Target Recycling: Problem Definition and Preliminary Analysis for ARIES-IFE-HIB

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With input from

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ARIES E-Meeting
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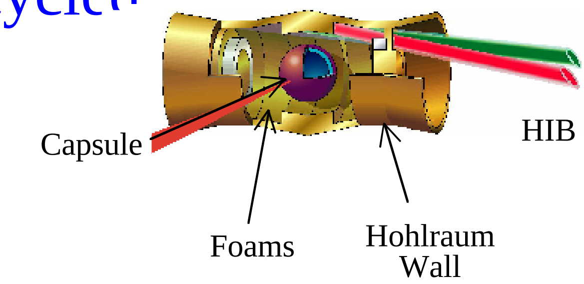
Objectives

- Answer two key questions:
  - How much target waste is generated during operation?
  - Should any candidate hohlraum wall material be excluded for failing to meet recycling criteria?
- Estimate target inventory during plant life and compare it with nuclear island
- Identify key elements for target recycling
- Develop recycling approach for ARIES-IFE-HIB to reduce target waste by 10 X or more
- Determine initial parameters for activation analysis:
  - In-chamber irradiation history
  - Duration of cooling period for **each** material
  - Timeline of recycling and fabrication processes
  - Calculational model for pulsed activation code
- Develop design solutions for materials with potential recycling problems and evaluate impacts of tradeoffs such as target inventory, waste volume, recycling cost, etc.

Background

- Each year, 10-20 tons of activated hohlraum materials will be disposed of in repositories, if not recycled



LLNL Closed-Couple Target Design

Capsule Radius*	2.34 mm
Hohlraum Wall Thickness*	15 µm
Rep Rate	4 Hz
# of Shots	126 million shots/FPY
Plant Lifetime	40 FPY
Volume of Hohlraum Walls	0.0085 cm^3/target
	1.1 m^3/FPY
	43 m^3/40 FPY
Mass of Hohlraum Materials	10-21 tons/FPY
	400-840 tons/40 FPY

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

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Candidate Hohlraum Wall Materials*#

Materials		Composition (wt %)	Density (ton/m^3)	Mass/FPY (tons/FPY)
Gold/Gadolinium (ref.)	$_{79}Au/_{64}Gd$	50/50	13.5	15
Gold	$_{79}Au$		18.9	20
Tungsten	$_{74}W$		19.4	21
Lead	$_{82}Pb$		11.3	12
Mercury	$_{80}Hg$		13.6	15
Tantalum	$_{73}Ta$		16.6	18
Lead/Tantalum/Cesium	$Pb/Ta/_{55}Cs$	45/20/35	9.1	10
Mercury/Tungsten/Cesium	Hg/W/Cs	45/20/35	10.6	11
Lead/Hafnium	$Pb/_{72}Hf$	70/30	11.9	13

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

\# Highly pure materials assumed for activation analysis

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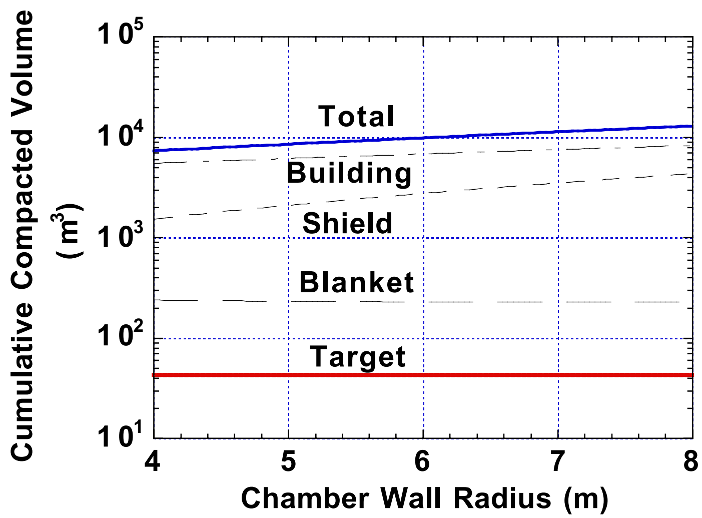
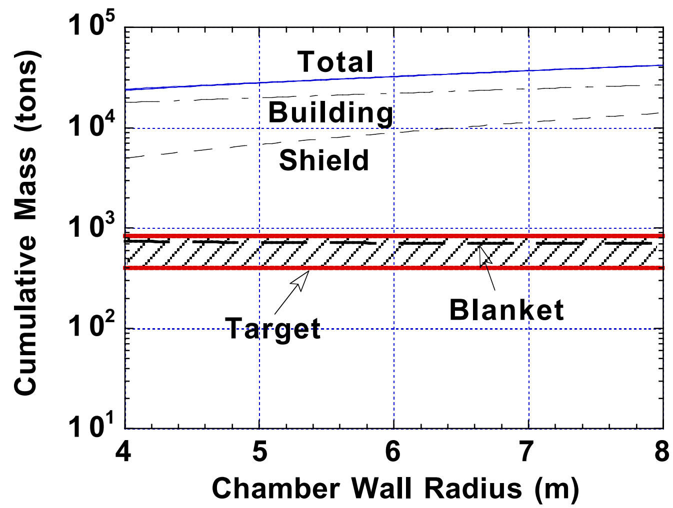
Hohlraum Wall Materials Represent Small Waste Stream for IFE





