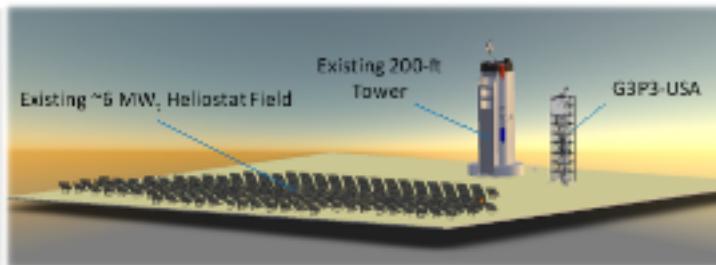


Gen3 Particle Pilot Plant (G3P3) Receiver Design and Testing



SAND2020-11936PE



PRESENTED BY

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SNL: Nathan Schroeder, Henk Laubscher, Lindsey Yue, Brantley Mills, Reid Shaeffer, Joshua Christian, and Kevin J. Albrecht

Others: Georgia Tech, King Saud U., DLR, ANU, CSIRO, U. Adelaide, CNRS-PROMES, CARBO Ceramics



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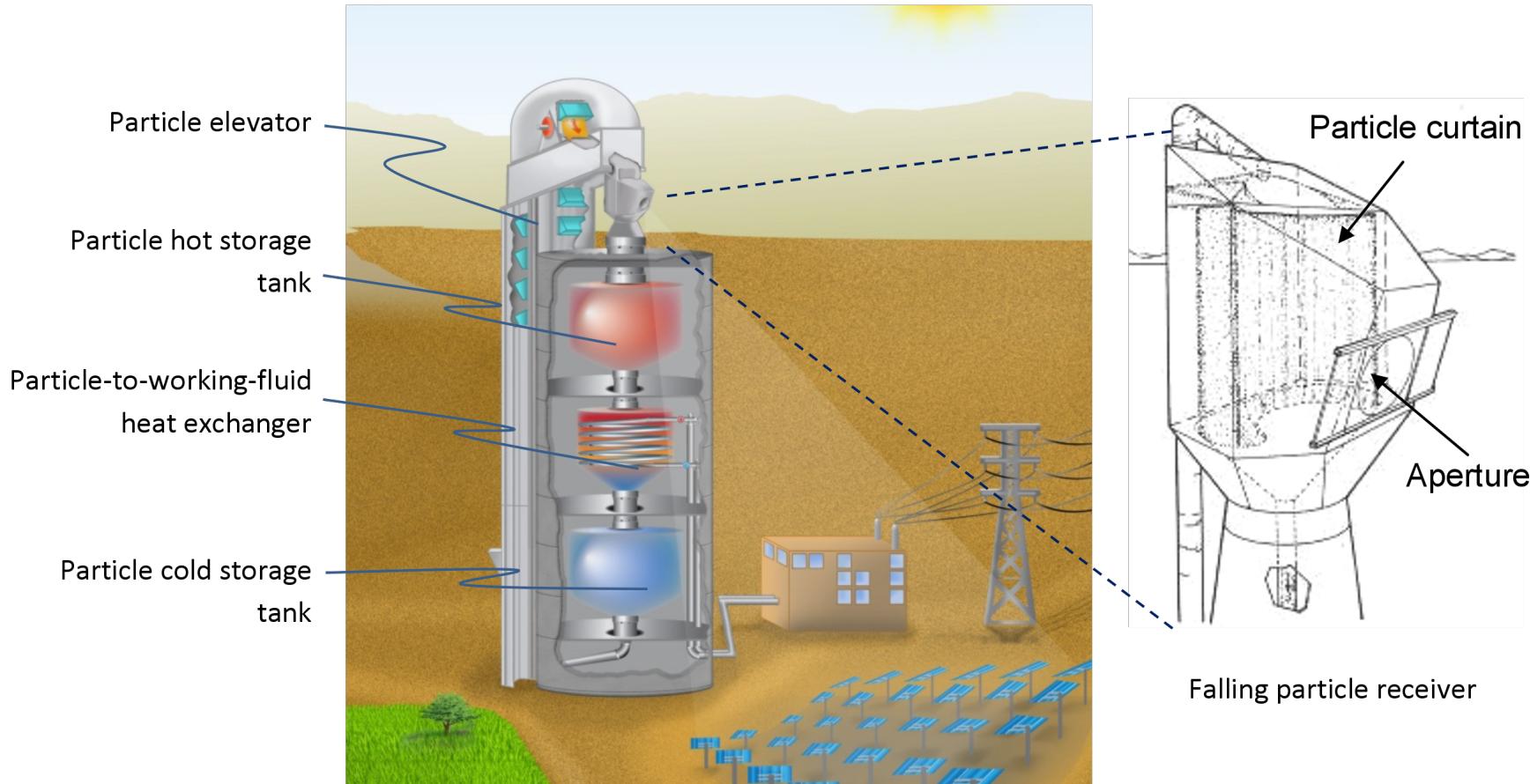


- Introduction and Objectives
- Receiver Design
- On-Sun Testing
- Lessons Learned

Background and Introduction



High-Temperature Particle-Based CSP

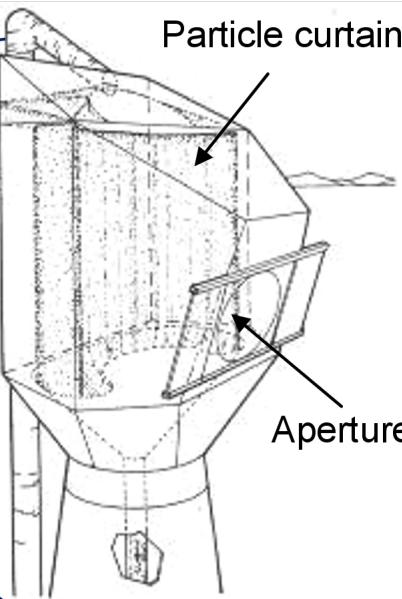
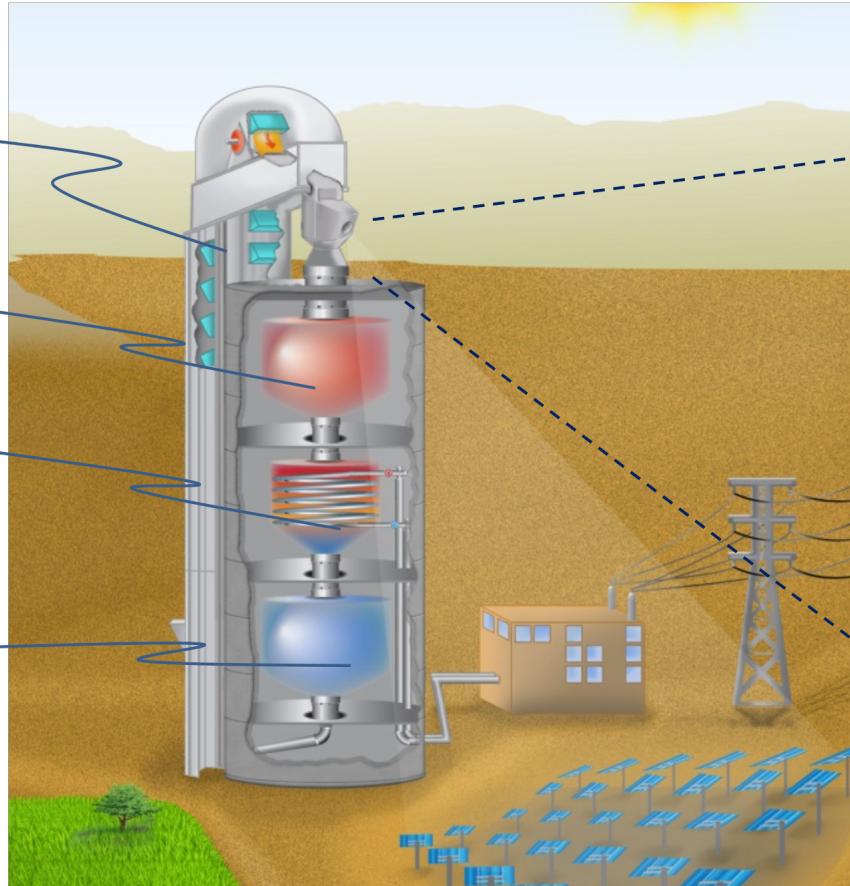


