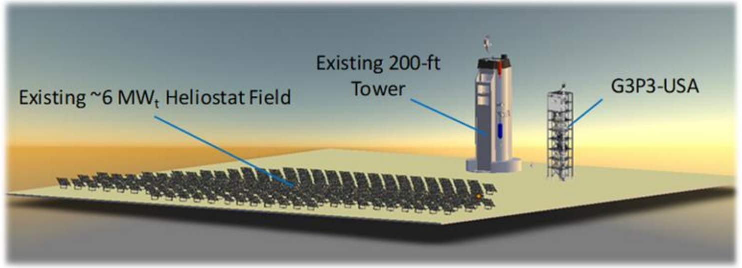
Falling Particle Receiver Development at Sandia National Laboratories



Presented by:

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Special Thanks:

Cliff Ho, Nathan Schroeder
and the rest of the G3P3 Team

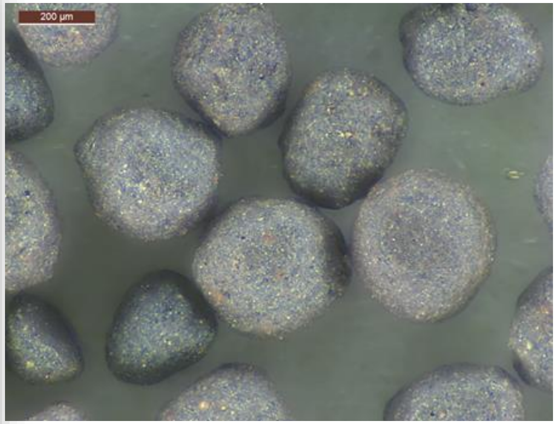
Particle-Based Concentrating Solar Power

- Particle technology is a leading candidate to couple with next-generation concentrating solar power (CSP) systems

- Advantages of particles in CSP:
  - Able to achieve high temperatures (>800°C)
  - Low parasitics (gravity driven)
  - Low cost heat transfer medium
  - Efficient storage
  - Direct irradiation (absence of flux limitations)
  - No trace heating is necessary

- Sandia National Laboratories has a long history of researching particles for CSP technologies with renewed interest over the past decade

