Development of a Fluidized Bed CVD System for Coating UO_2 Particles with Tungsten

NASA Advanced Exploration System (AES) Project:
Nuclear Cryogenic Propulsion Stage

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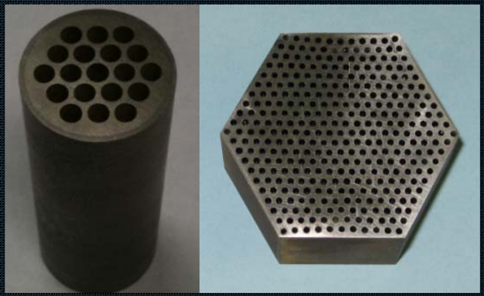
Background

- NTP fuels under development
  - W-60vol%UO_2 CERMET



- Minimize erosion
  - Prevent H_2 propellant at ~3000 K from reducing UO_2 fuel kernels
  - Requires each fuel kernel to be clad in tungsten
- Coat spherical dUO_2 powders with 40 vol% W
- Coated spherical powders advantageous for HIP
  - Higher powder packing %TD
  - Minimize powder segregation

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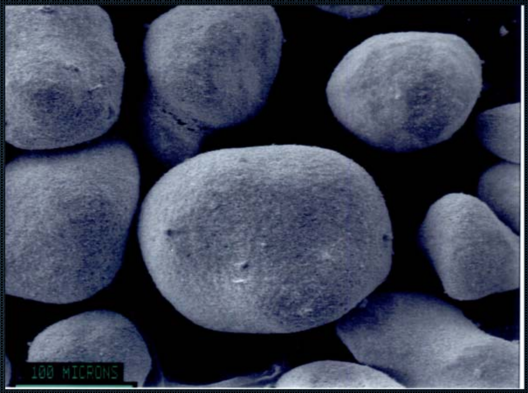
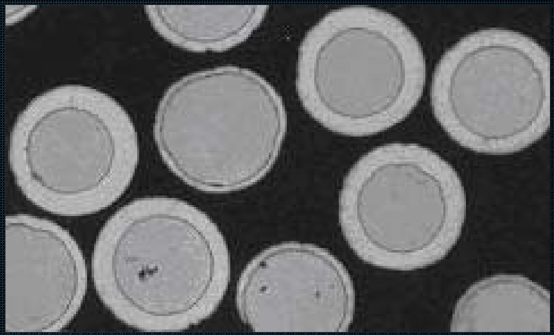
Problem & Objectives

- WF_6 process
  - Residual F exacerbates fuel loss
  - HF bi-product
- WCl_6 process
  - Minimal Cl contamination
  - More complex than WF_6 process (solid-to-vapor vs. gaseous reagent)
- Vendor cost to coat dUO_2 excessive
- Develop a lab-scale prototype that utilizes the WCl_6 process that enables cost effective coating of spherical dUO_2 powders



SEM Micrograph of spherical uncoated particles

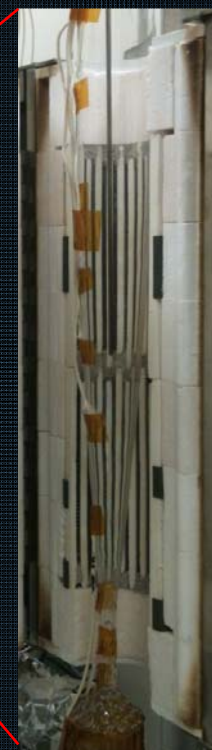

SEM micrographs of spherical coated particles

Apparatus & Procedure

- WCl_6 process

$$WCl_6 + 3H_2 \xrightarrow{930^\circ C} W + 6HCl$$

- Fluidized bed reactor (H_2/Ar 10:1 ratio)
- Raining feed system (fill and drain powder hoppers)
- 3rd generation system (25 g quantities)



