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DESIGN AND MODELING OF LIGHT-TRAPPING TUBULAR RECEIVER PANELS

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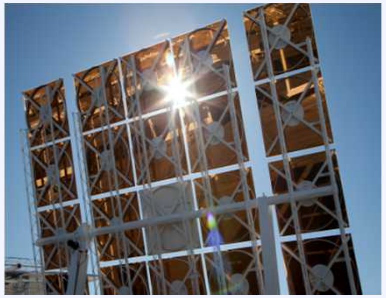


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NNSA National Nuclear Security Administration

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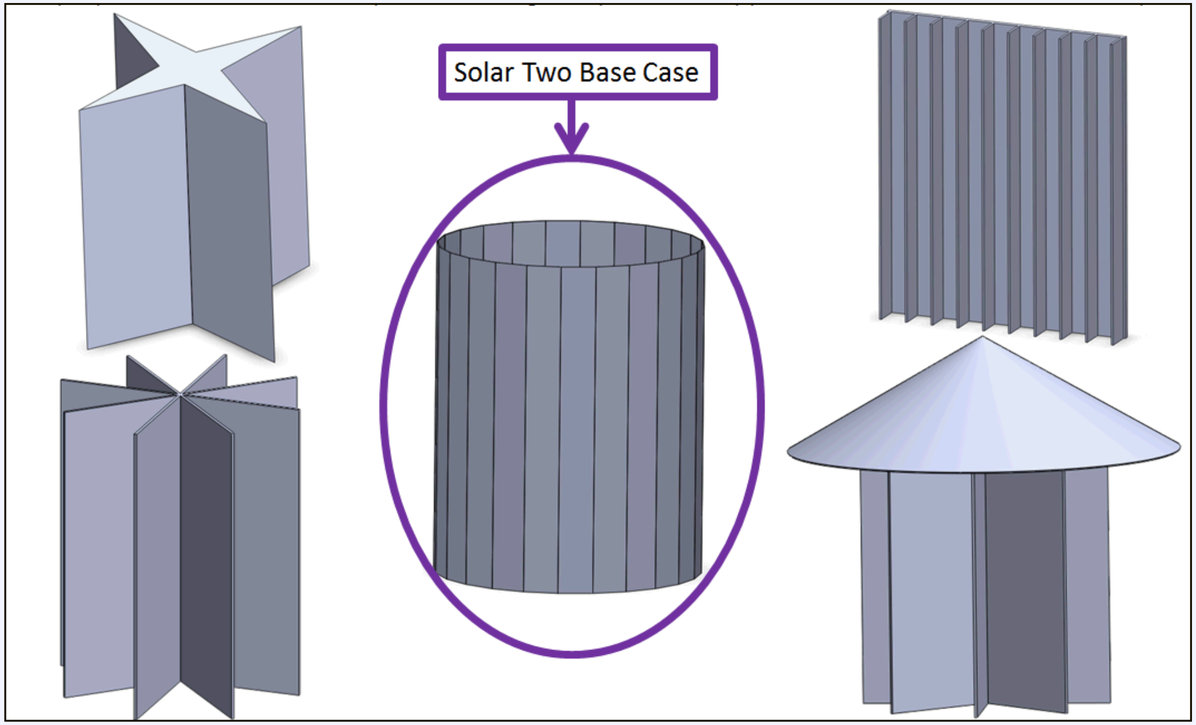
Introduction



- Increase thermal efficiency through geometry manipulation of high-temperature, external receivers
  - Current external designs re-emit nearly 100% of thermal radiation back to the environment
  - Natural convection heat loss can be "trapped" with geometry manipulation

Presentation Overview

- Objectives
- Approach
- Results
- Conclusion

Objectives

- Increase thermal efficiency of external receivers
  1. Increase the **light trapping** and effective solar absorptance
  2. Reduce the thermal emittance of the receiver by taking advantage of **local view factors in the hottest regions** of the receiver
  3. Increasing **geometric concentration ratio** of the receiver through the use of a smaller overall aperture size (optical intercept) while maintaining the same exposed surface area and power

