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NSTX-U

Liquid lithium loop system to solve challenging technology issues for fusion power plant

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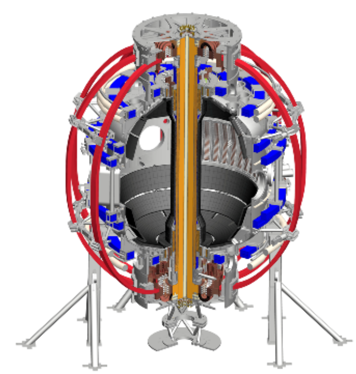
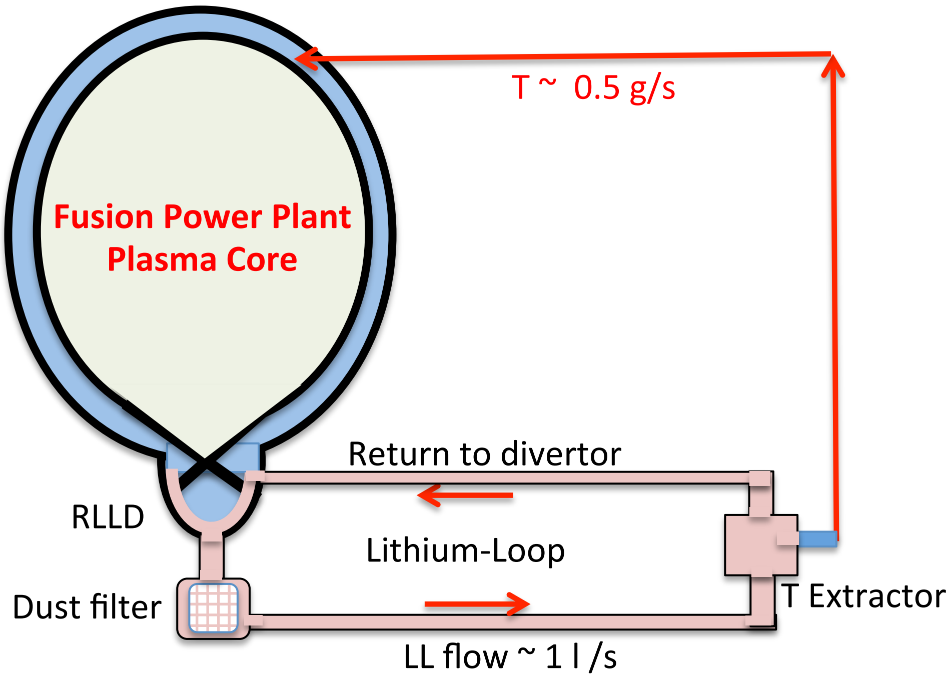
PPPL



Talk Outline

- Motivation of lithium (Li) in fusion reactor
- Divertor heat and particle handling using radiative liquid lithium divertor (RLLD, Active RLLD)
- Liquid Lithium(LL) -loop system
  - General description
  - Dust removal
  - Tritium recovery methods
  - Tritium Inventory
  - LL and tritium clean-up



- Summary

Why lithium (Li) for fusion energy development?
Some Li related facts and information

- Li is the lowest Z = 3 metal – compatible with hot fusion plasmas
- Liquid lithium (LL) has a wide operating temperature range of 180 -1344°C – expected LL operating temperature of 200 – 400°C (low lithium vapor pressure) – compatible with fusion reactor environment
- Lithium reacts and captures D, T, O – Can provide strong divertor particle pumping – e.g., low-recycling radiative divertor

- Lithium as PFC were investigated by many fusion devices with mostly beneficial results on plasmas: TFTR, NSTX and LTX (PPPL, USA), FTU (ENEA, Italy), T-11M (Trinity, RF), T-10 (Kurchatov Institute, RF), TJ-II (CIEMAT, Spain), EAST (ASIPP, China), HT-7 (ASIPP, China), DIII-D (GA, USA), ISTTOK (IPFN, Portugal) and KTM (NNC RK, Kazakhstan).
- The fourth International Symposium on Liquid Metal Application for Fusion Device (ISLA-2015) : held in September 2015 at Granada, Spain. http://www-fusion.ciemat.es/quixplorer/

Radiative LL Divertor Concept (RLLD, ARLLD)

