

The background of the slide is a composite image of space. In the foreground, the blue and white horizon of Earth is visible. Above it, the grey, cratered surface of the Moon is shown. Further back, the reddish-orange planet Mars is visible. In the upper right corner, there is a colorful nebula with orange, yellow, and blue hues. The NASA logo is in the top right corner.

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

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

**NETS 2012
22 March 2012**

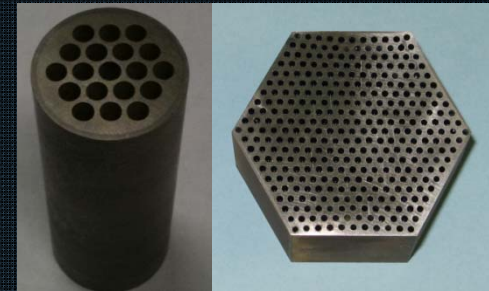
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Background

- NTP fuels under development
 - W-60vol%UO₂ CERMET
- Minimize erosion
 - Prevent H₂ propellant at ~3000 K from reducing UO₂ fuel kernels
 - Requires each fuel kernel to be clad in tungsten
- Coat spherical dUO₂ powders with 40 vol% W
- Coated spherical powders advantageous for HIP
 - Higher powder packing %TD
 - Minimize powder segregation

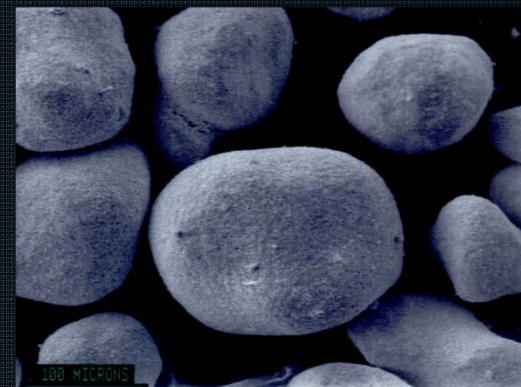




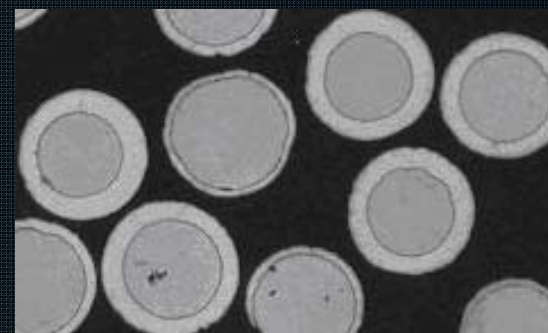
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Problem & Objectives

- 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



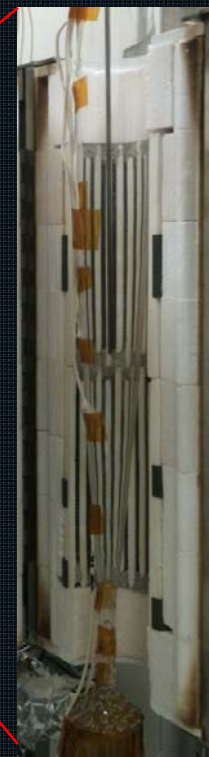
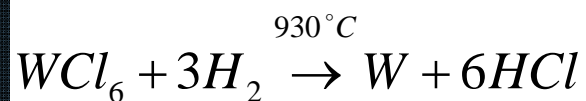
SEM micrographs of spherical coated particles



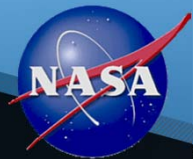
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Apparatus & Procedure

