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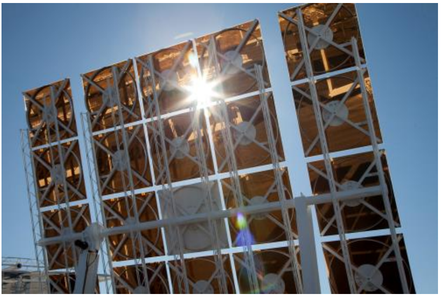
Charlotte, North Carolina, June 26 – 30, 2016



Performance Evaluation of a High-Temperature Falling Particle Receiver

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SAND2016-XXXX

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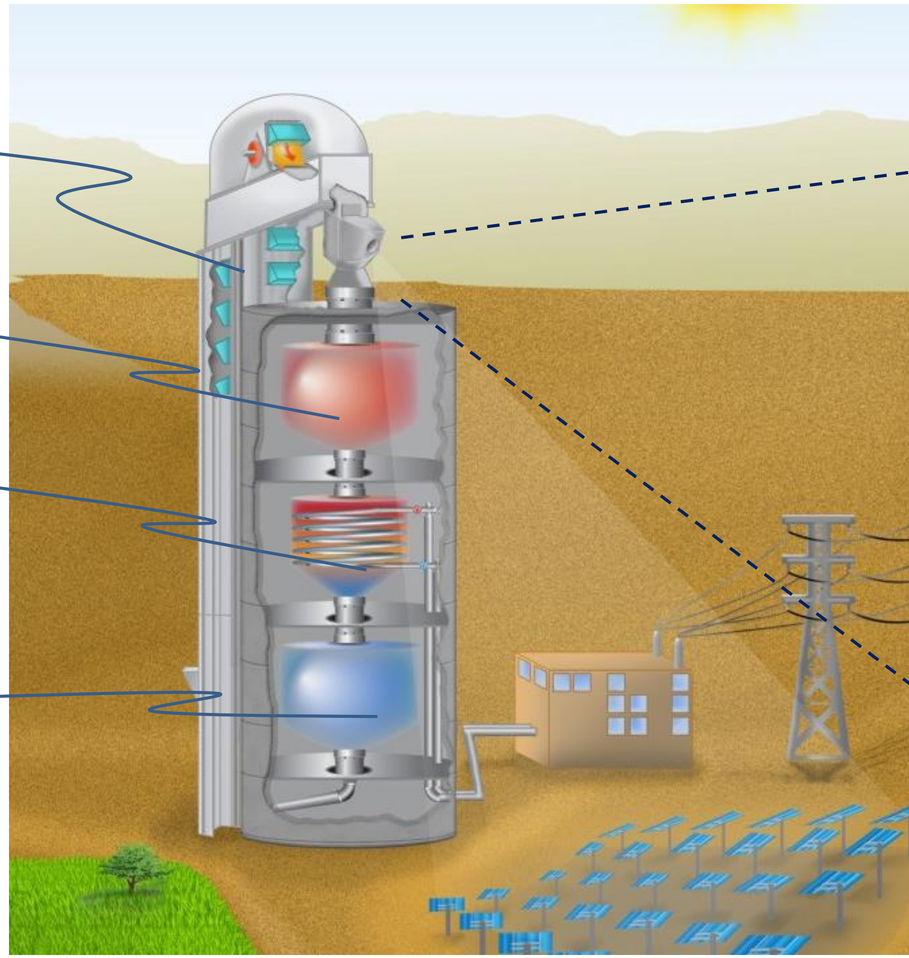
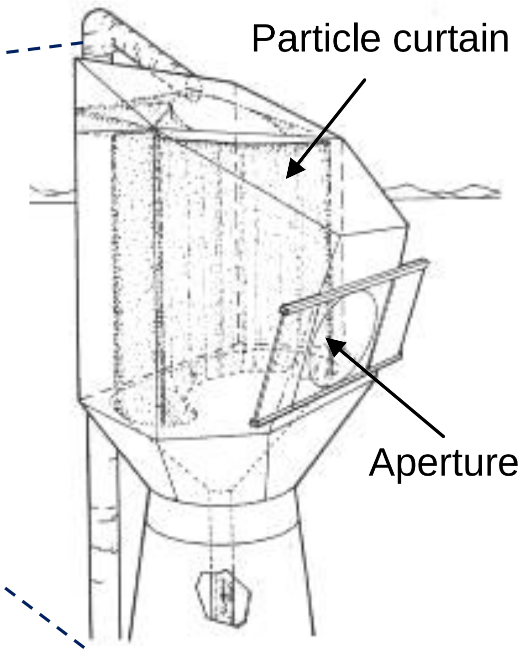
Overview

- Introduction
- Particle Receiver Testing
- Challenges & Lessons Learned
- Findings and Next Steps

High Temperature Falling Particle Receiver
(DOE SunShot Award FY13 – FY16)





Falling particle receiver

Goal: Achieve higher temperatures, higher efficiencies, and lower costs

Advantages of Particle Receivers

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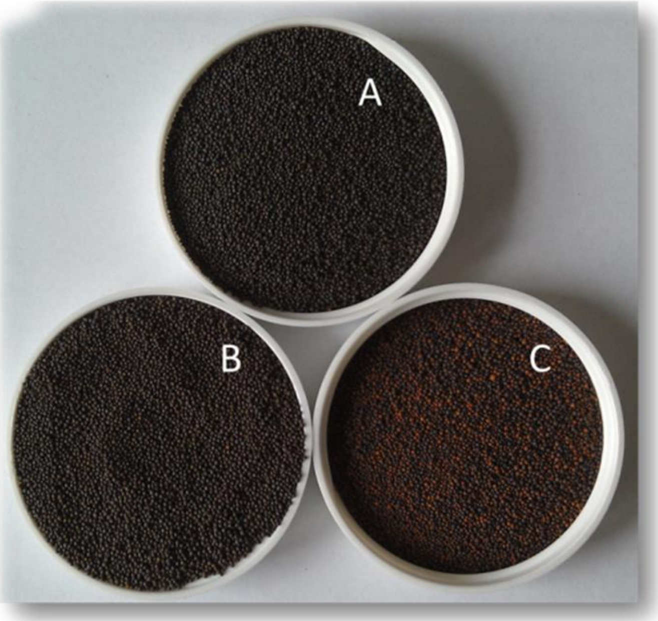
- Direct heating of particles
  - Higher temperatures than conventional molten salts
    - Enable more efficient power cycles
  - Higher solar fluxes for increased receiver efficiency
- Direct storage of hot particles
  - Reduced costs

particle Power



CARBO ceramic particles (“proppants”)

History

Particle Receiver Research at Sandia

- 1980’s
  - Feasibility study, modeling, bench-scale testing
- 2007 – 2008
  - First on-sun particle receiver test at Sandia
    - Batch run – no continuous operation
    - “Low” temperatures (up to ~300 ˚C)
    - Low thermal efficiency (~50%)
- Goal of current work (2013 – present)
  - Higher temperature (> 700 ˚C particle outlet)
  - Higher thermal efficiency (> 90%)
  - Continuous on-sun operation at 1 MW_t