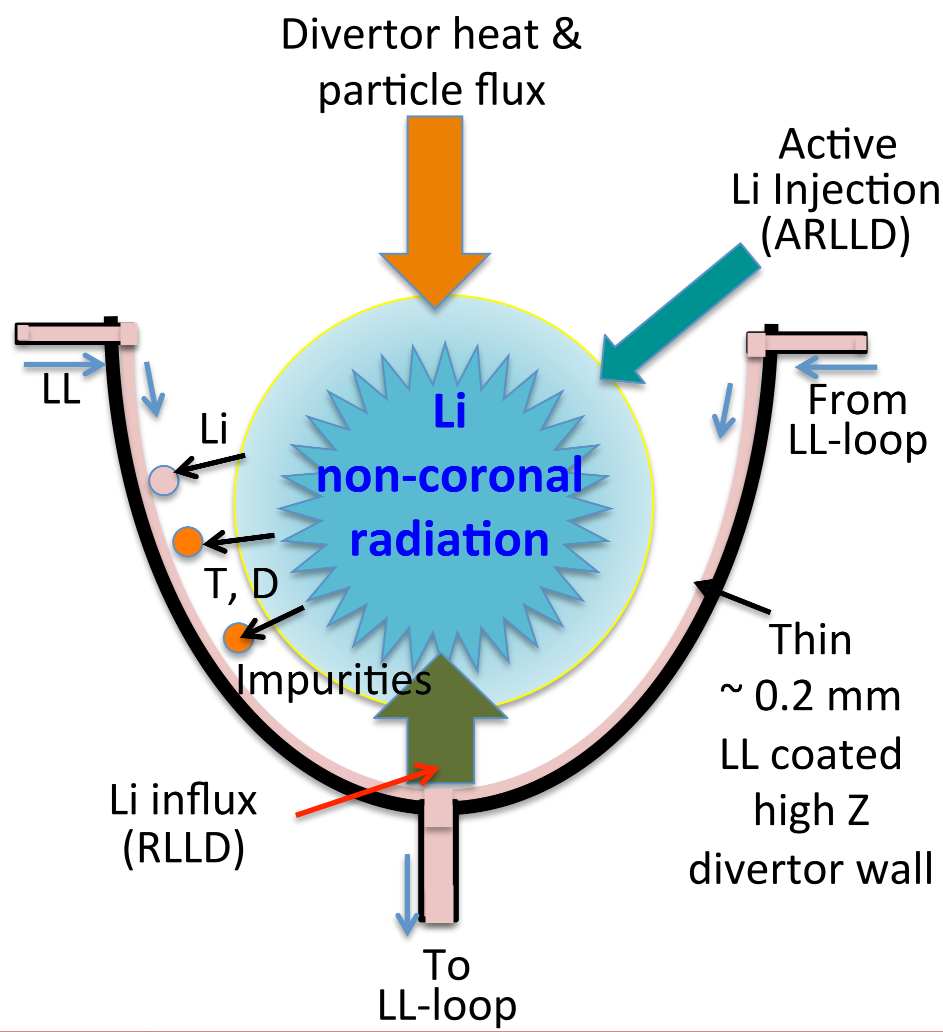
Possibility of Radiative Divertor with Low Recycling!

- Conventional radiative divertor proved effective in reducing divertor heat flux – however often caused plasma confinement degradation.
- Li with non-coronal radiation* could significantly reduce divertor heat flux. Li injection shown effective in heat flux reduction in EAST.

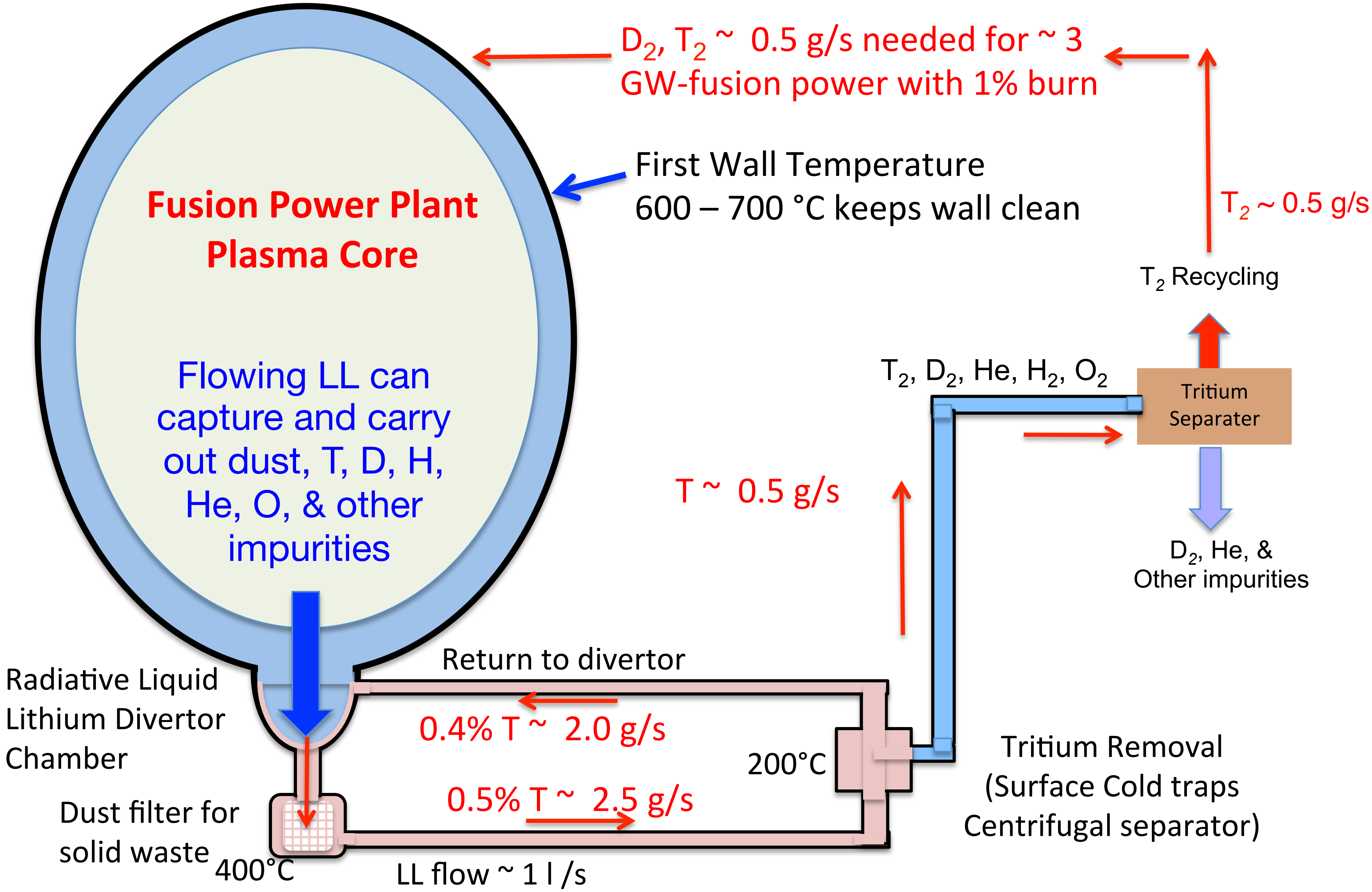
*S. V. Mirnov et al., PPCF (2006)

- Li can provide strong particle pumping for low recycling divertor.
- LL provides renewable protective layer for high-Z substrate.