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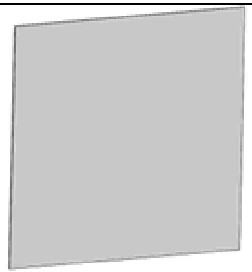
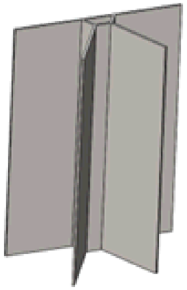
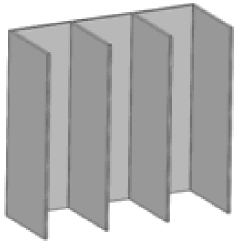
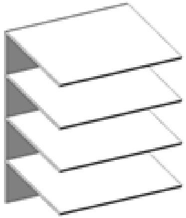
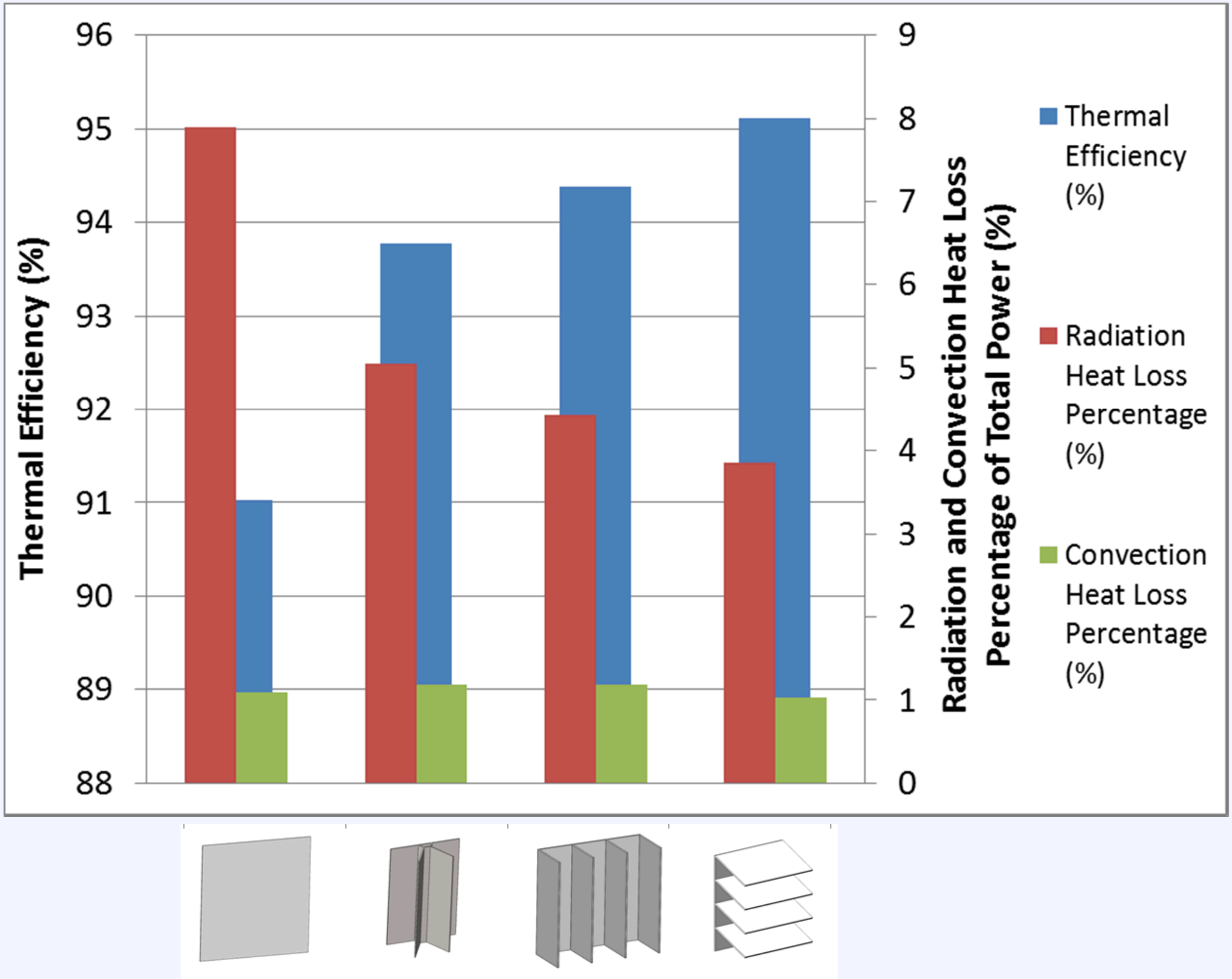
Receiver Designs

