

# Canadian Boiler Society 2019 Education Days

## Using Numerical Simulation to Diagnose Boiler Tube Failures

Speaker:

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CFD Engineer, Brais, Malouin & Associates



**Energy, Combustion, Heat  
Transfer, and Energy Efficiency**

# Context

- Power & Water Production Facility
  - Built in 1997
  - Electricity Production & Water Desalinization
  - Equipment Investigated:  
Auxiliary Boiler (VU-60)



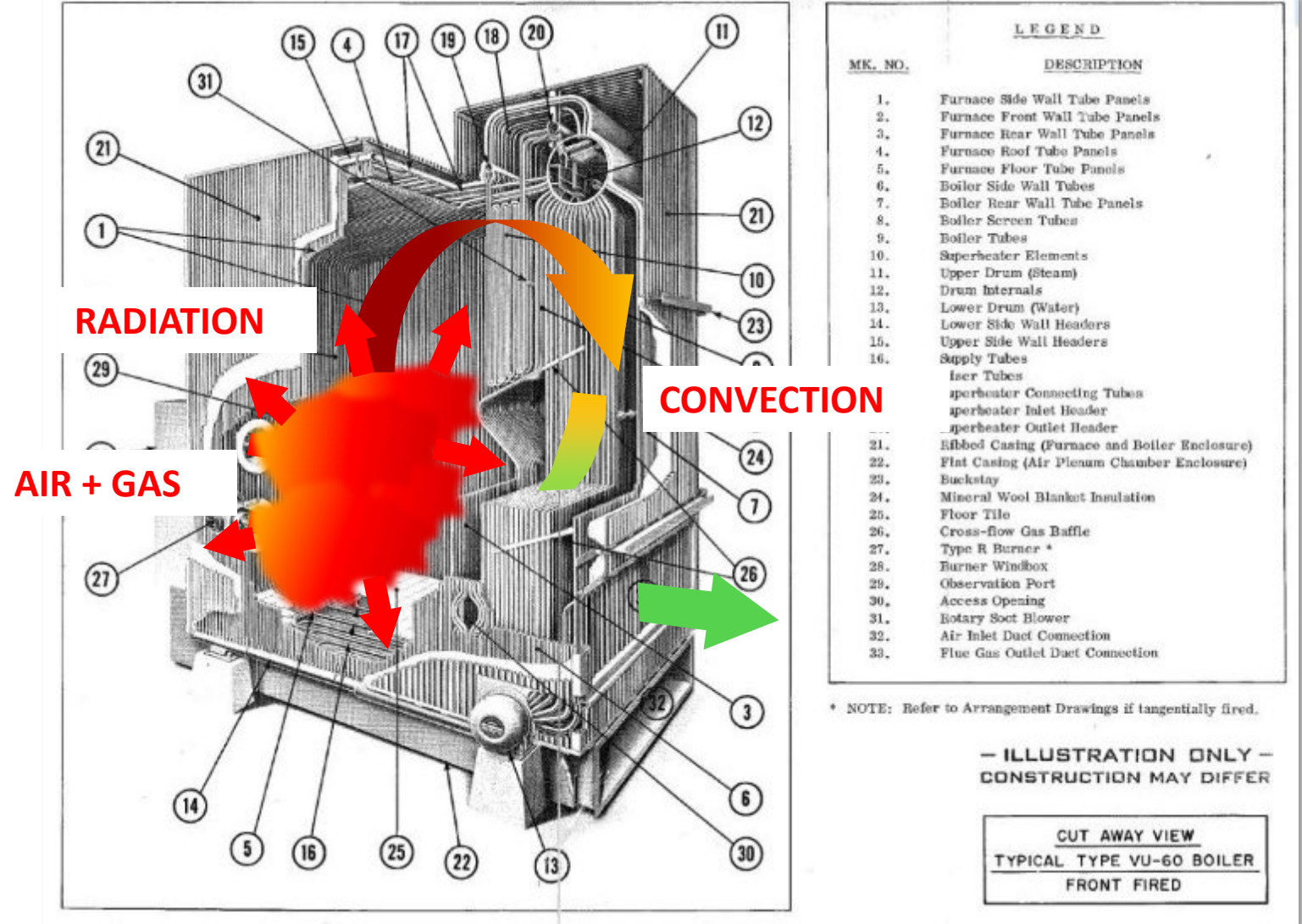
# Context

- VU-60 Auxiliary Boiler
  - Production: 369 ton/hr Saturated Steam
  - Operating Steam Pressure: 22 bar
  - Steam used for Water Desalinization Plant
- Started operation in 1999
- Fuel: Natural Gas
- 6 Front Fired Burners



# Context

- VU-60 Auxiliary Boiler
- Typical Arrangement



# Context

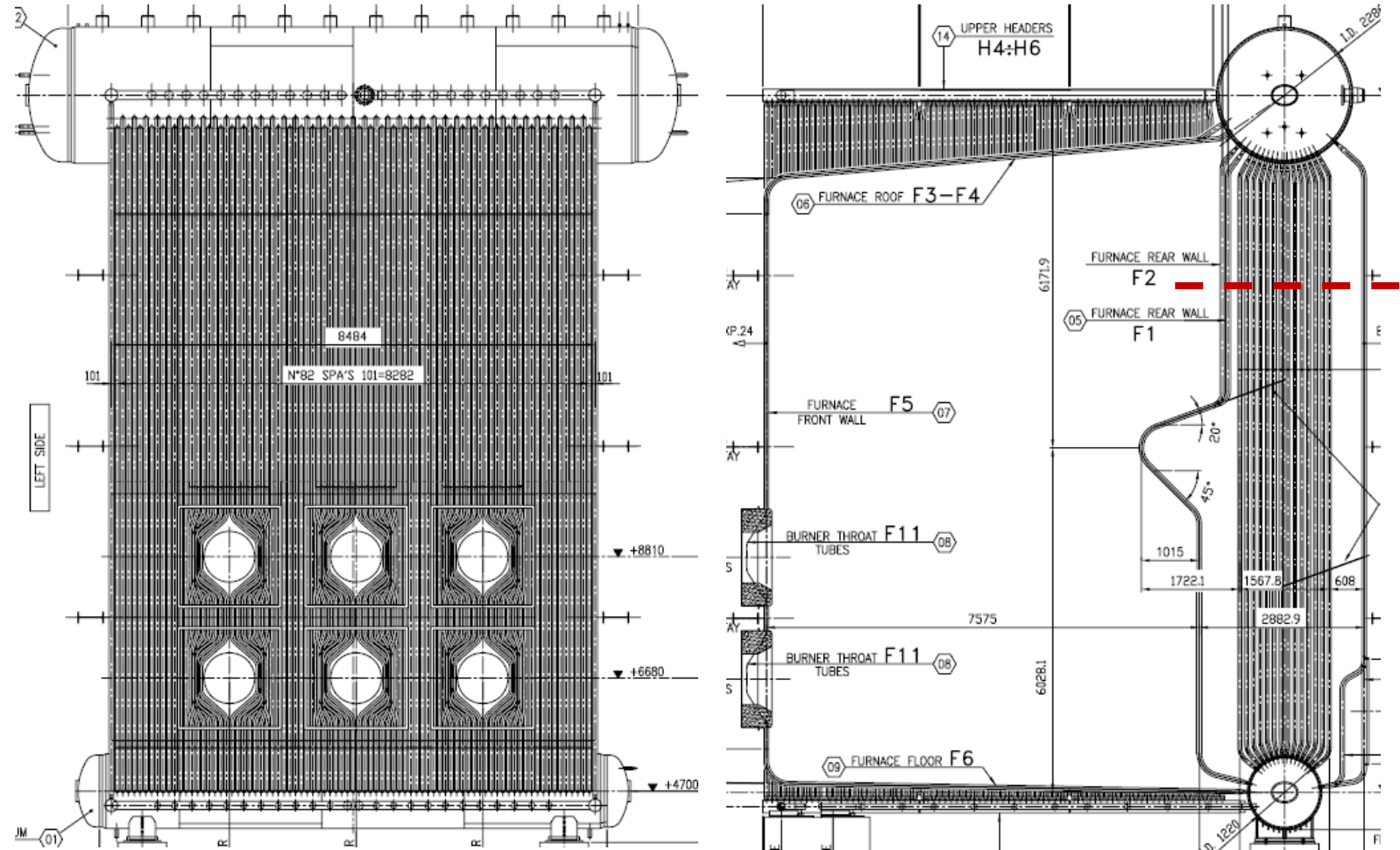
- VU-60 Auxiliary Boiler
  - Since 2001, **Many Tube Failures** Event at Full Load Capacity
  - In December 2017: **Multiple Tube** Failures in the **Convection Bank**
  - These Tube Failures Occurred Shortly after a **HRSO Trip**
  - HRSO Trip Caused a Sudden Steam Pressure Drop **from 16 to 9 bar**