M. Ono et al., RLLD - NF 2013, ARLLD - FE&D 2014



A LL-Loop as a part of Fusion Reactor "Ecosystem"
Continuously Removing Dust, T, D, H, He, O, & Other Impurities



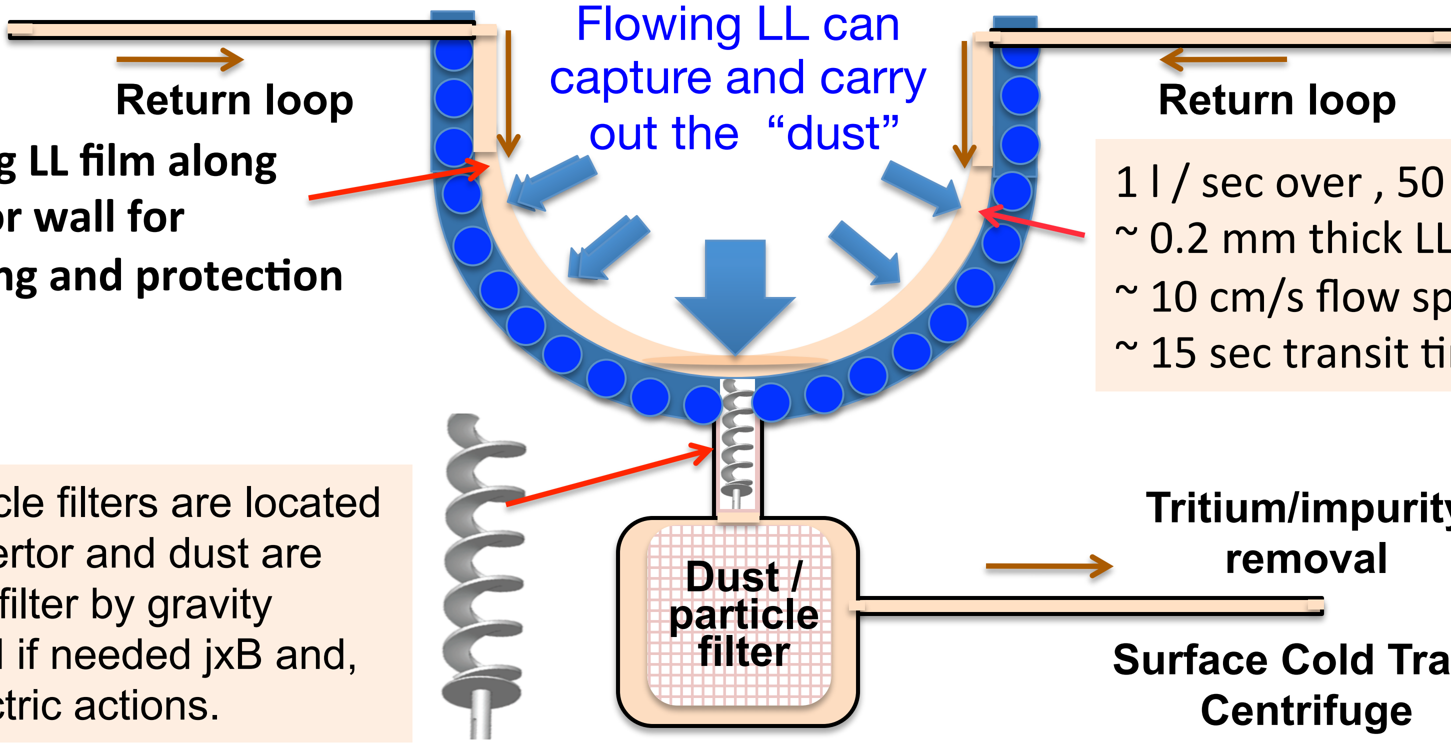
Dust Generation Identified as a Serious Issue for Fusion Reactor*

0.5 g of dust generation per second results in 17 tons per year!

*G. Federici et al., NF 2001

- With 0.1% dust fraction by weight in 1 l/sec LL flow, can carry away 17 tons of dust in a year!
- While LL may also reduce the dust generation in divertor, the philosophy is to remove the dust as much as possible whenever generated.

"Uchi-mizu" in Kyoto



Dust/particle filters are located below divertor and dust are carried to filter by gravity action and if needed jxB and, themoelectric actions.