Base Case Study-Flat Plate Receiver; Height = 2 m; Width = 2 m; Exposed Surface Area = $4m^2$	
Radial Finned Receiver; Height = 1.5 m; Width = 1 m; Exposed Surface Area = $4m^2$; Fin length = 0.4 m	
Linear Vertical Fin Receiver; Height = 0.95 m; Width = 1 m; Exposed Surface Area = $4m^2$; Fin length = 0.4 m	
Horizontal Slate Fin Receiver; Height = 0.84 m; Width = 1 m; Exposed Surface Area = $4m^2$; Fin length = 0.4 m	

Distributed Flux Thermal Efficiency: Single Aim Point CFD Study



Approach

- Perform ray tracing on receiver design to down-select to a single design for experimental testing
- Perform structural analysis on the design to ensure it can withstand the given boundary conditions
- Design the experimental setup for receiver testing

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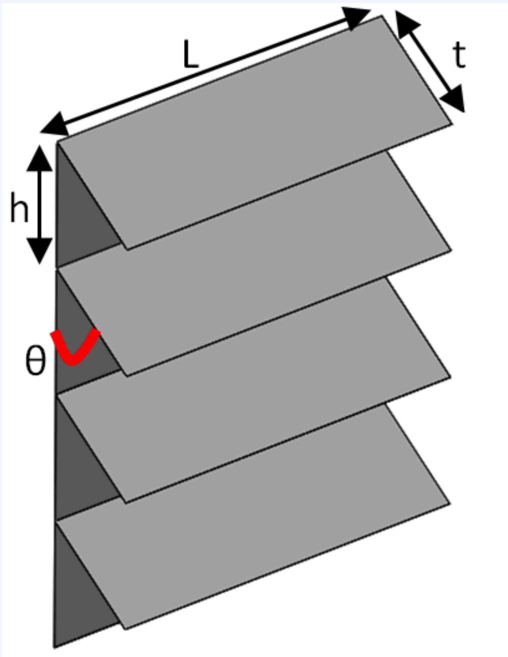
Ray Trace Modeling

1. Ray trace model (SolTrace) used to determine/select the receiver design with the best overall effective absorptivity
2. Ray trace model used to optimize the chosen receiver design
    1. Number of tubes in a fin panel
    2. Number of tubes in a back wall panel
    3. Number of panels

