Combustion Performance and Emissions Optimization through Integration of Miniaturized High-Temperature Multi-Process Monitoring System

May 20, 2021

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NATIONAL ENERGY TECHNOLOGY LABORATORY

2021 Spring Project Review

For Energy and Environmental Solutions

REACTION ENGINEERING INTERNATIONAL

Disclaimer

No proprietary information is included in this presentation

Agenda

- Project Overview
- Technical Discussion
  - R&D in Pilot-scale Testing Facility
  - Demonstration at Leland Olds Station
  - Summary
- Plan

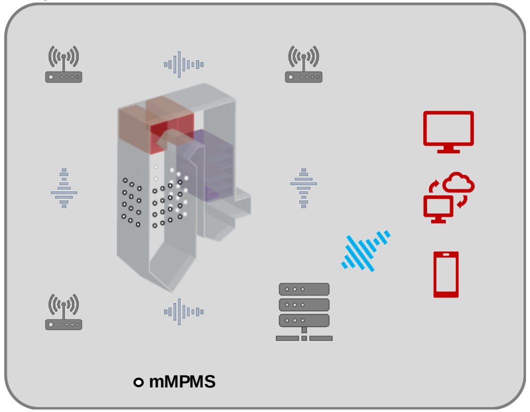
Reaction Engineering International

- Founded 1990 with Strong University and Specialist Affiliations
- Managed more than 40 government R&D projects in the past 15 years
- Has both management experience and technical expertise in the combustion and gasification related R&D programs
- Expertise
  - Combustion, Gasification, Fuel Conversion & Pollutant Emissions
  - Unique, Proprietary Modeling Capabilities & Tools
  - Laboratory and Field Testing
  - Specialized Equipment & Controls

Project Objectives

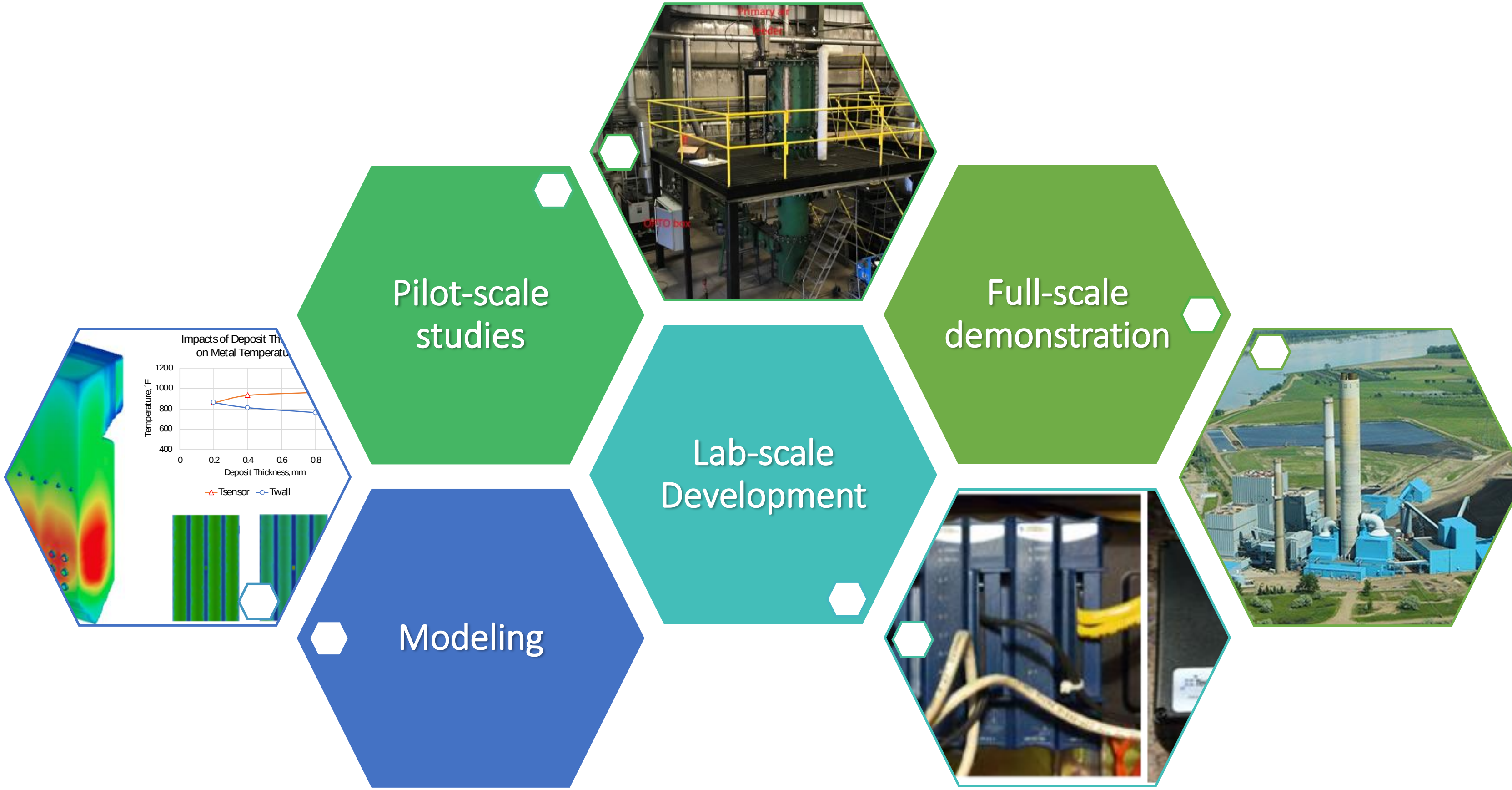
- Develop and demonstrate a miniaturized high temperature multi-process* monitoring system (mMPMS) that can provide a real-time indication of boiler condition in a ***lignite-fired*** full-scale boiler
- Develop and implement logic algorithms for the plant DCS to ***improve boiler energy efficiency, soot blowing, and NOx emissions*** by automated control of boiler operations

**metal wastage, heat flux, metal surface temperature, ash deposit thickness and ash deposition rate*



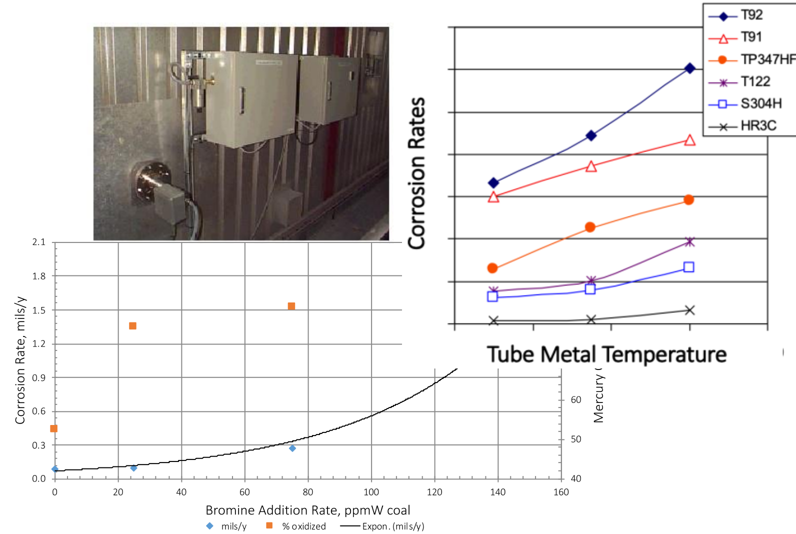
Conceptual Schematic of Boiler Condition Monitoring using mMPMS

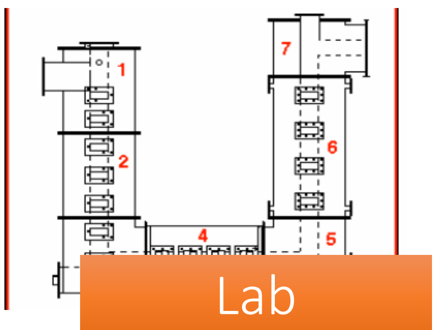
Technical Approach



Leveraging REI's Previous Works

- Electrochemical metal wastage sensing system has been applied to
  - low and high temperature zones of the boiler
  - waste-to-energy system
  - material testing for ultra-supercritical steam condition and oxy-firing combustion
- EN-based system provides high sensitivity, real-time, on-line monitoring technology





Project Team

Prime Recipient

REACTION ENGINEERING INTERNATIONAL

- *Project Management*
- *mMPMS Development*
- *Mechanism Derivation*
- *Computational Modeling*
- *Signal Conditioning and Data Communication Module Development*

Sub-Awardees

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Pilot-scale Testing

BASIN ELECTRIC POWER COOPERATIVE
A Touchstone Energy® Cooperative

Full-scale Demonstration

Bill Smith Engineering, LLC

Boiler Control Logic

Project Schedule

Year 1
Oct 2018 – Sep 2019

- Design and construction of prototype sensor body
- Design and fabrication of data processing unit
- CFD analysis of full-scale lignite coal-fired boiler

Year 2
Oct 2019 – Sep 2020

- Construction of power and cooling unit
- Development of data processing software for lignite fired unit
- Test and validation of multi-process sensor in a lignite firing pilot-scale combustor
- CFD analysis of demonstration site's full-scale lignite-fired boiler
- Demonstration of multi-process sensor in a commercial scale lignite coal-fired boiler

