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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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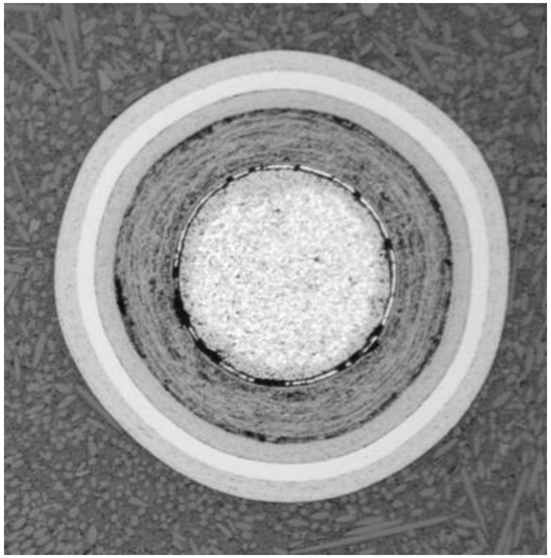
Outline

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

Background Information

- High Temperature Gas-cooled Reactor (HTGR)
  - Graphite moderated, helium cooled reactor (750°C ≤ T_{exit} ≤ 900°C)
  - Fuel kernels 425 µm - 500 µm; 10.8 - 11.2 g/cm^3
  - Kernels hermetically sealed in 4 coating layers (TRISO particle)
  - Layers form the primary containment for fission products

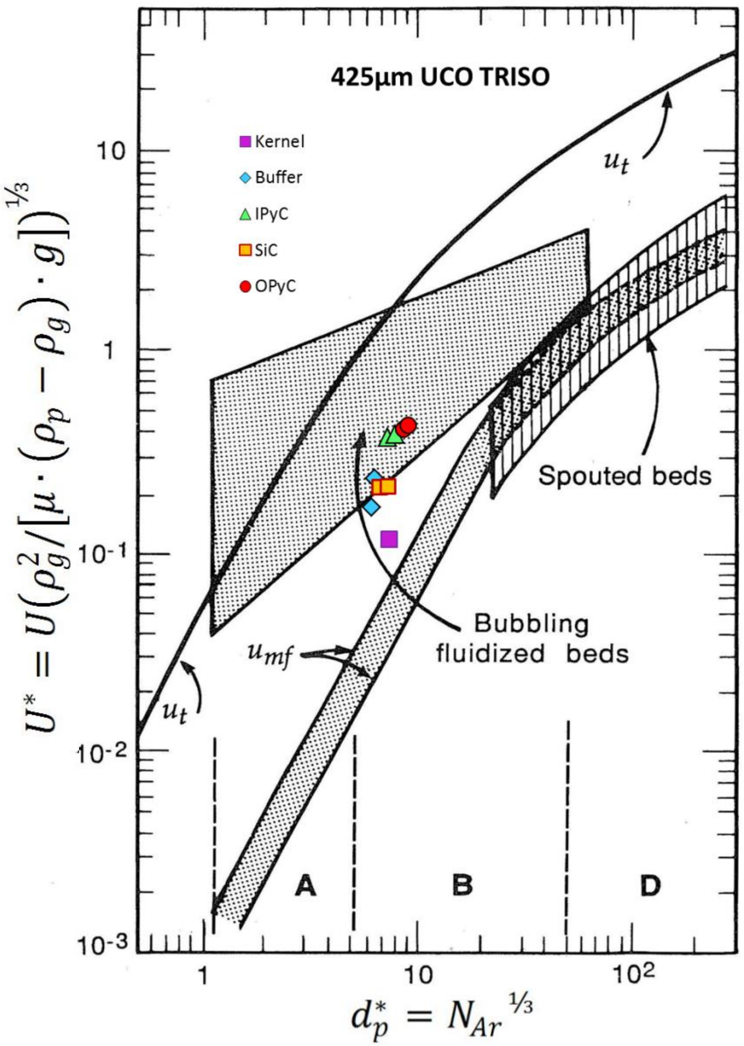


Design Considerations

- 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

Design Considerations

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



Design Considerations

- 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

Design Considerations

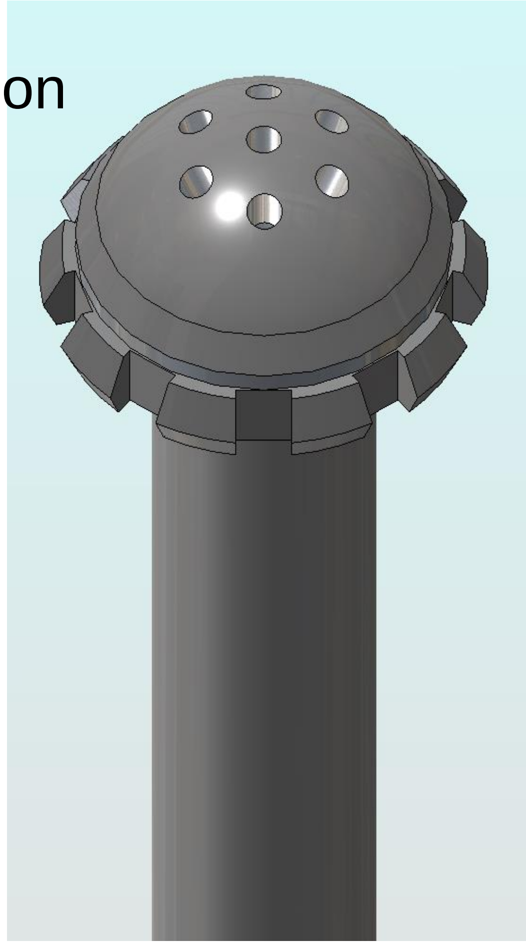
- "Blind" process (no internal instrumentation)
  - Pressure instruments on gas lines verify bed movement
  - Modeling of instantaneous conditions with CPFD Barracuda VR software

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

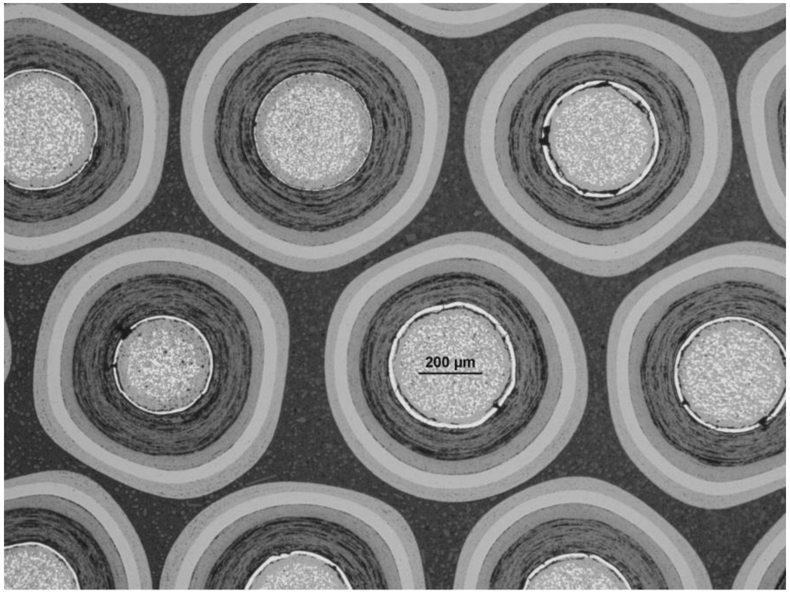
CVD Furnace Design

- 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



Questions?

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