- **Typical dimensions**:

Component	Shape	Inner Radius	Thick.	Structure	Height
Chamber Wall	Sphere	R_w	1 cm	SiC	
Blanket	Sphere	R_w+0.01m	40 cm	20% SiC	
Bulk Shield	Cylinder	R_w+0.41+1* m	2 m	80%Conc.,10%SS	3 R_i
Building	Cylinder	R_w+3.41+10* m	1 m	85%Conc.,10%SS	2 R_i

Hohlraum walls constitute only 0.6% of cumulative volume and < 4% of cumulative mass

* Gap

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Hohlraum Wall Materials Represent Small Waste Stream for IFE (Cont.)

- Target recycling should be considered if blanket/shield recycling is a top-level requirement for ARIES-IFE-HIB

- One of ARIES' "**goals**" is to recycle all components

$\Rightarrow$ Develop target recycling approach for ARIES-IFE-HIB:

  - to reduce waste
  - to enhance repository capacity
  - to lower consumption of materials with limited resources

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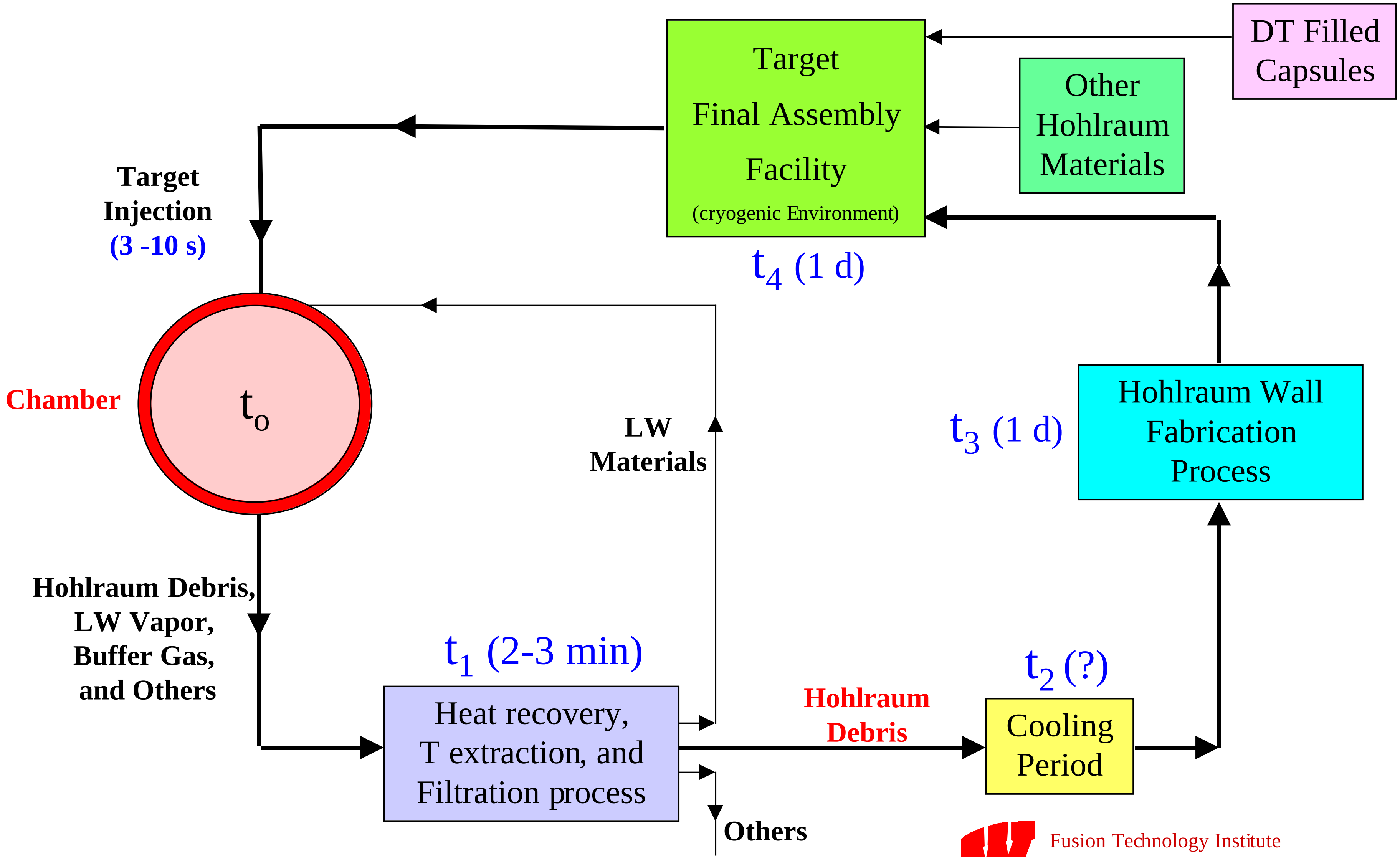
Hohlraum Recycling Process