Year 3
Oct 2020 – Sep 2021

- Control logic development and implementation for automated control

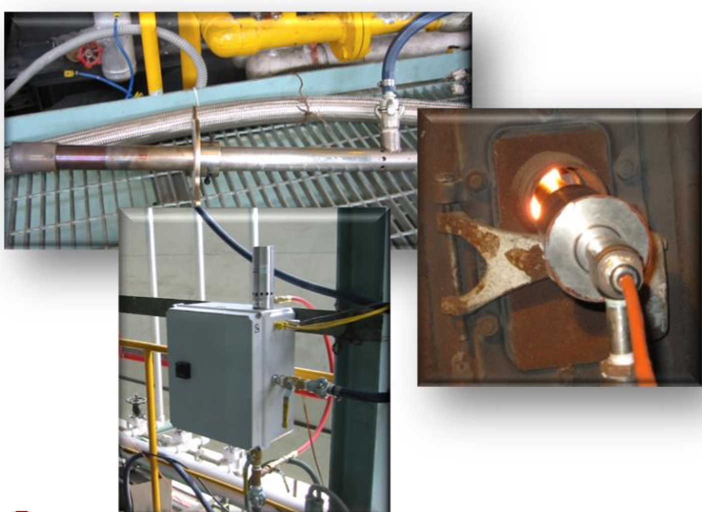
- *Pilot-scale testing delayed due to the COVID-19 pandemic and the following facility shutdown has been completed in July 2020*
- *The full-scale demonstration has started in February 2021*

mMPMS Design Concept

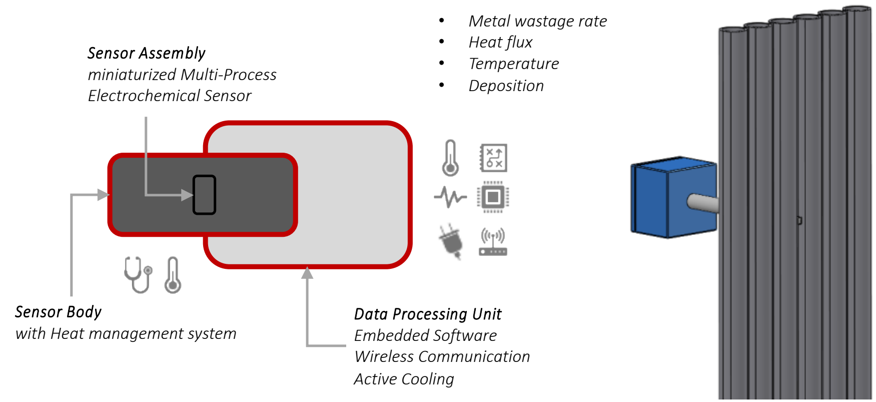
miniaturized Multi-Process Monitoring System

Legacy Sensor System

- Existing sensor placed in air-cooled probe
- Requires access port where tubes have been bent to allow access
- Need cooling air arrangement including cooling valve



mMPMS

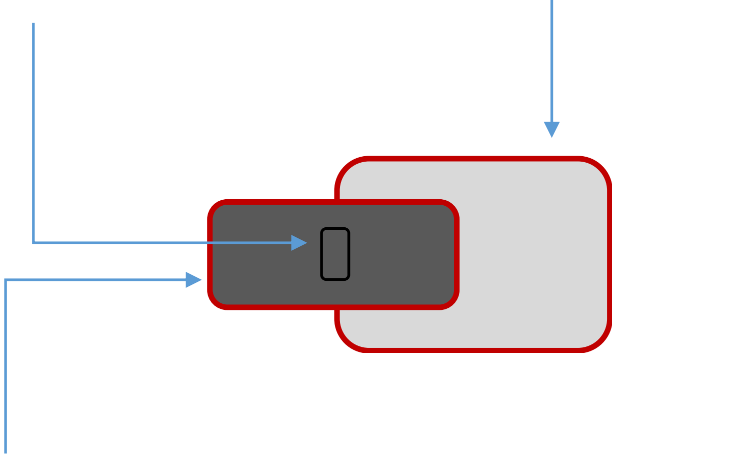


- Use the gap in the membrane for sensor insertion
- Sensor embedded in body with heat management module “without” cooling air
- Multi-process measurements to help condition-based monitoring
- Requires only 110 V power to data processing unit (with active cooling)

Key mMPMS Components

Sensor Assembly

- *New ceramics assembled with metal elements*
- *Designed and machined to fit the membrane hole*
- *Designed to reach within ¼” of tube crowns*



Sensor Body

- *Designed for specific waterwall at Hunter plant*
- *Designed to fit the sensor assembly*
- *Based on heat transfer modeling to optimize heat management*

Data Processing Unit

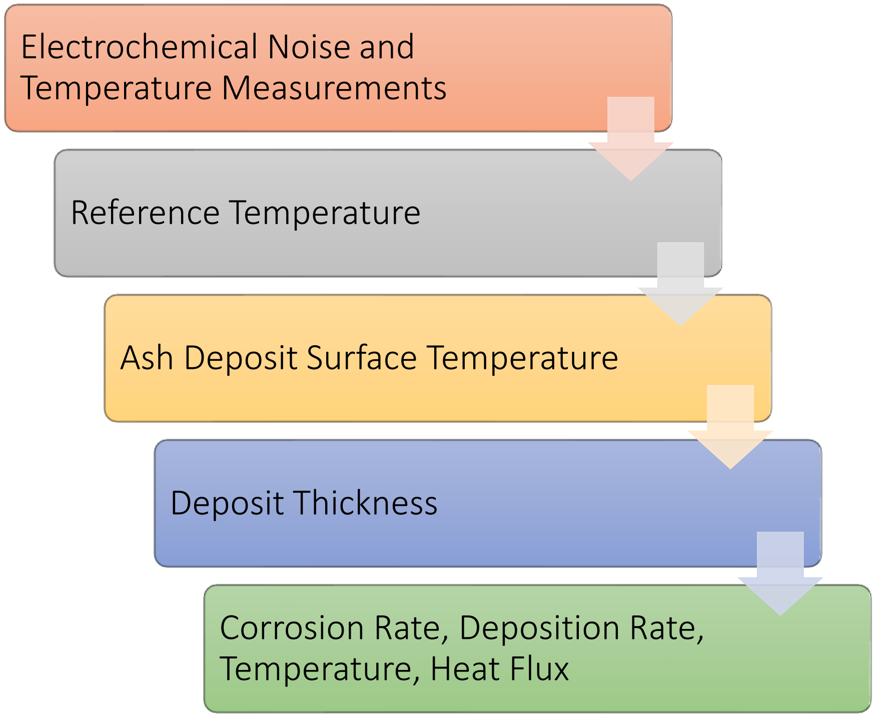
- *Signal conditioning module*
- *Hardened electronics with cloud-capable software*
- *Designed using industrial Internet of Things (IIoT) paradigm*
- *Scalable system to support unlimited sensors*
- *Processing power to enable future support for machine learning/artificial intelligence*
- *Active Cooling*

Signal conditioning module

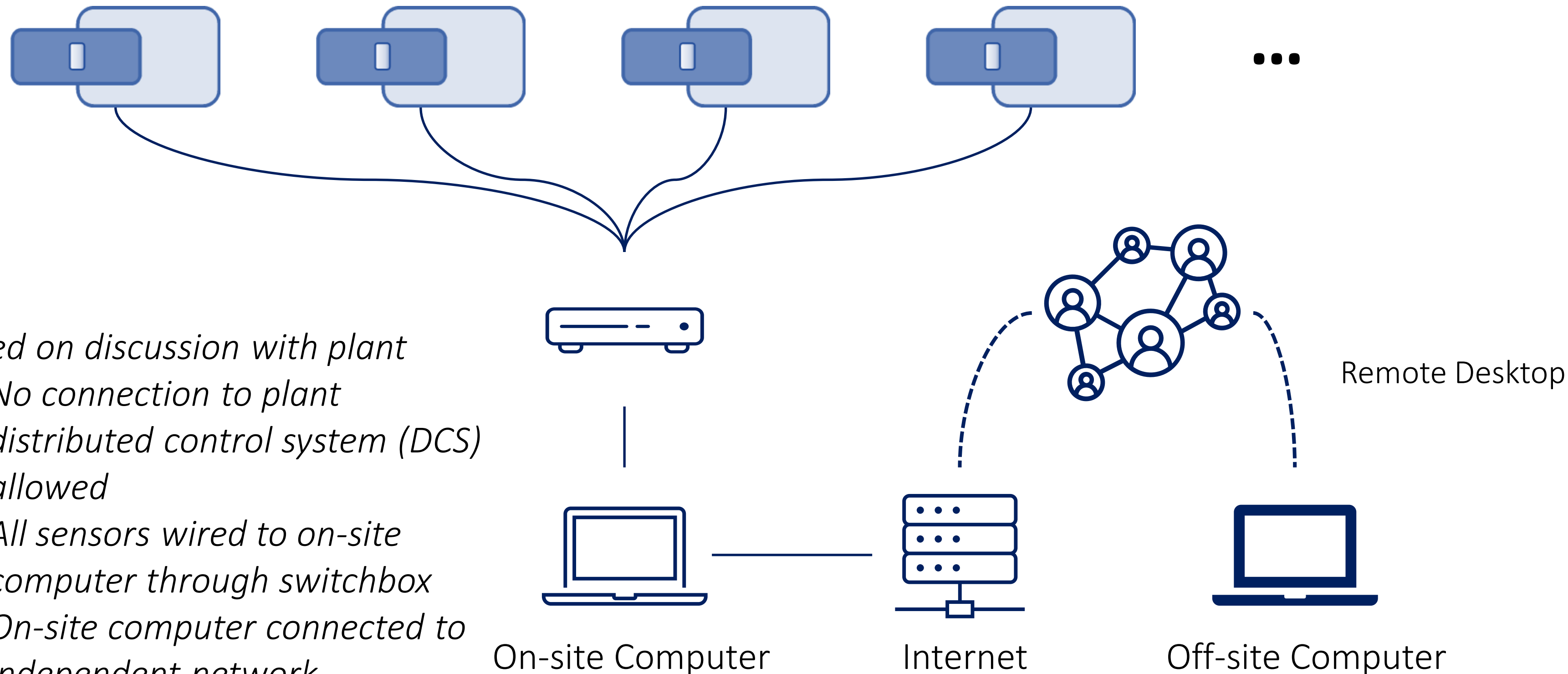
- *Updated and improved the existing signal conditioning module*
- *Simplified electronic design and increased resolution to allow detection of localized attack*
- *Implemented full digital signal conditioning*
- *Implemented full digital data communications*
- *Embedded “smart” electronics at board level (embedded controller)*

