Radiological Issues for Thin Liquid Wall Options

L. El-Guebaly, P. Wilson, and D. Henderson

Fusion Technology Institute
University of Wisconsin - Madison

With input from
M. Sawan, R. Peterson, I. Sviatoslavsky, E. Mogahed (UW),
R. Raffray (UCSD),
L. Waganer (Boeing),
W. Meier, R. Moir (LLNL),
S. Abdel-Khalik, M. Yuda (GT),
and D. Petti (INEEL)

ARIES Meeting

April 22 - 23, 2002

UW

THE UNIVERSITY of WISCONSIN MADISON

Objectives

- Develop activation approach for liquid wall supply methods:
  - Tangential injection
  - Porous wall injection
- Identify activation issues for candidate liquid wall (LW) materials:

Liquid Metals*	Molten Salts
LiPb	Flibe#
Pb	
Sn	

- Consider two extreme activation cases:
  - No mixing of LW material with breeder (worst case)
  - Mixing of LW material with breeder inside and outside chamber (proposed for ARIES-IFE-HIB)
- Develop design solutions for activation problems

* No major activation problems expected for Li

$(LiF)_2$, BeF_2. Flinabe (NaF, LiF, BeF_2) exhibits similar behavior

THE UNIVERSITY of WISCONSIN MADISON

Activation Assessment

- **Includes**:
  - Activity for safety analysis
  - Decay heat for LOCA/LOFA analysis
  - Waste management:
    - Means for waste minimization:
      - Use same liquid breeder for LW
      - Clean-up LW and reuse in other devices
      - Clear from radiologically controlled area if Clearance Index < 1 (unlikely)
    - Waste disposal in repositories:
      - Generate only low level waste (LLW) to meet ARIES requirements
      - Any high level waste (HLW)?

THE UNIVERSITY of WISCONSIN MADISON

LW and Breeder Options

Blanket:

Liquid breeders:

- LiPb*
- Flibe□
- Flinabe
- Li#
- LiSn

Solid breeders:

- Li_2O**, Li_2ZrO_3, Li_4SiO_4, Li_2TiO_3, $LiAlO_2$

Candidate LW Materials

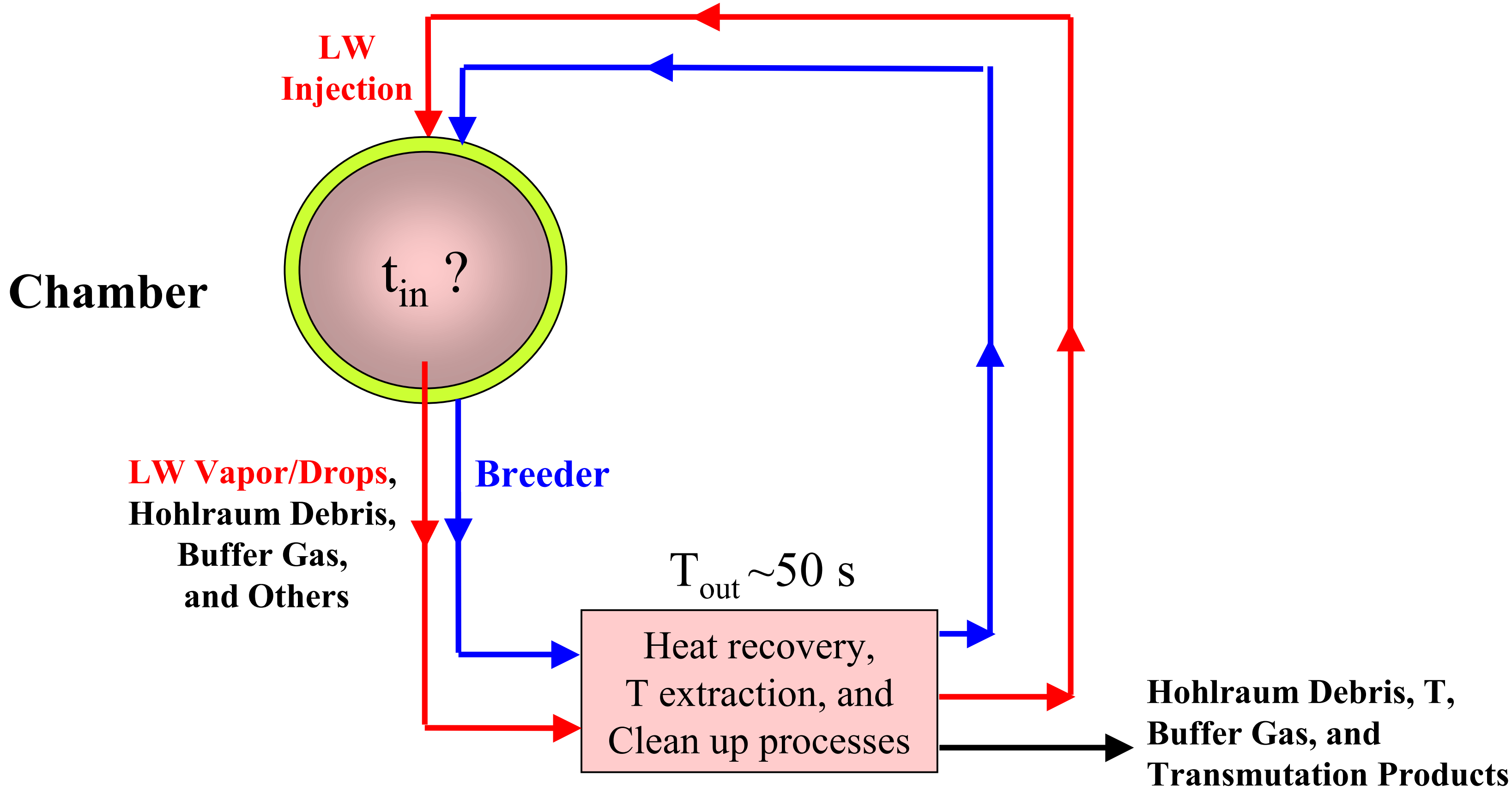
Preferred	Backup
LiPb*	Pb
Flibe□	
Flinabe	
Li#	Ga
LiSn	Sn
Pb**	Sn, Ga