# Context

- VU-60 Auxiliary Boiler

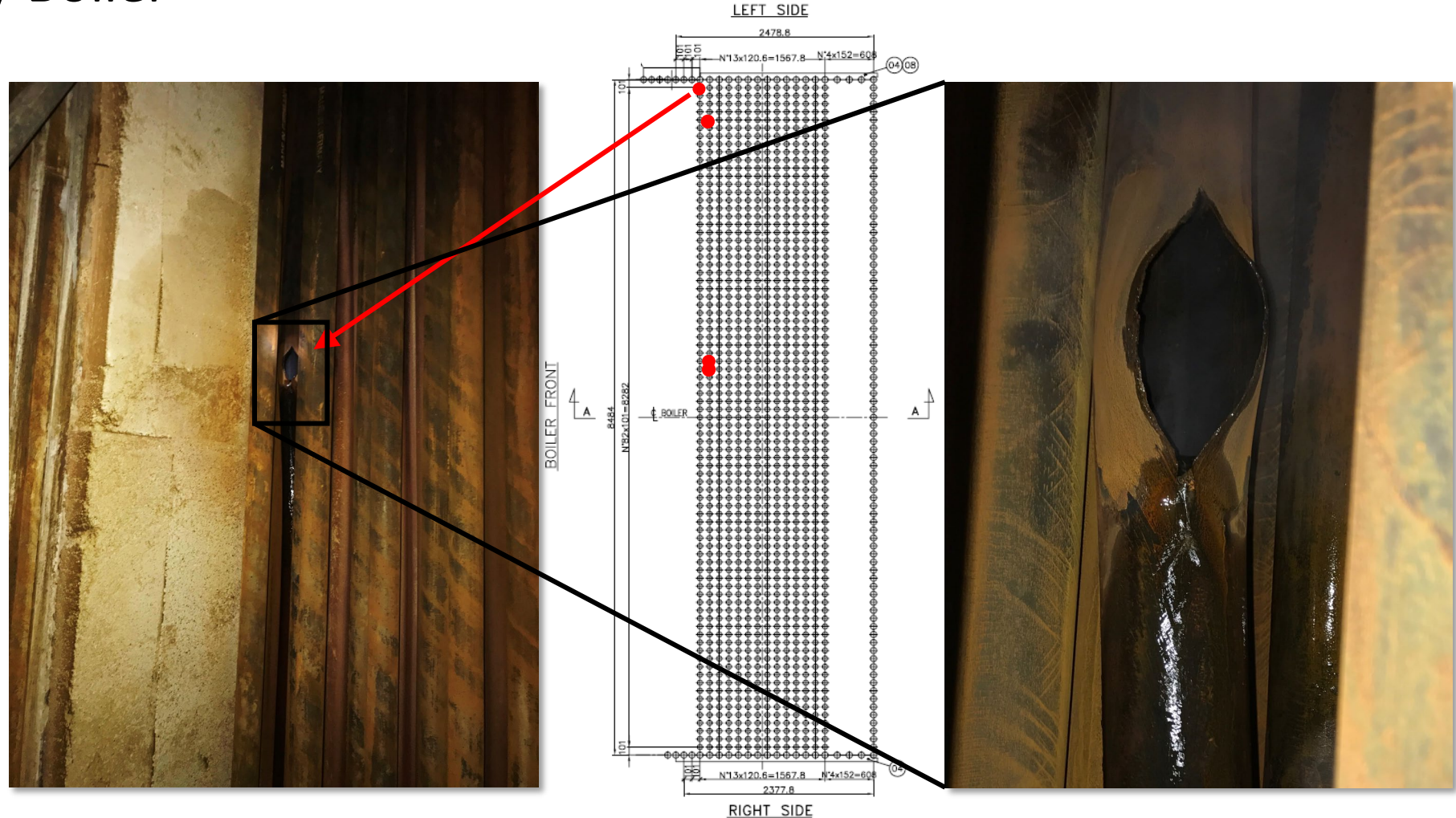
- Latest Failure Event: **2017**



# Context

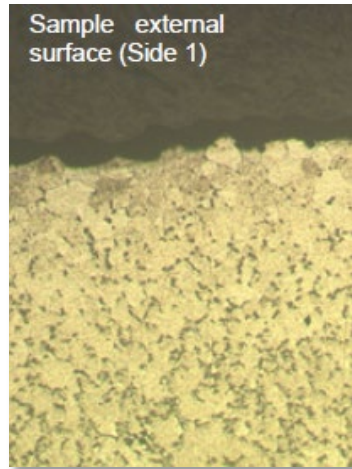
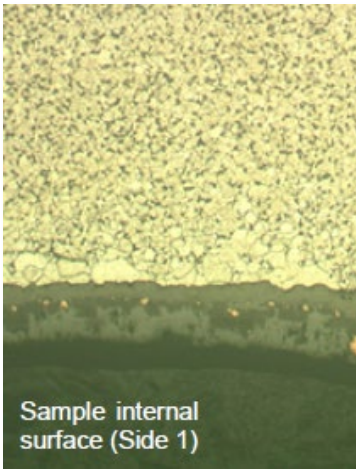
- VU-60 Auxiliary Boiler

- Latest Failure Event: **2017**



# Preliminary Analysis

- Long Term Overheating



- External micro-crack developed at wall of the tube
- No internal deposits
- Internal/external grain structure difference
- A thick oxide layer is observed



- **All Indicative of Long Term Fatigue (overheating)**



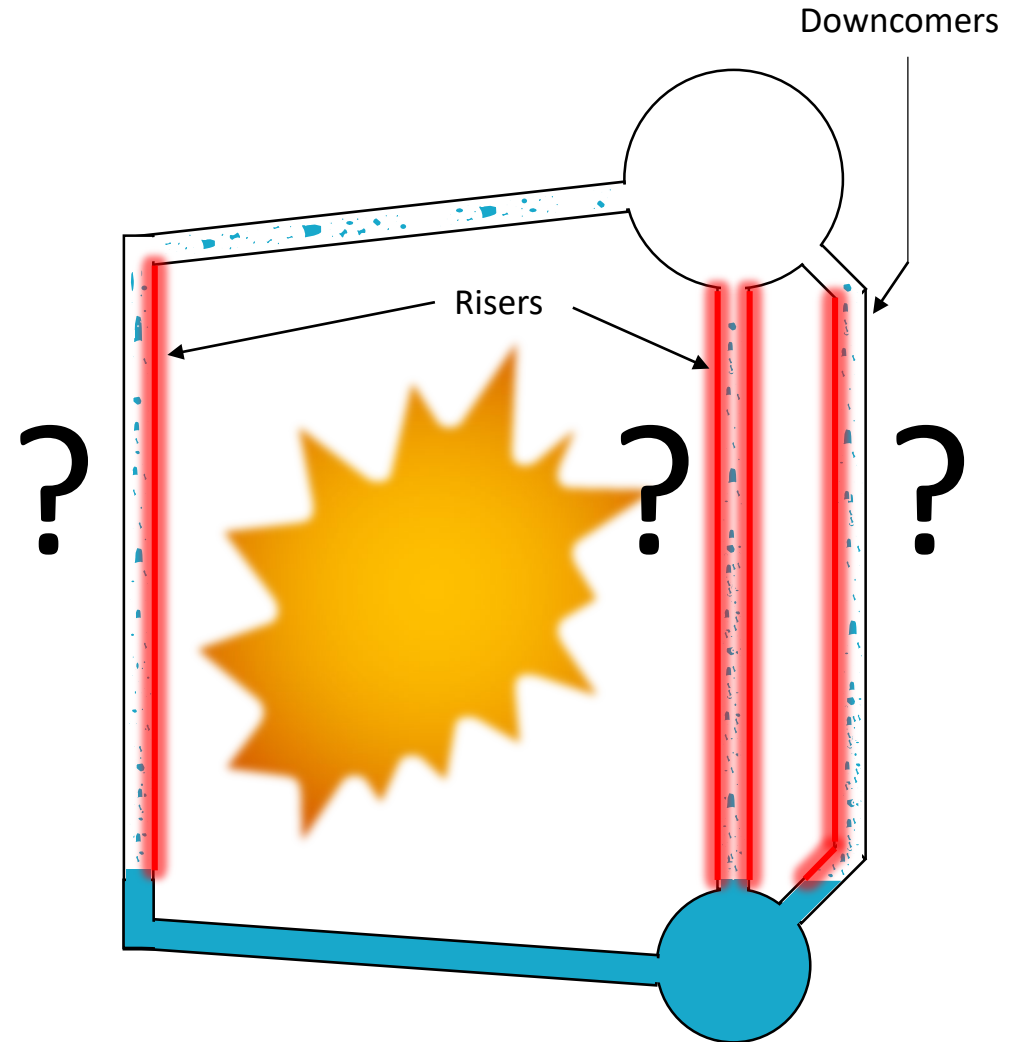
# Preliminary Analysis

- Pressure Drop Event

- Multiple Tube Failures in the Convection Bank
- Failures occurred shortly after the trip of a combined cycle boiler
- Steam Pressure dropped from 16 to 9 bar

## WATER WILL FLASH!

- Downcomers: Void Fraction 0 → 93%
- ↓
- Circulation Will Stop
- ↓
- Tubes not Cooled Anymore
- ↓
- **Overheating**
- ↓
- **Short-Term Failure**



# Preliminary Analysis

- Short Term Overheating



- Shape of rupture indicates short term rapid overheating
- Lack of cooling = weakened part of tube will yield first
- Consistent with pressure drop event



Figure 3.2 Short-term overheating in which bulging occurred before rupture. Note the chisel-like rupture edges.

- Phenomenon is well documented  
(The NALCO Guide to Boiler Failure Analysis)

# Preliminary Analysis

- Boiler Design
  - Failures always occur in same region
  - Tubes may have been weakened by long term overheating
  - Subsequent failure caused by depressurization event

• Flame Shape?

• Hot

• Adequate Hot Gas Flow?

Combustion Analysis  
using CFD



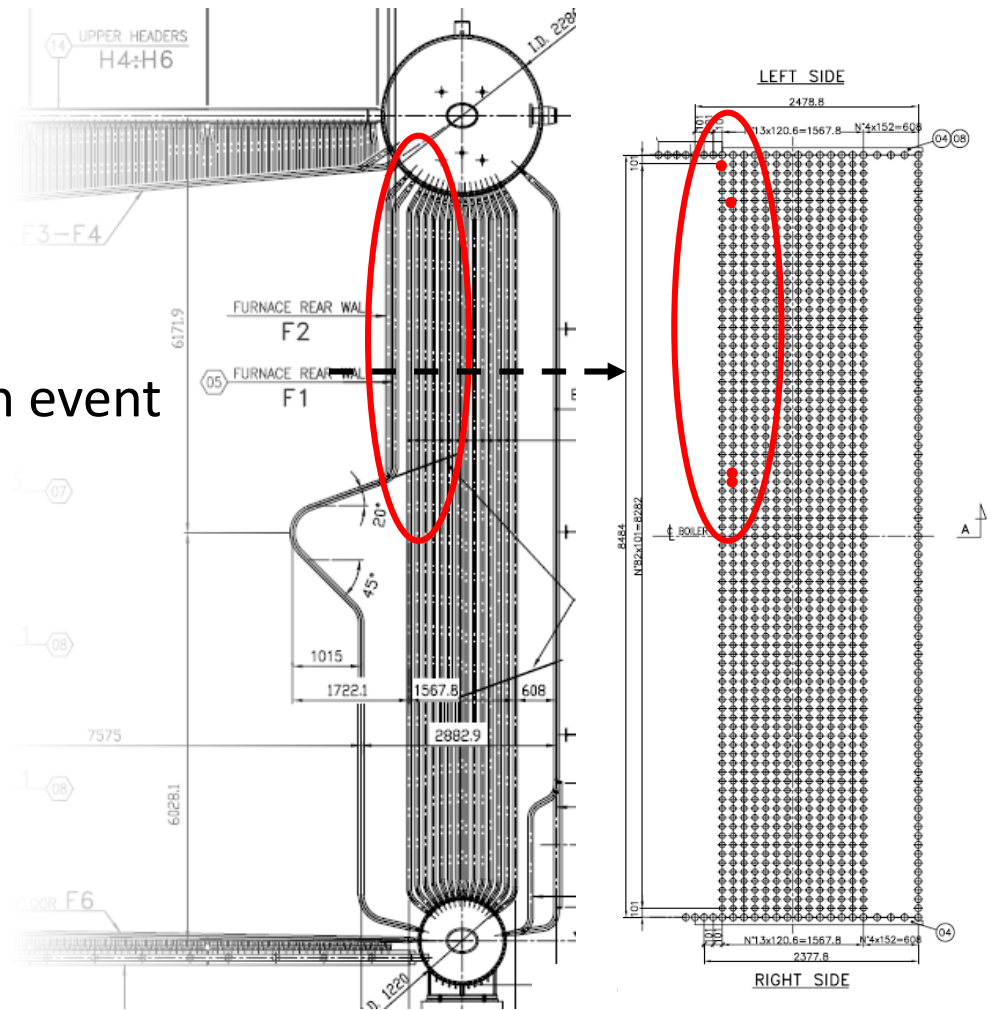
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Water/Steam Circulation  
Analysis using In-House  
Code

ht?

tubes Adequate?



