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# Sandia Perspective on Ablative Material Testing

## AFOSR/NASA/SNL Ablator Modeling Workshop

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# Outline

- Background
  - Sandia Flight Testing Experience
  - Emerging Needs/Technology Gaps
- TPS Material Development
  - Simulations
  - Experiments
- Conclusions

# Sandia's Historical Roots in Hypersonic Reentry Systems

**U.S. RV Performance**
- Ballistic vehicle dynamic behavior
- Component environments and performance

**Materials Development**
- Heatshields
- All carbon-carbon vehicles
- Antenna windows
- Nosetips
- Oxidation-resistant carbon-based materials

**Flight Testing**
- Pioneered the soft recovery of hypersonic vehicles for post-flight inspection
- Most vehicles, One-of-a-kind, unique R & D tests
- High risk, excellent track record (>96% of flight test objectives satisfied)

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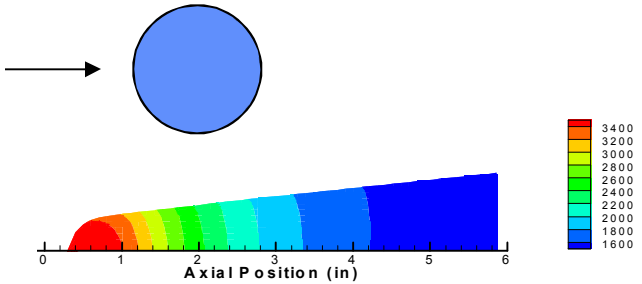
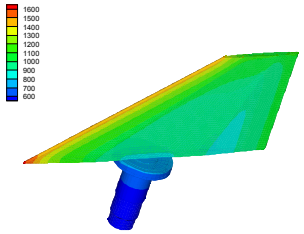
# Emerging Needs

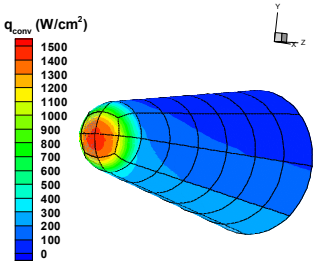
- **Boost-Glide Vehicles Cruise for long periods of time in the atmosphere.**
- **Conventional materials are not suitable to withstand the high heat pulse at pullout and long-duration heat soak.**
  - **Need new materials.**
- **Transition correlations based on ballistic flight data may not be adequate.**
  - **Methods which include more of the relevant physics, like stability theory, may be required to accurately predict transition.**

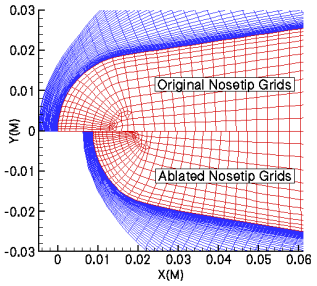
# TPS Material Development

- **New materials are developed and analyzed using a variety of methods:**
  - **Simulation**
    - **Heavily used for comparative and scoping studies.**
    - **Requires experimentally determined physical and chemical material properties.**
    - **SNL has a variety of aerothermal tools ranging in fidelity from engineering tools for simple shapes and one-dimensional ablation codes through coupled flowfield/material response codes for general geometries.**