Multi-Process Monitoring

- Leveraged the legacy metal wastage monitoring capability
- Developed quantitative heat flux and deposition correlation based on sensor signal
- Tested and validated during pilot-scale testing



Remote Access & Data Communication



Based on discussion with plant

- *No connection to plant distributed control system (DCS) allowed*
- *All sensors wired to on-site computer through switchbox*
- *On-site computer connected to independent network*
- *Remote desktop software to connect to on-site computer*

R&D on Pilot-scale Testing Facility

Pilot-scale Testing @ University of Utah

- Pilot-scale testing in 100 kW down-fired combustor at University of Utah (UoU) in Salt Lake City, Utah
- 4 different fuels
  - Lignite*
  - PRB (UoU has in storage)
  - Bituminous – Illinois 6
  - Wood
- Increased workscope includes $Mg(OH)_2$
  - Commonly added for deposition/slagging control
  - Utilize pilot data to improve model deposit properties for plants that use additive

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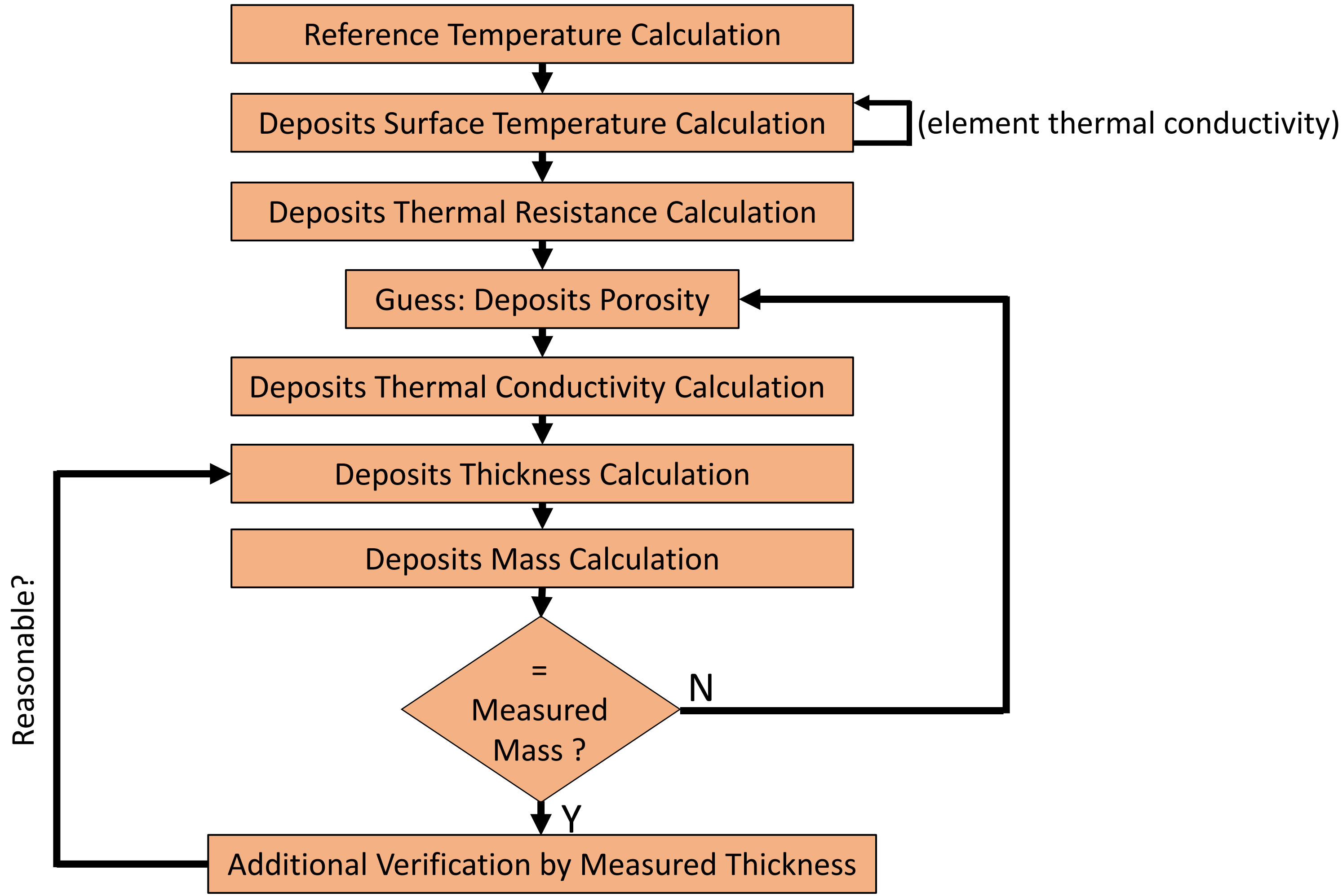
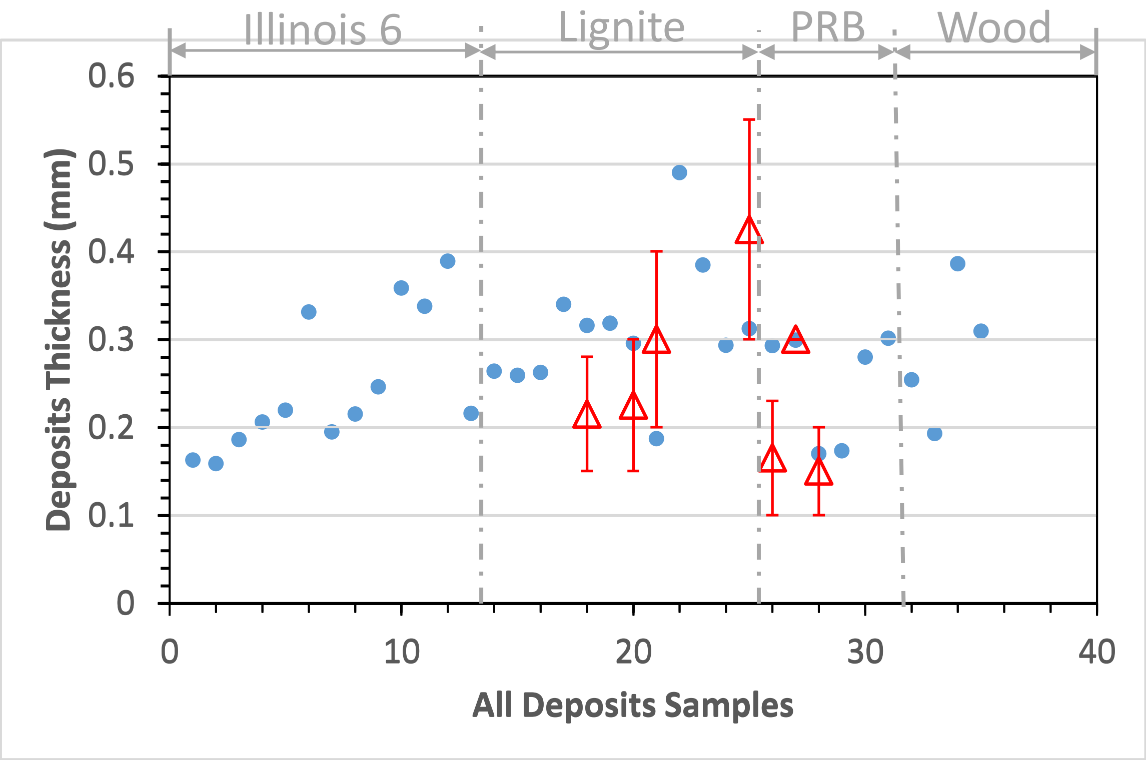
Ash Deposition Correlation Development



Measured and Calculated Deposits Thickness



- The calculated deposits thicknesses agree well with the measured deposits thicknesses

Demonstration at Leland Olds Station

Basin Electric Power Coop (Demonstration)

Leland Olds Station

BASIN ELECTRIC POWER COOPERATIVE

A Touchstone Energy® Cooperative

Plant is interested in ash management and boiler tuning

- Located near Stanton, North Dakota
- Two lignite-fired units with total generating capacity 669 MW
    - Unit 1 – 222 MW opposed wall-fired PC (demonstration plant)
    - Unit 2 – 447 MW opposed wall-fired cyclone

Demonstration Plan

Mounting hardware installation during Outage

- Support pipe
- Cutting the hole in the webbing

Pre-demonstration site visit

- After mounting hardware installation
- Site preparation check list (Equipment, Desired operating conditions…)

