

Recycling of Target Materials vs. One-Shot Use Scenario

L. El-Guebaly
and

P. Wilson, D. Henderson, A. Varuttamaseni

Fusion Technology Institute
University of Wisconsin - Madison

ARIES Project Meeting
October 2-4, 2002
PPPL



Objectives

- Update target recycling analysis for thick liquid wall concept.
- Identify pros and cons for recycling and one-shot use options.
- What is the preferred option for ARIES-IFE-HIB power plant?

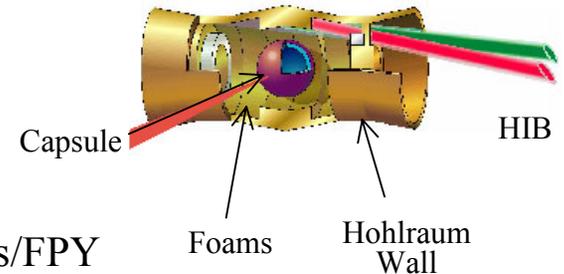
Metrics: Activation (WDR and Clearance)

Overall cost

Design complexity

HIB Target Parameters

Capsule Radius*	2.34 mm
Hohlraum Wall Thickness*	15 μm
Target yield	458.7 MJ
Rep Rate	4 Hz
# of Shots	126 million shots/FPY
Plant Lifetime	40 FPY (47 y)
Availability	85%
Volume of Hohlraum Wall	0.0085 $\text{cm}^3/\text{target}$ 1.1 m^3/FPY 43 $\text{m}^3/40 \text{ FPY}$
Mass of Hohlraum Materials	3-21 tons/FPY 120-830 tons/40 FPY



**LLNL Close-Coupled
Target Design**

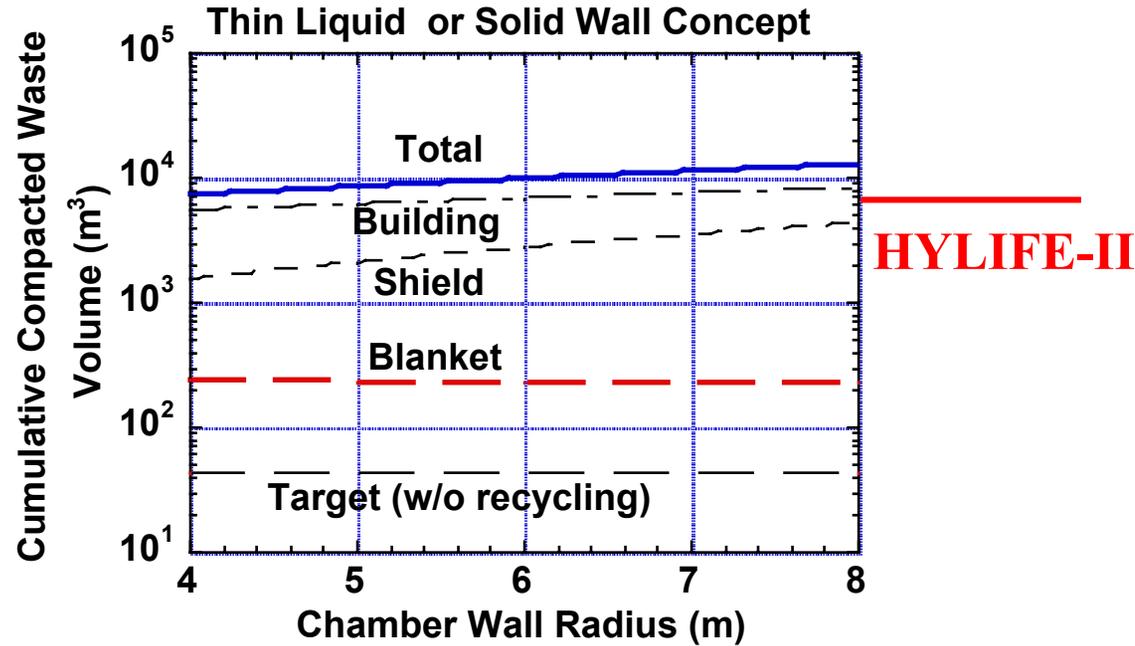
* D. Callahan-Miller and M. Tabak, Phys of Plasmas, Vol 7, p 2083, May 2000

