REINHOLD ENVIRONMENTAL Ltd.

2016 NOx-Combustion-CCR Round Table Presentation

February 1 & 2, 2016, in Orlando, FL / Hosted by OUC

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Technologies for Improving Boiler Performance

Brian Moore (Orlando Utilities Commission)
Stephen Dean (Duke Energy)
George Kychakoff (Enertechnix)

Reinhold Conference
(Orlando, FL)

Slag Management

The Start of IR Imaging in Boilers

Visible image through port

Chemical Recovery in Pulp Manufacture

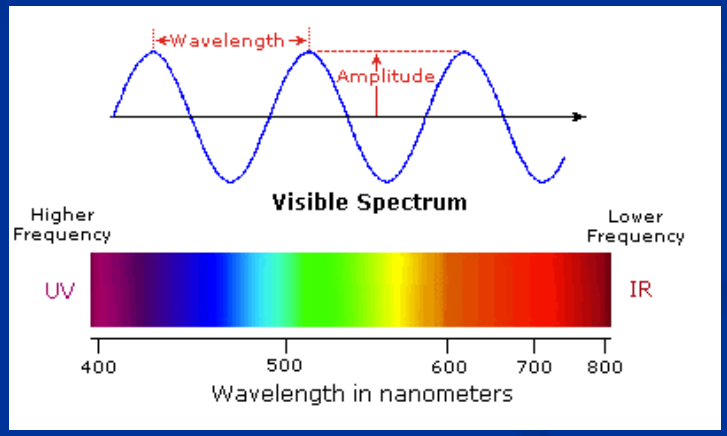
Smelt Bed at Bottom of Boiler

Smelt Water-Explosions

Why Infrared?

Main Visible Image Obscuration is due to Particle Scattering

UV is less than 400 nm



IR is greater than 800 nm

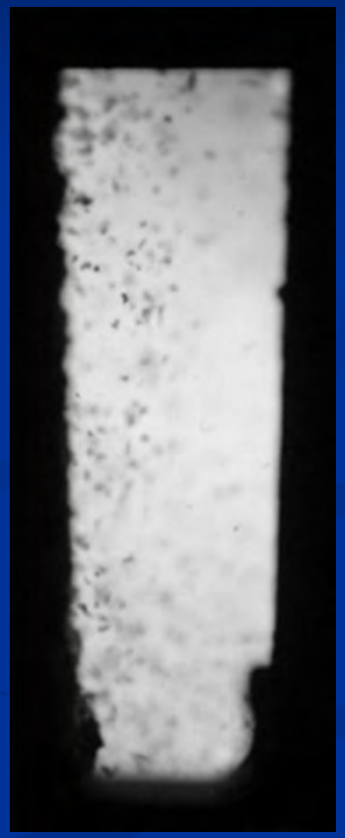
Particle Scattering Decreases as Wavelength Increases

- ~ $1/\lambda^4$ Rayleigh Scattering

So viewing with longer wavelengths is desirable?

IR Imaging in Boilers (Broad-Band)

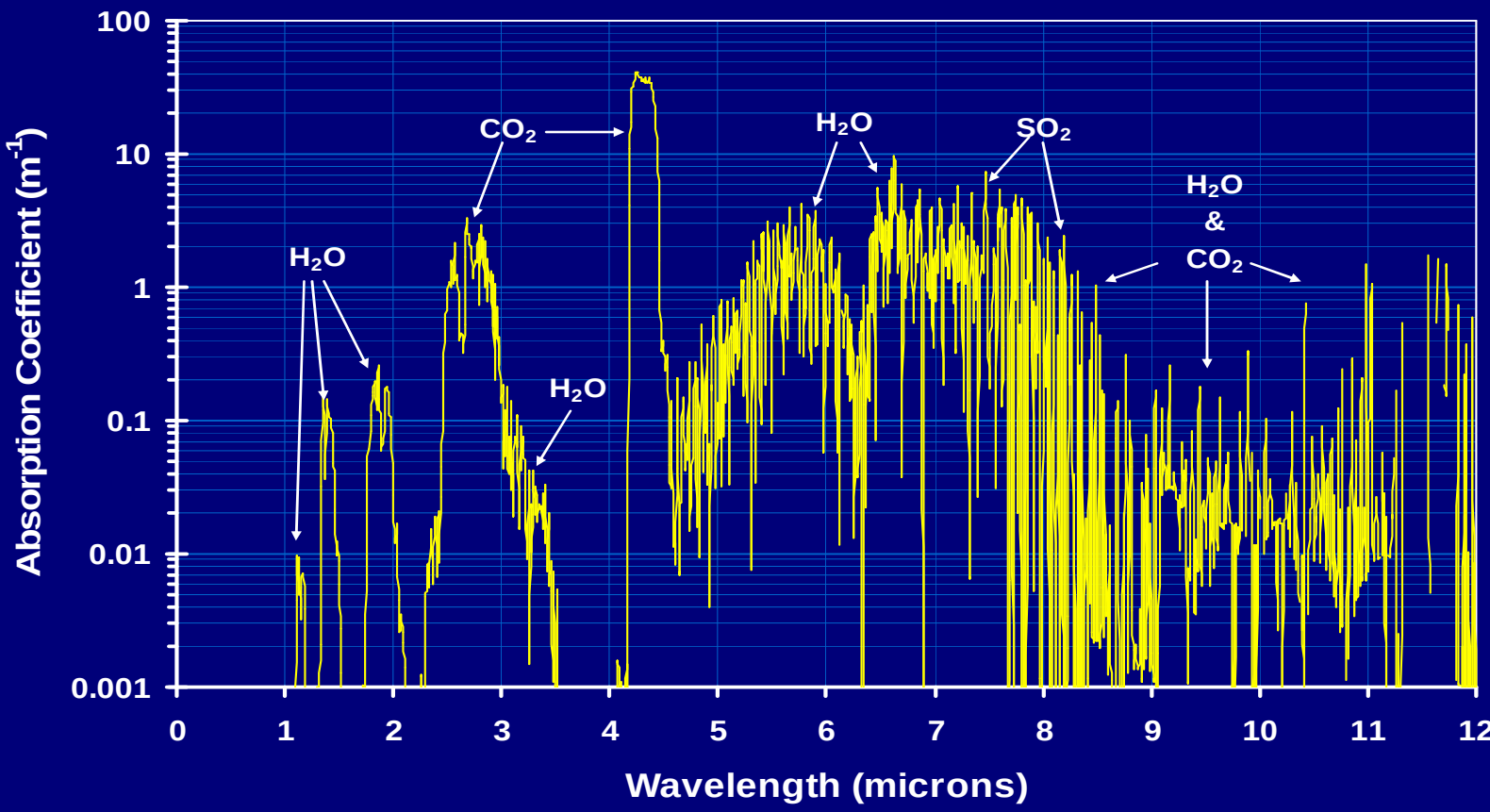
Visible image
through port



IR image
through port

Viewing Windows Limited

Molecular Absorption



Patents 7,437,025 and 7,956,326

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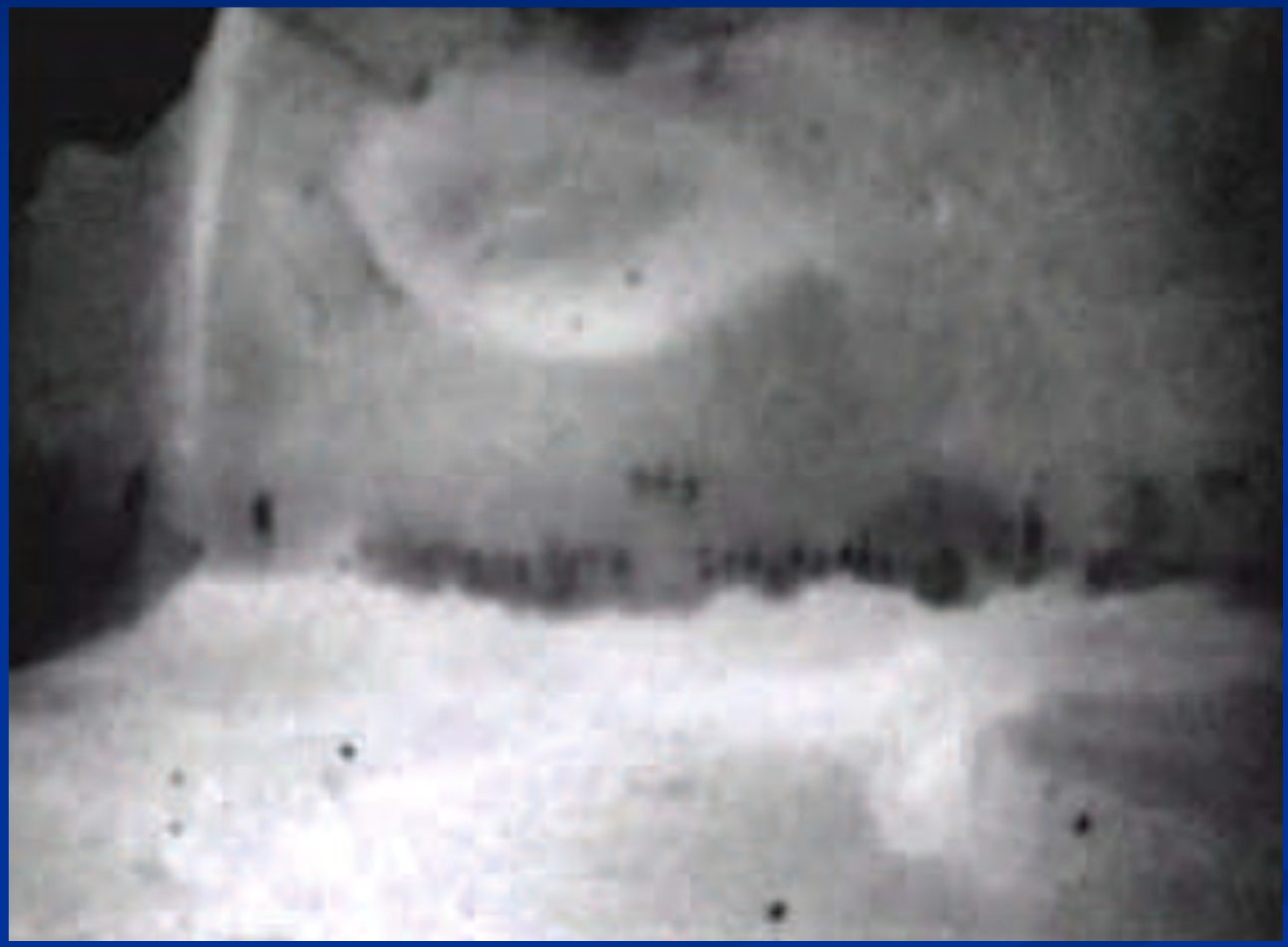
Mid-Wave IR Image



