Parabolic Trough Receiver Thermal Performance

Parabolic Trough Workshop

Golden, Colorado

March 9, 2007

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Parabolic Trough Receiver or Heat Collection Element

- ***Key to good performance at parabolic trough power plants***
  - ***Problems with glass breakage appears to be resolved with new designs and O&M procedures.***
  - ***New receivers improve optical and thermal performance***

Source: Solargenix – APS 1-MW Trough Plant

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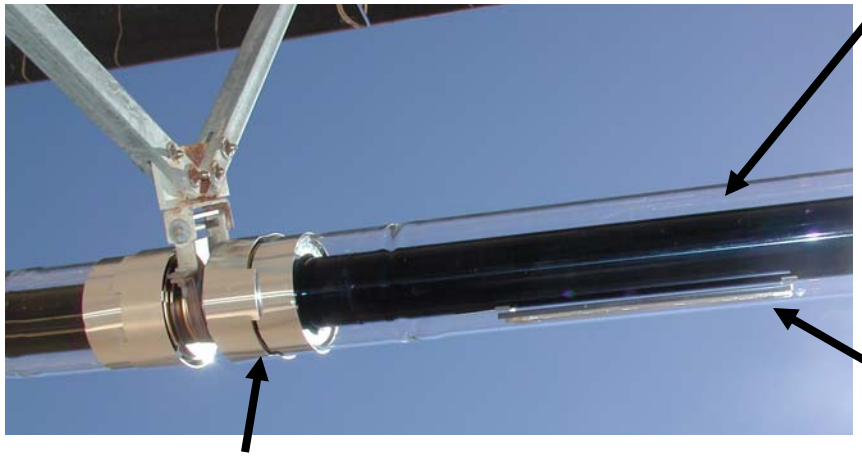
Parabolic Trough Receiver or Heat Collection Element

New Solel UVAC Receiver



Borosilicate Glass Tube
w/ Anti-Reflective Coating

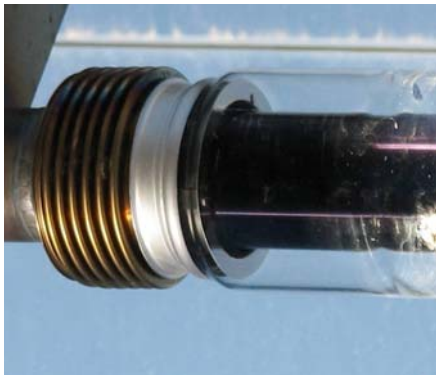
Stainless Steel Tube
w/ Cermet Selective Coating

Getters to Absorb Gases
(Hydrogen)

Protective Shielding for
Glass-to-Metal Seal

Solel UVAC

Bellows &
Glass-to-Metal Seal



New Schott Bellows

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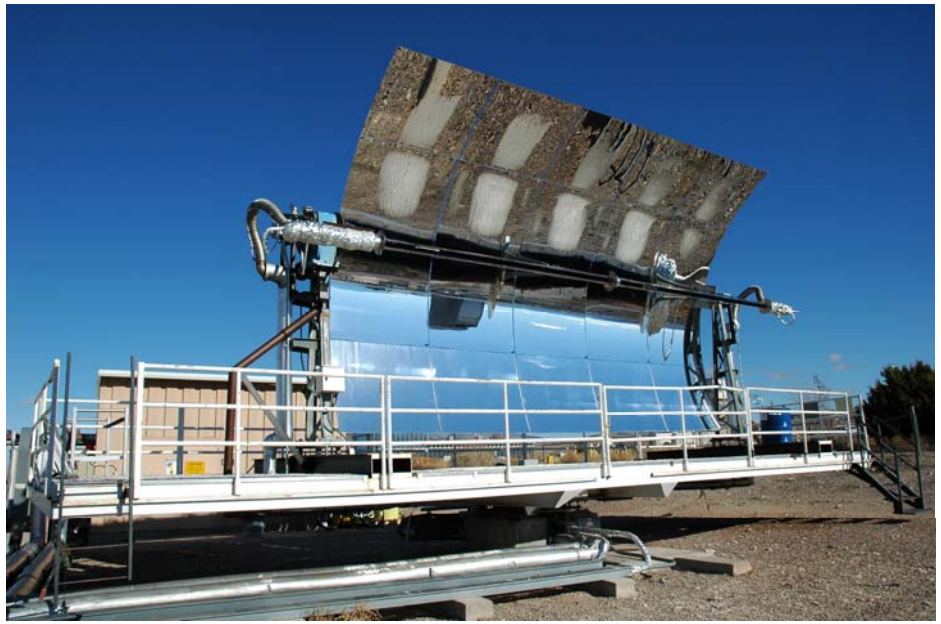
Parabolic Trough Receiver Thermal Testing

- Outdoor – Thermal Loop Tests
  - Use measurement of flow and temperature difference to calculate energy gained or lost.
  - Sandia Rotating Platform, Plataforma Solar de Almería EuroTrough Collector, SEGS Collector Test Loops
- Indoor
  - Electric resistance heating
    - Heat receiver to steady state temperature
    - Electric power consumed is the thermal loss
  - DLR, Schott, ENEA,NREL

Parabolic Trough Receiver Thermal Testing

- **Receiver testing on AZTRAK rotating platform @ Sandia**
  - Luz Black Chrome (1993)
  - Luz Cermet (1993)
  - Solel UVAC (2003)
  - Schott Cermet (2004)
- Advantages
  - 2-Axis Tracking
  - On-sun or off sun testing
- Disadvantages
  - Only one collector element tested & 2 receivers
  - Low precision on measurements



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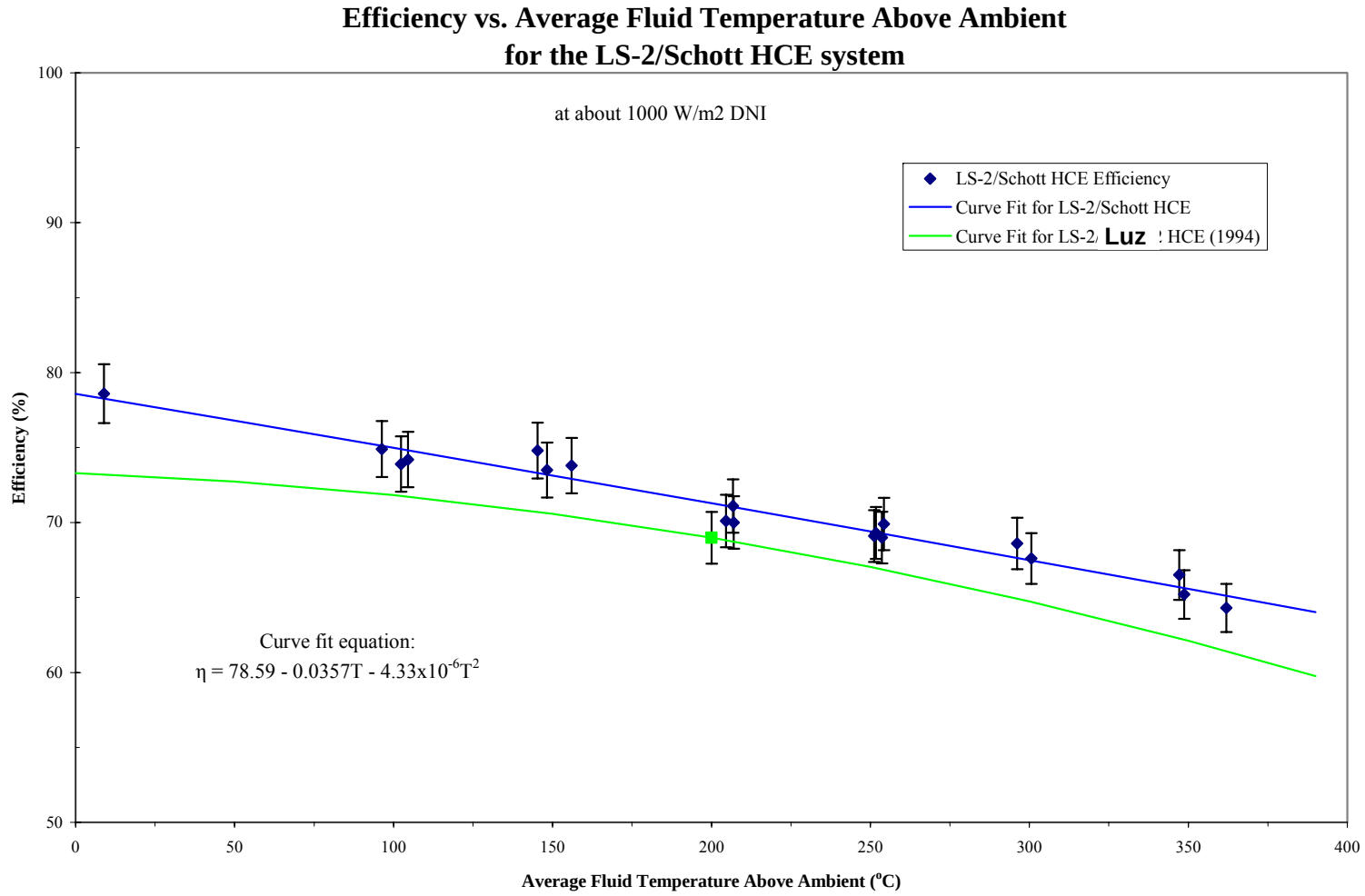
Parabolic Trough Receiver Thermal Testing