Selection Criteria for Hohlraum Wall Materials

- Target performance
- Fabricability (and complexity)
- Separability from Flibe
- **Waste inventory**
- **Activation and waste disposal**
- **Unit cost and overall cost.**

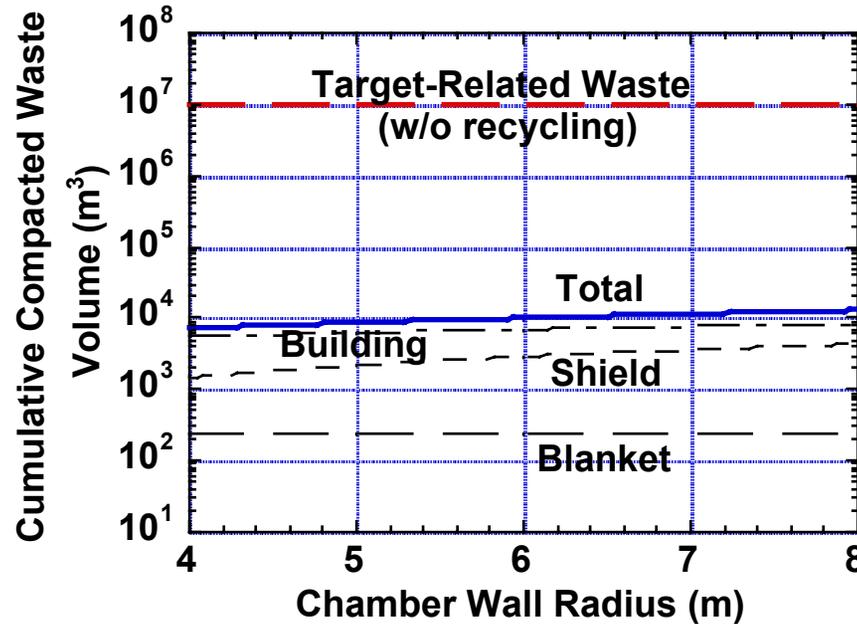


Hohlraum Wall Materials Represent <1% of IFE-HIB Waste Stream



Recycling is not a “must” requirement for ARIES-IFE-HIB unless materials have cost/resource problems (e.g., Au and Gd)

Example of IFE System Mandating Target Recycling



**Target-related waste exceeds building's by orders of magnitude
⇒ Recycle target-related materials**

Recycling Introduces Problems

- Produces high level waste (**HLW**) for most materials
 - Mandates **remote handling** in target fab (costly and slow process)
 - Requires **radioactive storage** system
- ⇒ **Recycling adds cost and complexity** to target fab. and design, and may violate ARIES top-level requirements