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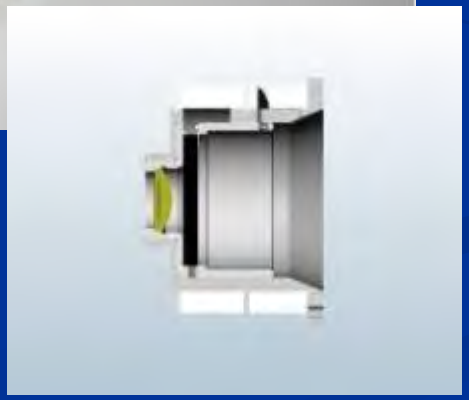
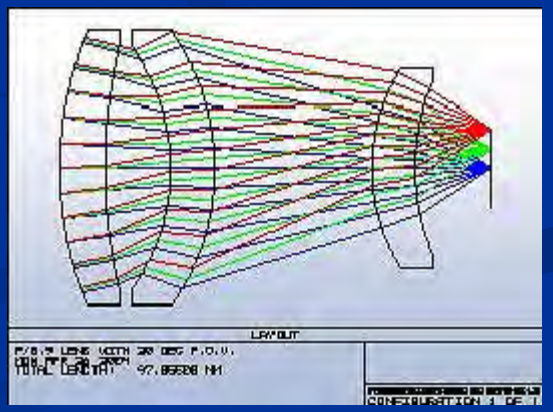
Mid-IR Camera Evolution

- Cooled Scanned Single Detector (HgCdTe)
- Extended Response Vidicons (Gen I)
- Cooled CCD Arrays (PtSI)
- Microbolometer Arrays
  - Ferroelectric (Gen II)
  - Silicon/Vox Arrays (Gen IIIA)
  - Hi Res Microbolometers (Gen IIIB)

Recovery Boiler Application

PyrOptix™ Boiler Inspection Camera





Power Boiler Video

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Other Solution Videos

- Locations
  - You Tube site
    - https://www.youtube.com/user/Enertechnix
  - Web Site:
    - www.enertechnix.com

Fixed Mount/Retract/Port Cleaner

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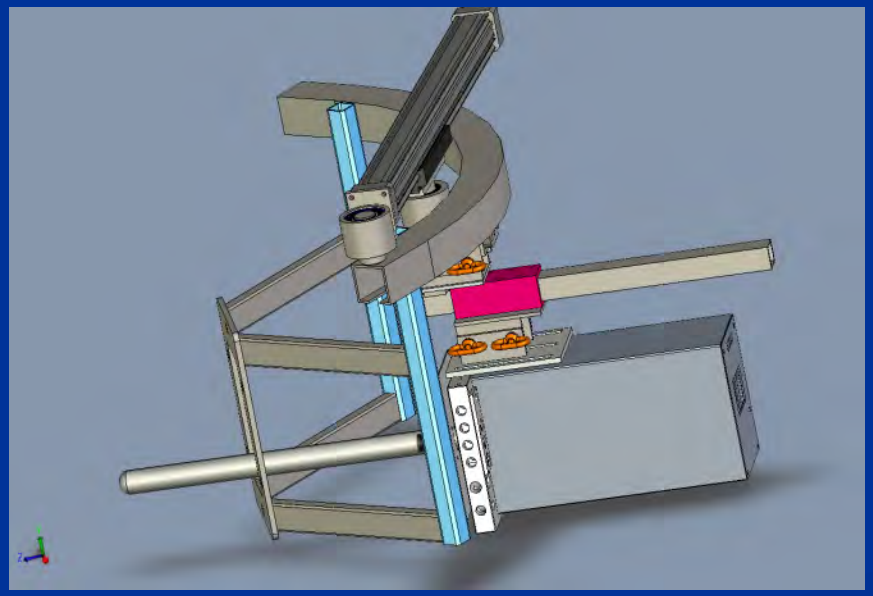
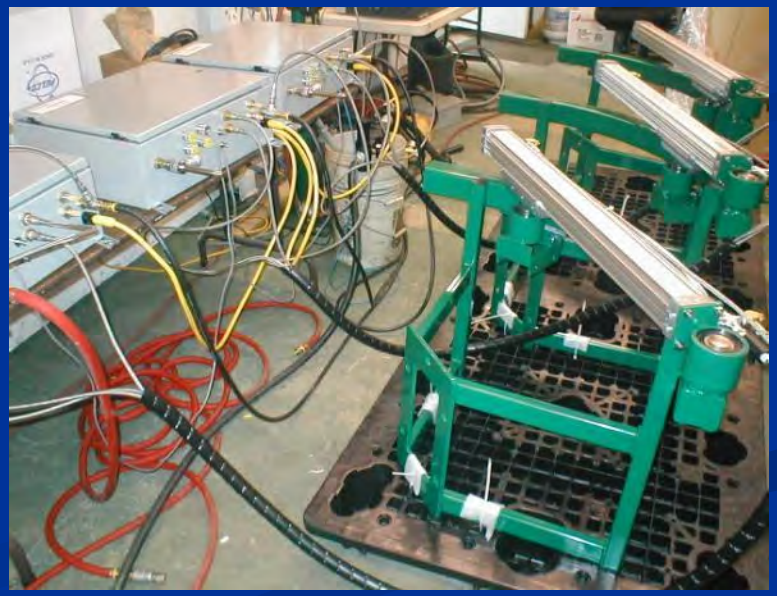
OptiTrack

- Mount swivels around lens tube tip
- View selected by remote in control room
- Product developed for Xcel Harrington Station





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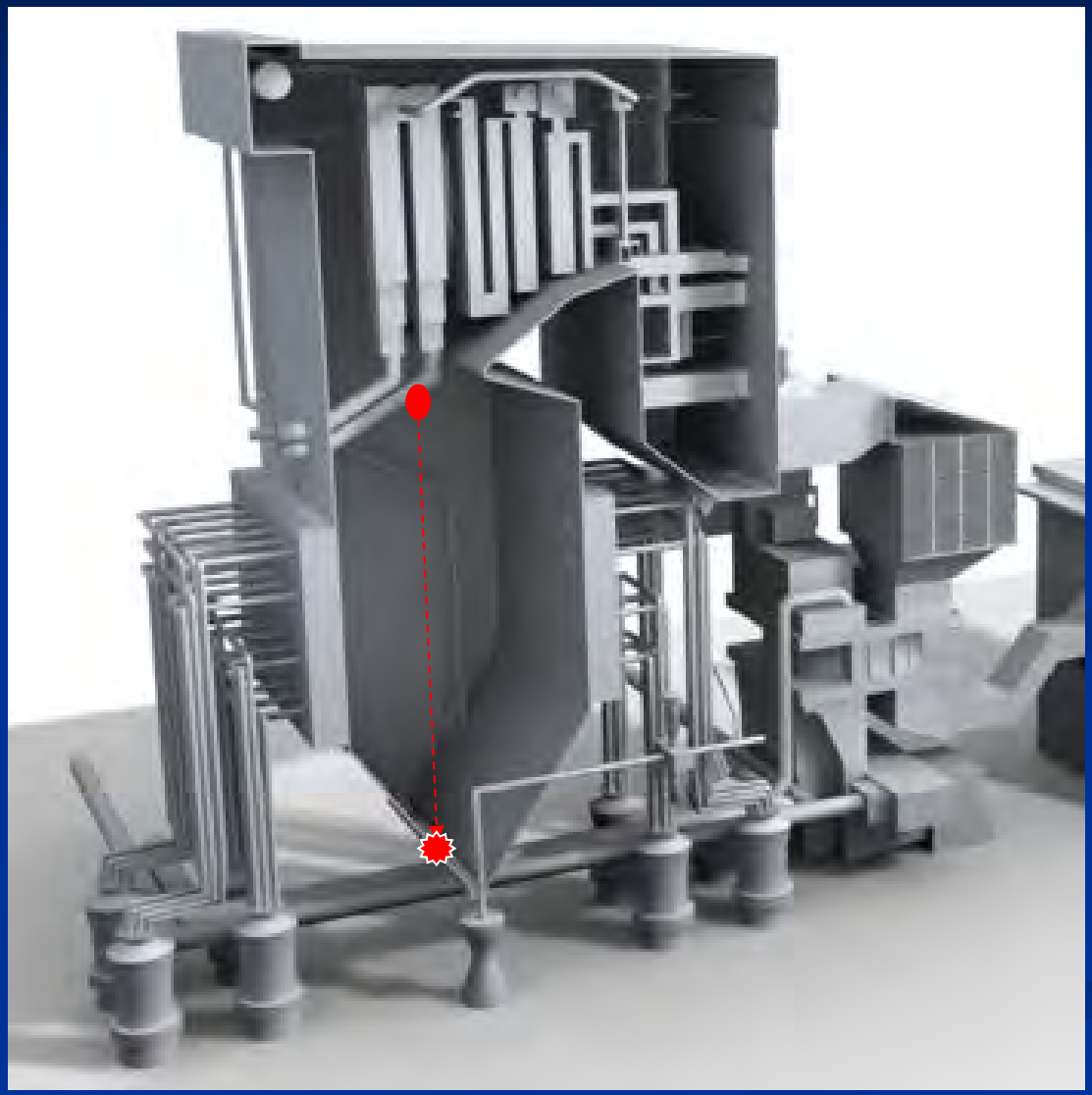
Boilers



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Automation

- Stand-Alone Camera Benefits are Significant
  - But Require Human Interpretation
- Expanded use in **Alarm** or **Closed-Loop Control** Applications requires Feedback based on Computerized Interpretation of the Image
- Enter **Slag Indexing**