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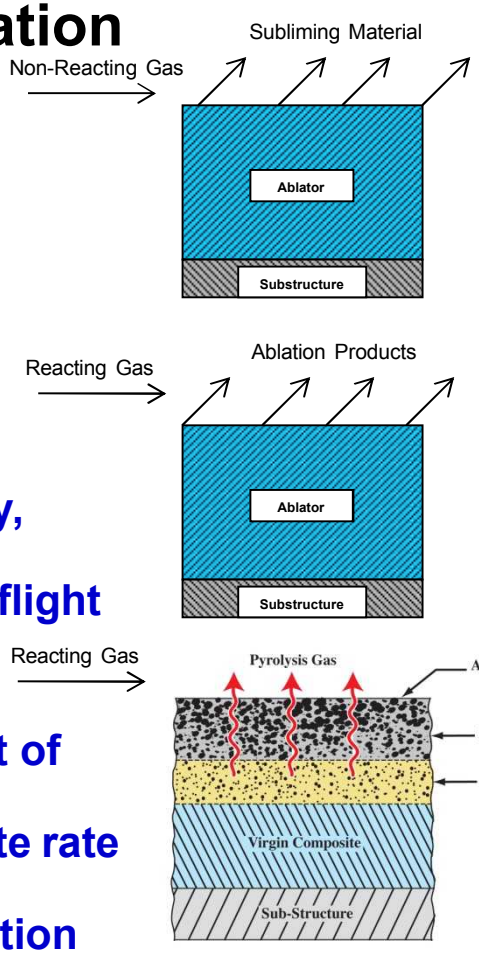
# TPS Material Development

- Some of the properties needed for simulation
  - Geometry/Material Layup
  - Flowfield Properties
    - Mach number
    - Reynolds number
    - Air Chemistry
  - Material Properties
    - Physical Properties
      - Density, Specific Heat, Thermal Conductivity, Emissivity
      - Needed over range of temperatures seen in flight (sometimes as high as 3000-4000 K)
    - Ablation Chemistry
      - Q* ablation models: no chemistry, need heat of ablation and melt/fail temperature
      - Non-decomposing ablators: equilibrium/finite rate surface chemistry model
      - Decomposing ablators: In-depth decomposition chemistry model (e.g. Arrhenius constants) and equilibrium/finite rate surface chemistry model



