Recycling Issues Facing Target and RTL Materials of Inertial Fusion Designs

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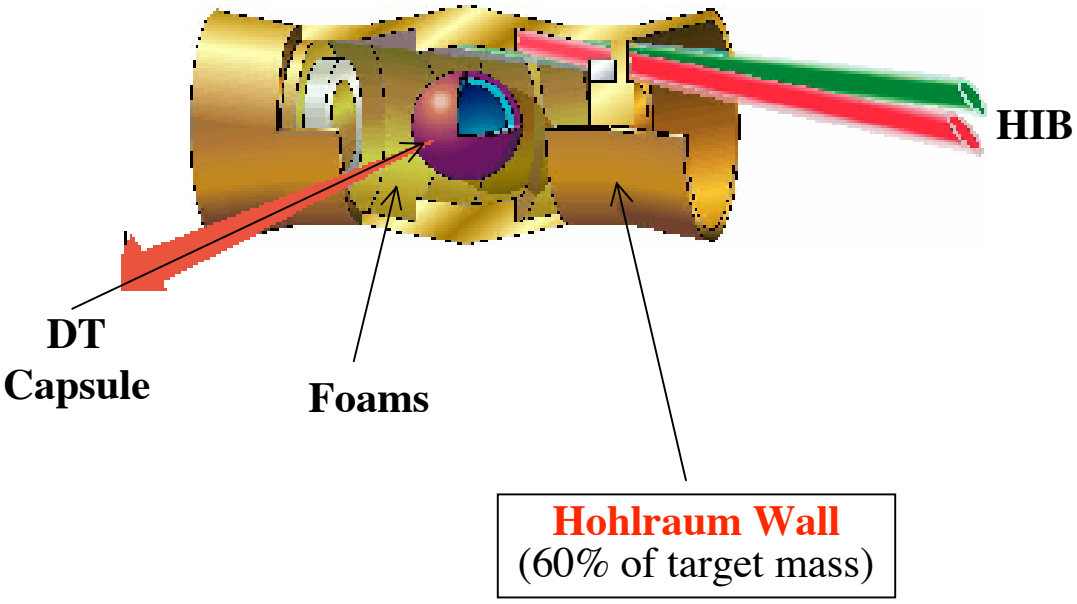
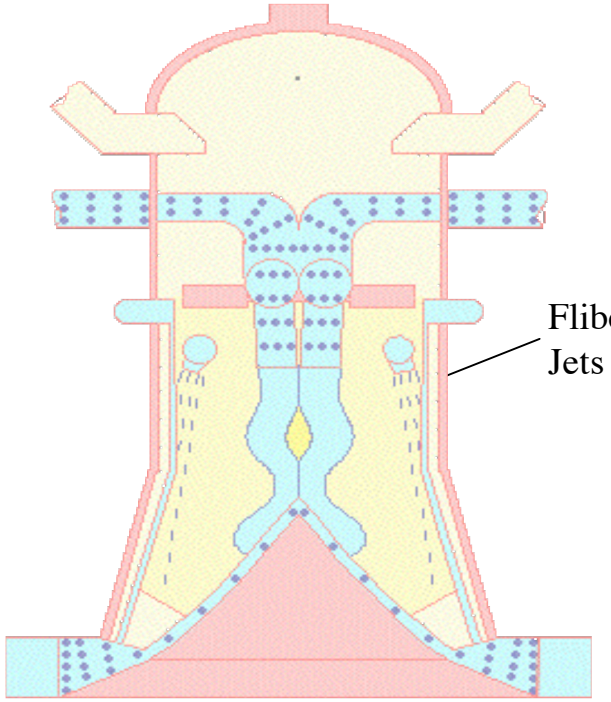
Objectives

- Advise IFE designers on best option to manage HI hohlraum wall radwaste and Z-pinch RTL radwaste:
  - One-shot use, then dispose in repository, or
  - Recycle during plant life (45-50 y)
- Highlight pros and cons of once-through and recycling scenarios.
- Develop irradiation history and timeline for recycling approach.
- Examine **conservative** recycling approach without slag or transmutation product removal.
- Monitor waste level and dose to equipment during recycling.
- Determine economic impact of recycling approach.

