Recycling of Target Materials vs One-Shot Use Scenario

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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?

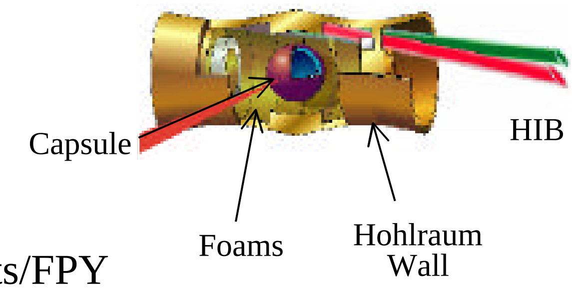
Metrics: Activation (WDR and Clearance)

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 cm^3/target
	1.1 m^3/FPY
	43 m^3/40 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**

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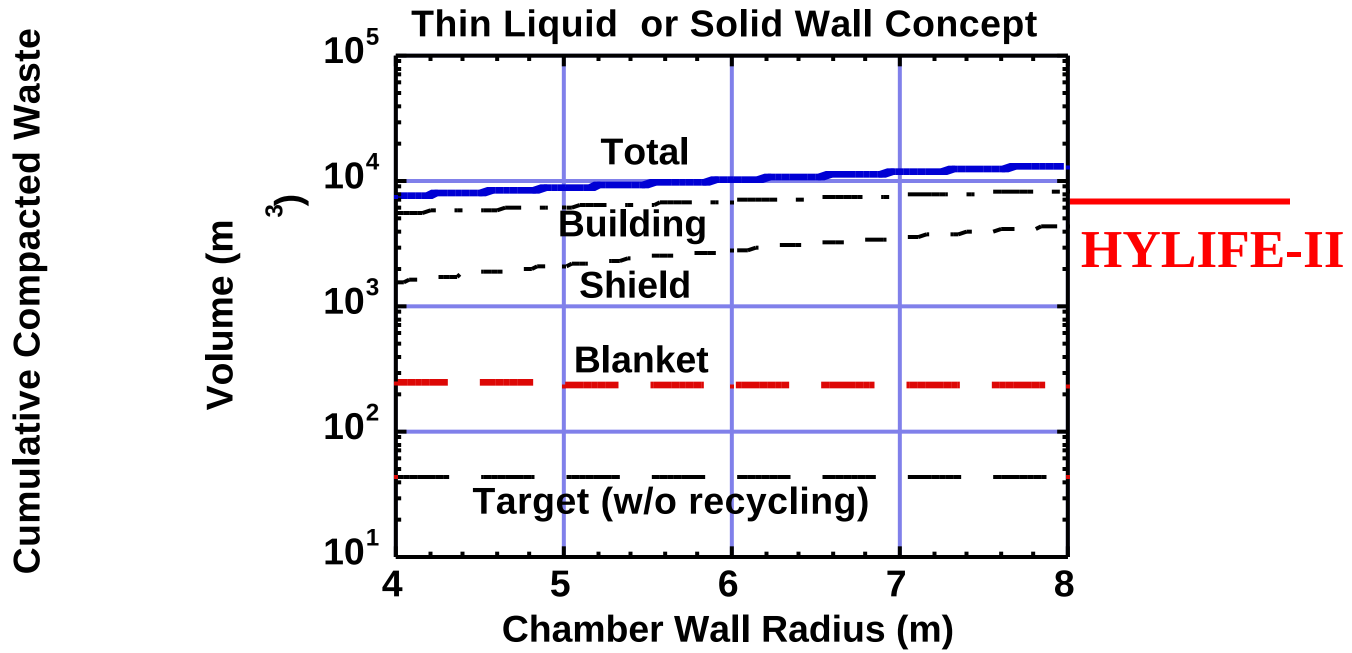
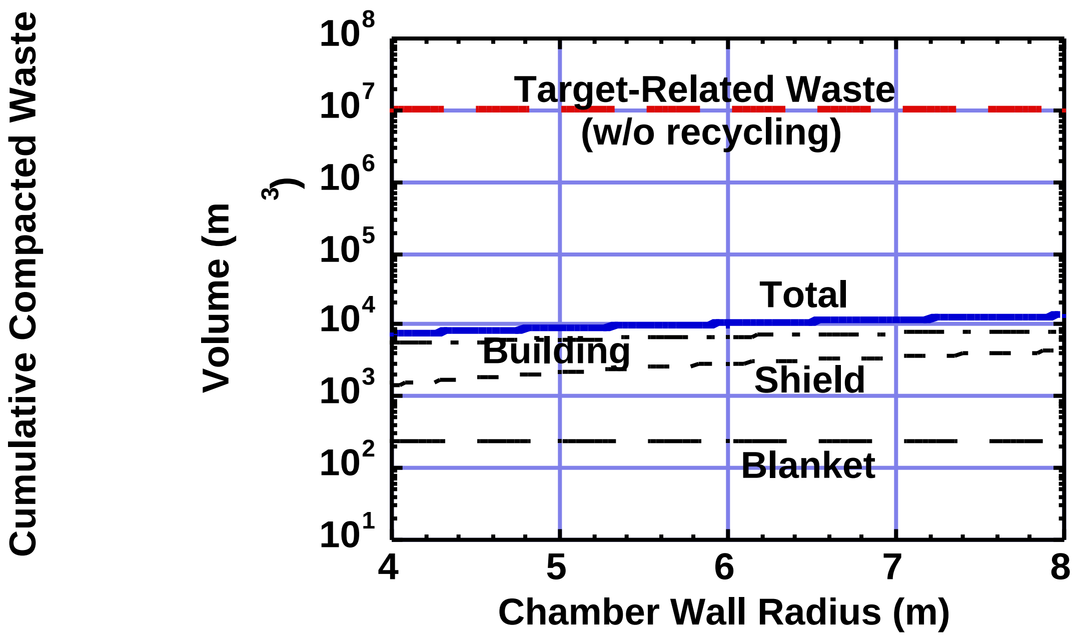
Hohlraum Wall Materials Represent <1% of IFE-HIB Waste Stream