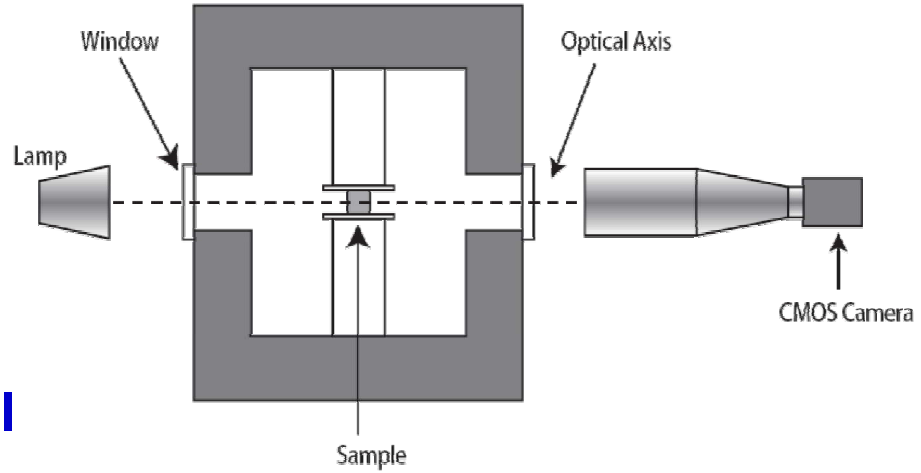
# TPS Material Development

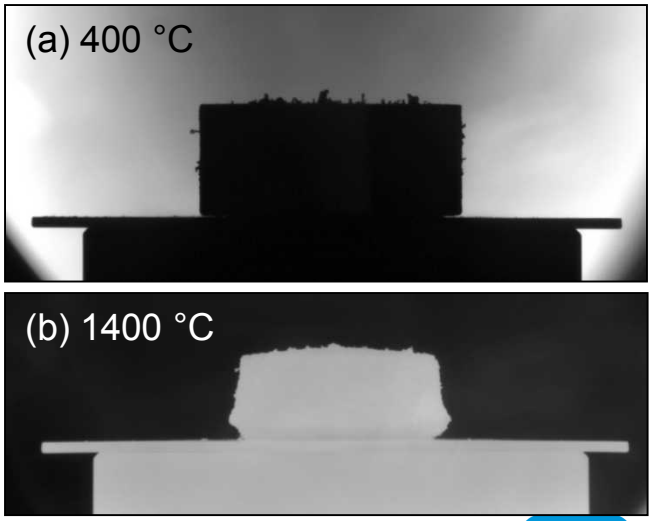
## – Experiment

- No ground experiment can match all of the relevant flight conditions of hypersonic reentry.
- Ablation tests are performed in a graded approach:
  - Ovens and torches provide high temperature for material screening and coatings research.
  - Hypersonic wind tunnels (HWT's) provide realistic flight M and Re but low enthalpy. Low temperature ablators (LTA's) are used for coupled heating/shape change studies.
  - Radiative facilities provide high heat flux and variable conditions to mimic flight heating profiles.
  - Arc jets provide high enthalpy, reasonable chemistry and shear to test real TPS materials.
  - Sled Tracks are high-velocity at sea-level facilities which may be useful for real gas chemistry effects.

# Materials Screening Capabilities

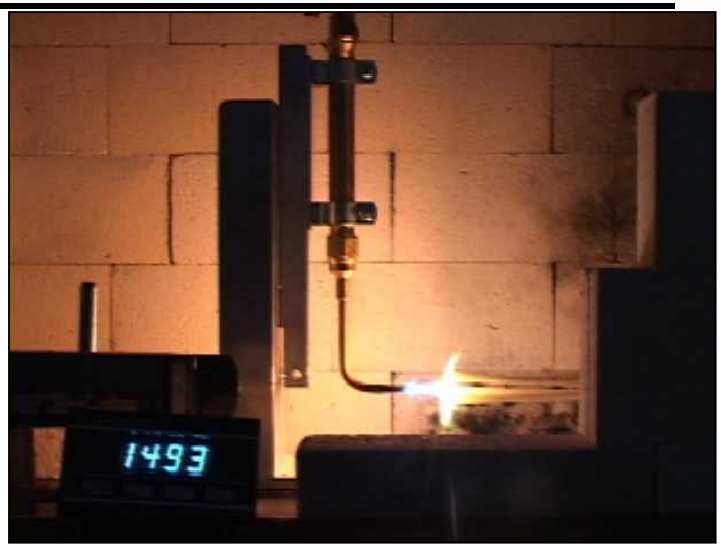
- **TOMMI (Thermal Optical Mechanical Measuring Instrument)**
  - **Combination of a high temperature oven and optical dilatometer.**
  - **Temperatures to 1700°C.**
  - **Useful for determining coating mechanism/failure.**
  - **May be used for TGA measurements.**

