GG Eden et al. 2016 Phys. Rev. Lett. 116 135002] suggest that Sn-Li does behave like a Li surface facing the plasma.

CPS
examples



IE Lyublinski, AV Vertkov, VA Evtikhin 2009 *Application of lithium in systems of fusion reactors. 2. The issues of practical use of lithium in experimental facilities and fusion devices*, in Plasma Devices and Operations, 17: 4, 265-85 DOI: 10.1080/10519990903172364
URL: http://dx.doi.org/10.1080/10519990903172364

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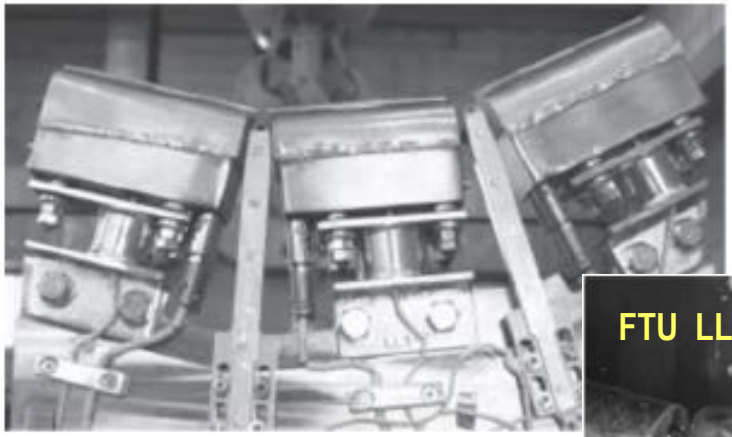
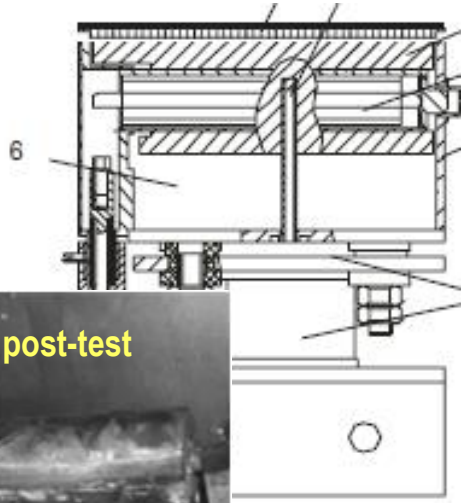
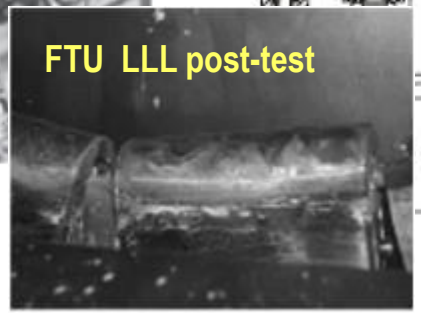
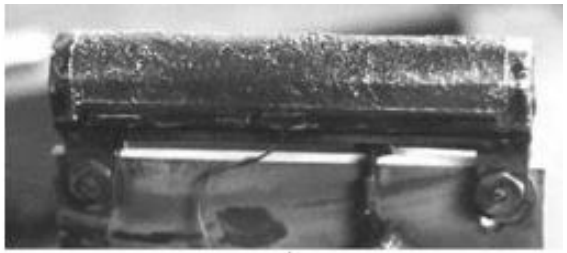
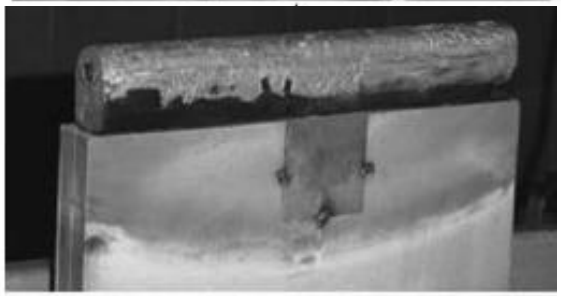