Recommendation: Use same breeder for LW to minimize waste

* HIBALL (UW-1981), HIBALL-II (UW-1984), LIBRA (UW-1990), LIBRA-SP (UW-1995)
□ OSIRIUS (LLNL-1992)
LIBRA-LiTE (UW-1991)
** Prometheus (MDC-1992)

THE UNIVERSITY of WISCONSIN MADISON

LW Cycle

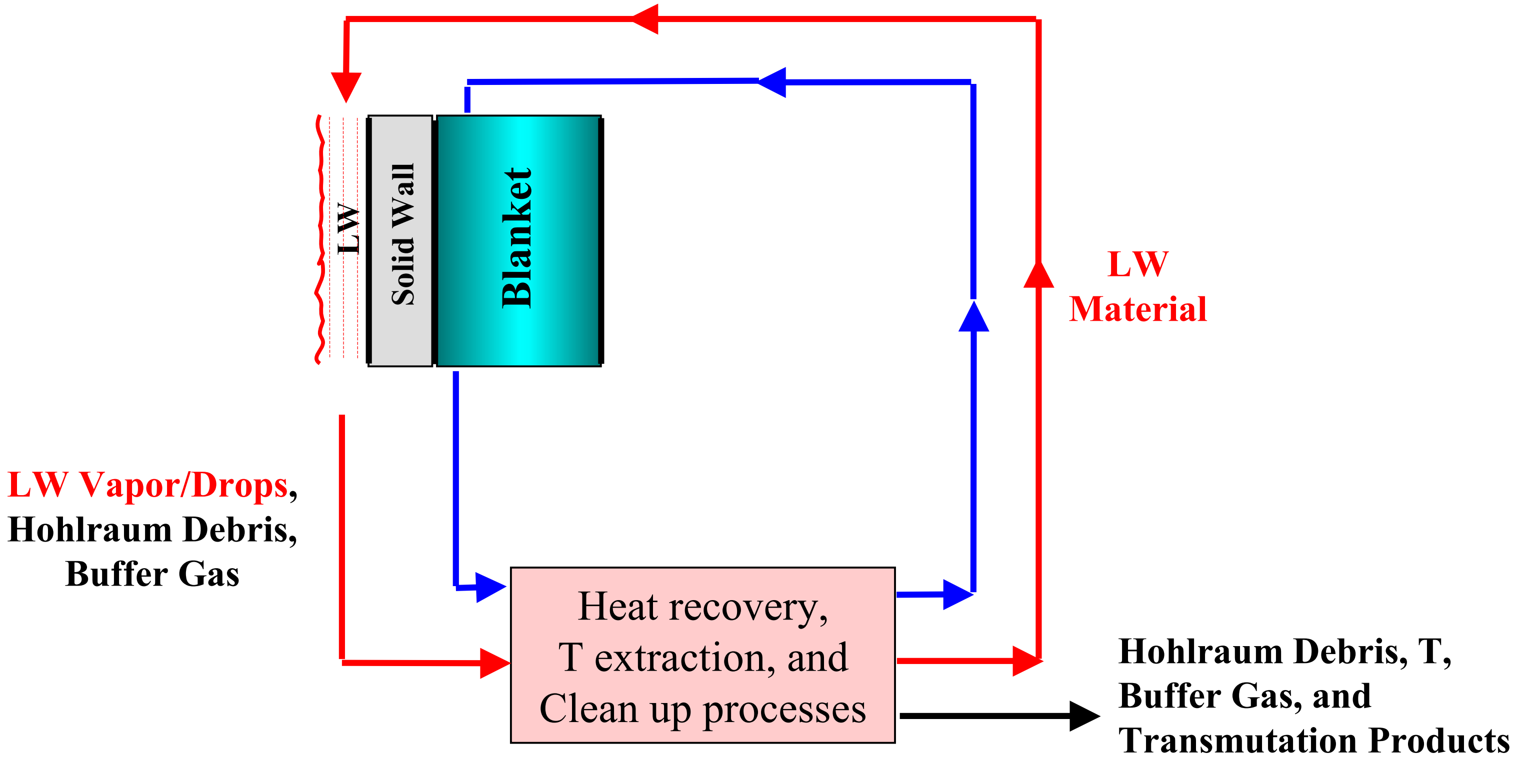


Ex-chamber residence time ≈ 50 s, per Waganer

In-chamber residence time for LW is unknown ⇒ parameterize it

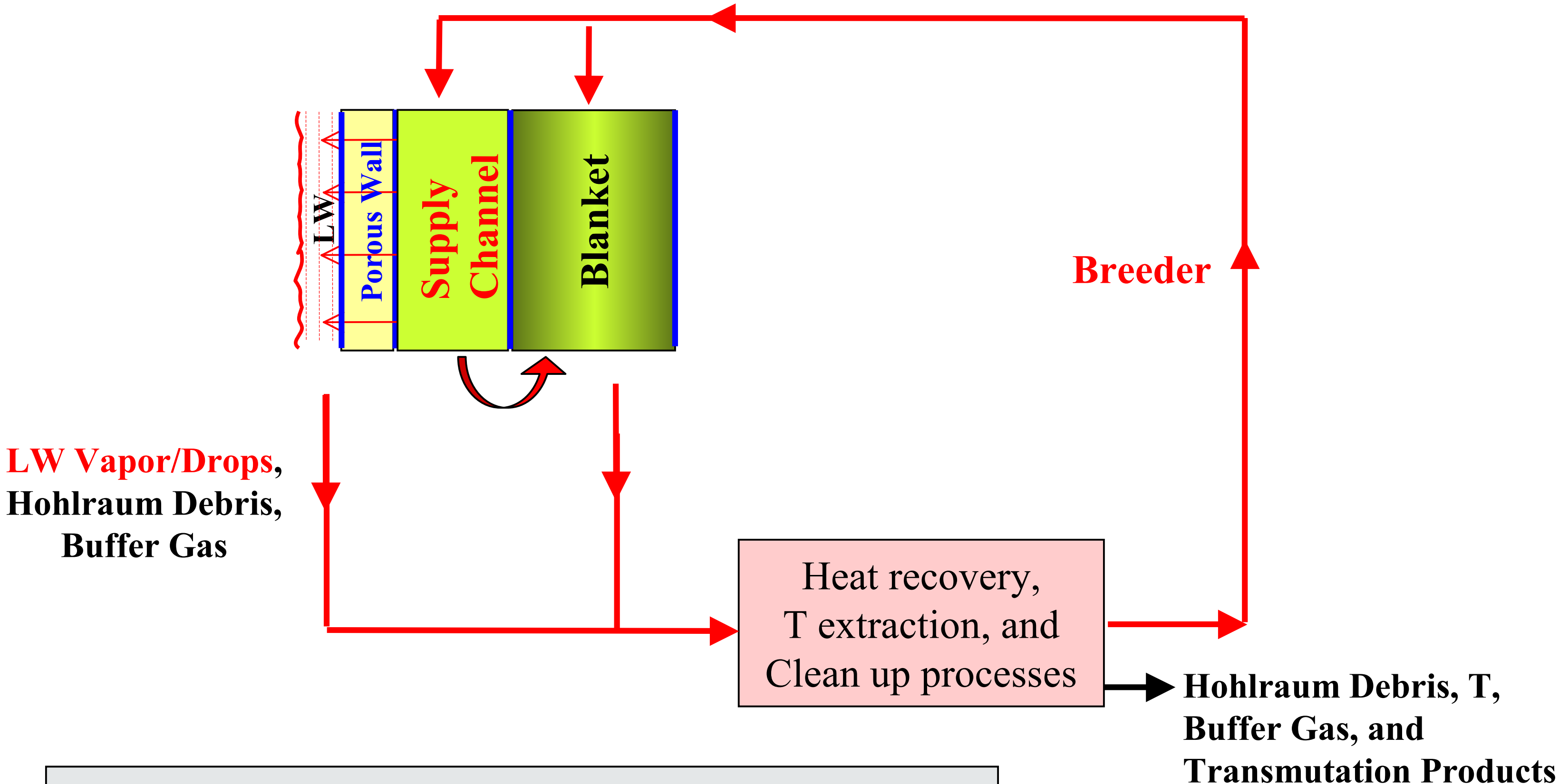