Background and Introduction

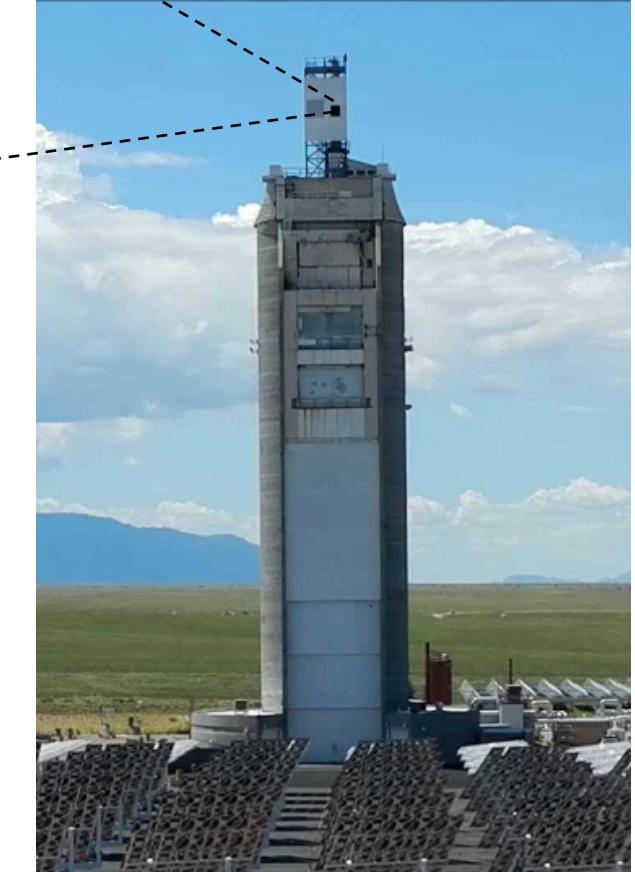


High-Temperature Particle-Based CSP

Particle elevator
Particle hot storage tank
Particle-to-working-fluid heat exchanger
Particle cold storage tank



Falling particle receiver

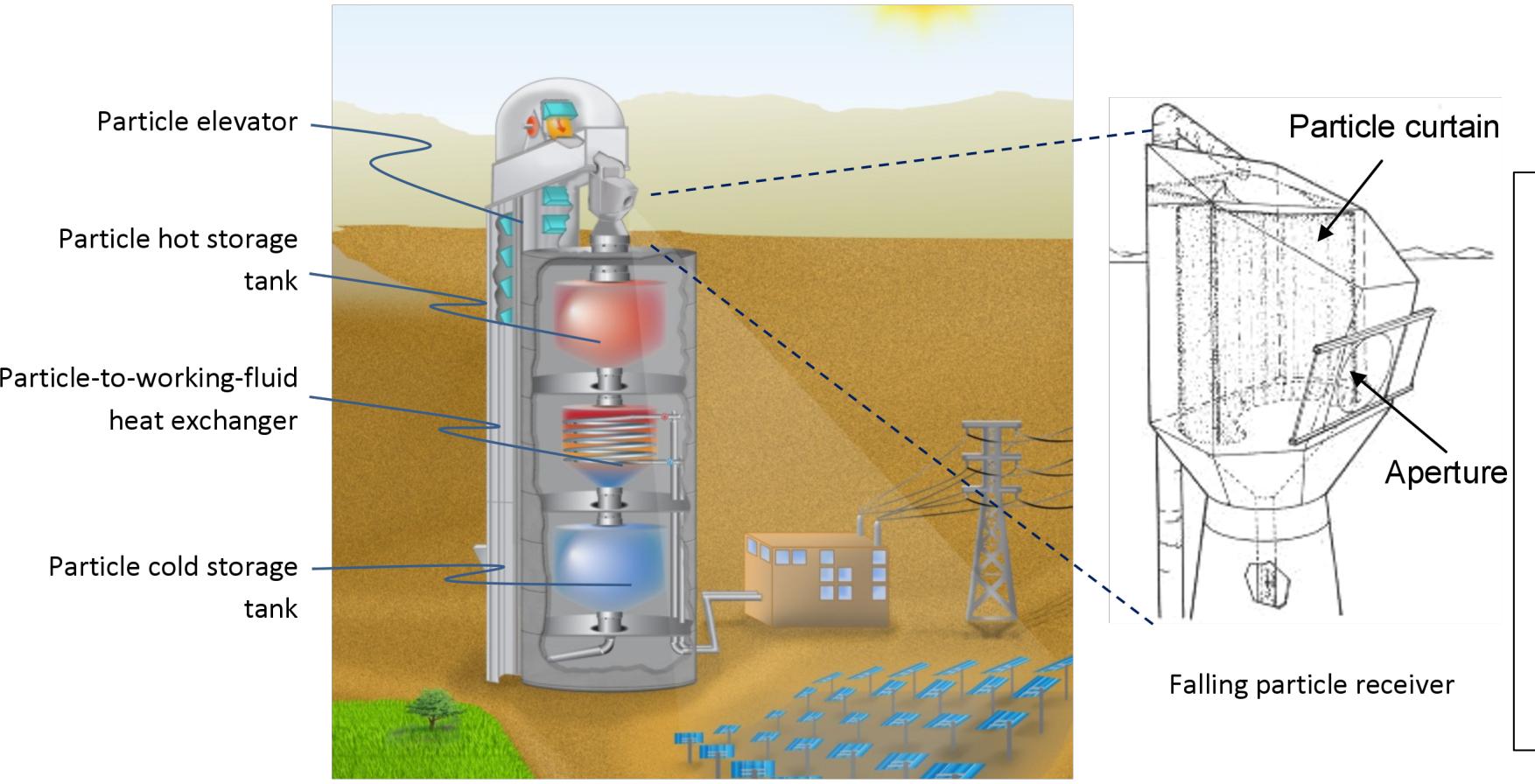


National Solar Thermal Test Facility
Sandia National Laboratories

Background and Introduction



High-Temperature Particle-Based CSP

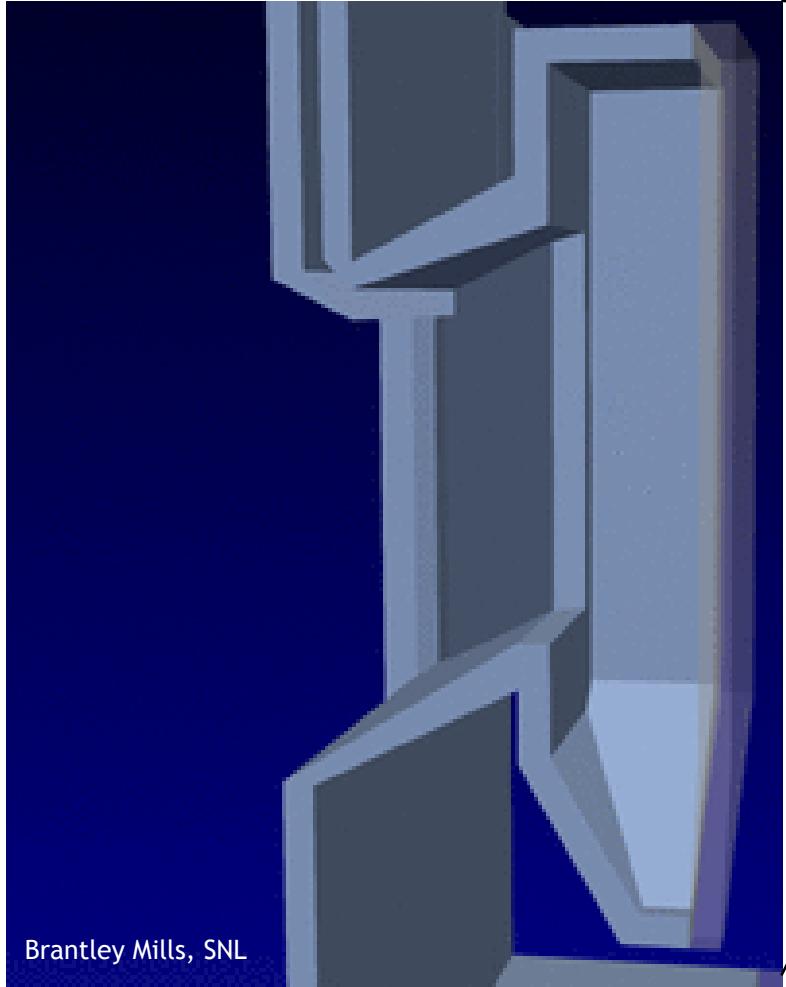


- Higher temperatures ($>1000^{\circ}\text{C}$) than molten nitrate salts
- Direct heating of particles vs. indirect heating of tubes
- No freezing or decomposition
 - Avoids costly heat tracing
- Direct storage of hot particles