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Hohlraum Recycling Process (Cont.)

- Separation Process:
  - On-line separation of elements leaving chamber (LW materials, buffer gas, D, T, C, Fe, Al, Be, Br, etc) from hohlraum debris, except transmutations (conservative assumption). For example, Au/Gd transmutations include Os, Ir, Pt, Hg / Nd, Pm, Sm, Eu, Tb, Dy, Ho, Er.
  - Some elements will be disposed of
  - Radioactive hohlraum debris (containing transmutations) will be stored and sent in batches to Target Fabrication Facility for recycling
- Cooling Period:
  - Materials dependent
  - Time could range from 0.5 hour to several years, depending on decay rate of activated hohlraum debris
  - Cooling periods ≤ 2 y reduce hohlraum inventory by 10 X or more
- Hohlraum Wall Fabrication Process:
  - Fabrication of recycled debris into radioactive hohlraum walls
  - Fabrication process takes ~ one day, per Nobile and Schwendt (LANL)
  - Capsule fabrication (DT filling, layering, holding, etc) and foam fabrication could be done in parallel with hohlraum wall fabrication
- Target Final Assembly Facility:
  - Assembly process of all components in cryogenic environment: capsule, organic and metal foams, and radioactive hohlraum wall
  - Assembly process takes ~ one day, per Nobile and Schwendt (LANL)

Hohlraum Recycling Process (Cont.)

- Hohlraum debris spend > two days outside chamber ($\Sigma_i\ t_i$, i=1- 4) for recycling, depending on cooling period
- Remote handling may be required during fabrication and assembly processes, depending on activation level at end of cooling period
  - ⇒ Limited personnel access to target fabrication facility
  - ⇒ More difficult and time consuming maintenance/repair of target fabrication equipment
- Target fabrication activities will be fully automated, per Schultz.
  - ⇒ Penalty of dealing with radioactive materials is not severe
- Storage space for radioactive materials is needed in ALL facilities
- Economics of recycling process should be addressed
- Losses during fabrication will be ignored

