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Solar Facilities for Thermal Protection Materials Testing

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Justin A. Smith
Aerosciences Department
Sandia National Laboratories
Albuquerque, NM 87185

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Outline

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- Radiative Heating
- Solar Facilities
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  - Solar Tower
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    - Sample Results
  - Solar Furnace
    - Overview
    - Sample Results

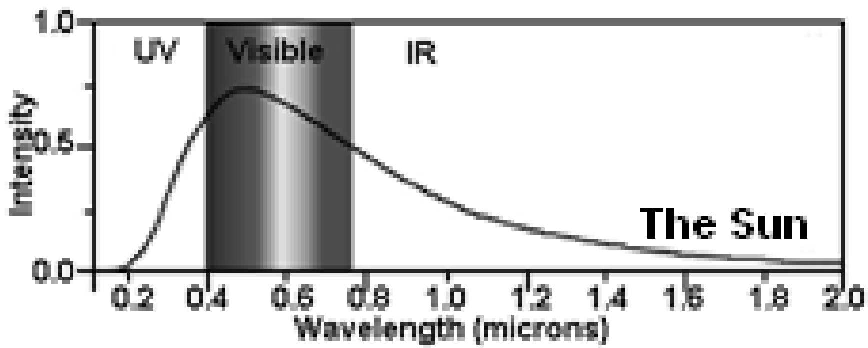
Ground Testing Facilities Comparison

- **Solar and laser thermal testing facilities attempt to simulate a primarily convective flight heating environment by a radiative heating source.**
- **This practice has some known shortfalls:**
  - Cold gas blown over the surface provides inadequate shear and will result in some degree of convective cooling.
  - Inadequate gas chemistry at surface (no atomic oxygen).
- **Comparison of Facilities:**

Facility	Heating Mode	Heat Flux	O_2 Mass Flux	Atomic Oxygen	Shear
Oven	Radiative and Free Convection	Low-Mid	Poor	Poor	Poor
Torch	Convective	Low-Mid	Poor	Poor	Poor
Solar	Radiative	Low-High	Fair	Poor	Poor
Solar with Supersonic Tunnel	Radiative with Convective Cooling	Low-High	Excellent	Poor	Fair-Good
Laser with Subsonic Tunnel	Radiative with Convective Cooling	Low-High	Good	Poor	Fair
Arcjet	Primarily Convective with some Radiative	Low-High	Good-Excellent	Fair-Excellent	Fair-Excellent

Radiative Heating

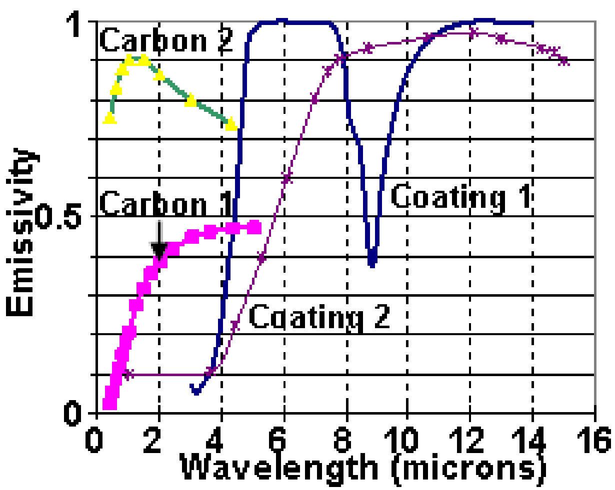
- **Considerations of material emissivity/absorptivity over a range of wavelengths are now important.**