- WCl_6 process
- 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

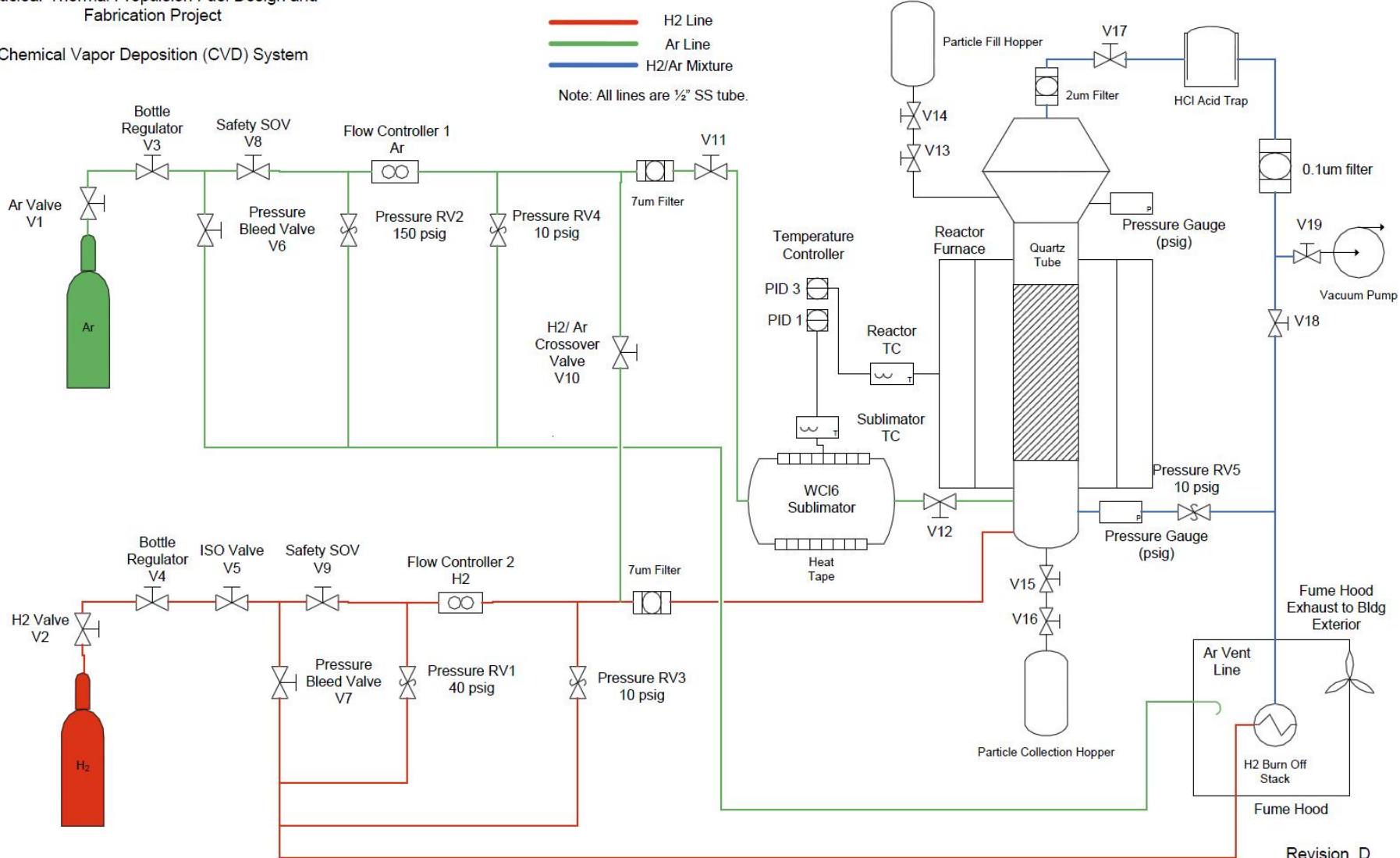


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CVD System Schematic

Nuclear Thermal Propulsion Fuel Design and Fabrication Project

Chemical Vapor Deposition (CVD) System



Revision D
11/30/11

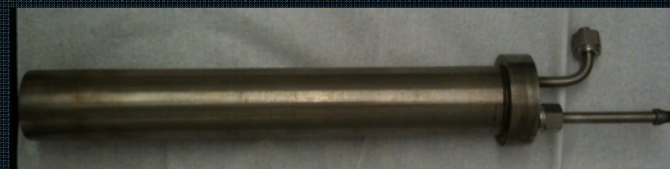


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Iterative Development



Reactor Design Evolution



Sublimation Design Evolution

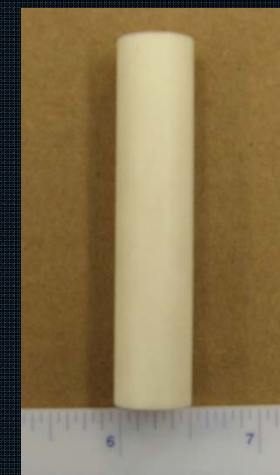


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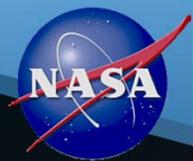
System Characterization Trials

