Design Requirements, Challenges, and Solutions for High Temperature Falling Particle Receivers

Joshua Christian

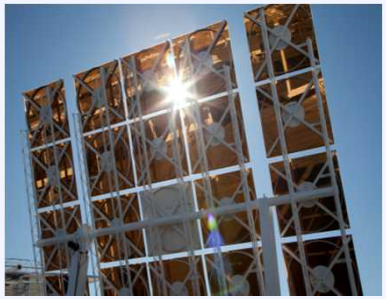
Clifford Ho

SolarPACES 2015; Cape Town, South Africa
October 13-16, 2015

SAND2015-8654C

Exceptional service in the national interest

Sandia National Laboratories

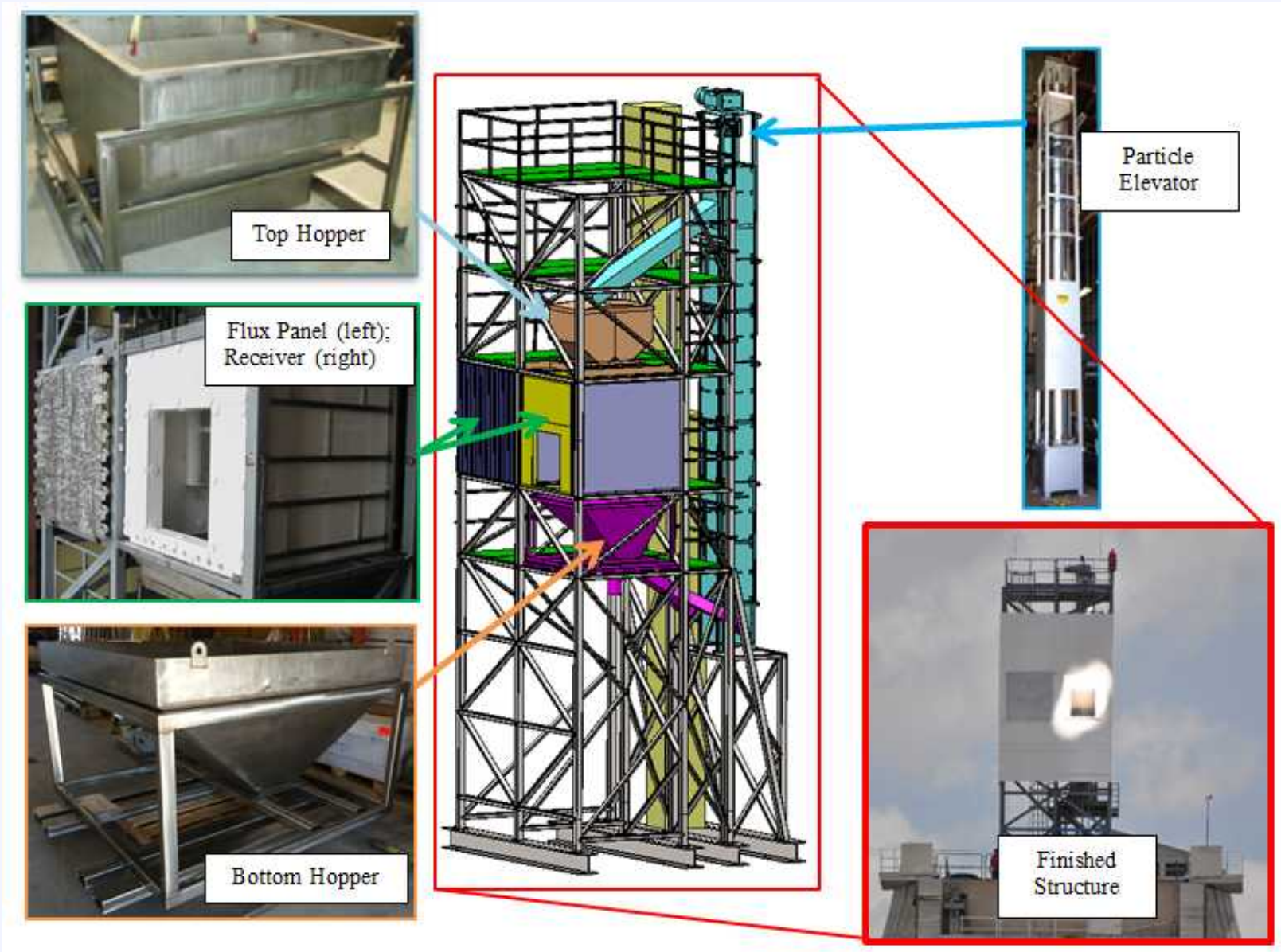


U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Introduction



Presentation Overview

- Objectives
- Approach
- Results
- Conclusion

Objectives

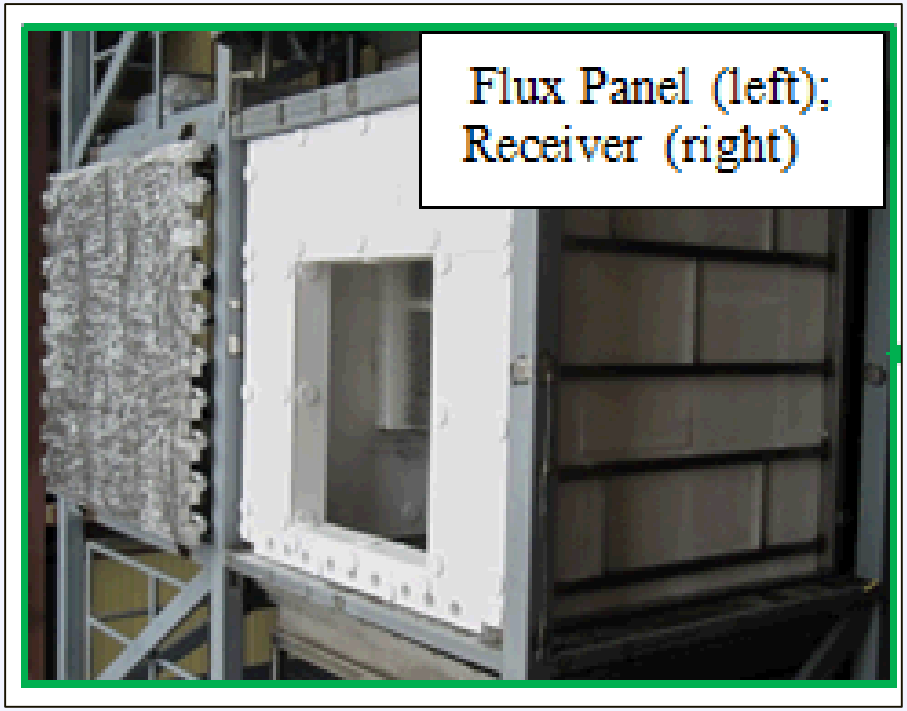
- A complete Falling Particle Receiver (FPR) was designed, fabricated, and tested at the National Solar Thermal Test Facility (NSTTF) to determine the efficiency and performance of the system
- Evaluate each component to determine:
  - What worked well?
  - What needed to be adjusted?
  - What needed to be replaced?

Presentation Overview

- Objectives
- Approach
- Results
- Conclusion

Design Requirements: Receiver

- Insulated and survive wall temperatures up to 1200° C
- Measure incident irradiance on particles
- Measure particle temperatures
- Provide stable flow conditions for particles
- Be an efficient reflector inside the cavity to increase the effective solar absorptance of particles
- Measure air temperatures
- Measure flux levels in cavity
- Provide particle curtain opacity control



Design Requirements: Hoppers

- Distribute particles for flow through cavity in a uniform curtain
- Measure mass flow rate of particles
- Retain particle heat (well insulated)
- Control the mass flow rate of the particles
- Ease of access for maintenance
- Provide an angle of repose of 30° or more for particle flow
- Filter debris from particles
- Protect stored particles from elements