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Parabolic Trough Receiver Thermal Testing

- **Receiver testing on EuroTrough Prototype @ Plataforma Solar de Almería**
  - Solel UVAC
  - Schott Cermet
- Advantages
  - Full collector tested (more receivers)
  - Better precision
- Disadvantages
  - Single E/W axis tracking
  - Reduced test flexibility

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Parabolic Trough Receiver Thermal Testing

- **Receiver testing on ENEA Loop**
  - Schott Receiver
  - ENEA Receiver (Summer 2007)
- Advantages
  - Molten Salt Test
  - Higher Temperatures
  - Two Collectors

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Parabolic Trough Receiver Thermal Testing

- **Loop Testing at the SEGS**
  - Solel UVAC (SEGS VI)
  - Schott Cermet (SKAL-ET, SEGS V)
- Advantages
  - Field testing in normal operation
  - Full loop tested
  - Comparison to other loops
- Disadvantages
  - Many factors affect results
  - Limited control of test

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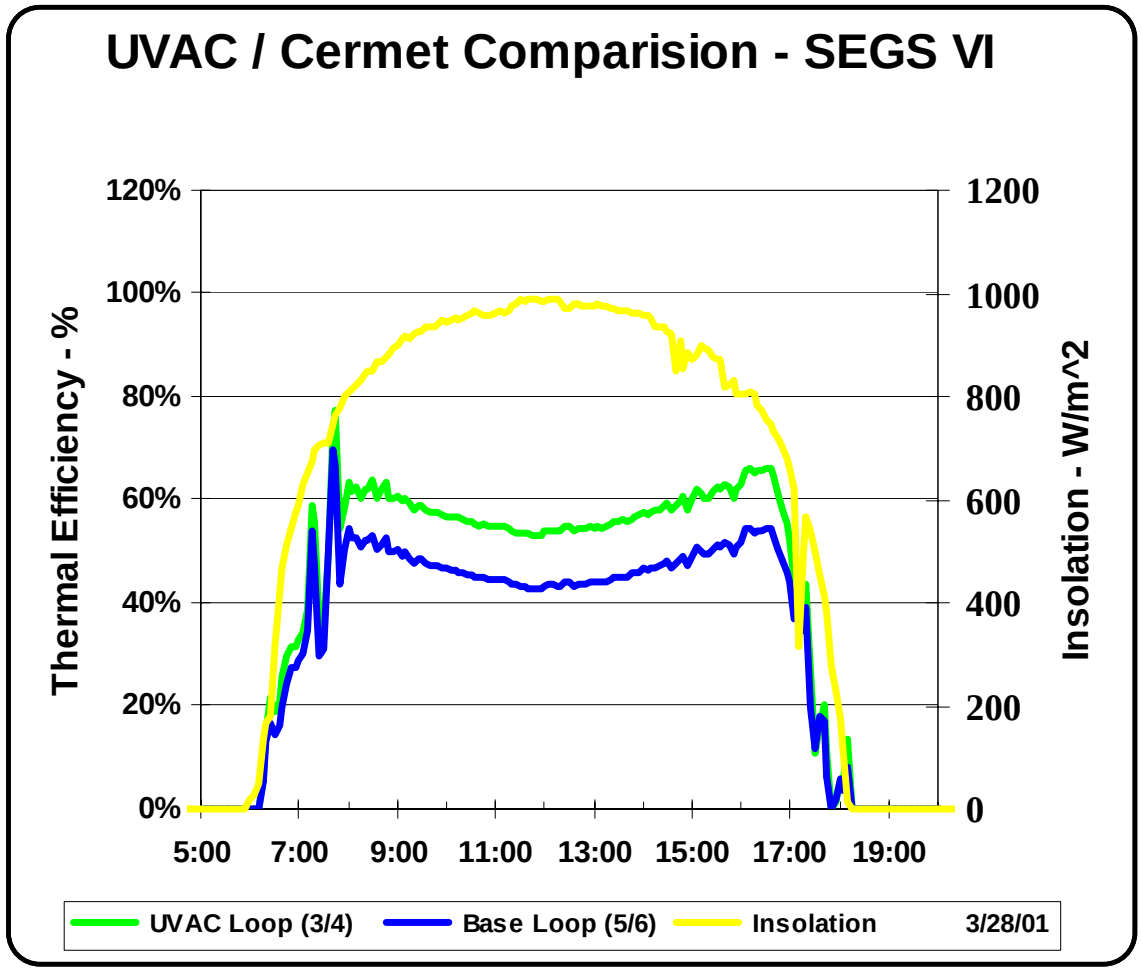
UVAC Test Loop Results @ SEGS VI
Performance or 192 HCEs



Receiver Thermal Loss Indoor Test Stand

DLR Receiver Test Lab

- Electric resistance heating
- At steady state power consumption is equal to thermal losses

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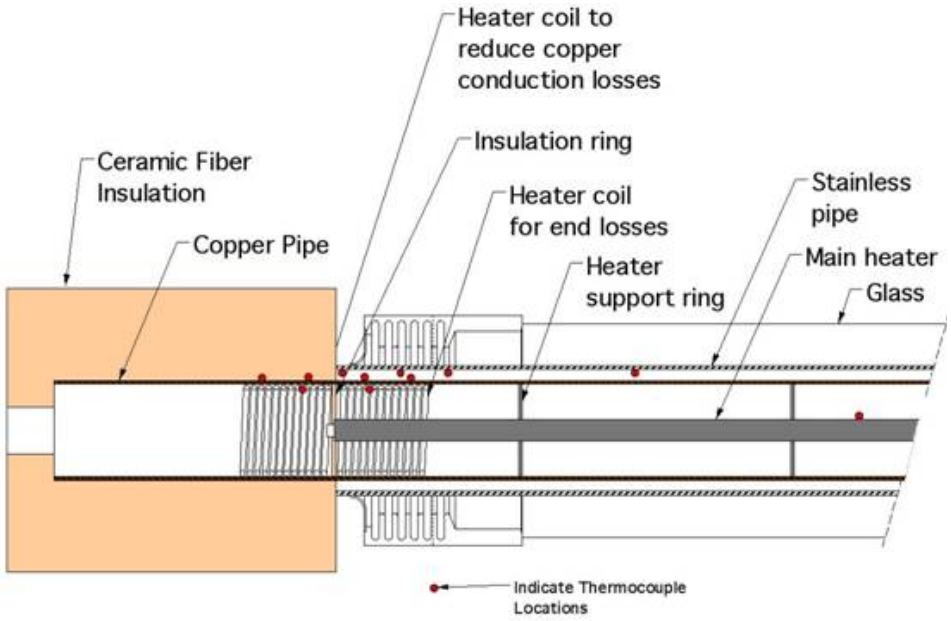
Receiver Thermal Loss Indoor Test Stand

NREL Receiver Test Lab

- Electric resistance heating
- At steady state power consumption is equal to thermal losses
- Similar to approaches used by DLR & Schott



Calvin Feik, Ray Hansen, Steve Phillips, Al Lewandowski, Carl Bingham, Judy Netter, Chuck Kutscher, Frank Burkholder