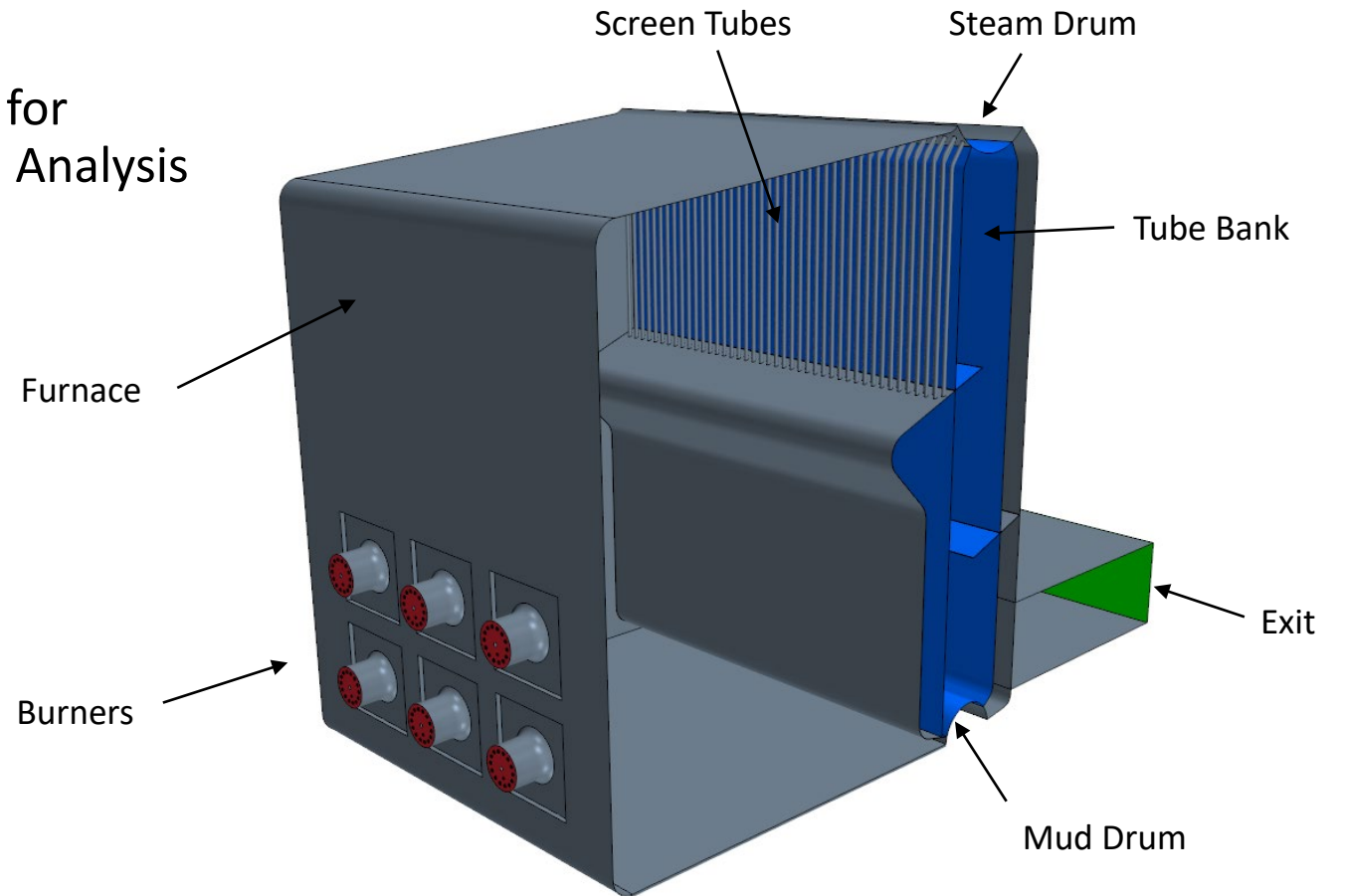
# Combustion Analysis using CFD

- **GOAL**

- Obtain Flow & Temperature Fields
- Detect any Potential Problems
- Obtain Heat Fluxes on Furnace Walls for Subsequent Water-Steam Circulation Analysis