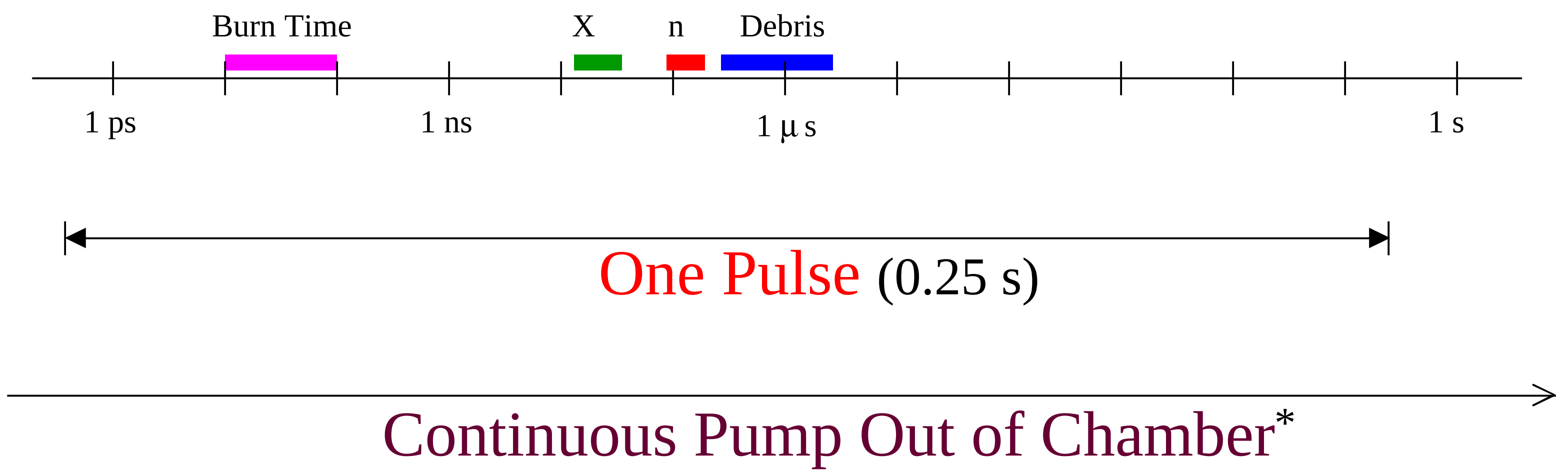
Several Factors May Prematurely Terminate Recycling Process Requiring New Hohlraum Materials

- Waste disposal rating of hohlraum debris violates Class C low level waste top-level requirements
- 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. Alternative option is to develop more forgiving target design!
- Accident dose at site boundary exceeds 1 rem following accidents in chamber and/or in Target Fabrication Facility

Species Arrival Time @ Chamber Wall

(5 m Radius Chamber, 4 Hz)

X-rays	**15-25 ns**
Neutrons	**90-150 ns**
Debris ions	**0.2-2 μs**



* Amount of pumped materials varies during pulse, per Sviatoslavsky

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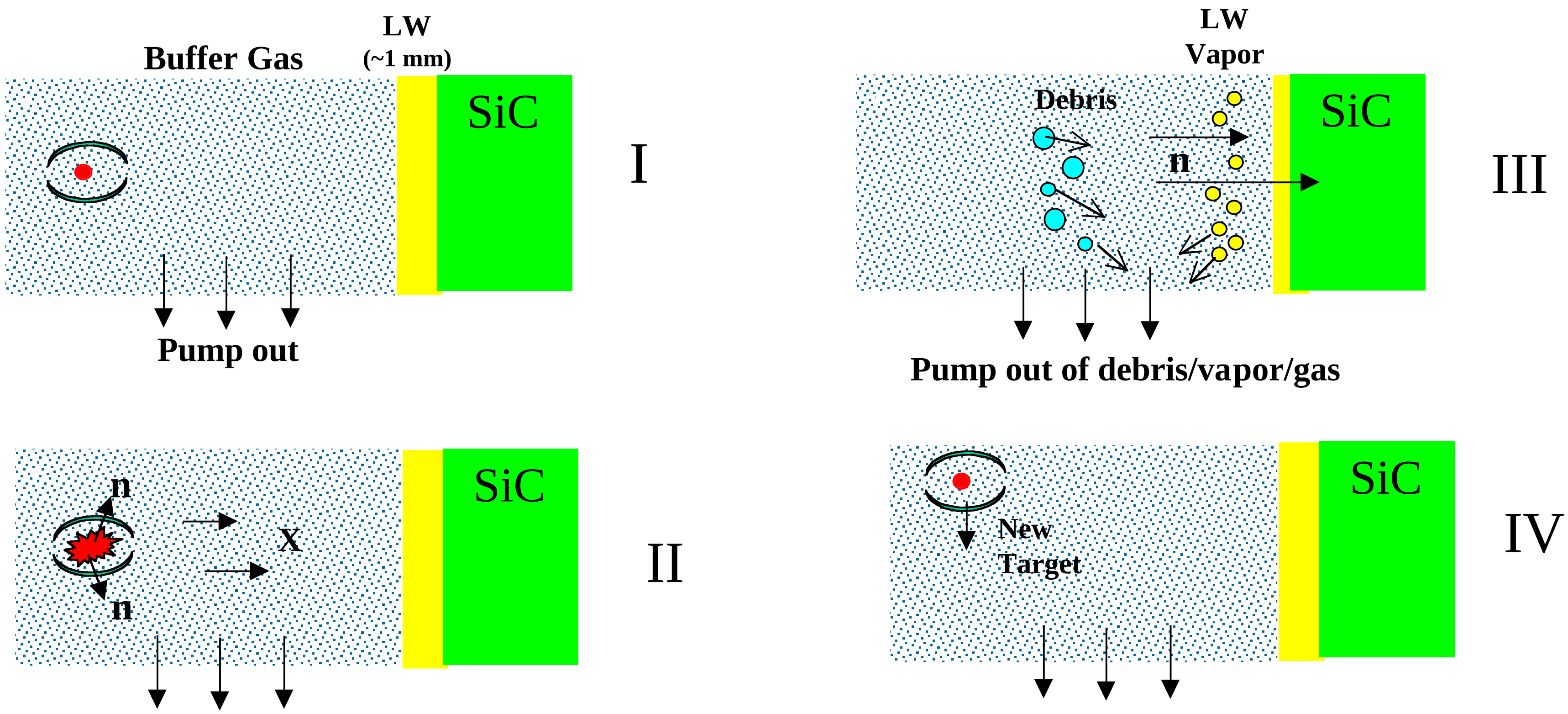
Sequence of Events - Option I