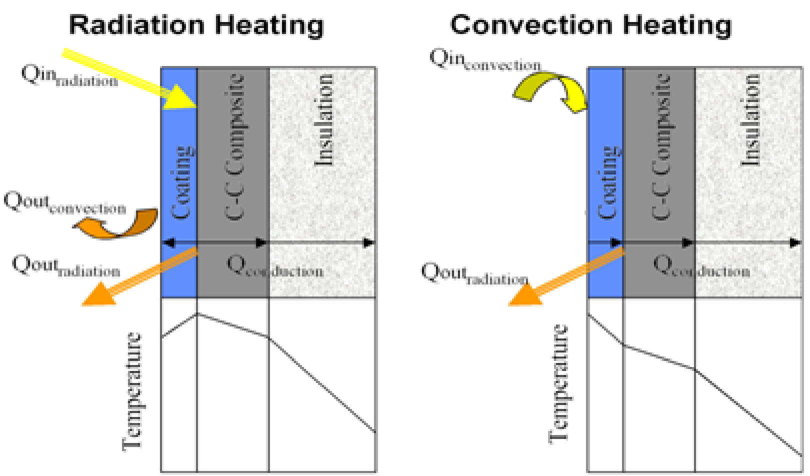


- **Emissivity/absorptivity are dependent on temperature and relative decomposition state of a material.**
- **May change greatly during testing.**
- **Affects heat absorbed and surface temperature read by pyrometers.**
  - Thus, emissivity and absorptivity should be well understood for a radiative heating test.

Radiative Heating

- **Because of different heat transfer mechanisms, materials that do well in one facility may perform poorly in another type of facility.**





- **Radiant heating facilities may be better suited for mechanistic and comparitive studies (material down-selecting) prior to arc jet and flight tests.**

Solar Facilities

- **Solar One/Solar Two (Mojave Desert)**
  - Solar Tower for electricity production - 10 MW
  - (1982-1986/1995-1999)
- **Plataforma Solar de Almeria (Spain)**
  - Solar Tower - 7 MW, Solar Furnace - 60 kW
- **Procedes Materiaux et Energie Solaire (France)**
  - Odeillo Solar Furnace - 1 MW
- **National Solar Thermal Test Facility (Albuquerque)**
  - Solar Tower - 5 MW, Solar Furnace – 16 kW
  - One-of-a-Kind in US

National Solar Thermal Test Facility

- **Operated by Sandia National Labs for the DOE**
- **Comprised of**
  - Central Receiver Test Facility (Solar Tower)
  - Solar Furnace
  - Engine Test Facility

    (Broke record for efficiency of Stirling Engine in Jan.: 31.25%)
  - Rotating Platforms

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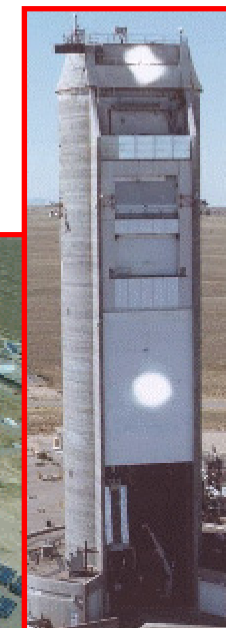
Central Receiver Test Facility (Solar Tower)

- **Heat is provided by a field of individually guided mirrors, called heliostats, which re-direct the sun's energy to a receiver mounted on top of the tower.**
- **Primary goal is to provide experimental data for design, construction, and operation of components and systems in solar thermal electrical plants.**
- **Additional Uses:**
  - Expose and measure thermal performance of components and materials.
  - Measure effects of aerodynamic heating on radar transmission.
  - Simulate nuclear thermal flash.
  - Astronomical observations.
  - Satellite calibration.

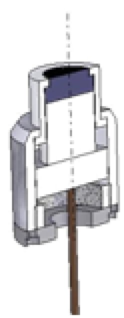


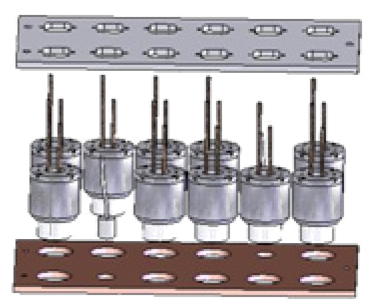
Central Receiver Test Facility (Solar Tower)

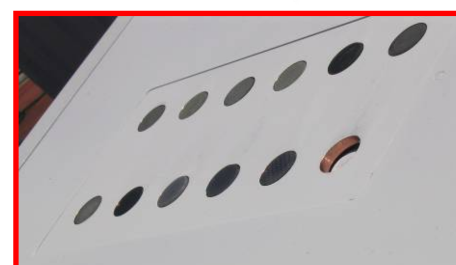
- **Characteristics**
  - Test bay is 60 m (200 ft) off ground on top of tower.
  - Additional test bay with small subsonic wind tunnel
  - Elevator can lift up to 91,000 kg (200,000 lbs)
  - 222 Heliostats covering 7 acres
  - Test time > 10 minutes, dependent on weather
- **Heat Source Properties:**
  - 5 MW total thermal power
  - Peak heat flux to 260 W/cm^2 (Temp ~ 2200 °C)
  - Time-varying flux to simulate flight heating profiles
  - Illuminates targets up to 2,800 m^2
  - Typical spot size of 2.8 m^2
  - 15 cm diameter spot size at max flux