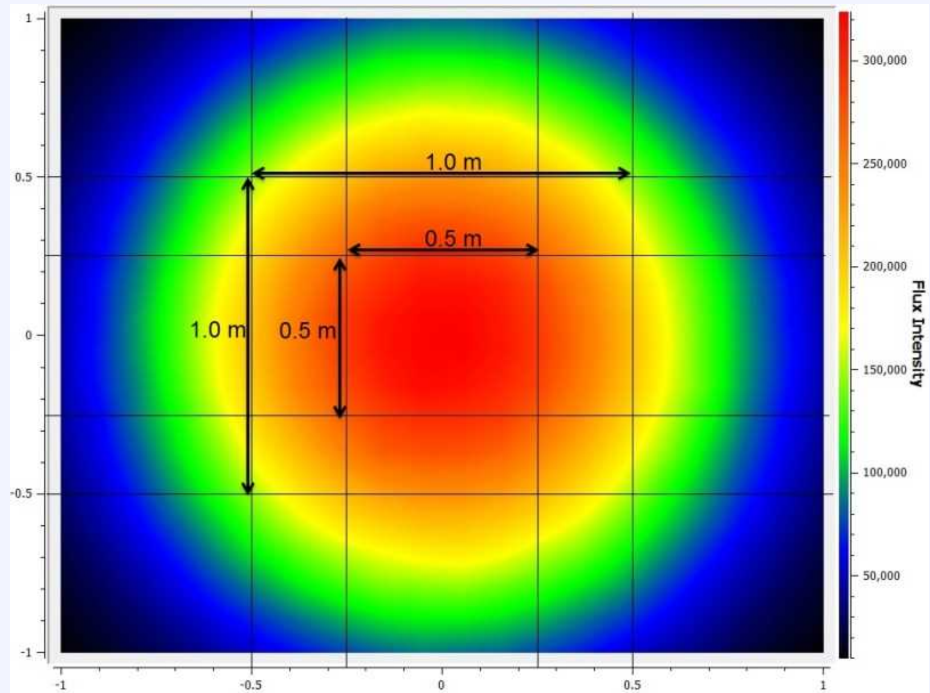
Ray Trace Modeling

Geometry	Surface Emissivity	Single Aim Point Effective Absorptivity	Four Aim Points Effective Absorptivity
	0.86	0.86	0.86
	0.96	0.96	0.96
	1	1	1
	0.86	0.94	0.93
	0.96	0.98	0.98
	1	1	1
	0.86	0.94	0.93
	0.96	0.98	0.98
	1	1	1
	0.86	0.96	0.96
	0.96	0.99	0.99
	1	1	1