- **SETUP**

- Computational Domain

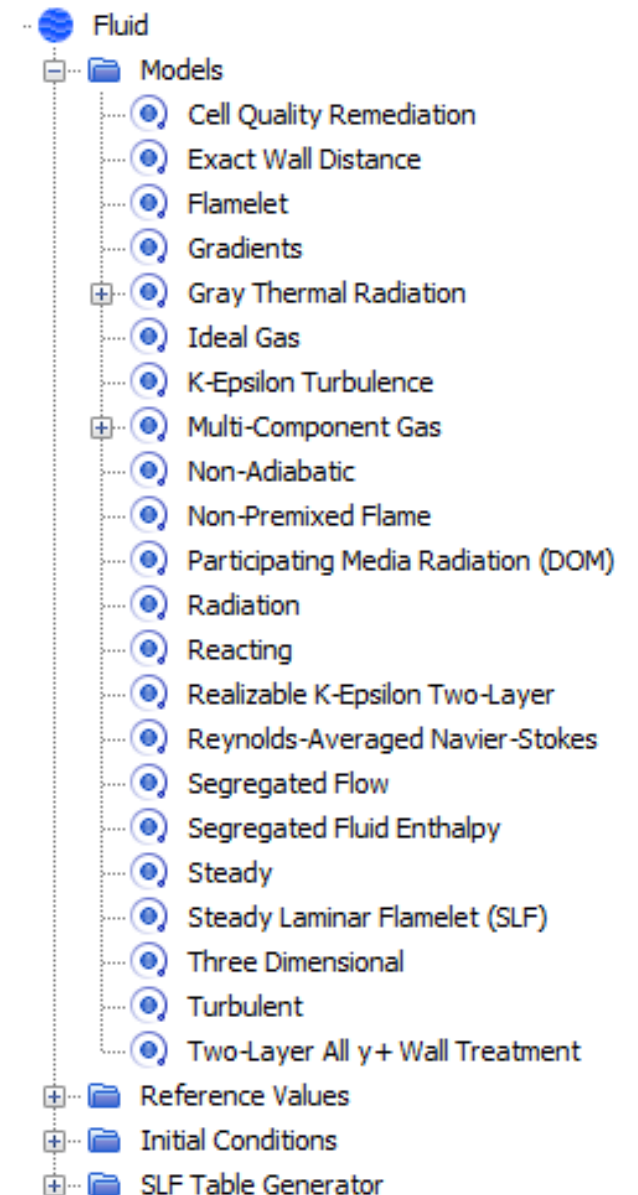




# Combustion Analysis using CFD

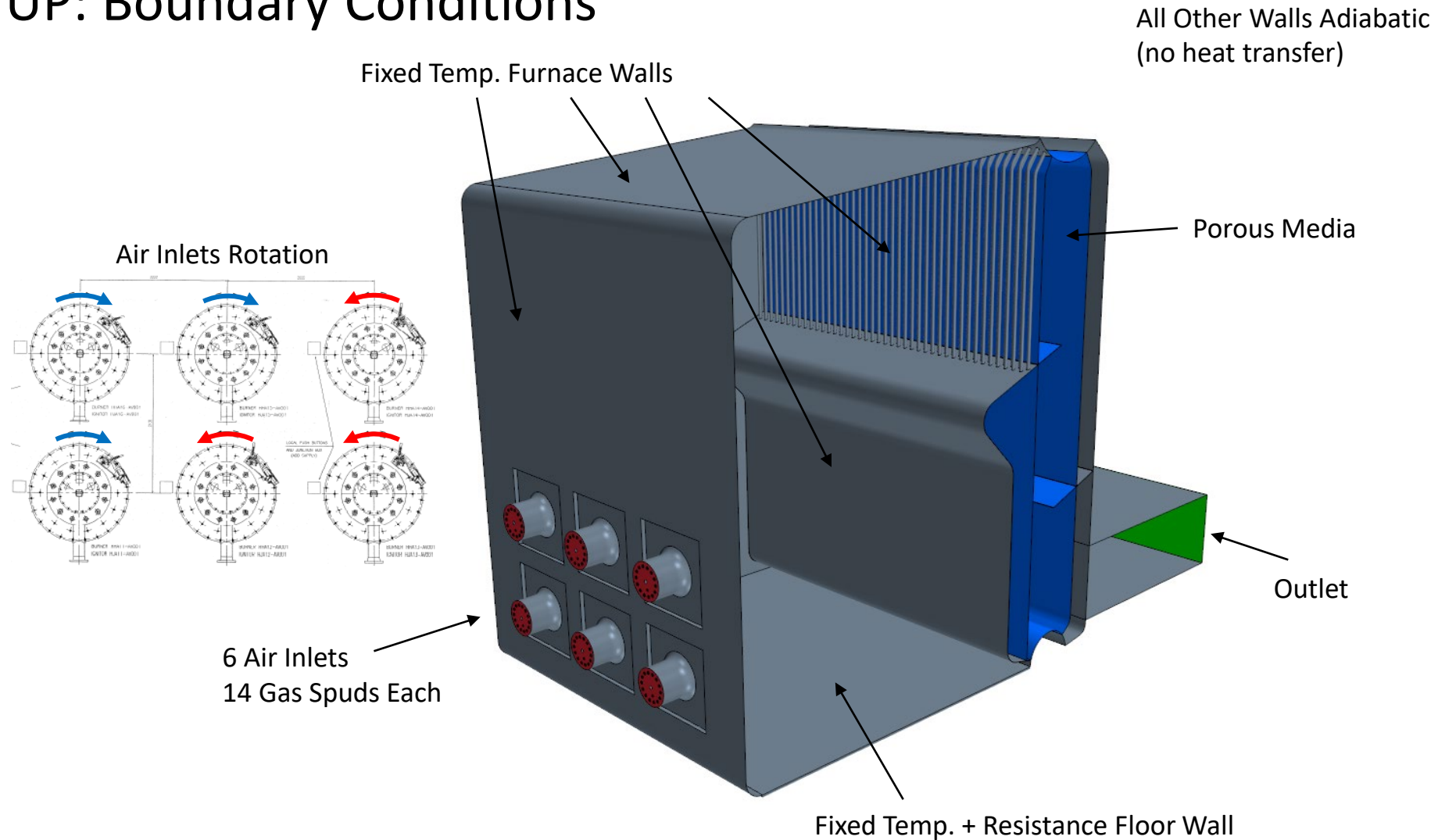
- **SETUP: Physics**

- Air + Natural Gas (9 Species Total)
- Steady State
- 2-Layer Realizable All  $y^+$  k- $\epsilon$  Turbulence Model
- Non-Premixed, Diffusion Flames  $\rightarrow$  SLF Model
- Gray Thermal DOM Radiation with Participating Media



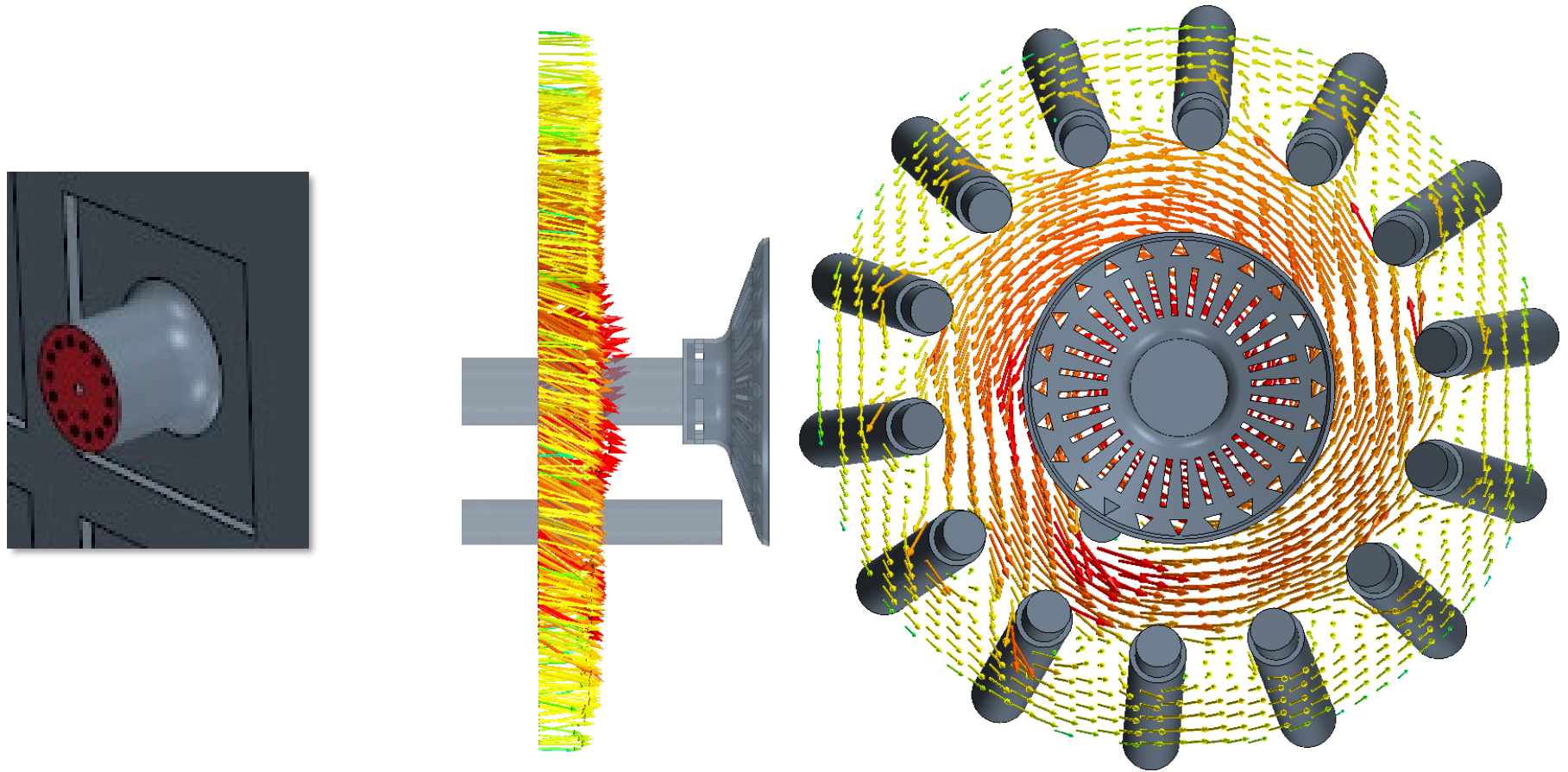
# Combustion Analysis using CFD

- **SETUP: Boundary Conditions**



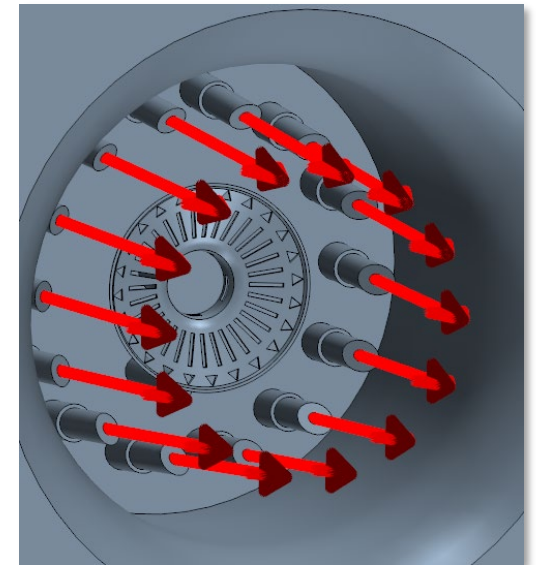
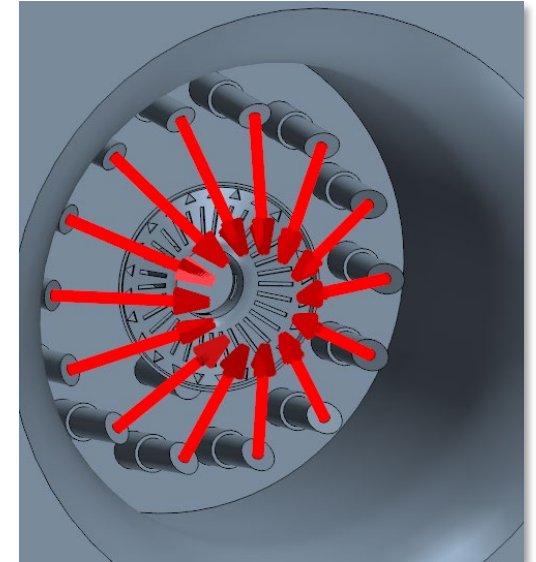
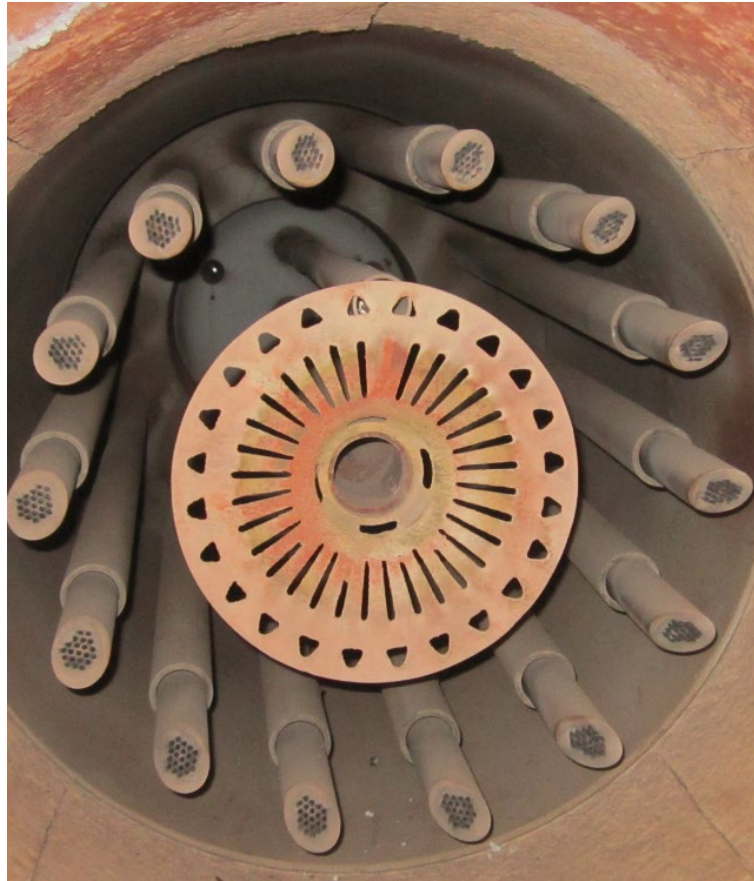
# Combustion Analysis using CFD

- SETUP: Boundary Conditions



# Combustion Analysis using CFD

- SETUP: Boundary Conditions
  - Exact Spuds Orientation Unknown
  - Realistic Limiting Cases:
    - Toward Center
    - Axial