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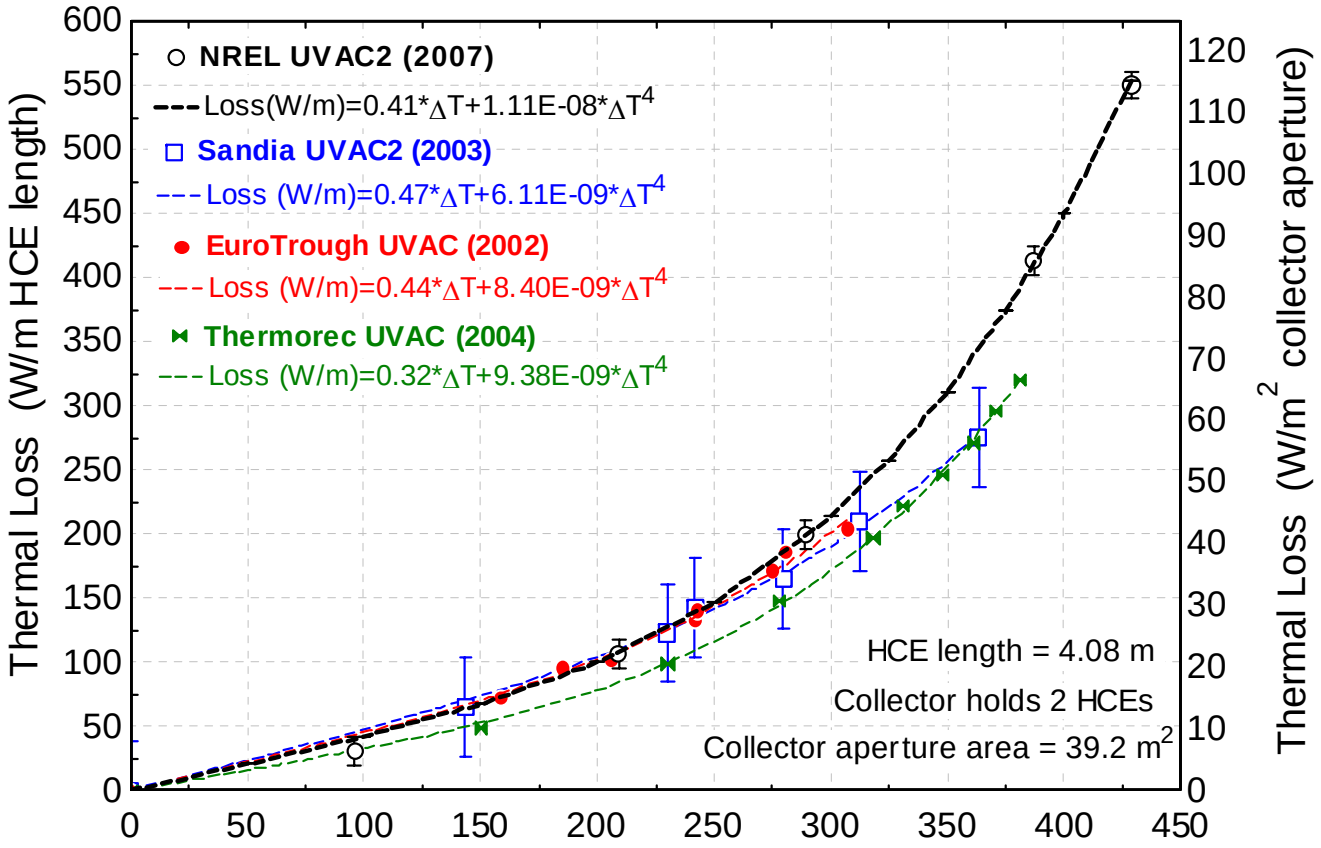
Receiver Test Results
Solel UVAC 2



T* - $T_{ambient}$ (°C)

in liquid cool-down tests, T* = T_{fluid}

in electric resistance testing, T* = $T_{absorber}$

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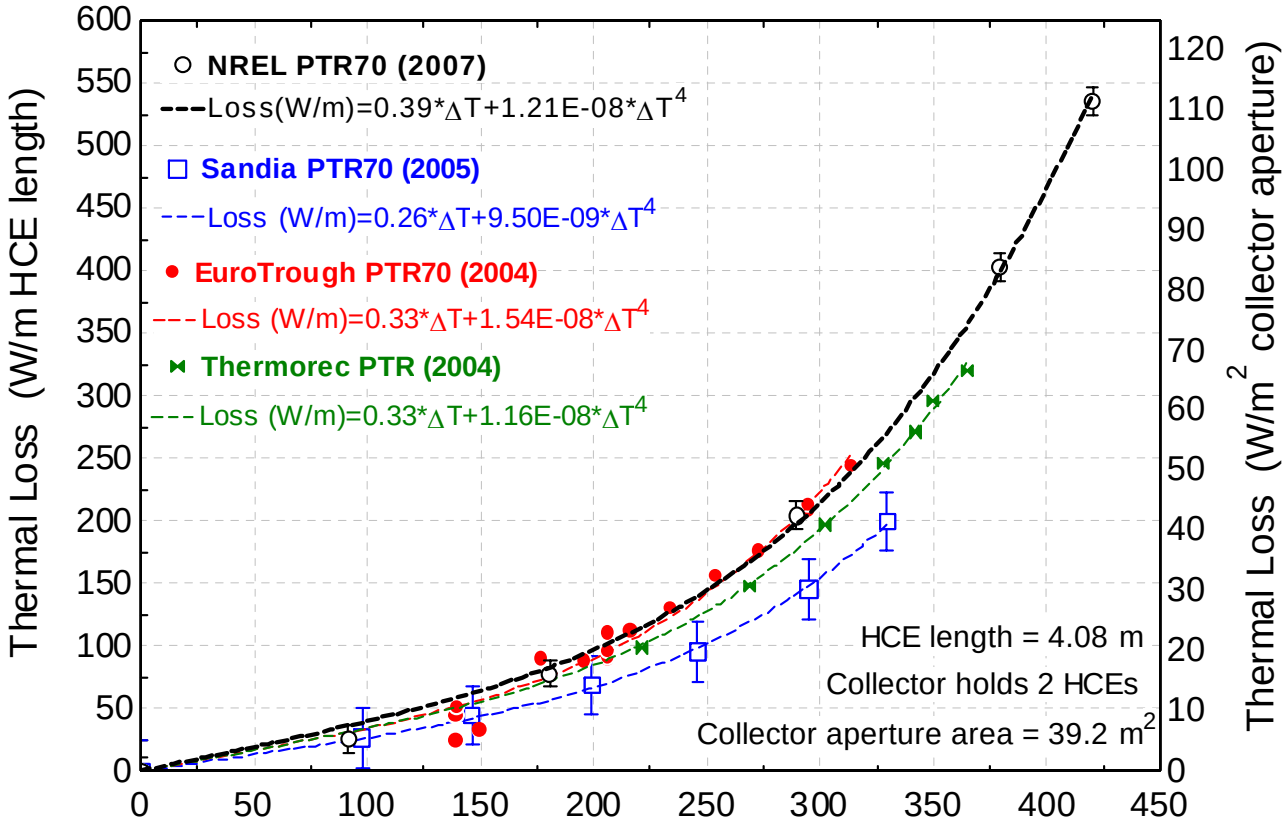
Receiver Test Results
Schott PTR70



T* - $T_{ambient}$ (°C)