Central Receiver Test Facility (Solar Tower)

- **Samples are tested on a water-cooled copper stand at the top of the tower:**
  - Fixture allows 12 simultaneous material samples/flux gages (1 in. dia) to be tested.
  - Air is blown across surface at 18 m/s to remove smoke/ablation products.
  - Samples are fitted in a zirconia sleeve, backed with zirconia insulation and aluminum.
  - Type K thermocouples mounted to sample and insulation backfaces.

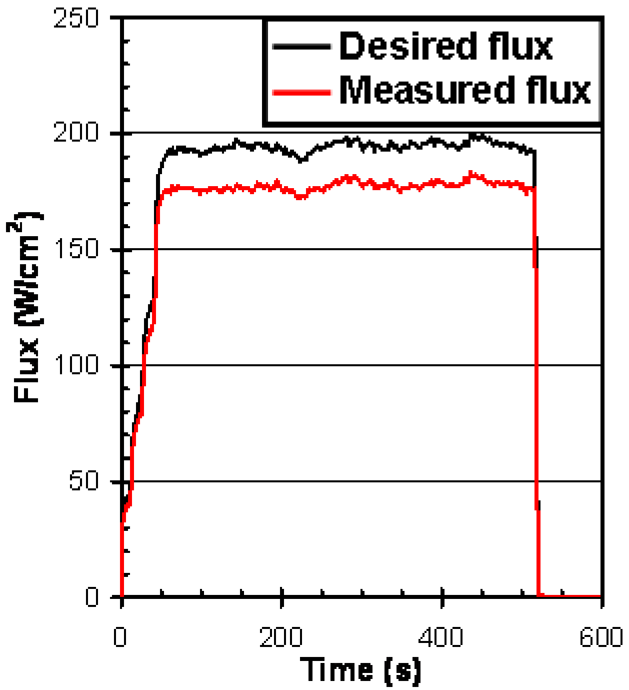


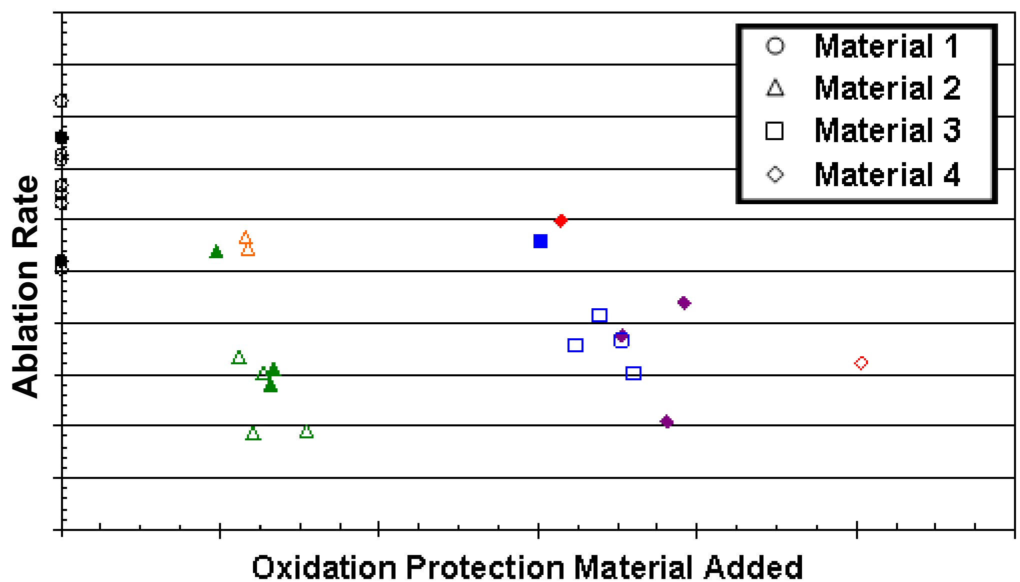




Central Receiver Test Facility (Solar Tower)