Jill Hruby
Sandia President

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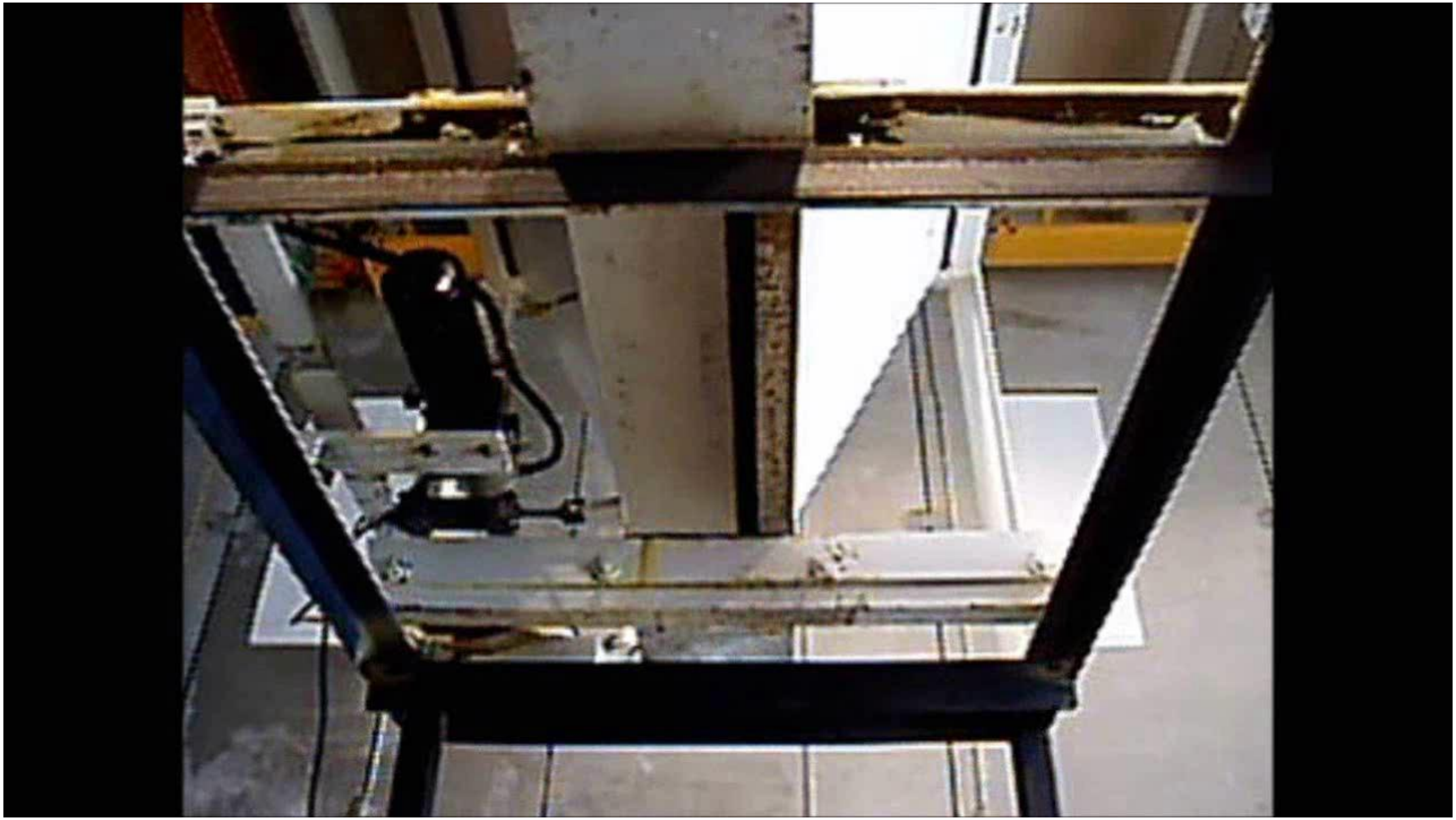
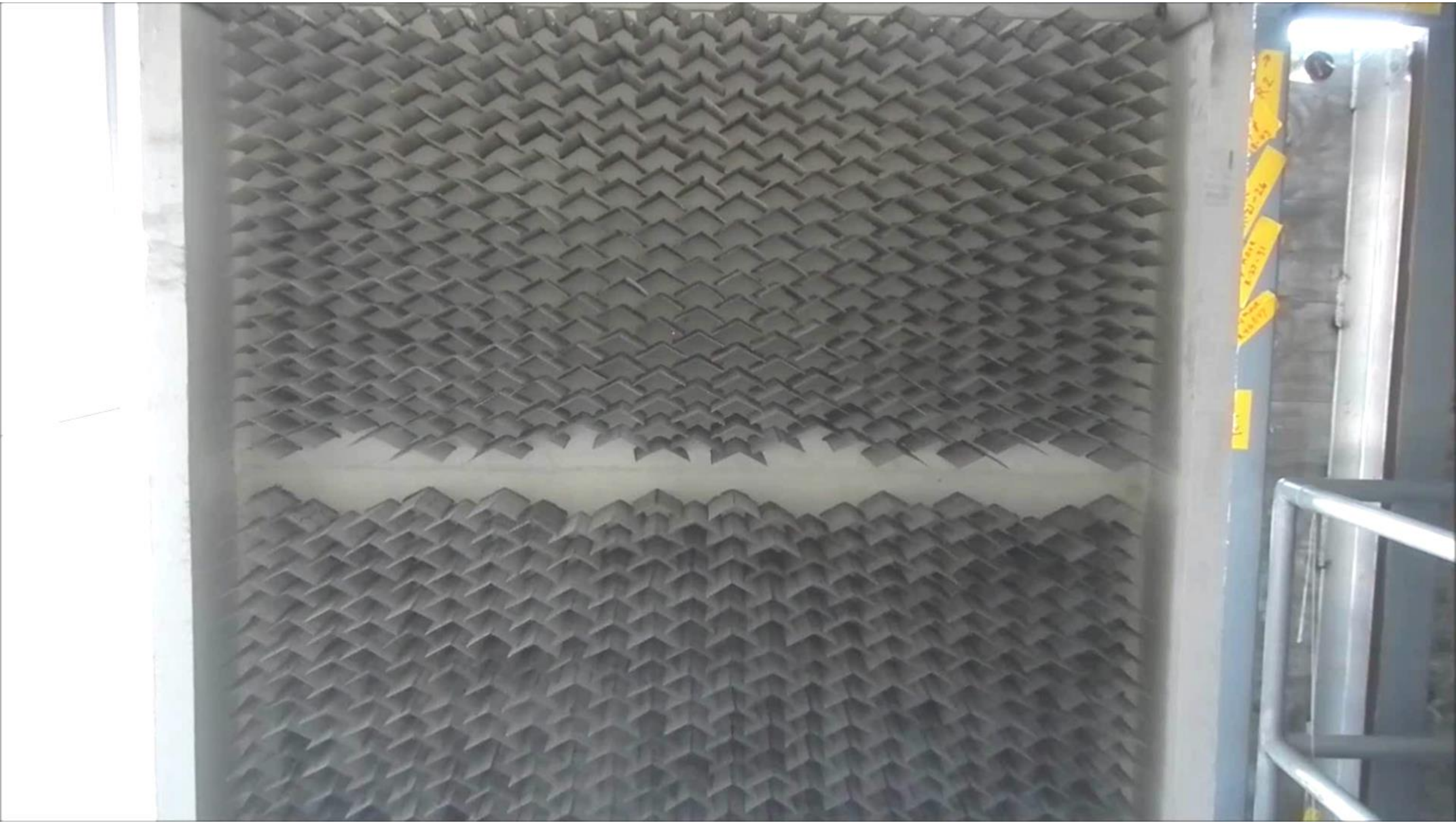
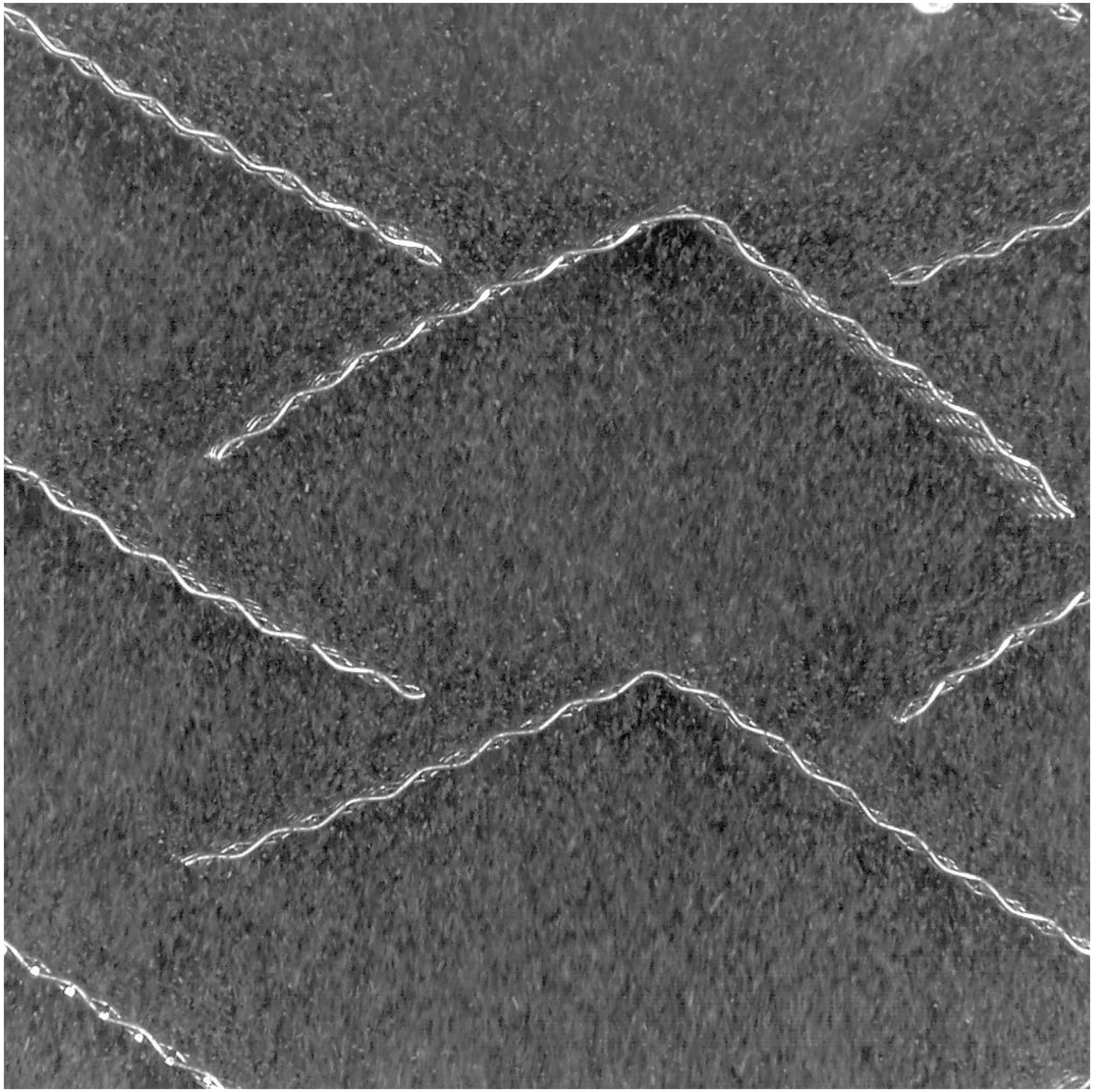
Particle Receiver Designs – Free Falling



