

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)

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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*

LiPb

Pb

Sn

Molten Salts

Flibe[#]

- **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, BeF₂. Flinabe (NaF, LiF, BeF₂) exhibits similar behavior



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)?



LW and Breeder Options

Blanket:

Liquid breeders:

LiPb*

Flibe[□]

Flinabe

Li[#]

LiSn

Candidate LW Materials

Preferred

Backup

LiPb*

Pb

Flibe[□]

Flinabe

Li[#]

Ga

LiSn

Sn

Recommendation: Use same breeder for LW to minimize waste

Solid breeders:

Li₂O**, Li₂ZrO₃, Li₄SiO₄,

Li₂TiO₃, LiAlO₂

Pb**

Sn, Ga

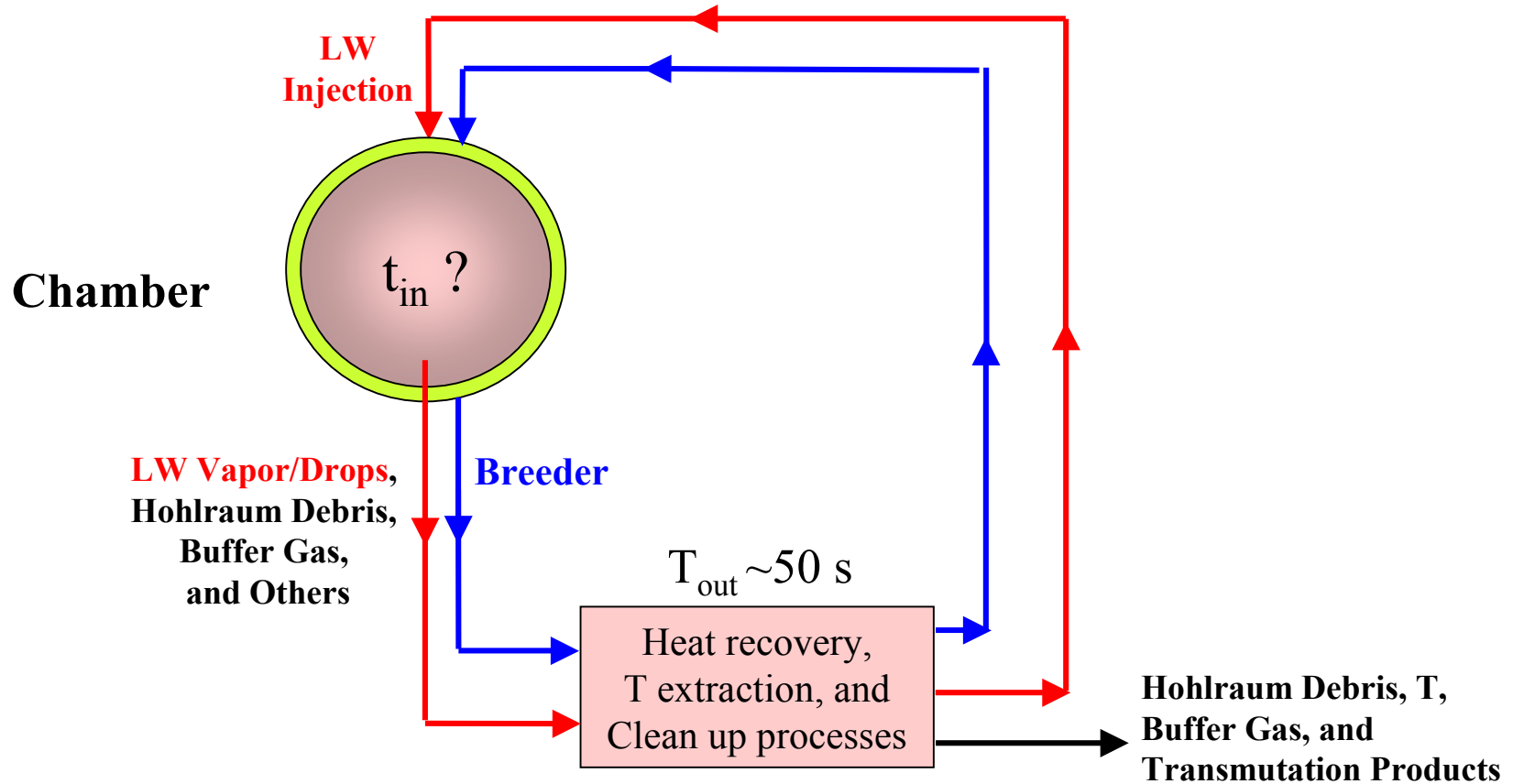
* HIBALL (UW-1981), HIBALL-II (UW-1984), LIBRA (UW-1990), LIBRA-SP (UW-1995)