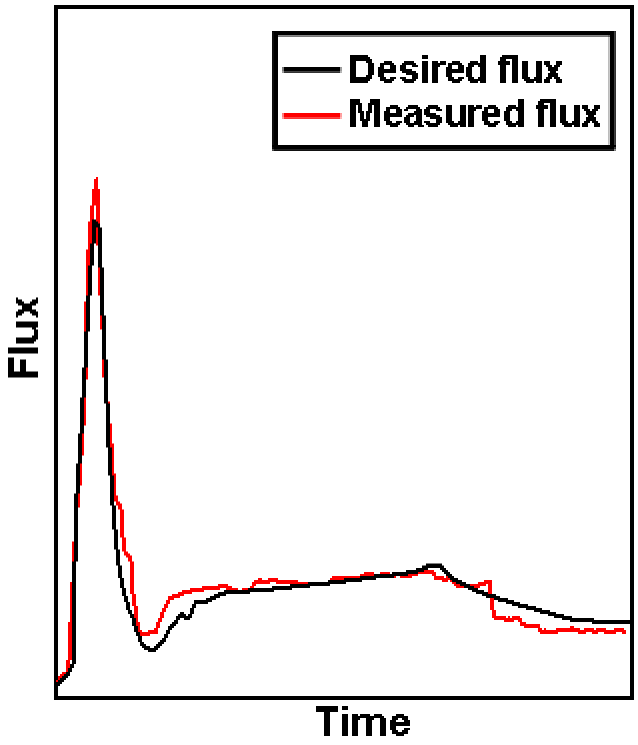
- **Materials are tested at a constant heat flux for simple, mechanistic studies.**
  - May look at things such as ablation rate, material loss, protection failure, etc. for material comparisons.





Central Receiver Test Facility (Solar Tower)

- **Tests at time-varying fluxes can closely simulate acreage flight heating profiles.**
  - Gives an idea of whether a material is expected to survive a specific flight-like heating profile.
  - Provides information on material response to heat flux gradients.
  - Provides integrated ablation information (through post-test measurement) for flight-like heating profiles.
  - Provides detailed in-depth temperature information for comparison to simulation.



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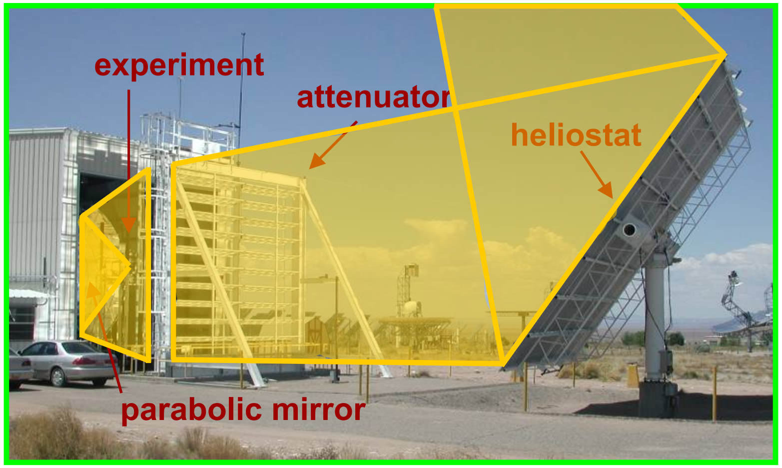
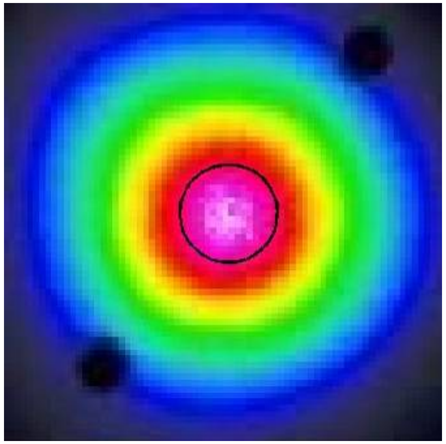
Solar Furnace