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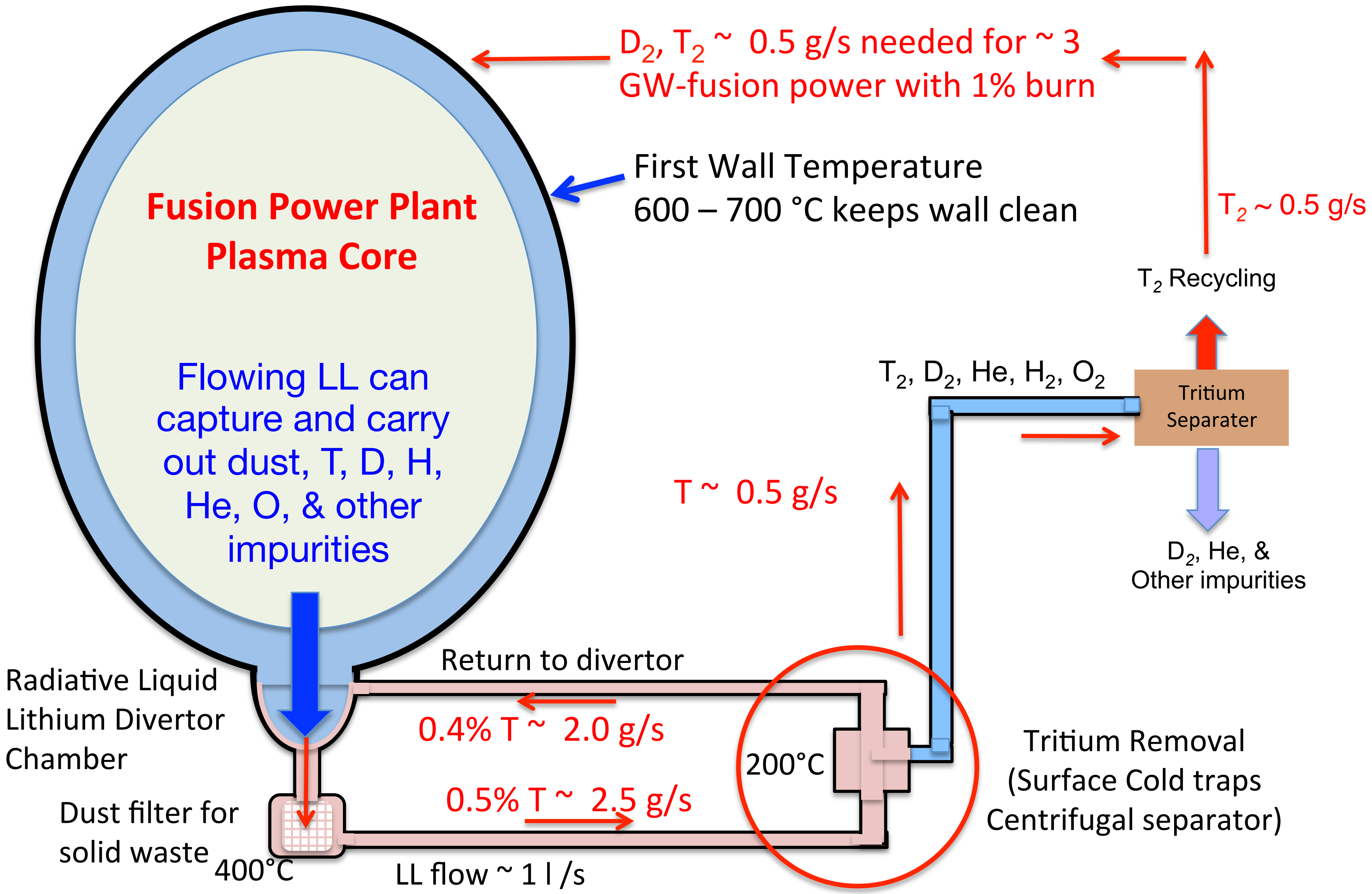
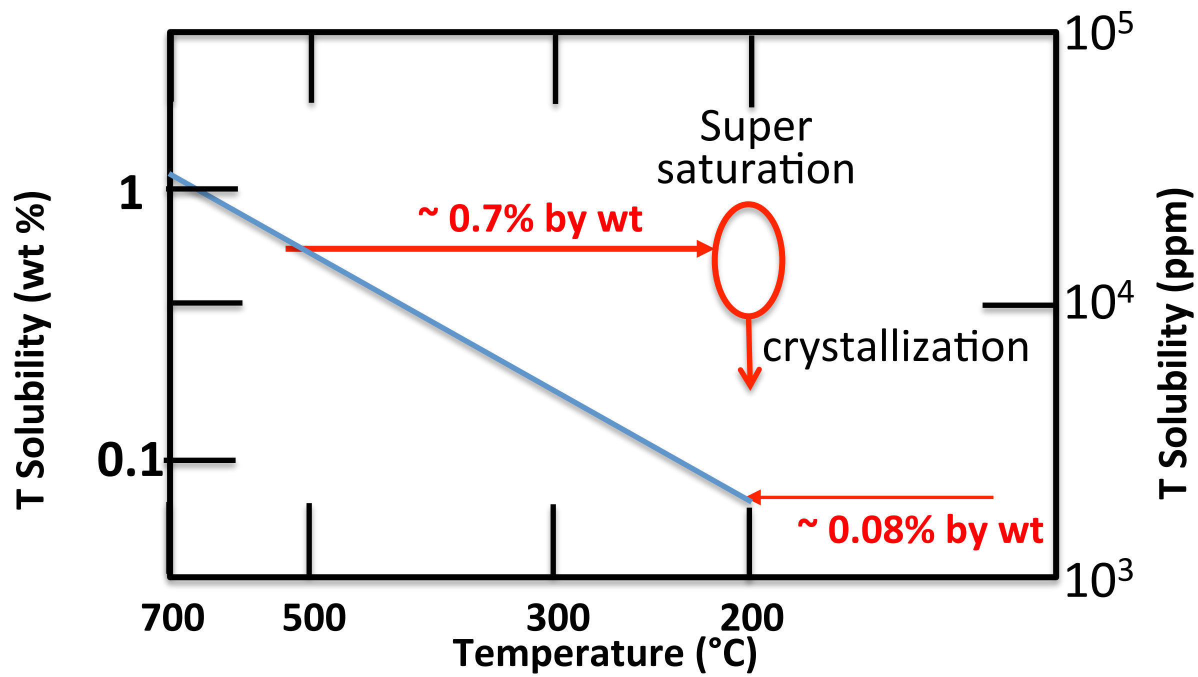