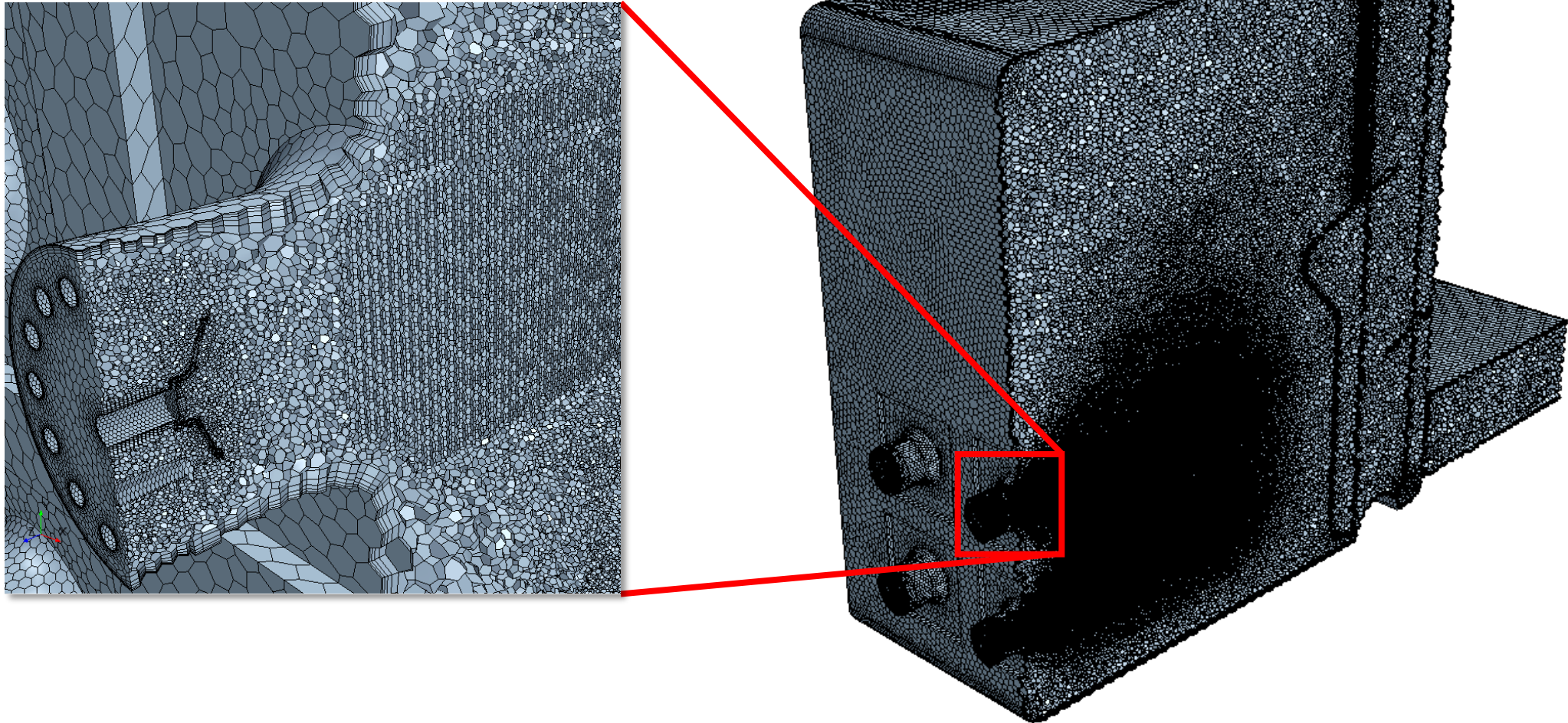




# Combustion Analysis using CFD

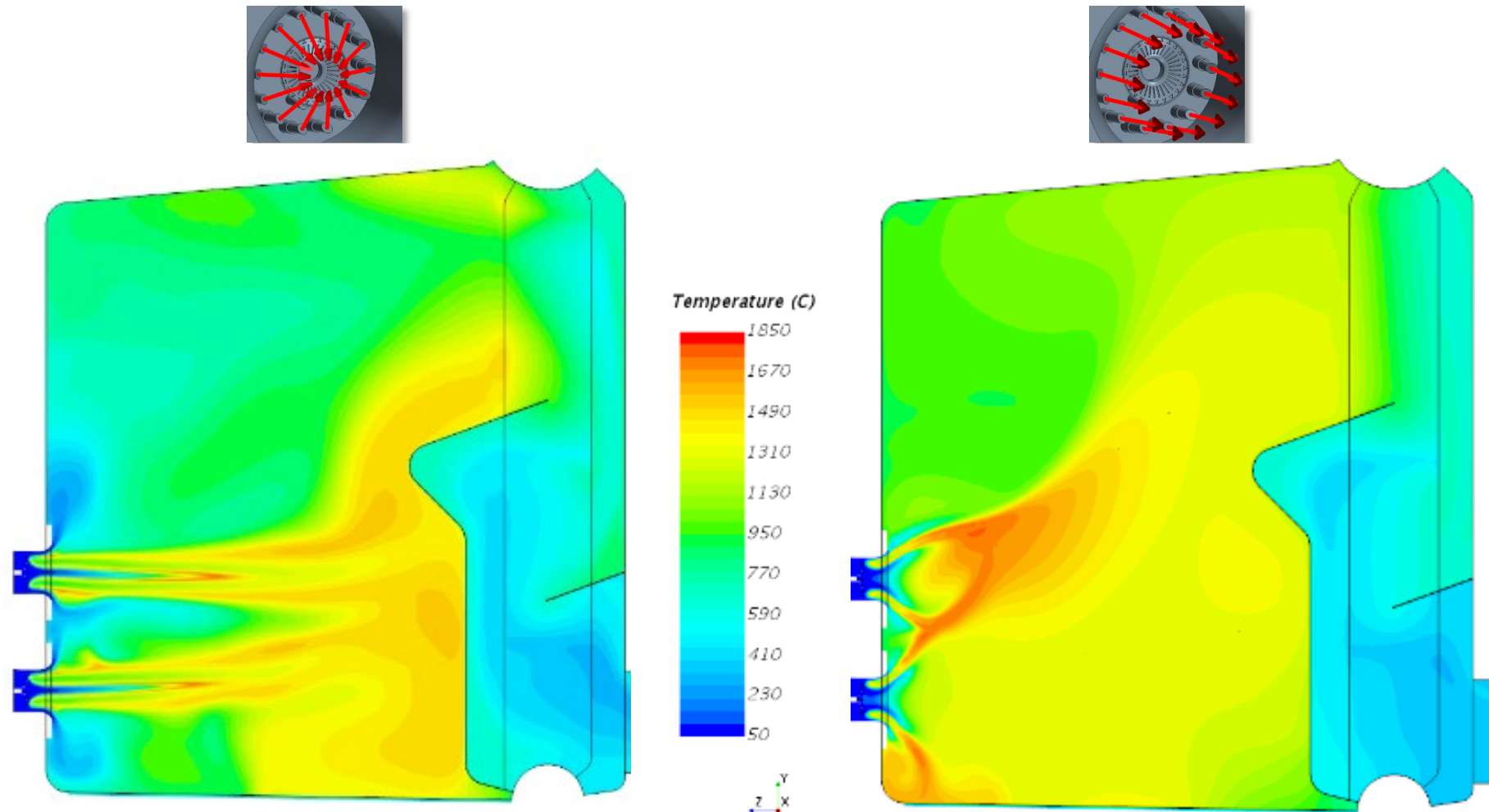
14M Polyhedral Cells

- SETUP: Mesh



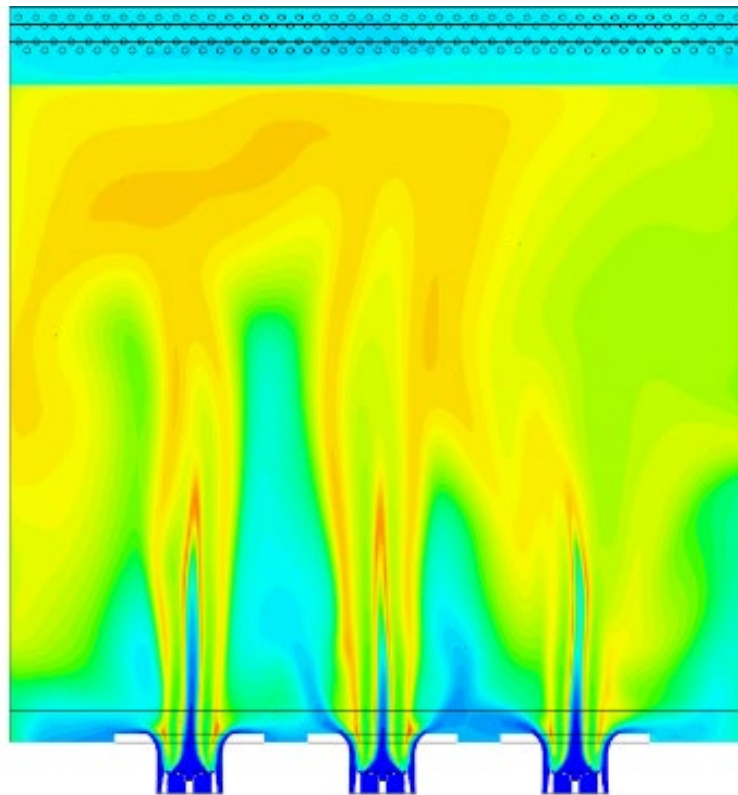
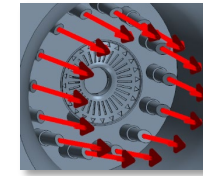
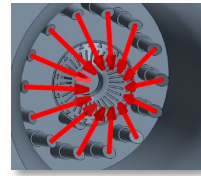
# Combustion Analysis using CFD