Representative IFE-HI Power Plant

LLNL Close-Coupled Target Design





HYLIFE-II

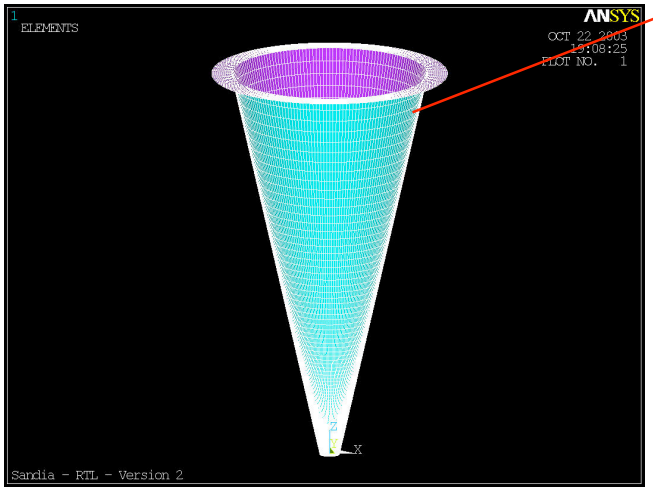
(Thick Liquid Wall Concept)

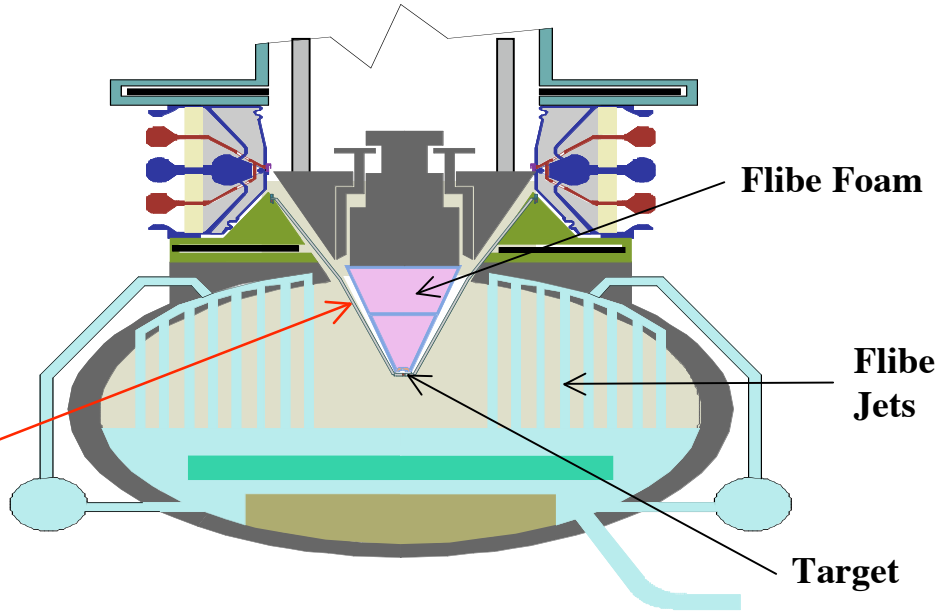
Z-Pinch Power Plant

Recyclable Transmission Lines (RTL)

Top diameter = 1 m
Bottom diameter = 0.1 m
Length = 5 m
Carbon Steel thickness = 0.0635 cm
50 kg* / RTL

* Needed for high electric efficiency.





Chamber
(12 units / plant)

Key Parameters

	ARIES-IFE-HI	Z-Pinch
Target Yield	460 MJ	3000 MJ
Rep Rate	4 Hz	0.1 Hz
# of Units per Plant	1	12
# of Shots per FPY	126 million	38 million
Au/Gd Hohlraum Wall or RTL Thickness	15 μm	0.635 mm
Mass of Hohlraum Wall or RTL	**0.1 g / target**	**50 kg / RTL**
Volume of Hohlraum Wall or RTL	**0.008 cm^3 / target**	**6000 cm^3 / RTL**
Availability	85%	85%
Plant Lifetime	40 FPY (47 y)	40 FPY (47 y)

