Feasibility of Recycling Hohlraum Wall Materials

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ARIES Meeting
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UW

Objectives

- Address feasibility of recycling candidate hohlraum wall materials:

	Mass (tons/FPY)	Cost* (M$/FPY)	Resources Problem?
Au/Gd (reference)	15	80	yes, Gd
Au	21	210	
W	21		
Pb	12		
Hg	15		
Ta	18	0.6	
Pb/Ta/Cs	10		
Hg/W/Cs	11		
Pb/Hf	13		
Hf	14	2.6	
Solid Kr @ 115.8 k	3	?	?
Solid Xe @ 161.1 k	4	?	?

* 10$/g-Au. 0.015 $/g-Gd, 0.187 $/g-Hf, 0.034 $/g-Ta, per Waganer (Boeing)

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Objectives (cont.)

- Lacking info on economic/resources problem, develop recycling approach for **all** hohlraum wall materials using ARIES design criteria and requirements
- Analyze two extreme cases:
  - One-shot use of hohlraum wall materials then dispose in repositories
  - Recycle without transmutation removal system
- Recommend design solutions for materials exihibiting recycling problems
- Investigate means for dealing with **large** quantity of radioactive gases @ EOL

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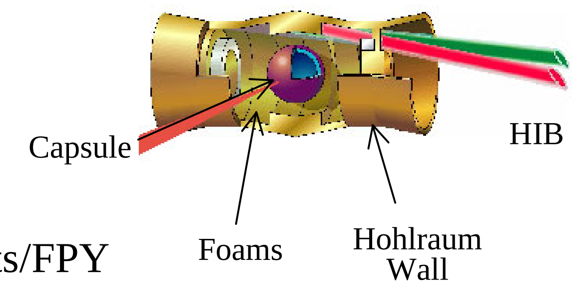
HIB Target Parameters

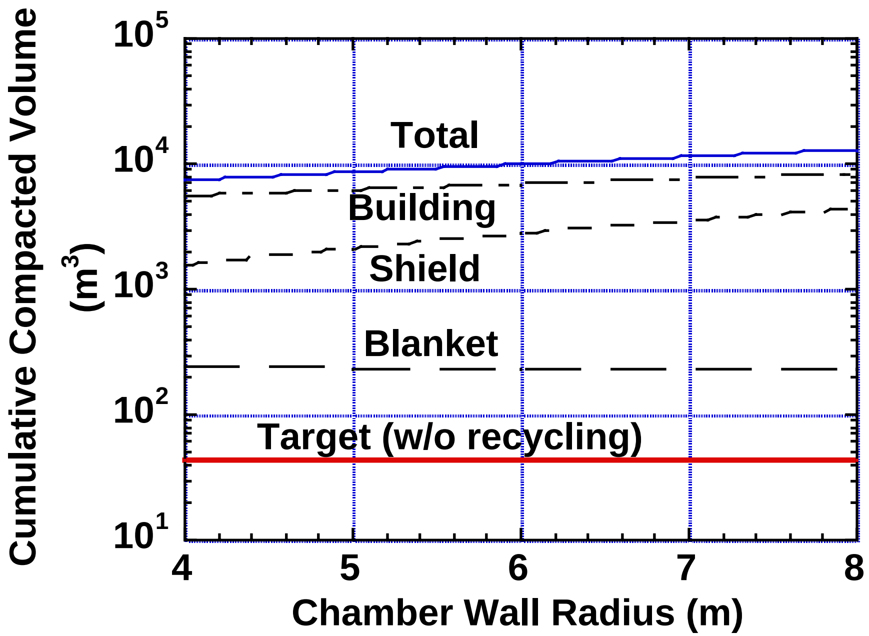
Capsule Radius*	2.34 mm
Hohlraum Wall Thickness*	15 μm
Target yield	458.7 MJ
Rep Rate	4 Hz
# of Shots	126 million shots/FPY
Plant Lifetime	40 FPY (47 y)
Availability	85%
Volume of Hohlraum Wall	0.0085 cm^3/target
	1.1 m^3/FPY
	43 m^3/40 FPY
Mass of Hohlraum Materials	3-21 tons/FPY
	120-830 tons/40 FPY