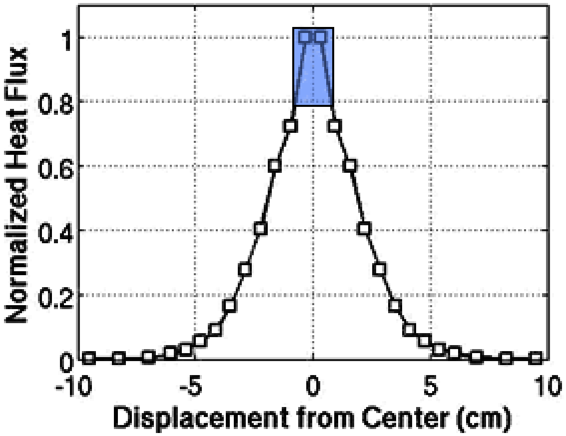
- **Heat is provided by a single large heliostat (95 m^2), which reflects sunlight through an attenuator onto a parabolic mirror that then focuses it onto the sample.**
- **Applications include:**
  - Investigating thermophysical properties of materials, including thermal expansion, thermal conductivity, specific heat, etc.
  - Simulating thermal effects of nuclear explosions on materials and components.
  - Determining the performance and failure thresholds of high-temperature ceramic and refractory materials.



Solar Furnace

- **Characteristics**
  - Test time >10 min., dependent on weather
  - Insolence meter automatically adjusts attenuator during test.
  - 3-axis gantry traverses sample.
  - 2 pyrometers, IR video, monitor surface temperature.
- **Heat Source Properties**
  - Flux calibrated pre- and post-test.
  - Variable heat flux to 800 W/cm^2
  - Theoretical Surface Temps > 3000°C (Current pyrometers measure up to 2500 °C)
  - Illuminates targets up to ~80 cm^2
  - Typical sample size 1.6 cm dia. (8 cm^2)





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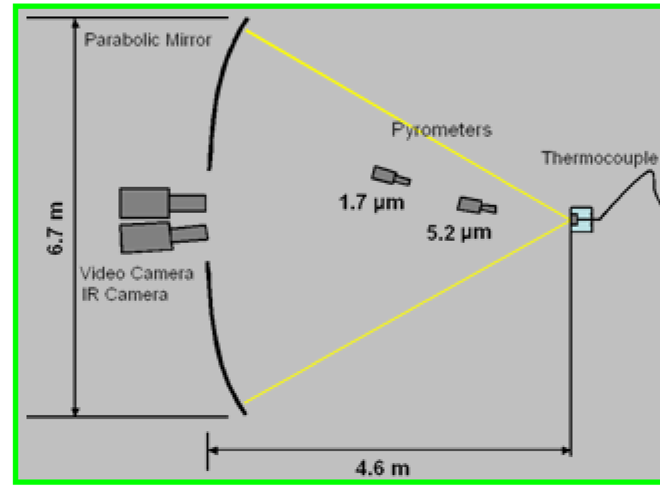
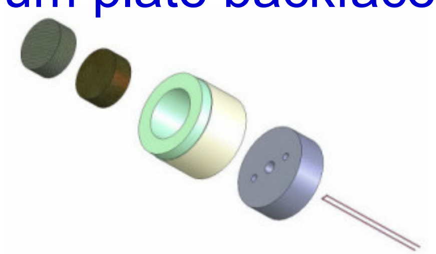
Solar Furnace

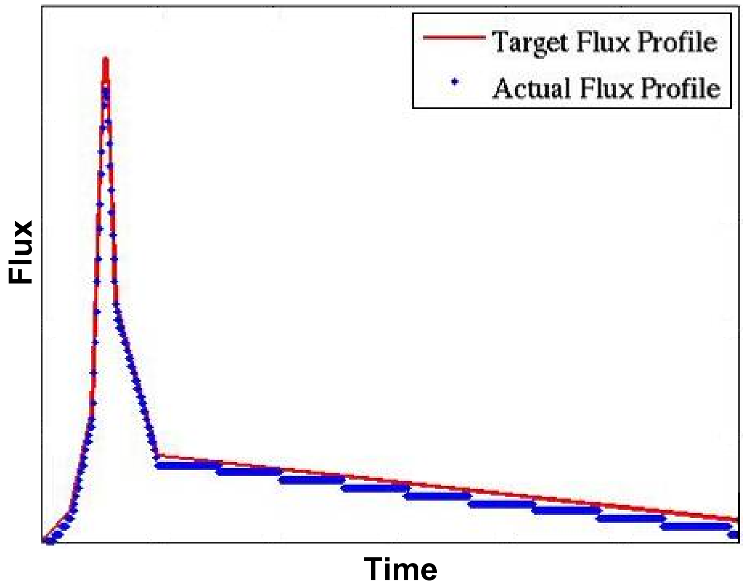
- **Samples are tested on a 3-axis traversing gantry:**
  - Up to 12 samples are mounted onto the test fixture (usually tested one at a time).
  - Air or nitrogen is blown across surface to remove ablation products. Possibility for small supersonic wind tunnel.
  - Samples are fitted over cylindrical plugs, of zirconia and aluminum and wrapped in a stiffened zirconia felt.
  - Type B thermocouples mounted to the aluminum plate backface.