□ OSIRIUS (LLNL-1992)

LIBRA-LiTE (UW-1991)

** Prometheus (MDC-1992)

LW Cycle

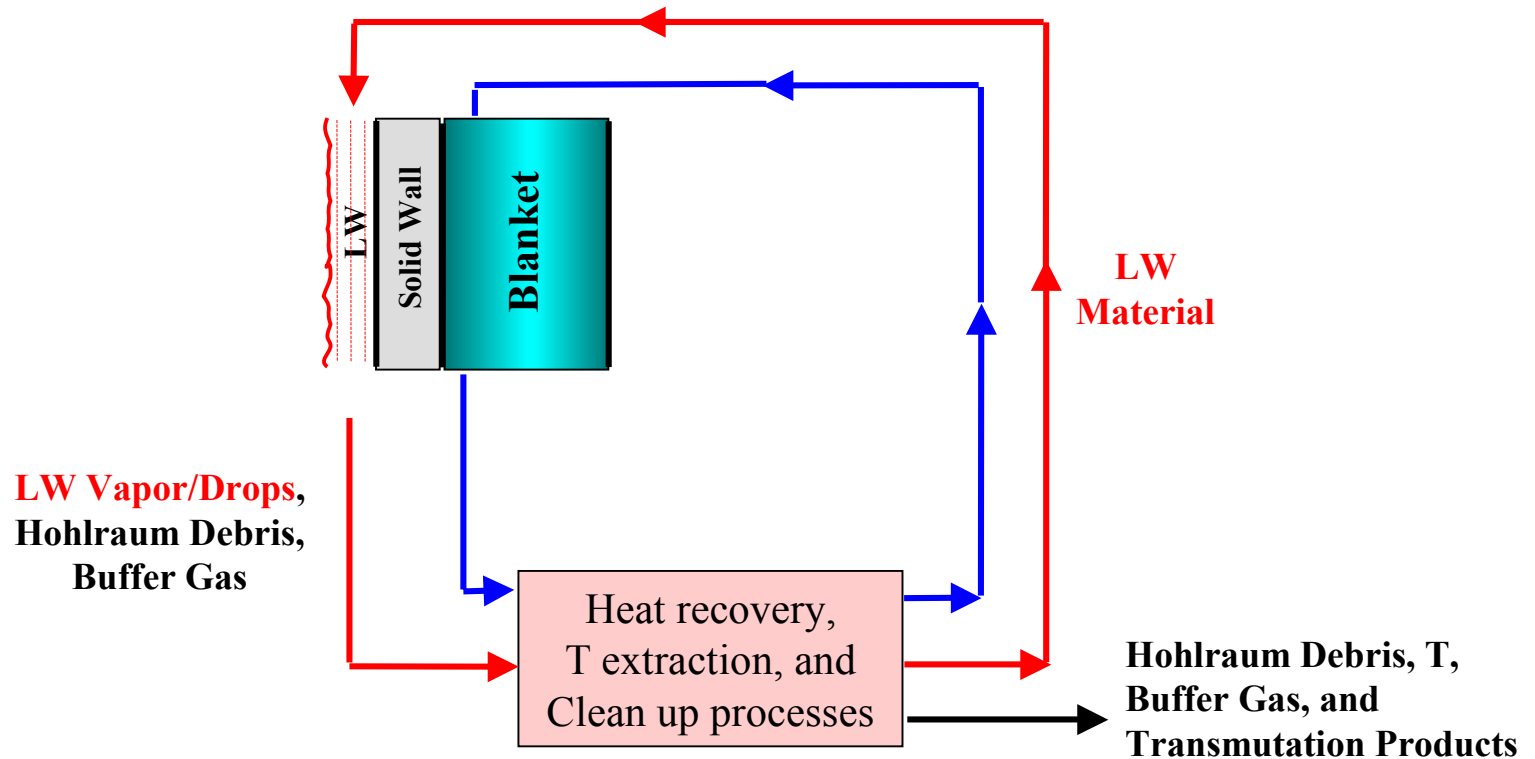


Ex-chamber residence time $\approx 50 \text{ s}$, per Waganer