LLNL Close-Coupled Target Design

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

Hohlraum Wall Materials Represent < 1% of IFE Waste Stream



Recycle costly/rare materials to reduce inventory by factor of 10 or more

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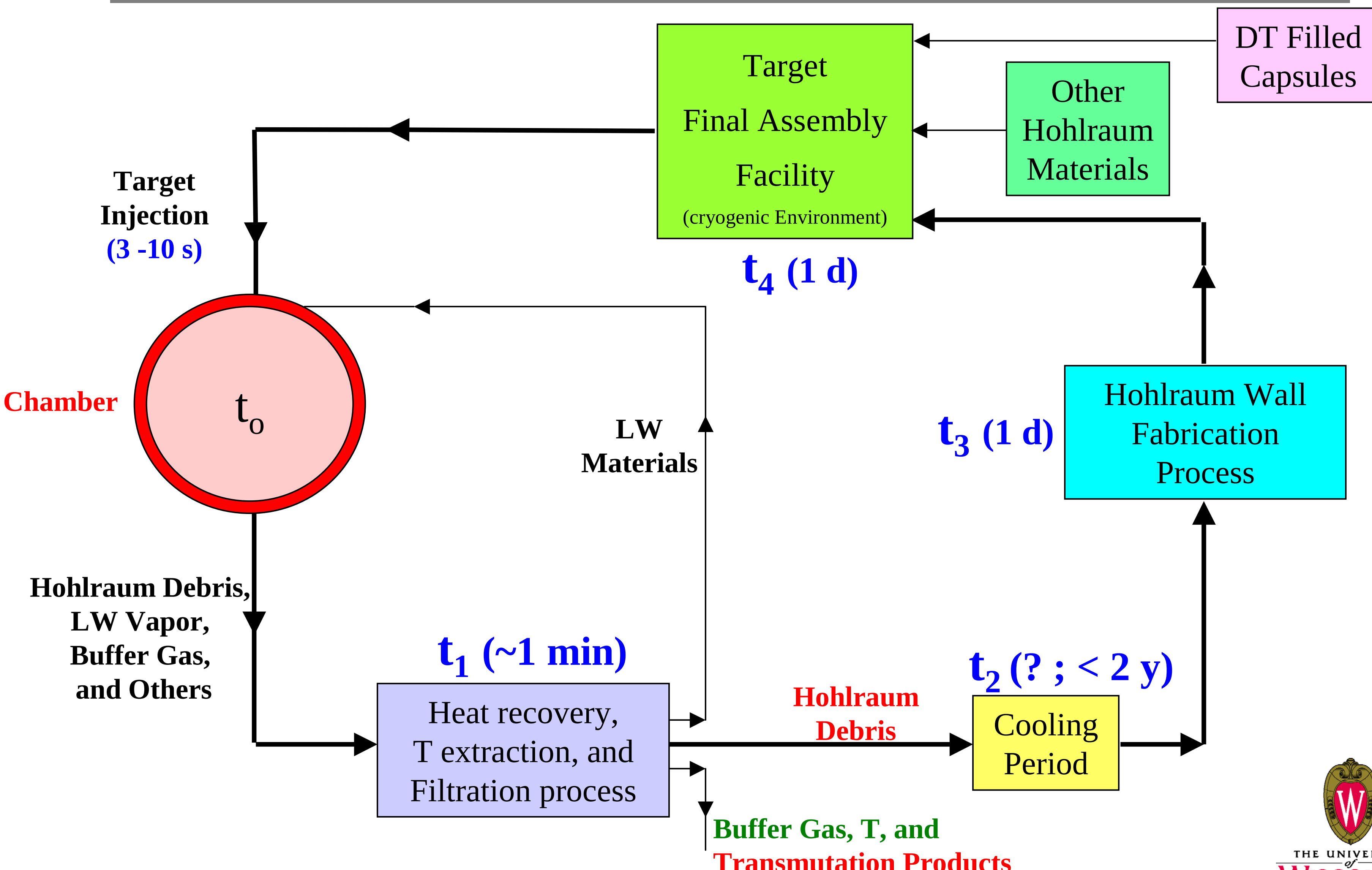
Hohlraum Wall Recycling Process