THE UNIVERSITY of WISCONSIN MADISON

Tangential Injection Option



No outside mixing of LW with breeder

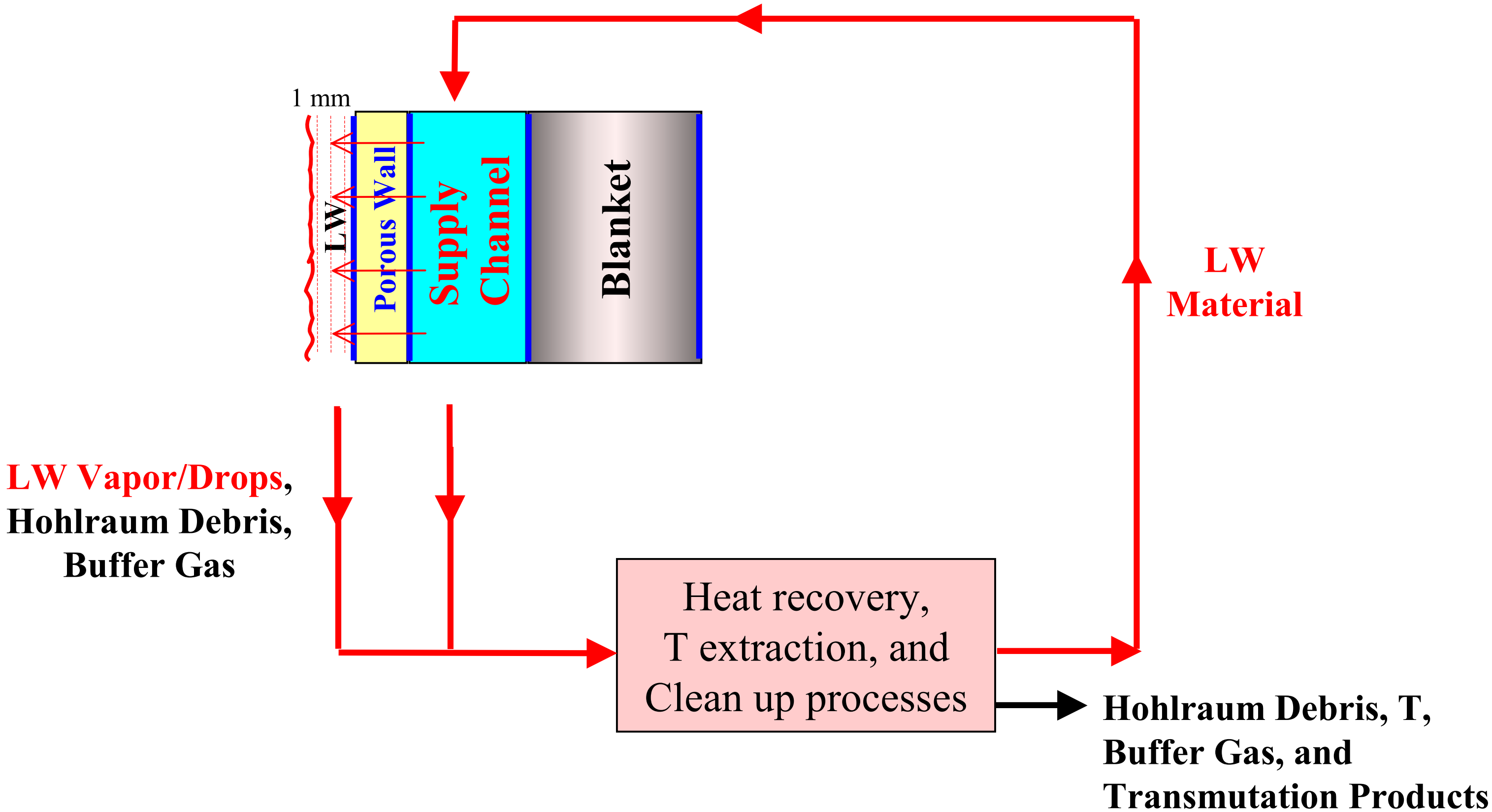
Porous Wall Injection - Option I
(Liquid Breeder Blanket - Proposed for ARIES-IFE)