- Results: Temperature - Center Burners

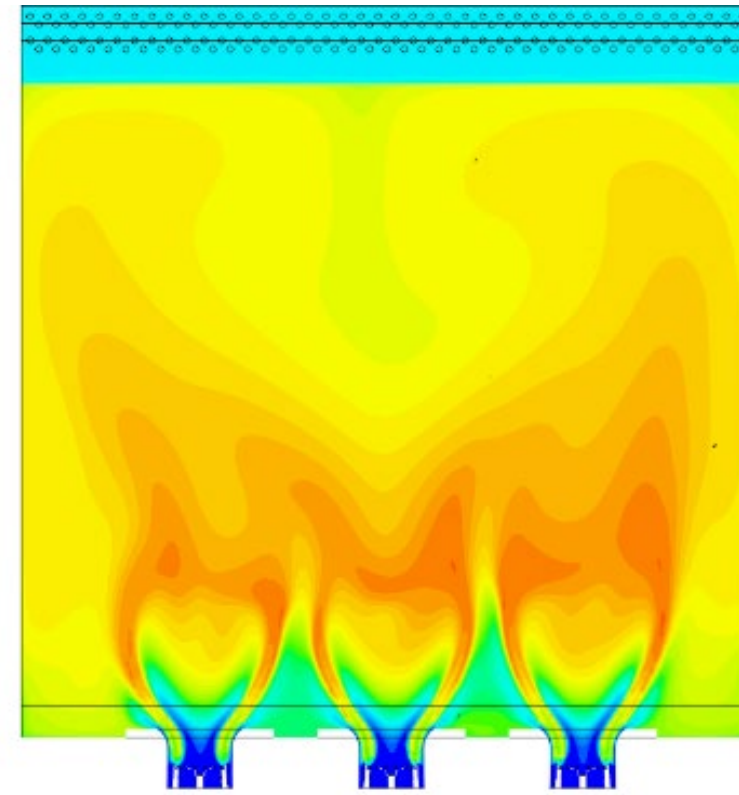
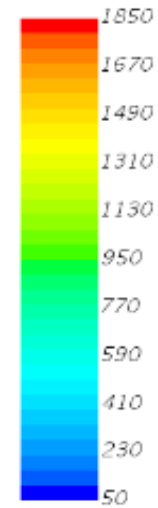


# Combustion Analysis using CFD

- Results: Temperature - Top Burners



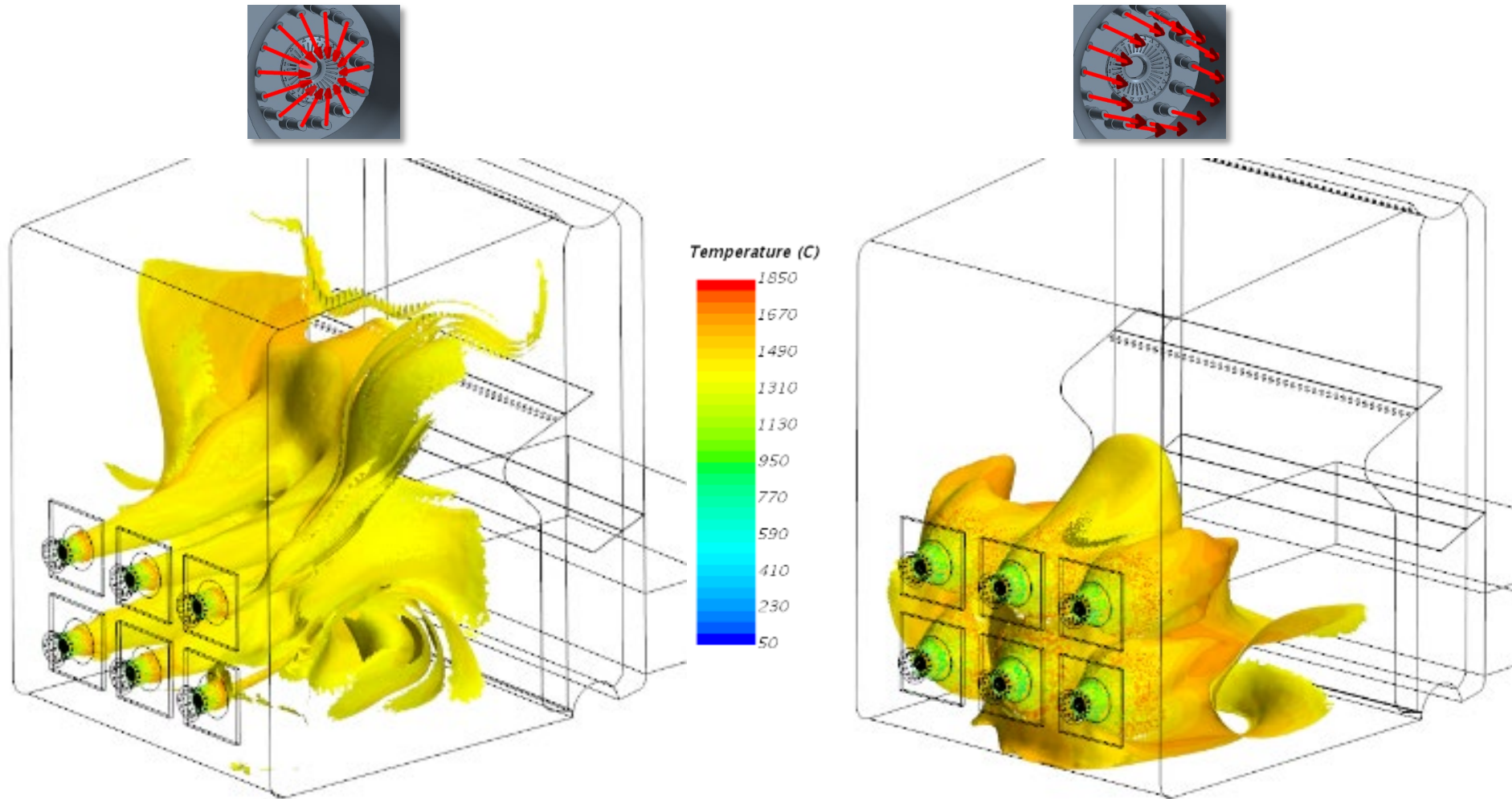
Temperature (C)