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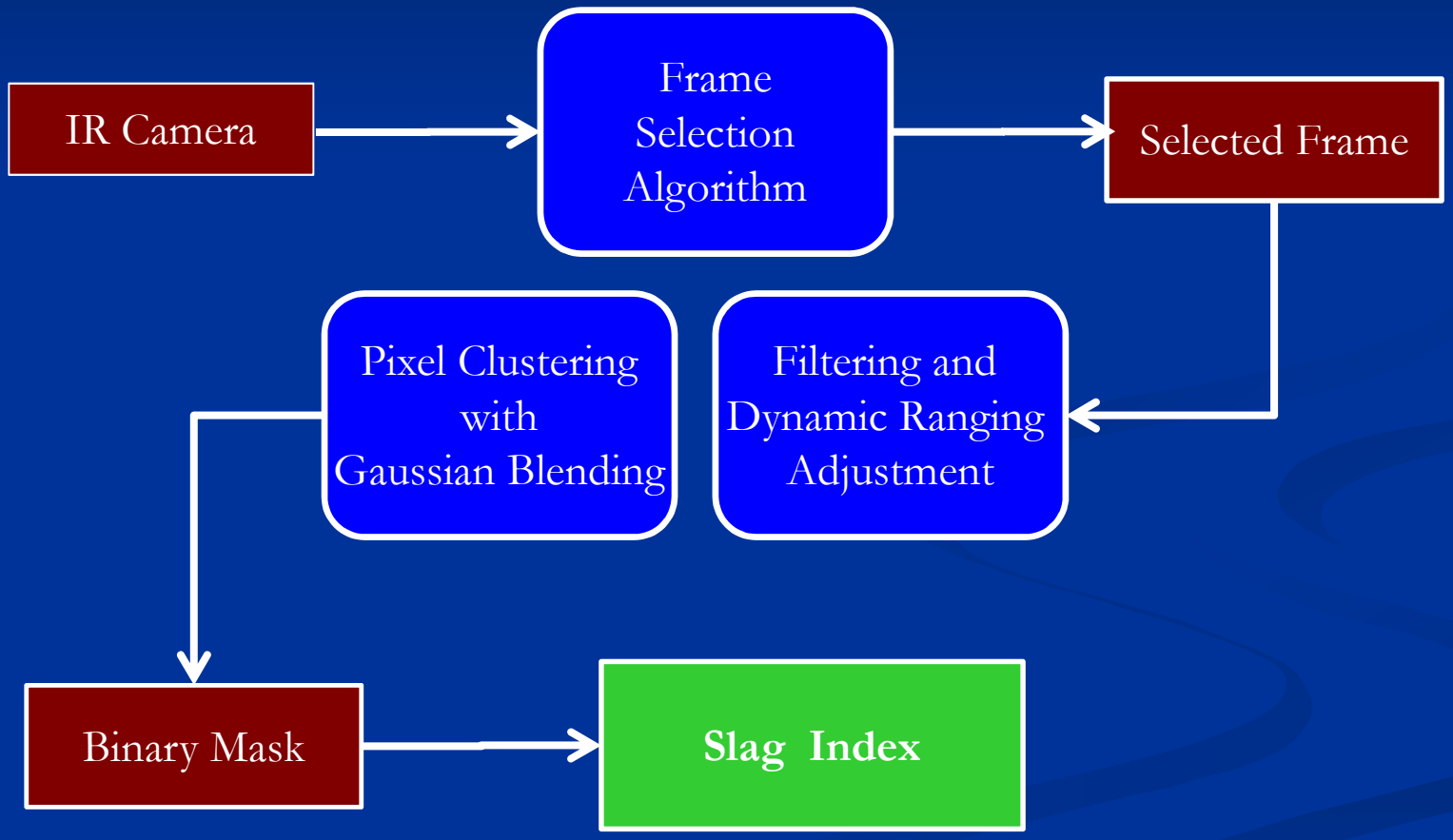
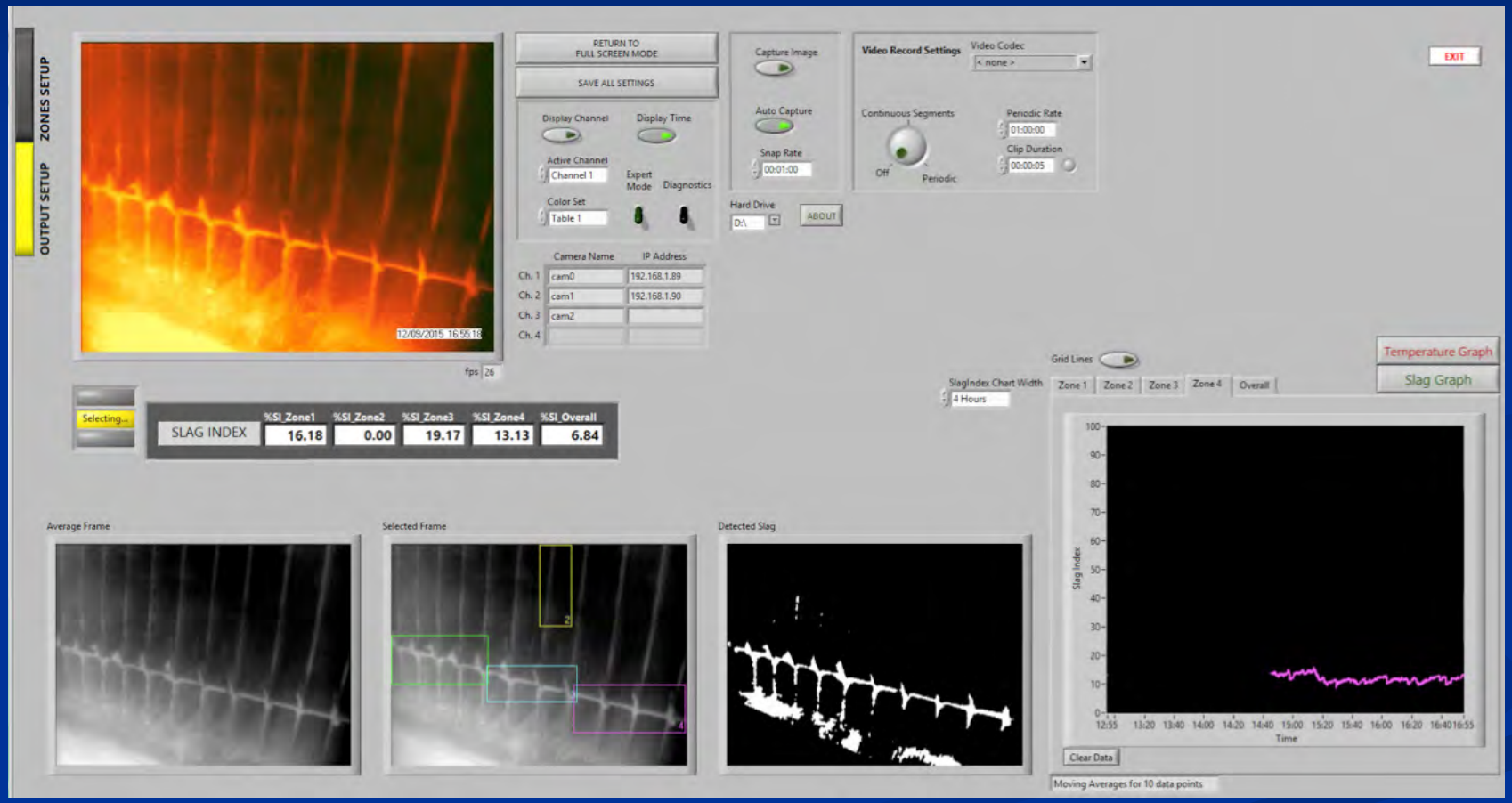
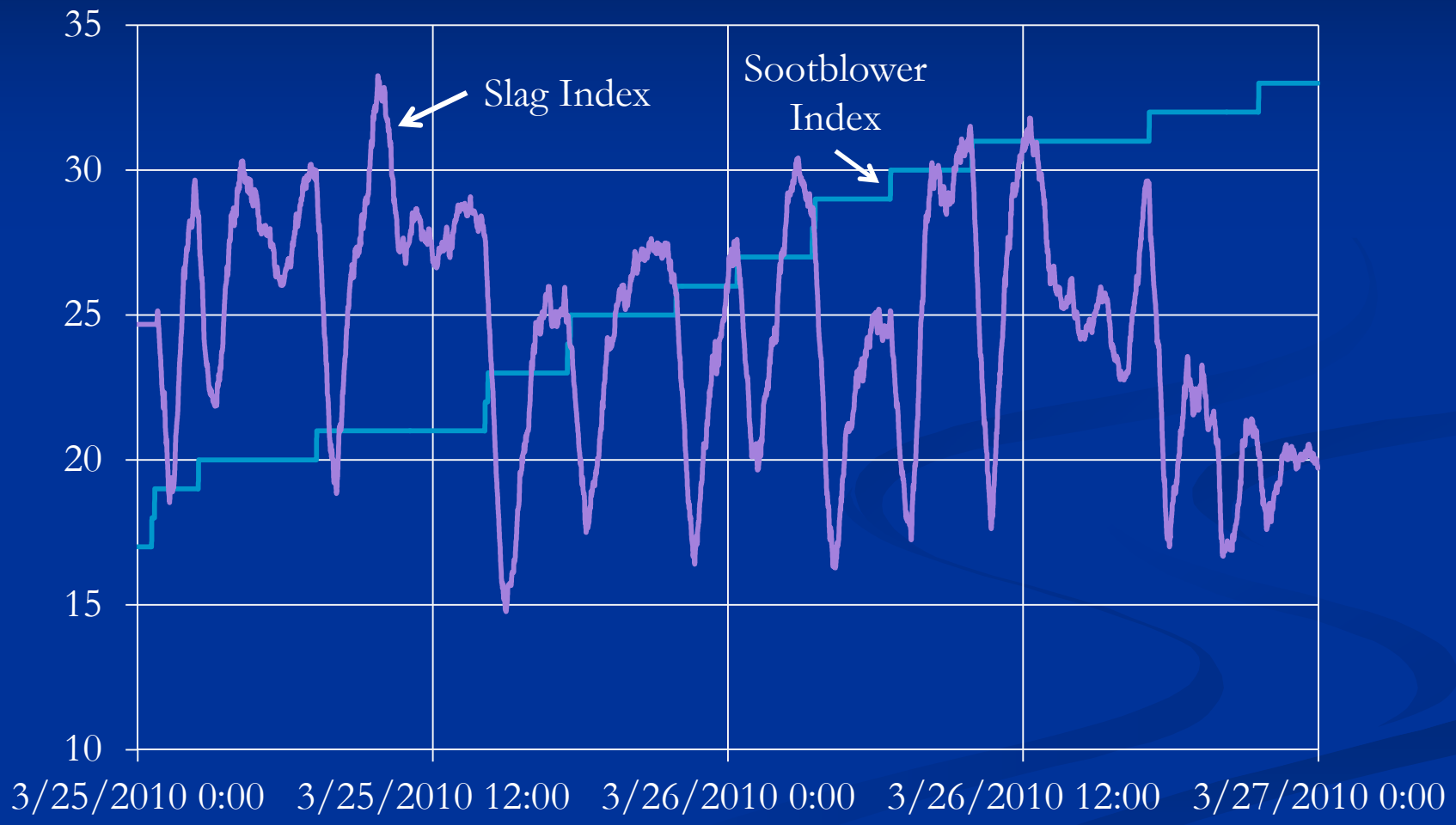
Computer Image Processing



Slag Index Dashboard



Data from Plant using PRB



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Brian Moore

OUC

Stanton

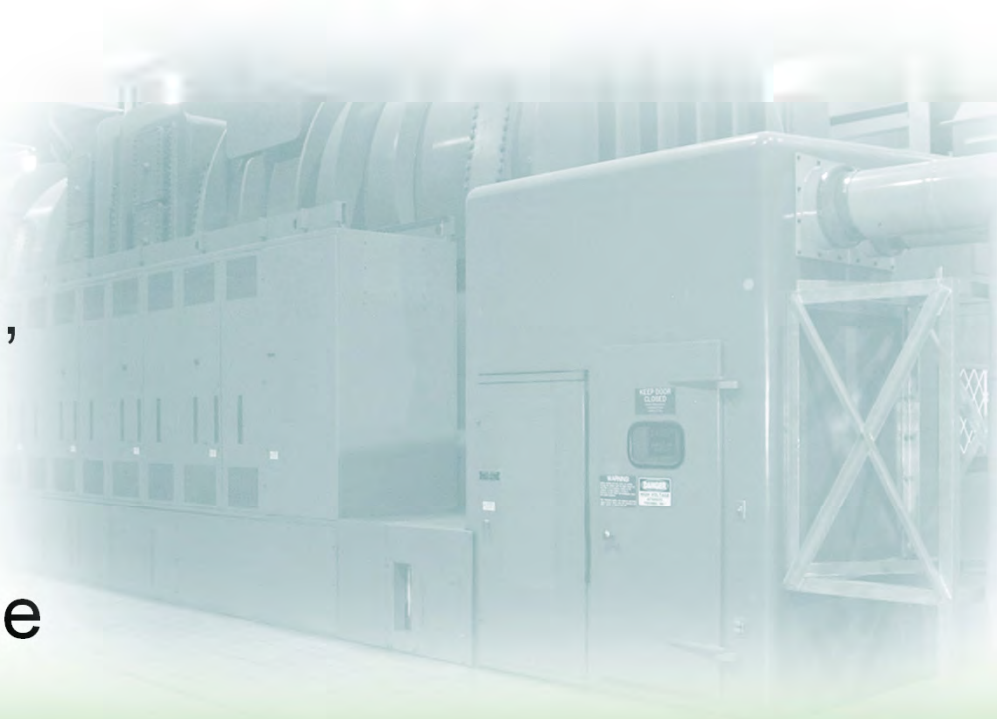
New Technologies for Improving Boiler Performance

