Activation Issues for Candidate Coating/Hohlraum Materials

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ARIES Project Meeting
8-9 March 2001
Livermore, CA

Key Design Issues for Target Coating/Hohlraum Materials

- Target performance (instability, gain, …) NRL,LLNL
- Target fabrication (cryo-layering, …) GA,LANL
- Target injection GA,LANL
- Target heating (emissivity, …) GA,UCSD
- Tritium retention/inventory/permeation ANL,LANL,GA
- Beam energy losses (driver cost; COE) LLNL,UCSD
- Safety: INEEL,UW,LLNL
  - Radioactive waste:
    - **WDR** (high or low level waste)
    - Volume (recycle hohlraum materials; economics !; repository capacity)
  - Off-site dose during accident

Candidate Coating/Hohlraum Materials

Laser
(NRL Target)

Gold	$_{79}Au$
Tungsten	$_{74}W$
Lead	$_{82}Pb$
Platinum	$_{78}Pt$
Palladium	$_{46}Pd$
Silver	$_{47}Ag$

HIB

Gold/Gadolinium	$_{79}Au/_{64}Gd$
Gold	$_{79}Au$
Tungsten	$_{74}W$
Lead	$_{82}Pb$
Mercury	$_{80}Hg$
Tantalum	$_{73}Ta$
$Pb/Ta/_{55}Cs$	
Hg/W/Cs	
$Pb/_{72}Hf$	

Periodic Table of Elements

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon		8 O Oxygen	9 Fl Flourine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorous	16 S Sulphur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron		28 Ni Nickel	29 Cu Copper	30 Zn Zinc		32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technecium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin		52 Te Tellurium	53 I Iodine	
55 Cs Cesium	56 Ba Barium	57 La Lanthanum	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	87 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89 Ac Actinium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium									

58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	64 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Germium	101 Md Menelevium	102 No Nobelium	103 Lr Lawrencium

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Main Parameters for WDR Analysis

Fusion Yield (MJ)	**160**	**400**
FW Radius (m)	4 ?	6.5 ?
Neutron Wall Loading (MW/m^2)	3.5	3.3
SiC/SiC FW Lifetime (FPY)	6	6.3
FW EOL Fluence (MWy/m^2)	**21**	
Rep Rate (Hz)	6	
# of Shots (million/y)	190	
Availability	85%	

- WDR depends strongly on EOL fluence
- 160 MJ case considered for activation analysis
- 400 MJ case will **not** alter conclusions

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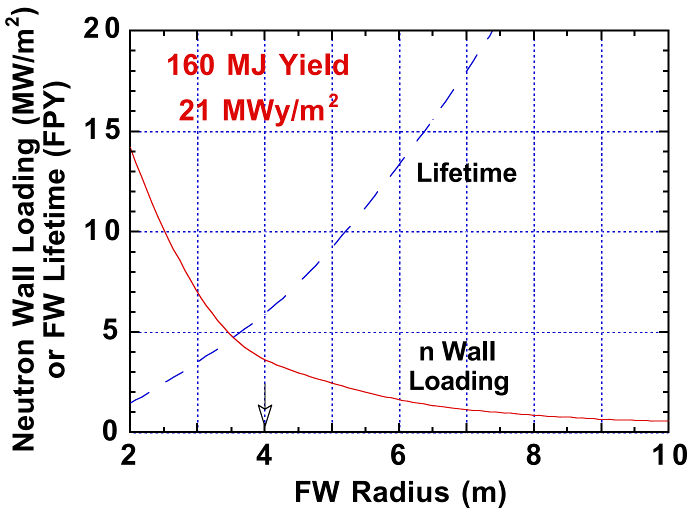
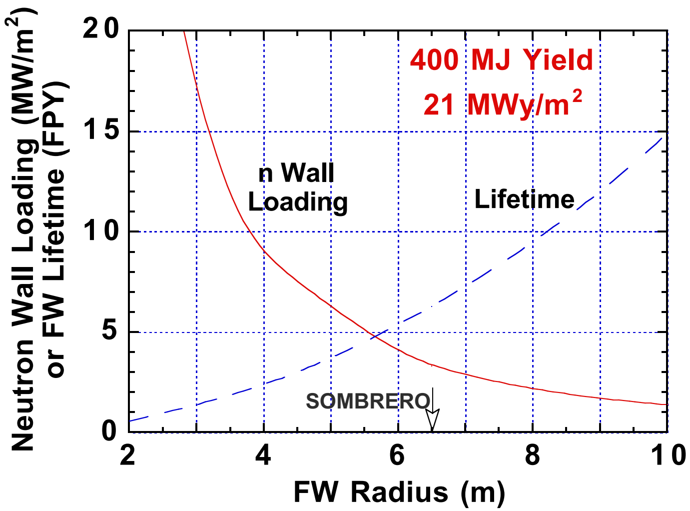
Variation of Neutron Wall Loading and Lifetime with FW Radius