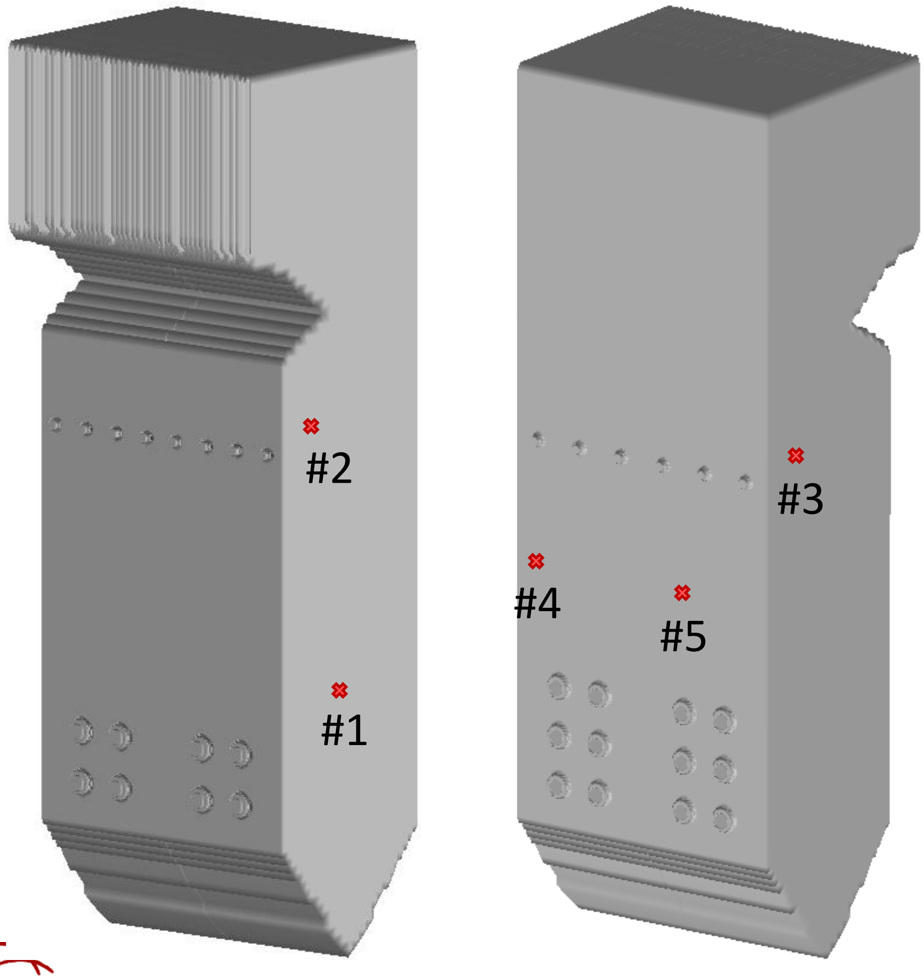
5-week Demonstration

- 5-week monitoring
- Targets Feb 2021 – March 2021
- *Monitoring continued*

Data Analysis & Control Logic Development

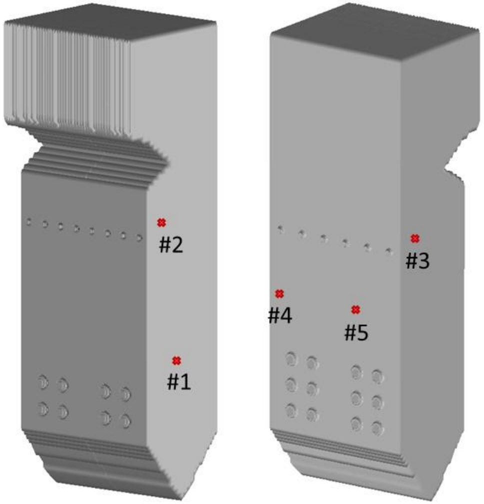
- Focus of Year 3
- Plant and sensor data review
- Boiler operation logic including soot blower operation

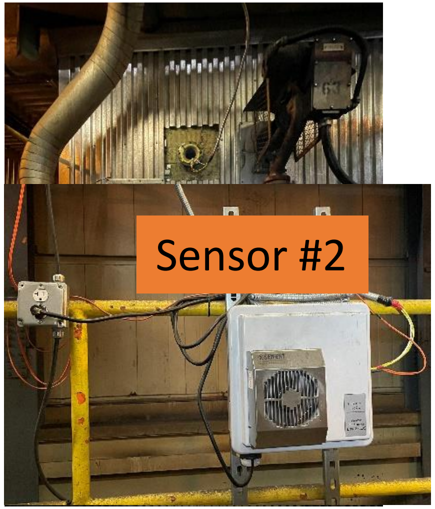
Sensor Locations



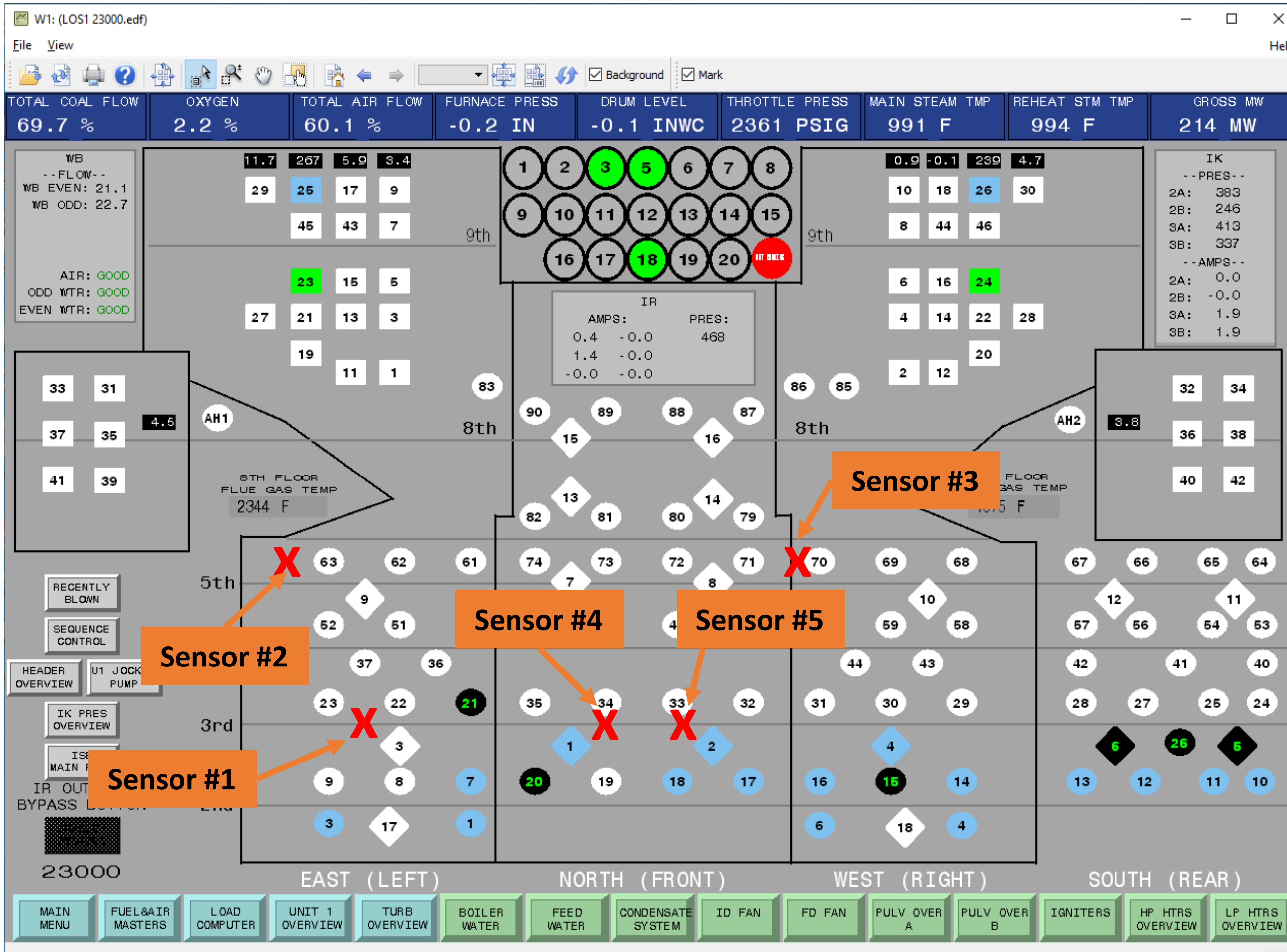
- Placement of 3 side wall sensors guided by plant experience
  - High deposition and moderate wastage rates
  - One sensor on Left wall just above windbox
  - 2 sensors slightly above OFA – 1 each on left and right wall
- Placement of 2 additional sensors on the front wall based on model predictions
  - Regions of shifting deposit pattern at different loads
  - Alternating reducing/oxidizing environment when cycling