In-chamber residence time for LW is unknown \Rightarrow parameterize it

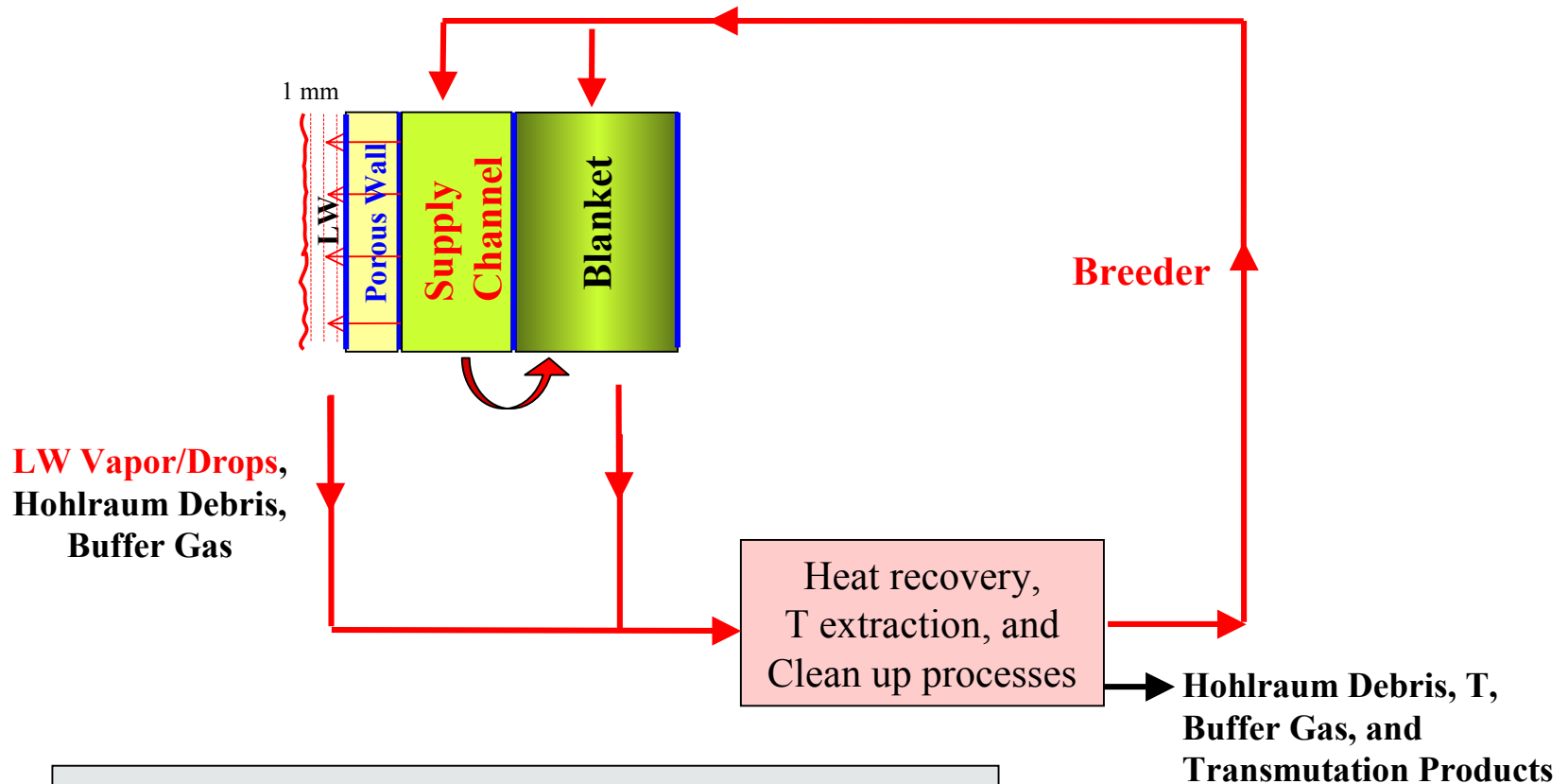


Tangential Injection Option