"Cold" Trap at 200 °C Could Remove T, D, H, and O

Cold trap can be regenerated at higher temperatures



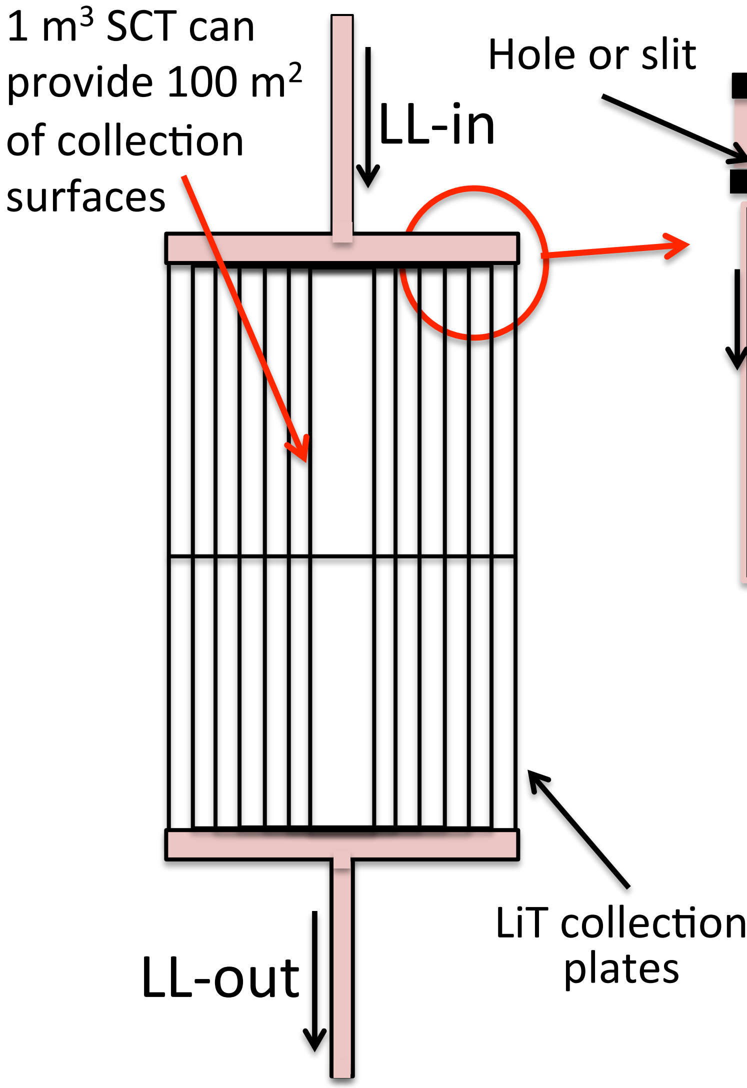
P.F. Adams JLCM 1975

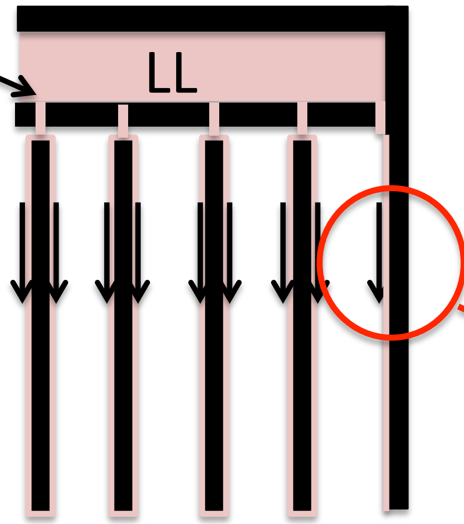
Surface crystallization in supersaturate solution

"rock candy"

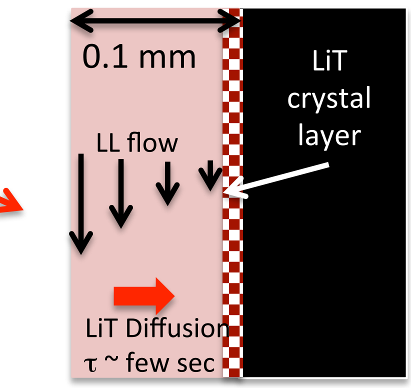
- At 200 °C, hydrogen can be reduced toward 0.08% level.
- Oxygen is also effectively reduced with cold trap (e.g., IFMIF).
- Nitrogen would require separate hot nitrogen trap if needed.