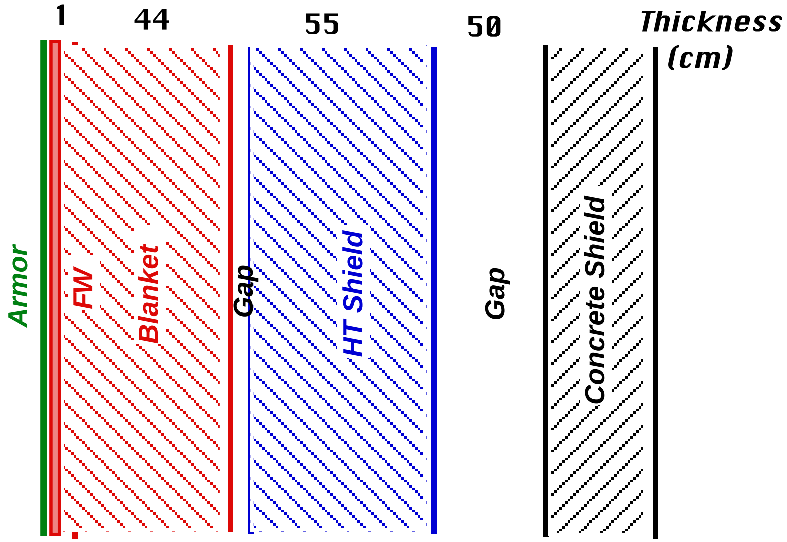




Larger FW radius $\Rightarrow$ Lower Γ $\Rightarrow$ Longer lifetime

Chamber Radial Build

Component	Composition
~0.2 cm Armor	C, W, or Au
1 cm FW#	SiC/SiC composites
44 cm Blanket#	20% SiC, 80% LiPb*
55 cm HT shield**	15% SiC, 10% LiPb, 75% B-FS
Concrete shield**	70% concrete, 20% steel, 10% He



replaceable
* 90% enriched Li
** not optimized

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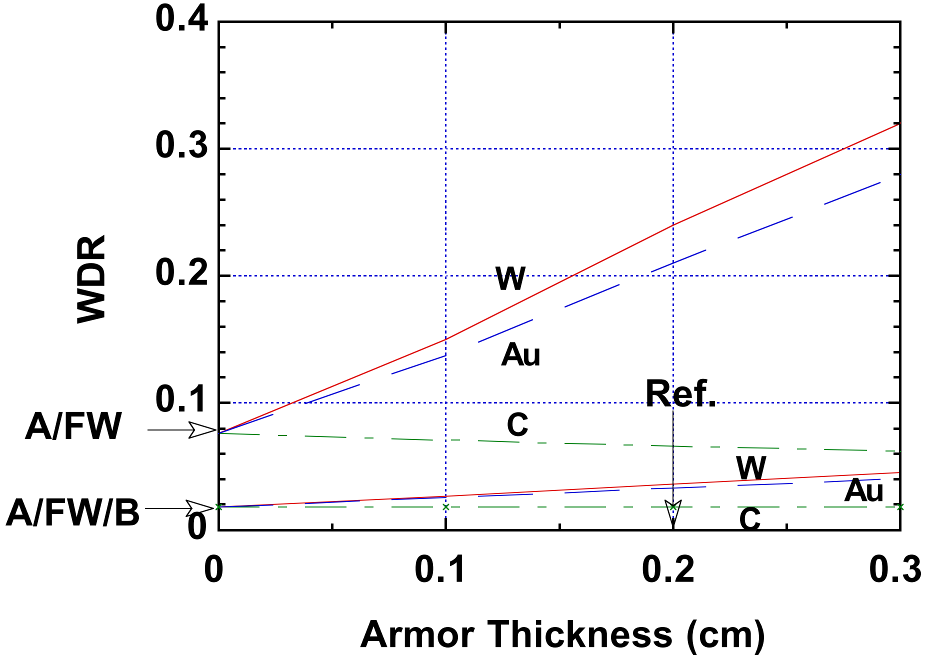
Impact of Armor on WDR* of FW and Blanket