CVD System

CVD System Schematic

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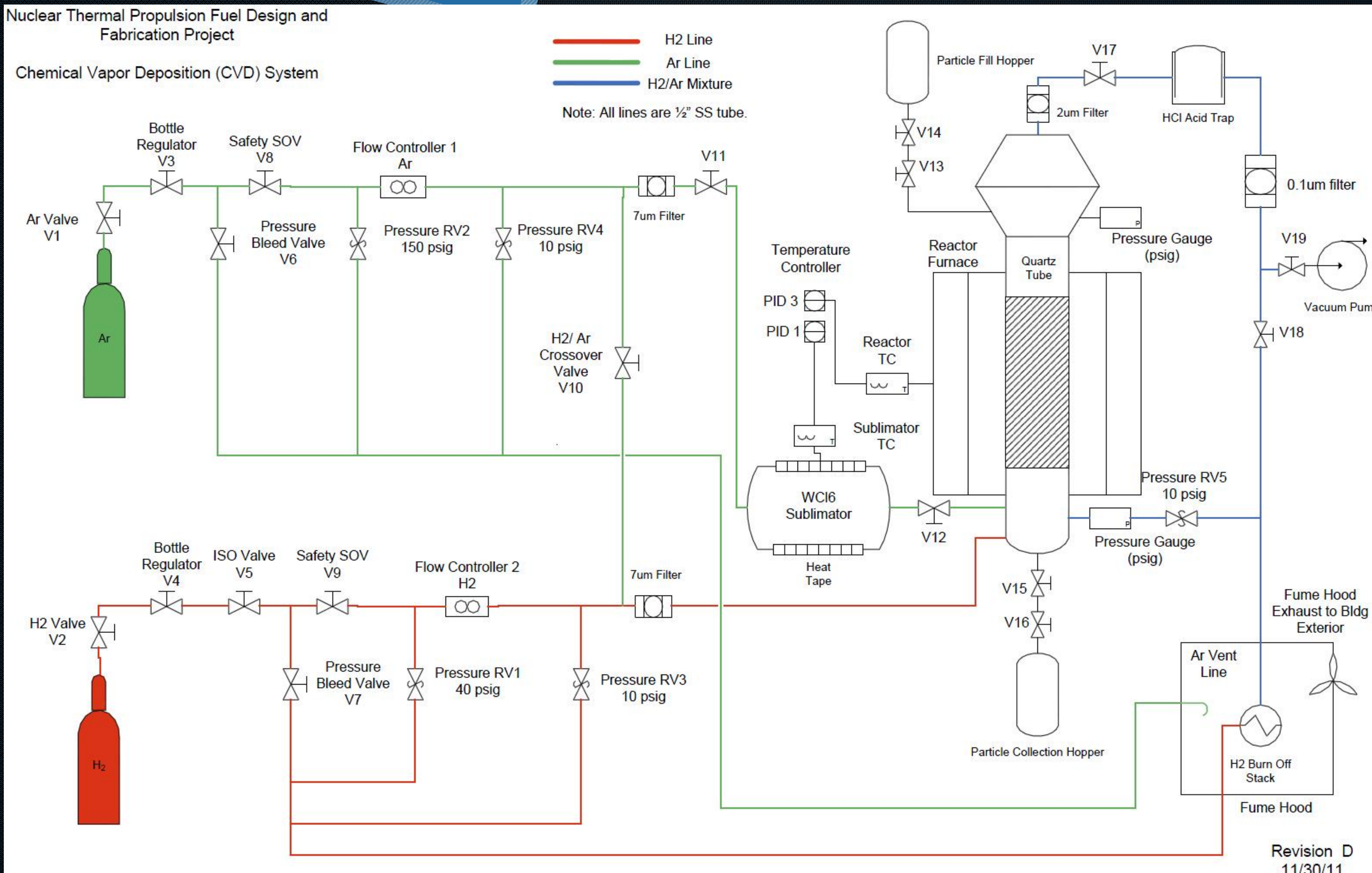

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Iterative Development

Reactor Design Evolution

Sublimer Design Evolution

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System Characterization Trials

- Minimum fluidization flow rate
  - Fluidization flow rate varies as particle density increases with increasing coating thickness
- Fluidization as a function of powder size
- Fluidization as a function of furnace temperature
- Powder column height as a function of flow rate and temperature
- Reactor temperature profile as a function of flow rate
- Sublimer temperature profile as a function of flow rate
- Coated Al_2O_3 substrates and ZrO_2 spherical powders

Batch	Powder Size (-/+ µm)	H_2 Mass Flow Rate (SLPM)		Ar Mass Flow Rate (SLPM)		Pressure (psig)
		25 C	930 C	25 C	930 C	
1	-106 / +90	20		2		5
2	-90 / +75					
3	-75 / +63	15	8	1.5	1	5
4	-63 / +53	15	8	1.5	1	
5	-53 / +45	15		1.5		5
6	-45 / +38					
7	-38	10		1		5