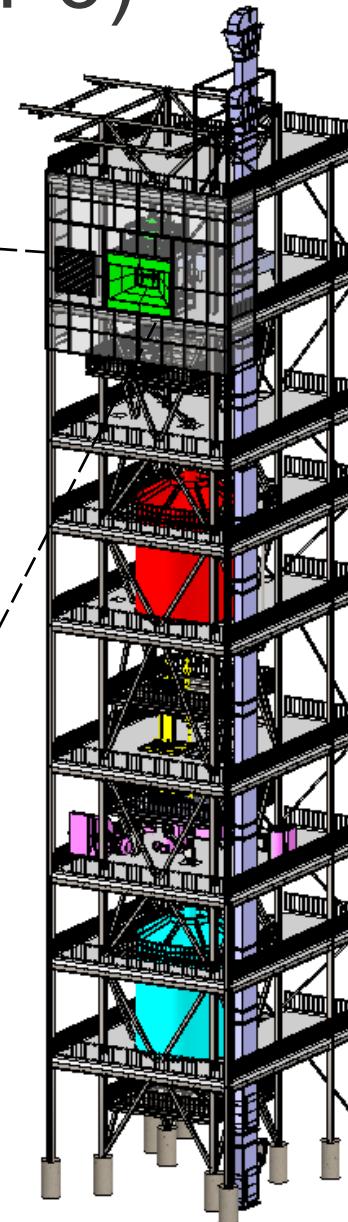
Gen3 Particle Pilot Plant (G3P3)



Next-Generation High-Temperature Falling Particle Receiver



Brantley Mills, SNL



K. Albrecht, SNL

Gen 3 Particle Pilot Plant

- $\sim 1 - 2 \text{ MW}_t$ receiver
- 6 MWh_t storage
- 1 MW_t particle-to-sCO₂ heat exchanger
- $\sim 300 - 400$ micron ceramic particles (CARBO HSP 40/70)

Objectives



- Present evolution of receiver design for G3P3
- Describe on-sun testing to evaluate performance of new design features and obtain operational experience
- Identify system interfaces, design challenges, and lessons learned



- Introduction and Objectives

- Receiver Design

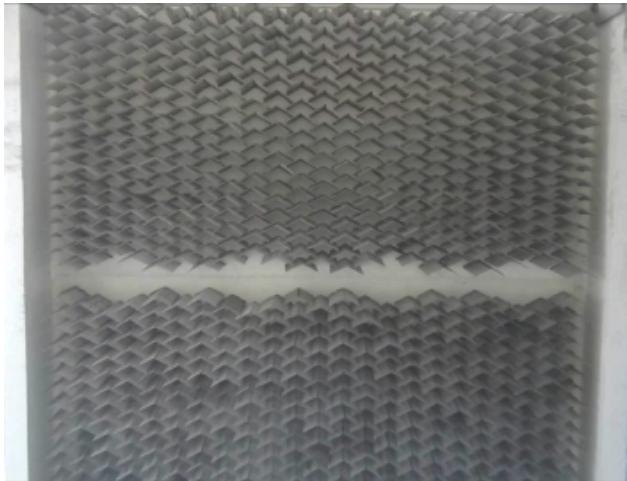
- On-Sun Testing

- Lessons Learned

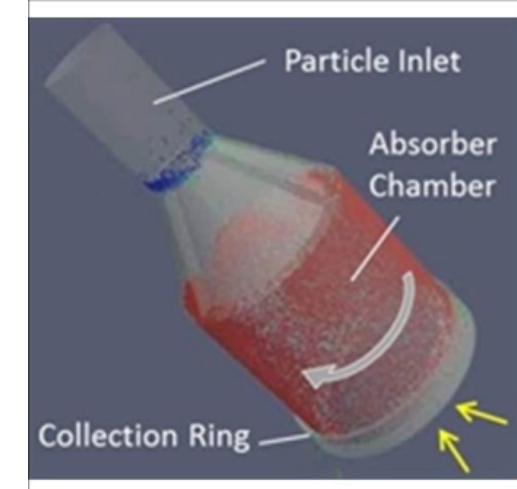
Alternative Particle Receiver Designs



Free-Falling (SNL)



Obstructed Flow
(Georgia Tech, King Saud U.)



Centrifugal (DLR)



Fluidized Bed



STEM - Magaldi Group

G3P3-USA Receiver Design Evolution



2020

2015 - 2018

NSTTF
1 MW_{th} FPR



Design Challenges
• Low thermal efficiency
• Sensitivity to wind

FPR = Falling particle receiver

Feature evaluation

Hood/Tunnel

Quartz Half Shells

Active Air Flow

Multistage

Optimized Cavity

Reduced volume with SNOUT

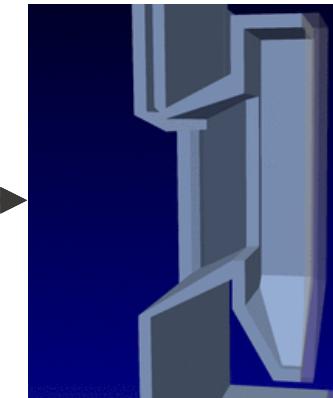
StAIR Receiver

Design refinement

Receiver Chimney

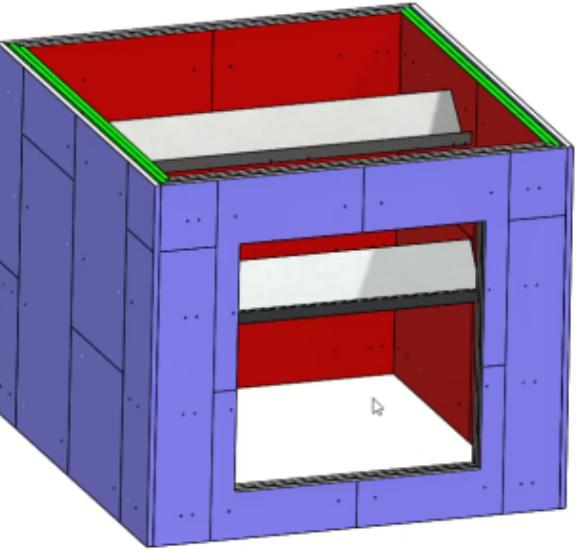
Ray Tracing Analysis

Optimized G3P3 FPR



Pathway
• Wind Evaluation
• Ground Testing
• On-sun Testing
• Model Validation

StAIR (Staggered Angle Iron Receiver) Testing

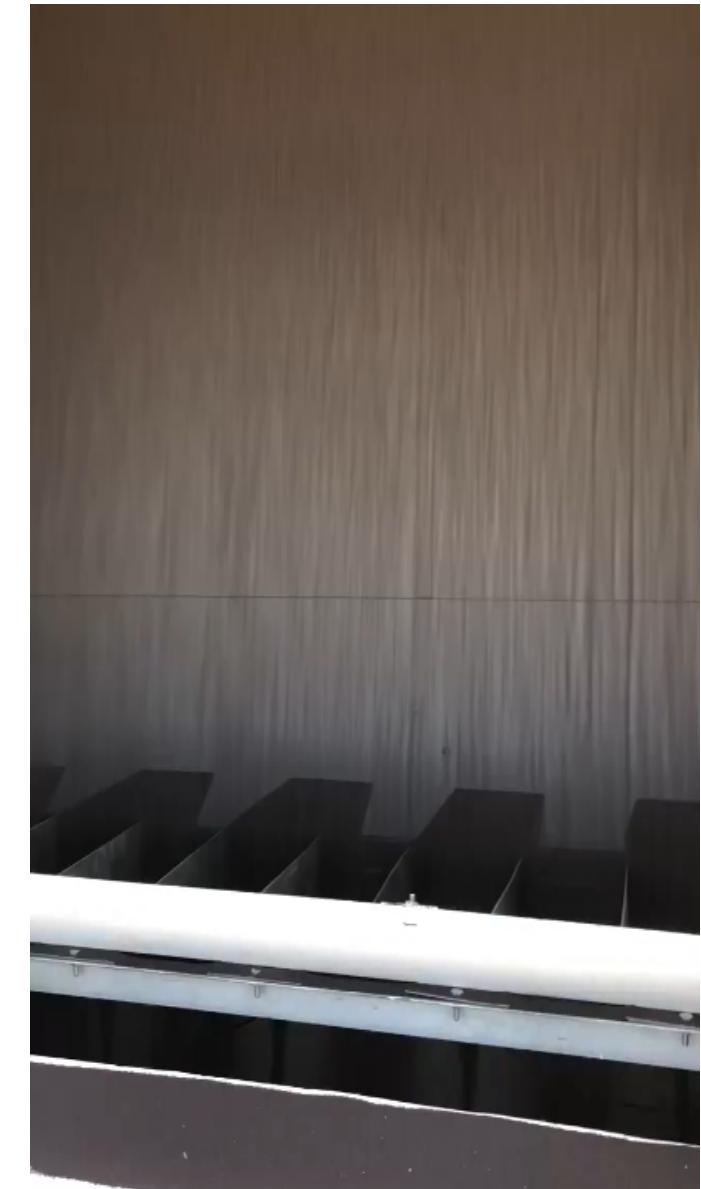


Drawing of “stairs” in receiver cavity

StAIRS create a more uniform and opaque particle curtain for increased solar absorptance



Particle flow over two-stair configuration (5 - 10 kg/s)