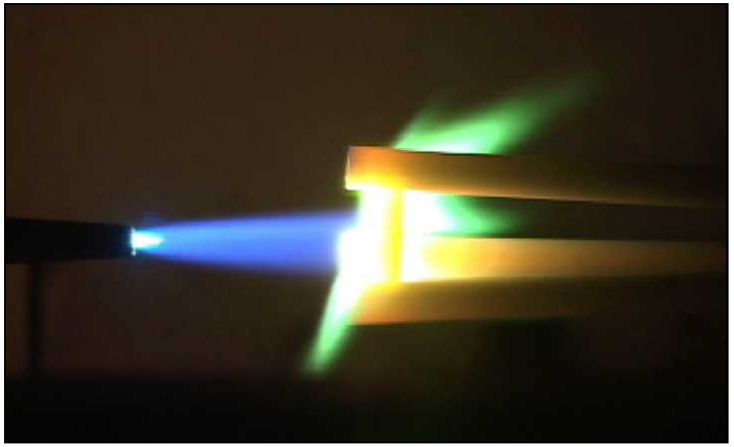


# Materials Screening Capabilities (cont.)

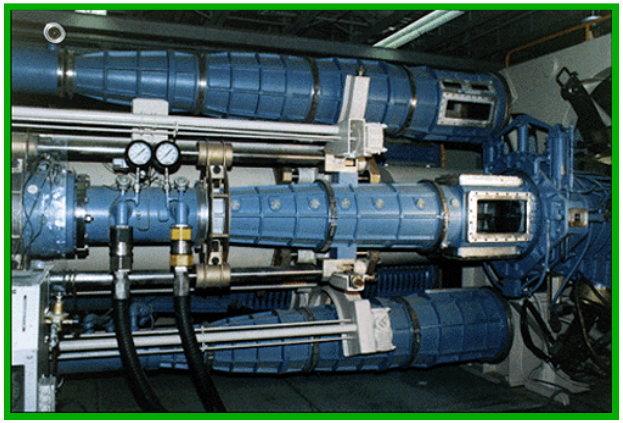
- Oxyacetylene Torch
  - Heat Flux – ~835 W/cm$^2$.
  - Multiple screenings with low turnaround time and low cost.
  - Can be programmed for heating profile.
  - Recommended for weeding out poor materials.



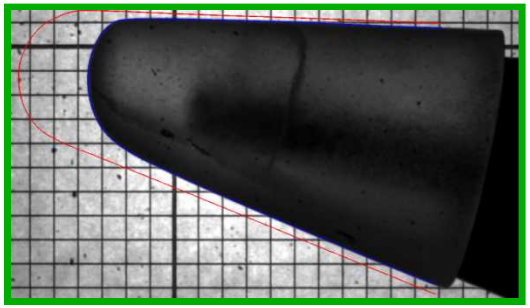



# Low Temperature Ablators

- Conventional Hypersonic Wind Tunnels
  - Can Match M and Re of flight
  - Cannot match enthalpy
    → Cannot test real TPS



- Low Temperature Ablators in HWT's
  - Sublime like many real TPS materials, but at lower enthalpy
  - Allow investigation of coupled shape change / convective heating effects