in liquid cool-down tests, T* = T_{fluid}

in electric resistance testing, T* = $T_{absorber}$

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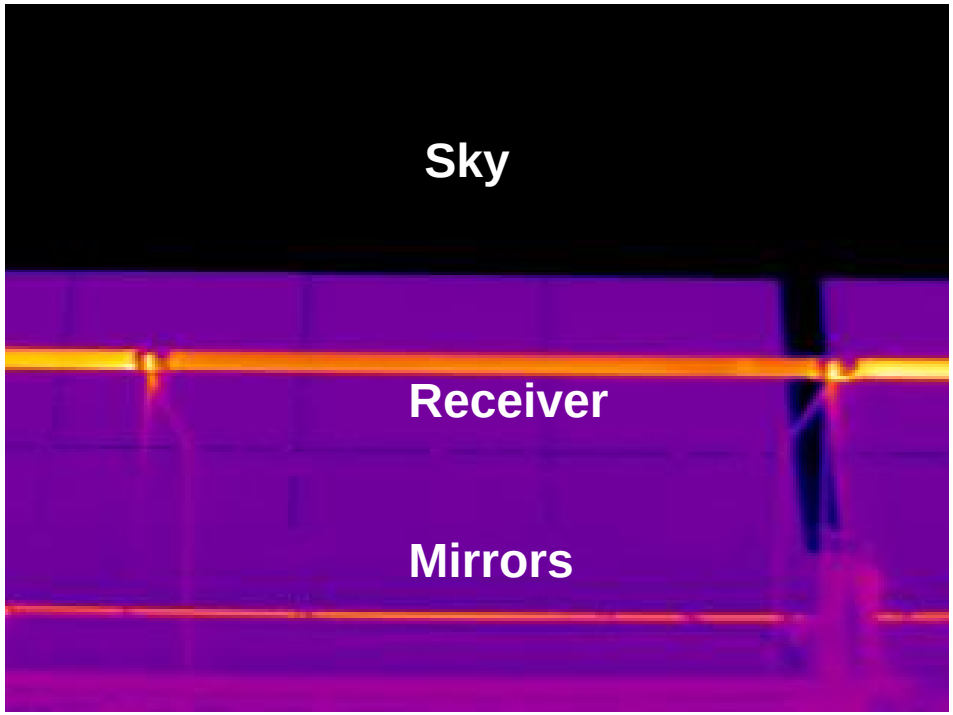
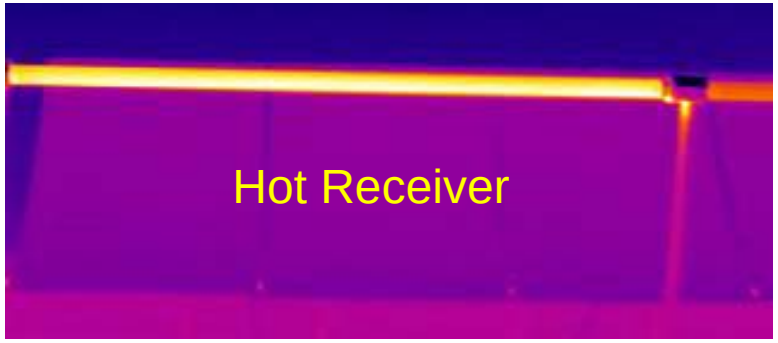
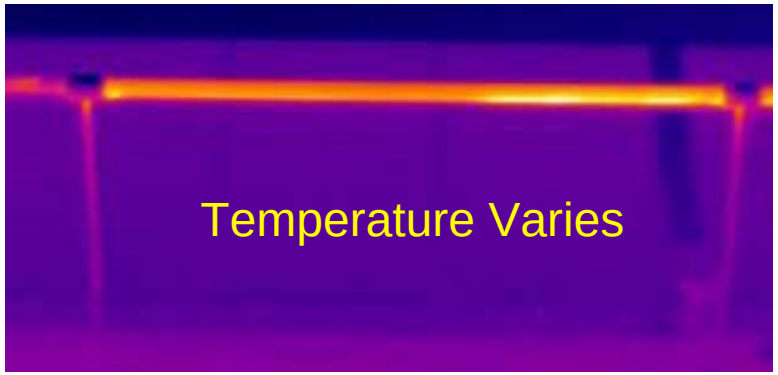
Receiver Field Survey For FPL Energy

Receiver Field Survey With Infrared Camera







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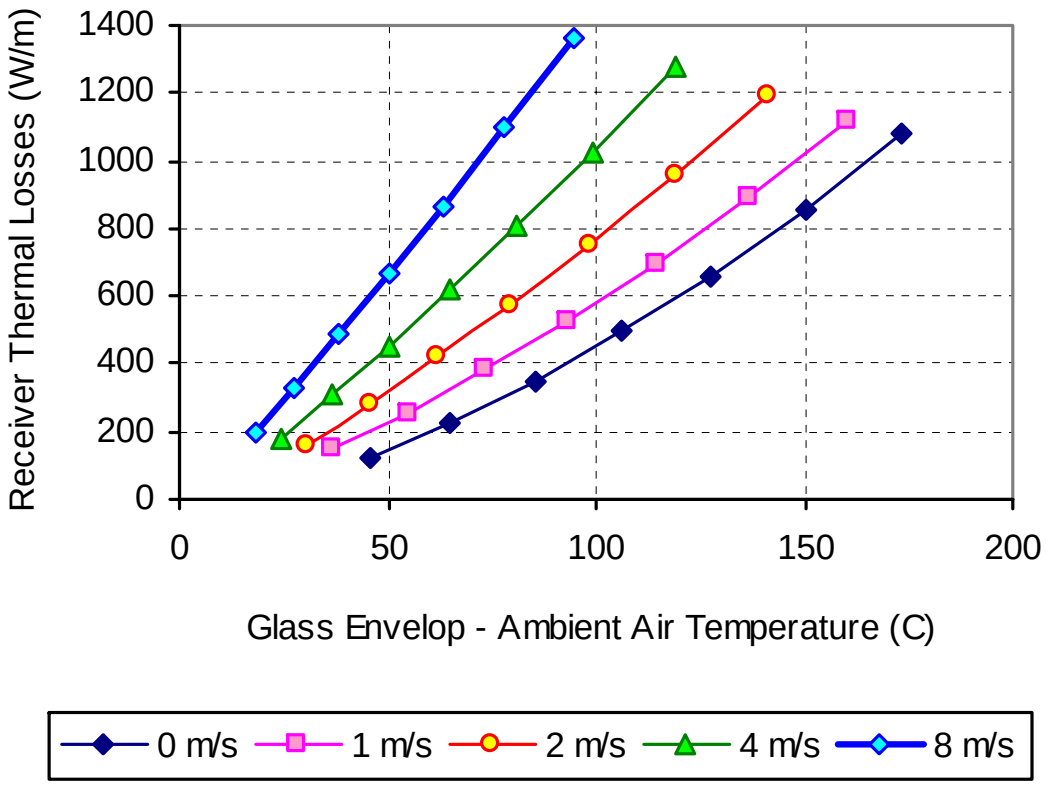
HCE Losses vs. Glass Temperature



For a known wind speed and ambient temperature, …

- Receiver thermal losses are a function of the glass temperature.
- Receiver condition doesn't matter (vacuum, lost vacuum, hydrogen)

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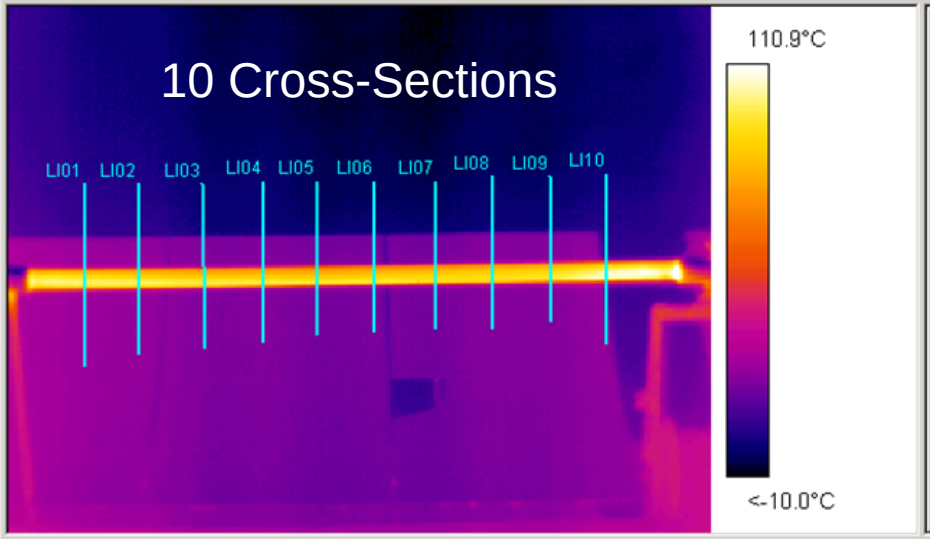
IR Camera Analysis Software