Pre-CVD Al_2O_3 Substrate

Sublimer Temp Profile Measurement

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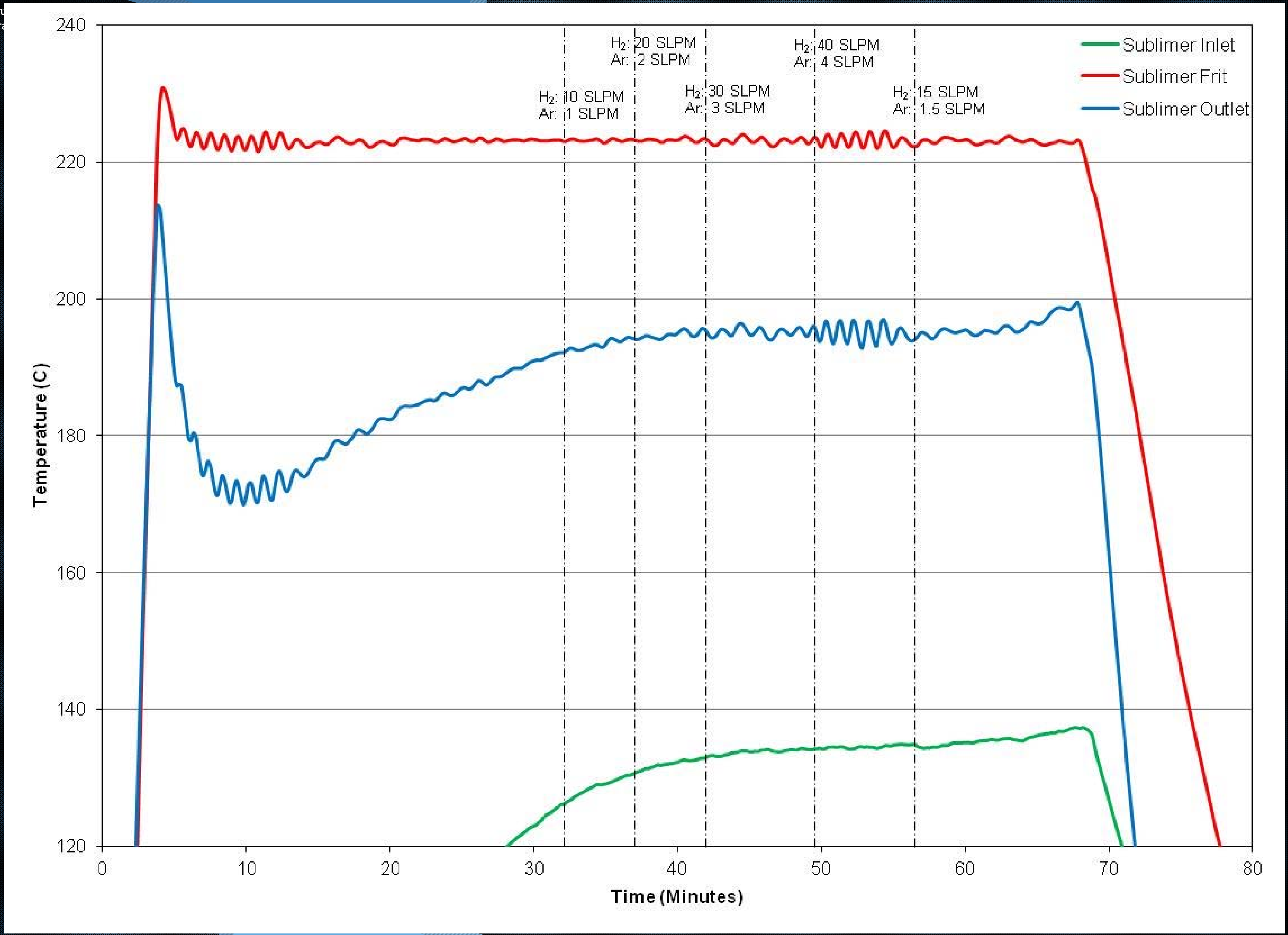