CARBO-HSP Particles

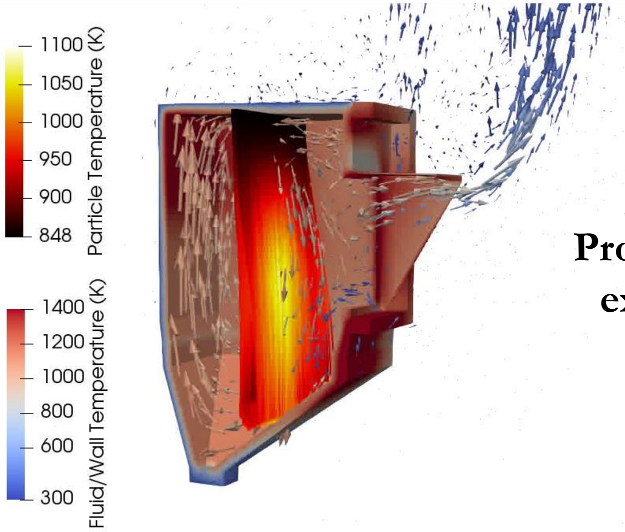


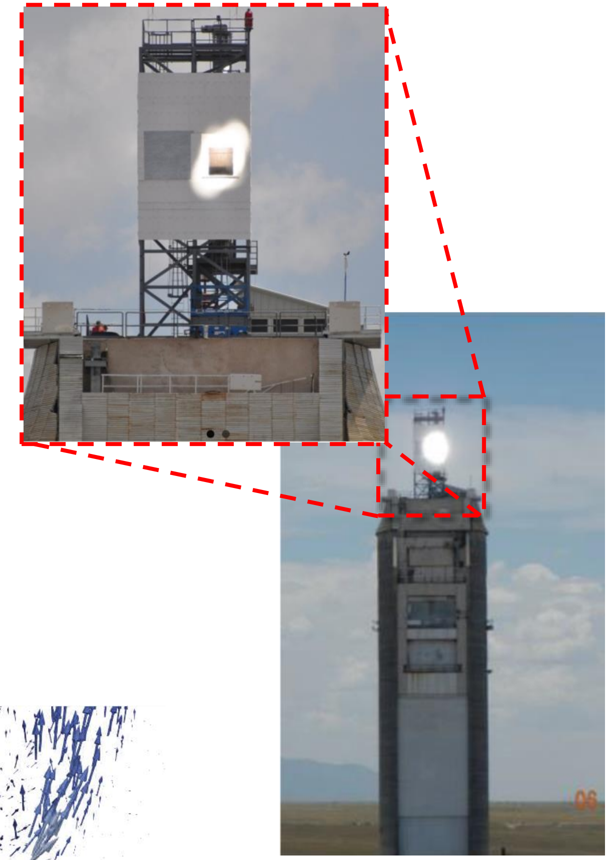
Yue, L., et al. (2019)

Particle Curtain

Falling Particle Receivers

- Falling particle receivers (FPRs) are cavities where particles are released in a curtain and fall via gravity past the beam of concentrated light
- Sandia has been experimentally testing FPRs at the NSTTF for years and measured average particle outlet temperatures > 800°C
- **Advantages** of FPRs:
  - Direct irradiance of the particles (fast response; absence of flux limitations)
  - Experimental evidence of reaching requisite temperatures
  - Low parasitics; only a single slide gate for control
  - Conceptually simple and inexpensive
- **Disadvantages** of FPRs:
  - High advective losses through aperture
  - Open aperture increase susceptibility to wind

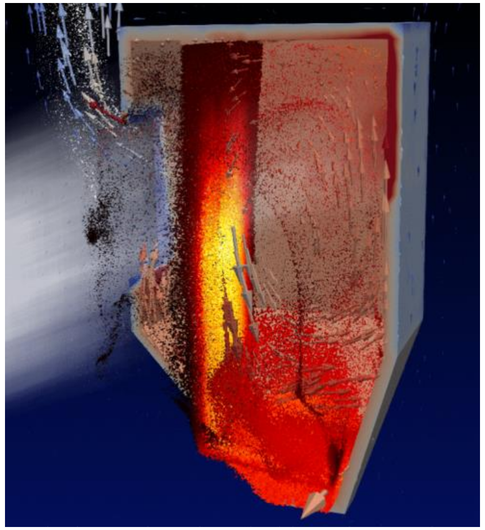




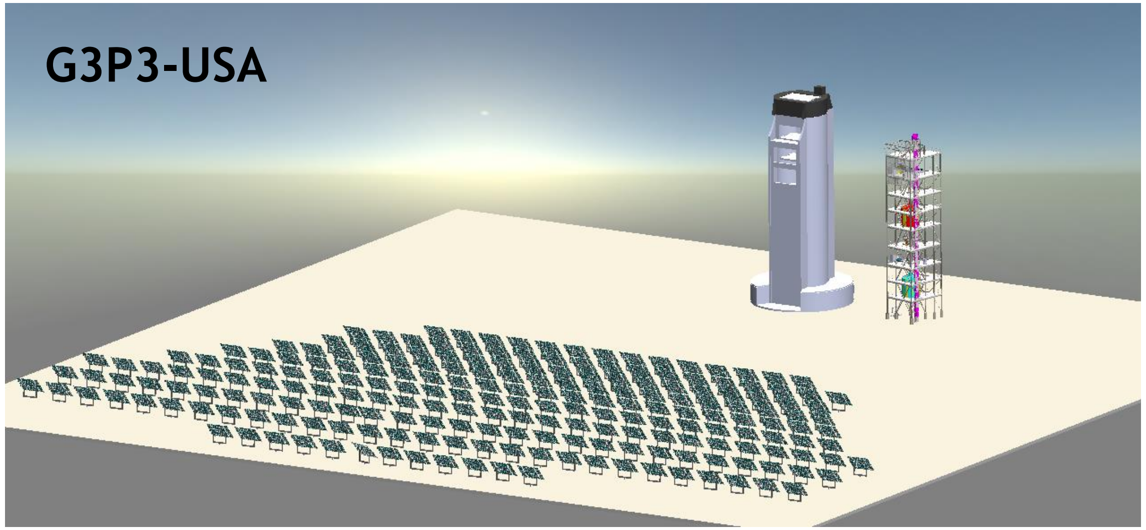
Prototype FPR at the top of the existing tower at the NSTTF