Use same breeder for LW to minimize waste

Route breeder exiting supply channel through blanket to increase ΔT and enhance thermal conversion efficiency

Porous Wall Injection - Option II
(Solid Breeder Blanket - Prometheus type)



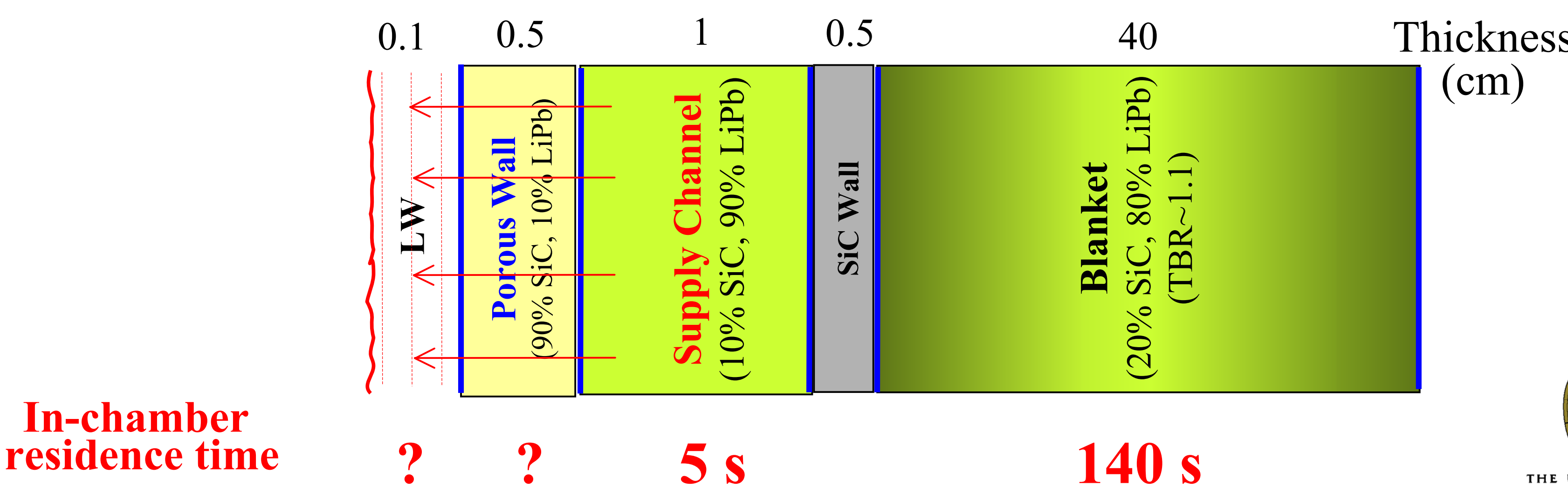
No mixing with solid breeder outside chamber (Prometheus type)