G3P3-USA Receiver Design Evolution

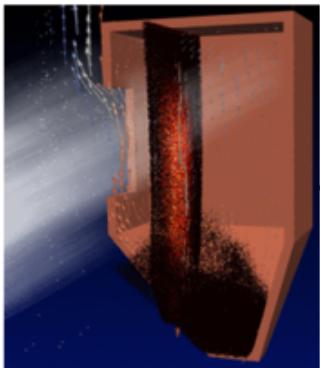
2020



2015 - 2018

Feature evaluation

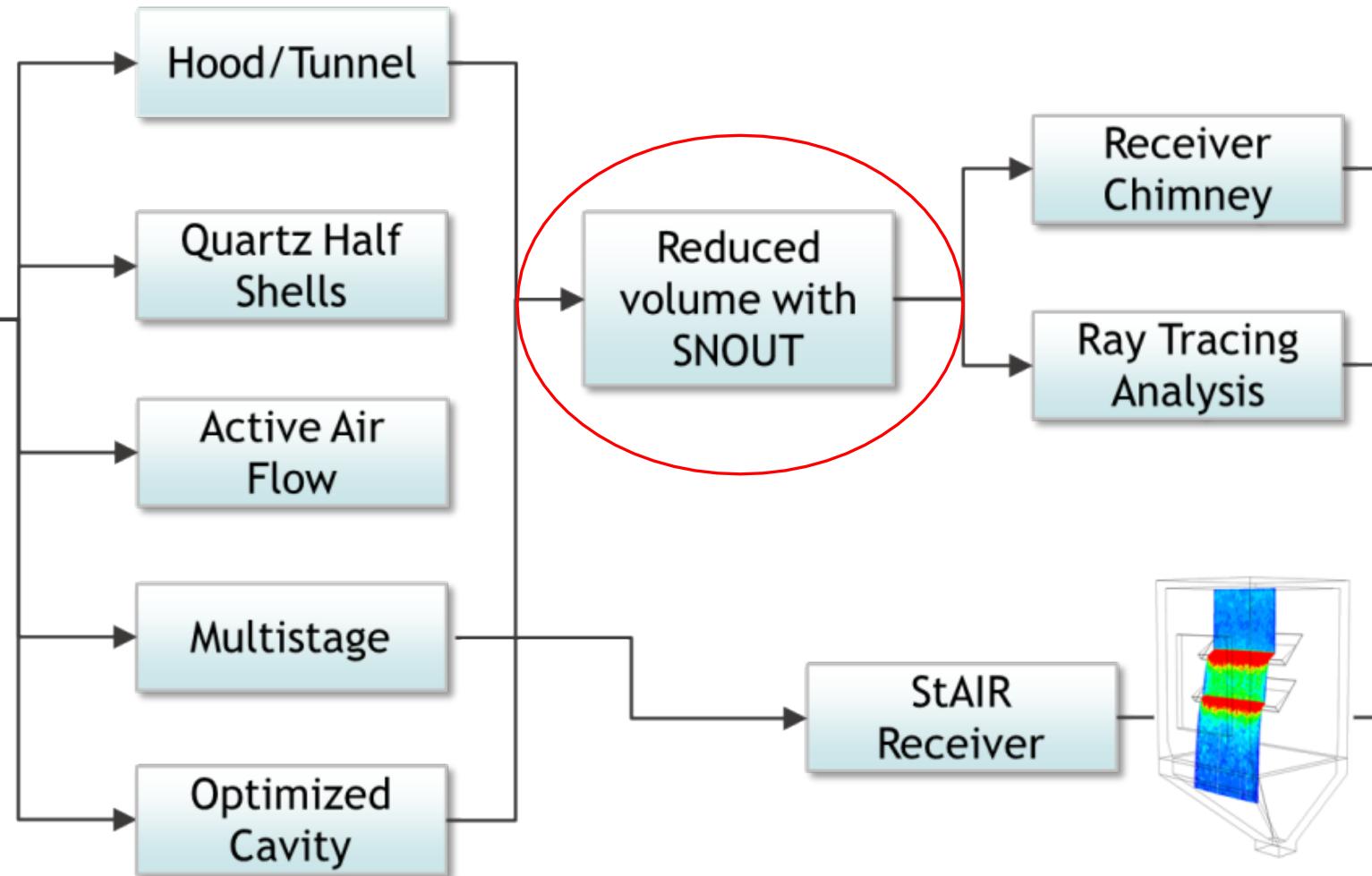
NSTTF
1 MW_{th} FPR



Design Challenges

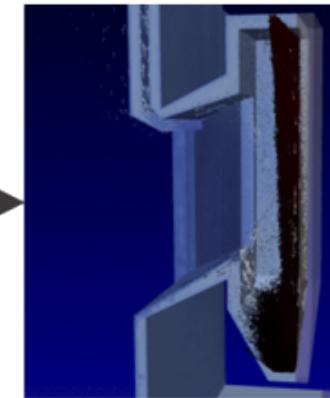
- Low thermal efficiency
- Sensitivity to wind

