Effects of Particle Size and Density on Reactivity
Low Enriched UO$_2$ Systems

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Background

Heterogeneous Systems - Particle Density Effect

• Particles ~ 1000 µm and 4.5 g/cc modeled as homogeneous at GNF-A
• Particles > 127 µm are heterogeneous (TID-7016)
• Non-conservative?

Homogeneous Systems - Bulk Density Effect

• Optimal Reactivity occurs at ~ 50 wt.% H₂O for a fixed mass of LEU.
• Is it credible that we can get 50 wt.% H₂O?
• Too conservative?
Introduction

Goal
To determine the effect of particle size and density on reactivity for low enriched UO$_2$ - H$_2$O systems

Particle Density
Heterogeneous Systems

Bulk Density
Homogeneous Systems
Heterogeneous Systems
The effect of particle size and density
### Optimum Particle Size

**Wt. Fraction $H_2O = \frac{W/F}{W/F + \rho_{fuel}}**

<table>
<thead>
<tr>
<th>W/F</th>
<th>Optimum Particle Diameter (µm)</th>
<th>10.96 g/cc fuel Wt. Fraction $H_2O$</th>
<th>4.5 g/cc fuel Wt. Fraction $H_2O$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.577</td>
<td>70,000</td>
<td>0.05</td>
<td>0.11</td>
</tr>
<tr>
<td>1</td>
<td>30,000</td>
<td>0.08</td>
<td>0.18</td>
</tr>
<tr>
<td>2</td>
<td>14,000</td>
<td>0.15</td>
<td>0.31</td>
</tr>
<tr>
<td>3</td>
<td>8,000</td>
<td>0.21</td>
<td>0.40</td>
</tr>
<tr>
<td>4</td>
<td>7,000</td>
<td>0.27</td>
<td>0.47</td>
</tr>
<tr>
<td>5</td>
<td>5,000</td>
<td>0.31</td>
<td>0.53</td>
</tr>
<tr>
<td>6</td>
<td>4,000</td>
<td>0.35</td>
<td>0.57</td>
</tr>
<tr>
<td>7</td>
<td>3,000</td>
<td>0.39</td>
<td>0.61</td>
</tr>
<tr>
<td>8</td>
<td>2,500</td>
<td>0.42</td>
<td>0.64</td>
</tr>
<tr>
<td>9</td>
<td>2,500</td>
<td>0.45</td>
<td>0.67</td>
</tr>
<tr>
<td>10</td>
<td>2,500</td>
<td>0.48</td>
<td>0.69</td>
</tr>
<tr>
<td>11</td>
<td>2,000</td>
<td>0.50</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Infinite System

Heterogeneous effect is independent of density for infinite systems.

Optimum $\Delta k/k = \frac{k_{het} - k_{hom}}{k_{hom}}$

<table>
<thead>
<tr>
<th>Particle Diameter (µm)</th>
<th>$\Delta k/k$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum</td>
<td>5</td>
</tr>
<tr>
<td>2,000</td>
<td>3.0</td>
</tr>
<tr>
<td>1,000</td>
<td>1.8</td>
</tr>
<tr>
<td>200</td>
<td>0.6</td>
</tr>
</tbody>
</table>

5 wt.% $\text{H}_2\text{O}$

<table>
<thead>
<tr>
<th>Particle Diameter (µm)</th>
<th>$\Delta k/k$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimum (2.75&quot;)</td>
<td>15</td>
</tr>
<tr>
<td>12,700 (0.5&quot;)</td>
<td>6</td>
</tr>
<tr>
<td>1,000</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Mass Limited System

Particle Density is important because leakage is important!

For 1,000 µm particles ≤ 4.5 g/cc, homogeneous is bounding up to 10,000 kg.

For 1,000 µm particles = 10.96 g/cc, heterogeneous effect is independent of mass.

\[
\frac{\Delta k}{k} = \frac{k_{\text{het}} - k_{\text{hom}}}{k_{\text{hom}}}
\]
Geometry Limited System

Heterogeneous effect is density and geometry dependent for geometry limited systems.

$$\frac{\Delta k}{k} = \frac{k_{\text{net}} - k_{\text{hom}}}{k_{\text{hom}}}$$

For heterogeneous particles ≤ 6 g/cc, homogeneous is bounding up to 119 L or infinite 2D array.

Heterogeneous effect is density and geometry dependent for geometry limited systems.
Homogeneous Systems
The effect of bulk density
Mass Limited System

Homogeneous 31 kg UO₂ Sphere

High density powder has less void space for water to occupy.
Density Dependent Safe Mass Limits

Higher safe mass limits can be developed for systems of a known density if agitation is not credible.

\[ y = 7.3914x^2 - 10.277x + 34.903 \]
\[ R^2 = 0.9999 \]
Conclusion

Effect of Particle Size and Density on Heterogeneous Systems

**Infinite**
- No density effect
- Large particle size effect

**Mass and Geometry Limited**
- Homogeneous bounds heterogeneous (≤ 6 g/cc) for systems with a high leakage component (≤ 50 kg, 119 L)
- 1,000 µm particles ≤ 4.5 g/cc are effectively homogeneous

**Effect of Bulk Density on Homogeneous Systems**
- Higher safe mass limits can be developed for systems of a known density if agitation is not credible.