Reactor Temp Profile Measurement

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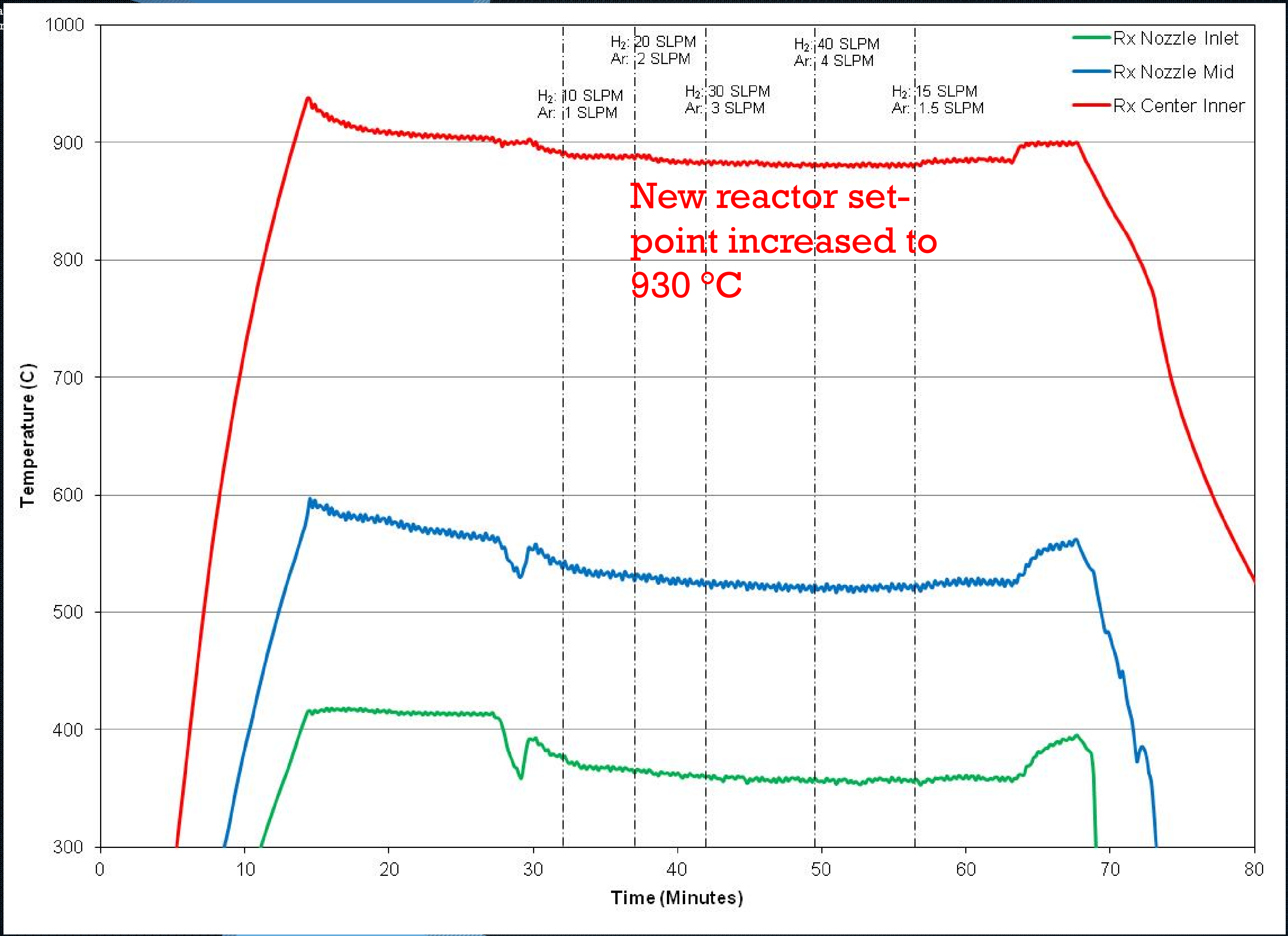