High Density Buffer Gas (~5 torr)



Dense gas stops x-rays and target debris

Hohlraum debris irradiated once per pulse with target flux at center of chamber

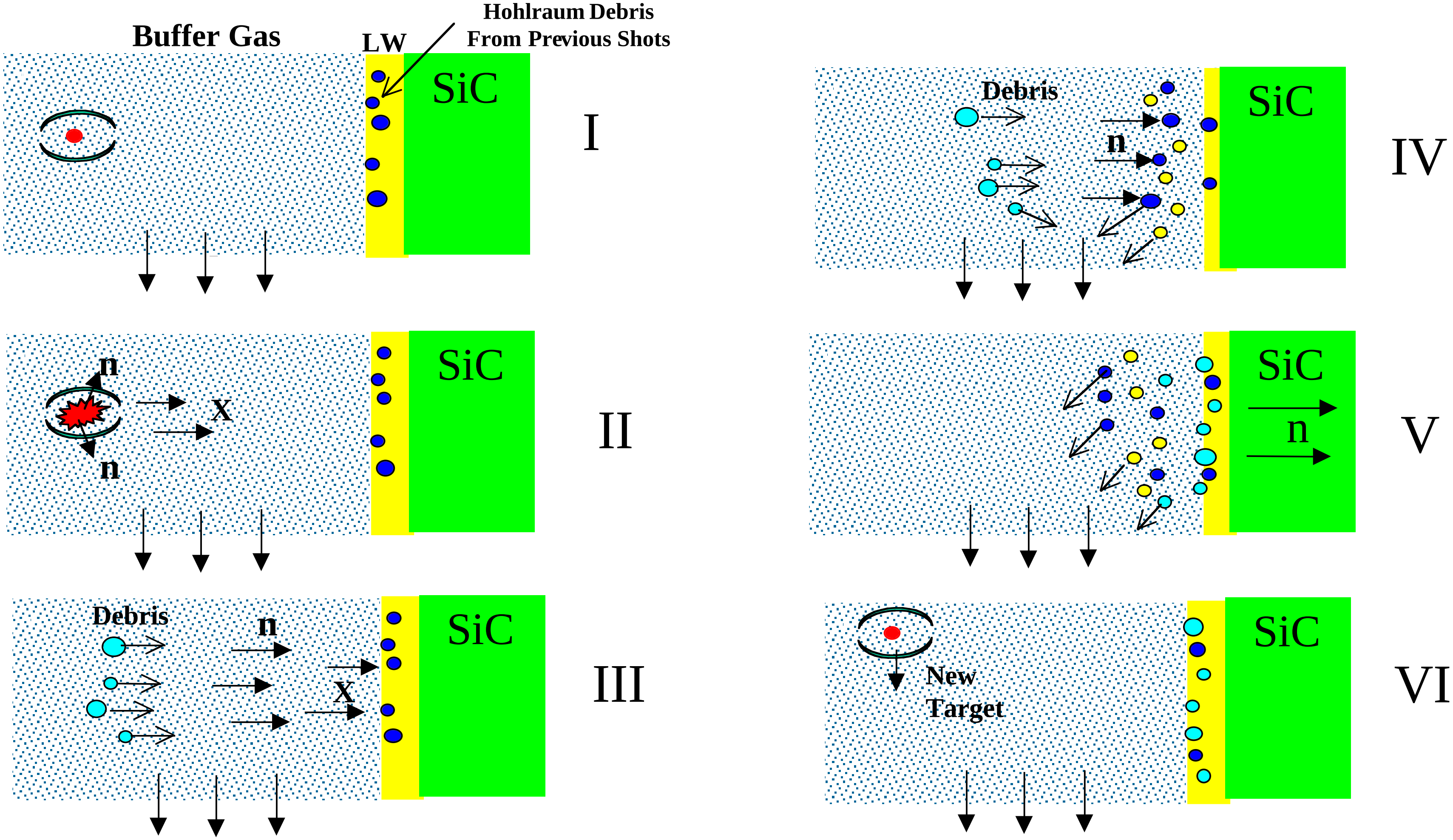
Sequence of Events - Option I (Cont.)