Design Requirements: Support Structure

- Spillage boards to protect all components from flux spillage
- Heat particles in ducts for pre-heat purposes
- Waterproof for all components
- Flux panel to measure irradiance
- Work platforms to access components for maintenance and repair

Design Requirements: Particle Elevator

- Transport heated particles

Presentation Overview

- Objectives
- Approach
- Results
- Conclusion

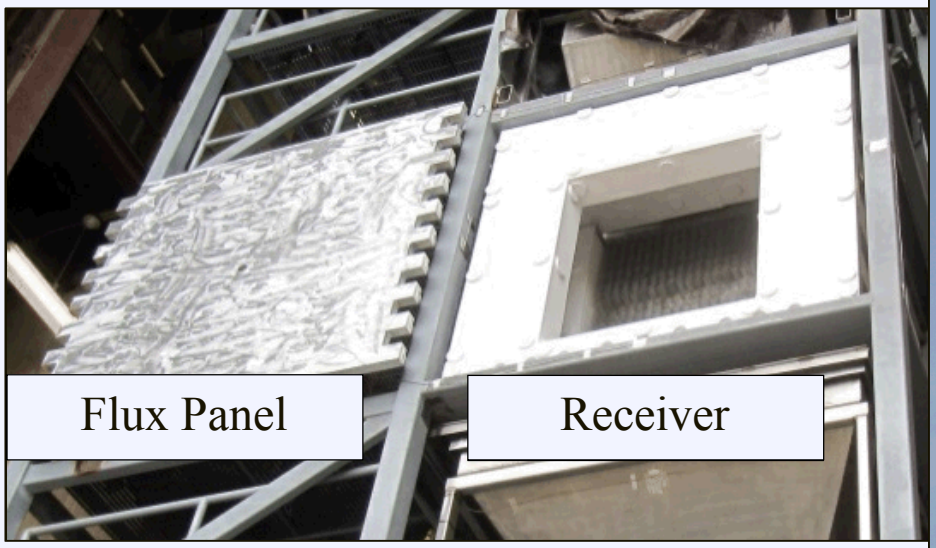
Design Requirements: Components need to be well insulated

- Receiver
  - Three layer, sandwiched insulation design
    - 25.4 mm HD board
    - 25.4 mm Microtherm micro-porous
    - 25.4 mm RSLE-57 board

- Hoppers
  - Internally insulated with 3 inches of micro-porous insulation
    - Can be difficult to work with
  - Need to protect insulation from direct particle contact/wear

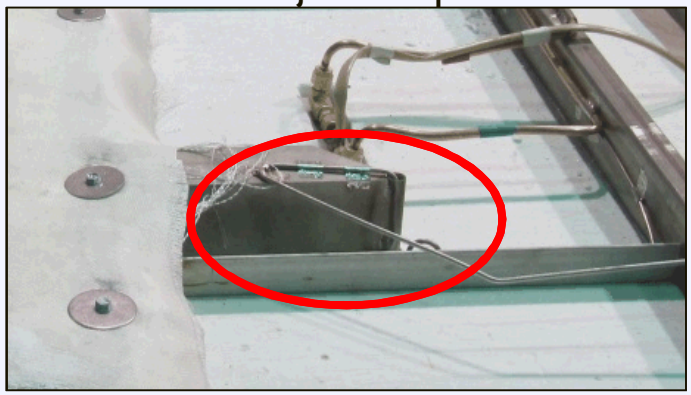
Design Requirements: Measure irradiance going into receiver aperture

- Flux Panel
  - Aluminum rectangular tubing
  - Ethylene-glycol/water cooled
  - Center Kendall radiometer
  - Known reflectivity for PHLUX flux measurement tool
  - Ray trace validation