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CVD Operations

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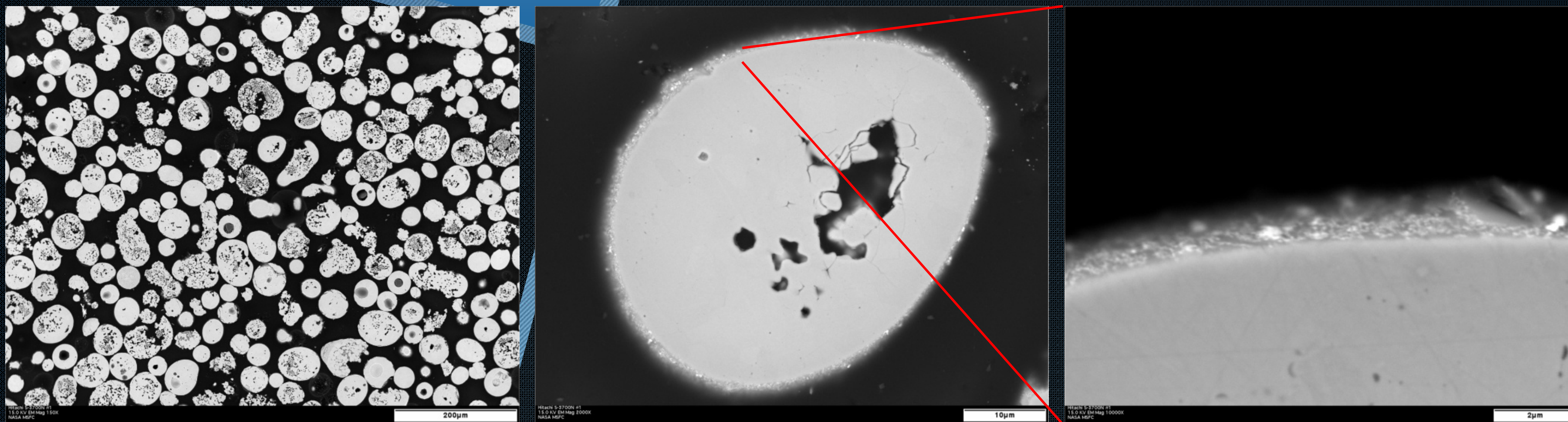
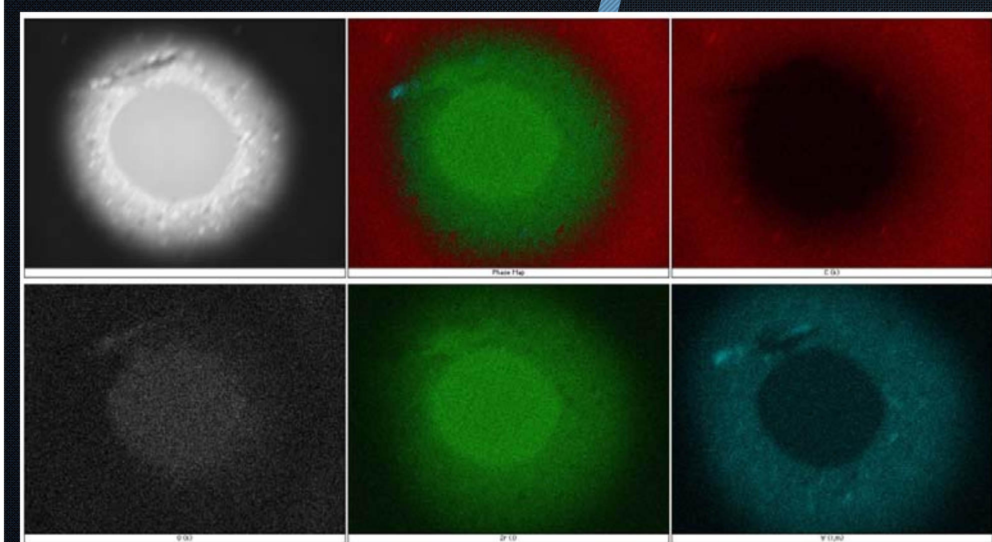
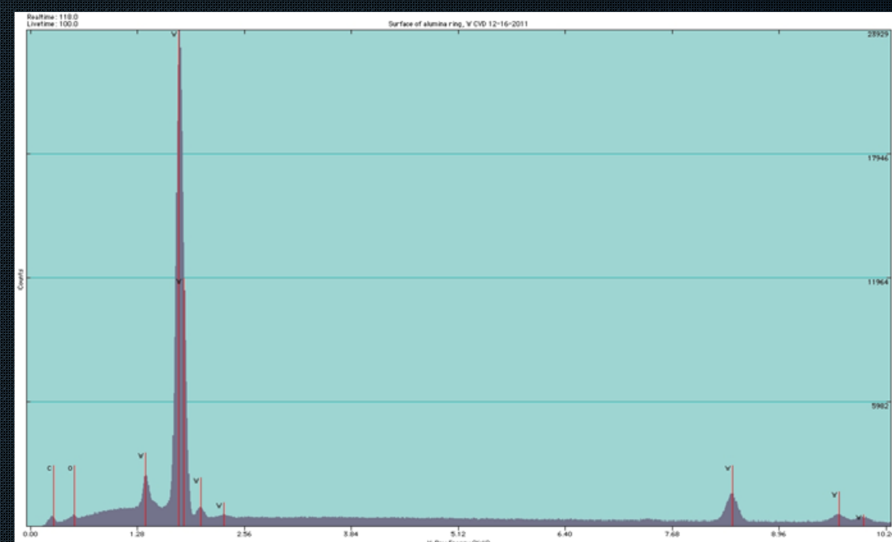
Powder Coating Trial Results