- 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

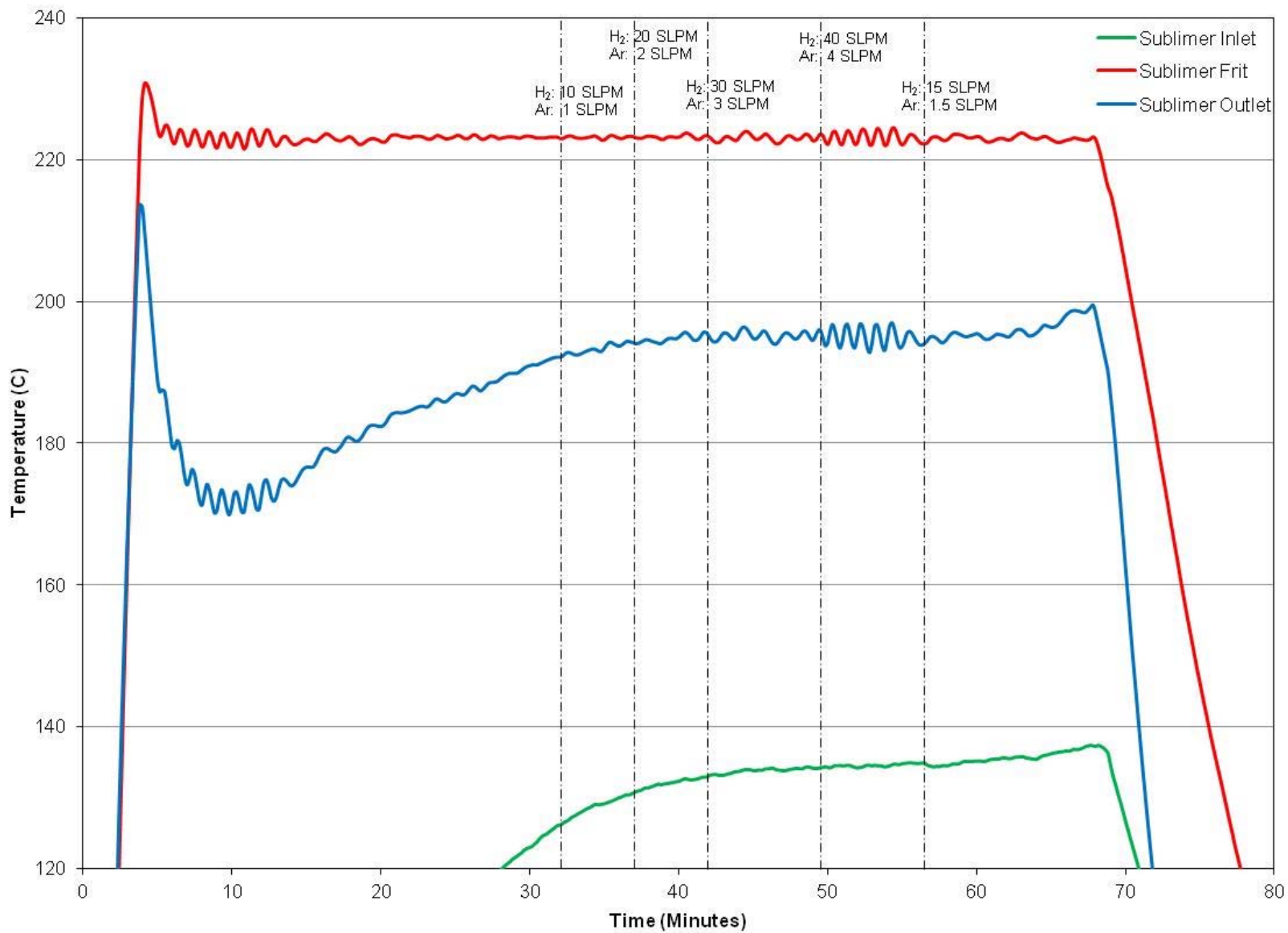


Pre-CVD Al_2O_3
Substrate