No outside mixing of LW with breeder

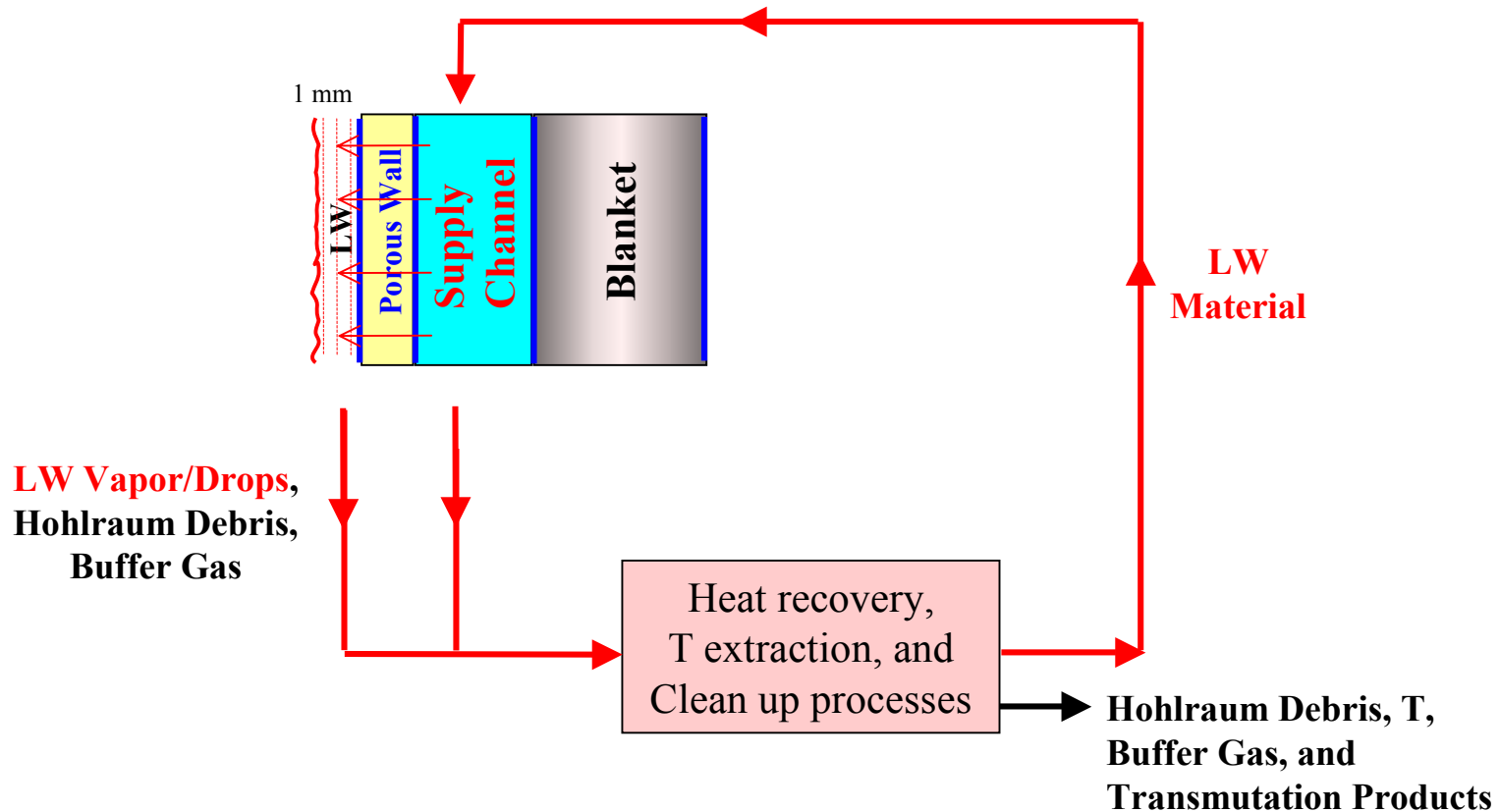
Porous Wall Injection - Option I (Liquid Breeder Blanket - Proposed for ARIES-IFE)