Brian Moore, Senior Engineer
Orlando Utilities Commission
Stanton Energy Center
February 2, 2016

OUC The Reliable One

Stanton Site Background

- Began operation in 1987
- 1879 MW (Gross)
- Fuels: Coal, Oil, Gas, Biogas, Solar
- Zero Liquid Discharge



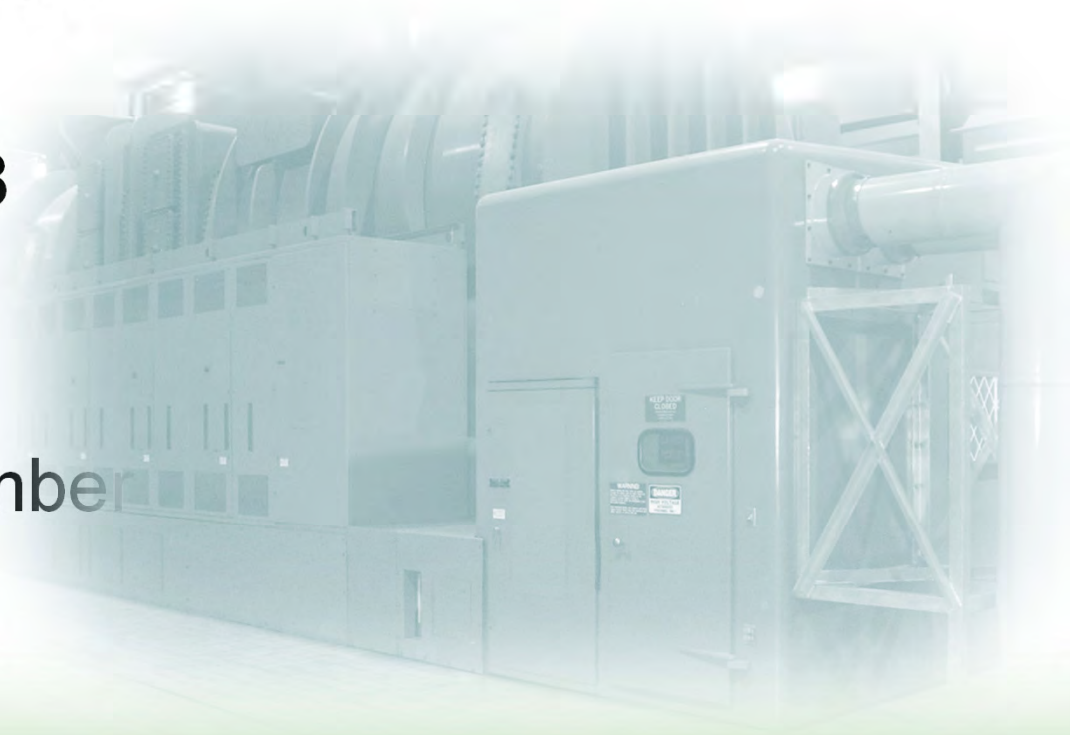
OUC The Reliable One

Environmental Controls

- SO2 Control: Forced Oxidized Wet FGD
- NOx Control: Low NOx Burners, Over Fire Air, SCR (Unit 2)
- Ash: Electrostatic Precips
- Acid Mist/HAPS: Dry Sorbent Injection (hydrated lime), ACI

Fuel Switching

- CAPP to ILB Transition
- 2011 ILB Testing – 8 Weeks
- 100% ILB on September 2015

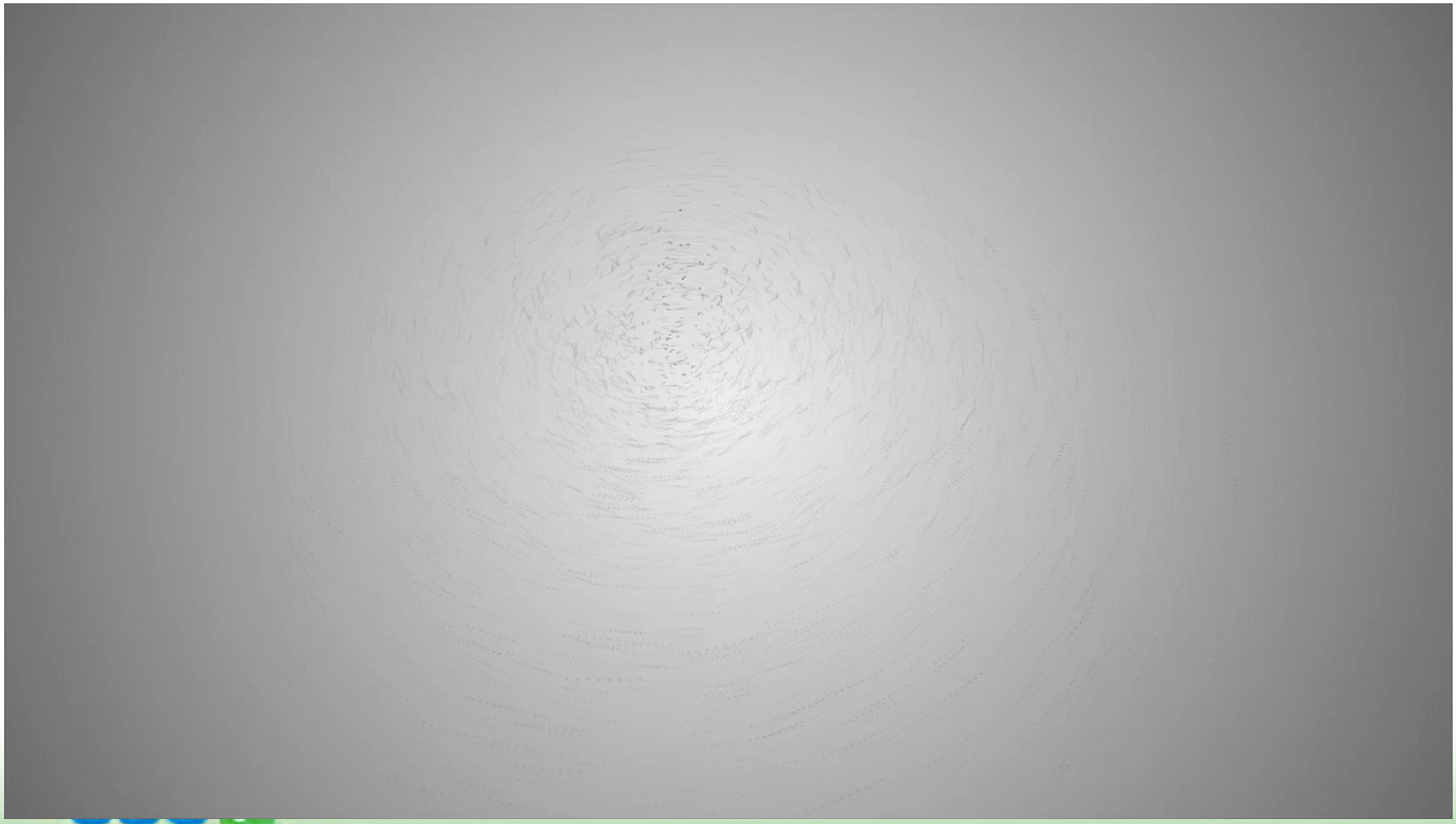


OUC The Reliable One

Enertechnix Camera

- Initial demonstration during 2011 ILB Testing
- Unit 1 installed Oct 2014, Unit 2 Nov 2014
- One camera per unit located at the front wall of boiler
- Provides Operations personnel with visual of upper furnace and superheater pendants

Stanton Time Lapse Video



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Stephen Dean

Duke Energy

Asheville 2

Belews Creek

Infra-Red Camera Applications Supporting Fuel Flexibility

Stephen Dean, Strategic Engineering, Duke Energy

Duke Energy Fuel Flexibility

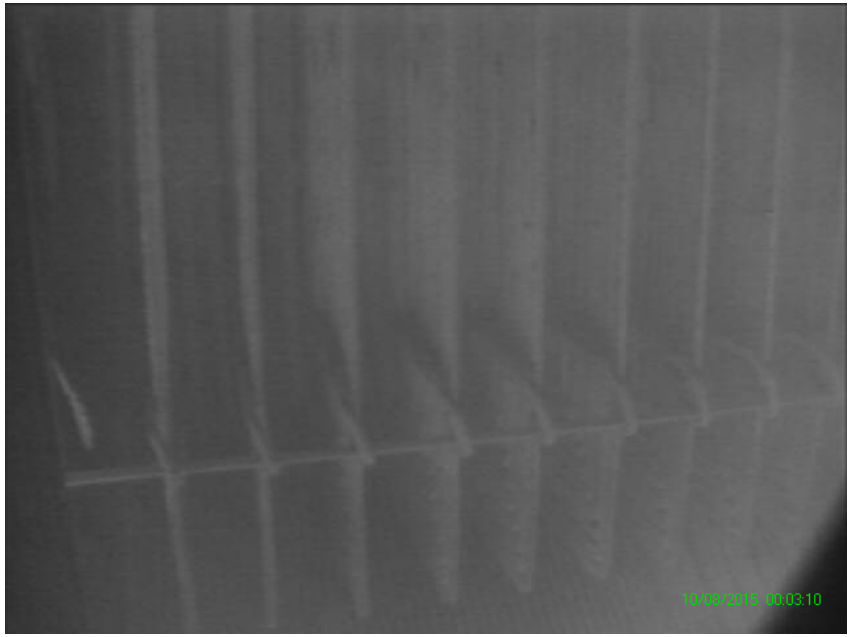
- Coal units designed to burn low ash, high ash softening temperature coals can be challenged to burn ILB & NAPP region coals
- FEGT, chemical addition to adjust ash fusion temperatures, diligent maintenance practices of sootblowers and instrument calibration, along with consistent fuel blending all become critical to successful operations
- Asheville, Allen, Marshall, Belews Creek, Roxboro & Mayo are all stations in NC being challenged with Fuel Flexibility

Duke Energy Fuel Flexibility

- Visual inspection through available viewports has always been a reliable way for operators to monitor ash build-up in their units
- Ash build-up where furnace pendants bridge can happen quickly leading to reduced thermal performance and channeling of flue gas/flyash and tube wall loss

Fuel Flexibility + IR Cameras

- Visual inspections of ash build-up can be difficult to see at high loads and dependent on viewport locations and inspector training.
- Infra-Red cameras see through the bright “shine” at high loads and are continuously available.