Particle Receiver Designs – Pachinko



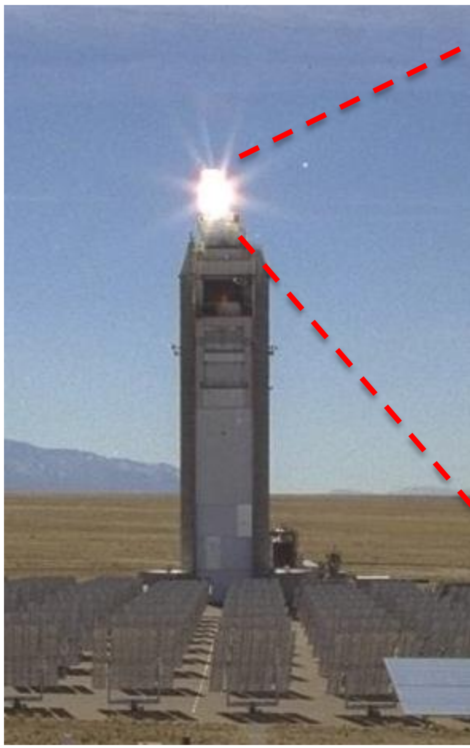
Particle Flow over Chevron Meshes

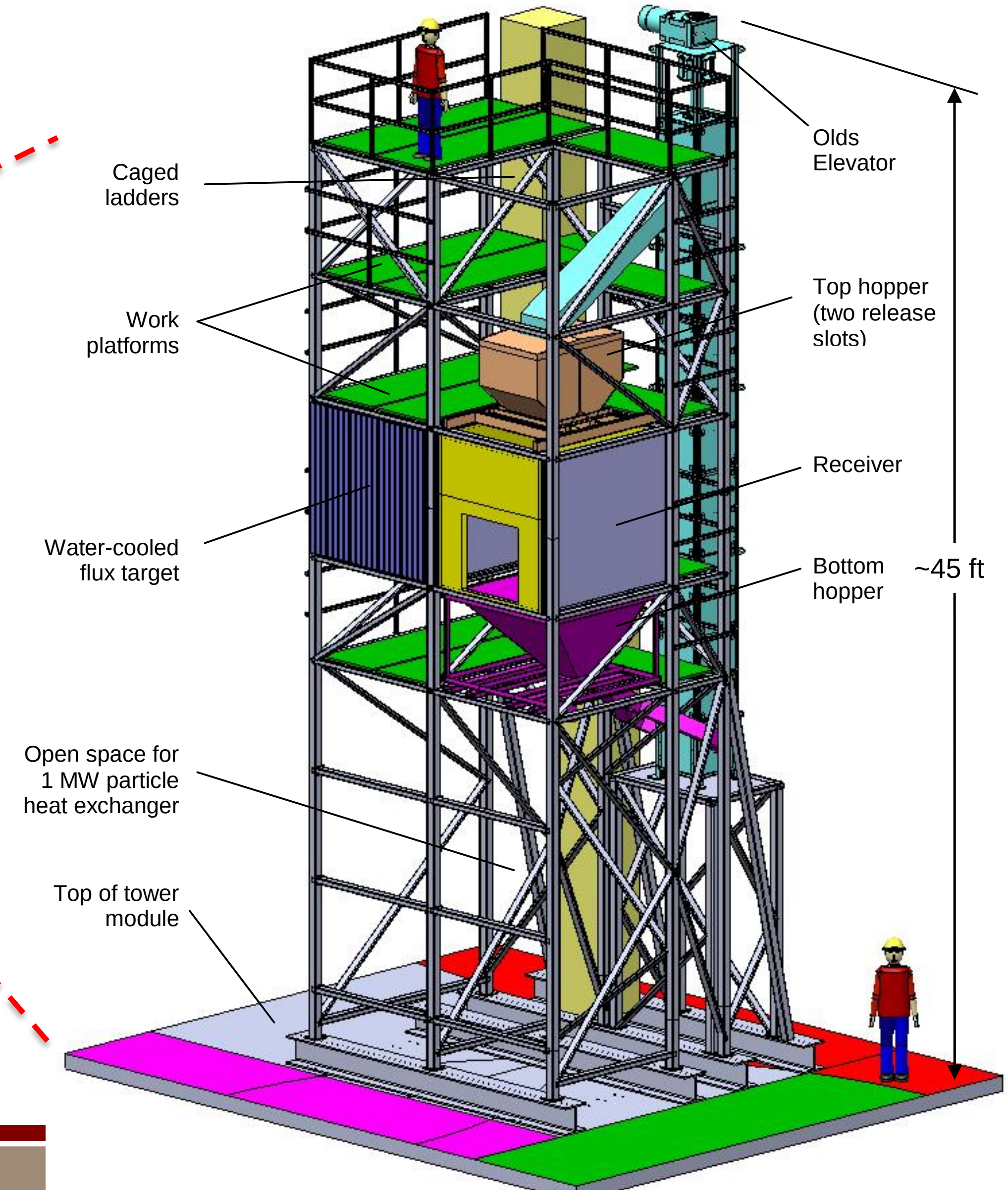


Pros: particle velocity reduced for increased residence time and heating

Cons: Mesh structures exposed to concentrated sunlight (~1000 suns)