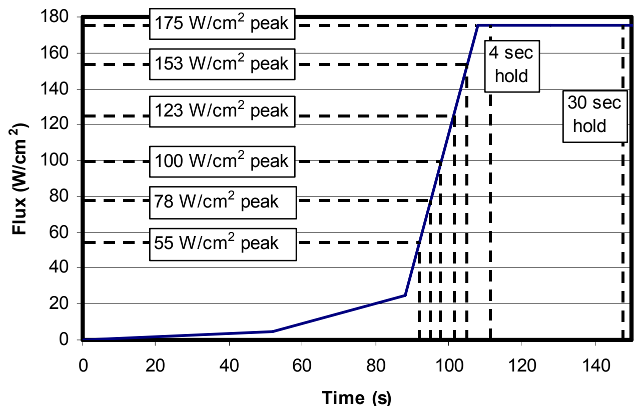
Solar Furnace

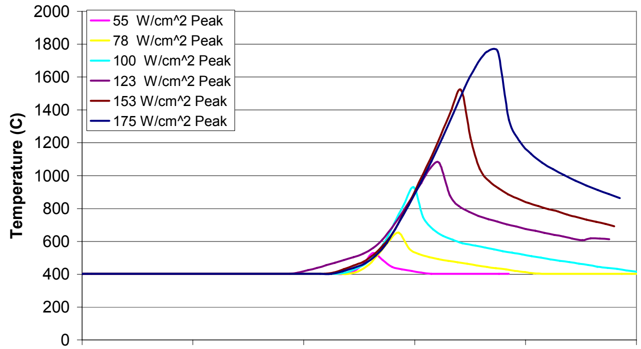
- **Attenuator Properties:**
  - 100 discrete positions.
  - From closed to fully opened in 2 seconds (max ramp rate ~400 $W/cm^2/s$)
  - Heat flux profiles more closely simulate flight.
  - Insolence meter close to facility adjusts for incoming solar energy changes in real-time.



Solar Furnace

- **Application**
  - Material evolution along simulated pullout heating profile.