THE UNIVERSITY of WISCONSIN MADISON

Representative Radial Build for LiPb Breeder Using ARIES-AT Design Rules

- SiC/SiC composite structure and LiPb LW/coolant/breeder
- Design parameters (per Raffray):

SiC T_{max}	1000 □°C
Surface heat flux	$\leq$ 1 MW/m^2
$\Rightarrow$ Chamber radius	$\geq$ 6 m
LiPb ΔT	200-300 °C
LiPb velocity	4-6 m/s
LiPb T_{max}	1100 □°C
LW Thickness	1 mm



Activation Parameters and Assumptions

- Perkins' neutron spectrum for HIB target (av. E_n=11.75 MeV)
- Parameters:

Target yield	458.7 MJ
Rep rate	4 Hz (0.25 s between pulses)
Chamber radius	6 m
Neutron wall loading	2.8 MW/m^2
Plant lifetime	40 FPY
Availability	85%

- In-chamber residence time for LW depends on evaporation and condensation processes. LW may survive thousands of pulses before being processed and re-injected into chamber

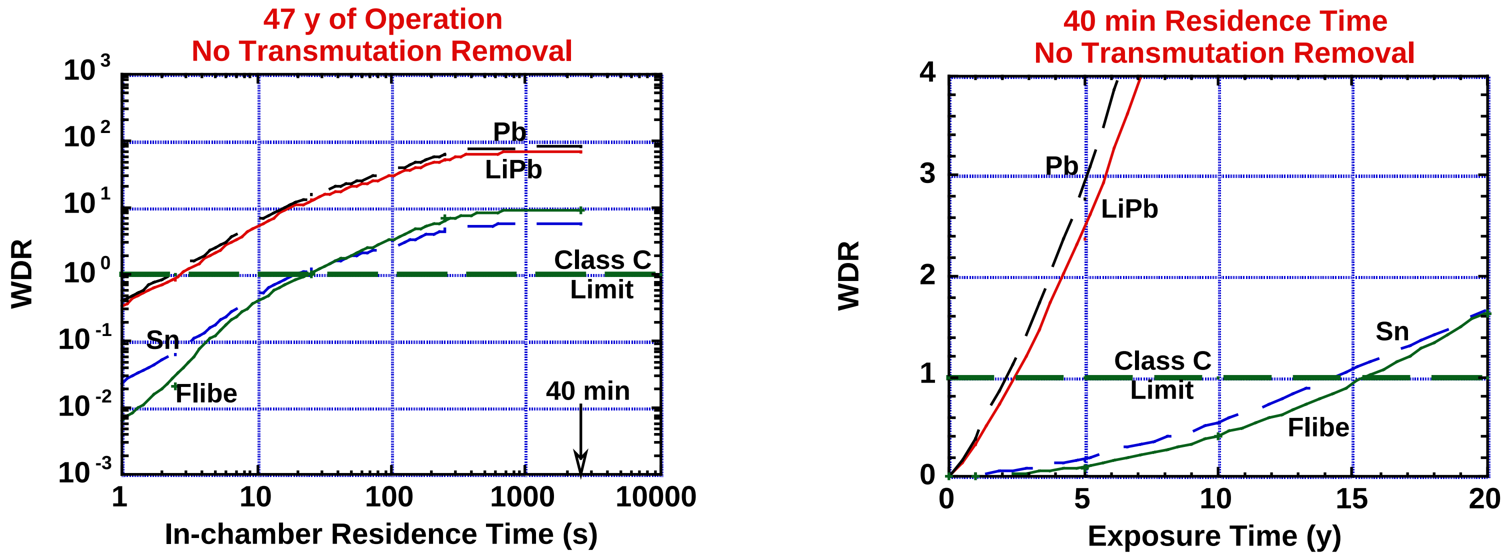
⇒ Parameterize in-chamber residence time between 0.25 s (1 pulse) and several tens of minutes (~10,000 pulses)

- Impurities included in all materials
- LW materials only. No target debris
- Same radial build used for all LW candidates
- No mixing during operation. Mixing with breeder @ EOL*
- Waste disposal rating (WDR) evaluated at 100 y after operation using Fetter's limits for LiPb, Pb, and Sn and NRC-10CFR61 limits for Flibe and Flinabe
- Exact model of **all** pulses using ALARA pulsed activation code