Prototype System Design



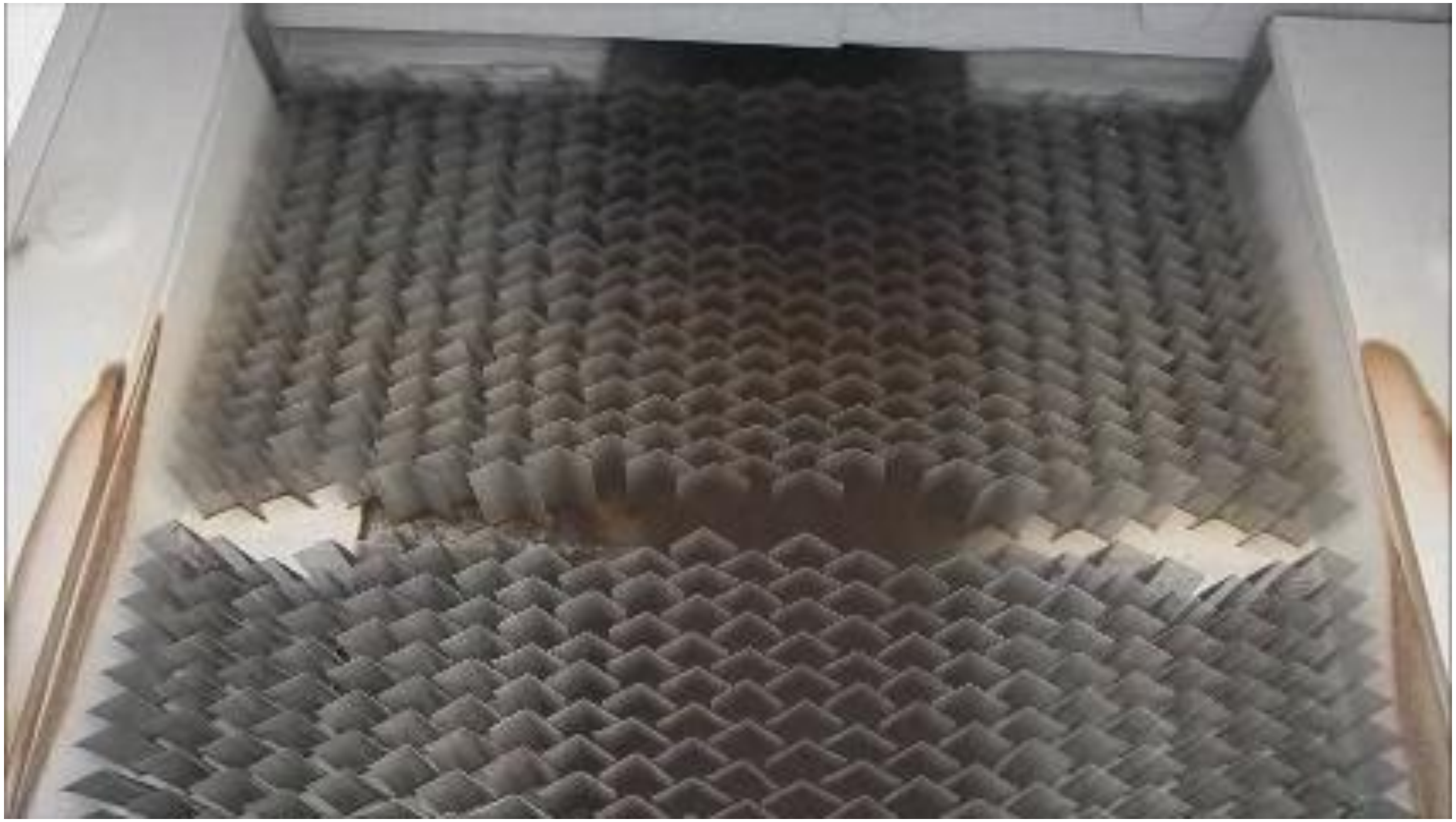


Lifting the system to the top of the tower

On-Sun Tower Testing

Over 600 suns peak flux on receiver
(July 20, 2015)

On-Sun Tower Testing



Particle Flow Through Mesh Structures
(June 25, 2015)

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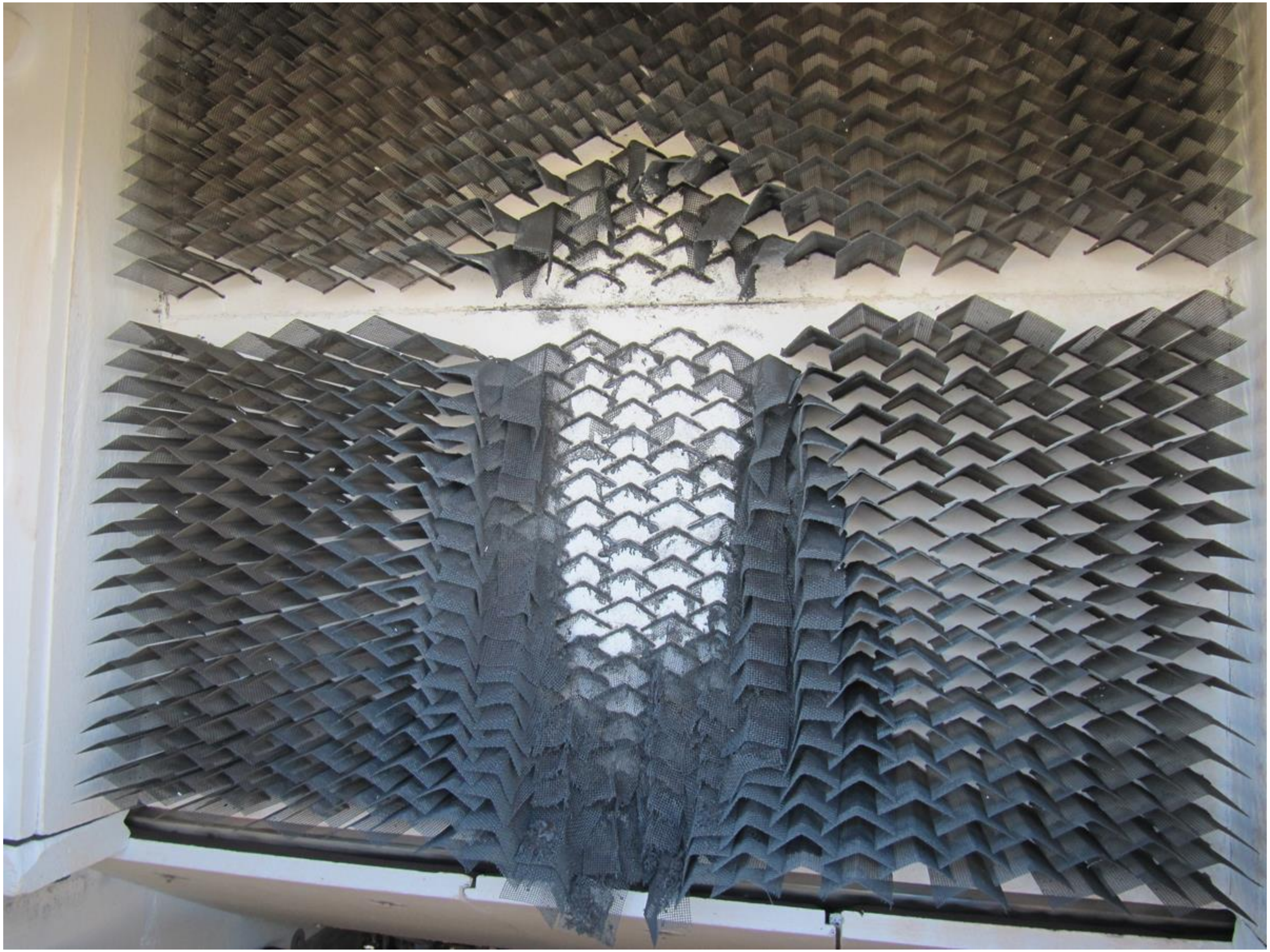
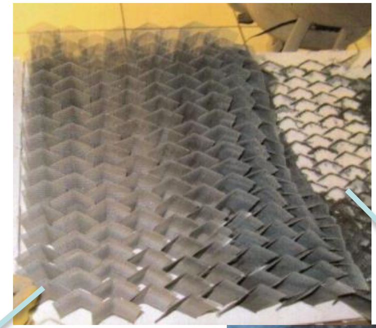
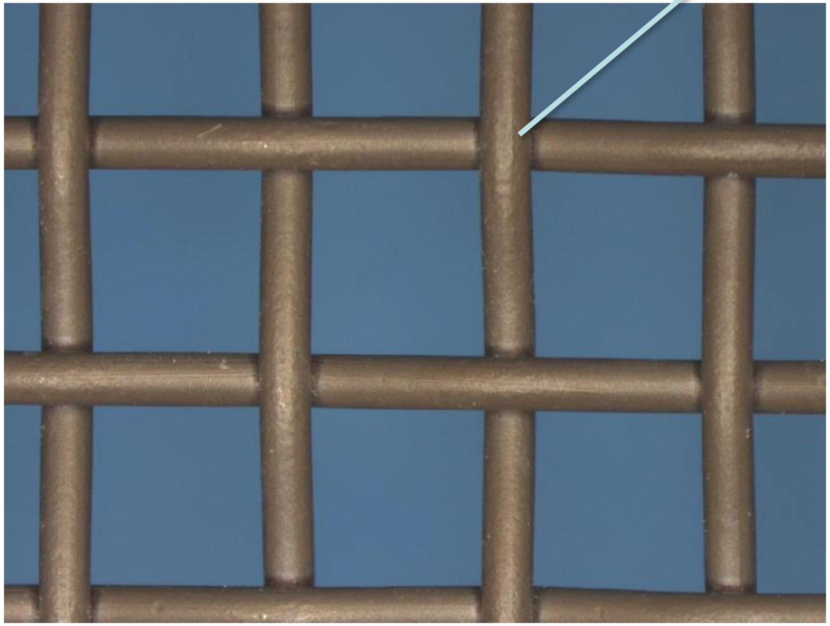
July 24, 2015 – Nearly 700 suns