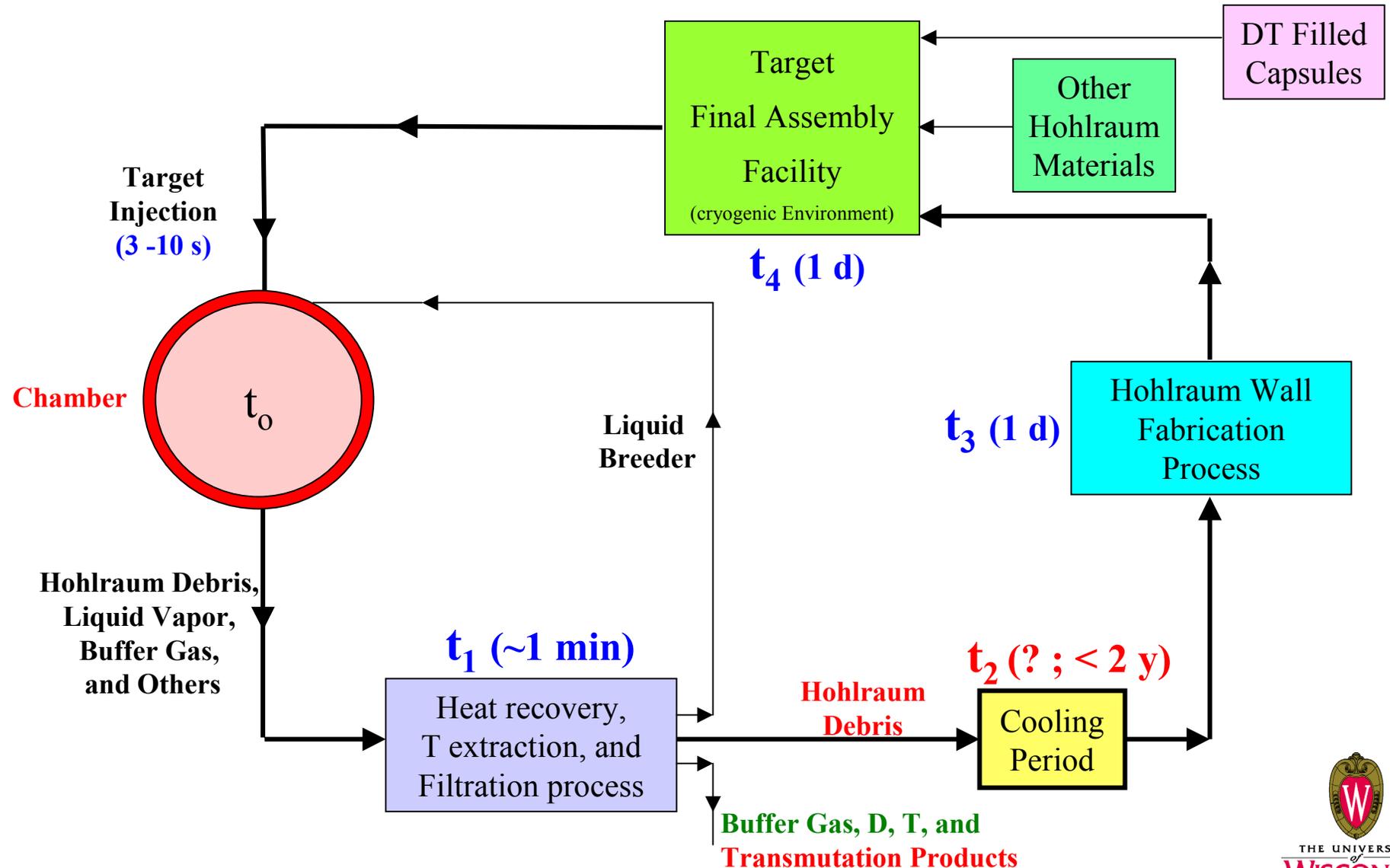


ARIES Design Requirements

Waste disposal rating (WDR)	1
Recycling dose [#]	3000 Sv/h
Accident dose at site boundary	1 rem

Radiation degrades optical, electric, mechanical, and physical properties of sensitive elements such as cables, electrical connectors, coatings, detectors, insulators, cameras, sensors, etc.

Cooling Period Controls WDR and Dose



Without cooling period, Recycling Generates High Level Waste Except for W, Ta, and Xe

<u>Candidate Hohlraum Materials</u>	<u>One-Shot WDR</u>	<u>Recycling WDR*</u>
Gold/Gadolinium (reference)	2×10^{-8}	3×10^5
Gold	0	645
Tungsten	2×10^{-6}	0.6
Lead	2×10^{-5}	31
Mercury	5×10^{-4}	11
Tantalum	0	0.5
Lead/Tantalum/Cesium	1×10^{-5}	13
Mercury/Tungsten/Cesium	2×10^{-4}	5
Lead/Hafnium	8×10^{-5}	24
Hafnium	3×10^{-4}	1.2
Solid Kr	0.01	68
Solid Xe	2×10^{-5}	0.2

* No cooling period. No transmutation products removal

All materials qualify as **Class A** (or C) LLW after one shot

Gd produces HLW shortly after operation (10 shots)

Several One-shot Use Materials Could be Released to Commercial Market After Storage Period

One-Shot Use Hohlräum Materials

Storage Period

(CI < 1 @ end of storage period)

Au	25 y
Ta	25 y
Hg	32 y
Hg/W/Cs	142 y
W	175 y
Au/Gd	225 y

Others cannot be released to commercial market for having high Clearance Index $\gg 1$ even after long storage period

At present, no US market exists for cleared metals



Cooling Periods ≤ 18 days Meet Both WDR and Dose Requirements[#]

Au/Gd	> 2 y
Au	12 d
W	6 d
Pb	13 d
Hg	5 d
Ta	1 d
Pb/Ta/Cs	17 d
Hg/W/Cs	18 d
Pb/Hf	12 d
Hf	2 d
Solid Kr	250 d
Solid Xe	7 d

[#] 47 y of operation. No transmutation products removal.