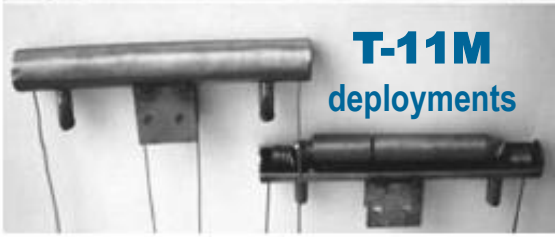
Initial FTU Liquid Li Limiter

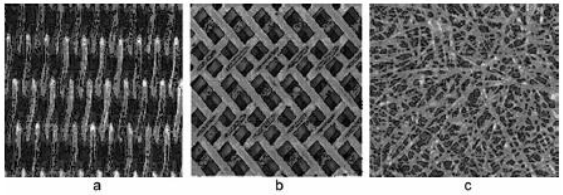




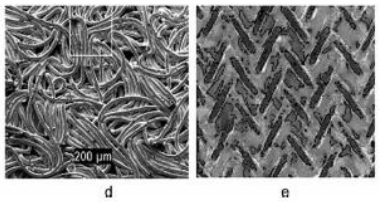








Targets for Li CPS in QSPA (a,b) and MK-200UG plasma guns



Felt/mesh types

CPS

examples

CPS deployment in KTM (Kazakhstan)

Preparation is extensive, e.g., includes testing of supply systems with NaK.

I. Lyublinski et al. / Fusion Engineering and Design 87 (2012) 1719–1723
I.E. Lyublinski et al. / Fusion Engineering and Design 88 (2013) 1862–1865

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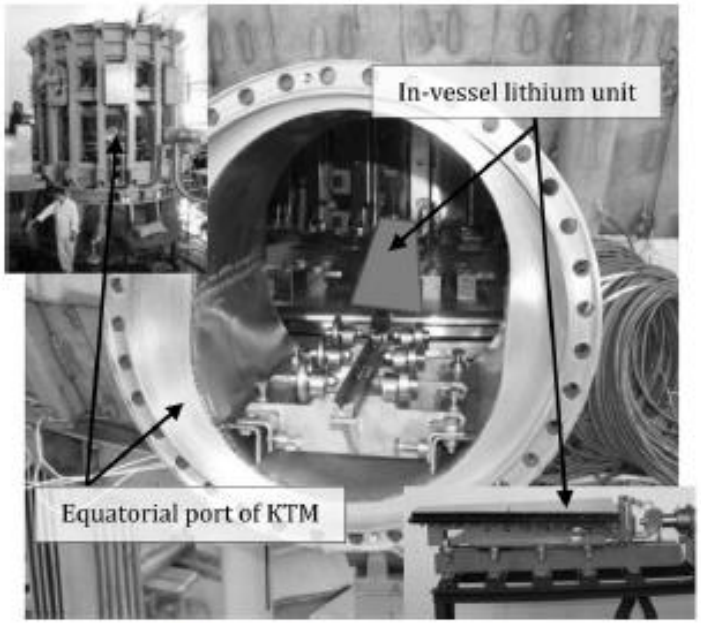


Fig. 2. In-vessel Li unit placed on KTM port.