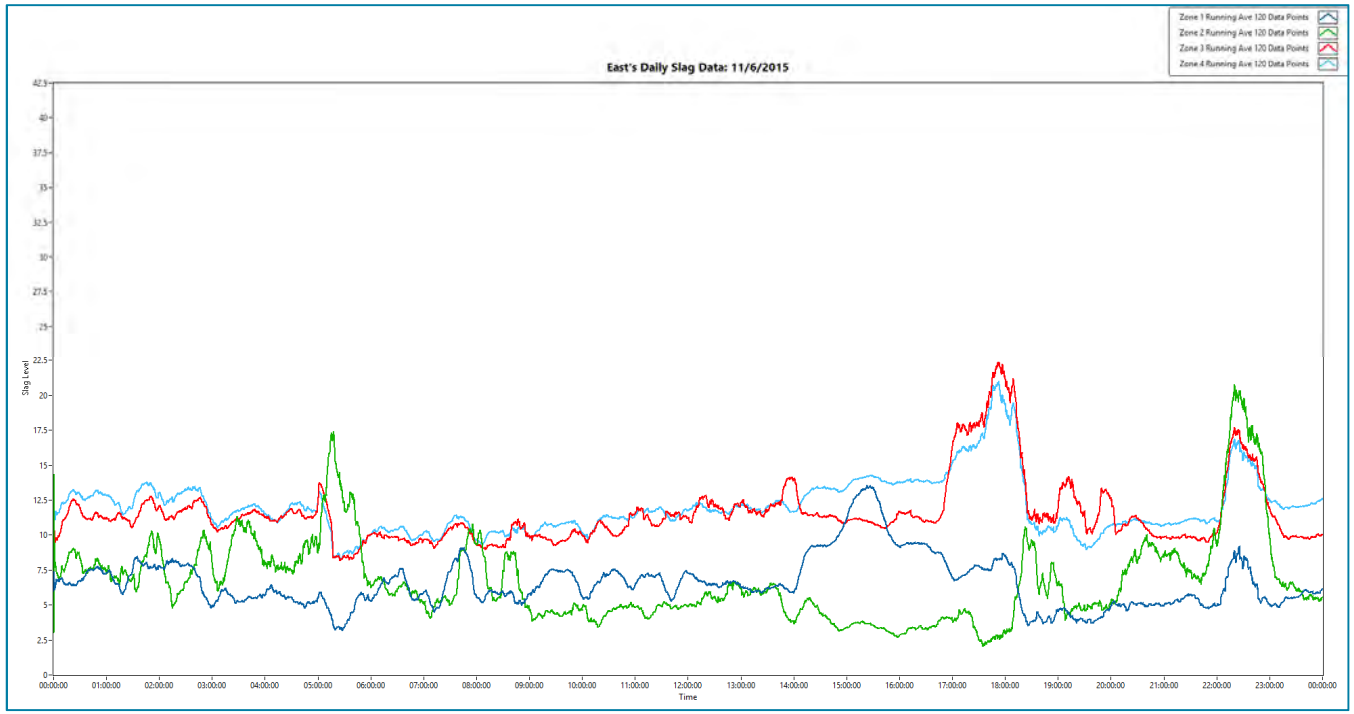


Fuel Flexibility + IR Cameras + Slag Index

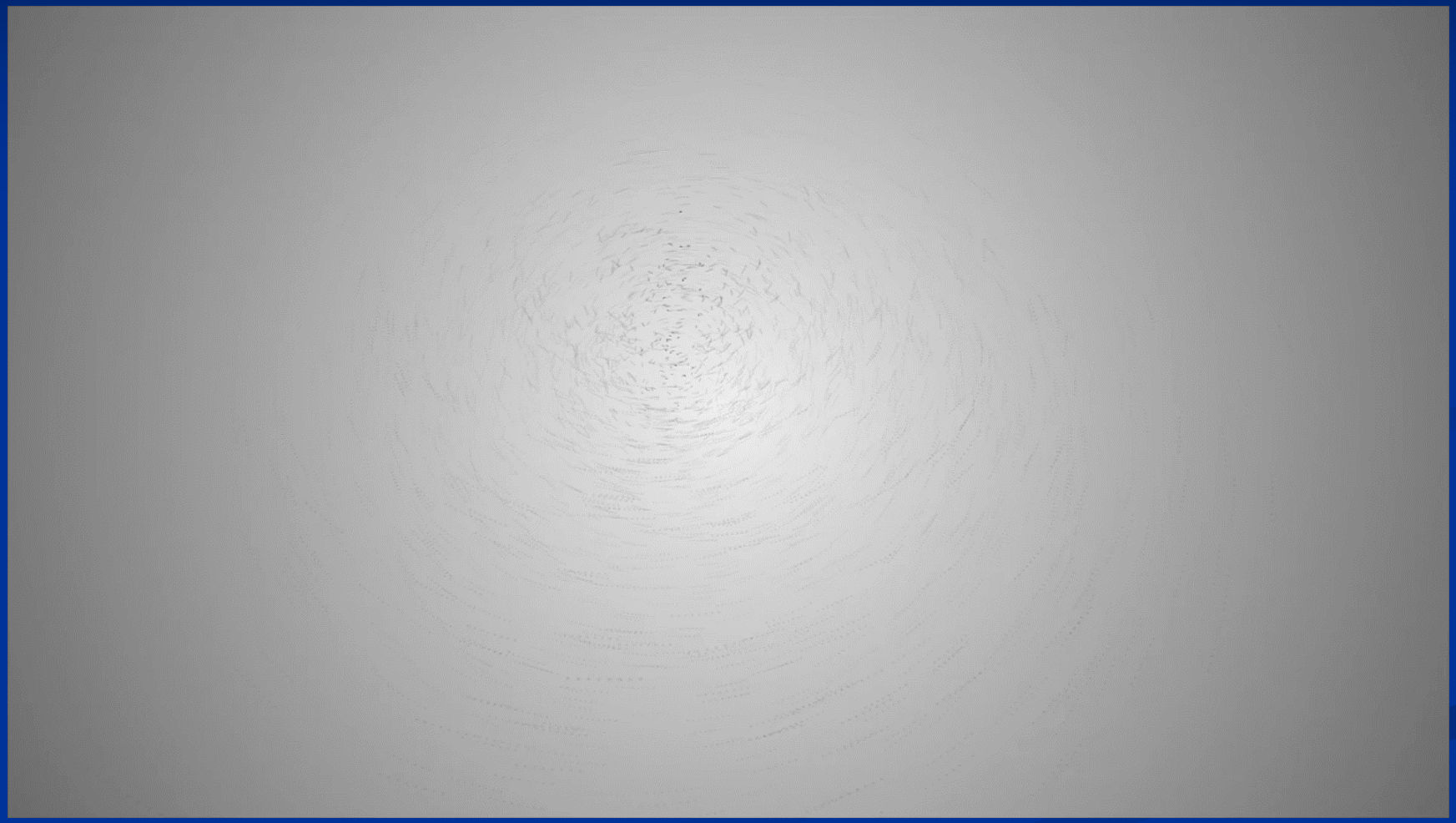
- Initial use of the IR cameras in something other than a temporary hand-held application was during a chemical addition trial in Asheville, Fall 2015
- This was also the first time using the Slag Index tool
- Videos, compressed video's, Daily Slag Index trends along with the live video/SI feed from the data collection PC were all available throughout the 45 day trial
- IR cameras + SI provided an extra set of eyes on the suspected slagging regions of the furnace giving the test team and station management confidence in the chemical reduction trial

Fuel Flexibility + IR Cameras + Slag Index

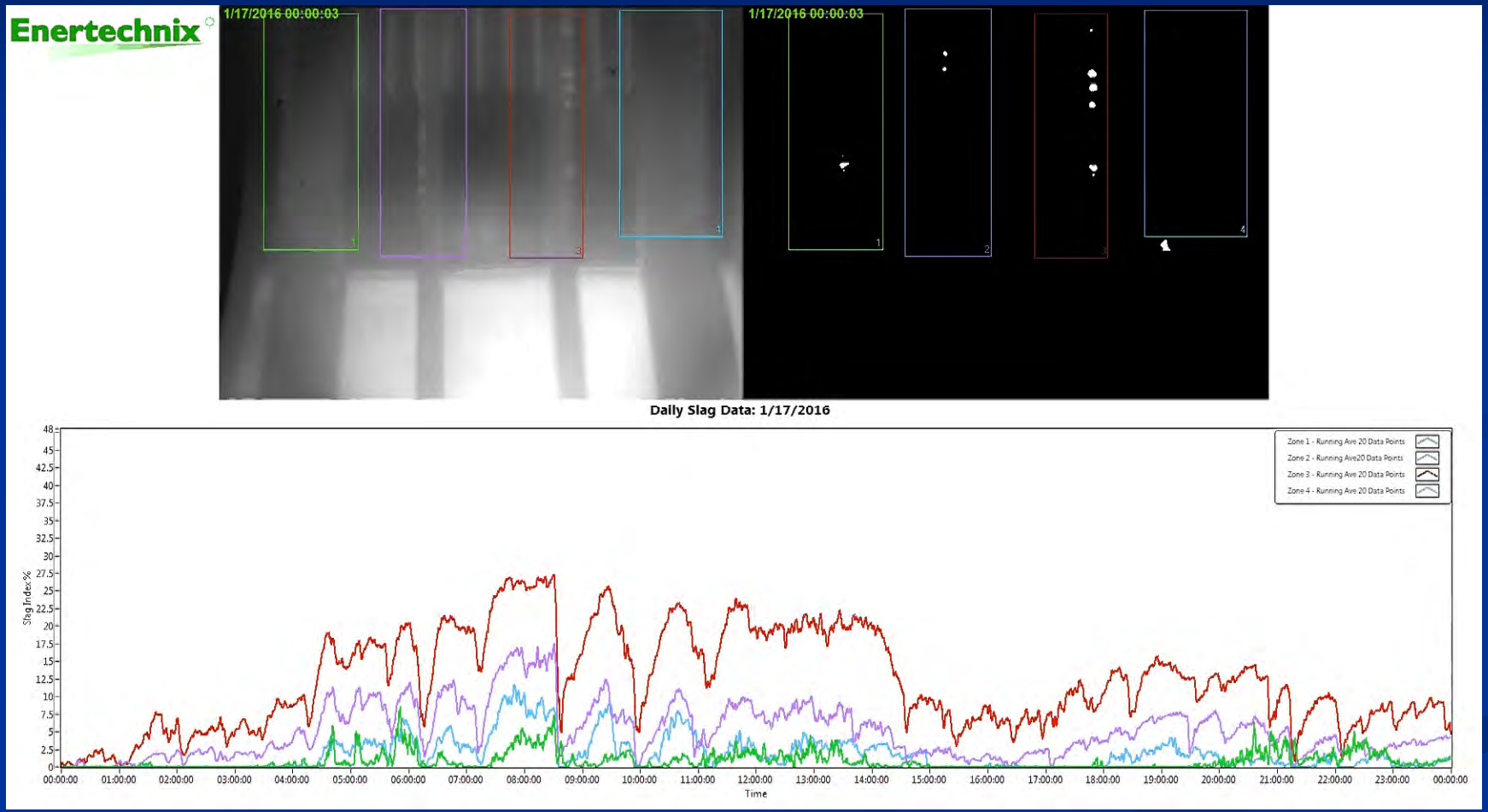
- Future test burns will include the portable IR cameras with SI software
- **Quantification of the slag build-up** throughout the test, correlated with unit operating data and coal analyses, provided new insight to operations with chemical addition
- Permanent camera installation @ Belews Creek complete and functional