Ray Trace Modeling

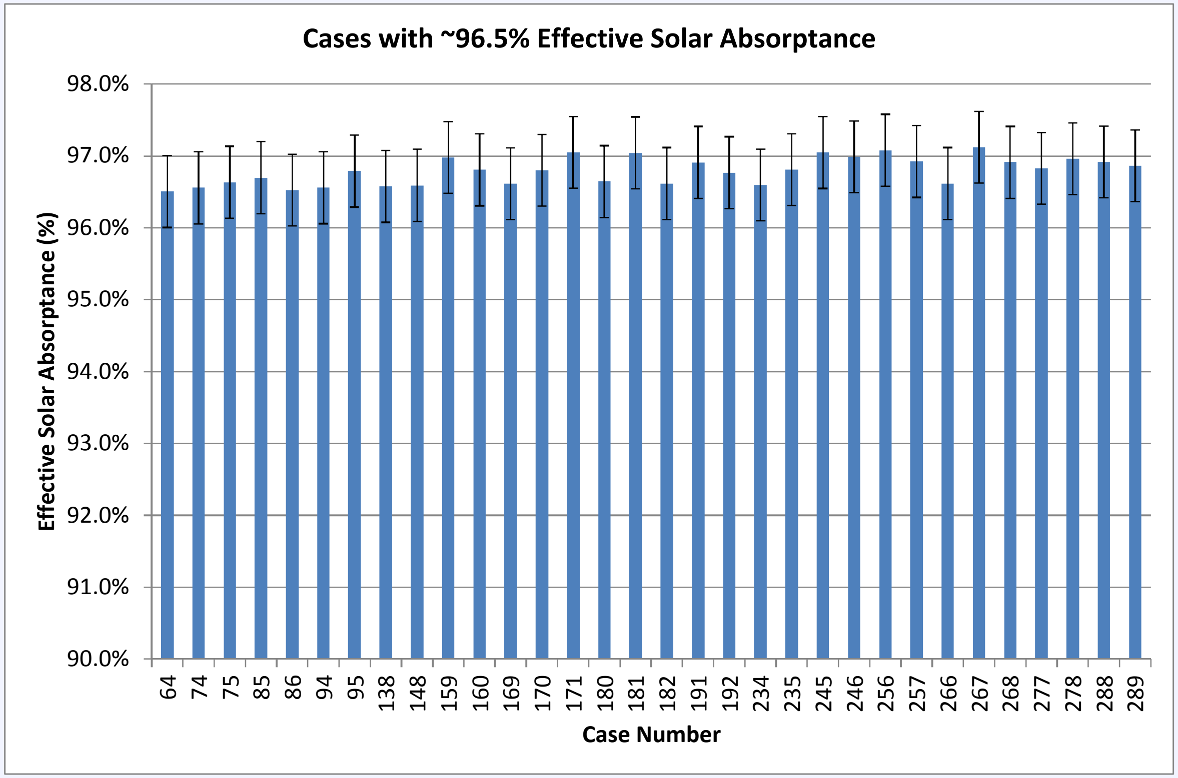


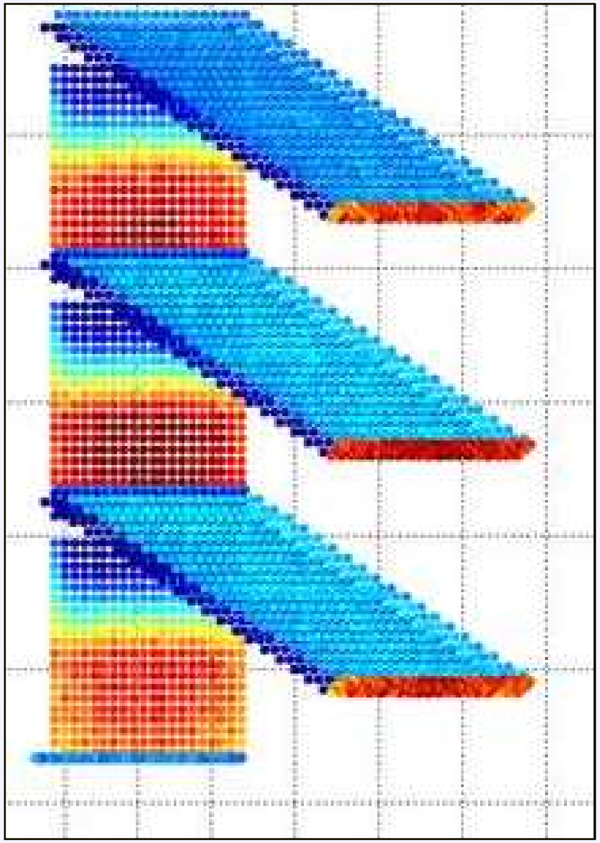
$$n_t = \frac{A}{2D^2N^2(n_h+1)} - \frac{n_h}{2}$$



Case	θ	N	n_h	n_t	Effective Solar Absorptance
64	45	3	13	18	96.5%
74	50	3	12	20	96.6%
75	50	3	13	18	96.6%
85	55	3	12	20	96.7%
86	55	3	13	18	96.5%
94	60	3	10	26	96.6%
95	60	3	11	23	96.8%
138	35	4	10	13	96.6%

Down Selection for Experiments





- Case 75 Selected for Experiments

Structural Design

- Pressures: 20 and 25 MPa
  - Initial testing pressure is ~1 MPa
- Temperatures: 700° C and 650° C (corresponding to respective pressures above)
- Outer Diameter: 12.7 mm
- Tube wall thickness: 1.651 mm
- Material: Haynes 230 or Inconel 625
  - Inconel 625 chosen based on availability

- Ortega, J., Christian, J., and Ho, C., 2015, "Structural Analysis of a Direct Heated Tubular Solar Receiver for Supercritical CO2 Brayton Cycle," ASME Energy Sustainability San Diego, California.