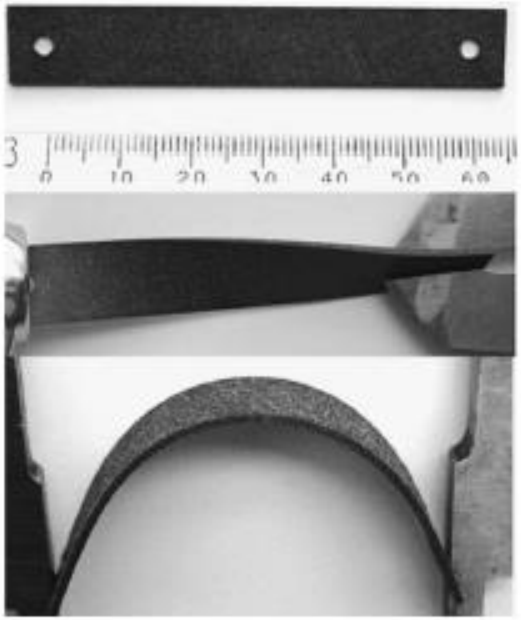
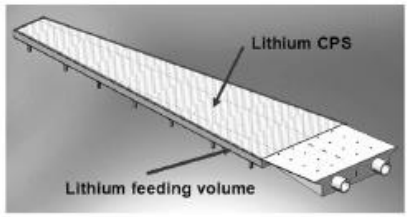


Fig. 4. Samples of flexible tungsten CPS.



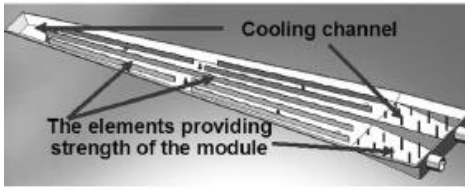


Fig. 3. Scheme and design of the lithium in-vessel unit of KTM.

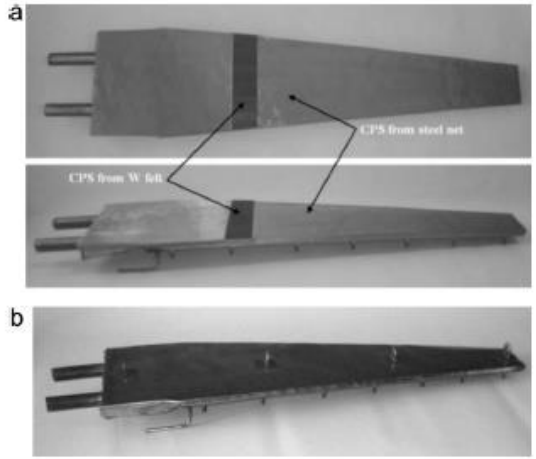


Fig. 4. The in-vessel lithium unit of MLD with CPS structure (a) and lithium unit with shielding foil on lithium surface (b).

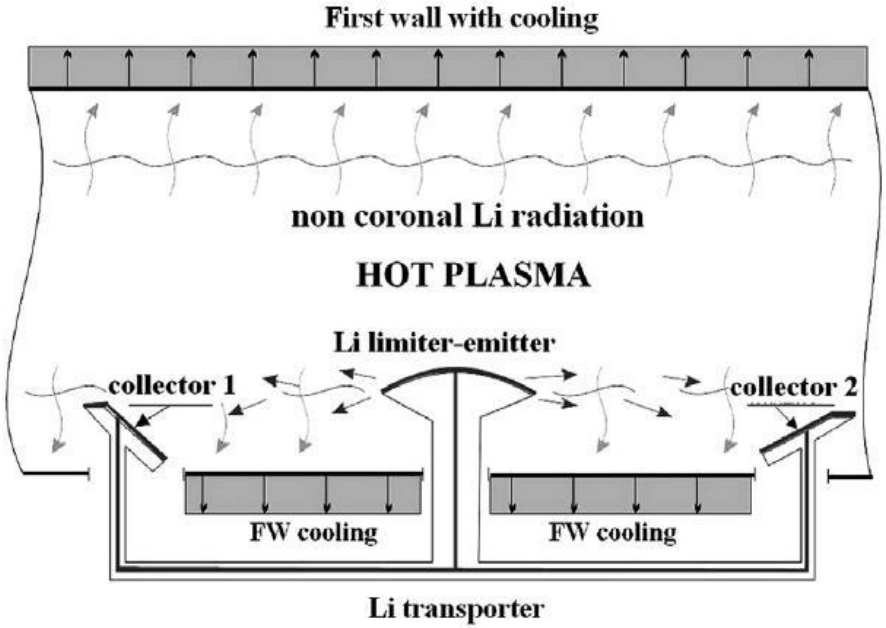
System proposed by Mirnov and collaborators

Limiters separately emit and collect Li. Li non-coronal radiation cools the plasma edge and protects the PFC itself from high transient power loads.