Belews Creek Time Lapse Video



Sample Daily Report



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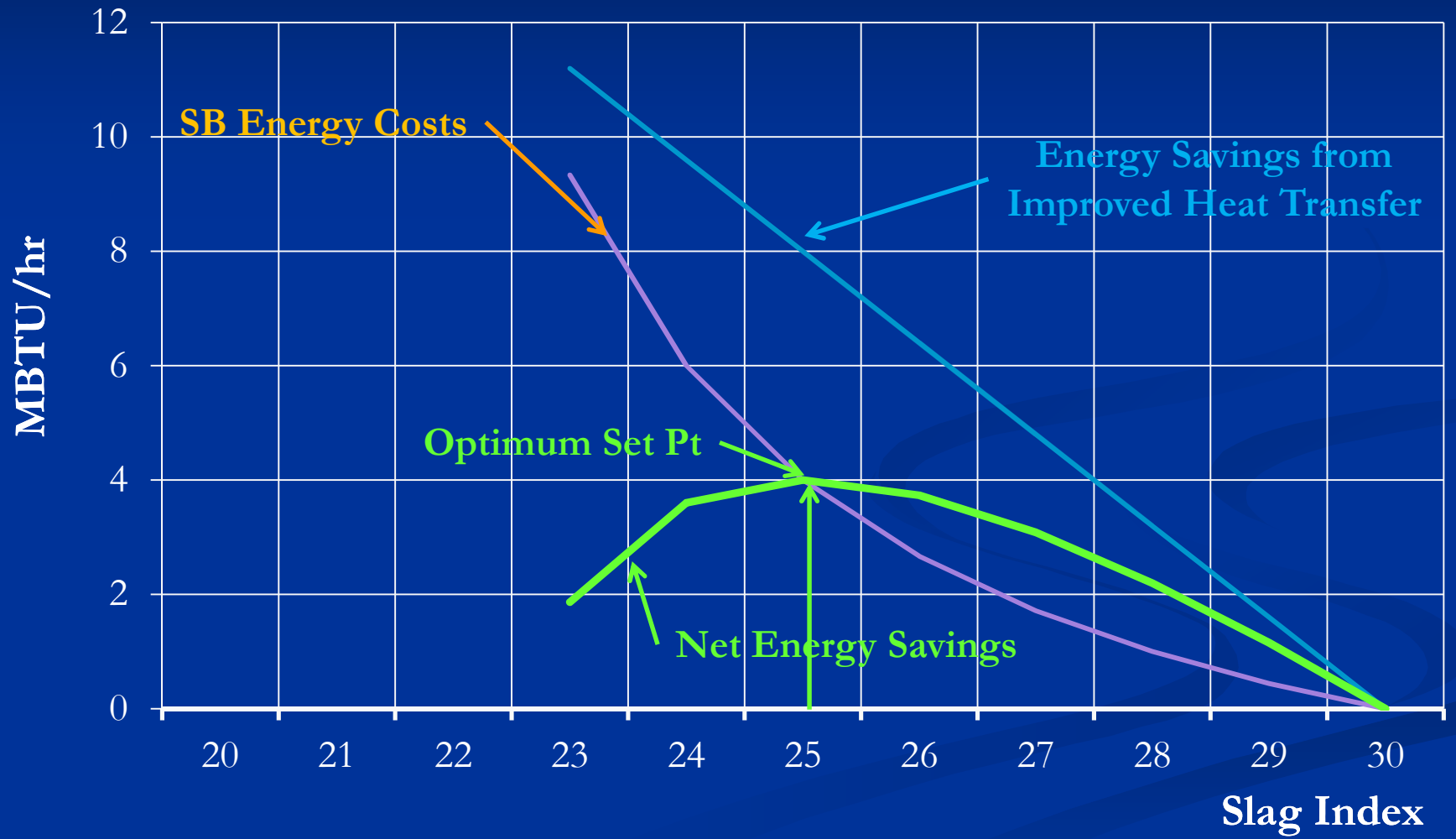
Quantifiable Benefits

- Maintenance Cost Reduction
- Reduced De-Rate
- Improved Steam Consumption
- Heat Rate Improvement
- SO_3 Reduction

Improved Heat Transfer



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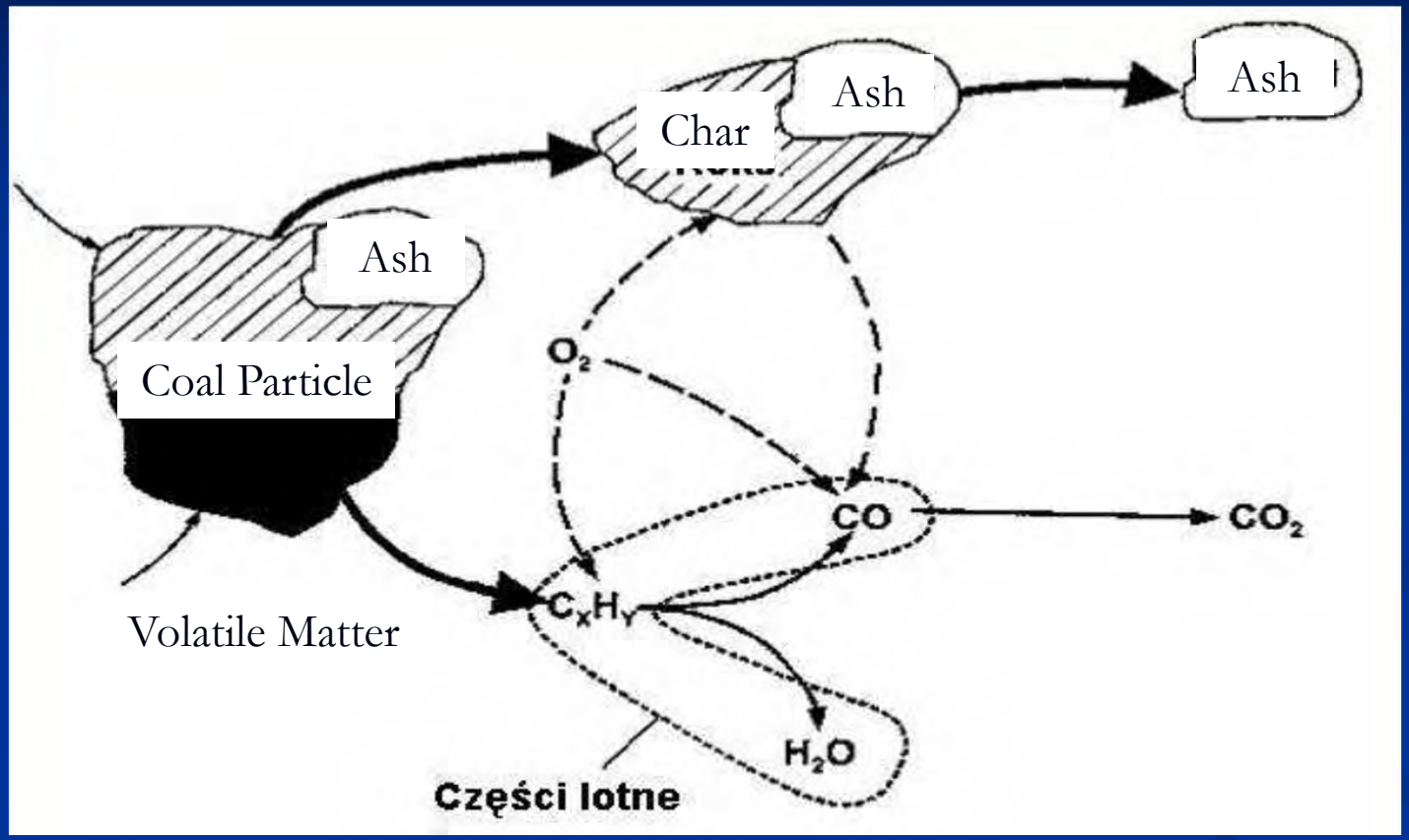
Questions

More Slag Management

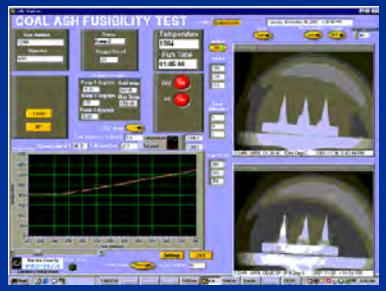
Coal Combustion is Complex



Molten Particles are Retained whereas Much of the Dry Ash Rebounds and is Re-Entrained in the Flue Gas

Ash Fusibility Test

- Ash Fusion Temperature
  - Stages of Softening and Flow



Index	Low	Medium	High	Severe
Ash Fusibility	> 2450 F	2250-2450 F	2100- 2250 F	< 2100 F

- Limitations
  - Weak Reproducibility, Variability up to 360 F
  - Ash Samples Reacted at Temps < Initial Deformation Temperature
  - Intrinsic Coal Variability

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Most Temp Measurements Limited

- Contact Methods (Thermocouples)
  - Single Point Measurement
  - Survivability
  - Radiative Corrections
- Optical Methods
  - IR Pyrometers: Short Range
  - Ash Particle Measurements: Need Presence of Ash in Certain Concentrations
  - Diode Laser Measurements: Alignment; Optical Maintenance

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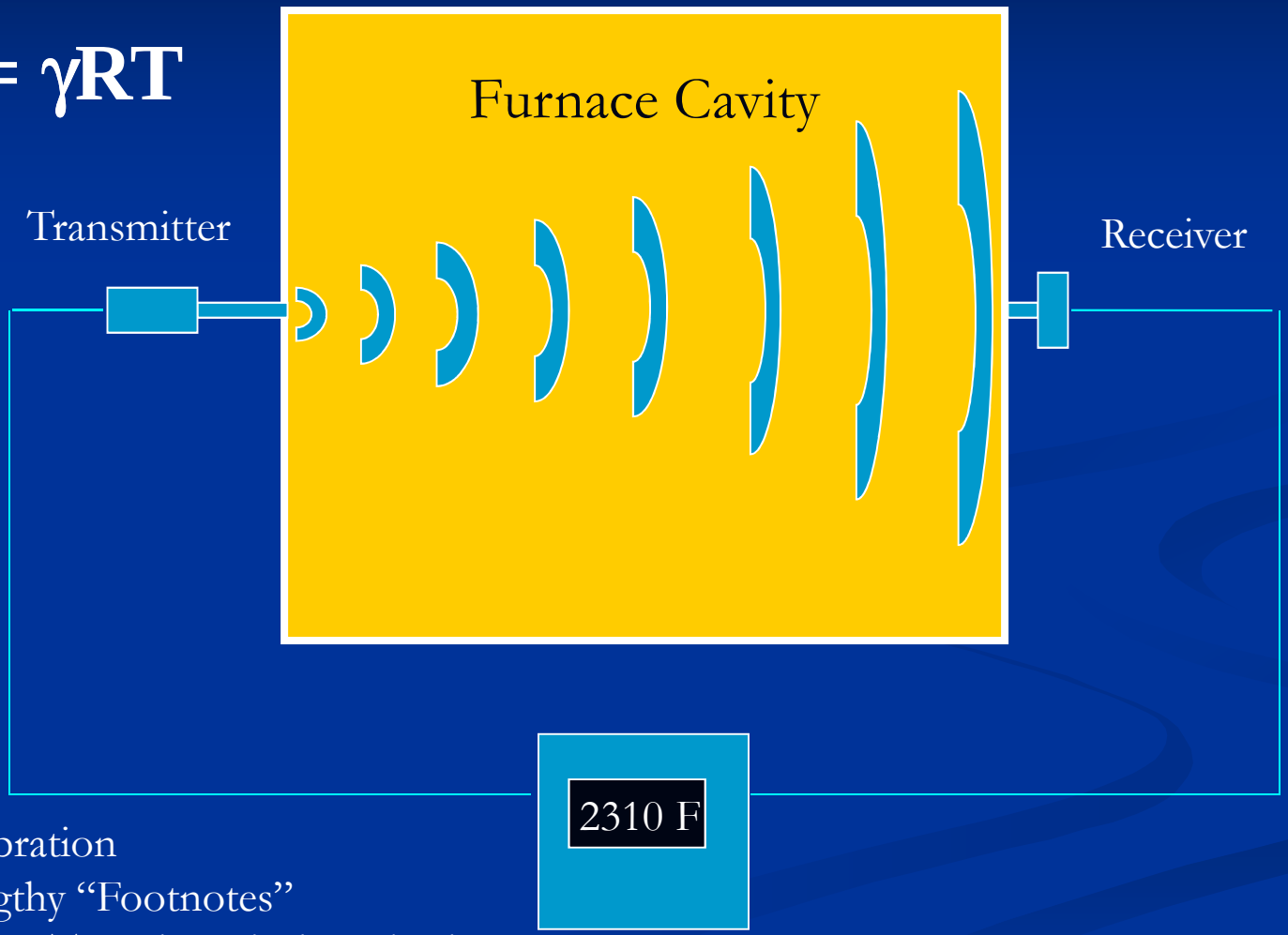
Acoustic Pyrometry