Surface Cold Trap (SCT) system to provide Large surface area to facilitate LiT crystallization





Flowing LL layer ~ 0.1 mm thick
Flow speed ~ 5 cm/s
Total LL volume ~ 10 l
Or 1% of SCT volume



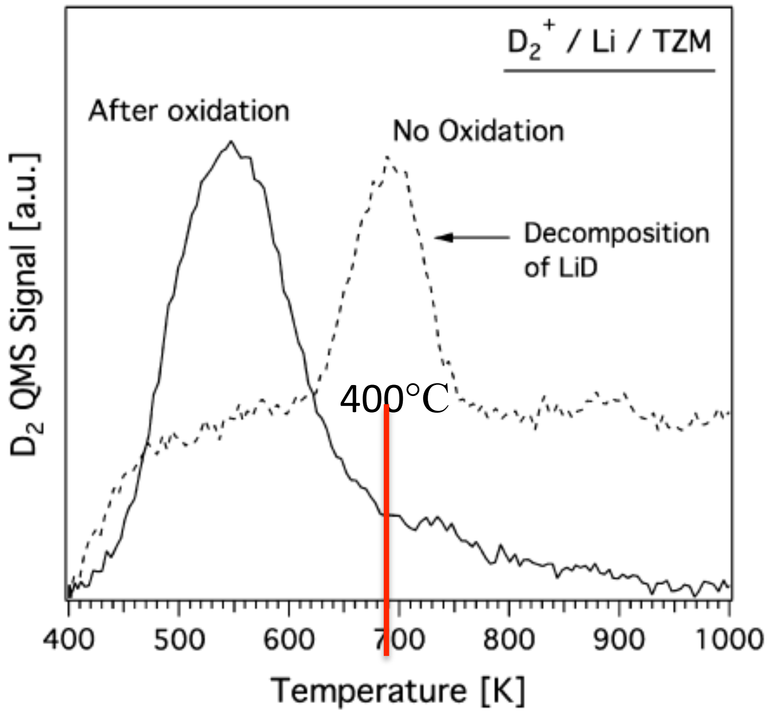
Advantage of SCT:

- Reduce the cold trap LL volume and T inventory.
- Facilitate LL draining and regeneration of T.
- Provide robust structural design regeneration cycle.
- Minimize probability of LL clogging.
- Facilitate the CT maintenance due to its simplicity.

Modest heating of SCT can release T from LiT

Release of D_2 shown by heating LiD film to ~ 400 - 600 °C

D_2 release from thin LiD film occurred at relatively lowTemperature ~ 400°C

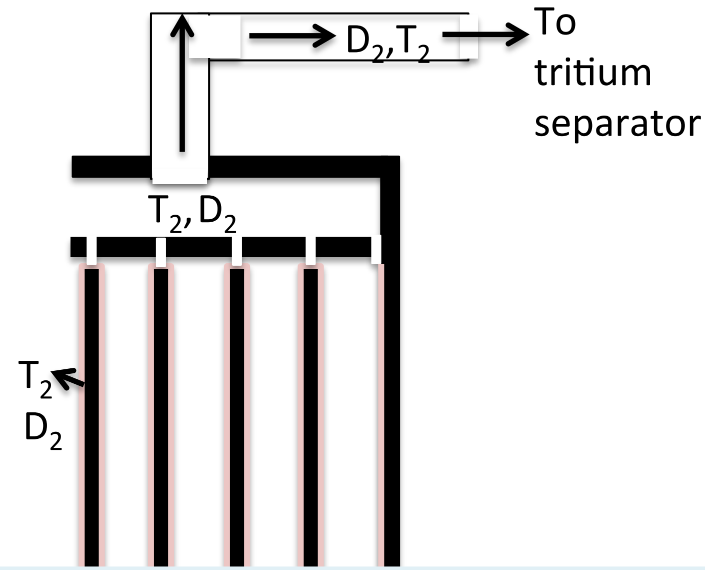


A.M. Capece, JNM (2015)

Similar observation by E. Oyarzabal et al., JNM (2015)

T recovery from SCT:

- The LL flow is diverted to another SCT.
- LL in the SCT is then drained
- The accumulated LiT on the surface of SCT is then heated to ~ 400 – 600°C to release T
- The released T pumped out for recovery.