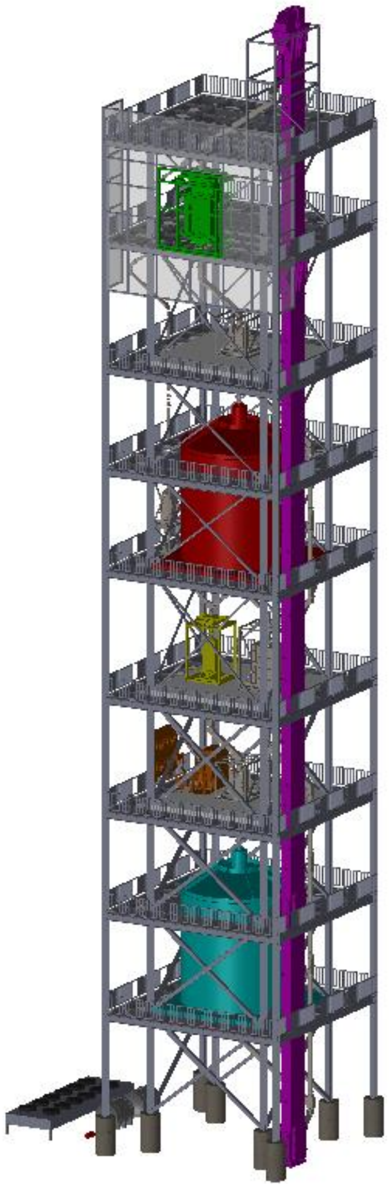
Falling Particle Receiver for the G3P3-USA

- The Generation 3 Particle Pilot Plant (G3P3-USA) is a next-generation CSP facility to be constructed at the National Solar Thermal Test Facility
  - Features a 2 MW_t falling particle receiver (FPR) with an optimized geometry, converging tunnel, and multistage features
- The FPR concept was also supported by the Technical Advisory Committee for G3P3-USA using Analytic Hierarchy Process
  - Allowed leveraging many developed FPR technologies



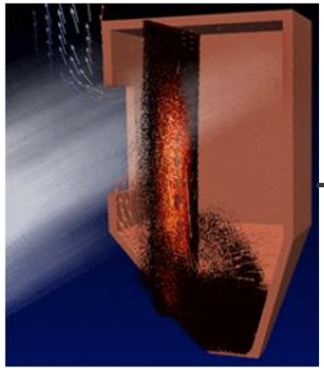
Visualization of the existing FPR at the NSTTF





G3P3-USA Receiver Design Evolution

NSTTF 1 MW_{th} FPR



Design Challenges
- Low thermal efficiency
- Sensitivity to wind

Feature evaluation

- Hood/Tunnel
- Quartz Half Shells
- Active Air Flow
- Optimized Cavity
- Multistage