# Combustion Analysis using CFD

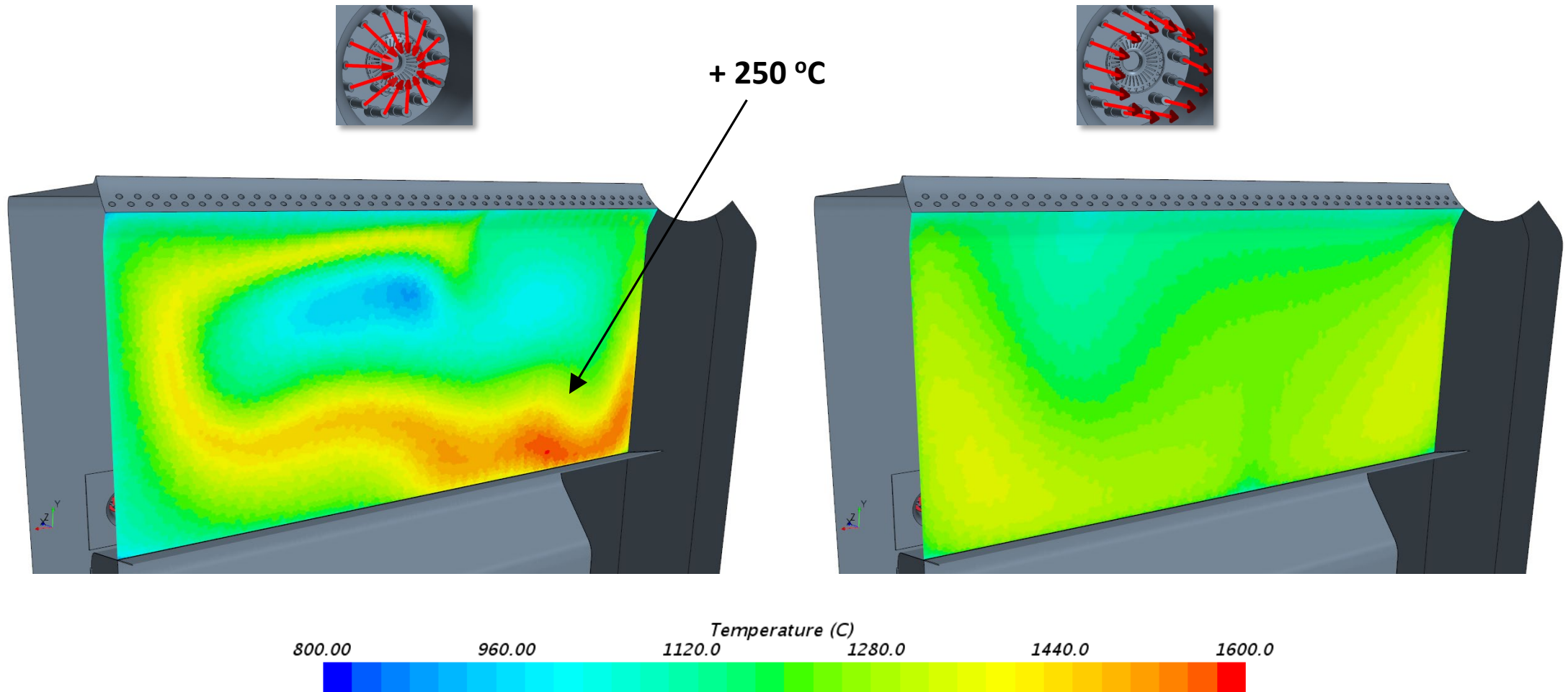
- Results: Flame Contours





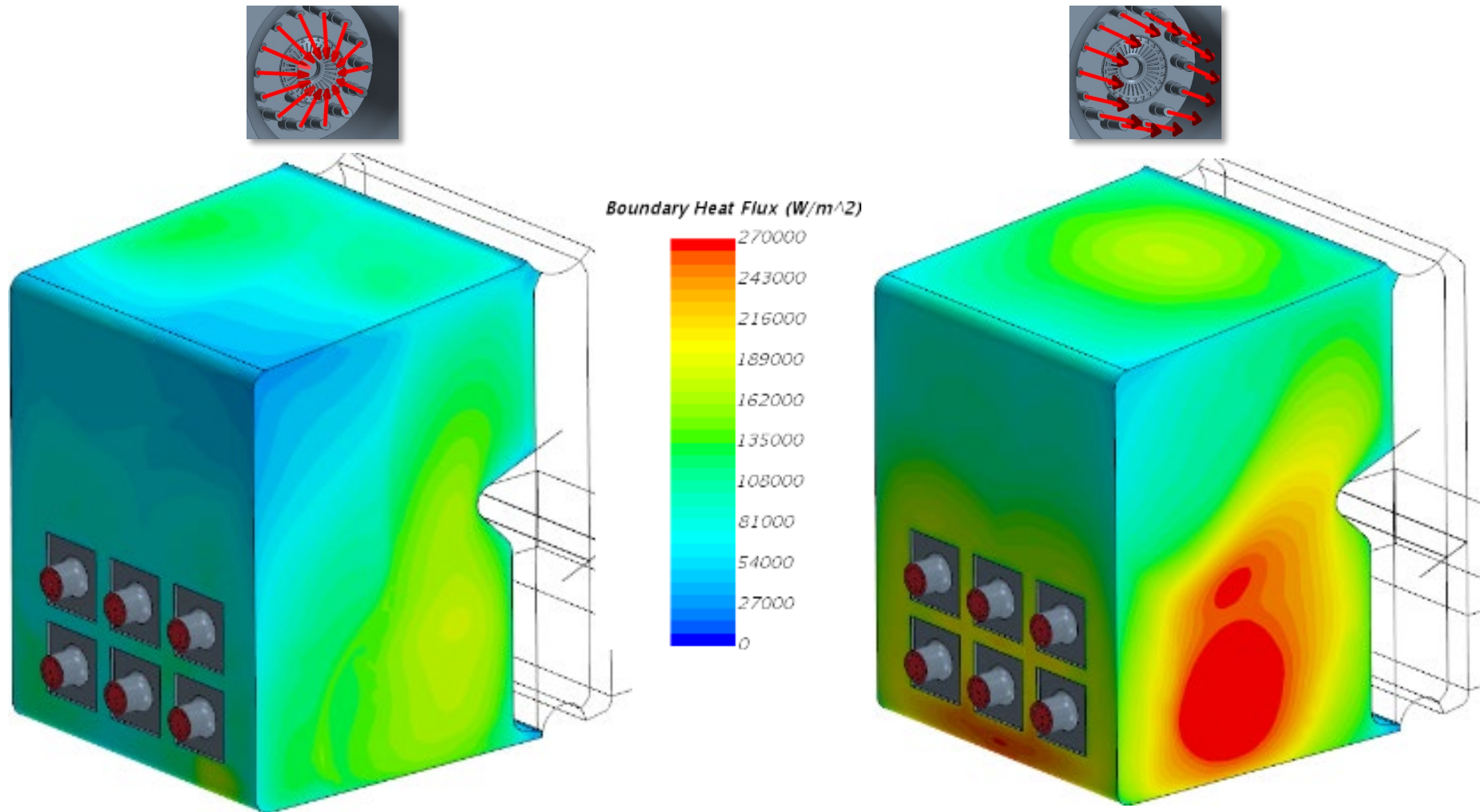
# Combustion Analysis using CFD

- Results: Temperature – Tube Bank Entrance (Close to Tube Failures)