High Density Buffer Gas (~5 torr)

- LW will be needed only for small chambers ($R_w < 4$ m), per Peterson
- **During burn**, 14 MeV neutrons interact with and activate hohlraum walls
- **After burn,** dense buffer gas (~5 torr) stops x-rays and debris before reaching chamber wall
- LW vapor, buffer gas, and activated debris are continuously pumped out for recycling
- **Conservative assumptions:**
  - Hohlraum materials get irradiated once per shot with energetic 14 MeV source neutrons at chamber center
  - Transmutations continue to build up with time in hohlraum wall materials
  - On-line atomic separation of hohlraum debris for recycling
  - After specific cooling period, recycled radioactive hohlraum materials spend at least 2 days in Target Fabrication Facility before target injection

Sequence of Events - Option II

Low Density Buffer Gas (~10^{-3} torr)



Hohlraum debris get irradiated several times with target and wall fluxes before leaving chamber

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Sequence of Events - Option II (Cont.)

Low Density Buffer Gas (~10^{-3} torr)

- **During burn**, 14 MeV neutrons interact with and activate hohlraum walls
- **After burn:**
  - X-rays evaporate 10 μm of LW loaded with debris from previous shots
  - At vicinity of chamber wall, neutrons (av. E_n = 11.8 MeV) interact with evaporated debris and also with remaining debris in LW
  - Slow debris from this shot get pumped out with buffer gas. Fast debris reach LW and get embedded in seeped LW
- Debris residence time in chamber depends on speed of liquid running down on chamber wall
- LW vapor, buffer gas, and activated debris are continuously pumped out for recycling
- **Conservative assumptions:**
  - Buffer gas will not stop all hohlraum debris
  - Debris get irradiated several times before being pumped out:
    - With energetic 14 MeV source neutrons at chamber center
    - With softer, less intense n flux at vicinity of chamber wall during subsequent shots
  - Transmutations continue to build up with time in hohlraum wall materials
  - On-line atomic removal of LW materials* and gases before start of recycling process
  - After cooling period, radioactive hohlraum wall materials spend at least 2 days in Target Fabrication Facility before target injection

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* up to 0.1 μm particles can be removed

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Remarks and Work Plan

- Target inventory (40 m^3, 600 tons) is small compared to total radwaste (10,000 m^3, 30,000 tons) of ARIES-IFE-HIB
- Ability to recycle should not limit hohlraum wall material choices, unless recycling is a top-level requirement for ARIES-IFE
- To meet ARIES' "goals", we will develop recycling approach for the reference hohlraum wall material (Au/Gd) and others, if time permits
- We will:
  - Develop irradiation models for Options I and II for ALARA **pulsed** activation code
  - Recommend cooling period that meet recycling requirements for **each** material