RVR with SNOUT

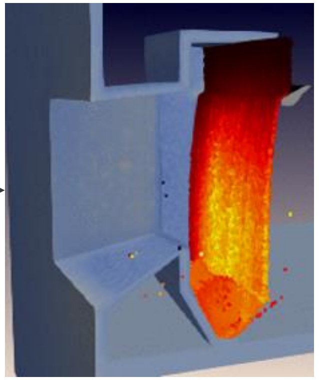
StAIR Receiver

Design refinement

- Receiver Chimney
- Optimizing Aperture
- Wind Relief Features

Design evaluation

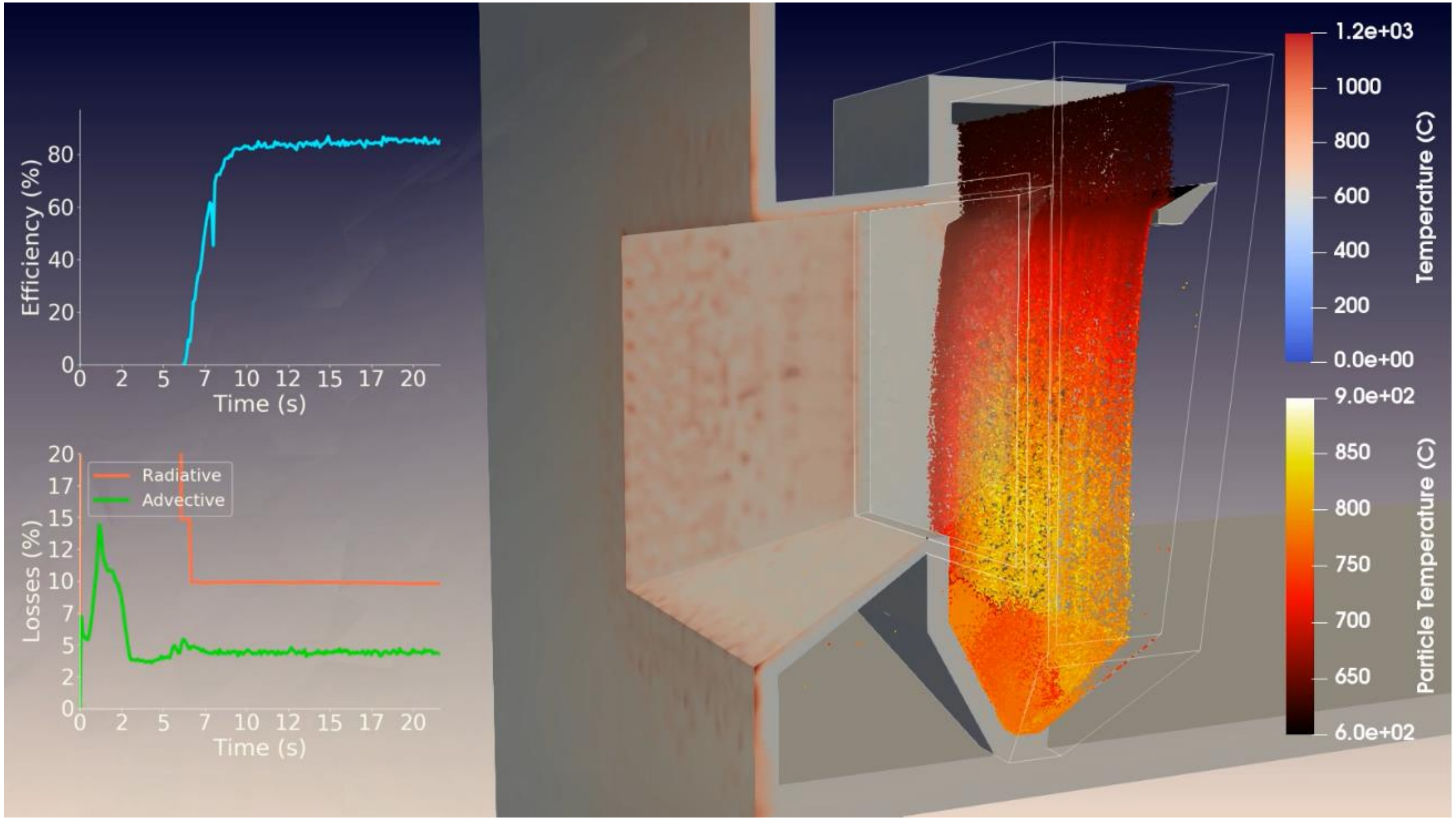
Optimized G3P3-USA FPR



Supporting Evidence
- Modeling Studies
- On-sun Testing
- Model Validation
  - Ground
  - On-sun