Objective: Non-coronal radiation of Li+ and Li++ circulating between plasma and PFC enhances power dissipation through.

T-11M is a small tokamak with limiters, no divertor. In T-11M they observed strong Li UV radiation.

Estimated cooling of ITER would require injecting 7 g/s of Li into the plasma column.



Design Integration: LS PFCs in CTF/DEMO

Many ideas for liquid surface PFCs are for divertors.

FWs are likely to be more challenging because the FW must be an integral structure with the blanket.

Maximum tolerable heat loads are a critical concern for the desired high power densities and heat loads in CTF or DEMO.

Fast flow systems would seem to have an advantage.

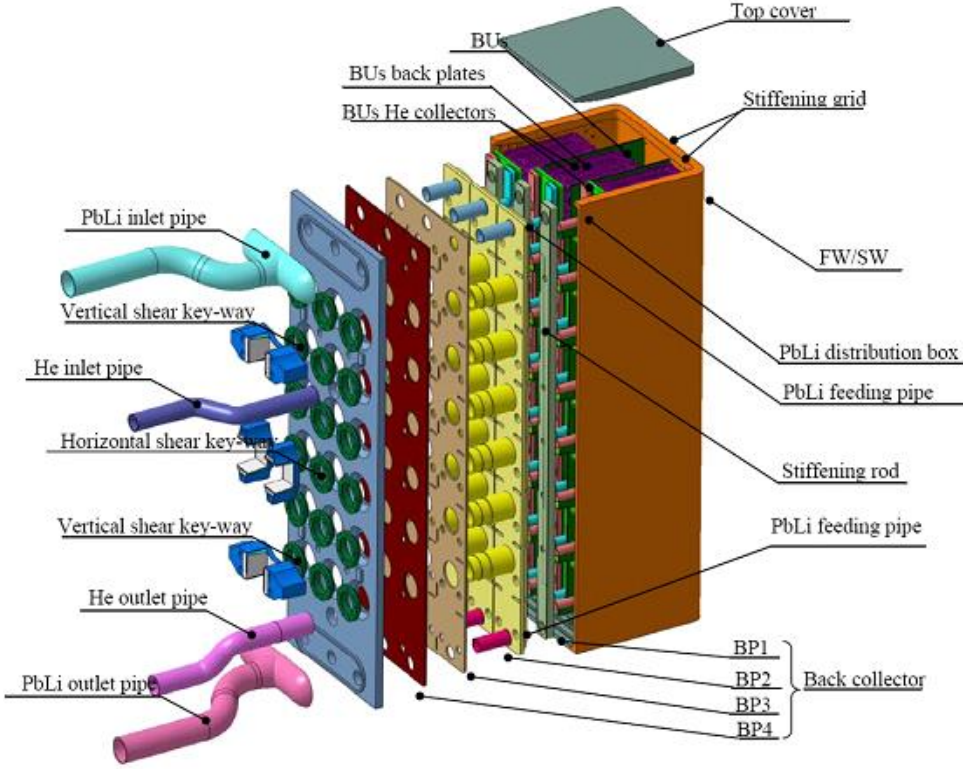
A CPS must transfer heat through the liquid and host structure to the substrate coolant.