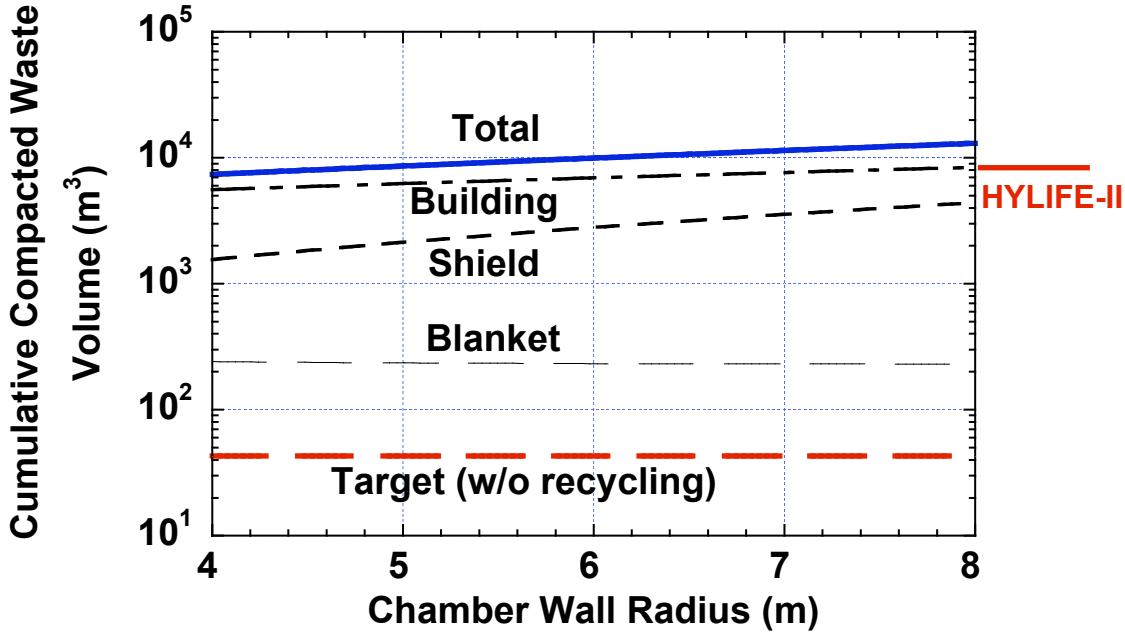
Pros and Cons of Recycling Scenario

- **Pros:**
  - Low inventory of radwaste.
  - Negligible material cost.

- **Cons:**
  - May generate high-level waste that violates ARIES top-level requirements.
  - Require radioactive storage facility in target fab.
  - Need purification system to deliver highly pure materials.
  - No hands-on and no personnel access to target fab.
  - Slow, remotely controlled process.
  - Costly process.