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 buildings 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

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ARIES Design Requirements

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

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

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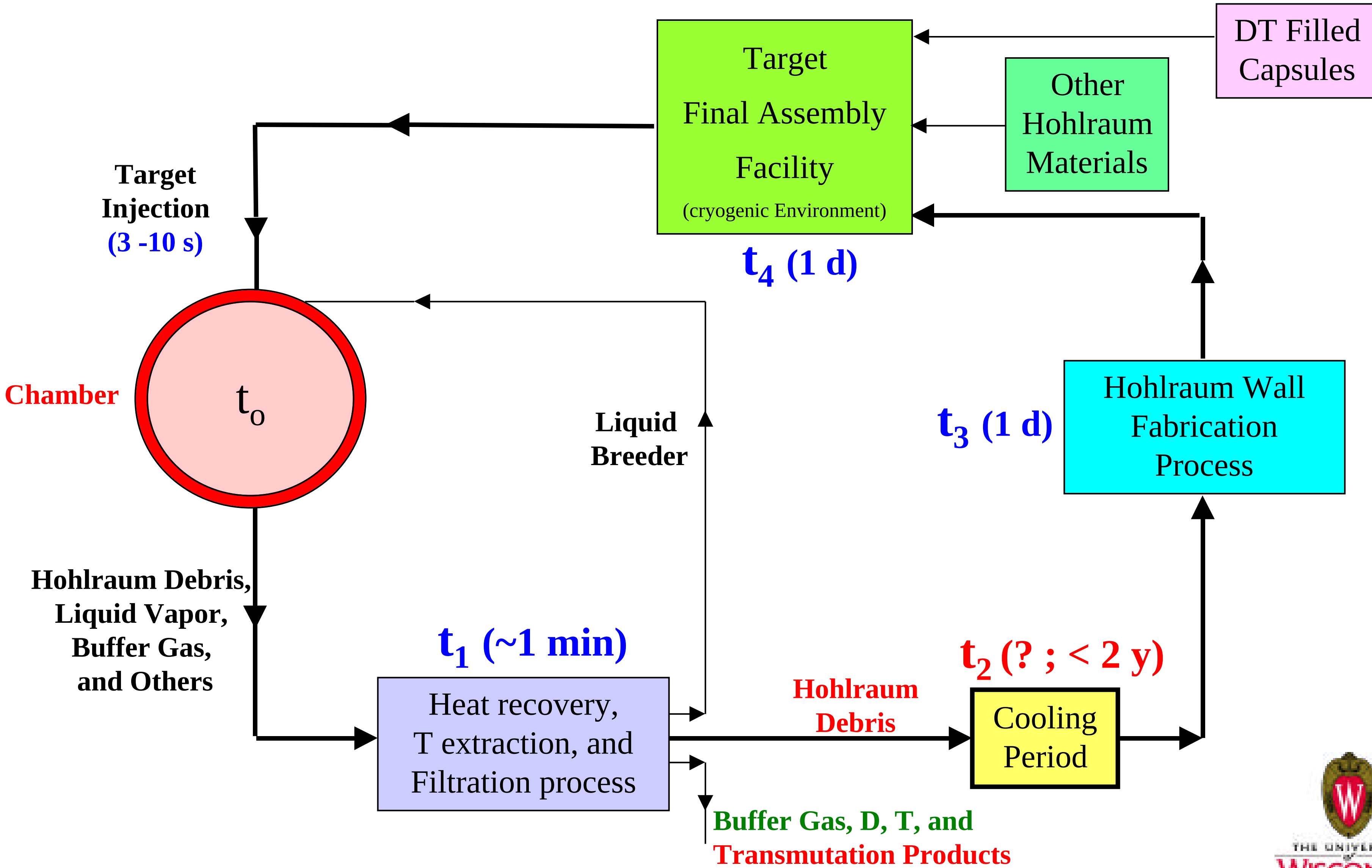
Cooling Period Controls WDR and Dose



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

Candidate Hohlraum Materials	One-Shot WDR	Recycling WDR*
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 Hohlraum Materials (CI < 1 @ end of storage period)	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 released to commercial market for having high Clearance Index >> 1 even after long storage period.

At present, no US market exists for cleared metals.

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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.

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Economic Impact# of Hohlraum Materials (Close-Coupled Target)

Hohlraum Materials	Relative Energy Loss** to Hohl. Wall	Driver Energy## (MJ)	Driver Cost# ($B)	Change in Direct Cost# ($B)	Change in COE#,* (mills/kWh) w/o Recycling	Change in COE#,* (mills/kWh) 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 hohlraum materials.

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

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Qualitative Comparison

	One-Shot Use Option	Recycling Option	
Inventory @ EOL	40 m^3 (< 1% of total waste)	< 1 m^3	
Materials' cost	Higher (< 1 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 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).
- Hohlraum walls represent small waste stream for IFE-HIB (< 1% of total nuclear island waste) 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
  - Radiation-free target Fab
  - Less complex design
  - 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, UWFDM-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.