FPR = Falling
particle receiver



Design evaluation

Optimized
G3P3 FPR



Pathway

- Wind Evaluation
- Ground Testing
- On-sun Testing
- Model Validation

SNOUT and Reduced Volume Receiver



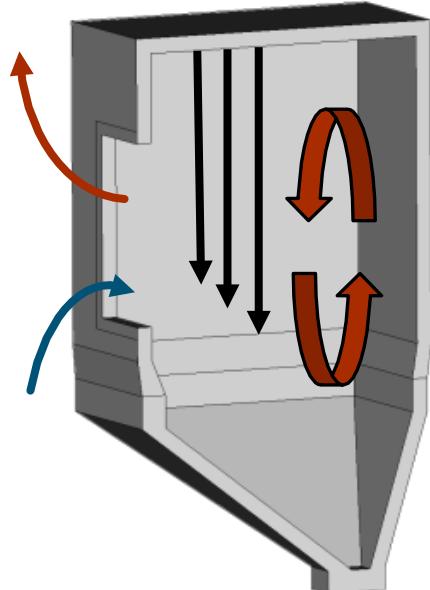
Baseline



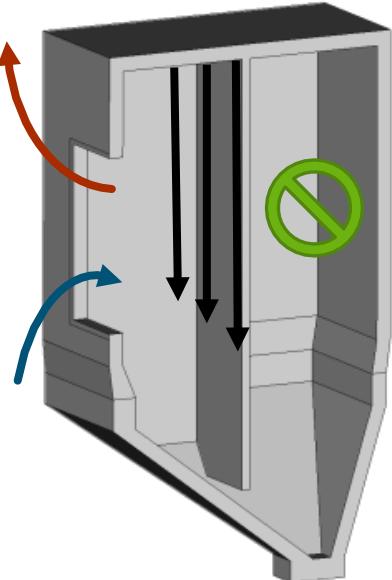
SNOUT



Baseline



Reduced volume receiver



Experiment



Simulation

SNOUT and reduced-volume reduced
advective heat loss by ~20 - 25%



- Introduction and Objectives

- Receiver Design

- On-Sun Testing

- Lessons Learned

Control Room and On-Sun Testing



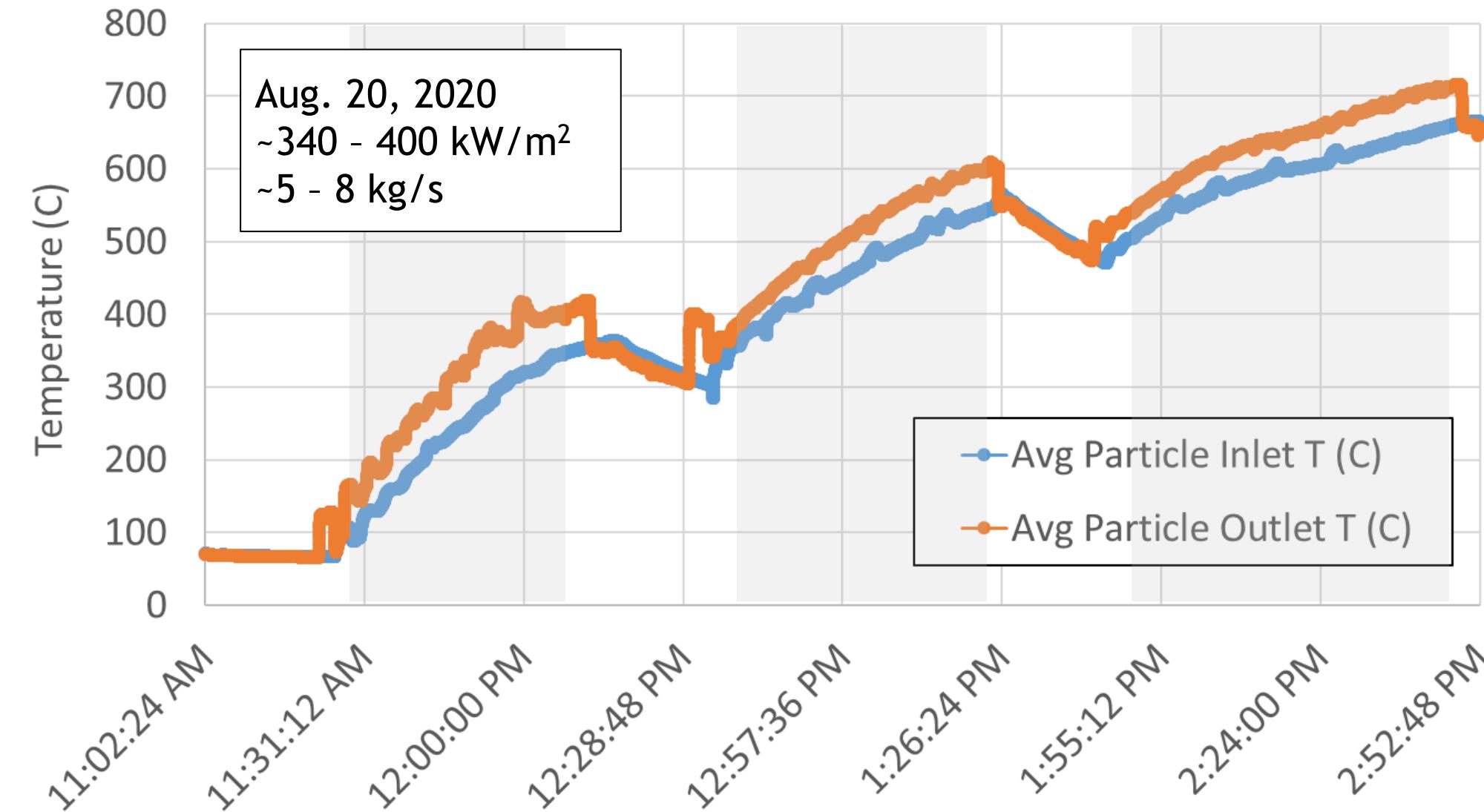
On-sun testing of
particle receiver with
StAIRs and reduced
volume



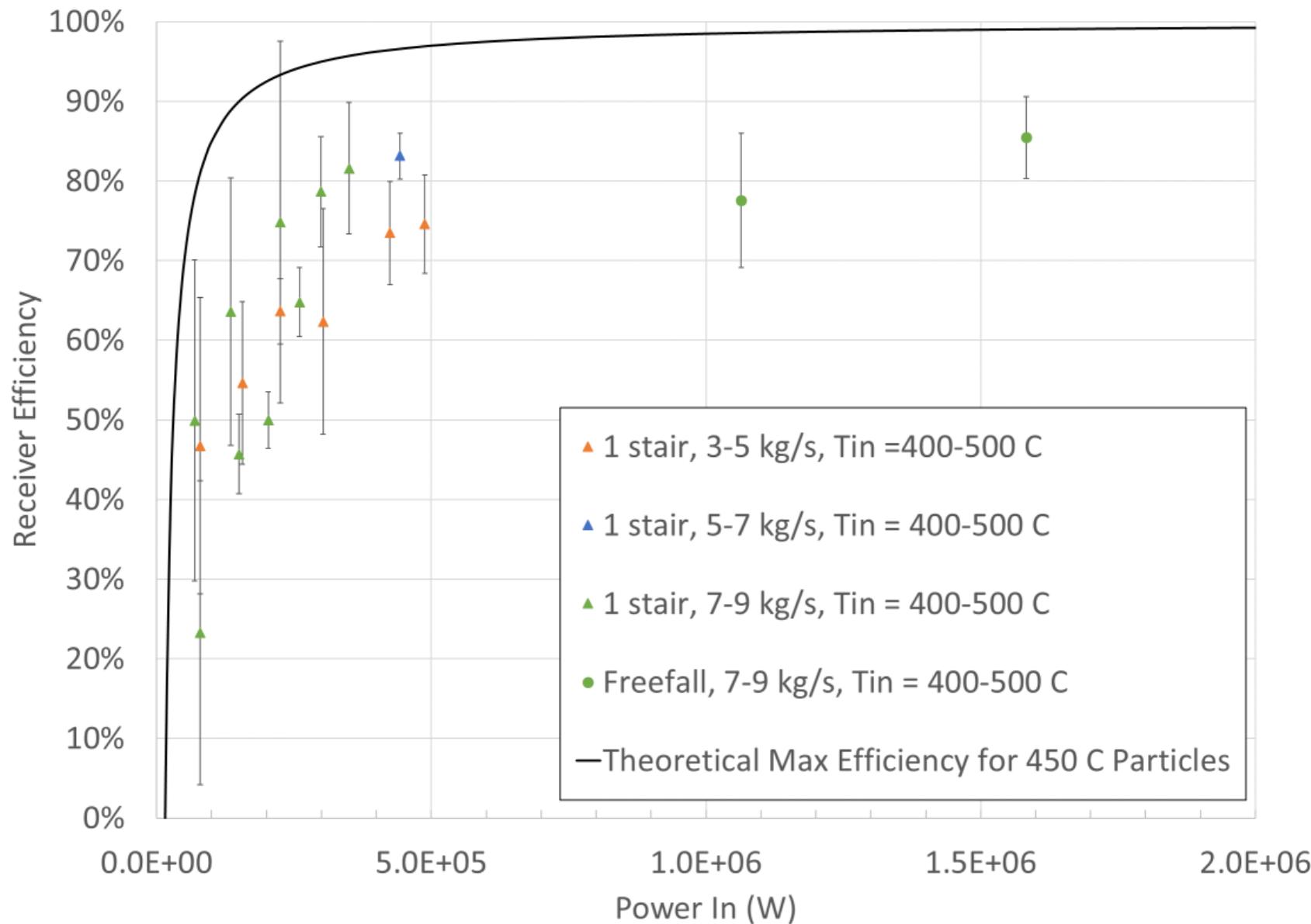
Sample of Test Log

Date	Start	End	Description	Weather
17-Aug-20	11h00	14h30	Receiver testing 500°C and 700°C, peak flux of 60 and 115 W/cm^2, two stairs	Very windy afternoon, Some clouds
18-Aug-20	11h00	14h30	Receiver testing 500°C and 700°C, peak flux of 60 and 115 W/cm^2, two stairs	Hazy from smoke
20-Aug-20	10h30	15h00	Test load cells, 50 W/cm^2, 500-600 °C, test single stair, top stair only	
21-Aug-20	10h30	14h00	Receiver testing, load cell troubleshooting, single top stair	Hazy from smoke, low DNI
4-Sep-20	10h30	15h00	Receiver test day, 500C @ 5kg/s and 10 kg/s, with 50 W/Cm^2 700C @ ±5kg/s and 50 W/cm^2 700C at 108W/cm^2	Good DNI clear skies