- Considerations other than waste disposal level will determine preferred armor material
- 0.2 cm W armor will be considered for further activation analysis

* Evaluated with Fetter's limits for highly pure armors (no impurities)

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Target Coating/Hohlraum

	Laser (~160 MJ)	HIB (~160 MJ)
Outer Radius	1.95 mm	6 mm
Equivalent Thickness	300 Å	60 µm
Mass per year	5 kg - Au#	70 tons - Au/Gd
Δ on FW armor @ EOL	8 µm	15 cm*
Δ Sticking on FW	**8 µm**	**~1 mm** (2.7 tons of Au/Gd)

- Could 2 mm armor support 2-4 tons of hohlraum materials?

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* Front layer will be melted by x-rays, per Peterson and Haynes

\# Costs $50,000 per year @ $10/gm

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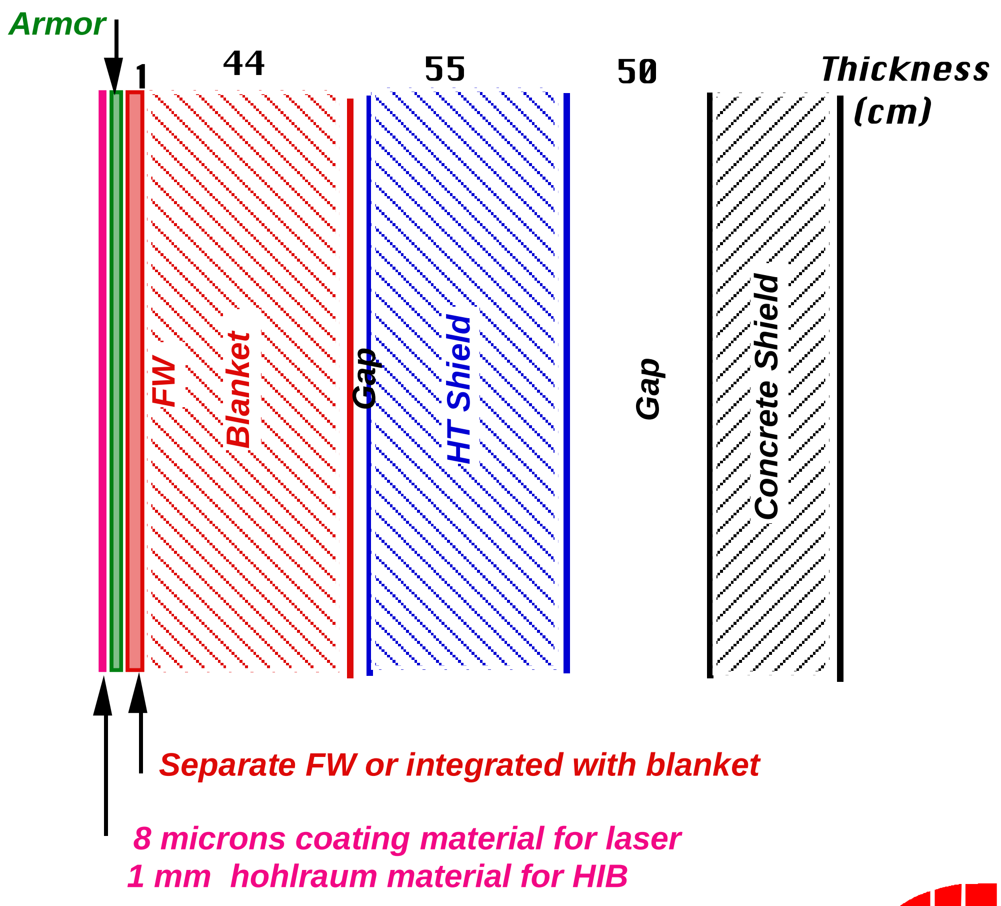
FW Will be Plated with Coating/Hohlraum Materials



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Activation Process of Coating/Hohlraum Materials

Laser

- During burn, coating gets activated by source neutrons
- After burn, coating materials condense on FW armor and get reactivated during subsequent shots
- Coating materials could penetrate 10 μm into armor, per Haynes
- FW/B will be disposed at end of service lifetime
- Main activation concern is WDR of FW/B plated with coating materials