Do not recycle unless process offers advantages

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



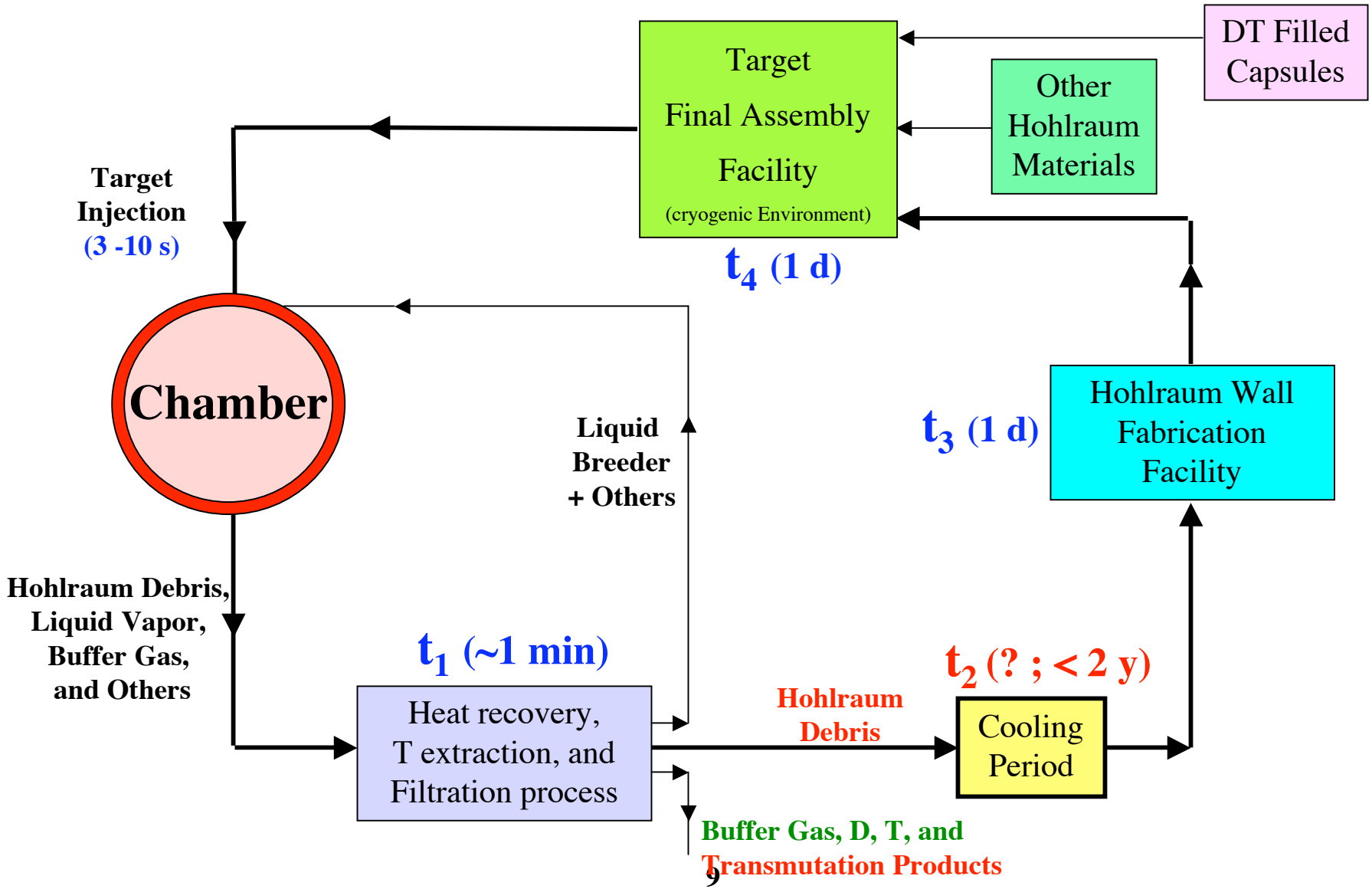
Recycling is not a "*must*" requirement for IFE-HI designs

Hohlraum Wall Recycling?!

- It is acceptable among ARIES team members that hohlraum wall materials should not be recycled.
- However, we developed a recycling approach to understand the problem and highlight the cost penalty and design complexity added to HI designs.
- Among wide range of candidate hohlraum wall materials, we selected three materials for this study:
  - Gold/Gadolinium (50/50 wt%)
  - Tungsten
  - Lead

IFE-HI Target Recycling Process

(Hohlraum Wall Materials Spend ≥ 2 days Outside Chamber)



Design Criteria and Codes

Waste disposal rating (WDR) **1**

(for **Class C** low-level waste)

Clearance Index **1**

(for waste containing traces of radionuclides)

Recycling dose **3000 Sv/hr**

(for **advanced** remote handling equipment)

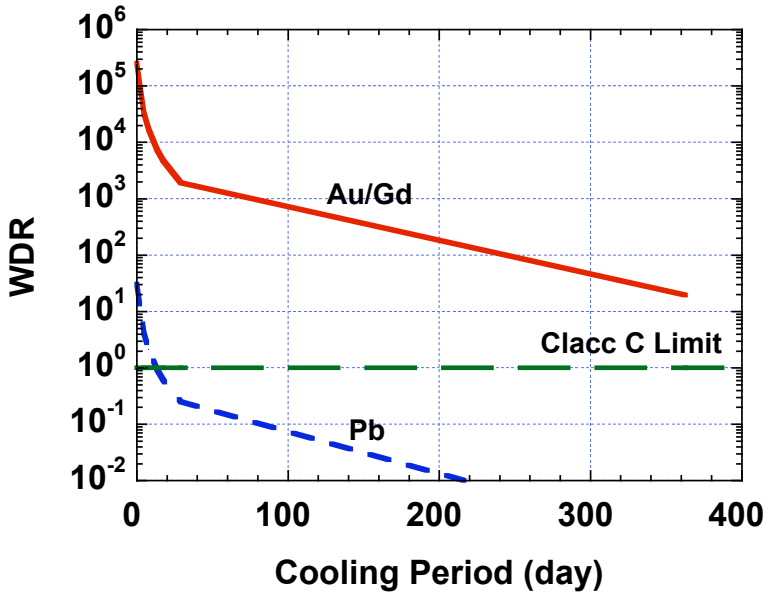
- **Codes and data:**
  - **DANTSYS Neutral-particle transport code**:
  - **ALARA Pulsed activation code**:
    Exact modeling of all pulses (~10,000)
  - **FENDL-2 Nuclear Data**:
    175 neutron and 42 gamma group structure