Design Requirements: Measure temperatures

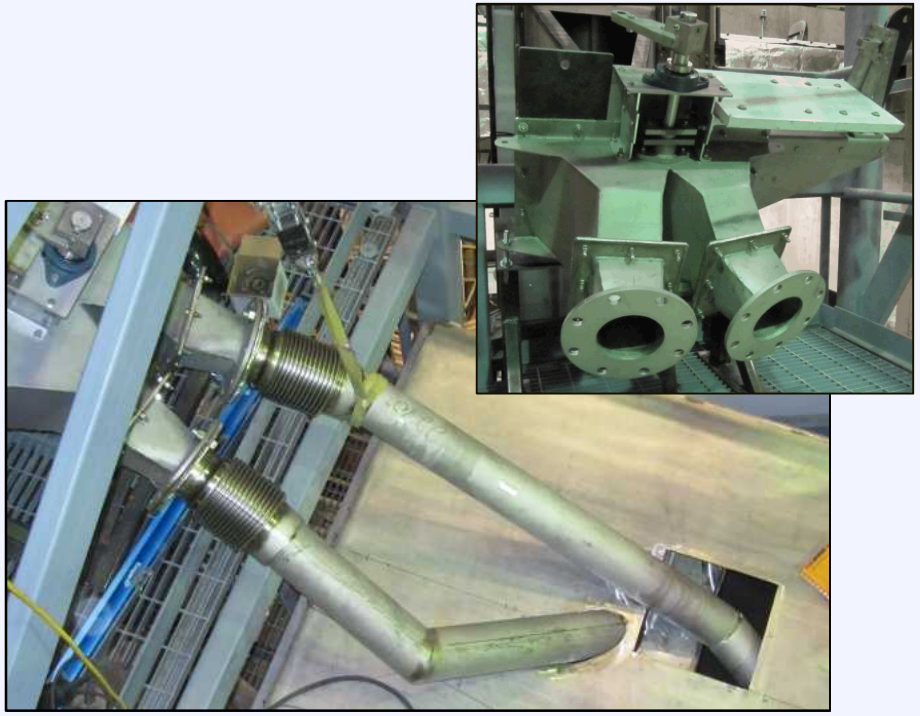
- Wall temperatures
  - Type K thermocouples (TCs) installed nearly through the receiver HD board (not exposed to direct irradiation)
  - Type K TCs installed on the outside walls of all major components
- Particle temperatures
  - Outlet funnels
  - TC directly in particle flow in ductwork between bottom hopper and elevator
- Air temperatures
  - Type K thermocouples (TCs) installed nearly through the receiver HD board (not exposed to direct irradiation)
  - Type K TCs installed on the outside walls of all major components



Design Requirements: Particle flow/distribution

- Top Hopper
  - Mass flow rate "plates" made of stainless steel with specified slot thickness
    - Controlled curtain opacity
    - Not easy to change mass flow rate of particles
  - Steel plates grow enough to disturb particle mass flow rate
  - Replace with ceramic or hard insulation board

- Diverter Valve
  - Splits particle flow from elevator to front, back, or both sections of top hopper
    - Ability to have two particle curtains in receiver cavity
  - Needs to be durable under high temperatures and particle wear