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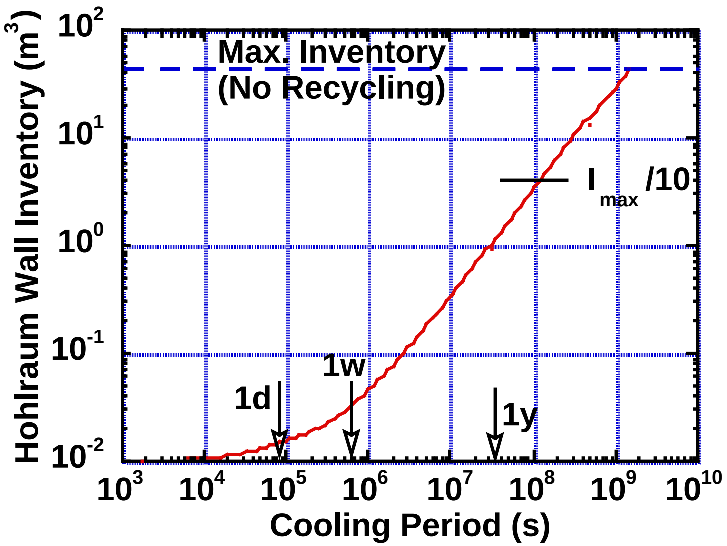
Cooling Periods ≤ 2 y Reduce Hohlraum Inventory by Factor of 10 or more

- Inventory varies linearly with cooling period
- Steady-state inventory accounts for:
  - 2 d back-up
  - t_2+1 d
  - 2 d for recycling
  - Short time in chamber
- 2 d backup inventory is needed to account for repair of recycling system; e.g., 0.006 m^3 (80 kg of Au/Gd)
- Store irradiated materials in 1h or 1d bins, depending on cooling period unit
- Start-up inventory !?
- More sophisticated approach could reduce inventory further



Recycling Introduces Problems

- Produces high level waste (**HLW**) for most materials
- Increases activity and decay heat
- Mandates remote handling (costly) in target fab
- Requires radioactive storage system
- Adds cost and complexity to target assembly/fabrication facility

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Several Factors May Prematurely Terminate Recycling Process Requiring Fresh Hohlraum Wall Materials

- **Waste disposal rating*** of hohlraum debris violates Class C low level waste requirement
- **Recycling dose*** exceeds hands-on or remote handling limits
- Accident dose at site boundary exceeds 1 rem following accidents in chamber and/or in Target Fab
- Transmutation level in hohlraum debris reaches limit set by target designers to minimize beam losses to hohlraum walls. Alternative option is to separate transmutations on-line and address feasibility and economic issues
- Decay heat of radioactive hohlraum materials raises frozen DT temp above 1.8 K before target injection. Mogahed's preliminary analysis showed insignificant change in temperature for LLNL target design meaning foams provide good thermal shield for capsule

* Most restrictive factors in descending order

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Potential Design Solutions for Materials with Recycling Problems

I- Filter out transmutations on-line ⇒ Cup(s) of HLW
Lowest LLW inventory
Recycle for plant life (47 y)
No cooling period

II- Limit exposure time (or end recycling process) and call for fresh materials
⇒ No transmutations removal system (unpractical)
No HLW
Exclude Gd
Larger LLW inventory than Option-I
No cooling period
Recycle for < 47 y

III- Store materials for < 2 y of cooling period before fabrication
⇒ No transmutations removal system (unpractical)
No HLW
Exclude Gd
Lower LLW inventory than Option-II
Recycle for plant life (47 y)

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No Major Change in Material's WDR after One Shot

Hohlraum Wall Materials	WDR	EOL Inventory	
		m^3	Tons
Gold/Gadolinium (ref.)	2×10^{-8}	43	580
Gold	0	43	830
Tungsten	2×10^{-6}	43	830
Lead	2×10^{-5}	43	480
Mercury	5×10^{-4}	43	580
Tantalum	0	43	710
Lead/Tantalum/Cesium	1×10^{-5}	43	390
Mercury/Tungsten/Cesium	2×10^{-4}	43	450
Lead/Hafnium	8×10^{-5}	43	510
Hafnium	3×10^{-4}	43	560
Solid Kr	0.01	43	120
Solid Xe	2×10^{-5}	43	150