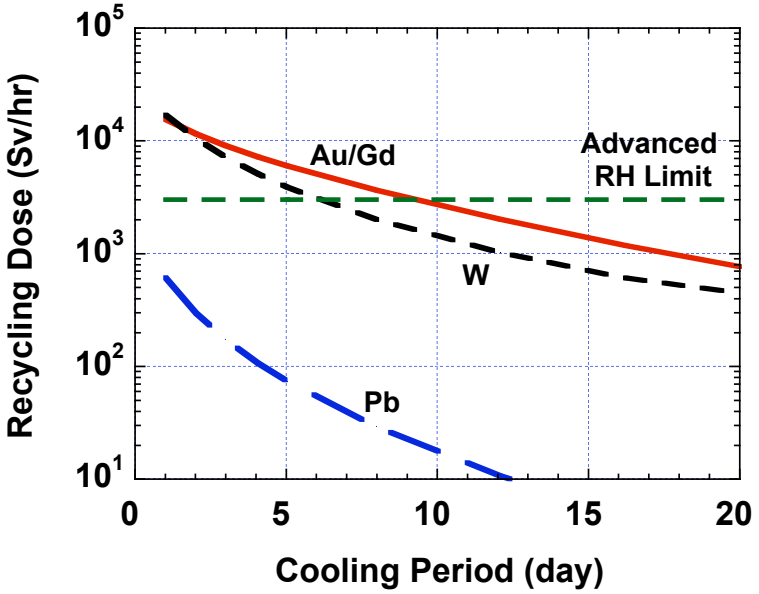
One-Shot Use Scenario Generates Very Low Level Waste White recycling Generates High-Level Waste

	One-Shot Use Scenario		Recycling Scenario
	WDR	**CI**	**WDR***
Gold/Gadolinium	2×10^{-8}	42	3×10^{5}
Tungsten	2×10^{-6}	14.9	0.6
Lead	2×10^{-5}	5.6	31

* No cooling period. No transmutation product removal.

Cooling Period Controls WDR and Dose





Au/Gd generates high-level waste that violates ARIES requirements

All materials meet advanced RH limit with < 10 d cooling periods

Recommended Cooling Periods that Satisfy Design Limits

	Cooling Period for WDR < 1	Cooling Period for Dose < 3000 Sv/h	Recommended Cooling Period
Au/Gd	**> 2 y*** (^{158}Tb)	**9.5 d** (^{196}Au)	**—***
Tungsten	**0** (^{186m}Re, ^{178n}Hf)	**6.2 d** (^{184}Re)	**6.2 d**
Lead	**13 d** (^{208}Bi, ^{202}Pb)	**< 1 d** (^{203}Pb, ^{202}Tl)	**13 d**

* Insignificant inventory reduction for cooling period exceeding 2 y.

Recycling Doubles HI Cost of Electricity

	One-Shot Use Scenario	Recycling Scenario
Cost per Target	**$ 0.4**	**$ 3.15**
Change to COE	~10 mills/kWh	~70 mills/kWh
COE	**~70 mills/kWh**	**~130 mills/kWh**

Doubling COE to recycle materials that present no waste burden to IFE-HI designs is unacceptable