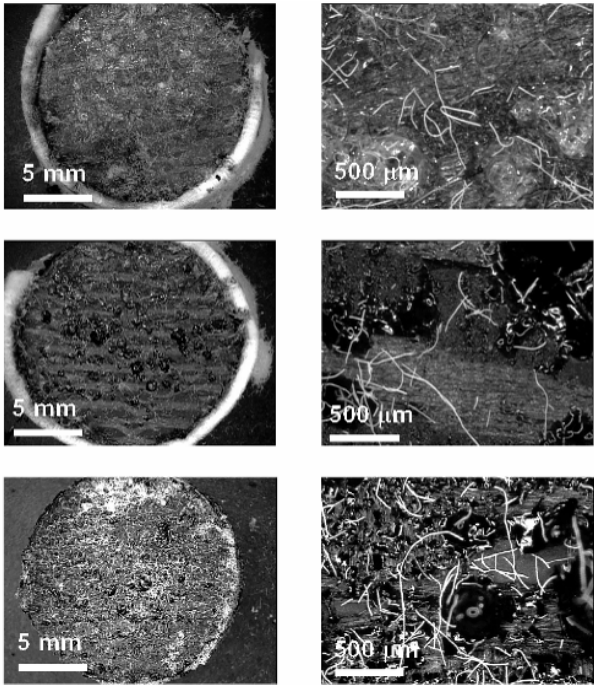




55 W/cm²

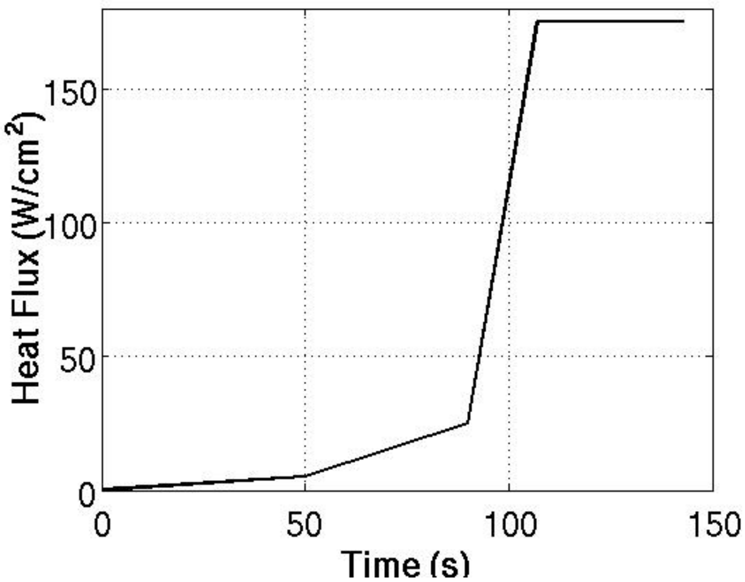
78 W/cm²

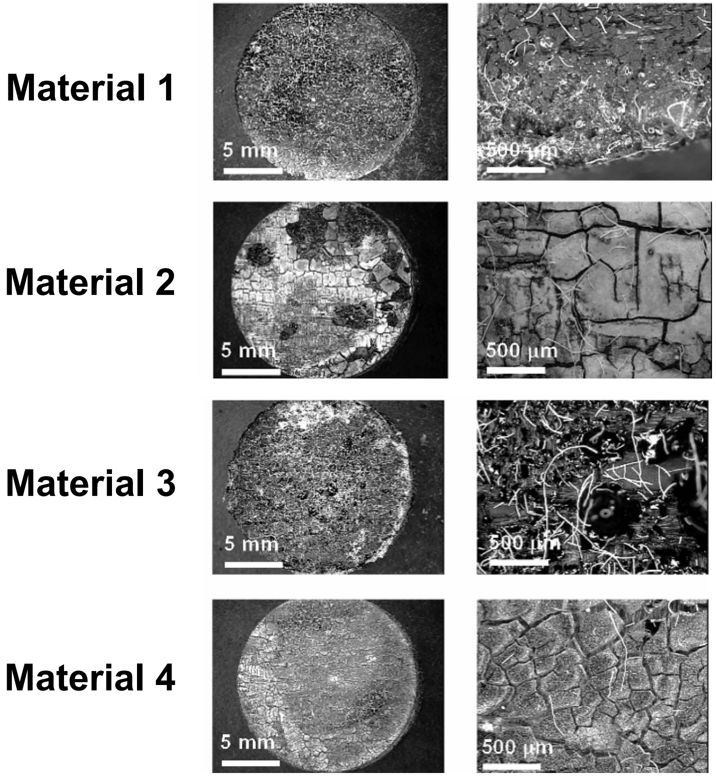
175 W/cm²



Solar Furnace

- **Application**
  - Material comparison under same heating profile.





Conclusions

- Radiative facilities can be a viable means of providing heat flux for material response and ablation studies.
- Because the heat transfer mechanisms in radiative and convective facilities are different, materials may perform differently in each type of facility and results must be taken in context.
- Sandia operates a 5 MW solar tower and 16 kW solar furnace, which can be used for material and ablation testing at realistic flight heating profiles.

Acknowledgements

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Contact Information

- **Website:** http://www.sandia.gov/Renewable_Energy/solarthermal/nsttf.html

- **Solar Tower:**
  - Cheryl Ghanbari, Test Engineer
    Sandia National Laboratories, Mail Stop 1127
    Albuquerque, NM 87185
    Phone: 505-845-3426
    E-Mail: cghanba@sandia.gov

- **Solar Furnace:**
  - Tim Moss
    Sandia National Laboratories, Mail Stop 1127
    Albuquerque, NM 87185
    Phone: 505-844-7356
    E-Mail: tamoss@sandia.gov