Without recycling, all materials qualify as Class C (or A) LLW after one shot

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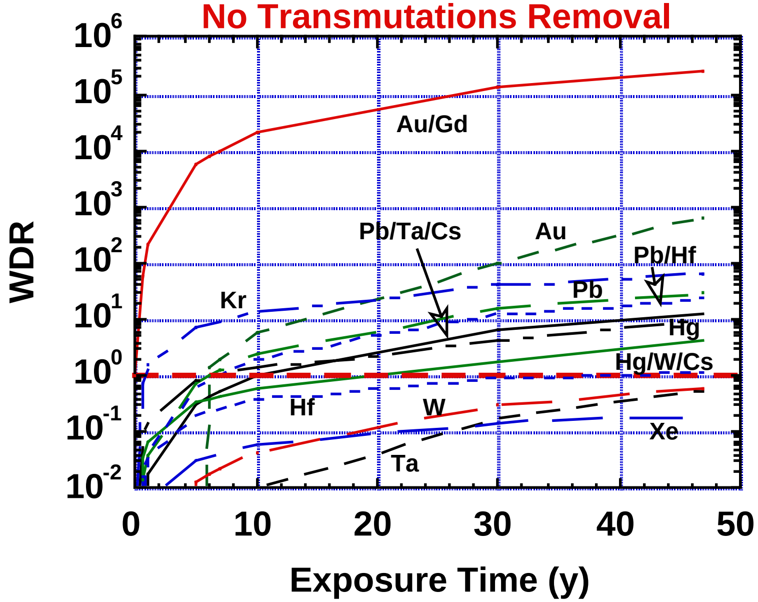
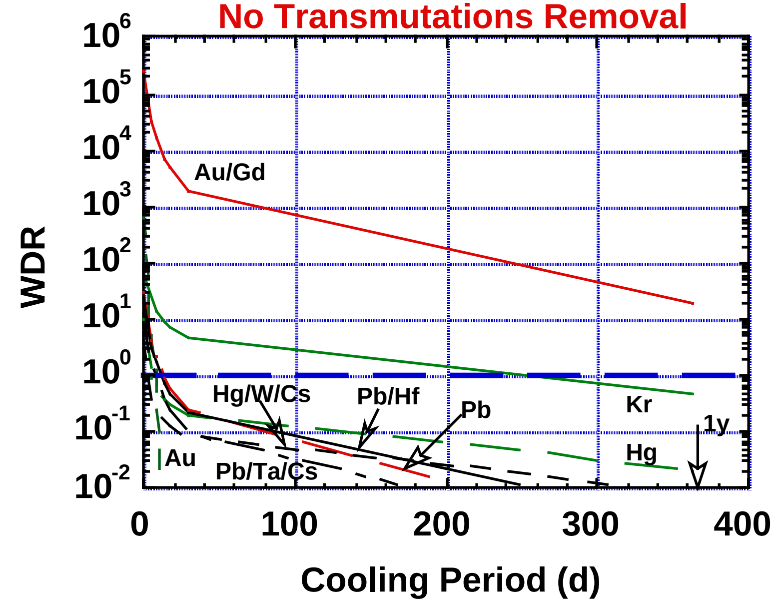
Limit Exposure Time or Cooling Period to Control WDR

No Cooling Period
No Transmutations Removal



47 y of Operation
No Transmutations Removal



- WDR reported at 100 y after exposure using Fetter's limits, except for Xe (NRC)
- Recommendations:
  - Gd generates HLW after 2.5 s (10 pulses) ⇒ Do not recycle Gd unless on-line clean-up system removes all Tb
  - W, Ta and Xe are Class C waste @ EOL even with no cooling period or clean-up system
  - For other materials :
    - Limit exposure time to 0.7 - 35 years for no cooling period, or
    - Extend cooling period to 0.6 - 250 days and recycle for 47 y of operation

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Use of Cooling Period to Control WDR is Preferred to Lower EOL Inventory