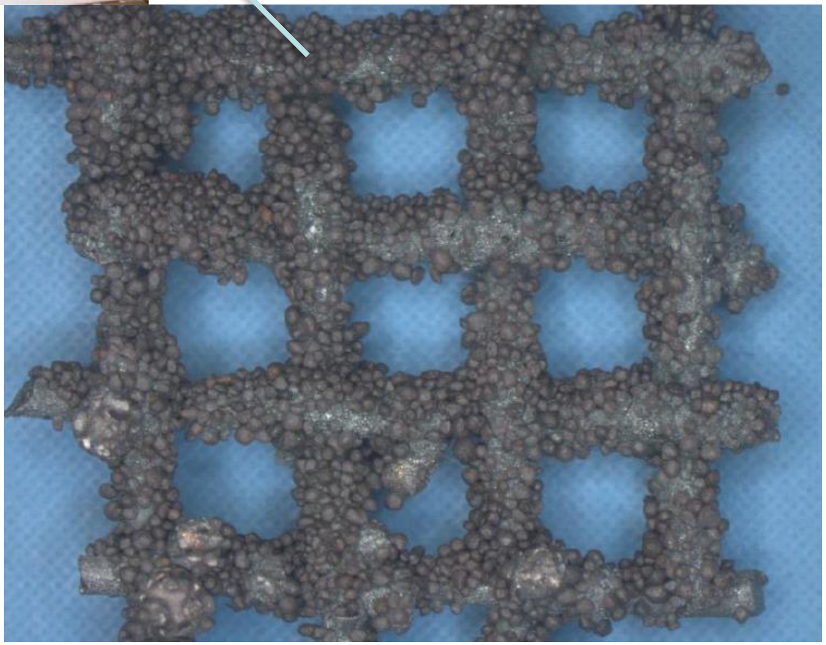


SS316 Mesh Failure Analysis





Mesh located far from failed region



Mesh located within failed region
(ceramic particles sintered on mesh)

Non-Uniform Particle Mass Flow

Particle Discharge Plate

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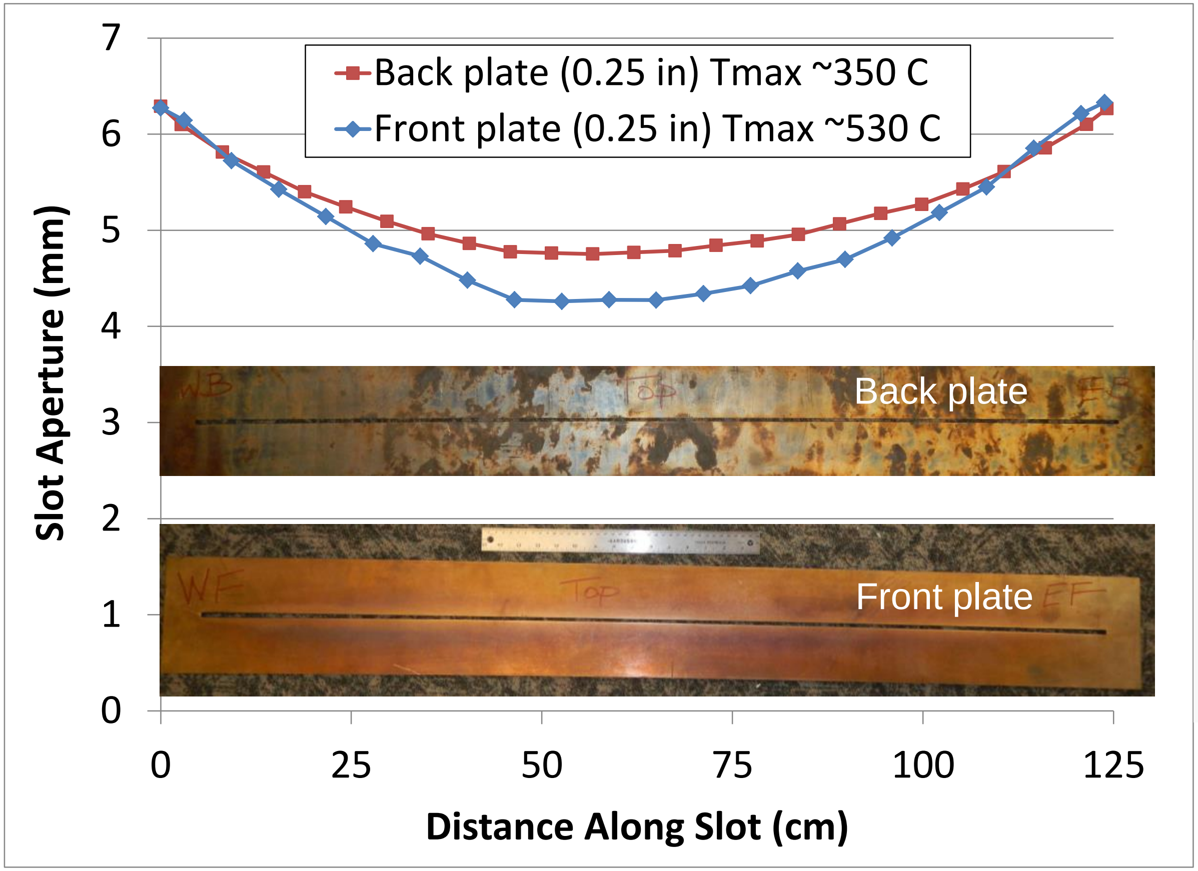
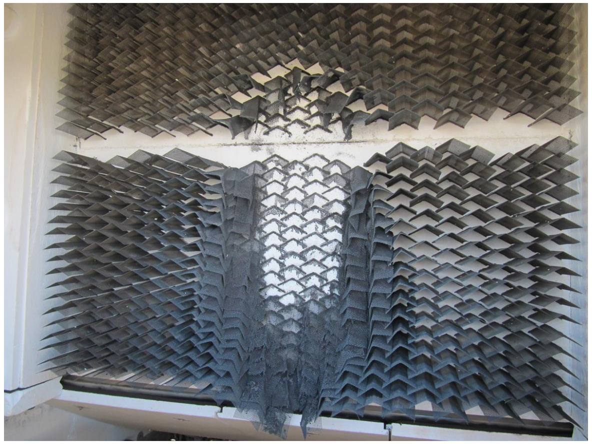
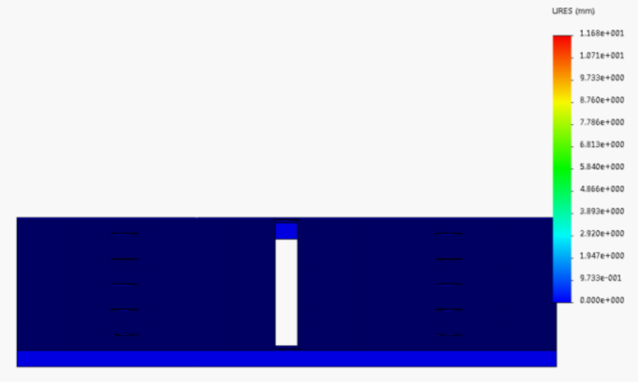


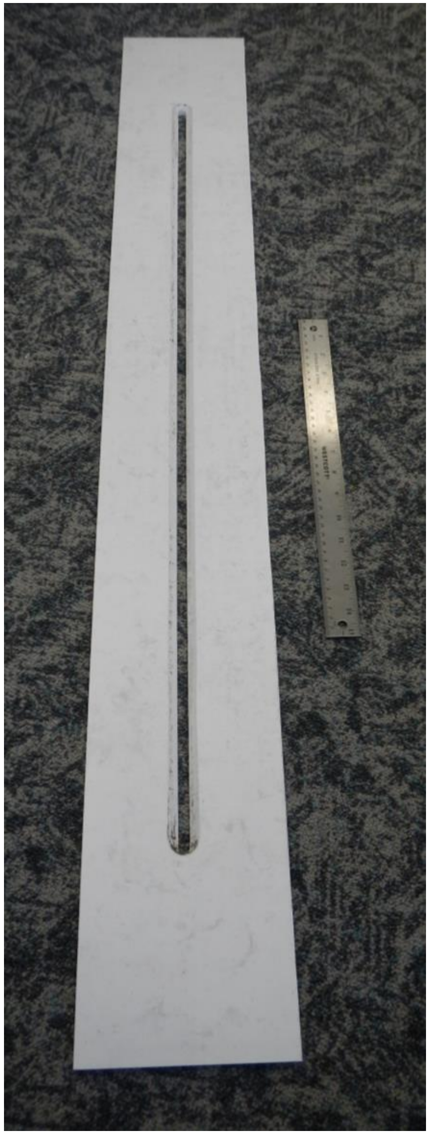




Simulation shows similar aperture reduction as data

Particle Discharge Plate Potential Solutions

- Low thermal expansion silica-based RSLE plate
  - Particle-wall friction still increases with increasing temperature
- Use elevator or other device for mass flow control