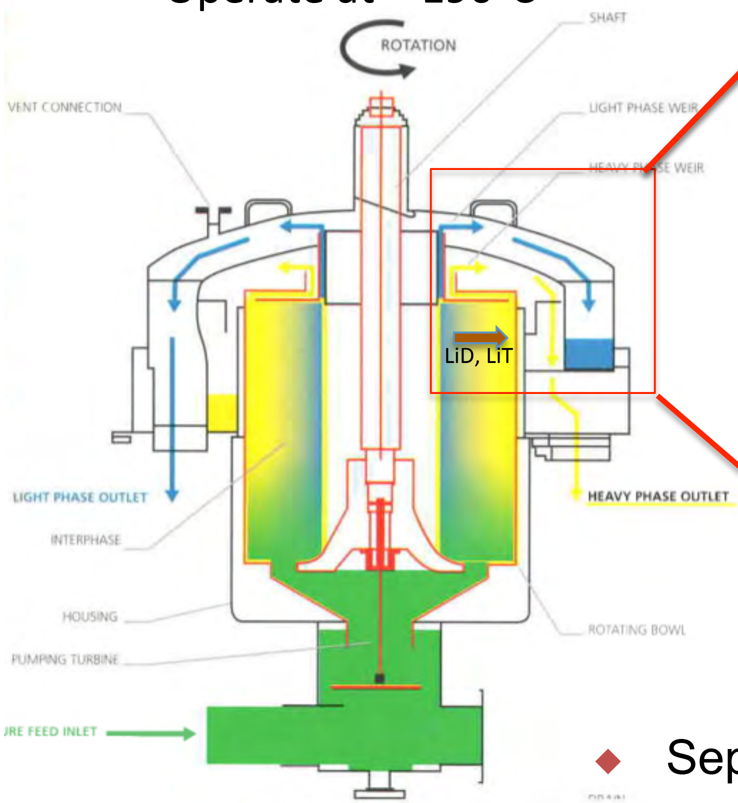


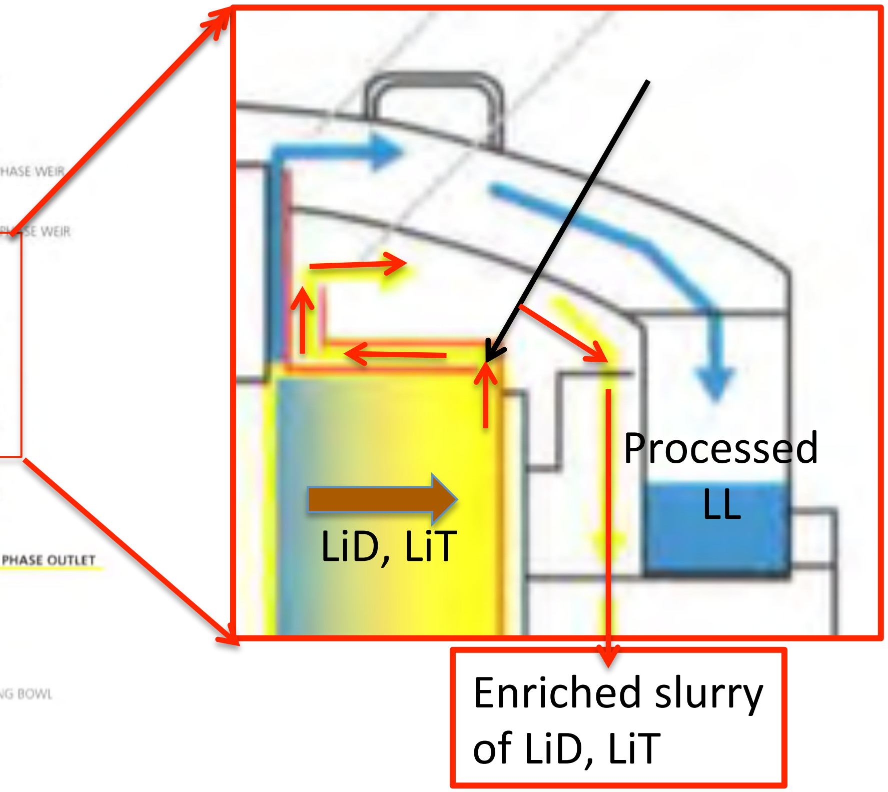
Quantification of Li-H crystallization and H-isotope release are being investigated in collaboration with University of Illinois – U.C.

Centrifugal separation of LiD, LiT also appears feasible

LiT, LiD ~ 1 g/cc is twice as heavy as LL ~ 0.5 g/cc

Centrifuge Separator
Operate at ~ 190°C



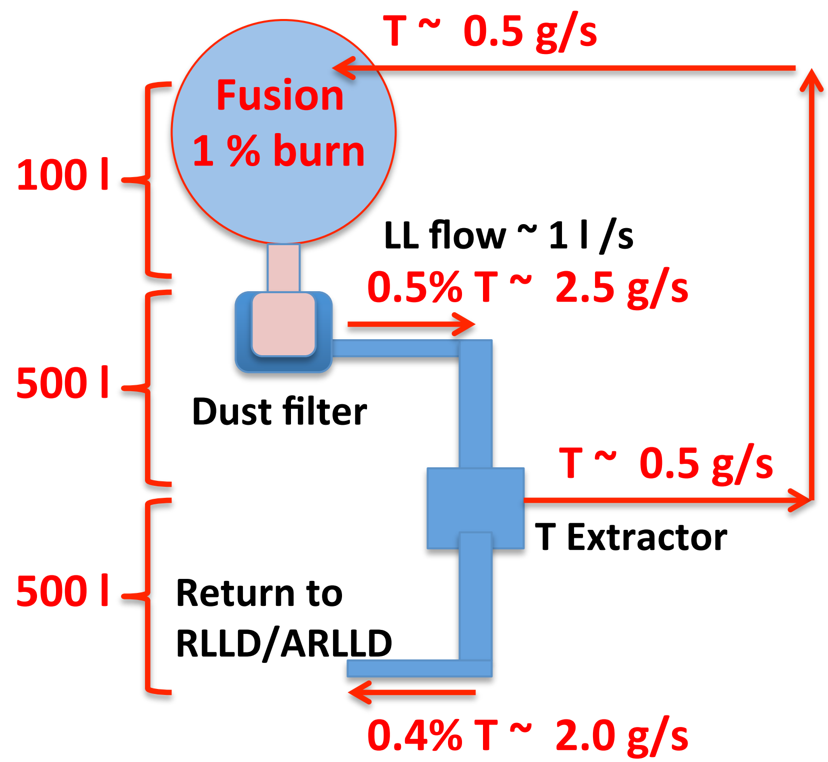


- Separation via cascaded centrifuges
  - Enriched slurry of LiD, LiT removed continuously at periphery
  - Need to prevent LiD, LiT accumulation
- Commercial units handle 60,000 liters/hour

Tritium (T) Inventory Control in Fusion Power Plant
~ 2.5 kg with 1100 l LL-loop system

T inventory in LL-loop system:

- 0.5 % (by weight) T concentration LL contains ~ 2.5 g of T / l
- LL inside VV may contain up to 100 l of LL or 0.25 kg
- LL in LL-loop before and in cold traps (~ 0.5%) may contain 500 l of LL or 1.25 kg
- LL after cold traps (~ 0.4%) may contain 500 l of LL or 1.0 kg
- Total tritium inventory in RLLD/ALLD may contains 2.5 kg of T.