Sublimer Temp Profile Measurement

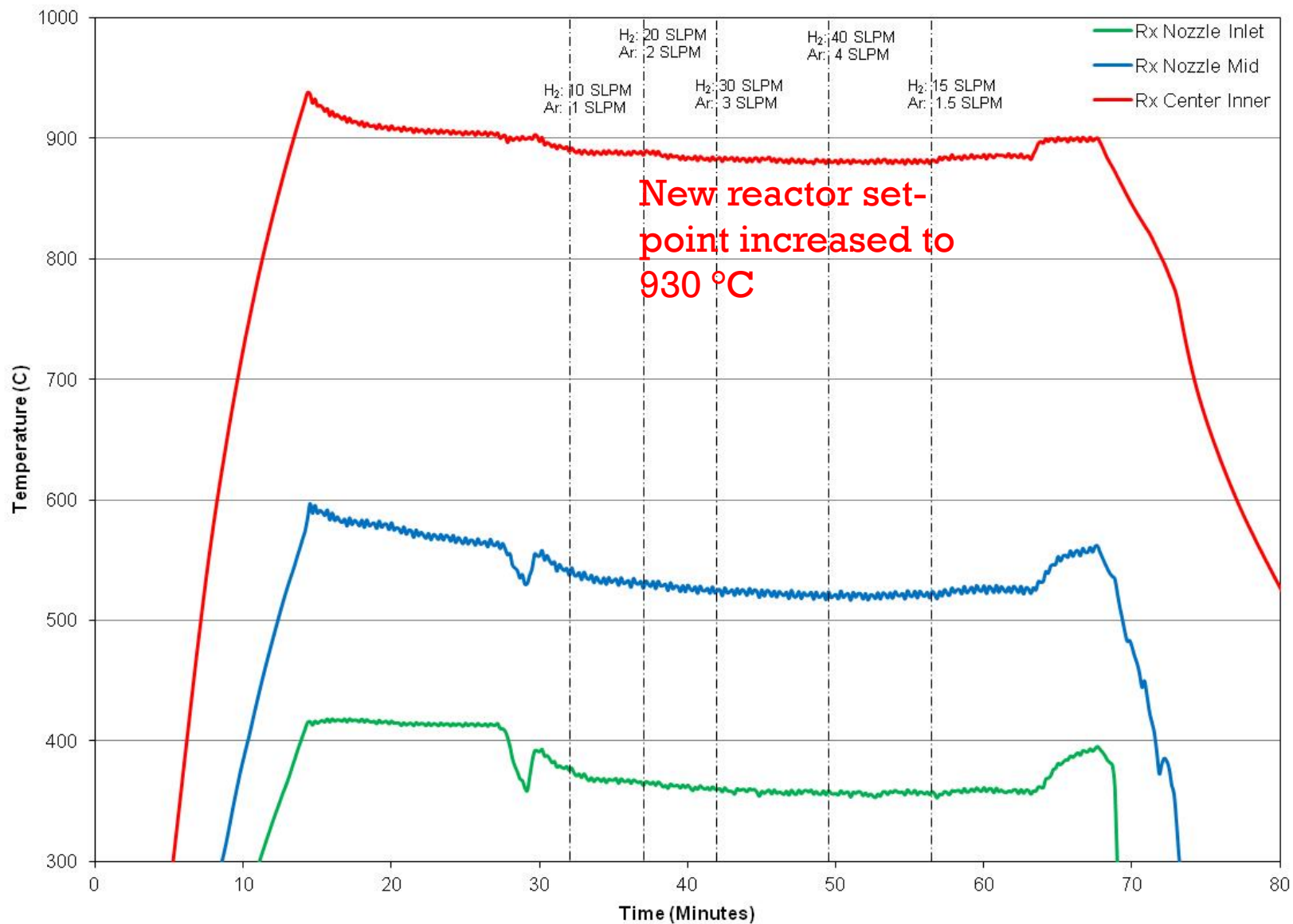
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Reactor Temp Profile Measurement