IFE-HI Conclusions

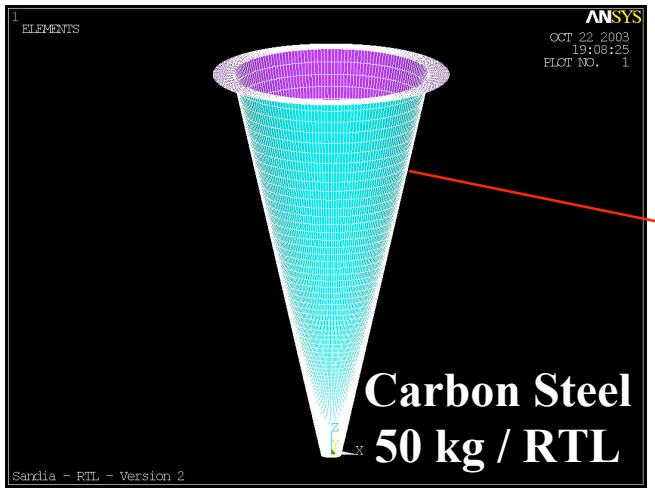
- HI Hohlraum walls represent small waste stream (< 1% of total nuclear island waste)

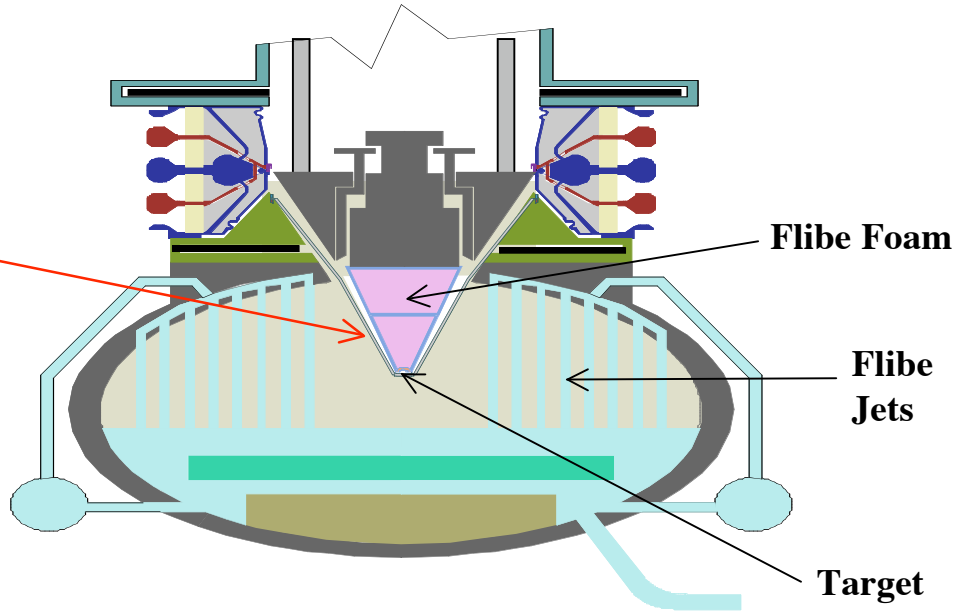
  ⇒ recycling is not a "must" requirement for IFE-HI concept.

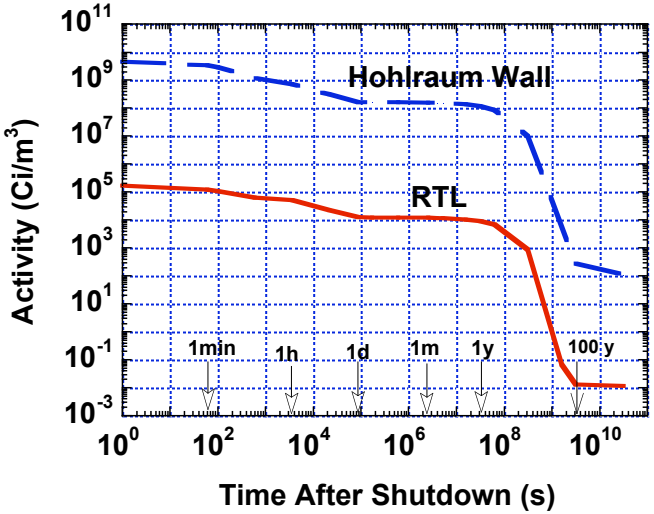
- Use low-cost materials once-through and dispose as Class A LLW instead of using expensive materials (such as Au and Gd). One-shot use scenario offers:
  - Attractive safety features
  - Radiation-free target Fab
  - Less complex design
  - Lowest COE

- Target factory designers prefer dealing with non-radioactive hohlraum wall materials and this assessment supports the feasibility of no-recycling approach for HI concepts.