No significant inventory reduction if cooling period exceeds 2 y (e.g., Gd)

On-line removal of transmutation products shortens cooling period and may allow recycling of Gd

Economic Impact[#] of Hohlräum Materials (Close-coupled Target)

Hohlräum Materials	Relative Energy Loss ^{**} to Höhl. Wall	Driver Energy ^{##} (MJ)	Driver Cost [#] (\$B)	Change in Direct Cost [#] (\$B)	Change in COE ^{#,*} (mills/kWh)	
					w/o Recycling	w/ Au and Gd Recycling
Au/Gd (\$80M/y)	1	3.3	2.03	0	0 + Au/Gd cost	0 + recycling cost
Pb/Ta/Cs	1.01	“	“	“	0	0
Pb/Hf	1.04	3.4	2.06	0.03	0.4	0.4
Hg/W/Cs	1.04	“	“	“	“	“
Au (\$210M/y)	1.25	3.7	2.16	0.13	1.8 + Au cost	1.8 + recycling cost
Ta	1.25	“	“	“	1.8	1.8
W	1.25	“	“	“	“	“
Hg	1.26	“	“	“	“	“
Pb	1.28	“	“	“	“	“

Courtesy of W. Meier (LLNL), Feb. 2001.

** Ref: D. Callahan-Miller and M. Tabak, Phys of Plasmas (Vol 7, p 2083, May 2000).

D Callahan-Miller (LLNL), personal communication (Feb. 2001).

* Using same target cost for all hohlräum materials.

Excessive recycling and material unit costs may outweigh benefits of Au/Gd

Qualitative Comparison

	<u>One-Shot Use Option</u>	<u>Recycling Option</u>
Inventory @ EOL	40 m ³ ($< 1\%$ of total waste)	$< 1 \text{ m}^3$
Materials' cost	Higher ($< 1 \text{ mill/kWhr}$ for all except Au and Gd)	Lower
Cleared metals	some	No
High level waste	No	Yes, Costly to dispose Violates ARIES requirement
Hohl. purification system	No	Yes Costly, complex
Cooling period	No	$< 18 \text{ d}$ Complexity
Radioactive storage facility	No	Yes Cost?
Remote handling in hohl. Fab	No	Yes Costly, slow, complex
Hohl. fabrication process	Fast	Slow No personnel access
Overall cost	Lower	Higher

One-shot use is preferred option for all hohlraum materials except Au and Gd

Conclusions

- **Recycling introduces** activation **problems**, adds complexity, increases COE, and mandates remote handling in target Fab (costly, slow, complex).
- Hohraum walls represent small waste stream for IFE-HIB (< 1% of total nuclear island waste) \Rightarrow **recycling is not a “must” requirement for ARIES-IFE-HIB unless materials have cost/resource problems (e.g., Au and Gd).**
- With or without recycling, **Au and Au/Gd hohlraums result in highest COE.**
- **One-shot use is preferred option for all materials except Au and Gd**, offering
 - Attractive safety features
 - Less complex design
 - Radiation-free target Fab
 - Lower COE
- **Make hohlraum out of breeding or liquid wall materials** (Pb, LiPb, Li?, Flibe?, Flinabe?) to avoid separation from liquid walls.
- **To recycle Au/Gd**, attractive scheme would combine controlled cooling period and efficient clean-up system to filter out small amount (cups?) of HLW. This waste could be burned in special module to avoid deep geological burial* of waste and meet ARIES Class C-only waste requirement.

* L. El-Guebaly, “Need for Special Burning Modules in Fusion Devices to Transmute Fusion High Level Waste”, University of Wisconsin, UWFD-1155 (June 2002).



Importance of Results and What needs to be done

- Recycling results do not impact feasibility of HIB concept.
- Target recycling analysis is almost complete. Oral paper will be given at 15th TOFE in November 2002. Work will be published in 2003 in Journal *Fusion Science and Technology*.
- Will perform analysis for new candidate hohlraum materials and provide WDR, recycling dose, and cooling period
- Will post on UW web site activation results for accident assessment.