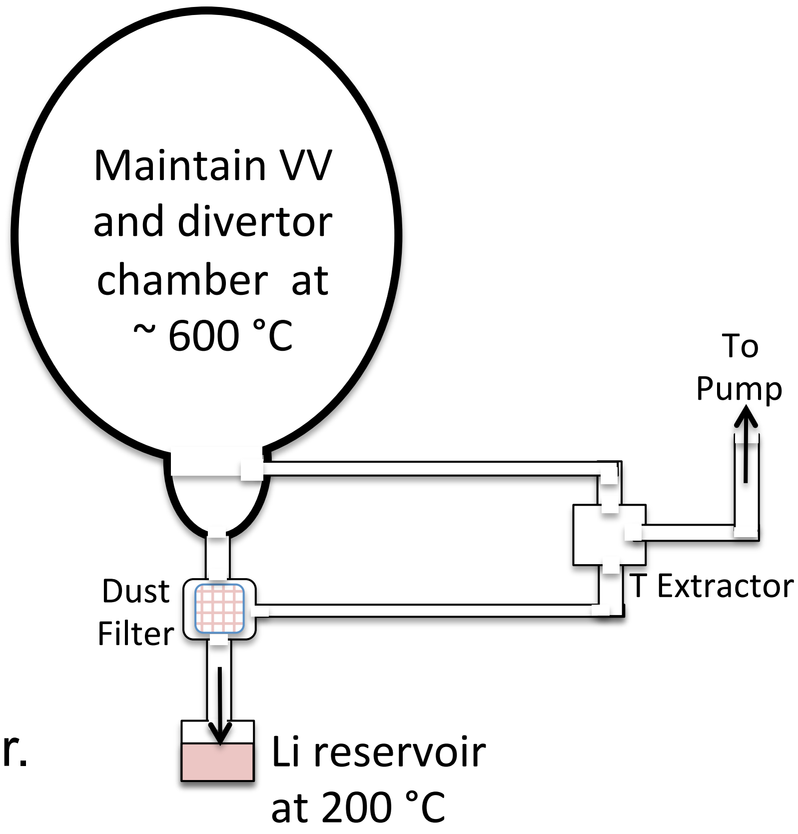


T inventory is quite manageable; ~ 2.5 kg with ~ 0.5% T in 1100 l LL system. Less with lower T%.

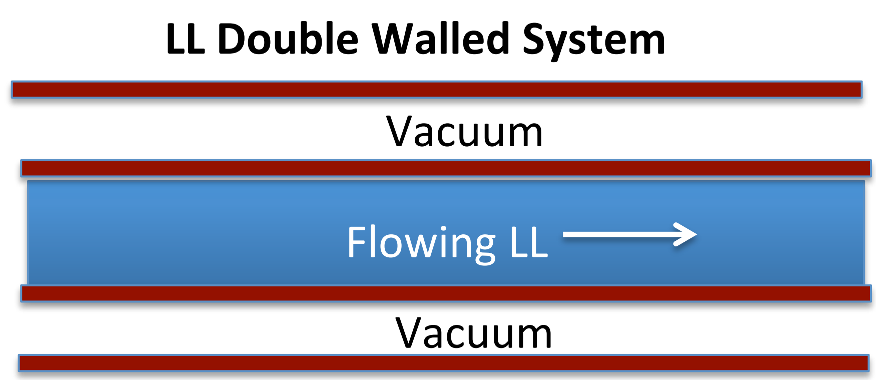
T % in VV	T(kg)
0.7	3.6
0.6	3.05
0.5	2.5
0.4	1.95
0.3	1.4

Li – T Clean-up Before Shutdown
In preparation for refurbishment/maintenance

- In preparation for shut down, drain LL into Li reservoir while keeping VV and divertor chamber at ~ 600 °C to release residual gas and Li.
- Continue pump and collect residual T released.
- Collect any residual Li into Li reservoir operating at ~ 200°C. Li vapor condenses on coldest surfaces which is the L reservoir.
- Shut down once all LL and T are collected.



Double walled for safety and tritium recovery
Also provide efficient thermal barrier



Double walled system for the LL loop system:

1. **Provide extra layer of safety protection. Should be able to detect the LL leak at early stage.**
2. **Vacuum provides good thermal insulation.**
3. **Any tritium migration into vacuum can be collected by the double walled system, essentially eliminating tritium loss from the system.**

Summary

- LL provides renewable surfaces and effective medium to protect high-Z divertor PFC substrates from steady-state and transient heat/particle flux in reactor.
- Lithium can provide an effective means of reducing divertor heat flux through non-coronal radiation without increasing recycling (RLLD and ARLLD)
- A modest LL-loop of ~ 1 l / sec could provide a means to remove dust/ impurities from reactor divertor chamber.
- The LL-loop system could provide an efficient way to remove tritium and control tritium inventory in fusion reactor.
- Surface cold trap and centrifugal systems are proposed for real time tritium removal in the LL-loop system.
- NSTX-U will conduct basic RLLD/ARLLD experiments in H-mode plasmas.
- LL-loop and T extraction R&D cam be performed with relatively modest investment.