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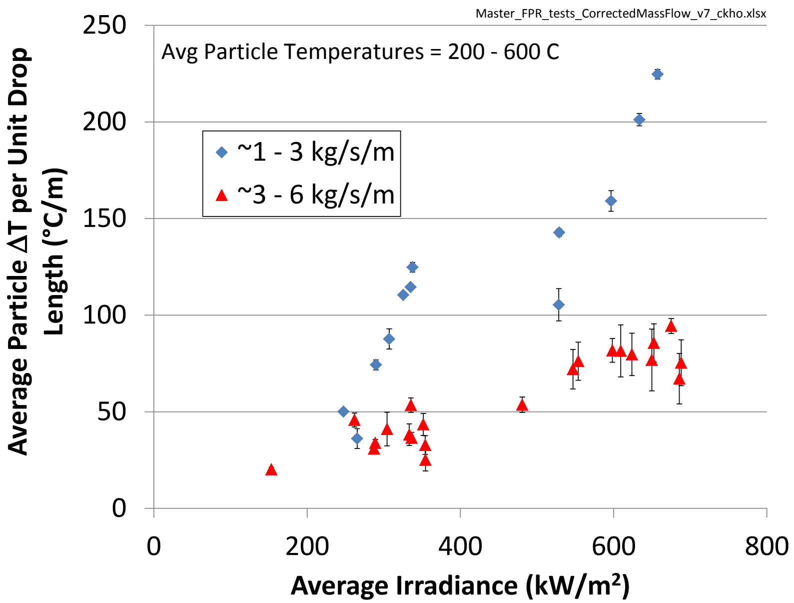
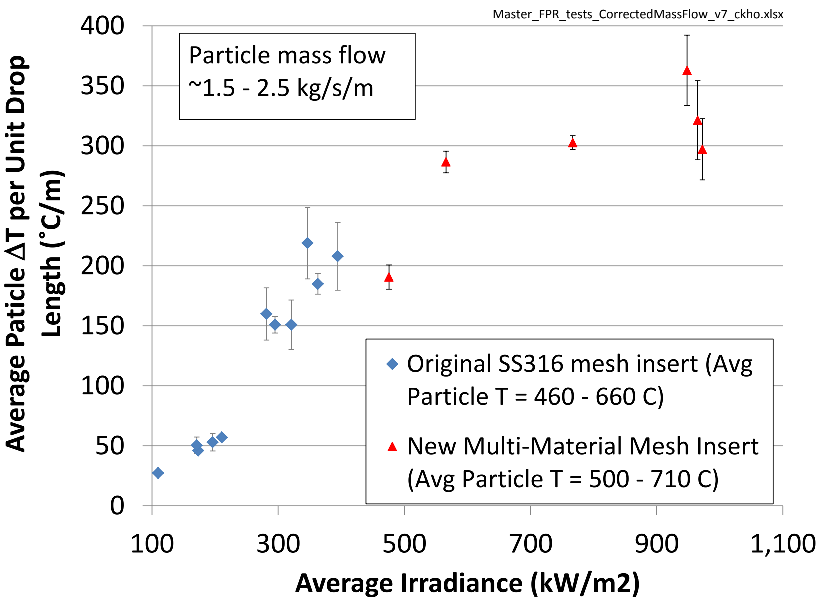
Findings

- Achieved average particle outlet temperatures > 800 ˚C
  - Peak particle outlet temperatures > 900 ˚C
- Particle heating up to ~200 – 300 ˚C/(m of drop); 1 – 3 kg/s
- Thermal efficiency up to ~70% to 80%



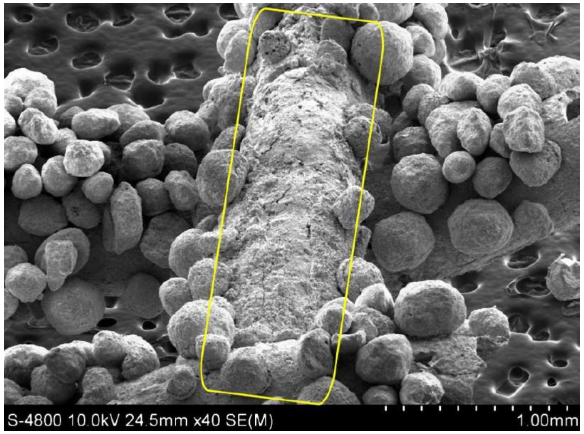
Free-Fall



Obstructed-Flow

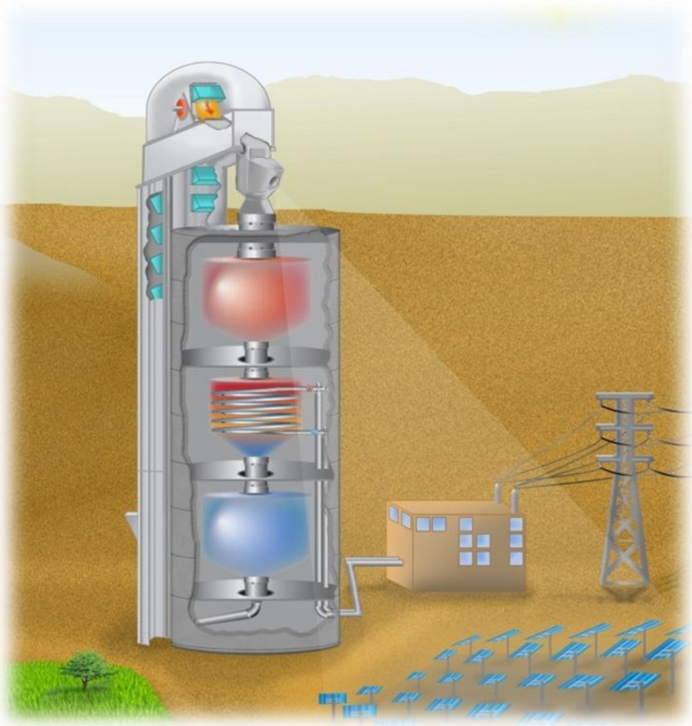
Lessons Learned

- Mesh materials (SS316) showed signs of wear
  - Evaluate alternative alloys or ceramics
- Particle mass flow was reduced at higher temperatures
  - Two reasons:
    - Narrowing of discharge slot
    - Higher particle/wall friction coefficient
  - Need active particle mass flow control and monitoring
- Particle loss was 0.06% of mass flow rate
  - 60% from loss through aperture (5.8 kg/hr)
  - 40% from attrition due to abrasion (3.6 kg/hr)
  - Mitigations
    - Deeper cavity; particle release further from aperture
    - Use low-particle-friction elevators



Particle loss from aperture during on-sun test

Questions?