Z-Pinch Power Plant

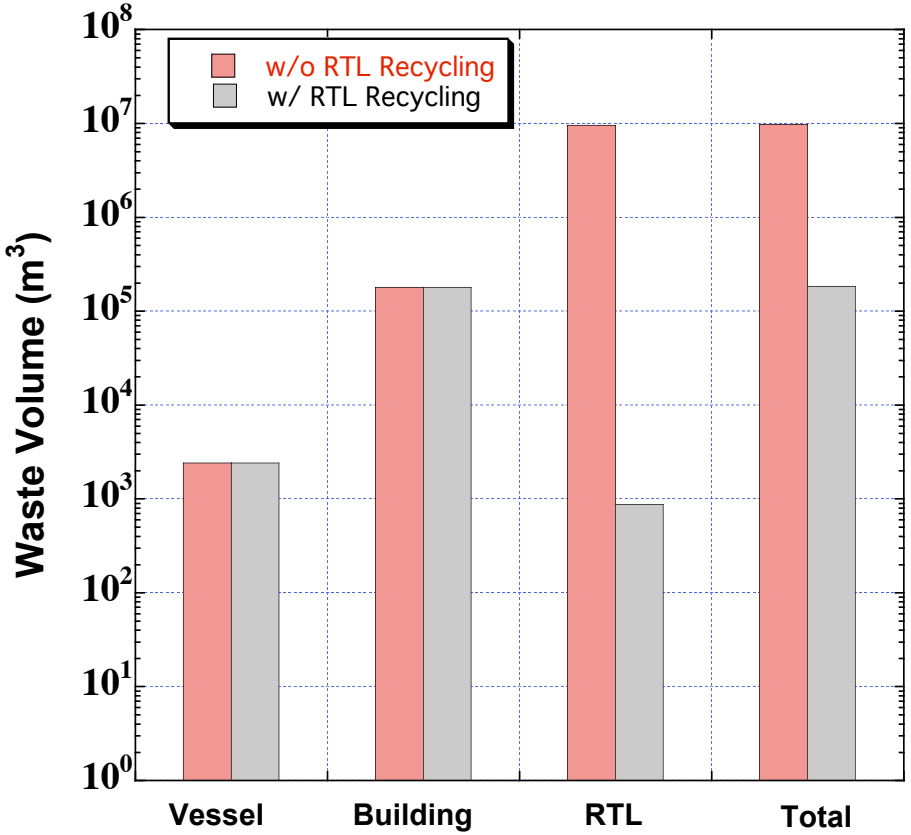






Less intense neutron flux and softer spectrum at RTL result in much lower activity, WDR, CI, and dose.

RTL Recycling is a "Must" Requirement to Minimize Waste Stream and Enhance Economics