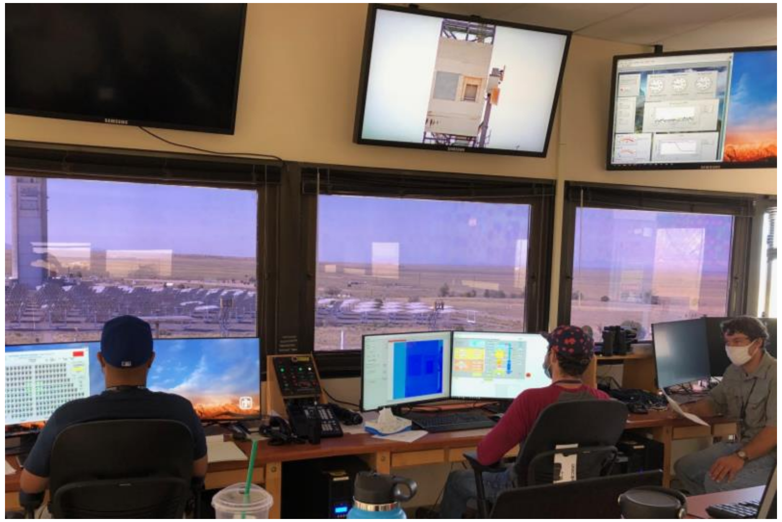
Final G3P3-USA FPR Design

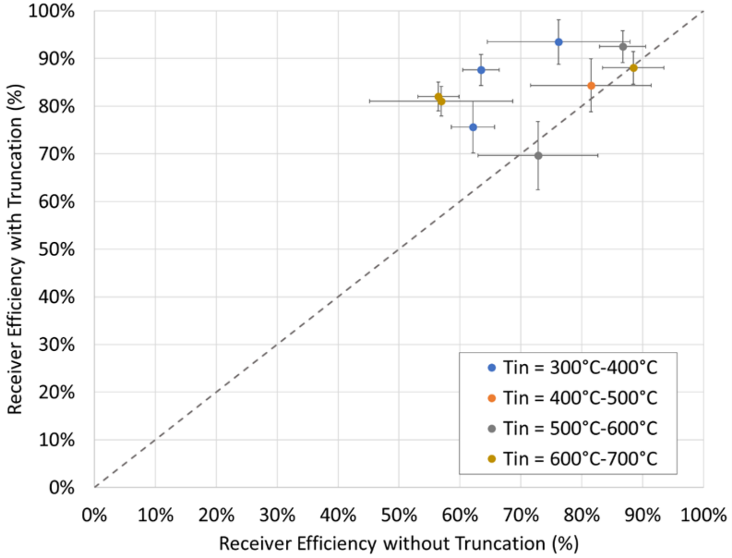
- Final G3P3-USA FPR:
  - Optimized cavity
  - SNOUT (e.g. tunnel)
  - Multistage design
- Targeted conditions:
  - $Q = 2$ MW
  - $T_i = 615°C$
  - $T_o = 775°C$
  - $\dot{m} \approx 8.75$ kg/s
- Quiescent performance:
  - **η = 85.1%**
  - Rad. Losses = 8.6%
  - Adv. Losses = 5.9%
  - Wall Losses = 0.4%



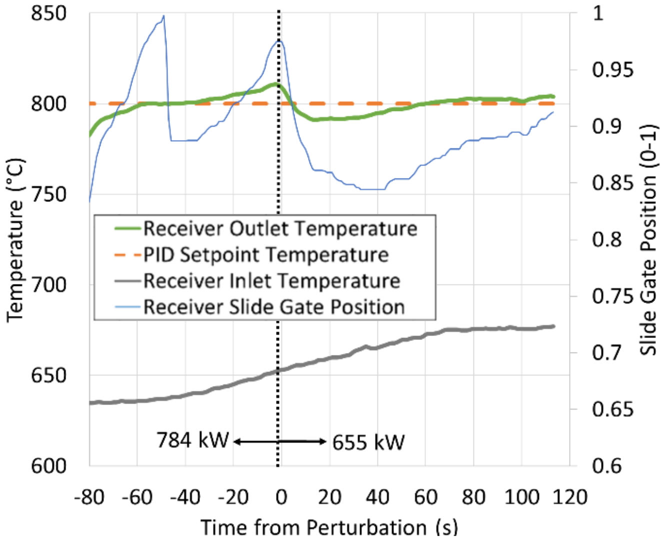
G3P3 Receiver Test Campaign

- Sandia leveraged experimental capabilities to mitigate risks in FPRs for G3P3-USA
  - Demonstrated improved **thermal performance** with new design features
  - Demonstrated **particle temperature PID controls**
  - Assessed integrated **multistage features** on-sun





