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Spouted bed design considerations for coated nuclear fuel particles

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Spouted Bed Design Considerations for Coated Nuclear Fuel Particles

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May 22 - 27, 2016



Outline

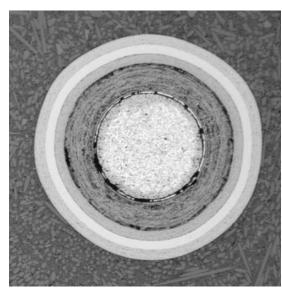
- Background
- Design considerations
- Nuclear fuel particle CVD furnace design
 - Converging section
 - Gas injector nozzle
 - Gas paths

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Background Information

- High Temperature Gas-cooled Reactor (HTGR)
 - Graphite moderated, helium cooled reactor (750°C \leq T_{exit} \leq 900°C)
 - Fuel kernels 425 μm 500 μm; 10.8 11.2 g/cm³
 - Kernels hermetically sealed in 4 coating layers (TRISO particle)
 - Layers form the primary containment for fission products







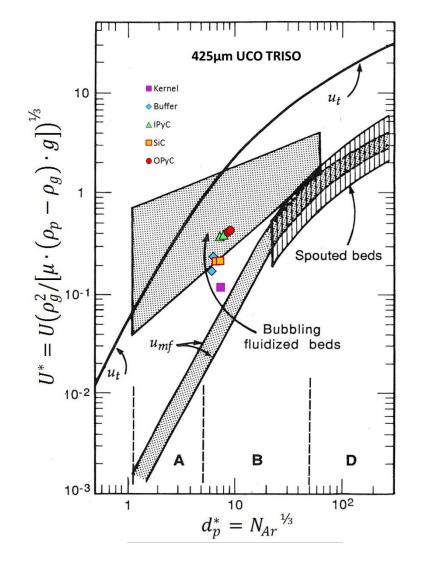
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- Nuclear criticality safety (geometrically safe)
 - Fissile material mass
 - Fissile material geometry
 - Neutron moderation, reflection, and absorption
- Depositions take place at 1230°C 1580°C
- No internal instrumentation
 - Limited material selection
 - Chemical contamination of product
 - Mechanical damage to nascent layers
 - Freeboard gas opacity and bed luminance



- Geldart Group B particles
 - Spoutable as shallow bed
 - Dynamic bed properties
 - Density (11 \rightarrow 3 g/cm³)
 - Diameter (425 \rightarrow 870 μ m)
 - Bed expands 8-fold
- Fluidized by hydrogen, argon, and precursor gases
 - Gases enter cold
 - Exothermic decomposition





- High particle integrity needed
 - Uniform layer thicknesses and densities
 - Highly isotropic pyrocarbon
 - High density silicon carbide
- Low reject fraction required
 - Minimize radioactive waste and fissile material recycle
 - High productivity
- No "dead" zones in the bed
- Uniform bed temperature profile
- Uniform particle residence times in the annulus



- "Blind" process (no internal instrumentation)
 - Pressure instruments on gas lines verify bed movement
 - Modeling of instantaneous conditions with CPFD Barracuda VR software

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CVD Furnace Design

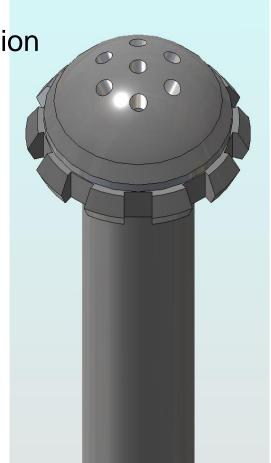
- Nuclear-grade graphite retort (15.2 cm ID)
- Converging section uniquely shaped
 - Narrow included angle at top (22°)
 - Promotes mass flow
 - Precludes dead zones
 - Wide included angle at bottom (116°)
 - Encourages spout stability
 - Prevents bulk bed levitation
 - Prevents gas impingement on walls
 - Accommodates gas distributor nozzle



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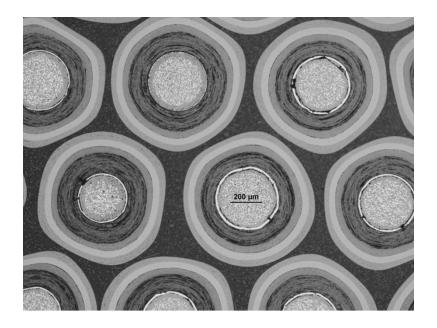
CVD Furnace Design

- Multiport gas distributor (graphite)
 - High gas flow without excessive penetration
 - Broader active coating zone
 - Domed to shed particles
- Annular gas orifice
 - Flanged rim
 - Reduced heat transfer
 - Offset for annular gap
 - Inert "auxiliary" gas around perimeter
 - Fluidizes bed at the bottom
 - Displaces reactive coating gases
 - Cools nozzle-retort interface



Results

- 2000 grams of uranium kernels per charge
- 160 coating runs accomplished
- Coating batches routinely meet fuel specifications
- Improved sphericity relative to lab-scale coater



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Questions?

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