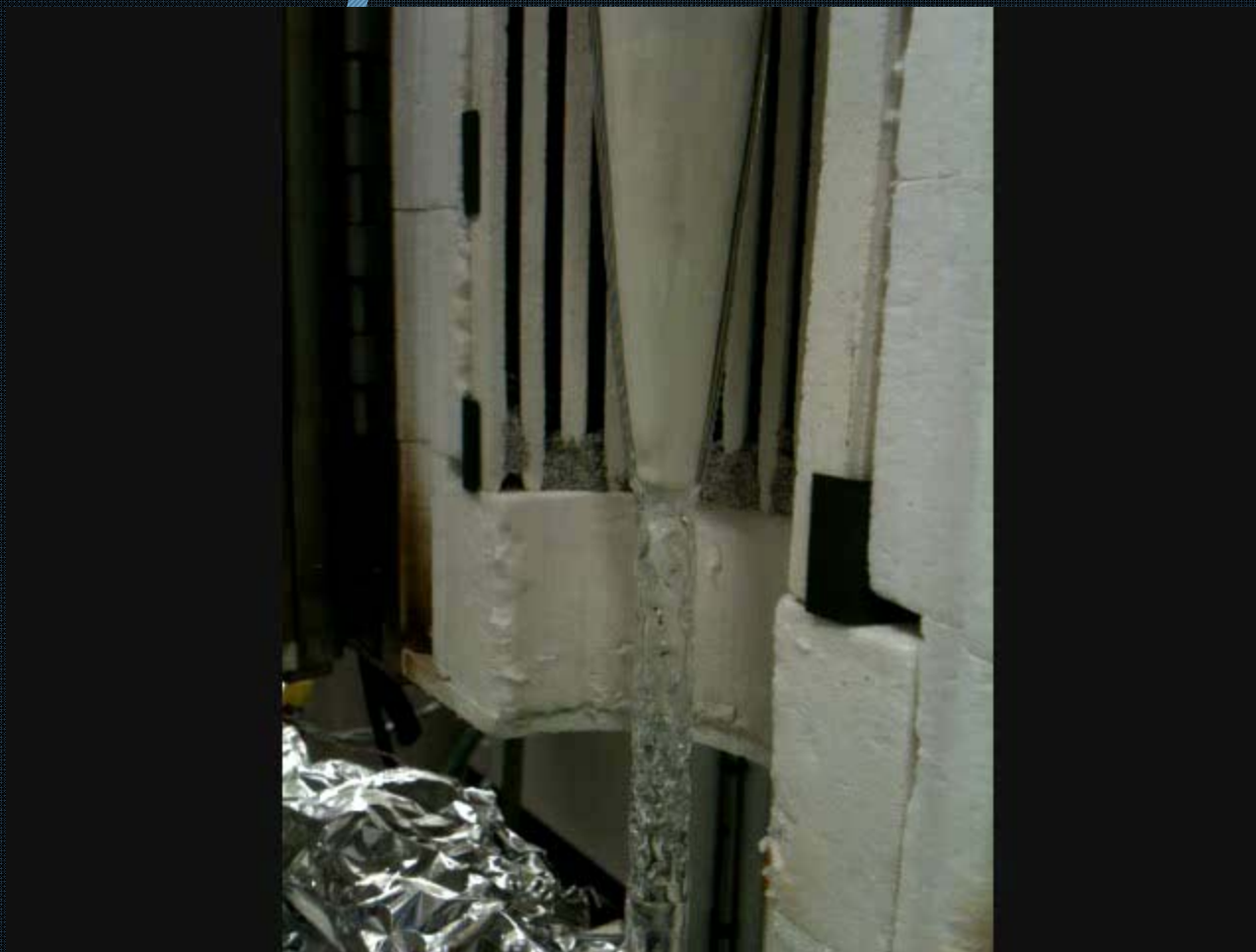
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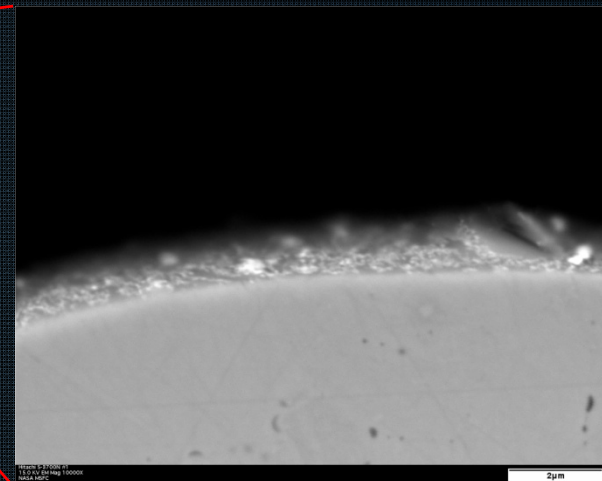