Improved thermal performance with inclusion of new features



Particle outlet temperature following perturbation (PID controlled)

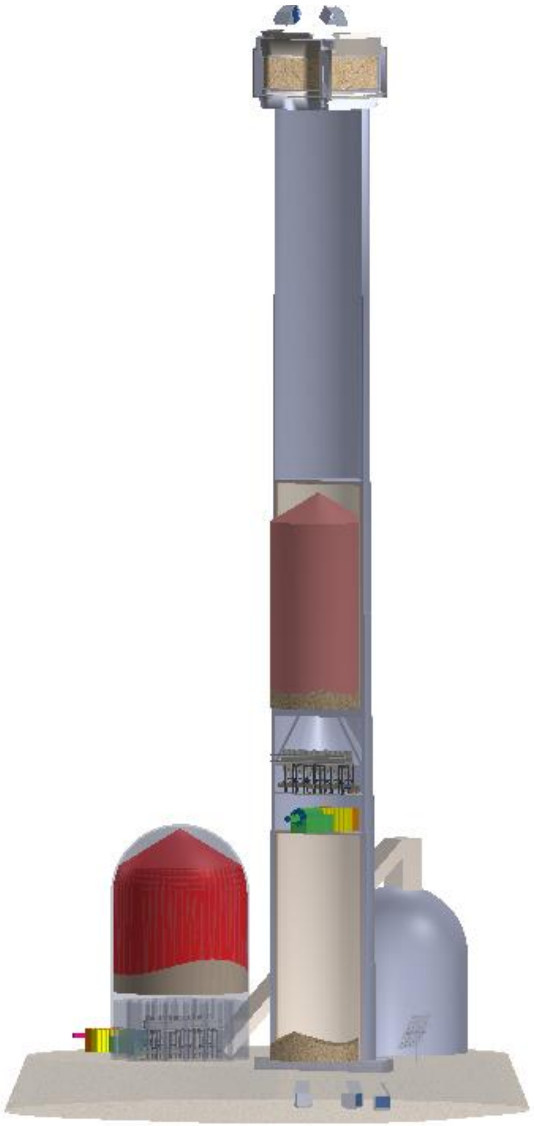
Multistage particle curtain

Path Forward for Commercial Deployment

- Risks have been defined for scaling up FPR technology to commercial systems up to 100 MWe

- **Risk:** Thermal efficiency is lower than expected and more vulnerable to wind impacts at commercial scales
- **Mitigations:**

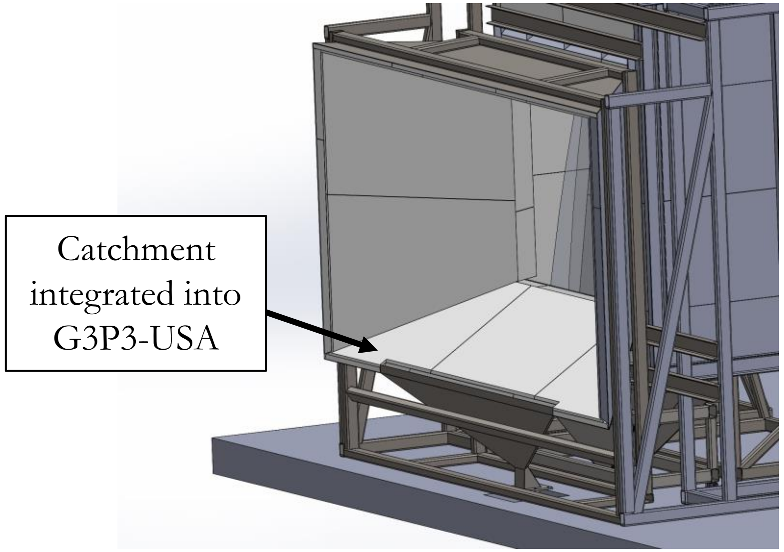
1. Features (SNOUT or multistage release) simulated and tested on G3P3 to reduce wind effects and improve particle curtain opacity
2. More accurate technoeconomic models including the effects are wind actively being developed to improve estimates for the levelized cost of electricity (LCOE)
3. Advanced CFD models of FPRs will leverage G3P3 data for model validation to improve confidence in predictions
4. Predictive models to forecast energy from anticipated weather conditions will be evaluated with G3P3 data