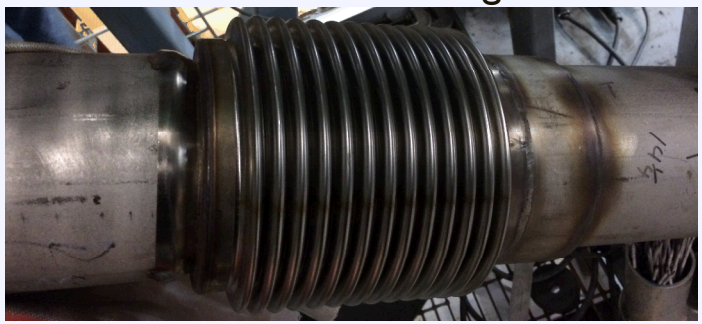


Design Requirements: Weatherproof/Debris filtering

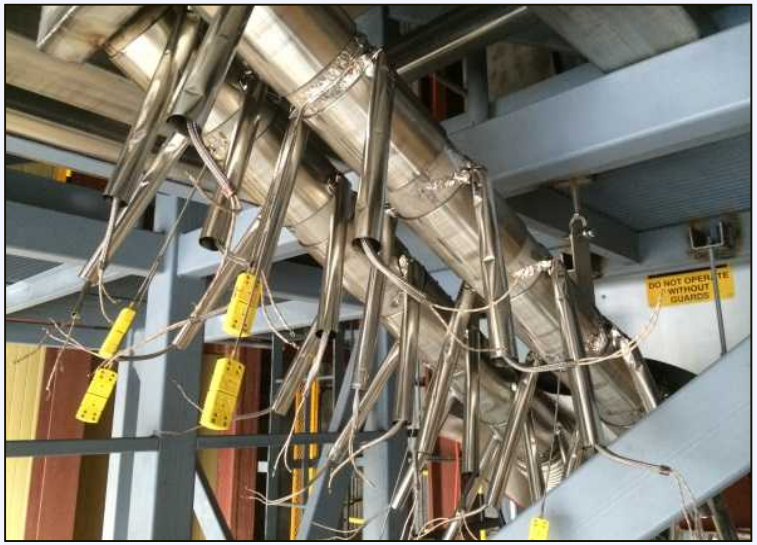
- Water-proofing/dust-proofing
  - Insulation blanket for ductwork and top of receiver insulation cannot get water-soaked
    - Aluminum lagging protects this insulation
  - One main entry point of water is through the aperture
    - Aperture "door" fabricated to be removable for testing/operation
- Debris filter in bottom hopper
  - Stainless steel mesh inserted high in the top hopper to filter any large debris from entering elevator
  - Cannot have mesh in ductwork due to flow restriction reducing mass flow rate of particles

Design Requirements: Structure for working/testing

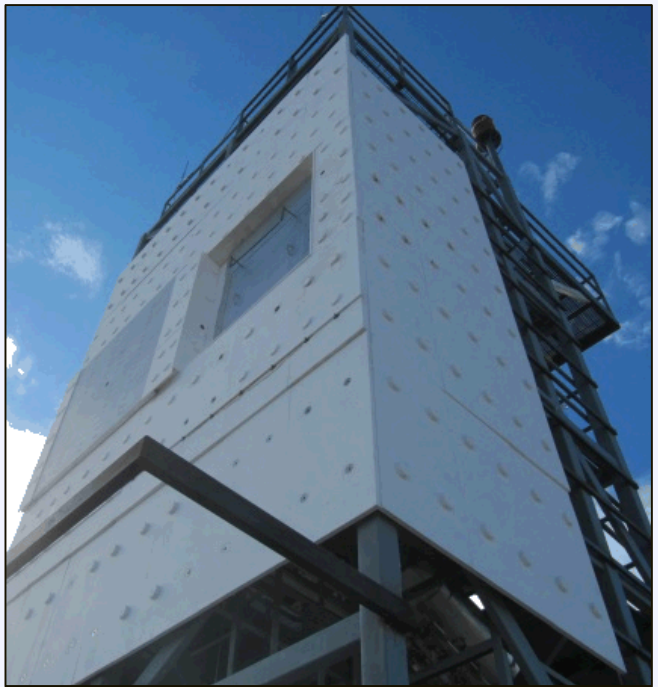
- Ductwork expansion
  - Stainless steel, in-line bellows to account for thermal growth



- Band heaters for particle heating/ductwork heating



- Spillage boards for structure protection
  - RSLE-57 for high flux (>1000 suns) regions
  - HD board (Unifrax) for low flux (<1000 suns) regions
  - Protection of stainless steel anchoring bolts/nuts from "pucks" made of RSLE-57 or HD board



Design Requirements: Particles/Particle Elevator

- Vertical lift elevator
  - Utilizes Archimedes screw principle with rotating casing and stationary screw
  - Non-abrasive lift system
  - Not efficient (<5%)

- Particle: Accucast ID50 Proppant
  - High solar absorptivity (>90%)
  - Non-sintering
  - Provide good flow dynamics
    - Stable curtain with 300 microns or greater particle diameters

Presentation Overview

- Objectives
- Approach
- Results
- Conclusion

Conclusions