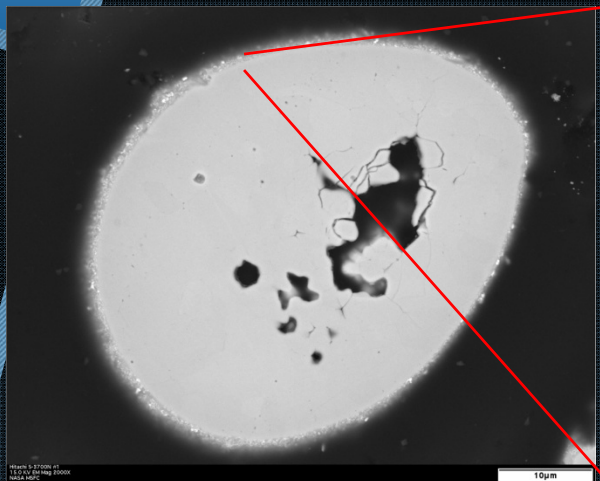
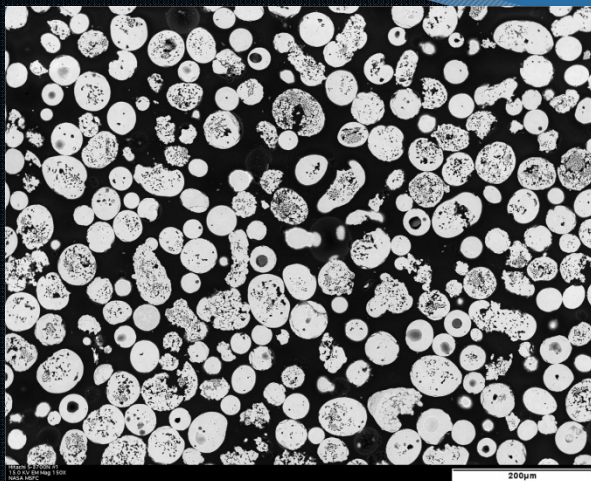
CVD Operations