Experimental Setup: Structural Design

Experimental Setup: Structural Design

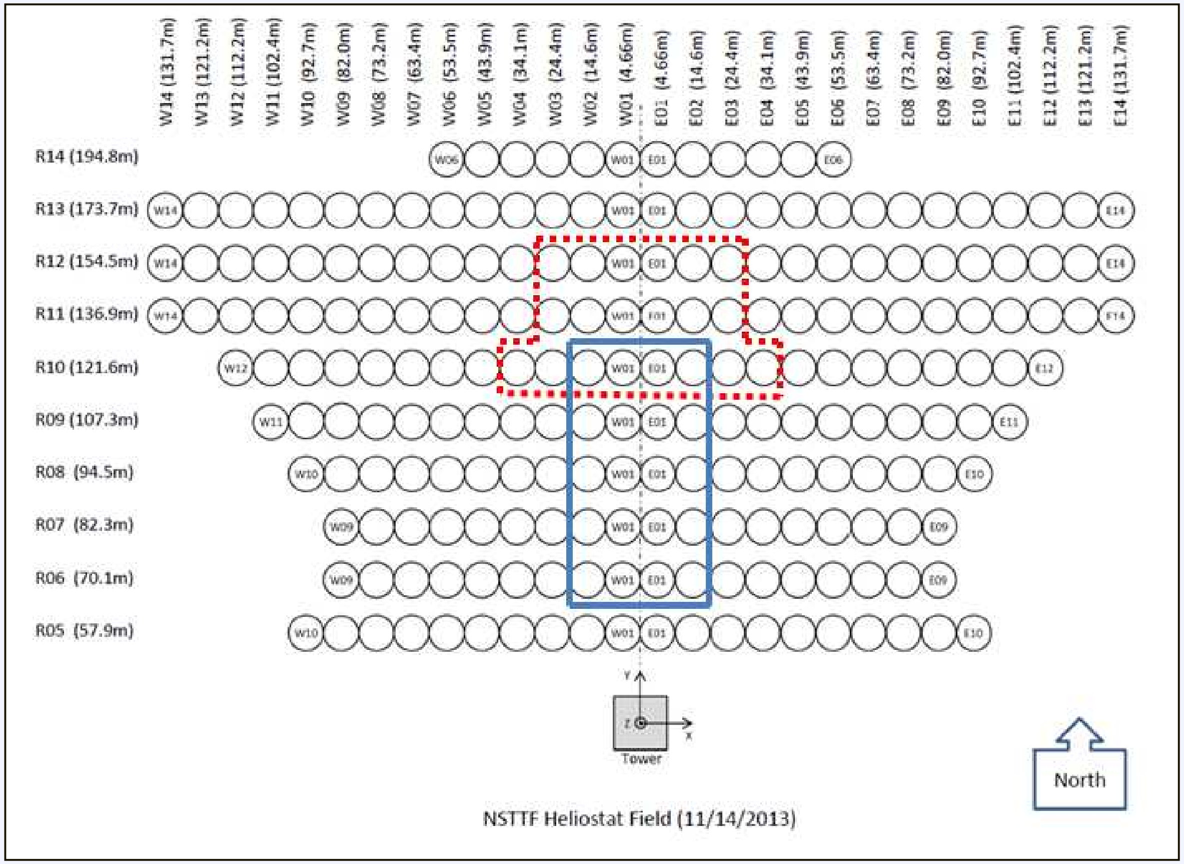
- 76.2 mm OD, Schedule 80 header
- 12.7 mm OD, 1.651 mm thick HTF tubes
- Welds specified according to ASME BPVC

Experimental Setup: Heat Transfer Fluid

- Oil-free compressed air at 125 psi
  - Expected outlet temperature from receiver is ~250˚C
  - Expected receiver wall temperatures 500-700˚C
- High temperature hose lines vent to outside of NSTTF solar tower

Experimental Setup: Solar Field

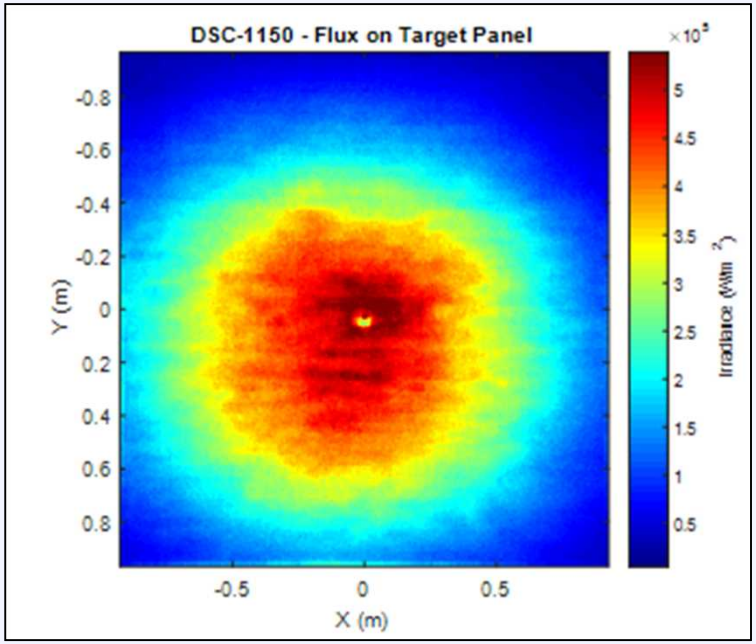
- Multiple heliostat configurations can be utilized to achieve required peak fluxes