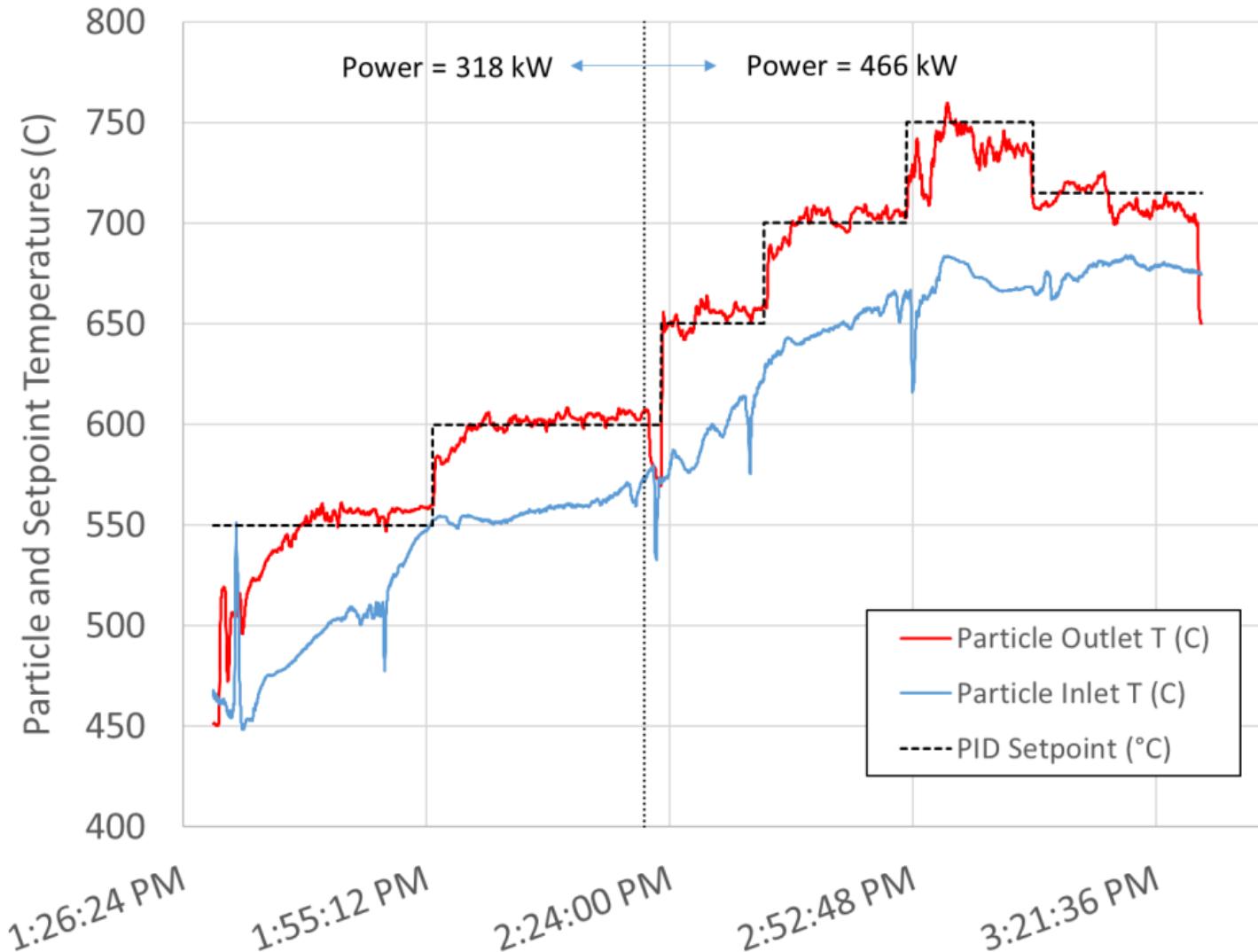
On-Sun Particle Temperatures



Receiver Efficiencies



Particle Temperature Control



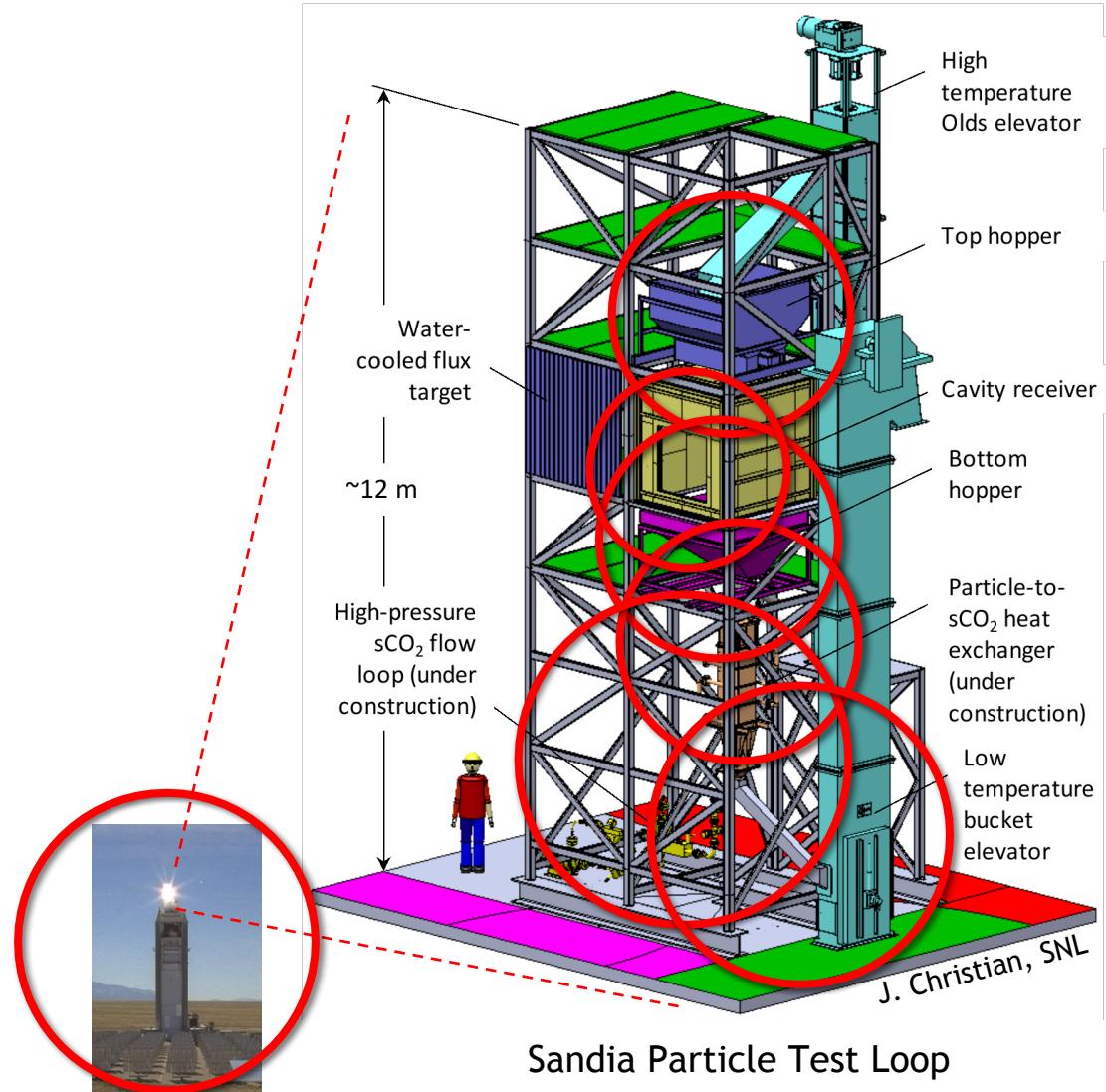
- Automated particle outlet temperature control using closed-loop PID controller



- Introduction and Objectives
- Receiver Design
- On-Sun Testing
- Lessons Learned

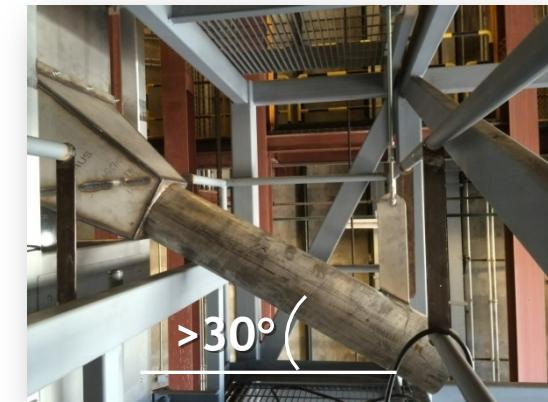
Mechanical Interfaces of System

- Particle feed to the receiver
- Concentrated sunlight to particles
- Receiver to storage/collection bin
- Storage to heat exchanger
- Heat exchanger to sCO₂ flow loop
- Heat exchanger to particle lift

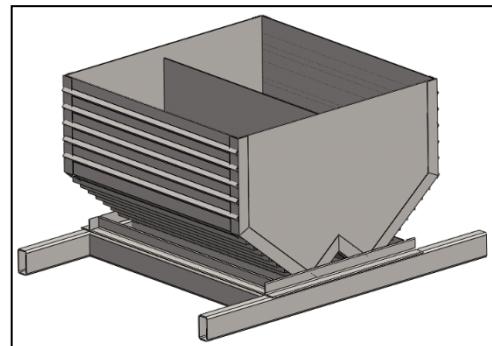


Particle Feed to the Receiver

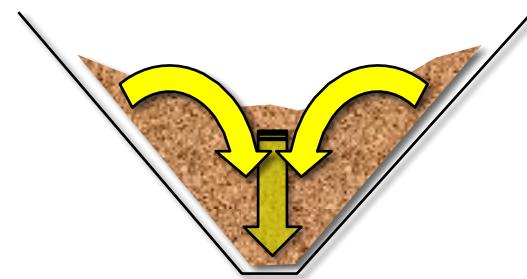
- Sufficient pipe inclination angle for flow
 - Particle friction changes with temperature
- Funnel flow and avalanching in top hopper