$$c^2 = \gamma RT$$



No Calibration
No Lengthy "Footnotes"
c.f. HVTs and Optical Methods

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Key Challenge

- Boiler Gases are Highly Attenuating
- Therefore Need
  - **High Energy Sound Source**, or
  - **Sophisticated Signal Processing**, or
  - **Both**

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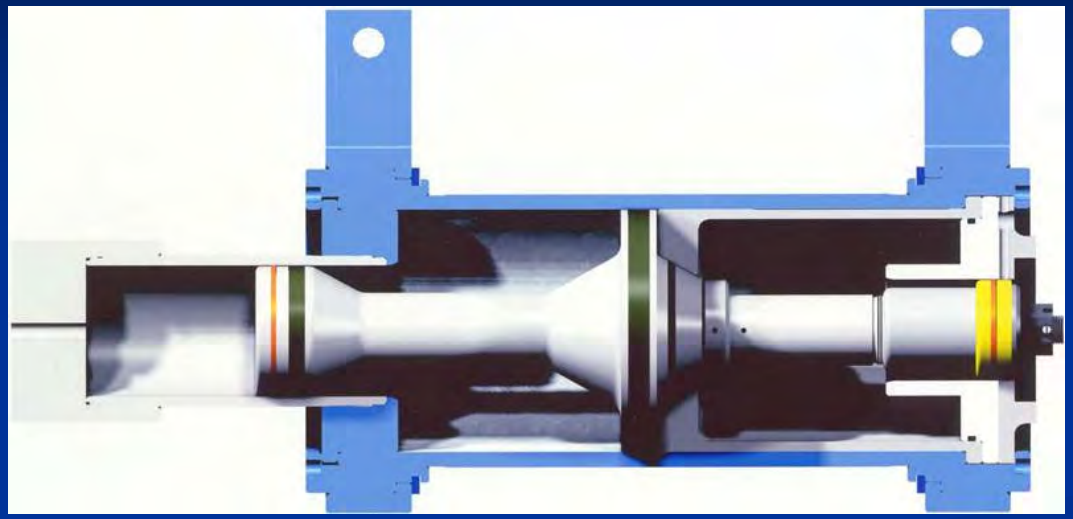
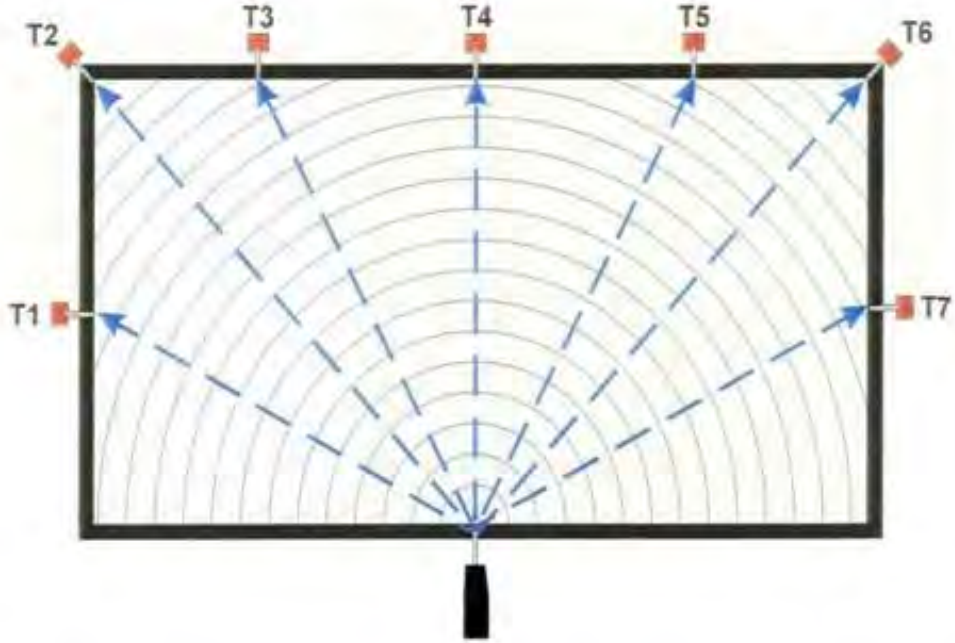
High Energy Sound Source



- Loud Sharp Acoustic Signal Generator
  - Uses Only Plant Air
  - Only Requires 2.5” Penetration

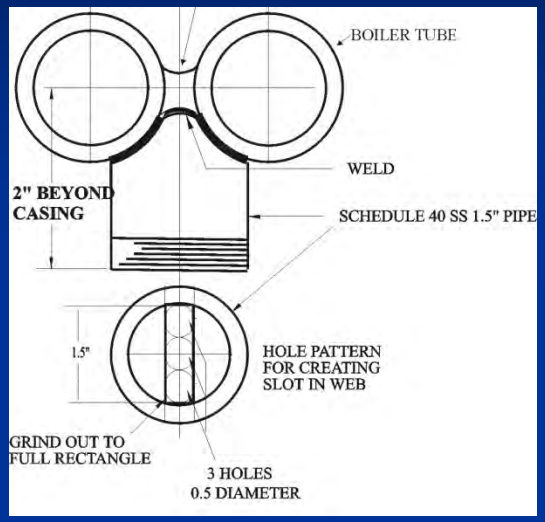
Practical Advantages

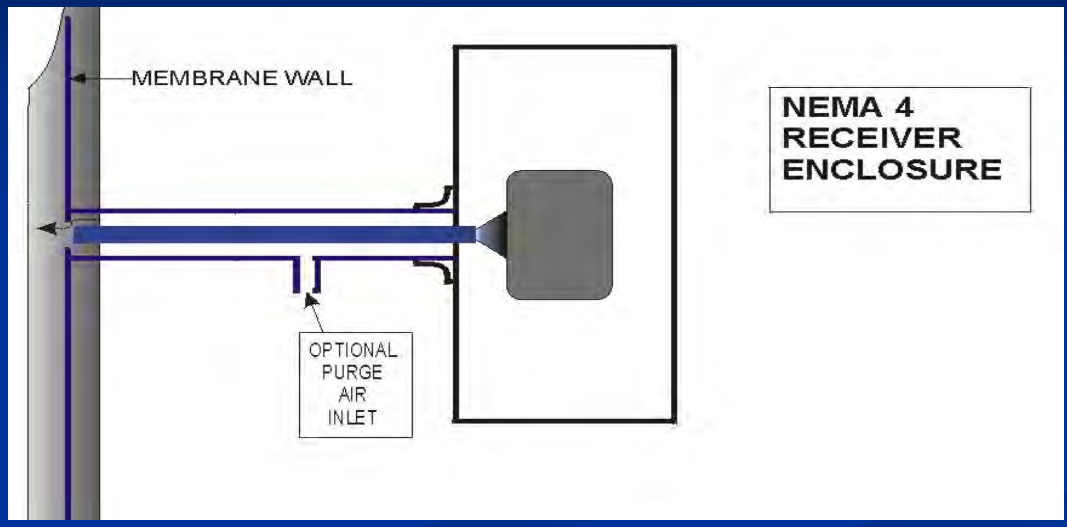


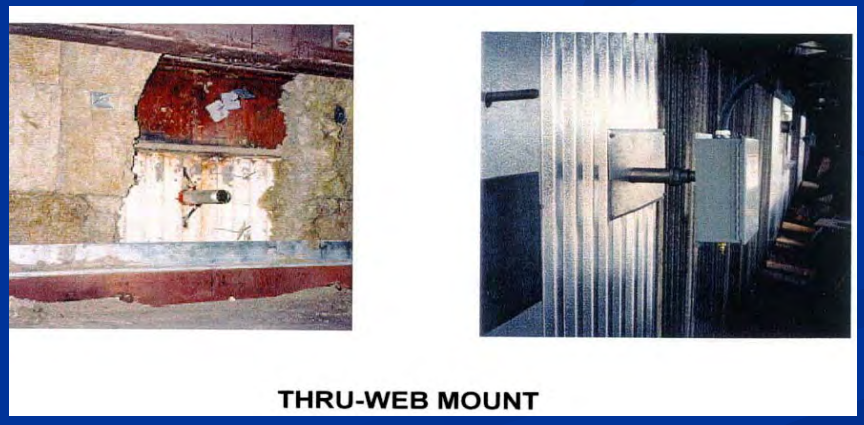
A SINGLE GENERATOR CAN PROVIDE SIMULTANEOUS SIGNALS TO MULTIPLE RECEIVERS AT VARIOUS ANGLES.

THIS PROVIDES SOLID, COMPARATIVE GAS TEMPERATURE DATA BETWEEN THE MEASUREMENT PATHS.

