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

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With input from
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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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capsule Radius*</td>
<td>2.34 mm</td>
</tr>
<tr>
<td>Hohlraum Wall Thickness*</td>
<td>15 µm</td>
</tr>
<tr>
<td>Rep Rate</td>
<td>4 Hz</td>
</tr>
<tr>
<td># of Shots</td>
<td>126 million shots/FPY</td>
</tr>
<tr>
<td>Plant Lifetime</td>
<td>40 FPY</td>
</tr>
<tr>
<td>Volume of Hohlraum Walls</td>
<td>0.0085 cm³/target</td>
</tr>
<tr>
<td></td>
<td>1.1 m³/FPY</td>
</tr>
<tr>
<td></td>
<td>43 m³/40 FPY</td>
</tr>
<tr>
<td>Mass of Hohlraum Materials</td>
<td>10-21 tons/FPY</td>
</tr>
<tr>
<td></td>
<td>400-840 tons/40 FPY</td>
</tr>
</tbody>
</table>

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## Candidate Hohlraum Wall Materials*#

<table>
<thead>
<tr>
<th>Materials</th>
<th>Composition (wt %)</th>
<th>Density (ton/m³)</th>
<th>Mass/FPY (tons/FPY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold/Gadolinium (ref.)</td>
<td>79Au/64Gd 50/50</td>
<td>13.5</td>
<td>15</td>
</tr>
<tr>
<td>Gold</td>
<td>79Au</td>
<td>18.9</td>
<td>20</td>
</tr>
<tr>
<td>Tungsten</td>
<td>74W</td>
<td>19.4</td>
<td>21</td>
</tr>
<tr>
<td>Lead</td>
<td>82Pb</td>
<td>11.3</td>
<td>12</td>
</tr>
<tr>
<td>Mercury</td>
<td>80Hg</td>
<td>13.6</td>
<td>15</td>
</tr>
<tr>
<td>Tantalum</td>
<td>73Ta</td>
<td>16.6</td>
<td>18</td>
</tr>
<tr>
<td>Lead/Tantalum/Cesium</td>
<td>Pb/Ta/55Cs 45/20/35</td>
<td>9.1</td>
<td>10</td>
</tr>
<tr>
<td>Mercury/Tungsten/Cesium</td>
<td>Hg/W/Cs 45/20/35</td>
<td>10.6</td>
<td>11</td>
</tr>
<tr>
<td>Lead/Hafnium</td>
<td>Pb/72Hf 70/30</td>
<td>11.9</td>
<td>13</td>
</tr>
</tbody>
</table>

# Highly pure materials assumed for activation analysis
Hohlraum Wall Materials Represent Small Waste Stream for IFE

- **Typical dimensions:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Shape</th>
<th>Inner Radius</th>
<th>Thick.</th>
<th>Structure</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber Wall</td>
<td>Sphere</td>
<td>$R_w$</td>
<td>1 cm</td>
<td>SiC</td>
<td></td>
</tr>
<tr>
<td>Blanket</td>
<td>Sphere</td>
<td>$R_w + 0.01$</td>
<td>40 cm</td>
<td>20% SiC</td>
<td></td>
</tr>
<tr>
<td>Bulk Shield</td>
<td>Cylinder</td>
<td>$R_w + 0.41 + 1^*$ m</td>
<td>2 m</td>
<td>80% Conc., 10% SS</td>
<td>$3R_i$</td>
</tr>
<tr>
<td>Building</td>
<td>Cylinder</td>
<td>$R_w + 3.41 + 10^*$ m</td>
<td>1 m</td>
<td>85% Conc., 10% SS</td>
<td>$2R_i$</td>
</tr>
</tbody>
</table>

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

⇒ Develop target recycling approach for ARIES-IFE-HIB:
  – to reduce waste
  – to enhance repository capacity
  – to lower consumption of materials with limited resources
Hohlraum Recycling Process

Target Final Assembly Facility (cryogenic Environment)

DT Filled Capsules

Other Hohlraum Materials

Chamber

Target Injection (3 -10 s)

Heat recovery, T extraction, and Filtration process

Heat recovery, T extraction, and Filtration process

Hohlraum Debris, LW Vapor, Buffer Gas, and Others

Hohlraum Debris, LW Vapor, Buffer Gas, and Others

Chamber

Hohlraum Debris, LW Vapor, Buffer Gas, and Others

Hohlraum Wall Fabrication Process

Hohlraum Wall Fabrication Process

Others

Others

Hohlraum Debris

Hohlraum Debris

Cooling Period

Cooling Period

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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 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
Sequence of Events - Option I
High Density Buffer Gas (~5 torr)

I
Buffer Gas
LW Vapor (~1 mm)
SiC
Pump out

II
n
x
n
SiC

III
Debris
Pump out of debris/vapor/gas

IV
New Target

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 \(\mu\)m 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

* up to 0.1 \(\mu\)m particles can be removed
Remarks and Work Plan

• **Target inventory** (40 m³, 600 tons) is **small** compared to total radwaste (10,000 m³, 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