Analysis | Position | Obj. Par | Image | Text comment

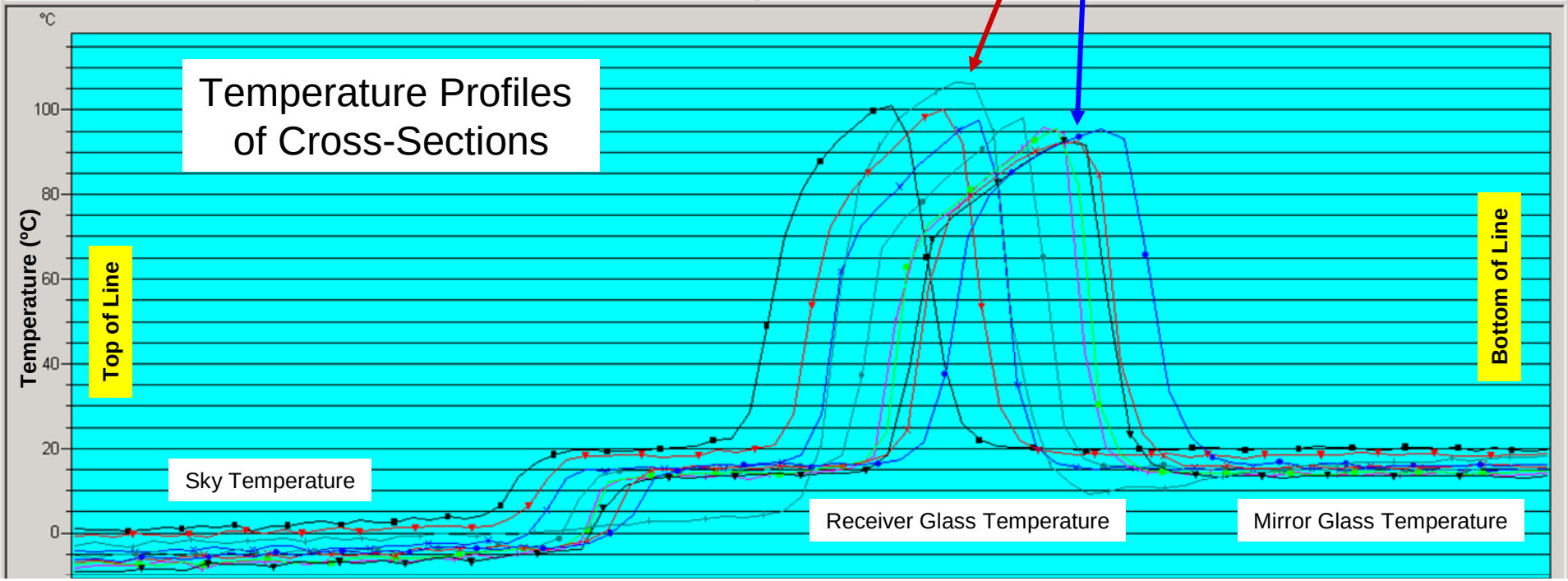
Label	Value [°C]	Min	Max	Max - Min
Image		<-10	130	*140
LI01		0	101	101
LI02		*-1	100	101
LI03		*-5	97	102
LI04		*-6	98	104
LI05		*-9	96	104
LI06		*-8	96	103
LI07		*-9	93	102
LI08		*-7	93	100
LI09		*-7	95	102
LI10		*-3	107	110

Max – Min of Cross-section Maximum 14°C

Max of Cross-section Maximums 107°C

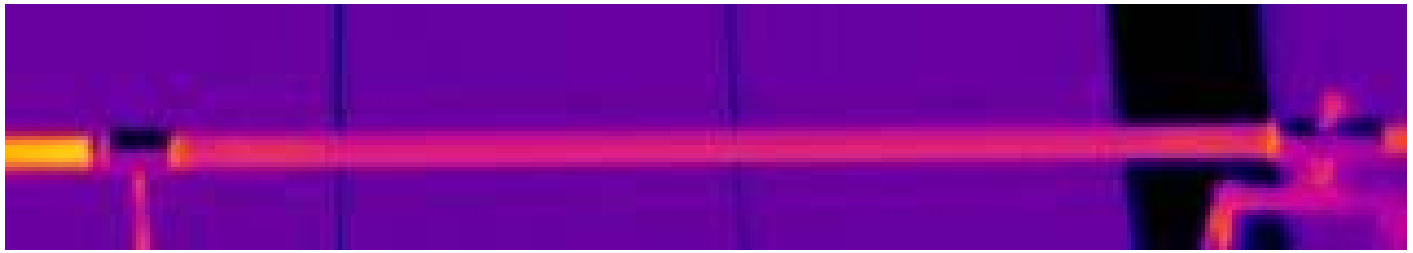
Min of Cross-section Maximums 93°C

Average of Cross-section Maximums 98°C

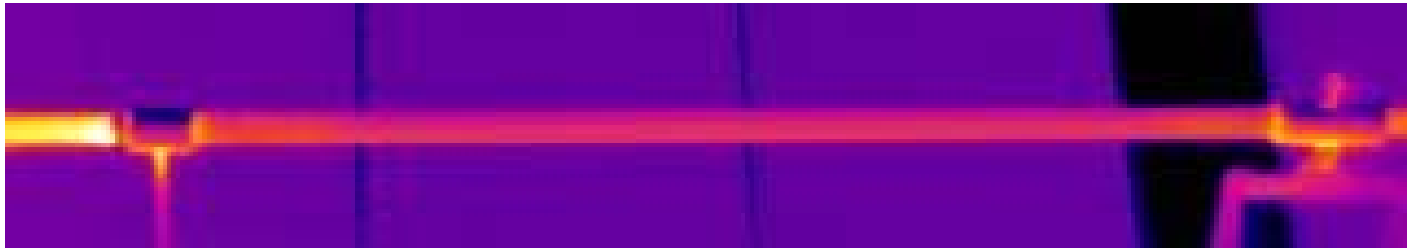


Solel UVAC2 (2 years old) with Vacuum

Visible Image of Receiver – Not Tracking



Infrared Image – Not Tracking (Glass Temp. 63ºC-66ºC)



Infrared Image – Tracking (Glass Temp. 68ºC-71ºC)

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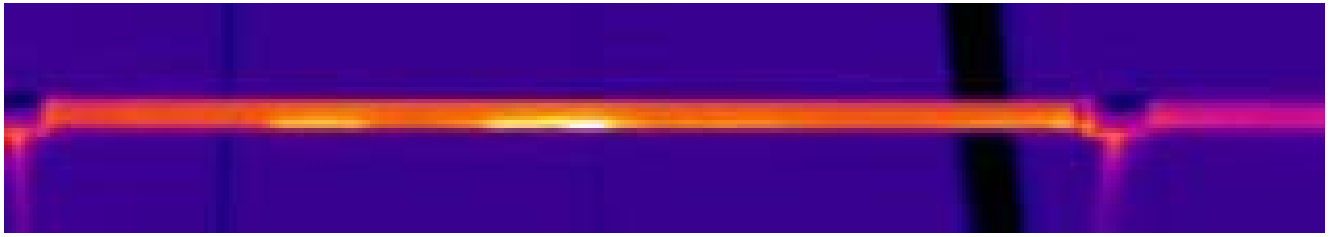
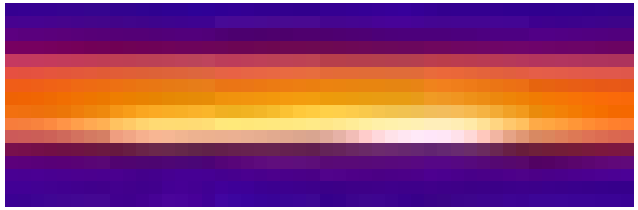
Luz Cermet with Vacuum

Visible Image of Receiver – Not Tracking

Infrared Image – Not Tracking (Glass Temp. 124ºC-141ºC)



Infrared Image – Tracking (Glass Temp. 138ºC-267ºC)