	Maximum Exposure Time*	Total Inventory @ EOL (m^3)
Au	5.9 y	0.1
W	47 y	0.01
Pb	6 y	0.1
Hg	6 y	0.1
Ta	47 y	0.01
Pb/Ta/Cs	9.5 y	0.06
Hg/W/Cs	19 y	0.04
Pb/Hf	6.4 y	0.09
Hf	35 y	0.02
Solid Kr	0.7 y	0.8
Solid Xe	47 y	0.01

* No cooling period. No transmutations removal

	Minimum Cooling Period#	Total Inventory @ EOL (m^3)
Au	8.2 d	0.03
W	0	0.01
Pb	13 d	0.06
Hg	5 d	0.03
Ta	0	0.01
Pb/Ta/Cs	7.5 d	0.04
Hg/W/Cs	3 d	0.02
Pb/Hf	11.5 d	0.06
Hf	0.6 d	0.02
Solid Kr	250 d	0.8
Solid Xe	0	0.01

47 y of operation. No transmutations removal

On-line removal of transmutation products prolongs exposure time and shortens cooling period further but generates cup(s) of HLW

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All Materials Must Meet Recycling Dose Limits

Hands-on limit*#:	
without ALARA principle	10 μSv/h
with ALARA principle	1 μSv/h
Conservative Remote handling limit*##	10 mSv/h
Advanced Remote Handling Limit+ (recommended for ARIES)	**3000 Sv/h**

* Ref: D. Petti et al., "Safety Analysis of Initiating Events", ARIES E-meeting, Oct 17, 2001. Same as Japanese and European limits

\# Based on 20 mSv annual limit for 2000 h/y worker

\## Based on arbitrary factor of 1000 above HO limit

\+ For fission waste, per N. Taylor. On-going EU recycling study will develop RH limit for fusion waste

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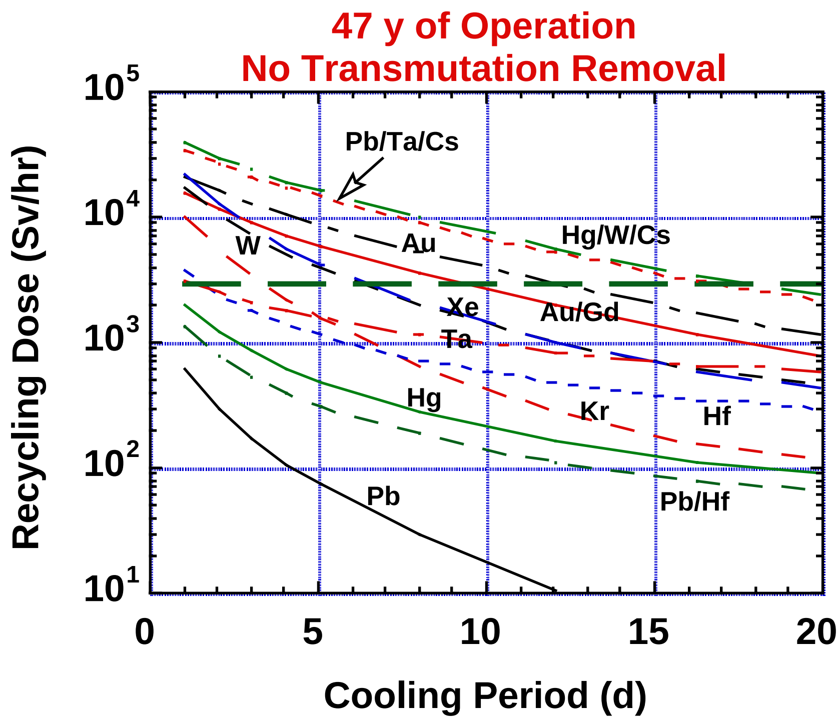
Recycling Dose



- Only Pb can meet HO limit (1 μSv/h) with long cooling period (~2 y)
- All materials meet advanced RH limit (3000 Sv/h) with <18 d cooling period
- On-line removal of transmutation products shortens cooling period

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Recommended Cooling Period to Meet Both WDR and Dose Requirements#