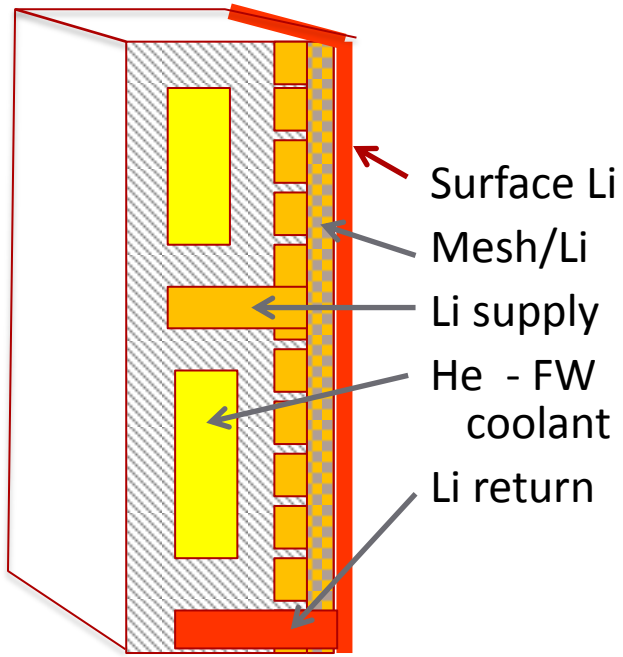
Also a CPS must (1) replenish the surface (?supply pipe), (2) remove slag (?GDC), and (3) remove tritium (?return pipe).

> This paper describes several processes at work in a wall with a LS PFC, and the considerations imposed by heat transfer and the power balance for the PFC as well as the structure needed for an integrated first wall and blanket ...

Design Integration: ?CPS FW in CTF/DEMO

Interruptions in the pattern of He cooling channels for additional channels for Li ingress and egress may pose problems for adequate cooling and thermal stresses.

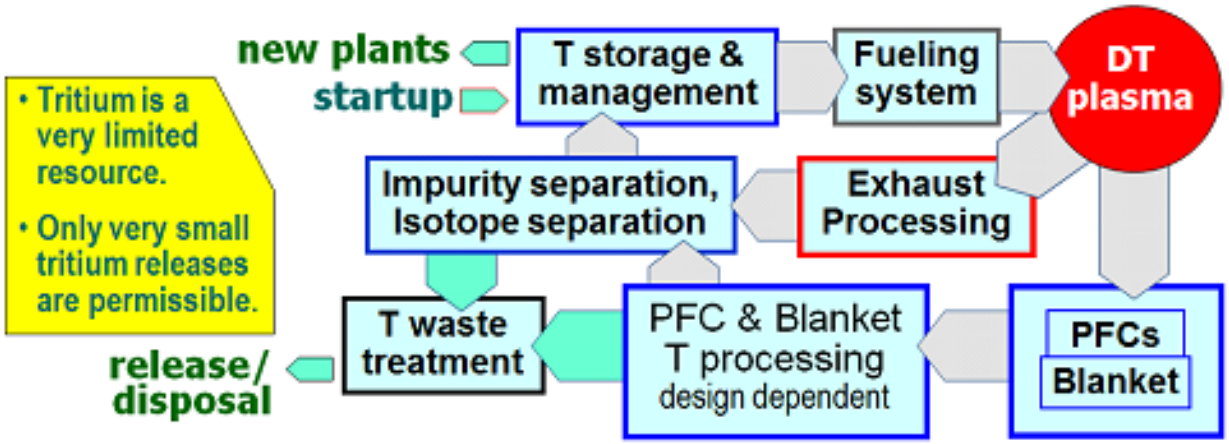




Count the fluid streams

Tritium Self Sufficiency

The operational parameters and uncertainties of the many components in the D-T fuel cycle affect the required TBR*.



High P and Low P streams

Heat exchange and tritium processing

Blanket

1. He coolant (high P)

Solid Breeder :
He purge (low P)

DCLL:
2. Pb-Li
3. He sweep (low P)

FW

He coolant (high P)

Fast Flow:
4. liquid, e.g., Li, Sn

CPS:
Li or Sn supply
Li or Sn return

Divertor

Fast Flow:
liquid, e.g., Li, Sn

CPS:
5. Li or Sn supply
6. Li or Sn return
7. He coolant (high P)

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THANKS