SEM micrographs of W coating on ZrO2 substrate (a) 150x (b) 2000x (c) 7000x



EDS Phase Maps



EDS spectra

3rd Generation CVD System

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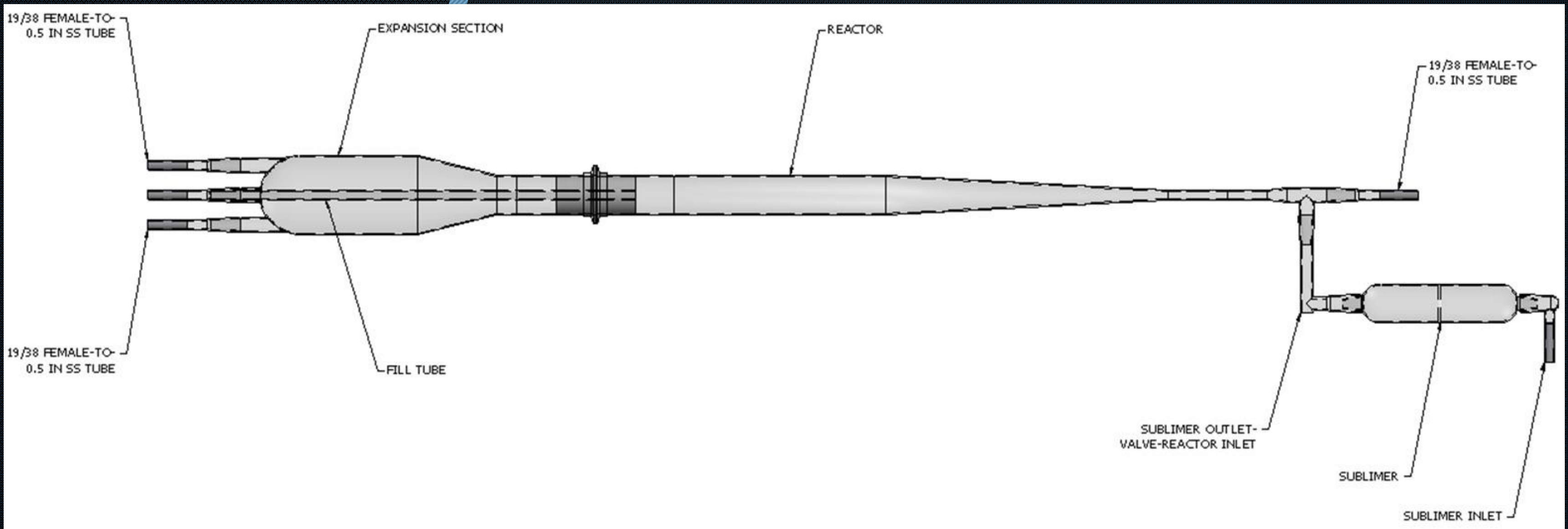
Spherical ZrO2 Powder (-53/+45 μm) before and after fluidization at room temperature



All Pyrex-Quartz CVD System Design Concept

Conclusions

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- Demonstrated viability and utilization of:
  - Fluidized powder bed
  - WCl_6 CVD process
  - Coated spherical particles with tungsten
- The highly corrosive nature of the WCl_6 solid reagent limits material of construction
- Indications that identifying optimized process variables with require substantial effort and will likely vary with changes in fuel requirements

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Future Work

- Optimize process variables in order to produce coating properties that meet requirements
- Characterize coatings as a function of substrate microstructure and process variables
- Design next-generation system to process larger quantities of power required for engine scale fuel fabrication

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- The opinions expressed in this presentation are those of the author and do not necessary reflect the views of NASA or any NASA Project.