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BACKUP SLIDES

Free-Fall vs. Obstructed Flow

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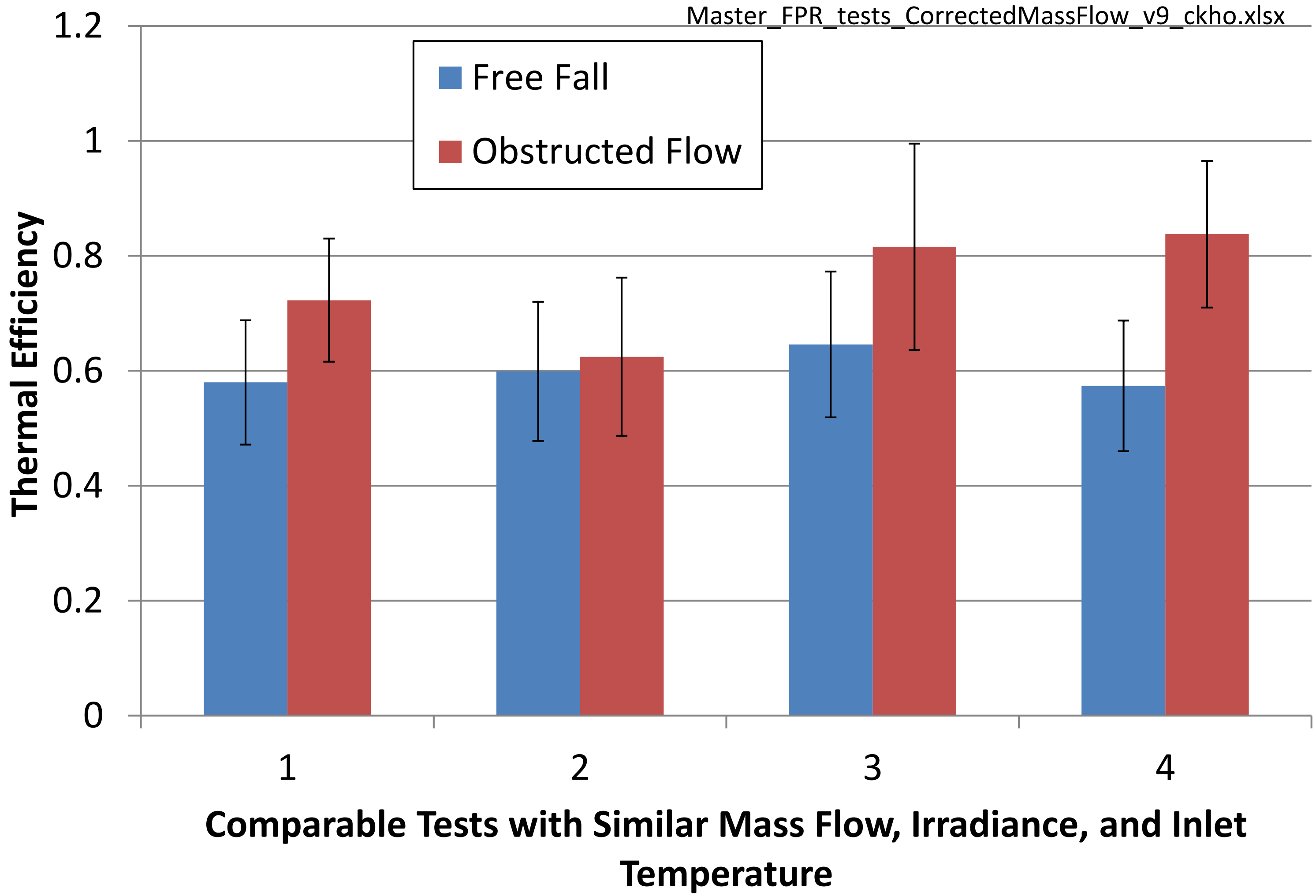
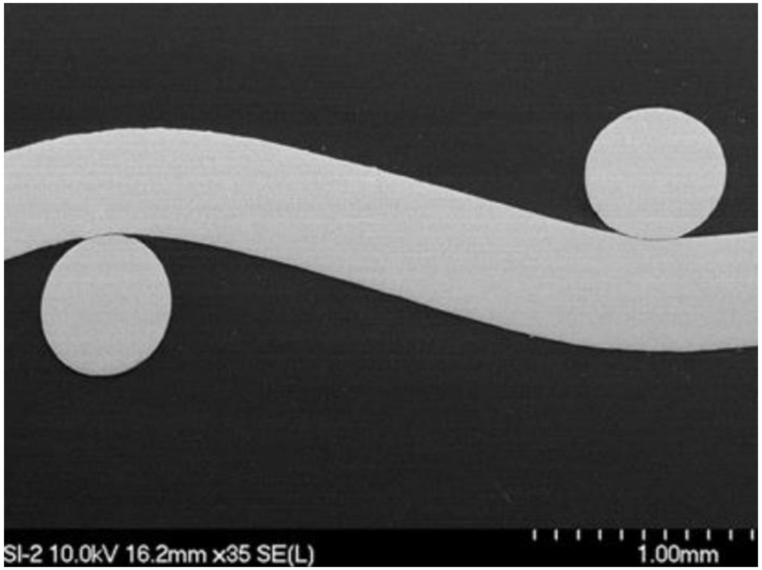
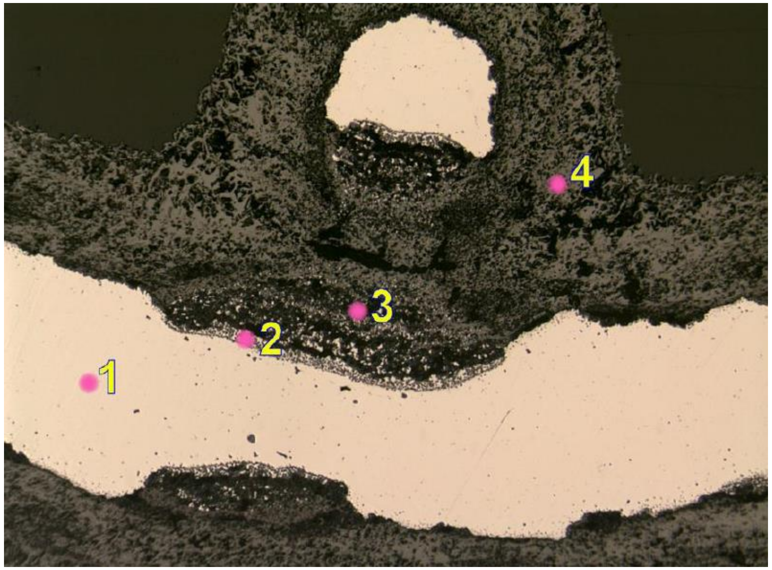


SS316 Mesh Failure Analysis



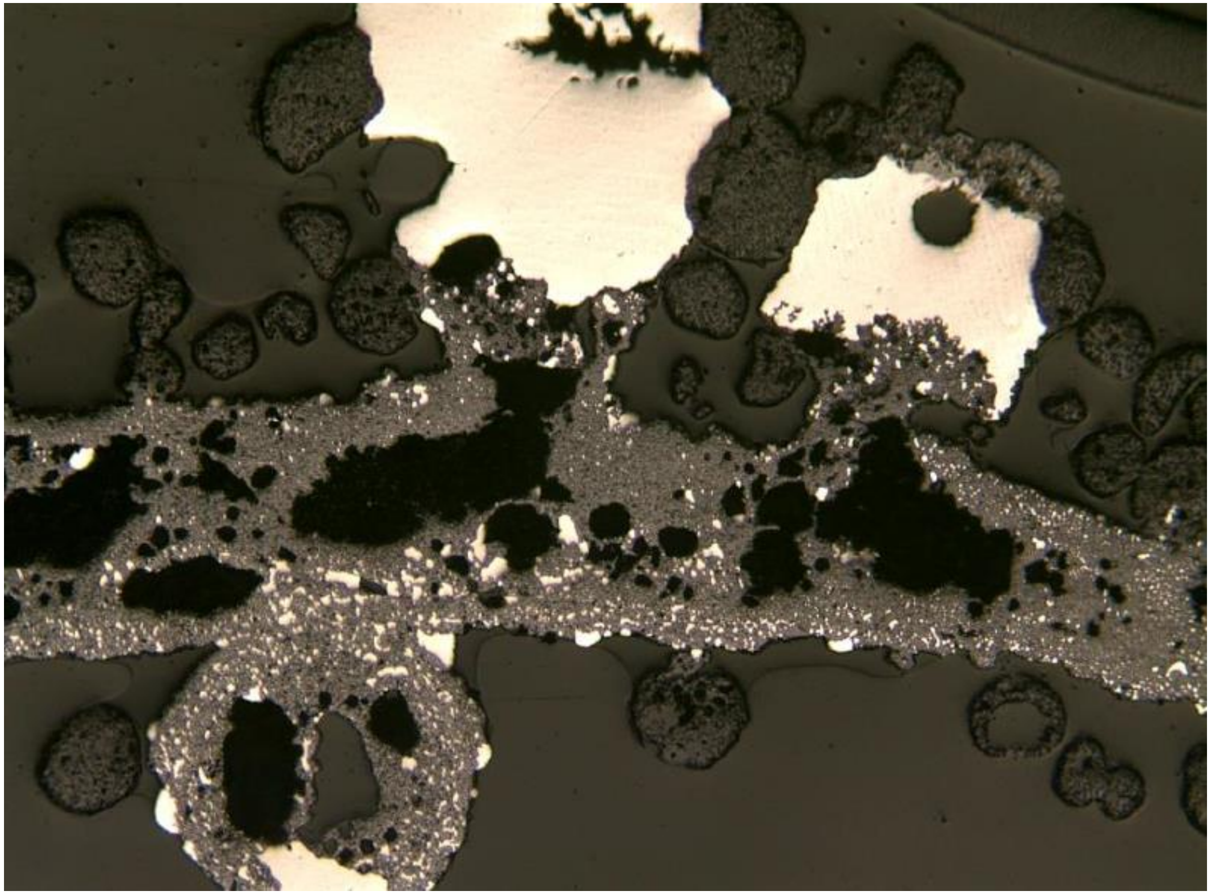


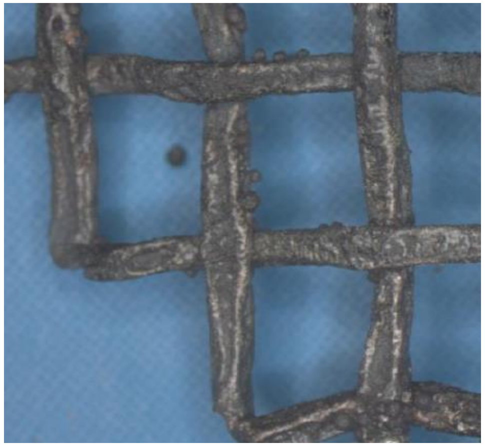
Top left: cross-sectional view of intact wire mesh