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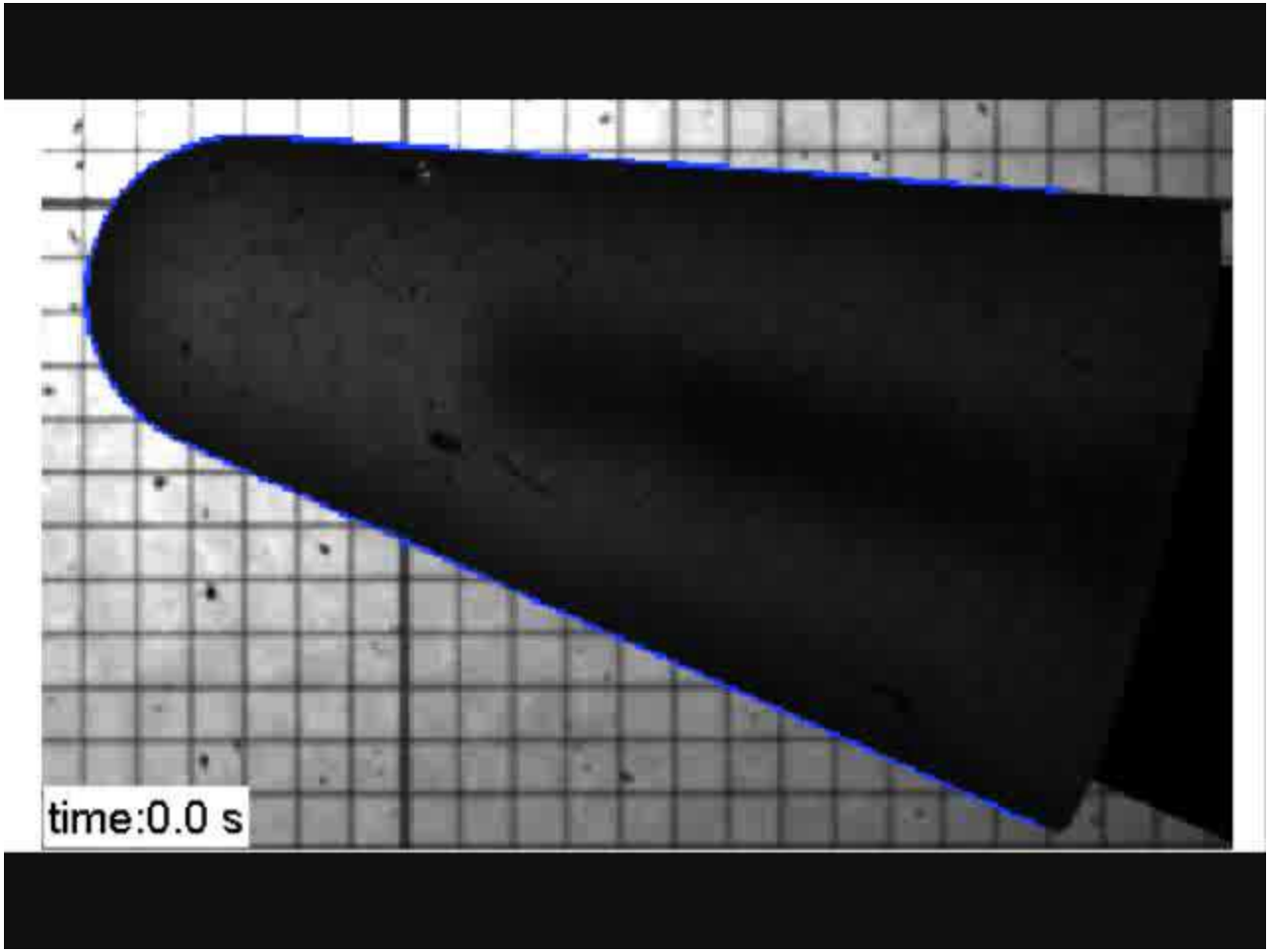
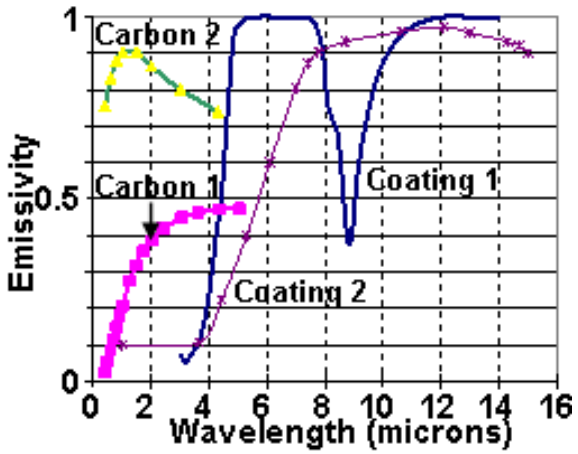
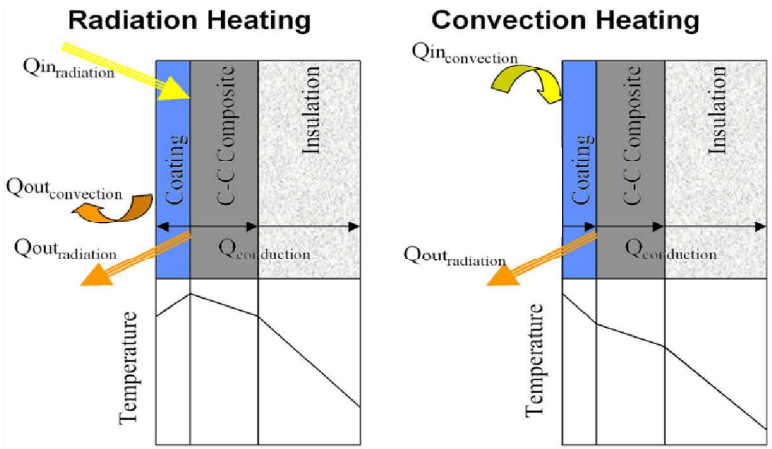
# Hypersonic Wind Tunnel