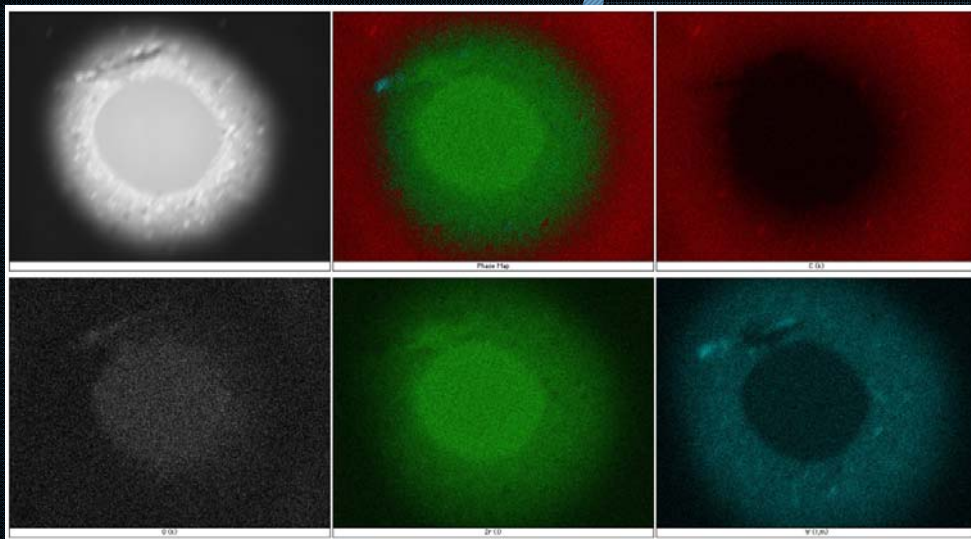


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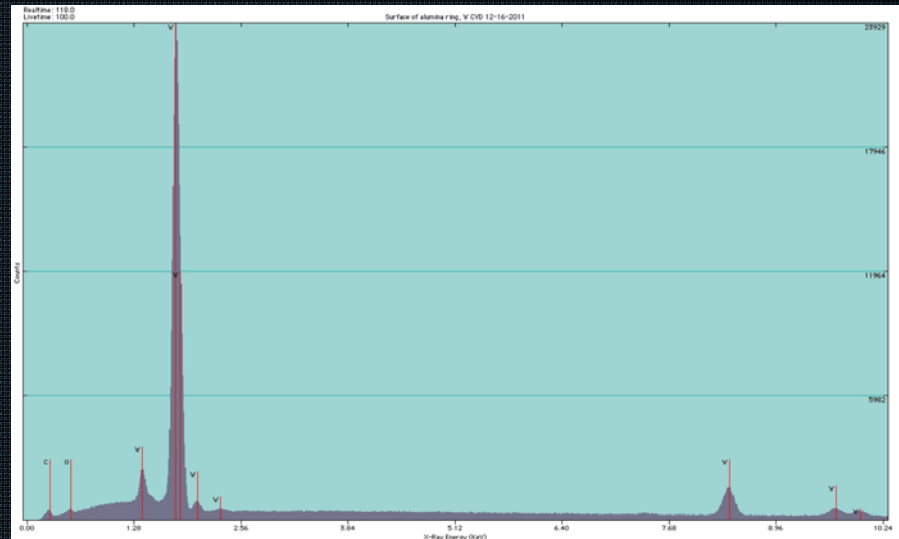
Powder Coating Trial Results



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



EDS Phase Maps



EDS spectra

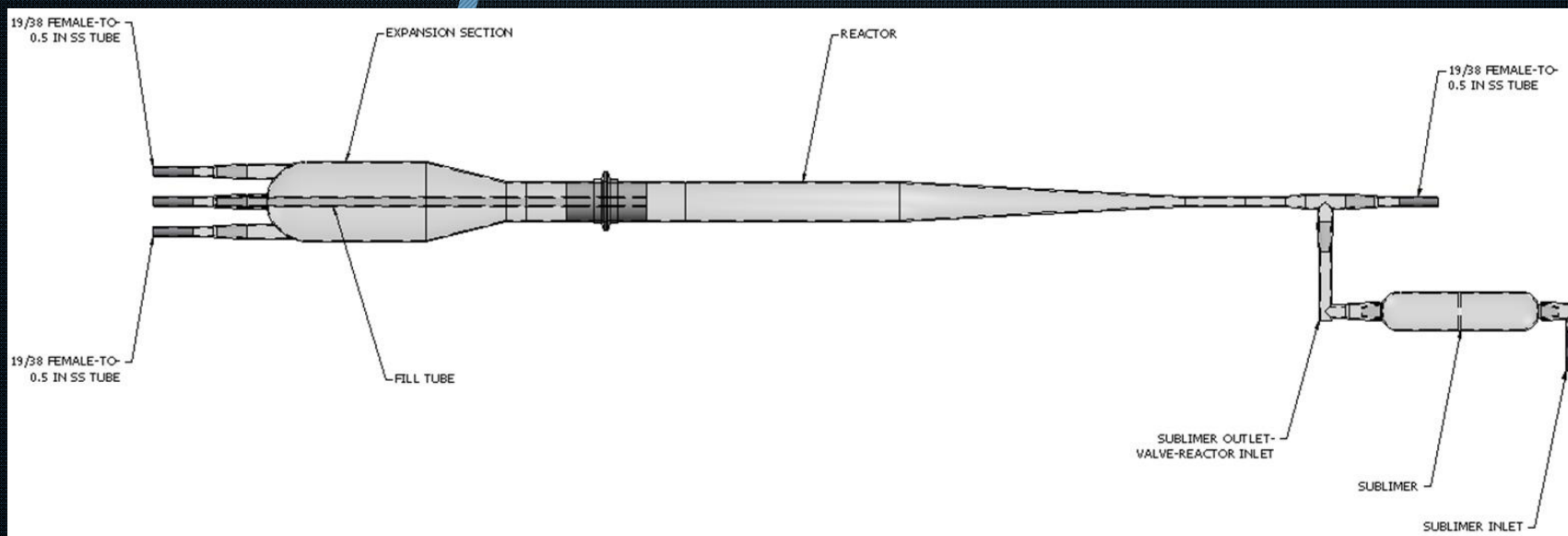


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3rd Generation CVD System



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



All Pyrex-Quartz CVD System Design Concept



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Conclusions

- 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 will 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 necessarily reflect the views of NASA or any NASA Project.