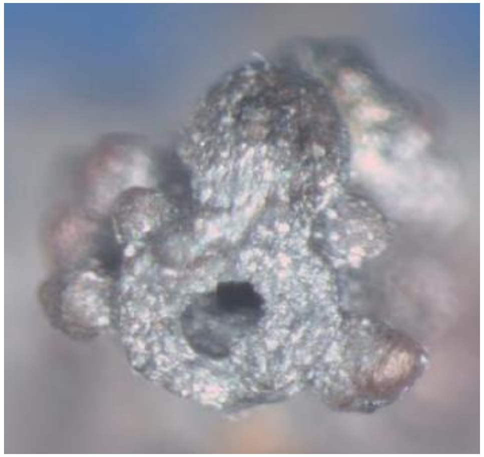
Top right: cross-sectional view of oxidized wire mesh

	Fe	Cr	Ni	Mo	O	Al	Si
	(Wt% EDS semi-quant, standardless EDS)						
Location 1 **Wire core**	67	20	6.7	5.2	-	-	-
Location 2 **"intermetallic layer"**	19	4.45	44	11	19	1.64	1.34
Location 3 **Oxidized zone**	22	18	4.39	5.26	48	1.1	1.75
Location 4 **Oxidized zone**	34	10	2.89	2.32	48	-	1.45

SS316 Mesh Failure Analysis

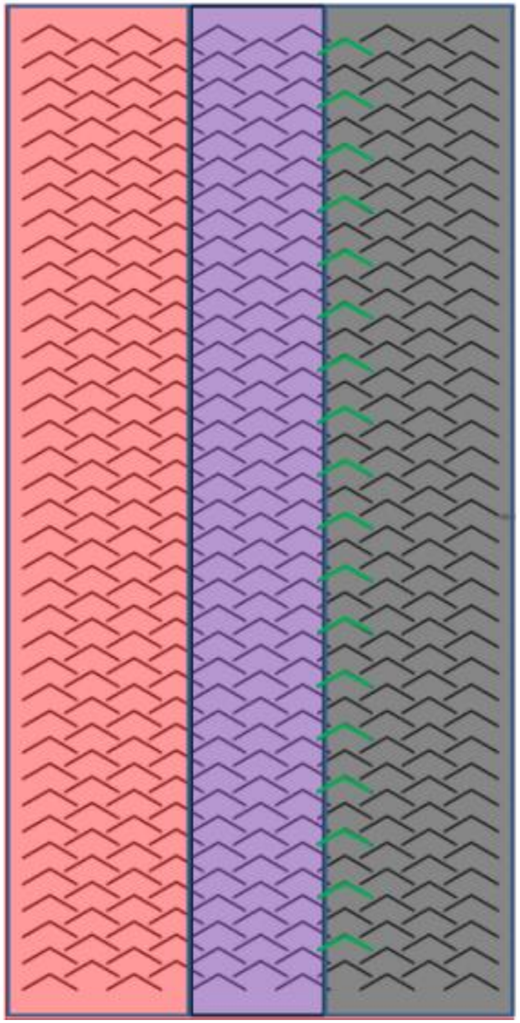






Cross-sectional view of oxidized wire mesh; wire ruptured and “leaked” molten steel out of oxidized shell (white is stainless steel, rough gray area is oxidized mesh)

Multi-Material Mesh Insert



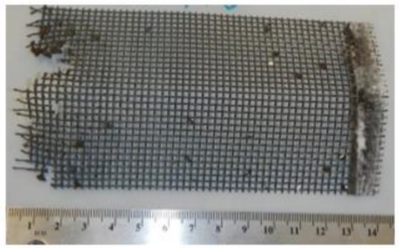
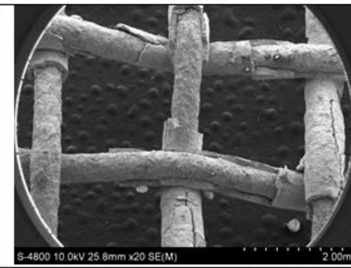
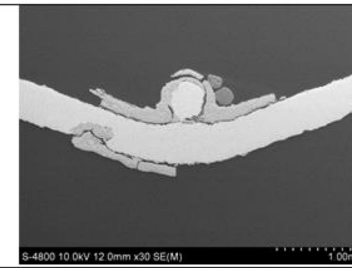
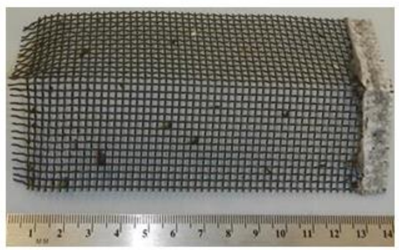
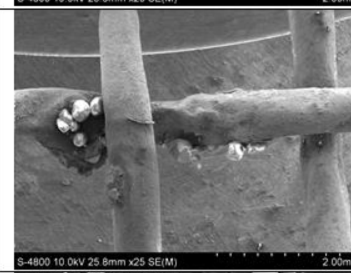
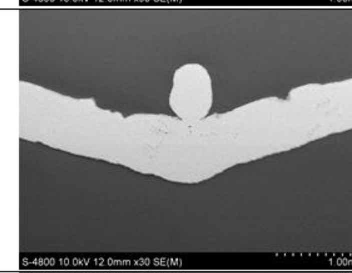
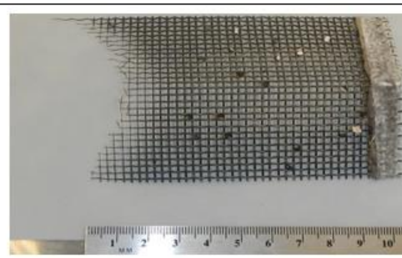
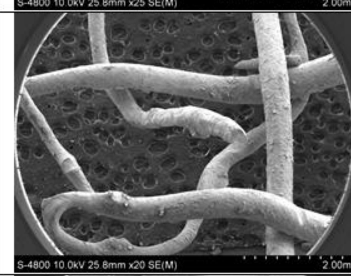
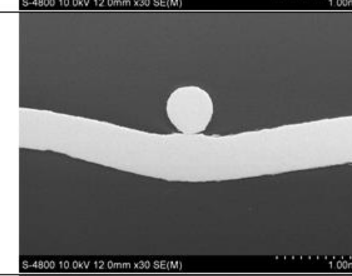
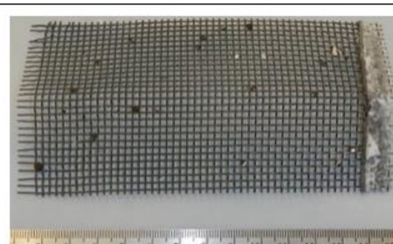
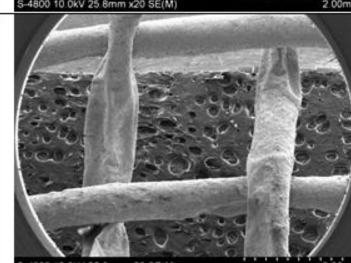
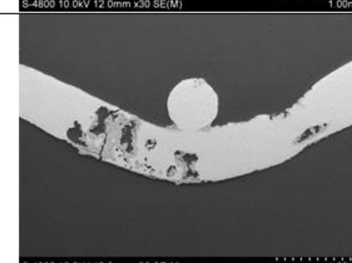
SS316

Inconel 601

Hastelloy C276

Hastelloy X

SEM Analysis of Multi-Mesh Materials

Material	Mesh Sample Pulled from Insert (left edge faced incident irradiation)	SEM Image of Damaged Interwoven Wires	SEM Cross Section
SS316			
Inconel 601			
Hastelloy C276			
Hastelloy X			

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