Simple, Inexpensive Receiver Installation







THRU-WEB MOUNT

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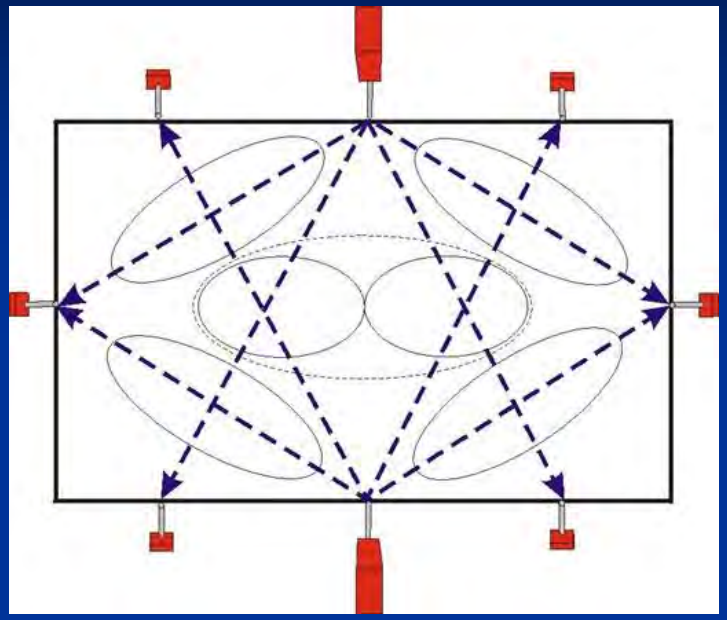
"Standard" Configuration



W

N

2316F

2535F

2411F

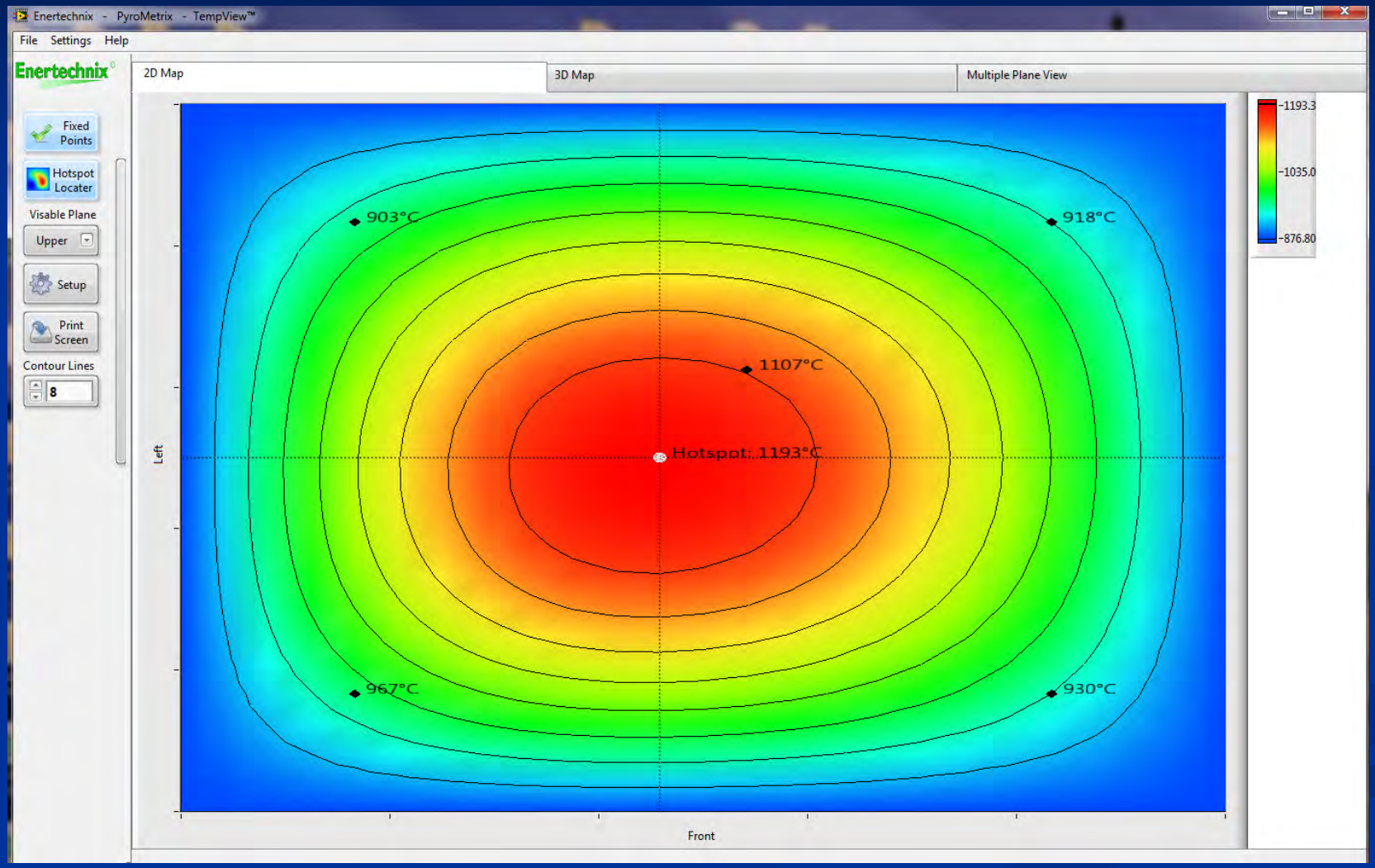
E

2290F

2303F

S

Temp Map: TempVIEW



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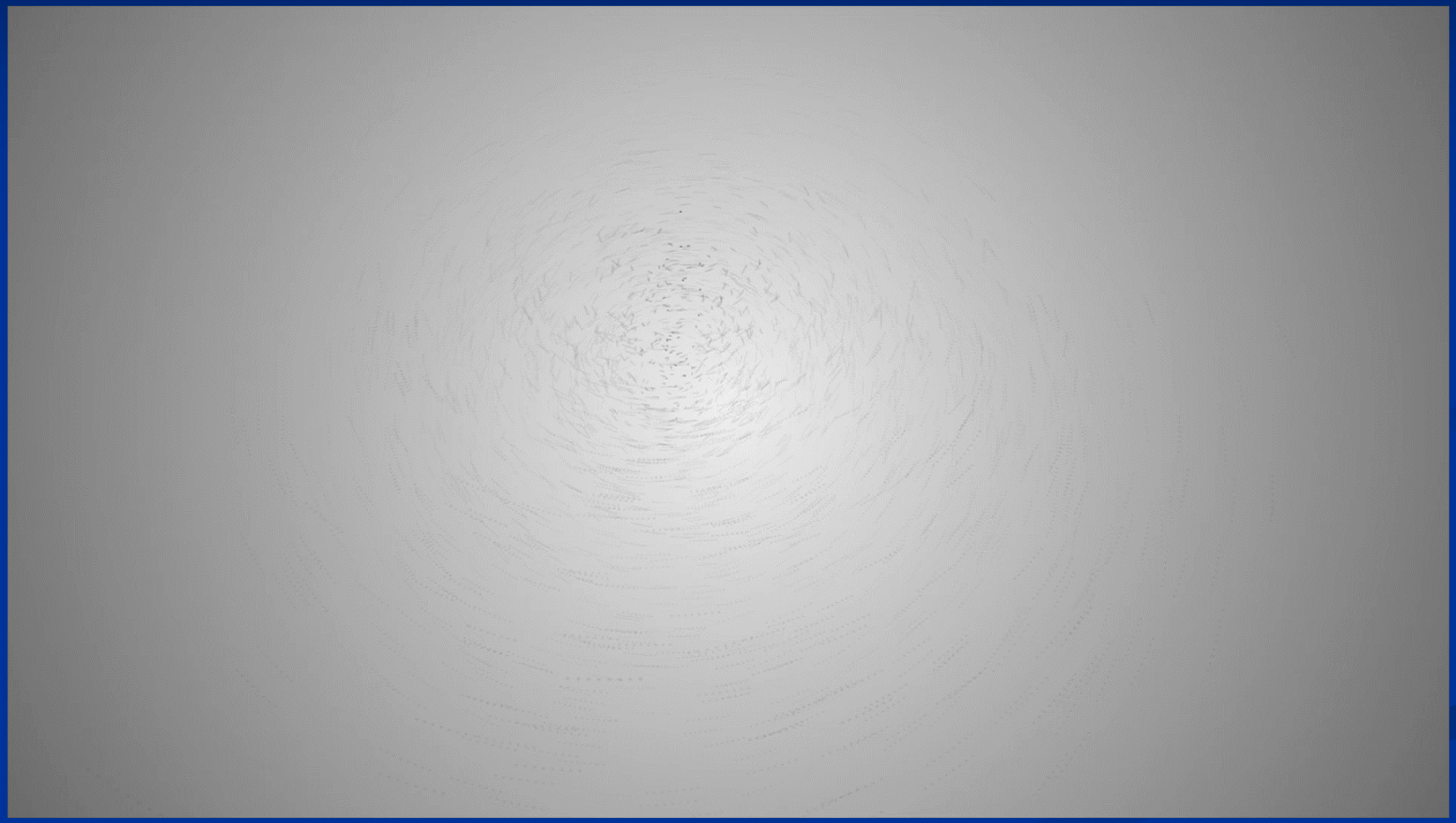
Example: Ninghai

- Latest Boiler Servicing Shanghai (1,000 MW)

Boiler Startup Data



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Combining AP and IR to Control Slagging

- IR Imaging Monitors Slag Formation in Upper Furnace
  - Shows Impact of Slag Depositions
  - Guards Against "Slag Monsters"
- Gas Temperature in Lower Furnace Controls Slag Formation
  - Helps to Keep Temperature Below Ash Fusion Temperature
  - Can be Monitored Using Acoustic Pyrometry

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Enertechnix

Thank You!

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Acoustic Pyrometry: Simple Physics

- Universal Gas Law

$$p = \rho RT$$

- Speed of Sound Related to Material Properties

$$c^2 = \gamma p/\rho$$

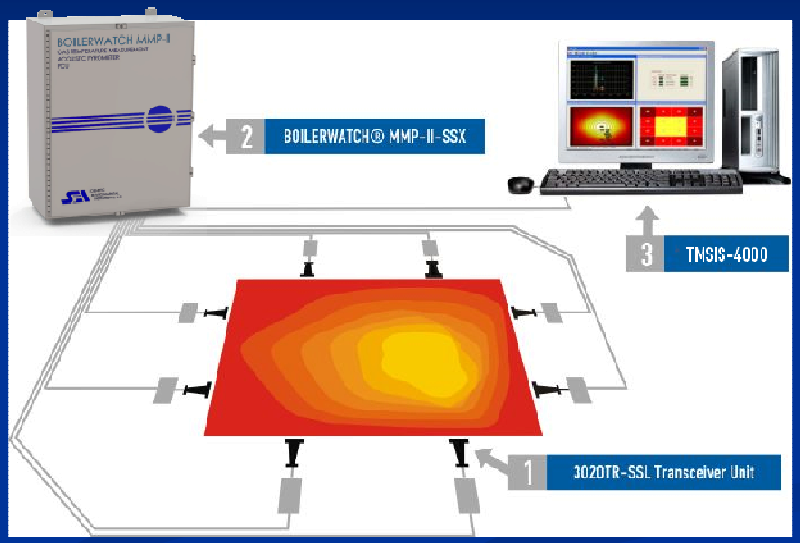
- Sound Speed Related to Temperature

$$c^2 = \gamma RT$$

No Calibration
No Lengthy "Footnotes"
c.f. HVTs and Optical Methods

Low-Energy Acoustic Pyrometer

- Method
  - Uses "Chirp" Source and Cross-Correlation
  - Large Horn Penetrations
  - Source Easier to Maintain



- Limitations
  - More Susceptible to Interferences (SB, Echoes, etc.)
    - Limited to Smaller Boilers
  - Accuracy Difficult to Verify
  - Difficult to Expand System (Large Penetrations)