# Radiative Facilities

- Radiative Facilities
  - Laser Facilities (LHMEL-WPAFB)
  - Solar Facilities (NSTTF-Sandia)
- The heating mechanism should be well-understood:
  - Emissivity/absorptivity are dependent on temperature, wavelength, and relative decomposition state of the material
    - May change greatly during testing
    - Affects heat absorbed and surface temperature read by pyrometers
- Materials that do well in one type of facility may perform poorly in another
  - Radiant heating facilities may be better suited for mechanistic and comparative studies (material down-selecting) prior to arc jet and flight tests.

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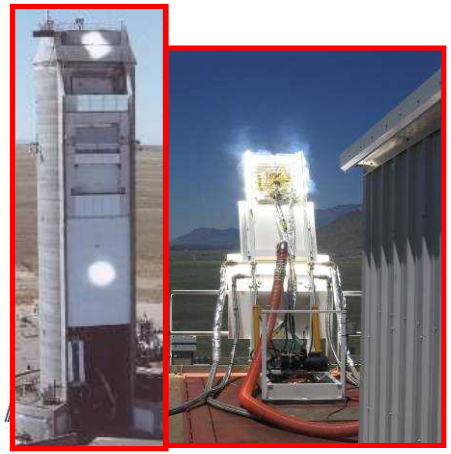
# National Solar Thermal Test Facility

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



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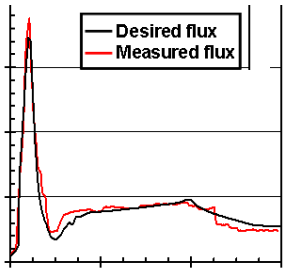
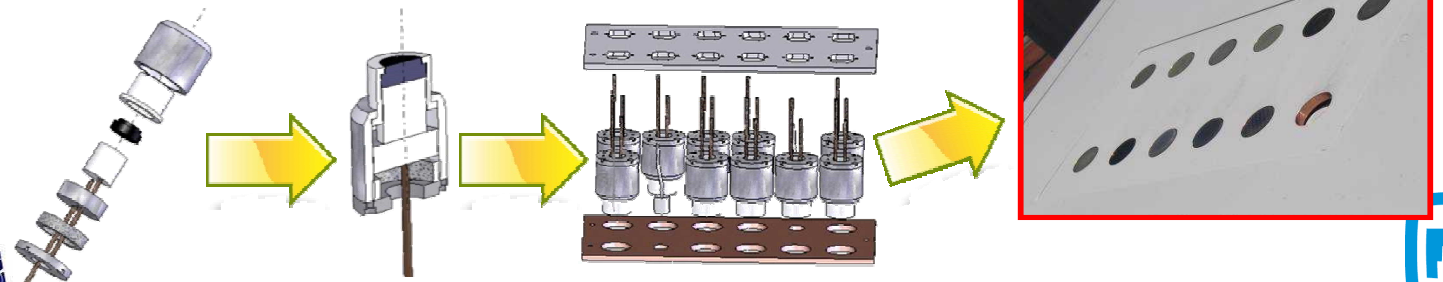
# Central Receiver Test Facility (Solar Tower)

- **Characteristics:**
  - Test bay is 60 m (200 ft) above ground on top of tower.
  - Additional test bay with small subsonic wind tunnel.
  - Time-varying Heat Flux to 260 W/cm$^2$ (15 cm dia.).
  - Test time > 10 minutes, dependent on weather.
  - Existing Fixtures
    - Allow 12 simultaneous material samples/flux gages (1 in. dia) to be tested.
    - Samples are fitted in a zirconia sleeve, backed with zirconia insulation and aluminum.
    - Thermocouples mounted to sample and insulation backfaces.