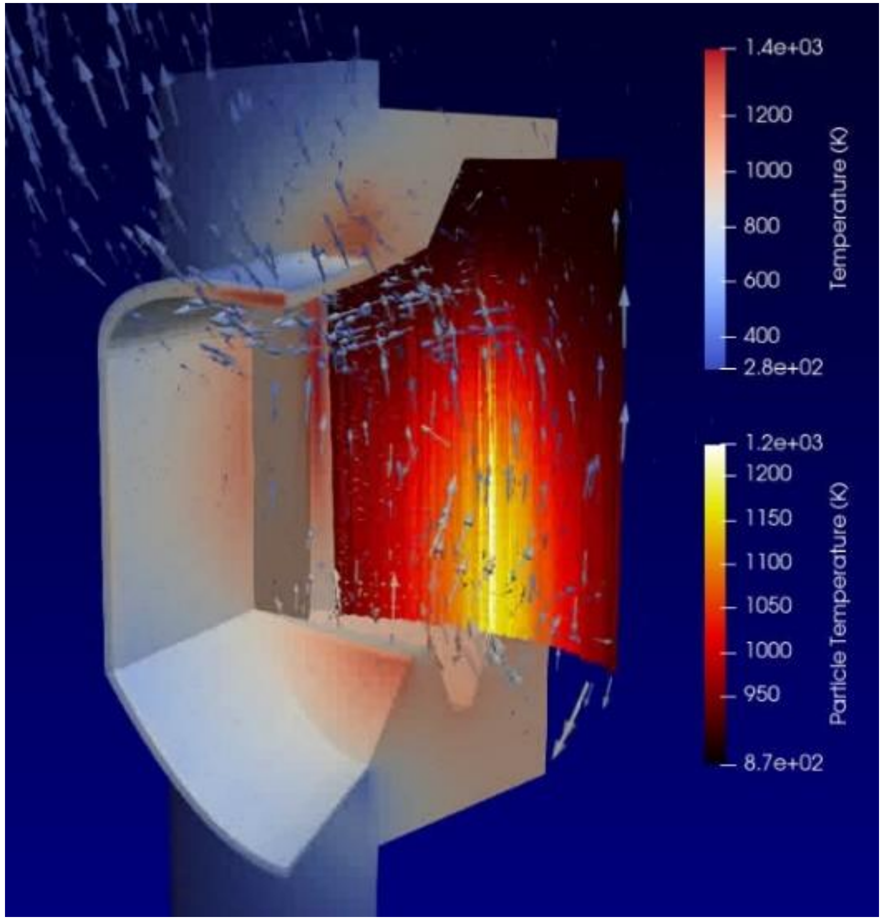


Rendering of a 100 MWe particle-based CSP plant

Path Forward to Commercial Deployment (contd.)

- **Risk:** Particle loss through aperture is high
- **Mitigations:**
  1. Studies performed do not show inhalation hazard from lost particles
  2. Particle loss is reduced with multi-stage release features
  3. Receiver features allow for re-capturing particles that escape the aperture and will be tested on G3P3