System Installation





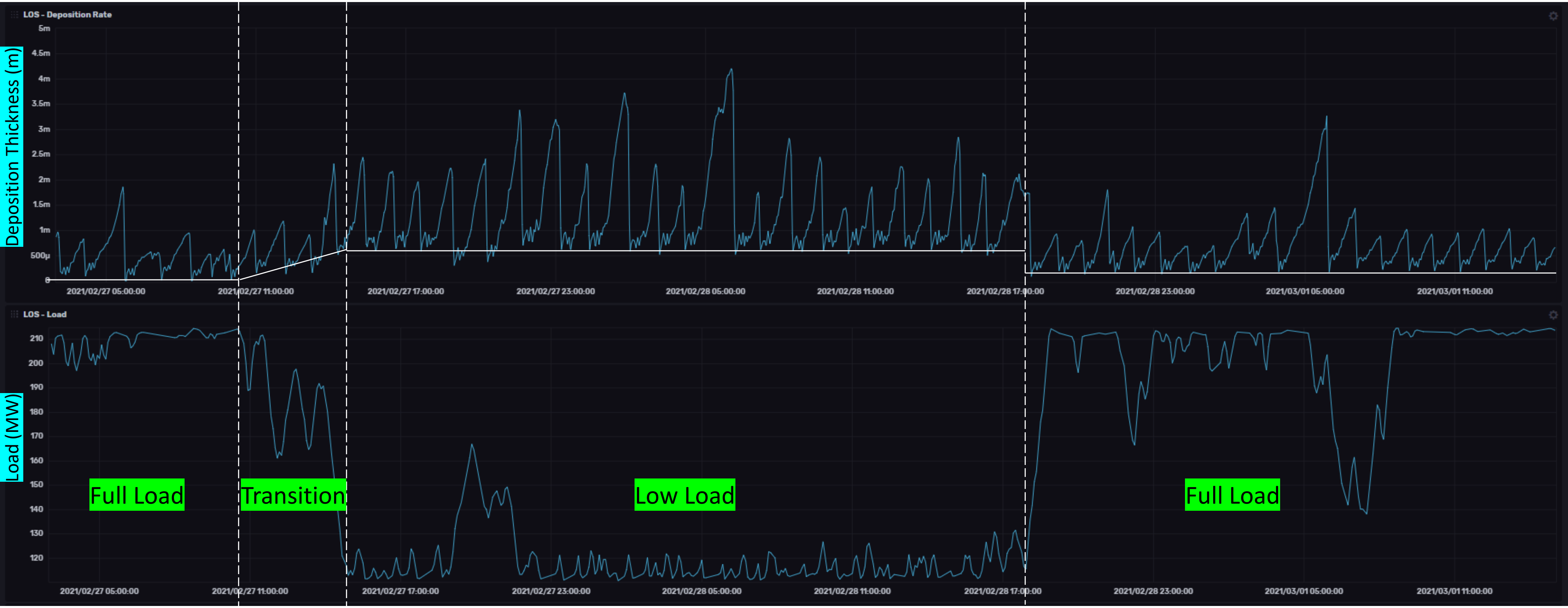
Soot Blower and Sensor Layout



Real Time Data: Deposition Thickness

Sensor #1, 3:00 Feb 27 – 15:00 Mar 1

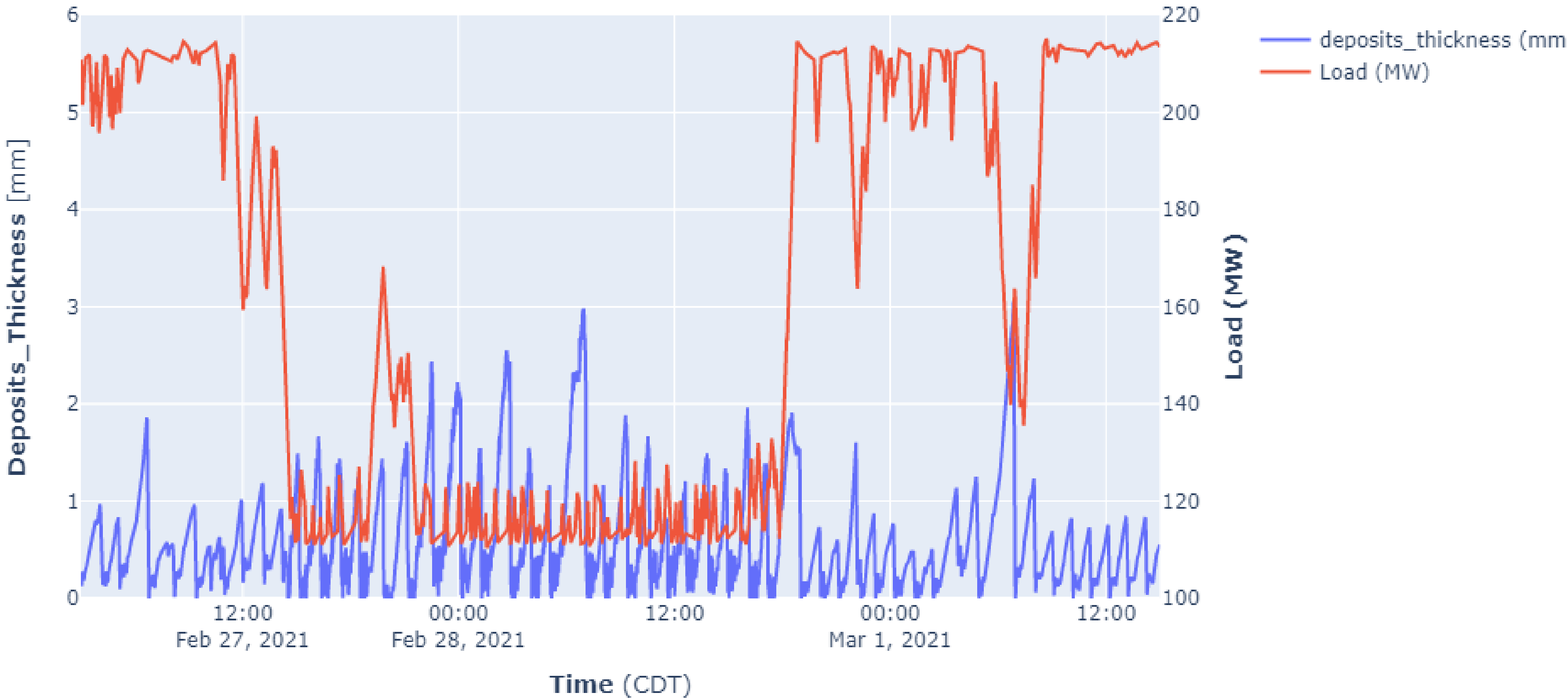
Tref = 1407 K



- The peaks in deposition thickness reflect the operation of the IR type soot blowers near the sensor (the frequency is about once per hour)
- The white bottom line represents a clean condition (~ 0 mm thickness) of the sensor after soot blowing

Real Time Data: Deposition Thickness - Calibrated

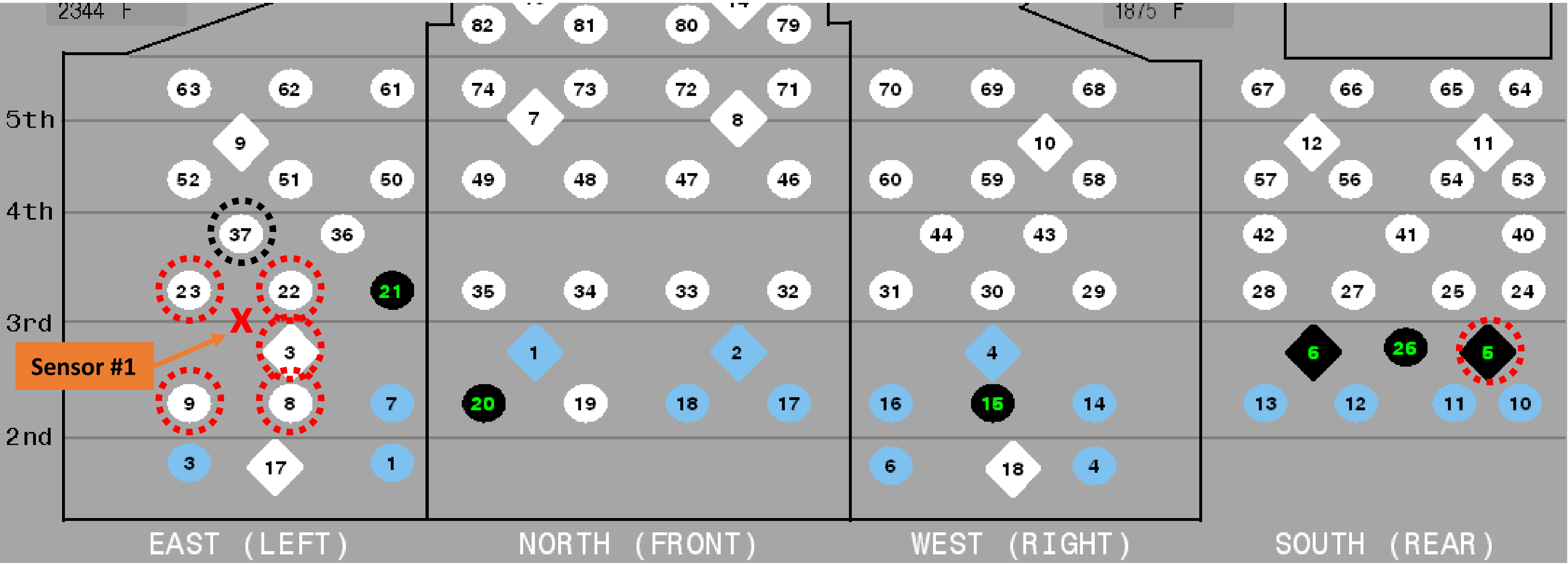
Sensor #1, 3:00 Feb 27 – 15:00 Mar 1



It is more reasonable to compare the deposits thickness between various loads after calibration

Test 1: Testing Procedure

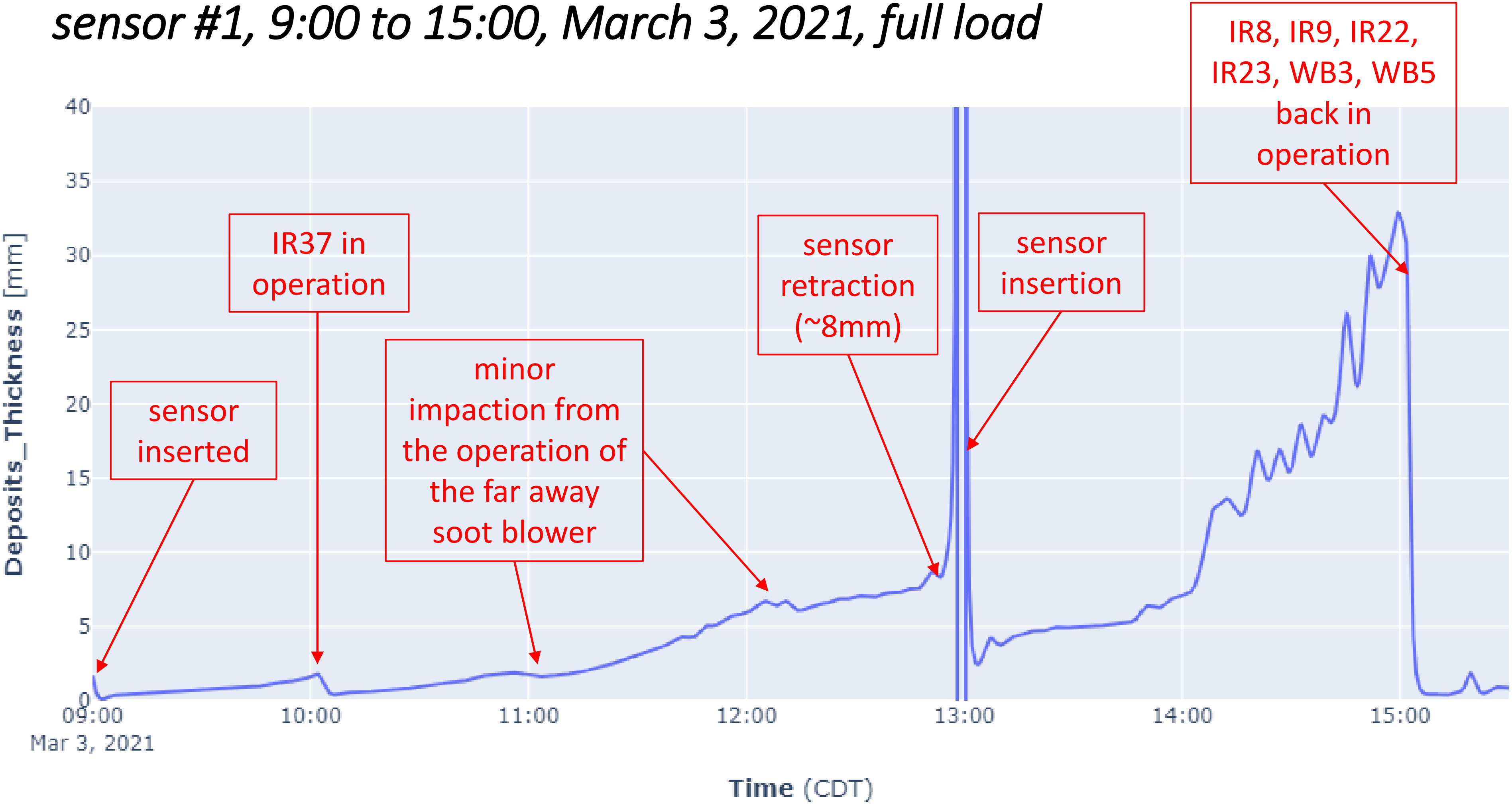
sensor #1, 9:00 to 15:00, March 3, 2021, full load