Pipe from particle elevator to top hopper



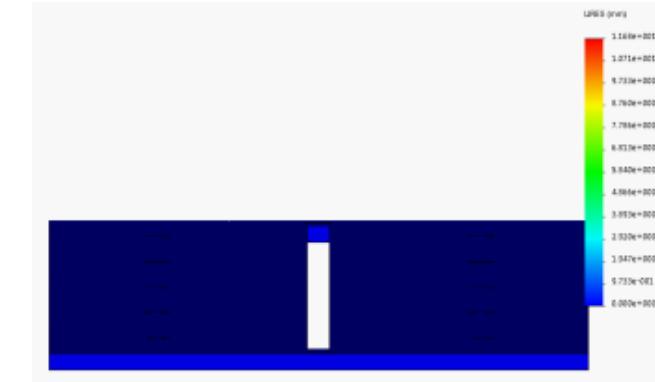
Top hopper



Funnel flow and avalanching

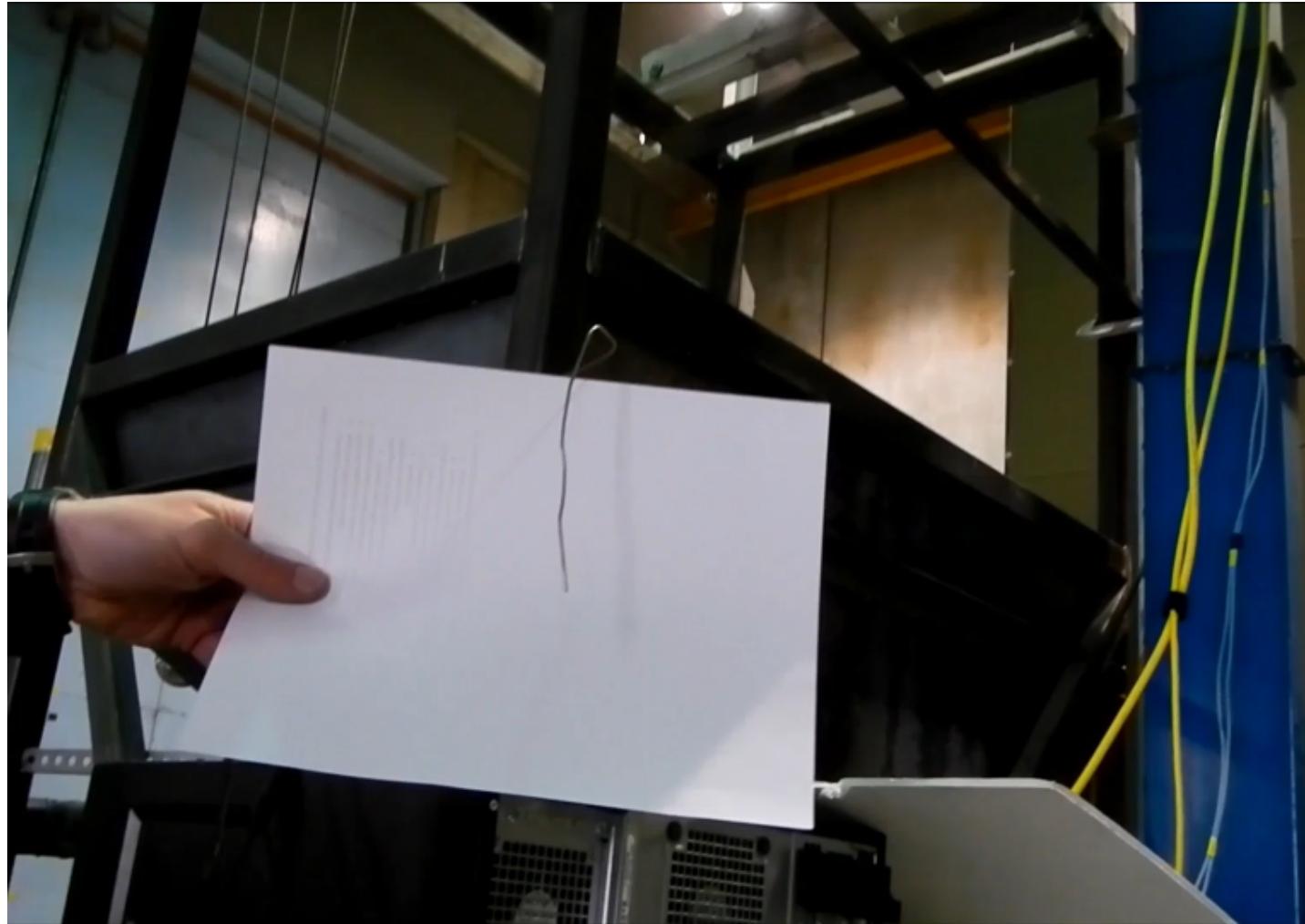
Particle Feed to the Receiver

- Initially used fixed-aperture plates to control mass flow rate into receiver
- Slotted plate deformed upon heating
- Reduction of particle mass flow rate led to melting of mesh structures
- Need automated particle mass-flow control to maintain constant particle outlet temperatures with varying irradiance



Staggered array of chevron-shaped mesh structures

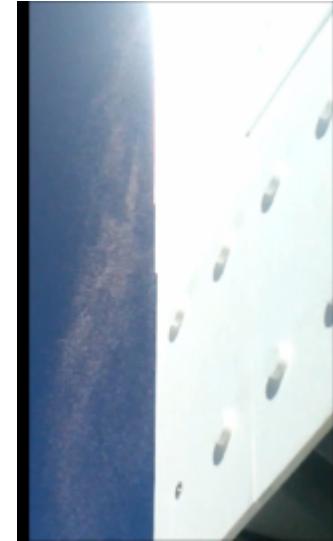
Particle Mass Flow Control - Demo



G. Peacock, K. Albrecht (SNL)

Concentrated Sunlight to Receiver

- Particle loss through open aperture
 - Trade-off between direct irradiance and particle losses
- Air curtains to reduce convective heat loss
- Light trapping with novel particle release patterns



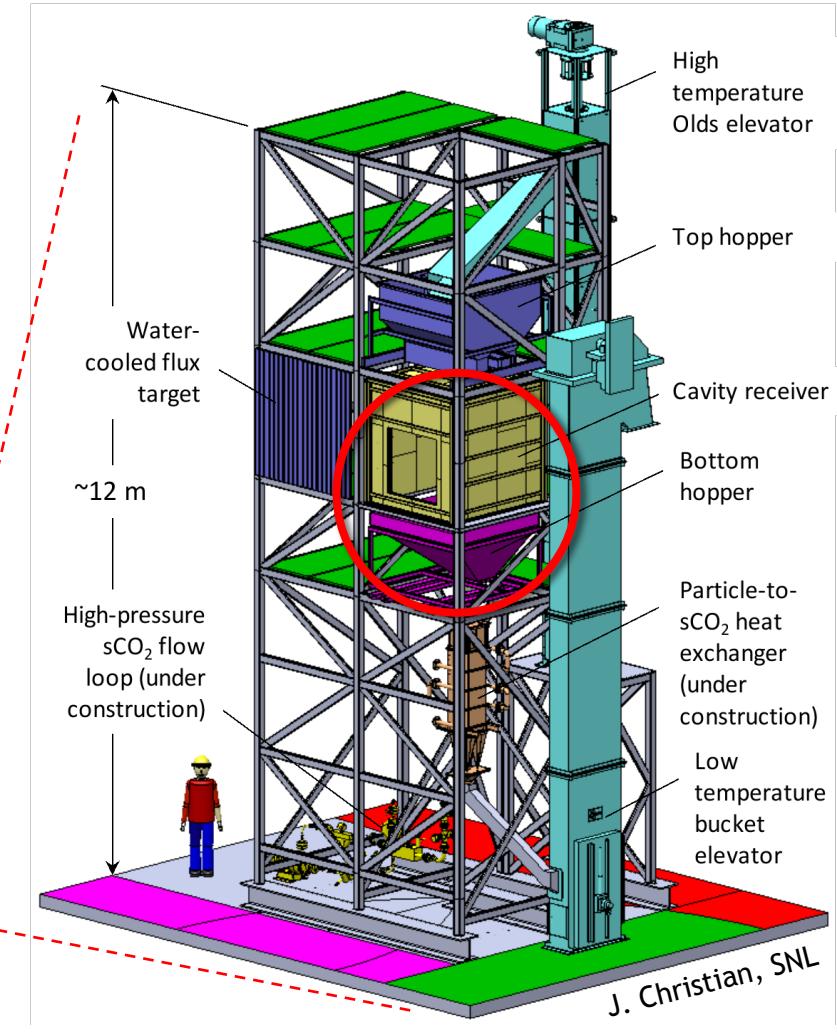
Nov. 2, 2015
3/8" slot - free fall
280 micron ACCUCAST
ID50
10-15 mph south wind
500 - 1000 suns



Pump and nozzles to produce air curtain across aperture

Receiver to Storage Bin

- Reduce wear from direct impact on walls
 - Design for particle to particle impact
- Minimize opening to reduce heat loss from storage
- Design for filtration of debris and particle fines



Sandia Particle Test Loop

Summary



Summary



- Next-generation high-temperature particle receiver designed and tested
 - Optimized geometry to reduce advective and particle losses
 - SNOUT wind protection
 - Stairs to increase particle-curtain opacity and stability
- Lessons learned
 - Designs need to be scalable to large sizes (~1000 kg/s required)
 - High-flux, high-temperature environments are harsh on materials and sensors
 - In-situ measurements of temperature, mass flow, irradiance, wind
 - Thermal expansion
 - Mass flow control
 - Transient operation (start-up and shut-down)