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)

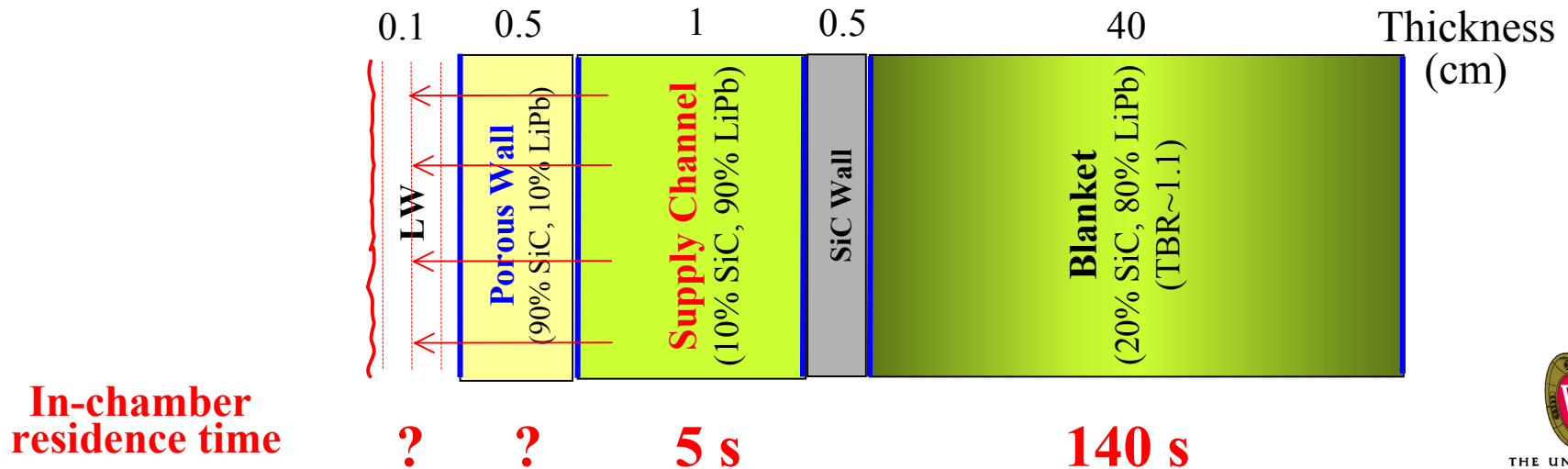


No mixing with solid breeder outside chamber (Prometheus type)