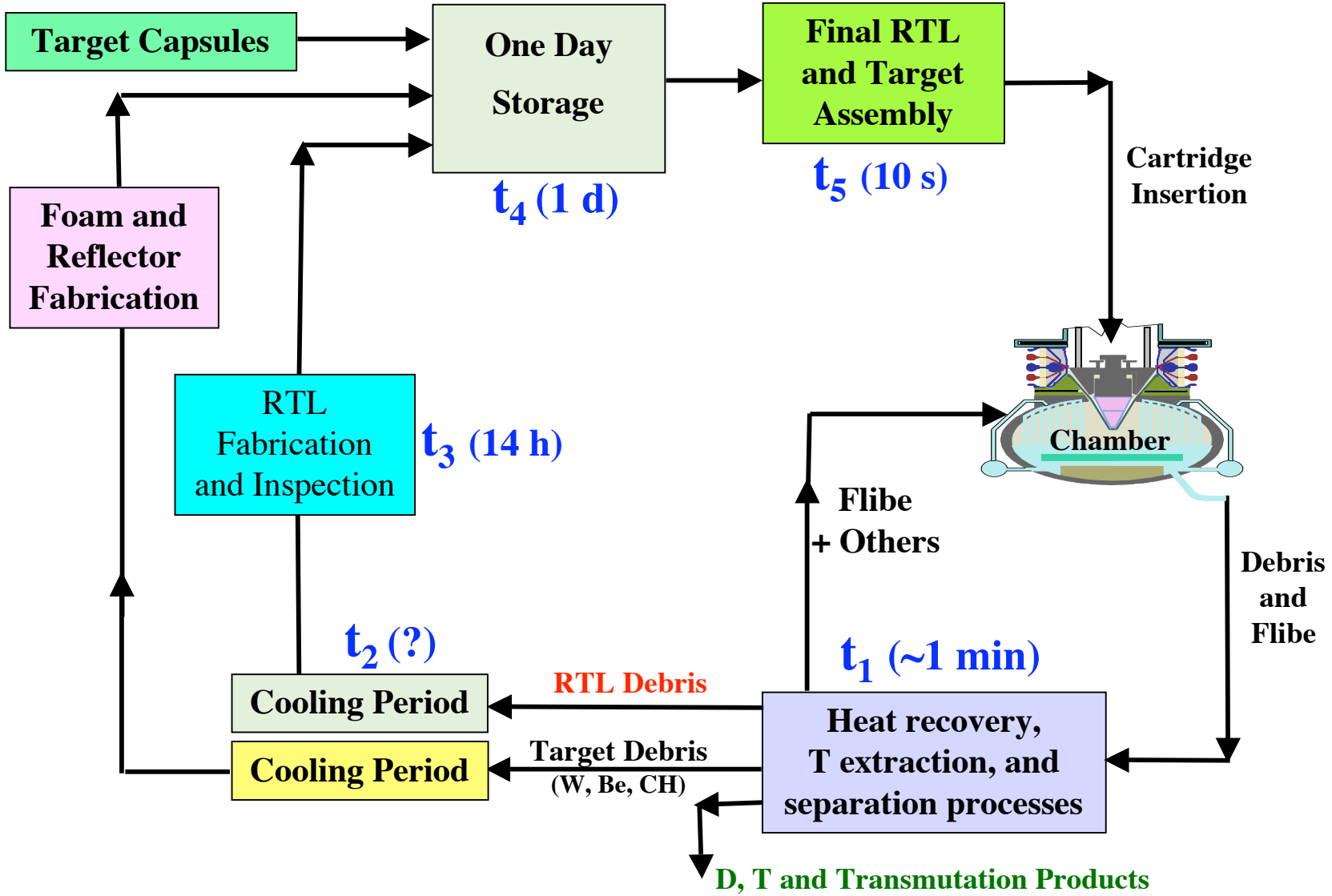


Without RTL recycling
Total RTL mass = 80 M Tons
Fabricated Steel Unit Cost = $10/kg
Total RTL cost = ~$800B

With RTL recycling
1.5 day RTL inventory
Total RTL mass = 8,000 Tons
Total RTL cost ~ $80M

RTL Recycling Process

(RTL Materials Spend ~1.5 day Outside Chamber)



RTL Results

	Results	Limits
WDR	**10^{-7}** Class C	1
	10^{-3} Class A	
Clearance Index	**0.1** @ 100 y	1
	1 @ 50 y	
Recycling dose rate (Sv/hr)	**160**	3000

Z-Pinch Conclusions

- RTL recycling is a "must" requirement for Z-pinch concept to minimize heavy metal throughput and enhance economics.
- Carbon Steel RTLs satisfy design requirements when recycled for entire plant life even without cooling period:
  - Class A low-level waste ⇒ Shallow land burial
  - Clearance index < 1 ⇒ Release to commercial market after 50 y
  - Dose < 160 Sv/hr ⇒ No hands-on recycling
- Online removal of transmutation products helps meet design requirements with wide margin, but complicates recycling process and generates high level waste.
- Recycling process must be accomplished remotely in 1.5 day.
- Advanced remote handling equipment should be developed to handle high dose rate (200 Sv/hr or more).
- COE should reflect cost of RTL remote recycling.

Overall Conclusions

- **Recycling offers advantages to Z-pinch while adds complexity and cost to HI systems.**

- **Recommendations**:
  - Use low-cost hohlraum wall materials for HI targets once-through, then dispose in repositories.
  - Recycle RTLs of Z-pinch.