	Cooling Period for WDR < 1	Cooling Period for Dose < 3000 Sv/h	**Recommended Cooling Period**
Au/Gd	> 2 y	9.5 d	NA*
Au	8.2 d	12.2 d	12.2 d
W	0	6.2 d	6.2 d
Pb	13 d	< 1 d	13 d
Hg	5 d	< 1 d	5 d
Ta	0	1 d	1 d
Pb/Ta/Cs	7.5 d	17.2 d	17.2 d
Hg/W/Cs	3 d	17.5 d	17.5 d
Pb/Hf	11.5 d	< 1 d	11.5 d
Hf	0.6 d	1.5 d	1.5 d
Solid Kr	250 d	4.5 d	250 d
Solid Xe	0	6.5 d	6.5 d

47 y of operation. No transmutation removal
* Insignificant inventory reduction for cooling period exceeding 2 y.

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

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Main Contributors to WDR and Dose

	WDR*	Dose#
Au/Gd (50:50)	^{158}Tb	^{196}Au
Au	^{192n}Ir, ^{194}Hg	^{196}Au
W	^{186m}Re, ^{178n}Hf	^{184}Re
Pb	^{208}Bi, ^{202}Pb	^{203}Pb, ^{202}Tl
Hg	^{192n}Ir, ^{194}Hg	^{202}Tl, ^{196}Au, ^{203}Hg
Ta	^{178n}Hf	^{182}Ta, ^{179n}Hf
Pb/Ta/Cs (45:20:35)	^{208}Bi, ^{202}Pb	^{132}Cs
Hg/W/Cs (45:20:35)	^{192n}Ir, ^{194}Hg	^{132}Cs, ^{203}Pb, ^{202}Tl
Pb/Hf (70:30)	^{208}Bi, ^{202}Pb	^{175}Hf
Hf	^{178n}Hf**	^{175}Hf, ^{179n}Hf**, ^{179}Lu
Kr	^{81}Kr (gas)	^{84}Rb, ^{82}Br
Xe	^{129}I, ^{135}Cs, ^{137}Cs	^{134}Cs, ^{132}Cs, ^{127}Xe (gas)

In some cases, same elements contribute to both WDR and dose

Efficient on-line clean-up system could remove almost all radioisotopes

* 47 y of operation with no cooling period. No transmutation removal
# Contributors at recommended cooling period for dose. 47 y of operation. No transmutation removal
** Difficult to separate

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Disposal of Radioactive Kr & Xe Gases
(valid also for chamber buffer gases)

Filter out solid transmutation products using cold traps, per Sze (UCSD)

Use laser-based isotope separation system for gases and solids, per Waganer (Boeing) [Ref: Prometheus Report, DOE/ER-54101, P 6.7-8 (1992)]

Store gases in glass spheres, per Nikroo (GA):

- Heat up glass shells
- Fill out shells with gases
- Cool down to trap gases inside shells
- Store for future use or dispose in repositories

Store Kr in hydrides, per Malang (FZK):

- Heat up hydrides
- Allow Kr to permeate through hydrides
- Cool down hydrides
- Store for future use or dispose in repositories

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Conclusions

- Hohlraum walls represent small waste stream for IFE (< 1% of total nuclear island waste) ⇒ recycling is not a must unless materials have cost/resources problems
- One-shot use of hohlraum generates 43 m^3 of very low waste (Class A)
- Recycling introduces activation problems, adds complexity, and mandates remote handling (costly) in target Fab
- WDR and recycling dose are most restrictive factors in recycling process
- Three potential solutions could solve recycling problems: **efficient** transmutation removal system, limited exposure time, and controlled cooling period
- **Highly efficient** on-line clean-up system removes **most** transmutation products and allow recycling of **all** materials
- In absence of **efficient** system, exclude Gd for generating HLW after 10 pulses and use other materials with 2-8% penalty in driver's cost and small hit in cost of electricity (< 5%)
- **Attractive scheme would combine efficient clean-up system and controlled cooling period. Additional cost and complexity should be addresses**.
- Clean-up system will filter out cup(s) of **HLW that could be burned in special modules to avoid deep geological burial***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", To be published in April 2002.

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