- The periodic increase-decrease of the real time deposits thickness is truly an interaction between the sensor and the soot blowers
- The reported absolute value of the real time deposits thickness is reasonable

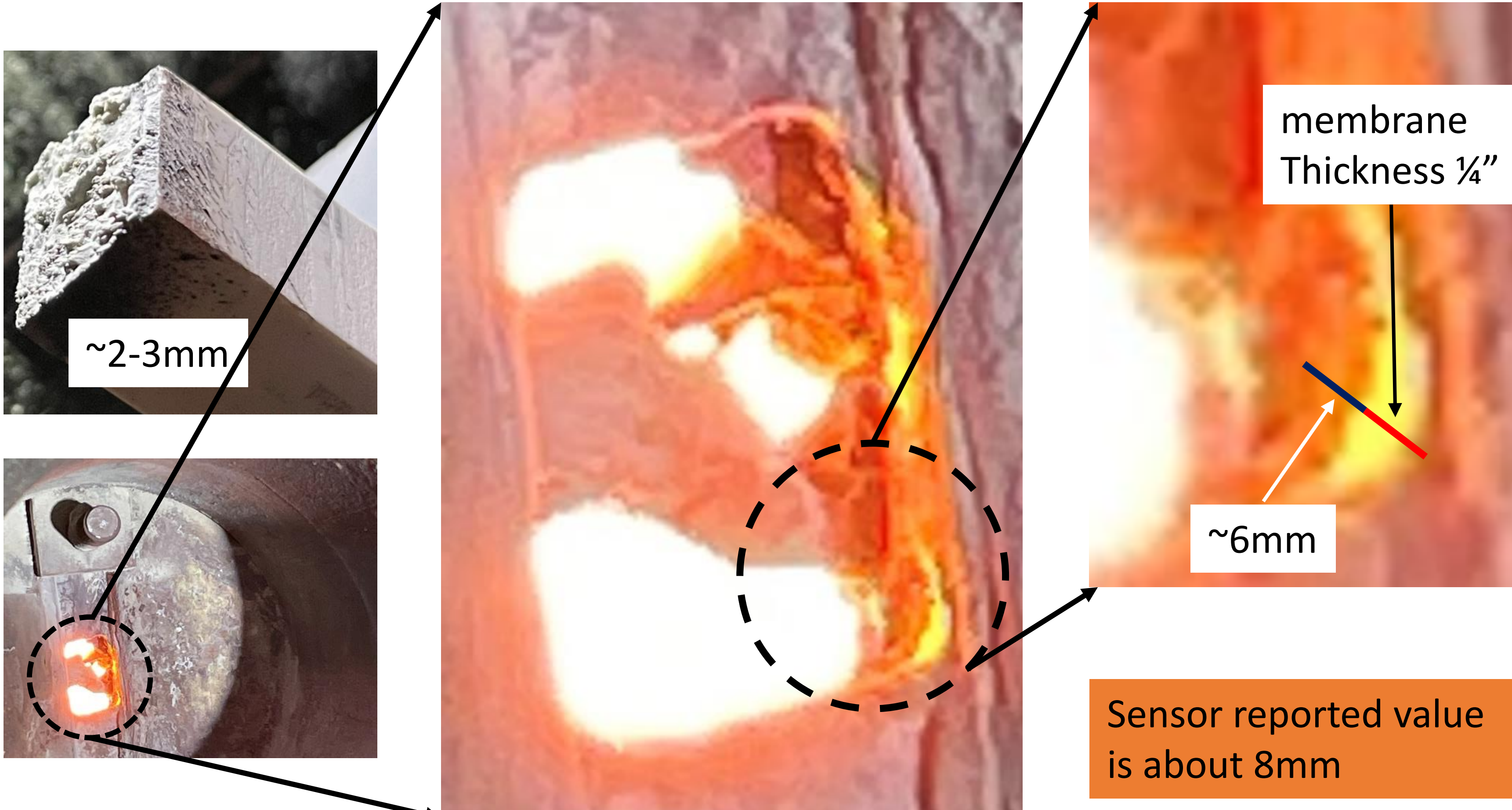
Test 1: Real Time Behavior

sensor #1, 9:00 to 15:00, March 3, 2021, full load



Test 1: Deposits Thickness Validation

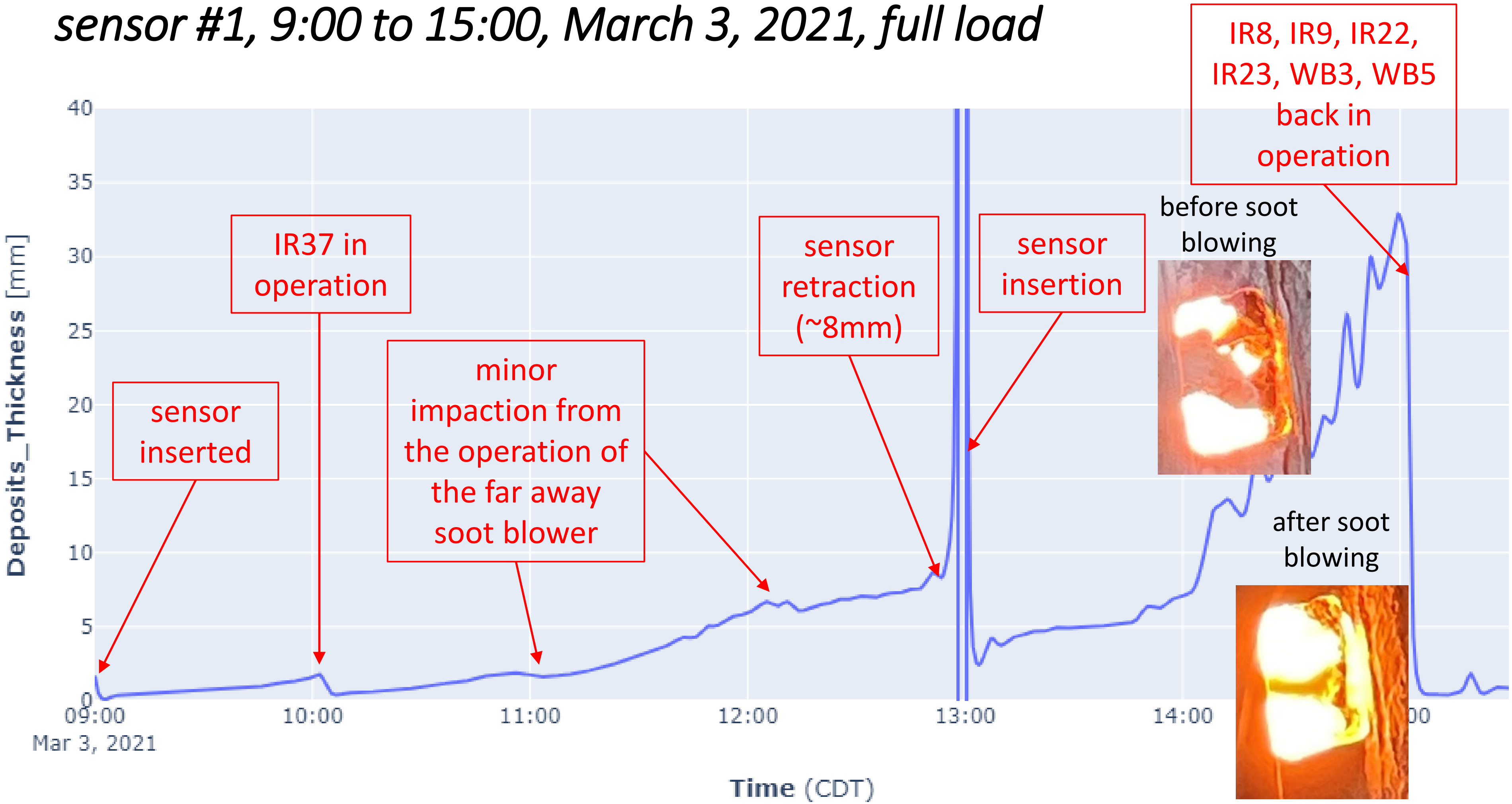
sensor #1, 13:00, March 3, 2021, full load