HIB

- During burn, hohlraum gets activated by source neutrons
- After burn, hohlraum materials condense on FW armor and get reactivated during subsequent shots
- In 2-3 wks, ~1 mm thick hohlraum materials accumulate on FW if T<1000 ^{o}C
- X-rays will melt additional layers
- Molten hohlraum materials run down (@ ~10 cm/s !), spending short time in chamber (minutes to days)
- Molten hohlraum materials will be collected at bottom of chamber for recycling after certain cooling period
- Main activation concerns are WDR of FW/B and recycling of collected hohlraum materials

Computational Tools and Model for Activation Analysis

- Spherical model
- Neutron and gamma transport analysis:
  - DANTSYS discrete ordinate code
  - 175 neutron and 42 gamma group structure
  - P_3-S_8 approximation
- Activation analysis:
  - ALARA code
  - Exact modeling of pulse sequence
  - 175 neutron group structure
- Nuclear Data:
  - FENDL-2 IAEA cross section library

Waste Disposal Criteria

- WDR < 1 means component qualifies as low level waste (LLW)
- All components should meet BOTH Fetter's and NRC-10CFR61 WD limits for Class C (or A) waste
- Reported WDR are for:
  - 160 MJ yield for laser and HIB targets
  - 21 MWy/m^2 EOL fluence
  - Highly pure coating/hohlraum/armor materials (no impurities)
  - Compacted solid waste (void excluded)
  - 100 years after shutdown (end of institutional control at disposal site)
  - Fetter's limit (more restrictive than NRC's for materials considered)
  - Volume average over :
    - Coating (or hohlraum) materials only
    - W armor and FW plated with Coating (or hohlraum) materials (C/A/FW)
    - W armor, FW, and blanket plated with Coating (or hohlraum) materials (C/A/FW/B)

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Waste Disposal Rating
(Laser)

	Coating Material*		C/A/FW	C/A/FW/B
	---		0.24	0.04
Au	0.87	(^{194}Hg)	0.24	0.04
W	1.03	(^{186m}Re)	0.24	0.04
Pb	3.6	(^{208}Bi)	0.24	0.04
Pt	169	(^{192n}Ir)	0.35	0.05
Pd	4.6×10^3	(^{108m}Ag)	**3.3**	0.4
Ag	1.7×10^5	(^{108m}Ag)	**114**	**12.4**

FW and blanket should be disposed as single unit if palladium is preferred coating

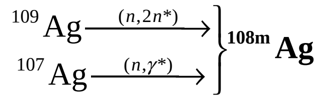
Silver causes waste disposal problem if thickness on FW > 1 μm

* 8 microns sticking on FW armor

Summary of Important Activation Pathways

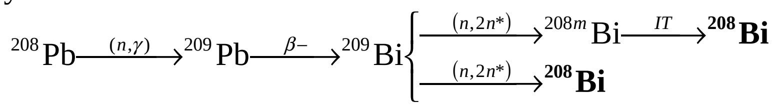
Target Material: **Ag** Major WDR contributor: **^{108m}Ag**

Pathways:



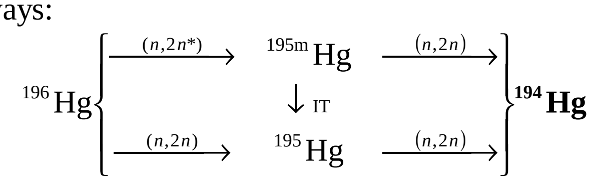
Target Material: **Pb** Major WDR contributor: **^{208}Bi**

Pathways:



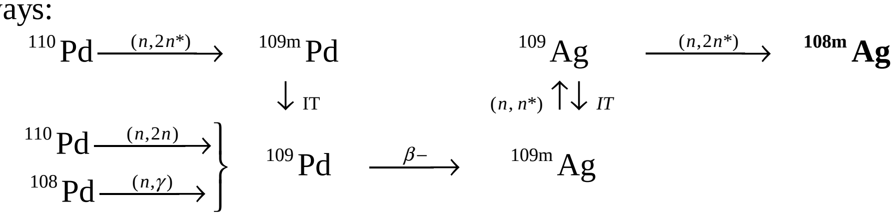
Target Material: **Hg** Major WDR contributor: **^{194}Hg**

Pathways:



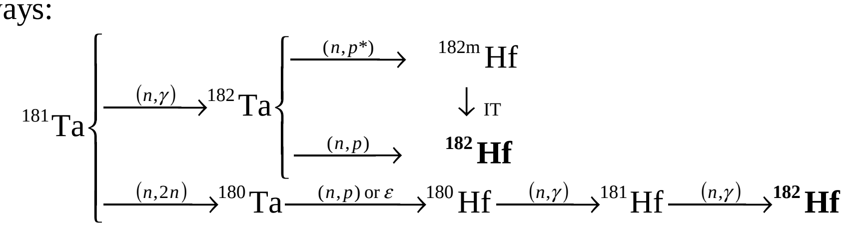
Target Material: **Pd** Major WDR contributor: **^{108m}Ag**

Pathways:



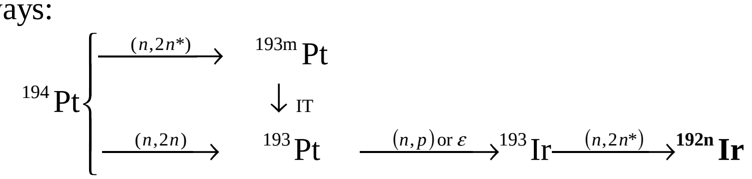
Target Material: **Ta** Major WDR contributor: **^{182}Hf**

Pathways:



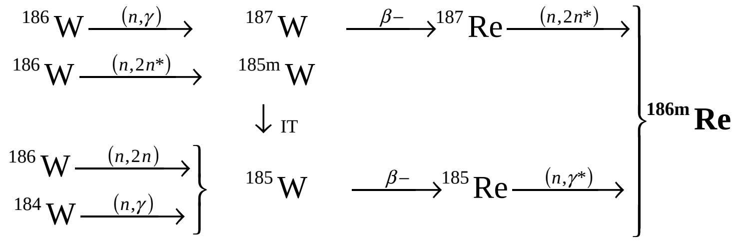
Target Material: **Pt** Major WDR contributor: **^{192n}Ir**

Pathways:



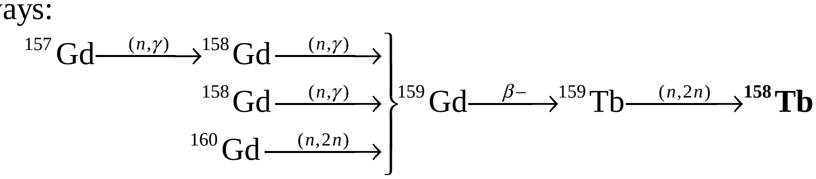
Target Material: **W** Major WDR contributor: **^{186m}Re**

Pathways:



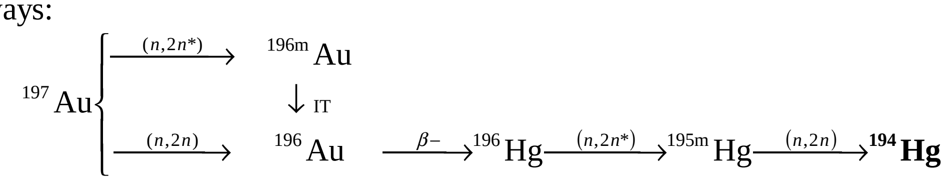
Target Material: **Gd** Major WDR Contributor: **^{158}Tb**

Pathways:



Target Material: **Au** Major WDR Contributor: **^{194}Hg**

Pathways:



Waste Disposal Rating (HIB)

Hohlraum Materials#			H/A/FW	H/A/FW/B
	---		0.24	0.04
Au/Gd (50:50)*	1.2×10^4	(^{158}Tb)	**924**	**107**
Au	0.87	(^{194}Hg)	0.28	0.043
Pb	3.6	(^{208}Bi)	0.5	0.068
Hg	0.4	(^{194}Hg)	0.25	0.04
Ta	0.06	(^{182}Hf)	0.22	0.04
W	1.03	(^{186m}Re)	0.3	0.045
Pb/Ta/Cs (45:20:35)	1.5	(^{208}Bi)	0.34	0.05
Hg/W/Cs (45:20:35)	0.26	(^{194}Hg, ^{186m}Re)	0.24	0.04
Pb/Hf (70:30)	2.9	(^{208}Bi)	0.44	0.06

Gadolinium causes waste disposal problem if thickness on FW > 10 μm

* atom %
\# Assuming 1 mm sticking on FW armor

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Energy Loss# and Economic Impact* of Hohlraum Materials Compared to Au/Gd