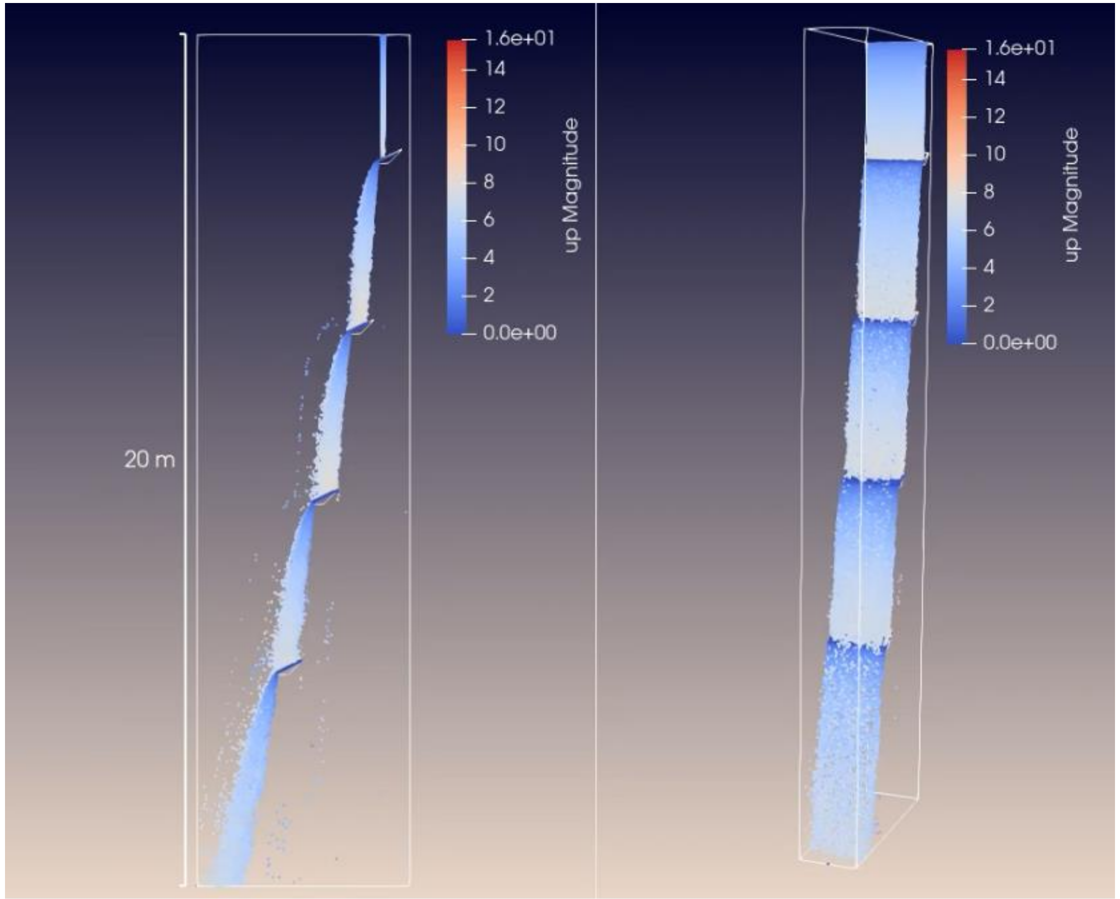




Visualization of a candidate 100 MWe falling particle receiver

Path Forward to Commercial Deployment (contd.)

- **Risk:** Multistage features do not scale for commercial systems
- **Mitigations:**
  1. Numerical studies of multistage features at commercial scales demonstrate acceptable curtain behavior
  2. Multistage features in G3P3 will be experimentally evaluated at mass flow rates approaching commercial scales
  3. Durability and survivability of multistage troughs will be evaluated for hundreds of hours of testing on-sun
  4. Alternative multistage designs can be pursued



Visualization of falling particles over a 20 m multistage drop

Summary

- Particle technology is a leading candidate to couple with next-generation concentrating solar power (CSP) systems

- G3P3-USA is a next-generation, particle based CSP facility to be constructed at Sandia National Laboratories at the National Solar Thermal Test Facility
  - Features FPR with an optimized geometry, converging tunnel, and multistage features

- Risks exist for scaling the FPR concept to commercial systems:
  - Low thermal efficiencies and vulnerability to wind, high particle attrition, scalability of design features (e.g. multistage)

- G3P3-USA will be a critical component in the mitigation of these risks