Sensor reported value is about 8mm

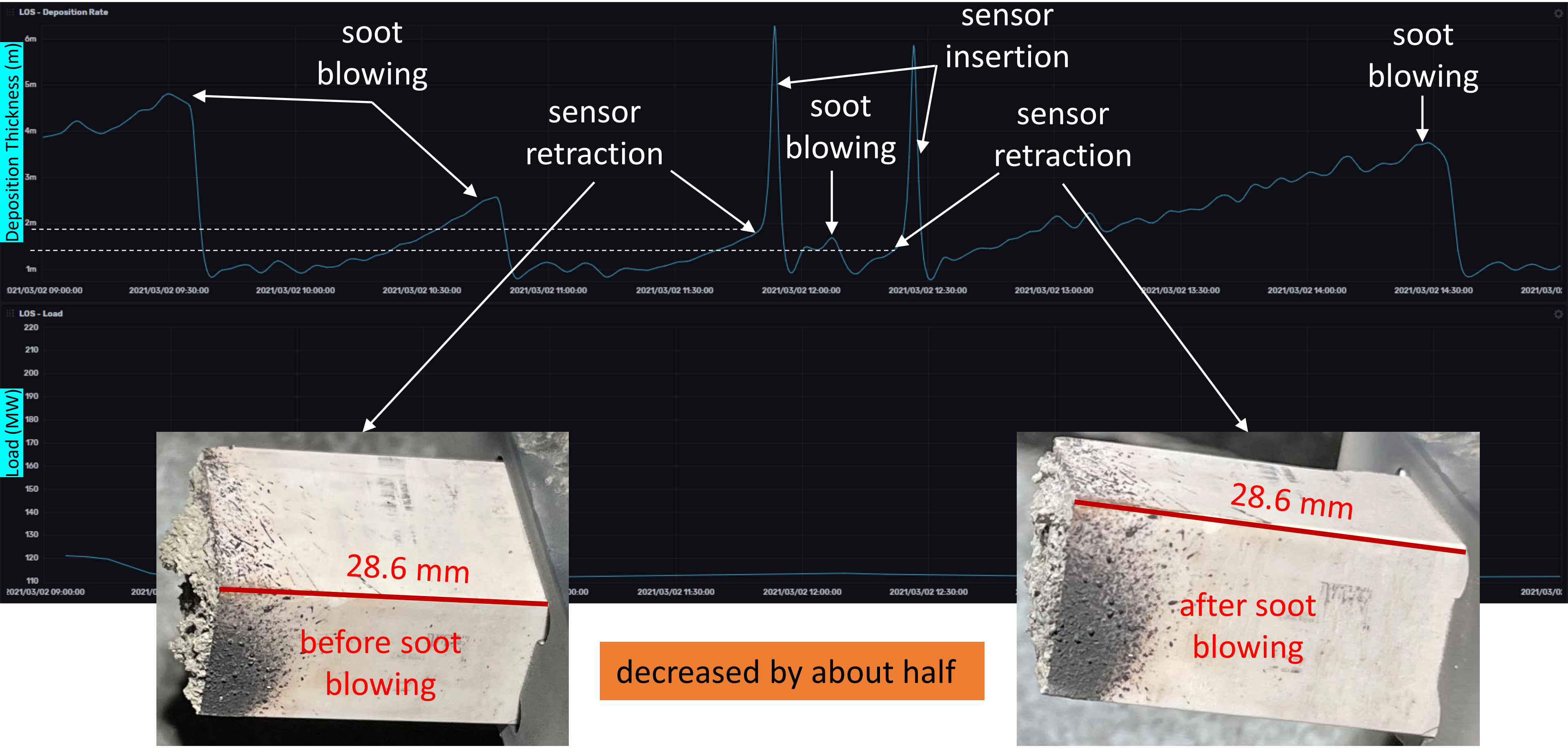
Test 1: Real Time Behavior

sensor #1, 9:00 to 15:00, March 3, 2021, full load



Test 2: Real Time Behavior

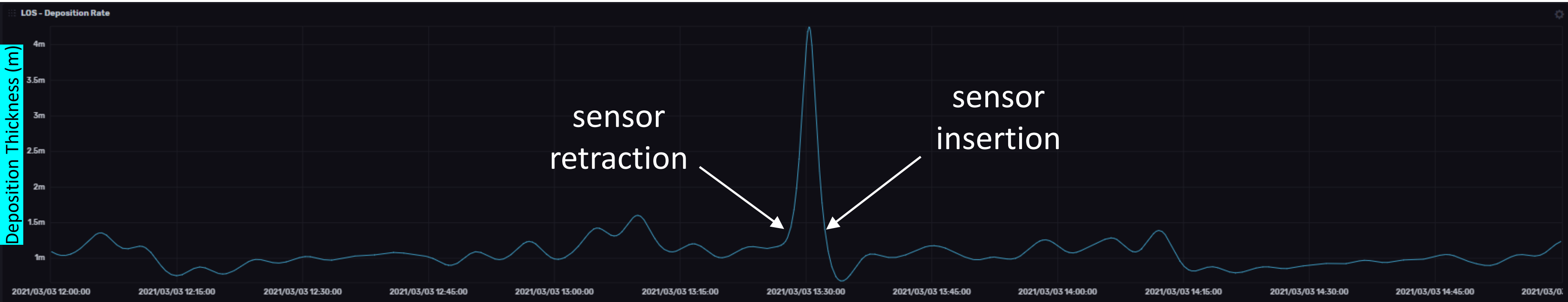
sensor #1, 9am to 15:00, March 2, 2021

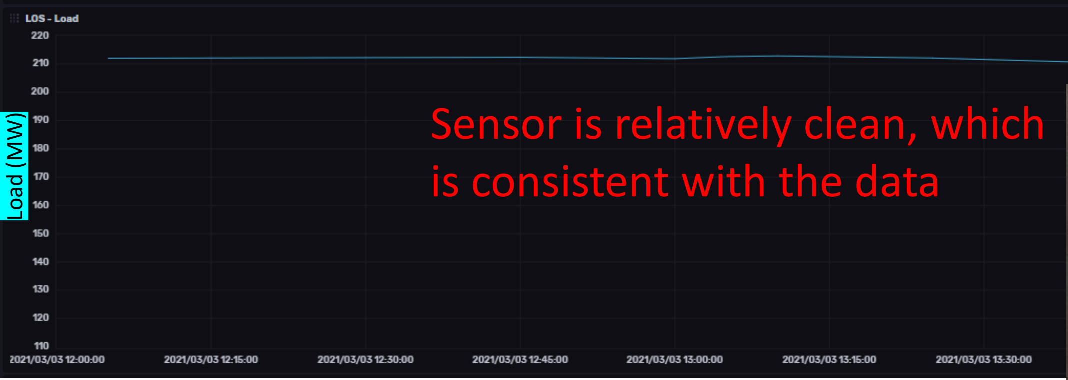


decreased by about half

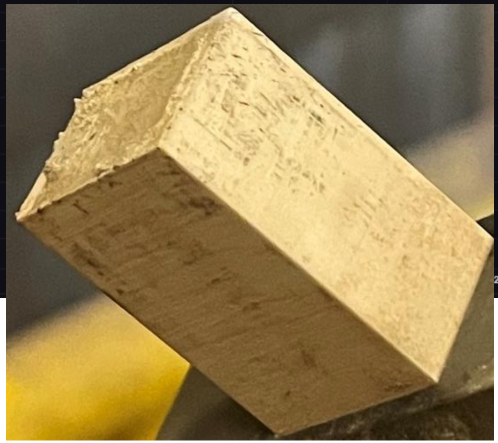
Test 3: Real Time Behavior

sensor #2, 12am to 15:00, March 3, 2021



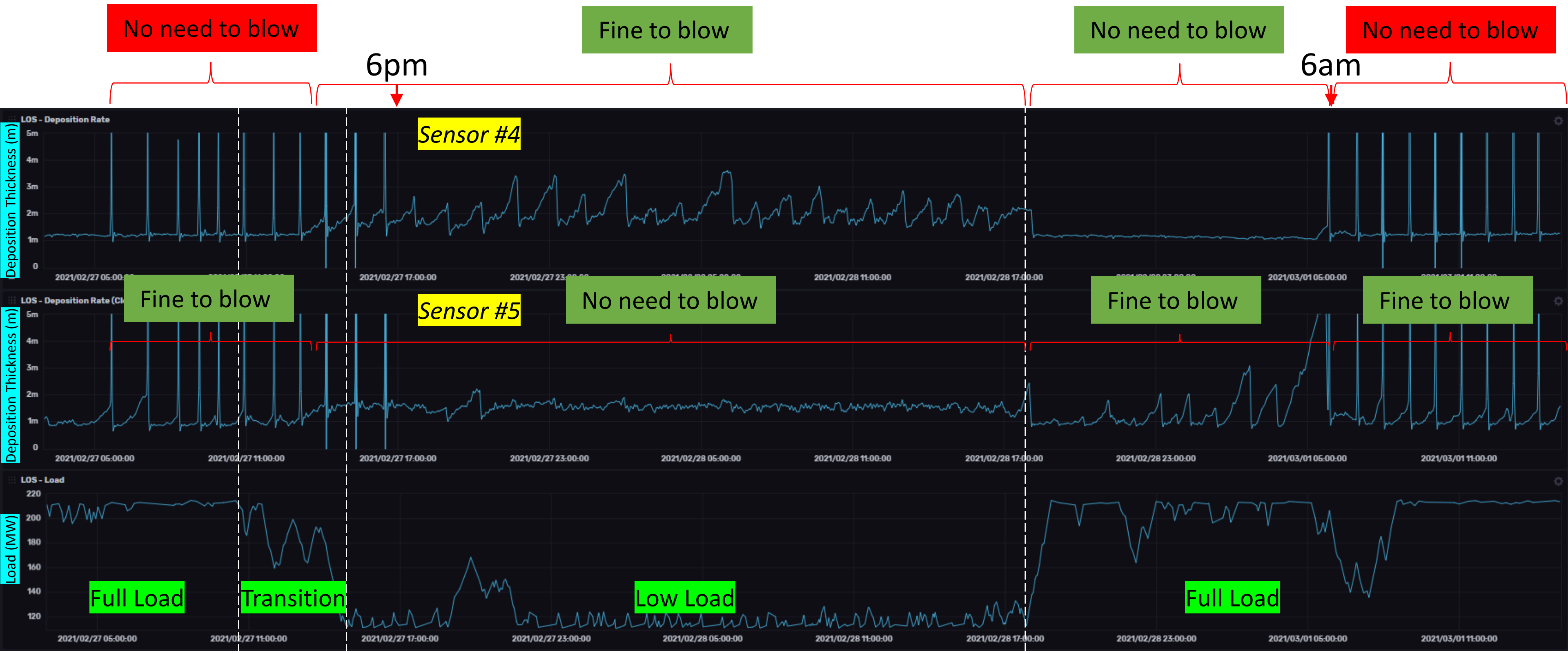


Sensor is relatively clean, which is consistent with the data



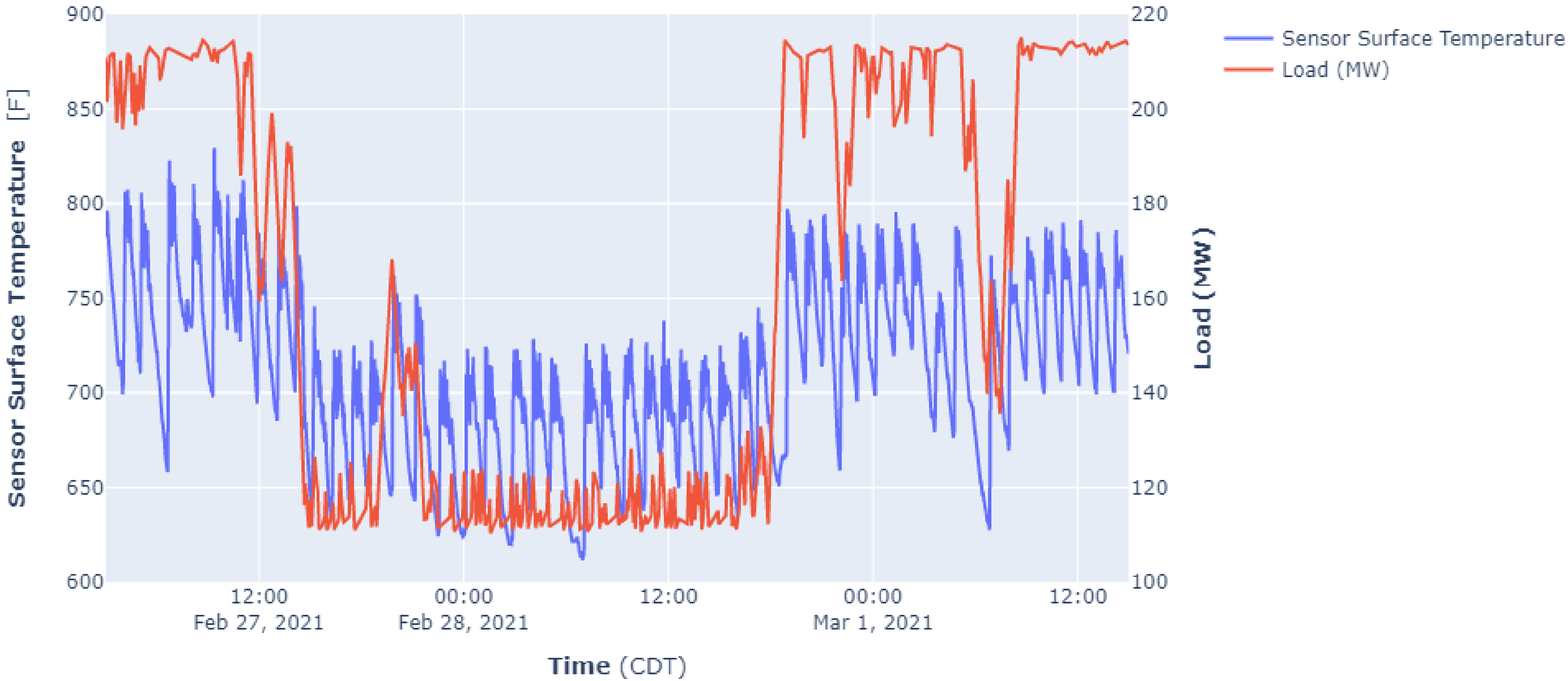
Real Time Data: Deposition Thickness

Sensor #4 & 5, 3:00 Feb 27 – 15:00 Mar 1



Real Time Data: Temperature

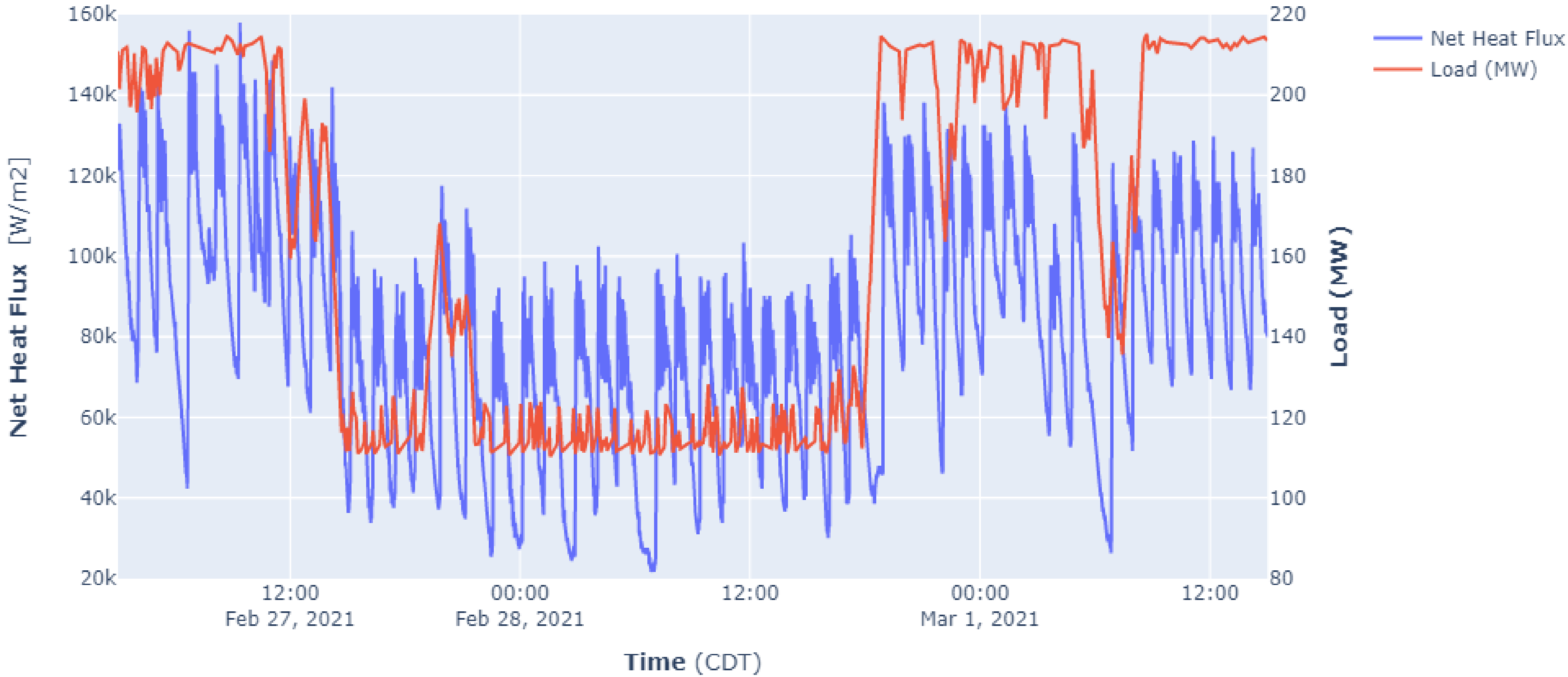
Sensor #1, 3:00 Feb 27 – 15:00 Mar 1



Sensor surface temperature is consistent with the low change

Real Time Data: Heat Flux

Sensor #1, 3:00 Feb 27 – 15:00 Mar 1



Heat flux is consistent with the low change

Summary

- Successful upgrade of REI's legacy corrosion monitoring system
    - Miniaturization and modification of the sensors accommodating membrane installation and passive cooling
    - Development of new signal conditioning module with improved data communication and resolution
    - Legacy data acquisition hardware successfully replaced with easily maintainable and scalable electronics
    - Development of new big data platform for collection and analysis
- Five miniaturized MPMS (i.e. mMPMS) sensors and associated control boxes were successfully installed through the membrane walls in LOS1
- Sensor deposition and corrosion data were collected during a 5-week testing campaign
- Pilot scale testing (University of Utah) verified reliability of new electronics, and provided for the development of a correlation for lignite-based deposit thickness
- LOS1 tests have confirmed that the sensors are very sensitive to the surroundings including operation of soot blowers and water lances (i.e. deposit growth) and impacts of boiler ramping (i.e. corrosion)
- Tests demonstrate that the mMPMS deposition measurements are qualitatively and quantitatively reliable
- Tests show that corrosion rates at the 5 sensor locations are generally very low except for spikes during load ramps

Plan

- Data analysis and control logic development will continue for the rest of the Year 3 in this project
- Presenting results at the following conferences:
  - *Clearwater Clean Energy Conference, June 20-24, 2021*
  - *The Thirty-Eighth Annual Pittsburgh Coal Conference, September 20-23, 2021*
  - *AFRC 2021 Industrial Combustion Symposium, October 10-13, 2021*

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