Hohlraum Materials	$E/E_{Au/Gd}$	Driver Energy** (MJ)	Driver Cost ($B)	Δ DC ($B)	Δ COE (mills/kWh)
Au/Gd	1	5.9/3.3	2.9/2.03	0	0
Pb/Ta/Cs	1.01	5.9/3.3			
Hg/W/Cs	1.04	6/3.4	2.93/2.06	0.03	0.4
Pb/Hf	1.04	6/3.4			
Au	1.25	6.7/3.7	3.16/2.16	0.26/0.13	3.7/1.8
Pb	1.28	6.7/3.7			
Hg	1.26	6.7/3.7			
Ta	1.25	6.7/3.7			
W	1.25	6.7/3.7			

Exclude Gd, select best material(s) based on considerations other than WD, and take small hit on COE (< 5%)

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

* Preliminary results from W. Meier (2/26/01)

** conventional / close-coupled target

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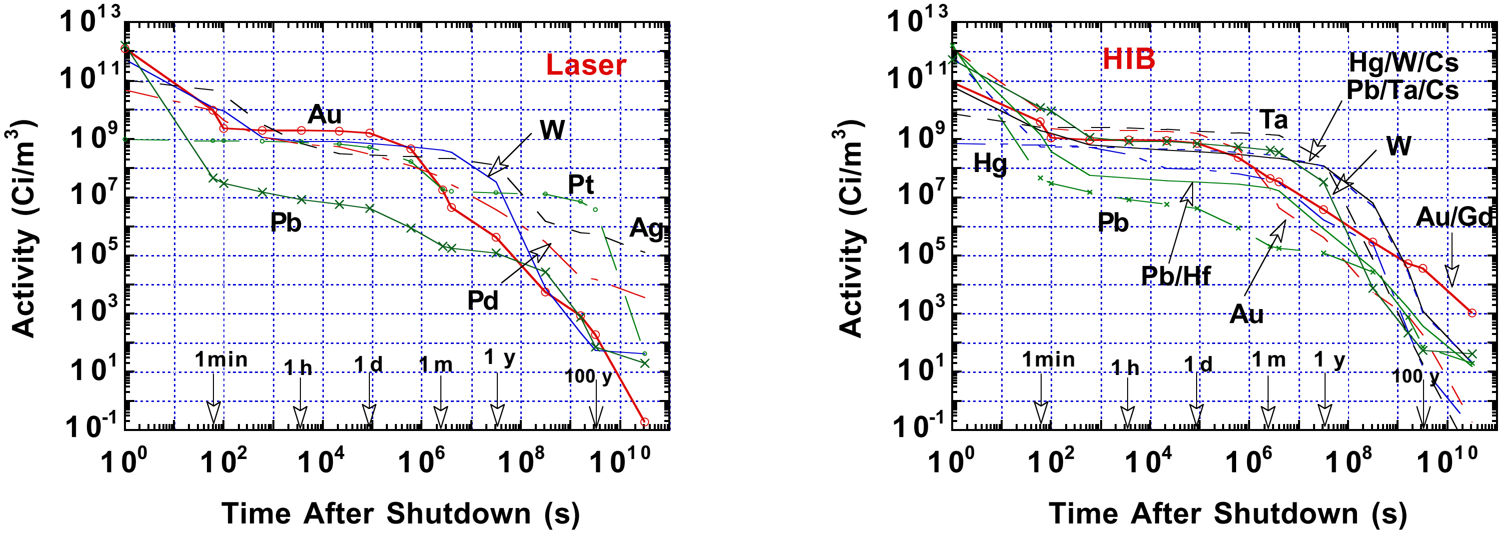
Activity of Coating/Hohlraum Materials Drops Rapidly After Shutdown



- Irradiation with **target flux** for tens of pico-seconds dominates early activity (< 1 min)
- After few minutes, almost all activities are due to reactivation with **FW flux**

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Conclusions

- No waste disposal problem identified for:
  - Au, W, Pb, and Pt for **Laser** target coatings
  - Au, W, Pb, Hg, Ta, Hf, and Cs for **HIB** hohlraums
- **Palladium** coating can be used for laser target if FW and blanket are disposed as single unit
- **Silver** and **Gadolinium** generate high level waste considering realistic thickness on FW > 1 and 10 μm, respectively. This violates ARIES top-level requirements that call for only low-level waste
- Other considerations (fabrication, dose during accidents, etc.) may exclude material(s) from recommended list