Getter dust is causing hot spots on the glass

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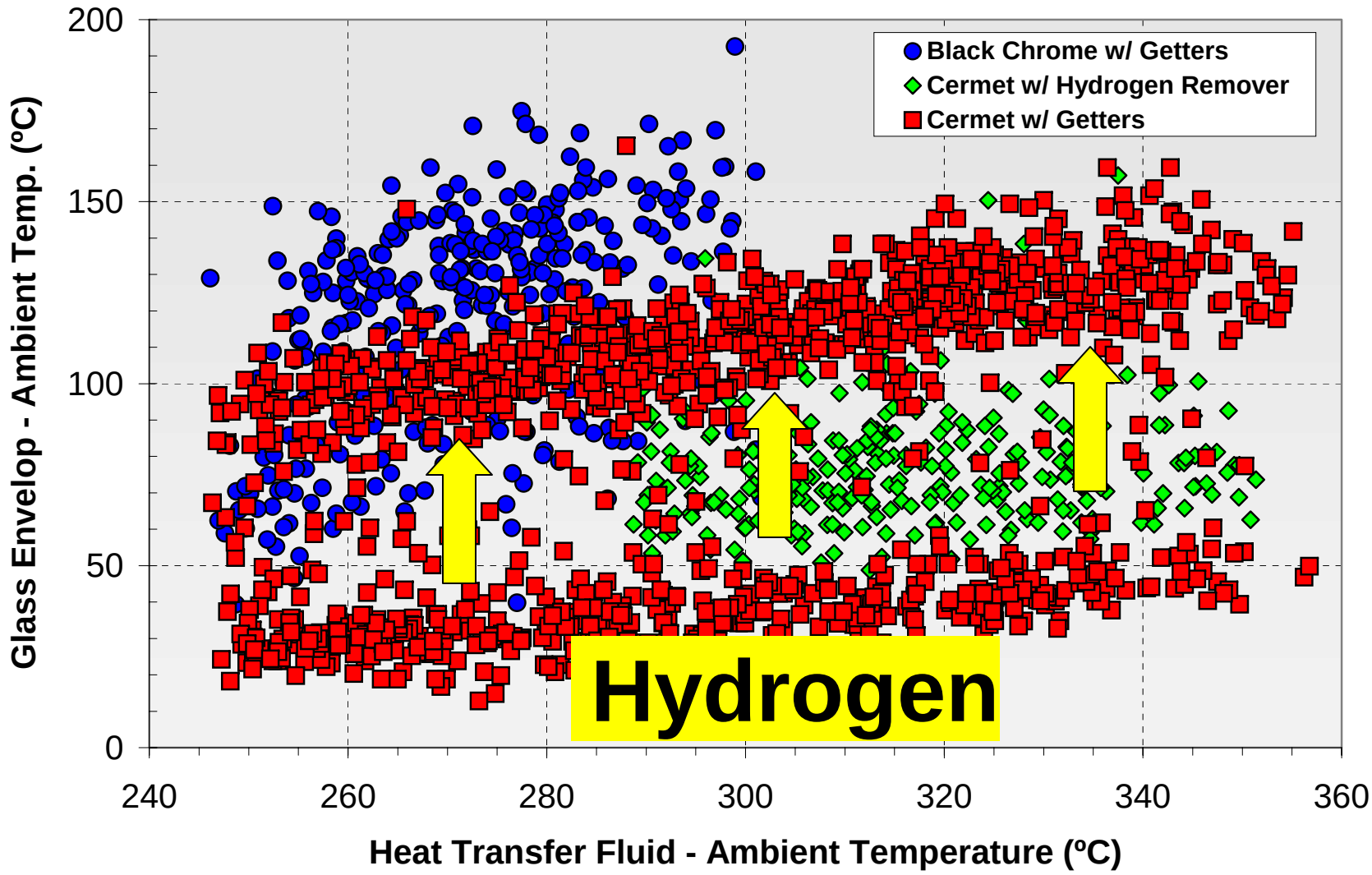
Field Test Results
SEGS VI



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Receiver Field Survey Conclusions

- IR camera provided a good approach for evaluating condition of a large number of receivers in the solar field.
  - A highly automated approach for imaging receiver and analyzing data developed
  - Good agreement between IR camera and thermocouple measurements
  - Able to take measurement while collectors tracking
  - Approximately 12,000 images of receivers taken (out of ~90,000 receivers)
- Results from testing:
  - Able to evaluate performance of various generations of original and replacement receivers.
  - Getter dust, dirt on glass, or fluorescent coating failure cause increased glass temperatures.
  - **Results indicate a potential hydrogen build-up in receivers in solar field**

IR Camera System Updates

- Improved automation of image acquisition
  - Integration of GPS for automated acquisition of images.

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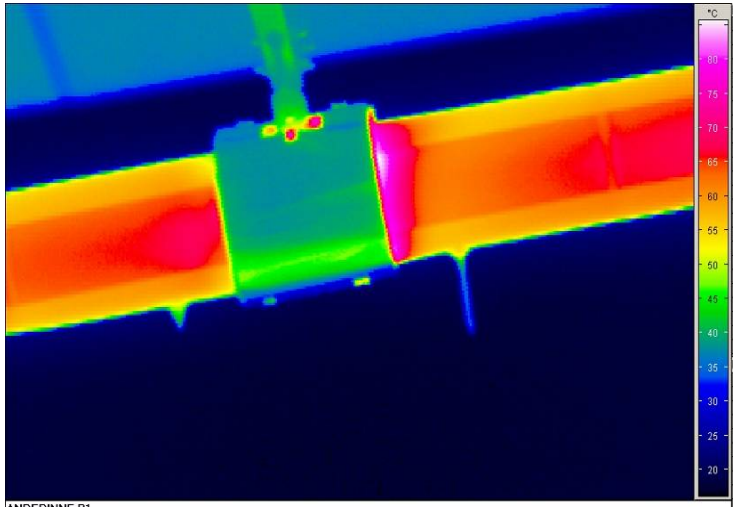
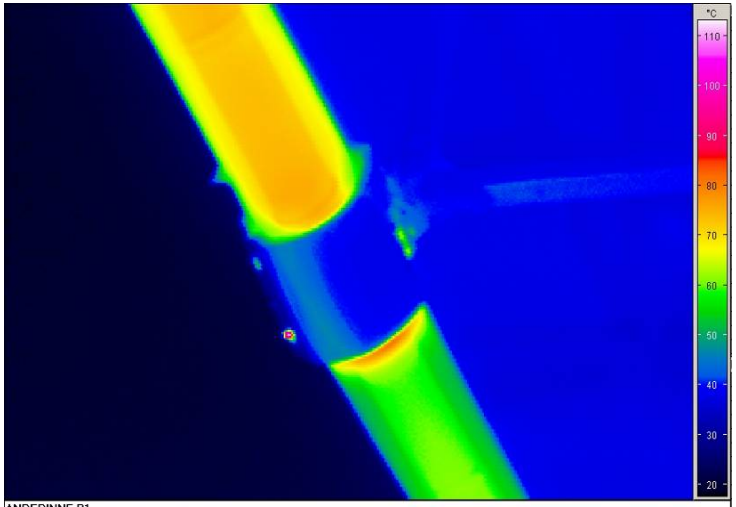
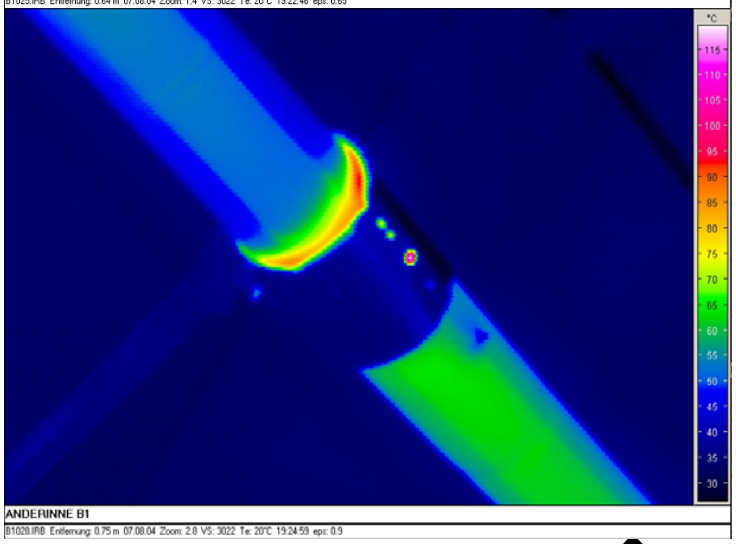
Infrared Camera Measurements through Glass







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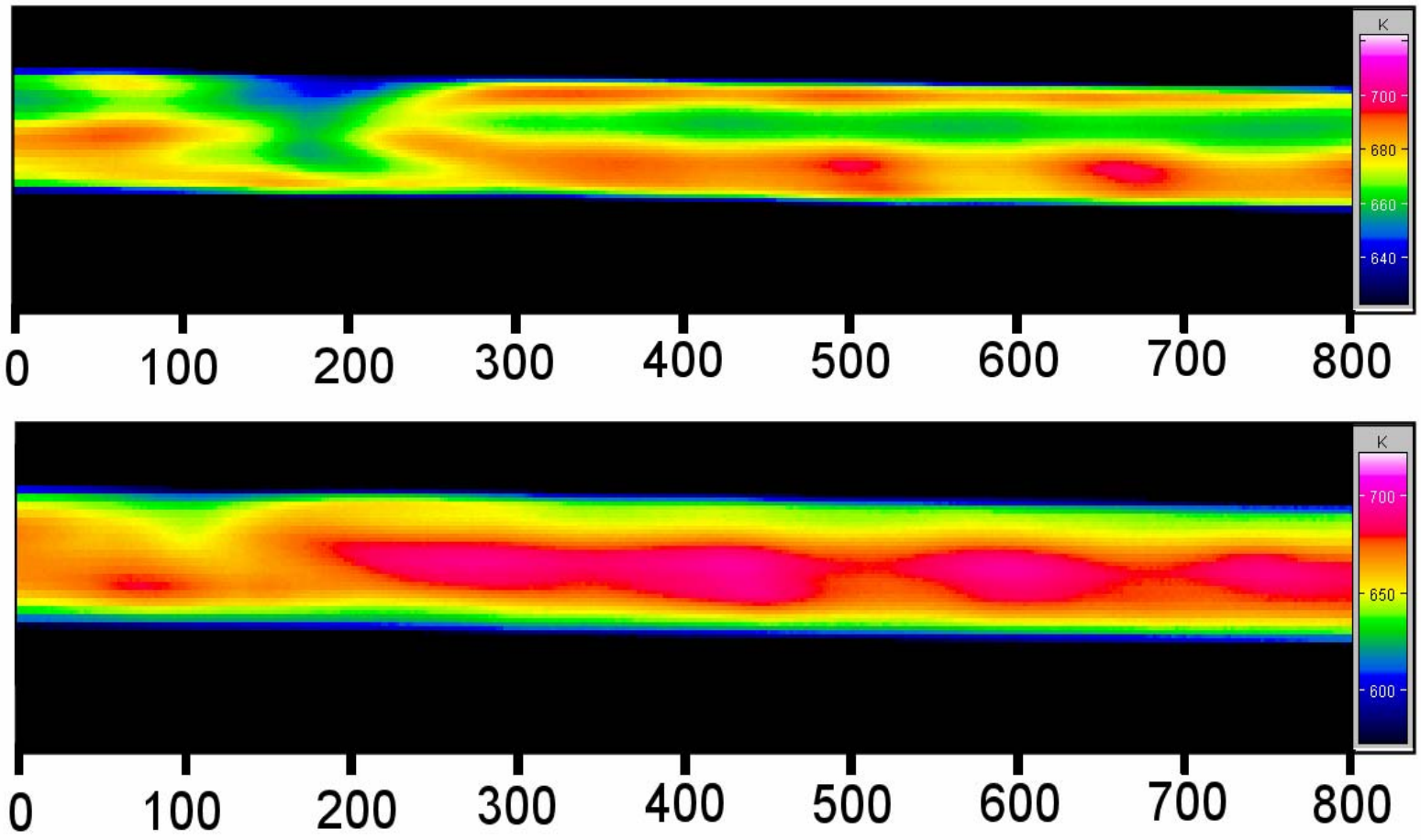
Absorber Surface
Temperature Measurement Results