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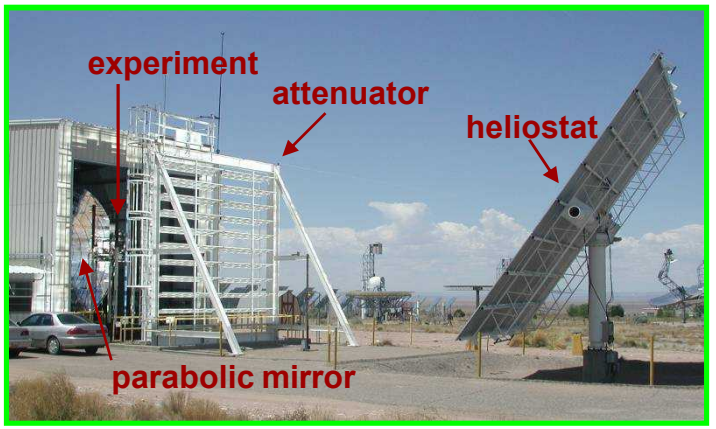
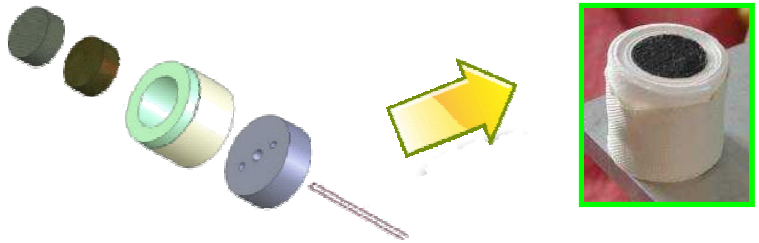
# Solar Furnace

- **Characteristics:**
- Heat is provided by a single heliostat which reflects sunlight through an attenuator onto a parabolic mirror that focuses it onto the sample.
- Test time >10 min., dependent on weather.
- Insolence meter automatically adjusts attenuator during test.
- 3-axis gantry traverses sample.
- 2 pyrometers, IR video, monitor temperature.
- Variable heat flux to 800 W/cm$^2$
- Theoretical Surface Temps > 3000 C.
- Illuminates targets up to ~80 cm$^2$.
- Typical sample size 1.6 cm dia. (8 cm$^2$).



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# Arc Jets/Plasma Facilities

- **Arc jets are the industry standard for predicting performance of TPS materials in flight**
- Sandia 2-MW Plasma Jet Facility
  - Operated in 1970's and early '80's
- Currently rely on external facilities
  - NASA Ames AHF/IHF
  - AEDC HEAT-H1, H2, H3
- Plasma Materials Test Facility
  - 60 kW beam
  - Electron Beam Coating Deposition
  - High heat flux testing of 100's of W/cm$^2$ for 100's of seconds


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# Sled Tracks

- **Sandia's Rocket Sled Track Facility:**
  - 10,000 ft long
  - Max Mach number: > 3, Mach 5 in the past
  - Test in air; helium and other gases in a tent
  - Uses: Penetrators, Aerodynamics, Accident Scenarios, Weapons Applications, TPS . . .

- **Holloman High Speed Test Track:**
  - 50,788 ft long
  - From subsonic to Mach 9
  - Uses: Boundary layer transition, Ram jets/Scram jets, TPS, weather . . .

# Conclusions

- Sandia is currently focusing significant efforts on a new generation of hypersonic boost-glide flight vehicles.
- Current TPS materials are not adequate to protect this new generation of flight vehicles for all necessary flight profiles.
- Efforts are currently underway to develop new TPS materials to withstand the high heat pulse at pullup and long thermal soak.
- New materials are screened and tested using a variety of simulation and experimental tools.