* Conservative assumption

THE UNIVERSITY of WISCONSIN MADISON

WDR - Tangential Injection
(No Outside Mixing with Breeder)



- WDR increases with LW residence time and saturates at ~ 40 min
- LW materials generate tons of **HLW** unless residence time and/or exposure time are controlled
- Sn and Flibe have lower WDR compared to Pb and LiPb
- **To reuse materials in other devices or dispose as LLW waste**:
  - Limit LW service life ⇒ higher inventory. Use fresh LiPb and Pb after 2-3 y and fresh Sn and Flibe after 14-16 y if in-chamber residence time ≥ 40 min (Bi impurity control below 43 wppm helps prolong LiPb/Pb service lifetime),
  - Or, control in-chamber residence time to ≤ 2-3 s for Pb/LiPb and 20-25 s for Sn/Flibe
  - Or, filter out cup(s) of transmutation products and dispose as **HLW**

THE UNIVERSITY of WISCONSIN MADISON

WDR - Tangential Injection - Cont.

(No Outside Mixing with Breeder)

WDR ≤ 1

No Transmutation Removal

	WDR*	Option I: Max Residence Time	Option I: Exposure Time	Option II: Residence Time	Option II: Max Exposure Time
LiPb	69	3 s	47 y	≥ 40 min	2.5 y
Pb	81	2.5 s	47 y	≥ 40 min	2.2 y
Sn	6	20 s	47 y	≥ 40 min	14.4 y
Flibe	9	25 s	47 y	≥ 40 min	15.6 y

On-line removal of transmutation products relaxes limits on residence/exposure times, thus reduces EOL inventory, but generates cup(s) of **HLW**

* ≥ 40 min in-chamber residence time and 47 y of operation

THE UNIVERSITY of WISCONSIN MADISON

WDR - Porous Wall Injection
(Outside Mixing with same Breeder)

- Example: Liquid breeder used in all components. Proposed for ARIES-IFE
- Blanket controls volumetric average WDR
- WDR is not sensitive to in-chamber residence time of LW
- Results for 47 y of operation:

	WDR*
LiPb	**10**
Flibe	**0.8**

- No waste disposal problem identified for Flibe even without clean-up system
- To reuse LiPb in other devices or dispose as LLW, filter out cup(s) of transmutation products and dispose as **HLW**
- Do not limit exposure time for sizable breeders (> 1000 tons)

* No transmutation removal.

THE UNIVERSITY of WISCONSIN MADISON

WDR - Porous Wall Injection
(No Outside Mixing with Breeder - Prometheus-type)

- Example: Solid breeder blanket with Pb (or Sn) seeping from supply channel through porous wall
- 1 mm thick LW controls volumetric average WDR#
  - ⇒ Need more accurate evaluation for in-chamber residence time
- Results for ≥ 40 min residence time and 47 y of operation:

	WDR*
Pb	**14**
Sn	**0.94**

- No waste disposal problem identified for Sn even without clean-up system
- Without LW contribution, WDR of Pb in supply channel is ~2 ⇒ **HLW**
- To reuse Pb in other devices or dispose as LLW, filter out cup(s) of Bi and dispose as **HLW**

* No transmutation removal

86% from LW and 14% from supply channel

Main Contributors to WDR

LiPb, Pb	^{208}Bi
Sn	^{108m}Ag, ^{121m}Sn, ^{126}Sn
Flibe	^{14}C

THE UNIVERSITY of WISCONSIN MADISON

Conclusions

- Employ same breeder for LW to minimize waste volume
- Tangential injection case without clean-up system:
  - All LW materials generates **HLW** if in-chamber residence time exceeds 2-25 s, depending on materials
- Porous wall injection case without clean-up system :
  - No waste disposal problems identified for Sn and Flibe
  - LiPb and Pb generate **HLW** if employed for 47 y
- On-line clean-up system removes cup(s) of transmutation products (**HLW**) and allows tons of LW materials to be reused in other devices or disposed as LLW
- Some results are sensitive to in-chamber residence time that is unknown and needs to be determined

THE UNIVERSITY of WISCONSIN MADISON