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	$\leq 1 \text{ MW/m}^2$
⇒ Chamber radius	$\geq 6 \text{ m}$
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:**

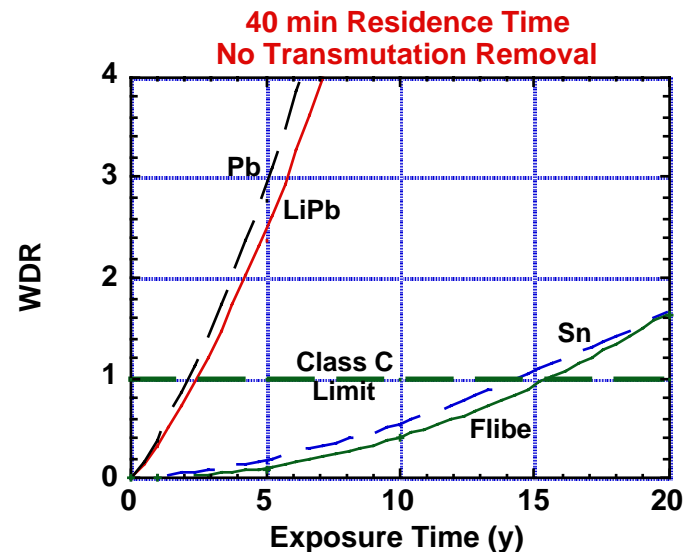
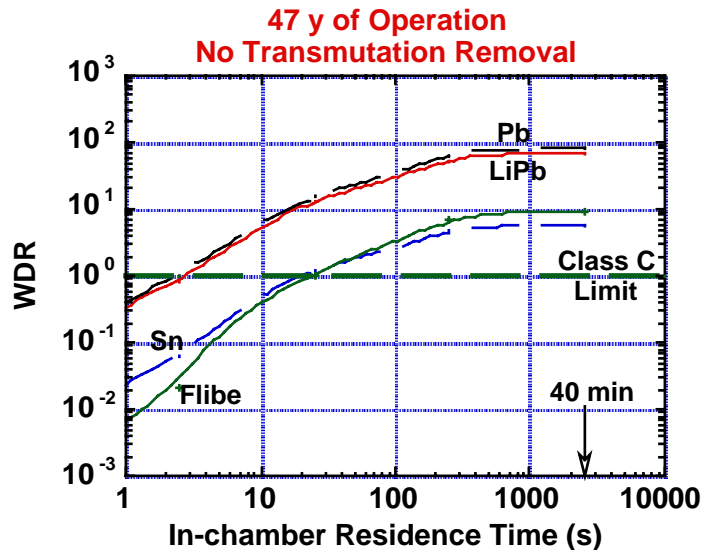
Target yield	458.7 MJ
Rep rate	4 Hz (0.25 s between pulses)
Chamber radius	6 m
Neutron wall loading	2.8 MW/m ²
Plant lifetime	40 FPY
Availability	85%
- **In-chamber residence time for LW depends on evaporation and condensation processes. LW may survive thousands of pulses** before being processed and 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

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 \Rightarrow 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**



WDR - Tangential Injection - Cont.

(No Outside Mixing with Breeder)

$$\text{WDR} \leq 1$$

No Transmutation Removal

WDR*		<u>Option I</u>		<u>Option II</u>	
		Max Residence Time	Exposure Time	Residence Time	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



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:

	<u>WDR*</u>
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.

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:

	<u>WDR*</u>
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 $\sim 2 \Rightarrow$ **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

$^{108\text{m}}\text{Ag}$, $^{121\text{m}}\text{Sn}$, ^{126}Sn

Flibe

^{14}C

Conclusions

- Employ same breeder for LW to minimize waste volume
- Tangential injection results in higher WDR than porous wall injection
- 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