NSTTF Heliostat Field (11/14/2013)

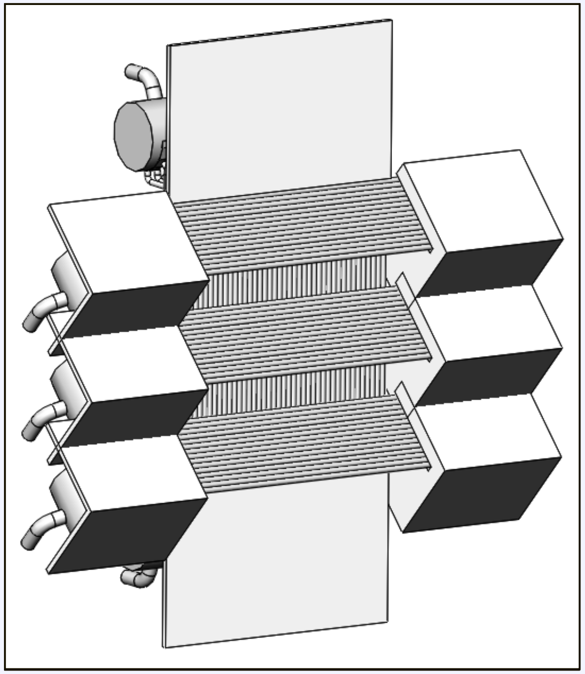
Experimental Setup: Flux Measurement Panel

- Ethylene-Glycol/Water mixture cooled rectangular tubes
- Single Kendall radiometer flux measurement
- Camera imaging to obtain flux distribution



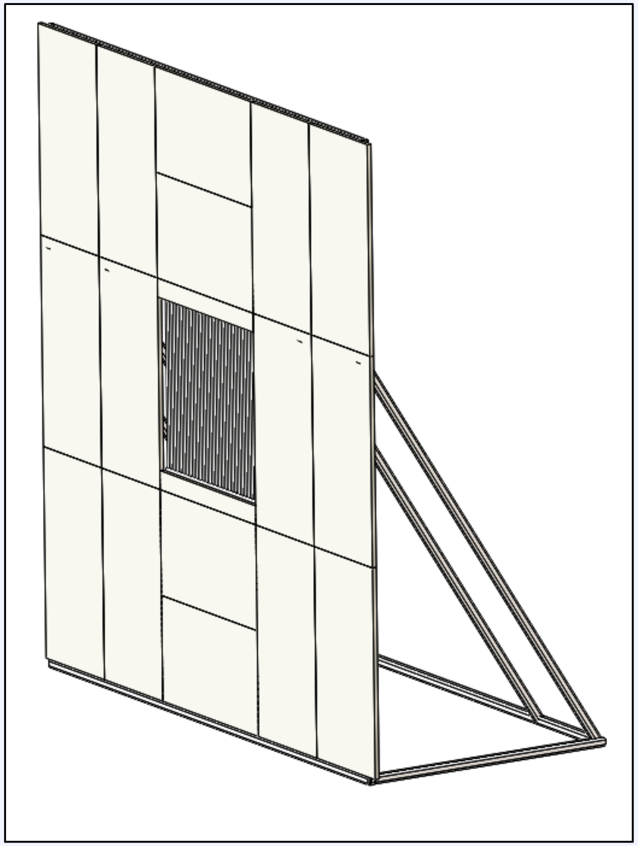
Experimental Setup: Insulation

- RSLE-57 insulation board used for peak flux regions
  - Good for regions >1000 suns
- Duraboard HD for spillage board used to protect surrounding structures from spillage
  - Good for regions <1000 suns



Experimental Setup: Accessibility

- Access to front of receiver for insulation installation
- Access for fabrication/installation of receiver



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Conclusions

- Horizontal slate fin receiver had the highest effective absorptivity and an optimized version has been selected for experimentation
- Experimental setup has been planned
  - Compressed air, 125 psi
  - Wall temperatures of 500-700˚C expected
  - HTF outlet temperature is expected to be 250˚C