Acknowledgments

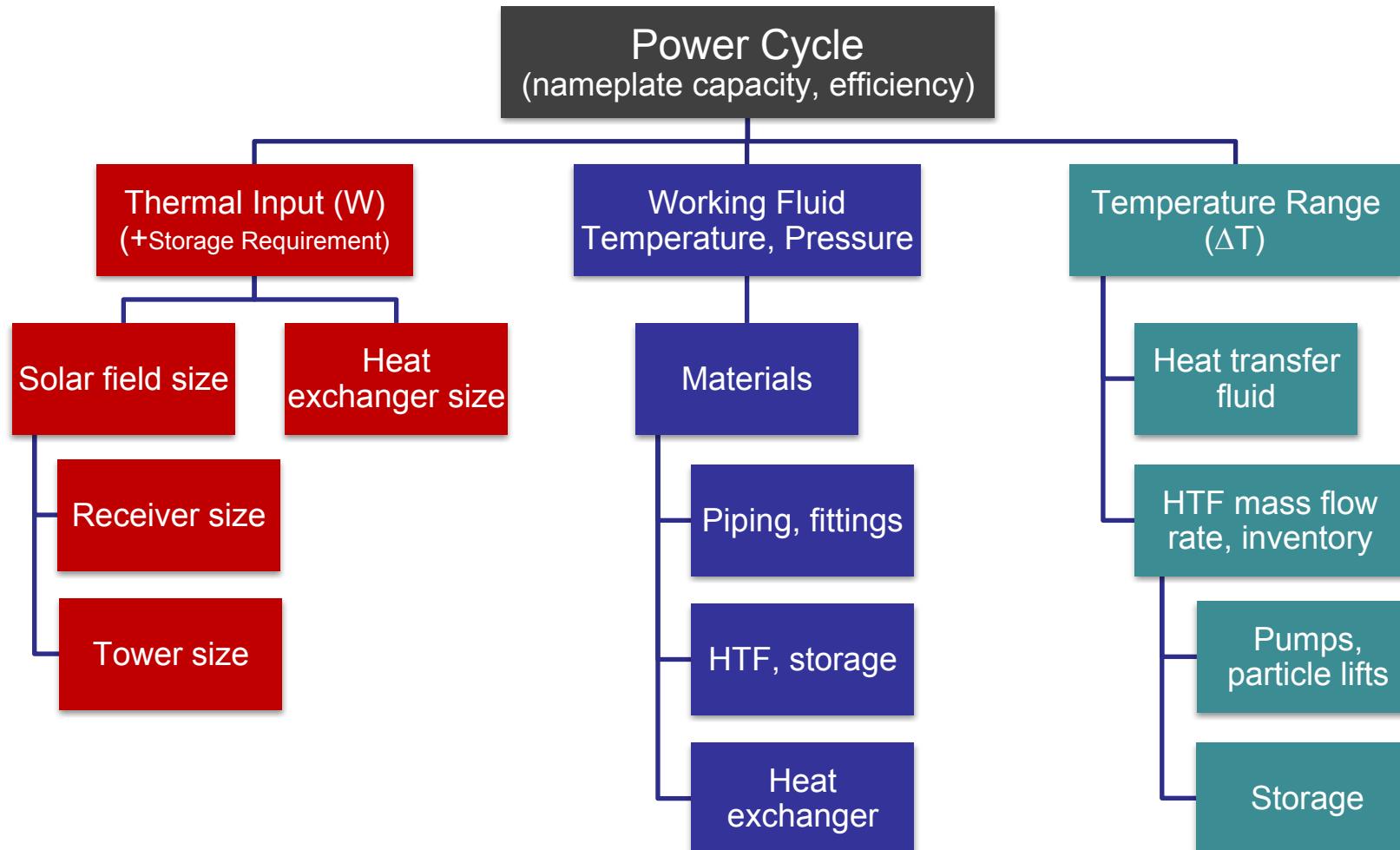


- This work is funded in part or whole by the U.S. Department of Energy Solar Energy Technologies Office under Award Number 34211
 - DOE Project Managers: Matthew Bauer, Vijay Rajgopal, and Shane Powers

Backup Slides

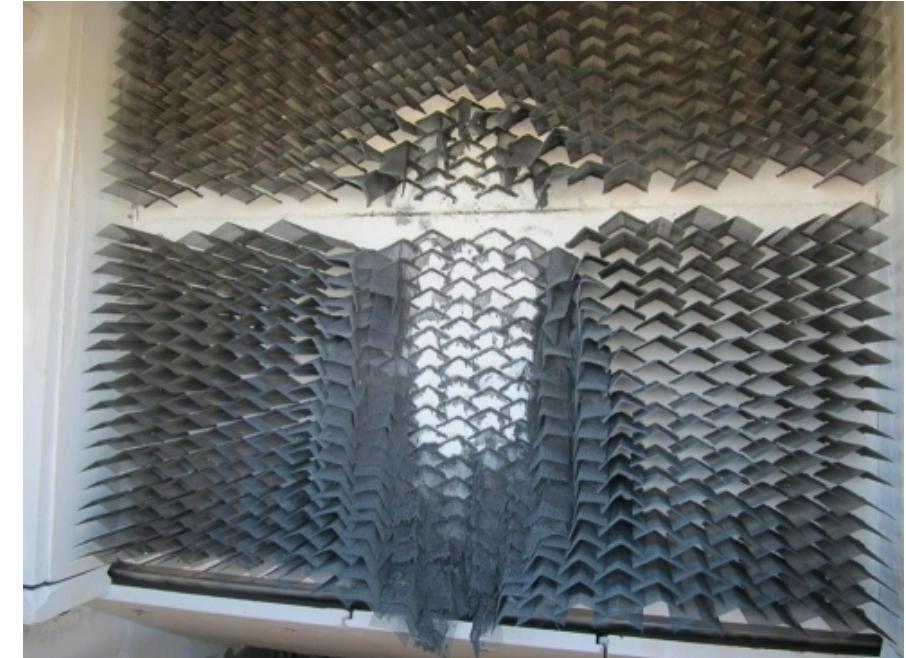
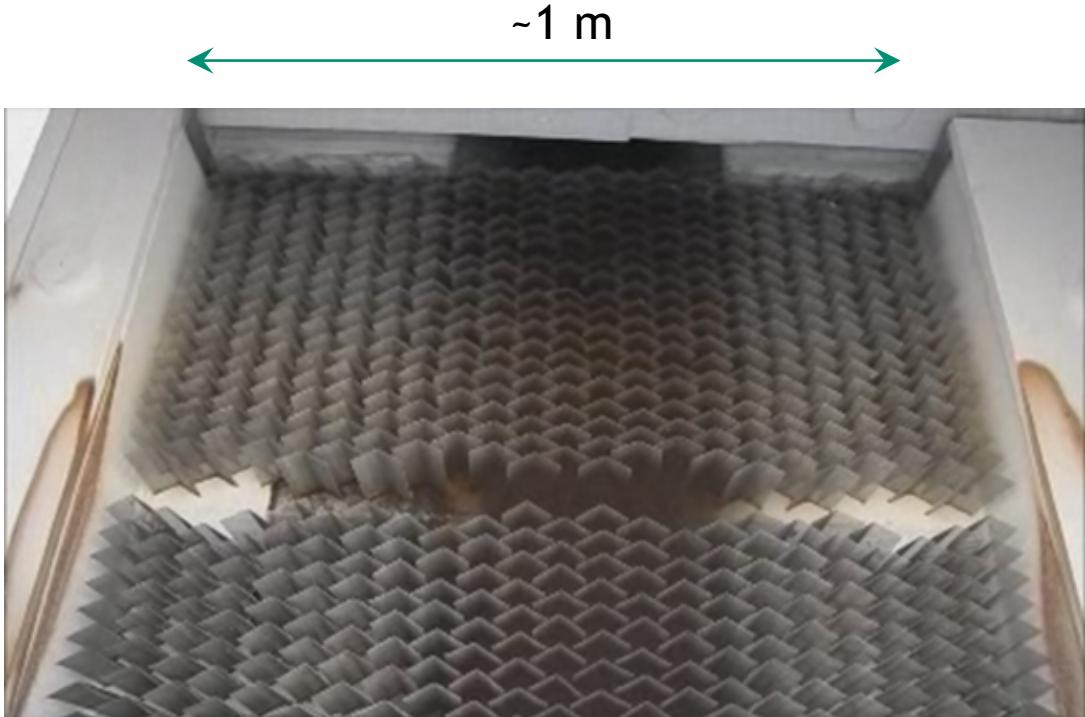


Thermodynamic Interfaces



\$\$\$ Costs \$\$\$

Overheating of Flow Obstructions



Failure of 316 SS mesh structures on July 24, 2015
~700 suns at ~1000 C (steel)

Uneven particle flow caused runaway heating and melting of obstructions