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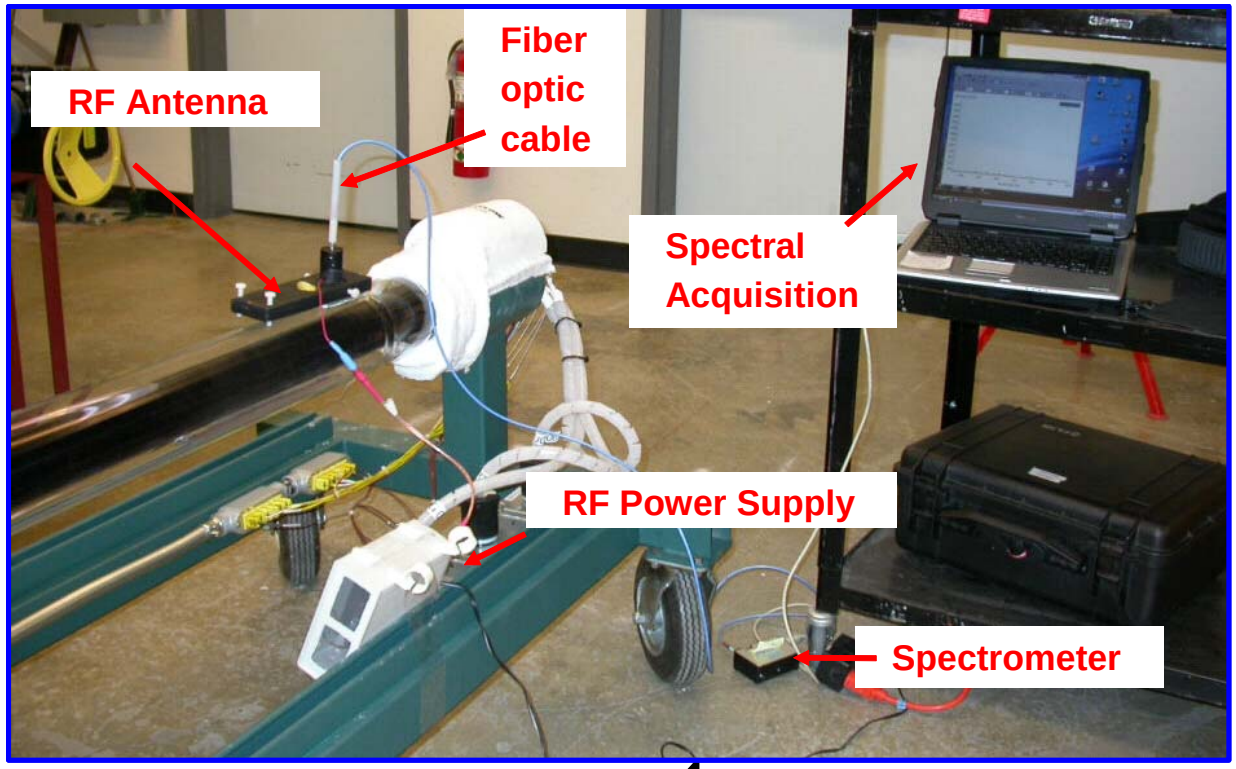
Non-Invasive Measurement of Gases in Trough Receiver

- Confined gases under low pressure emit characteristic spectra when a high voltage discharge is allowed to pass through the gases.
- The characteristic emission wavelengths provide the identity of the gas and the intensity of the emissions are proportional to the amount of gas.



Developed by:

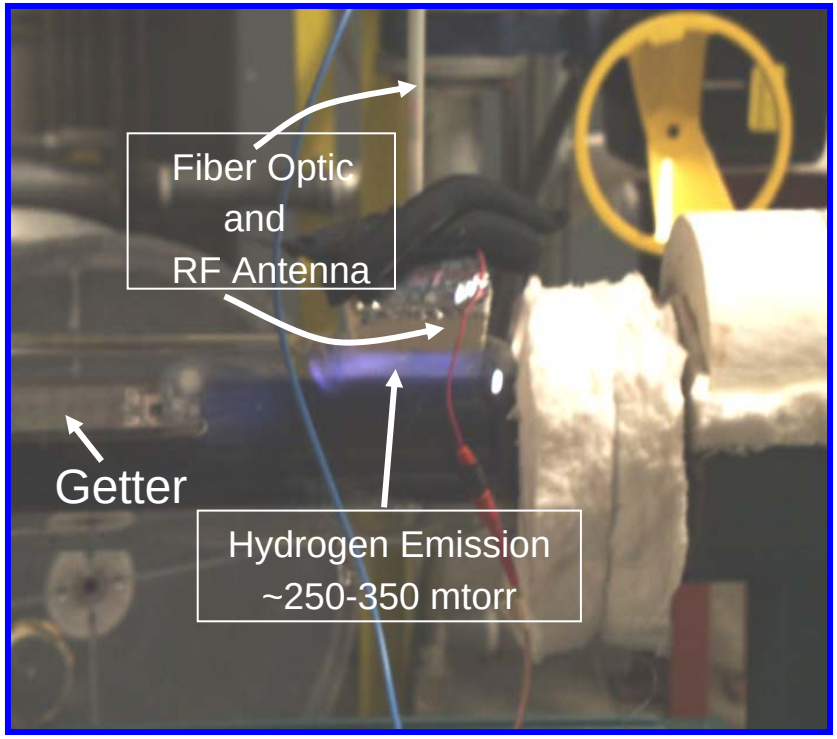
Bob Meglen
Latent Structures

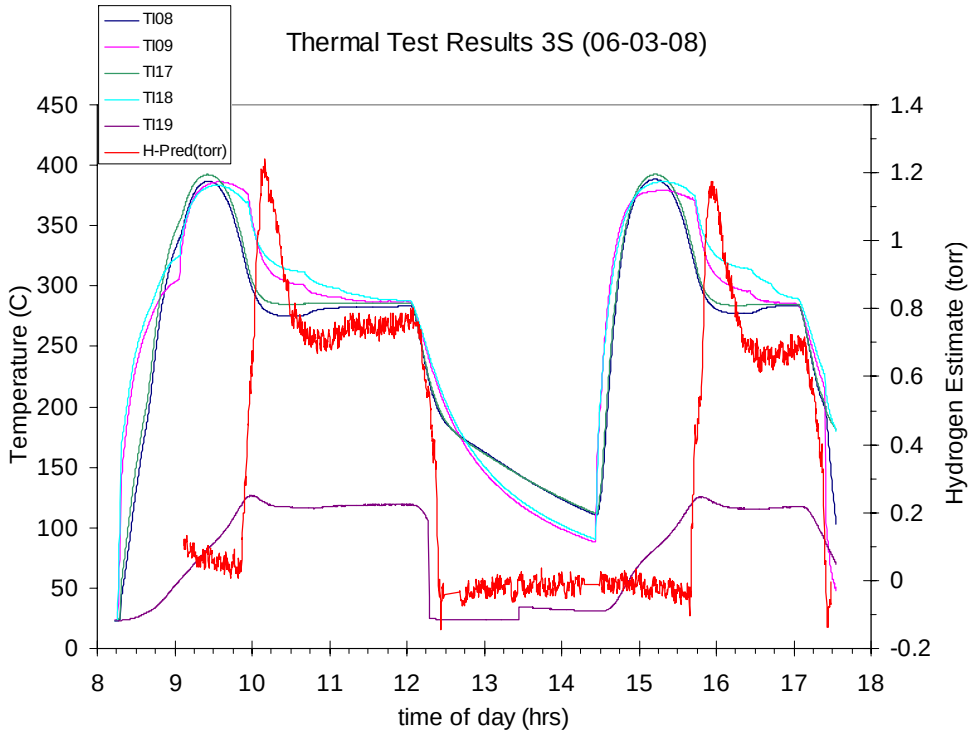
Latent Structures, LLC

&

Ed Wolfrum
NREL

Receiver Test Results
Gas Measurement





- **Hydrogen detected above ~300ºC**
- **Corresponds to Increase in Glass Temperature & Increased Thermal Losses on Hot Receiver**

Latent Structures, LLC

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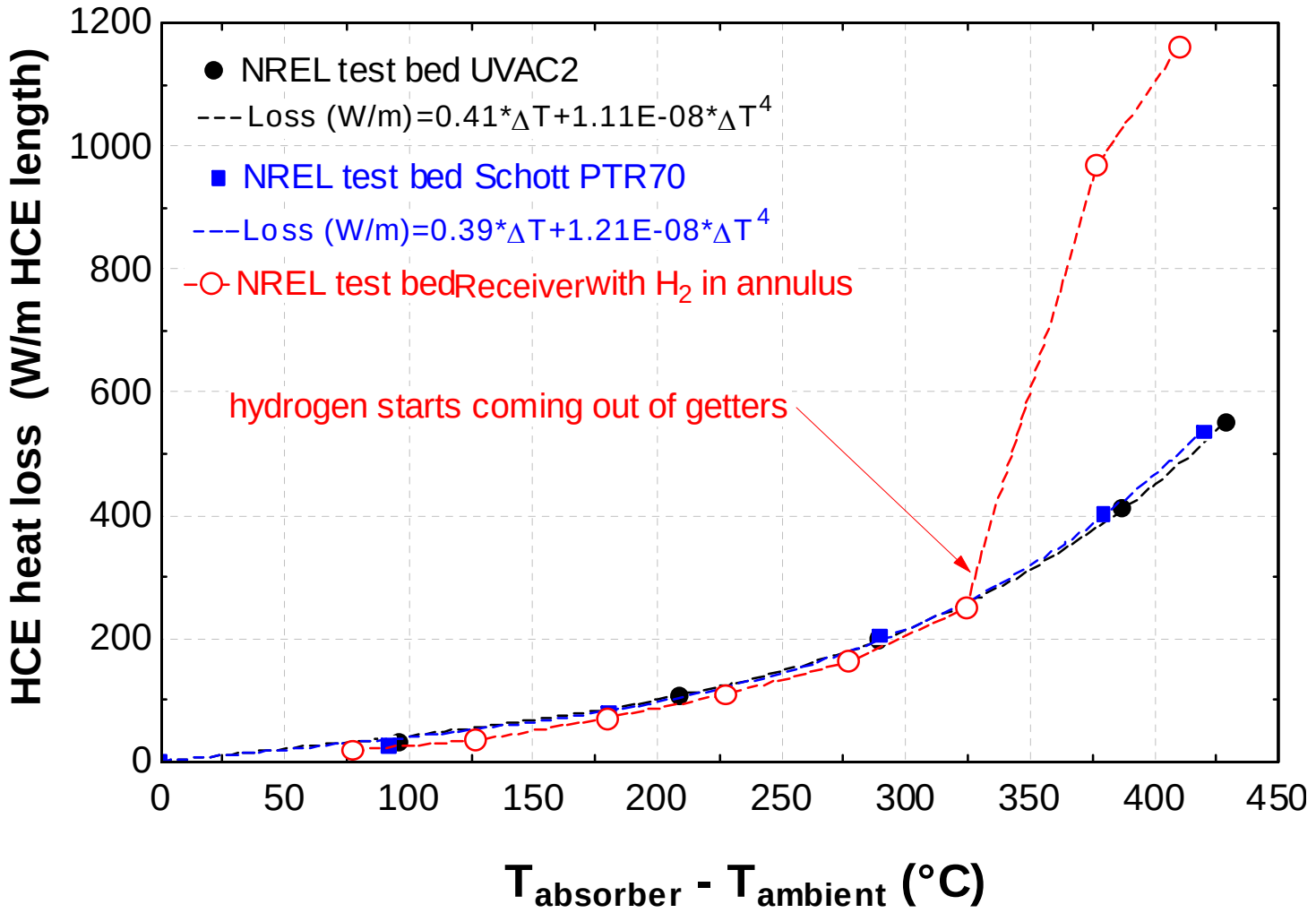
Receiver Test Results



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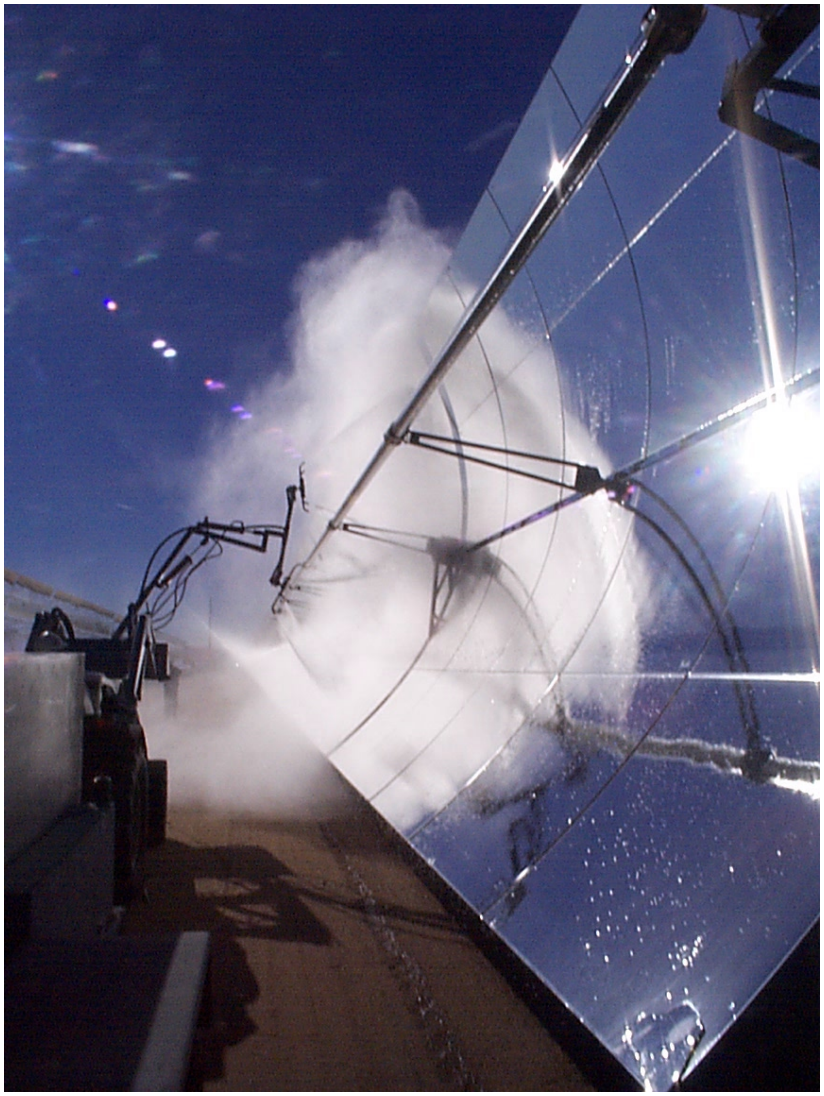
Receiver Test Conclusions
Conclusions

- Outdoor testing
  - 2-axis
  - Single collectors
  - Field Test Loops
- Indoor testing
- Rapid Field Observations

Mirror Washing

High Pressure Spray with Demineralized water



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Mirror Washing

Deluge wash with Demineralized water

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Thank You