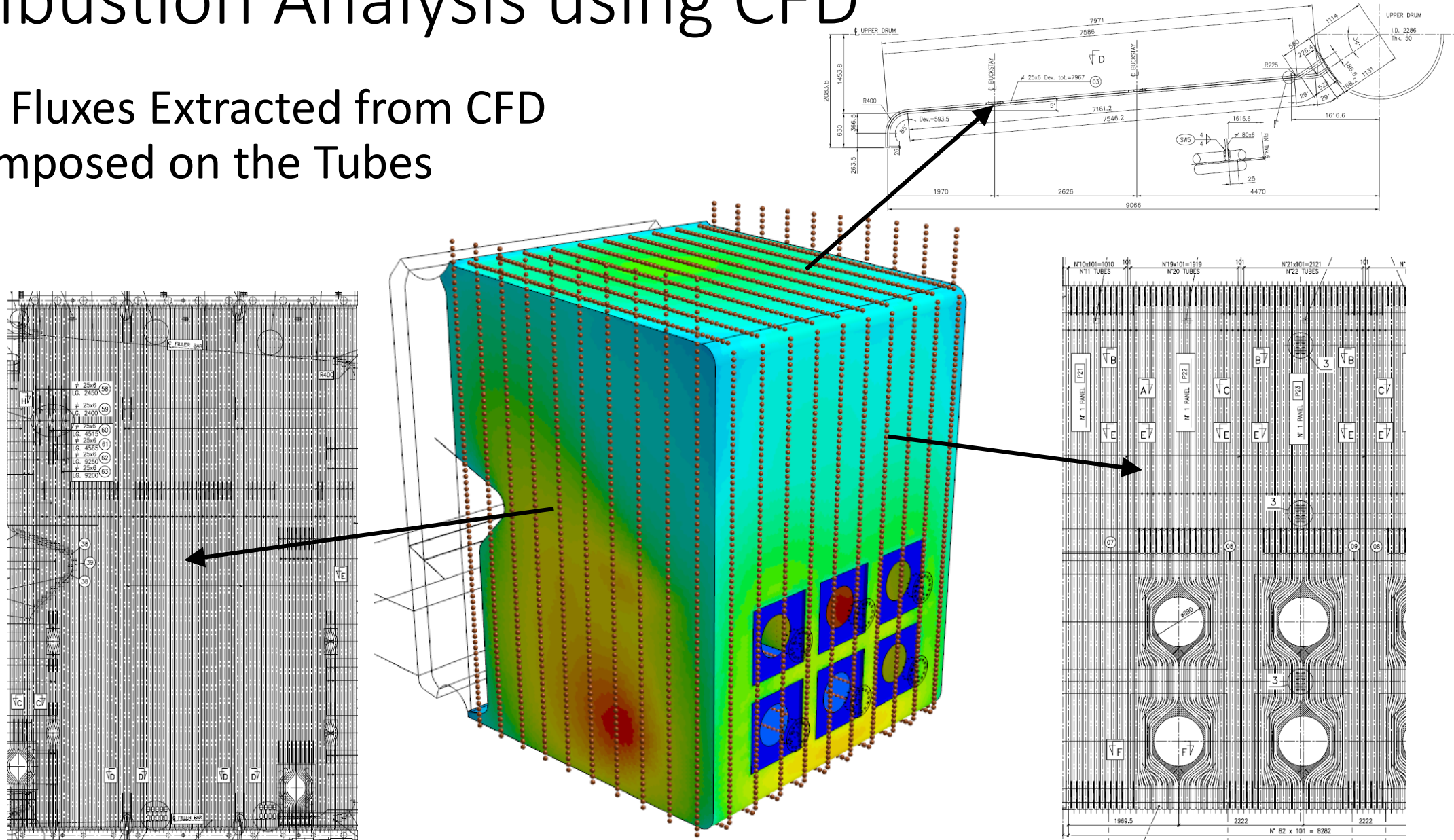
# Combustion Analysis using CFD

- Results: Heat Fluxes



# Combustion Analysis using CFD

- Heat Fluxes Extracted from CFD are Imposed on the Tubes

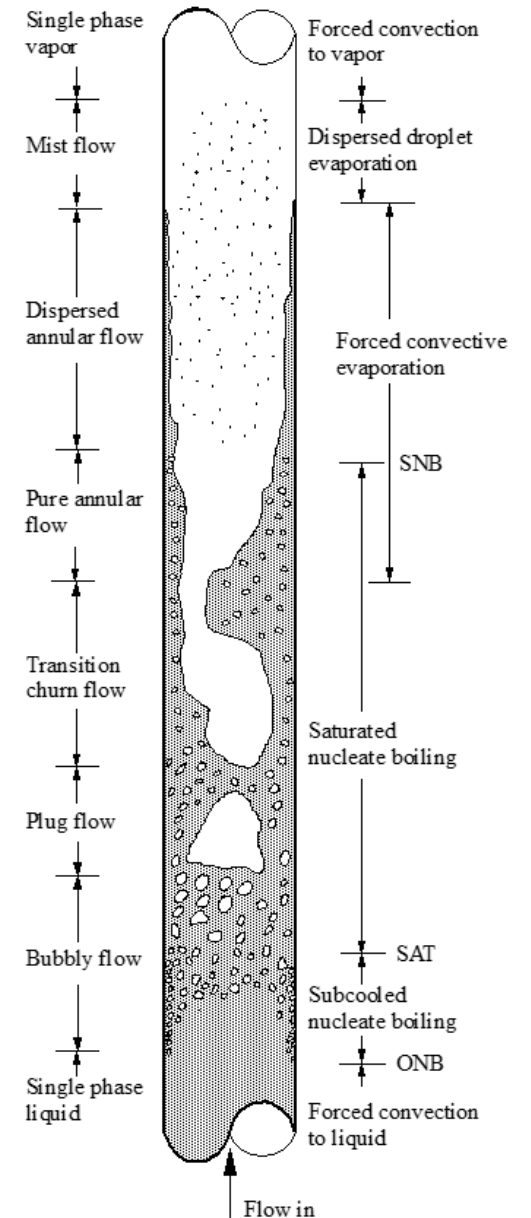




# Water/Steam Circulation Analysis

## • In-House Code

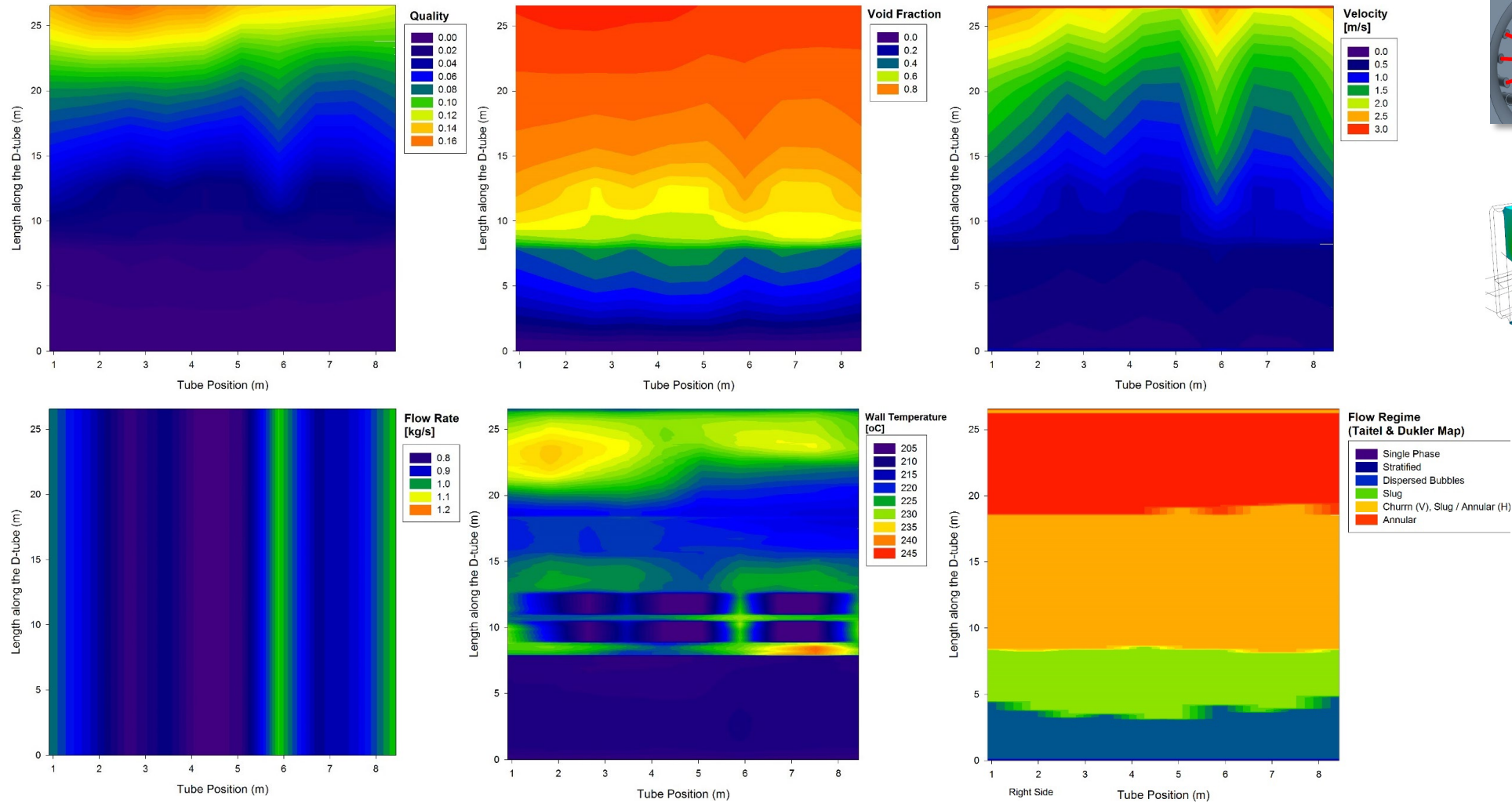
- Water-Side Two-Phase Circulation & Heat Transfer Calculations for All Tubes in Entire Boiler
- Flow Regime Prediction for Vertical and Horizontal Tubes
- Drift Flux Model (1D, Simple & Fast yet Accurate)
- Solve All Tubes Subject to
  - Local Heat Fluxes
  - Constant Driving Head (dP)
  - Risers & Downcomers Calculated
- Validated with 10k Measurement Points
- Outputs Include:
  - Quality
  - Void Fraction
  - Velocities
  - Total Circulation
  - Flow Rates
  - Furnace Tube Metal Temperature
  - Flow Regimes





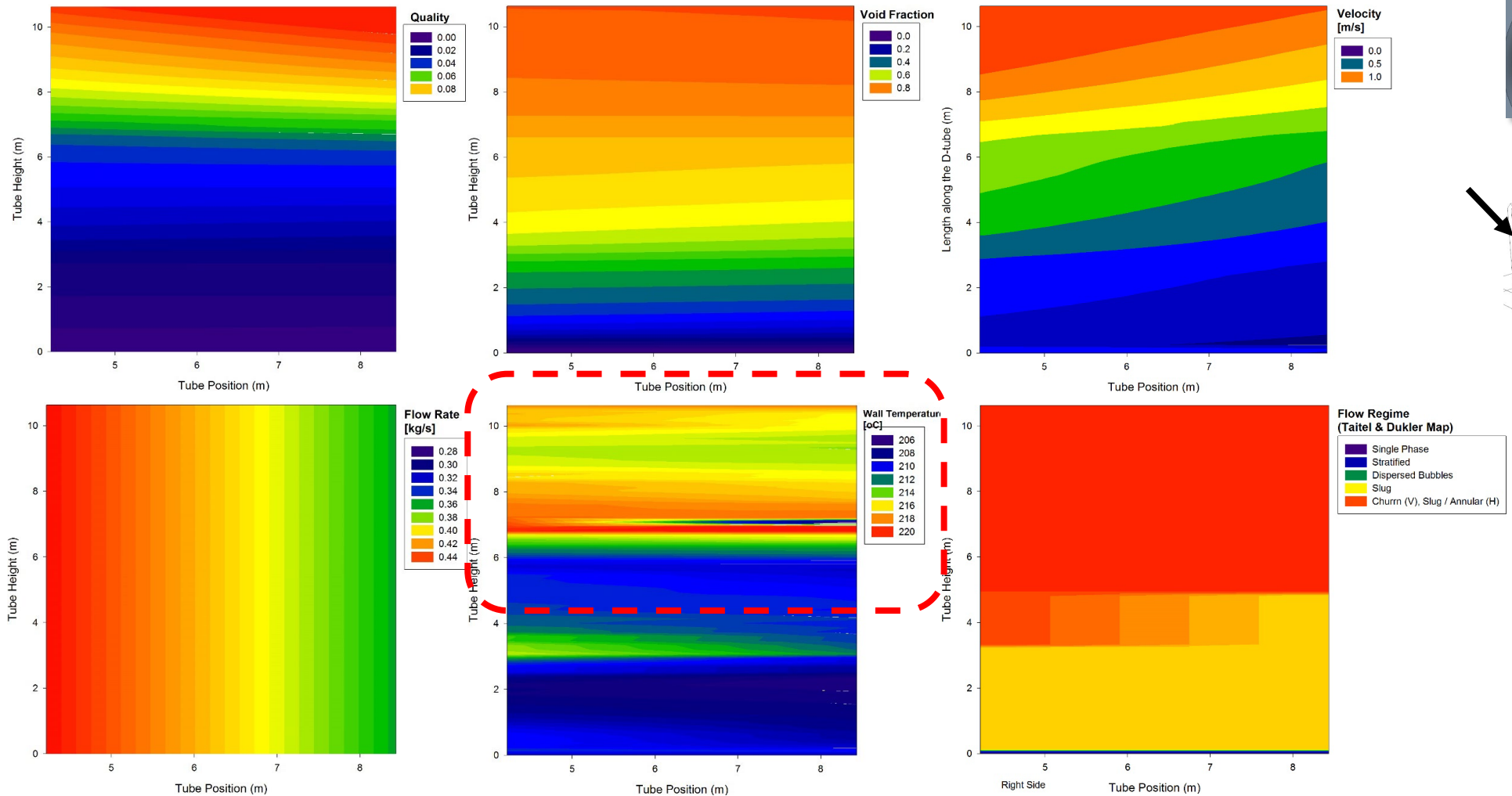
# Water/Steam Circulation Analysis

- Results: Flow in Tubes Panels - **Top/Front/Floor Panel**



# Water/Steam Circulation Analysis

- Results: Flow in Tubes Panels - **Tube Bank**

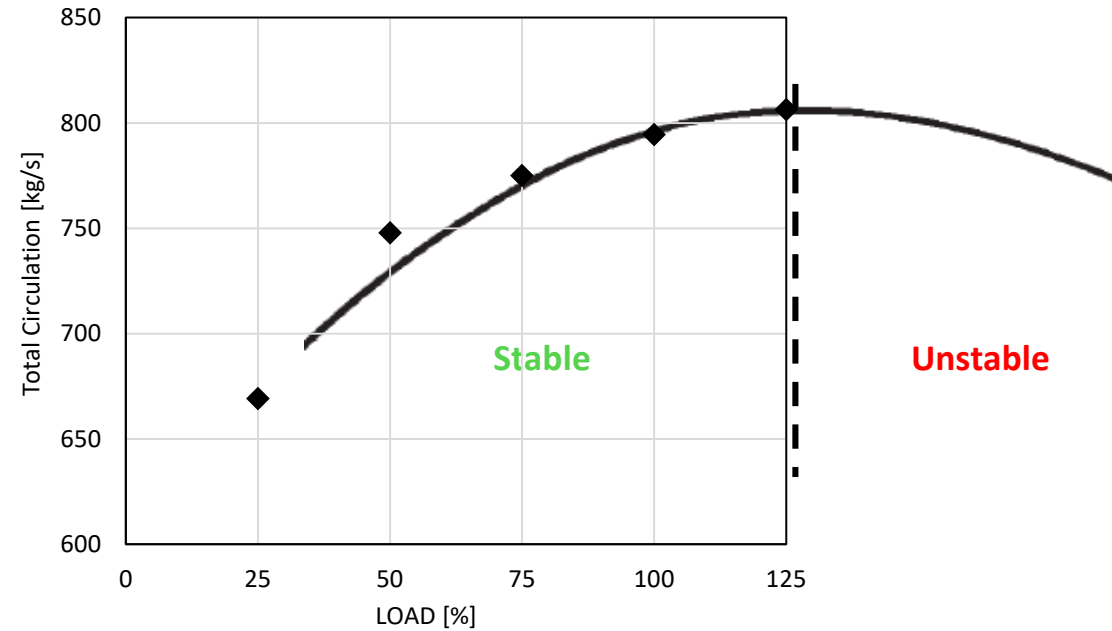


# Water/Steam Circulation Analysis

- Results: Total Circulation

Total Circulation =

$$\sum \textit{Steam} + \textit{Water}$$



- Diminishing Rate of Increase in Circulation with Load
- **ALARM! Getting Dangerously Close to Unstable Operation!**
- **Circulation is only 40% of Recommended Circulation for a VU-60, Needs to Increase!**

# Recommendations

## From Preliminary Analysis

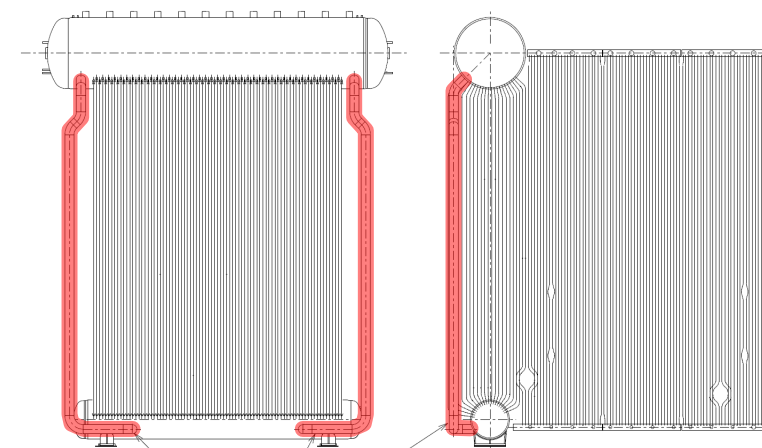
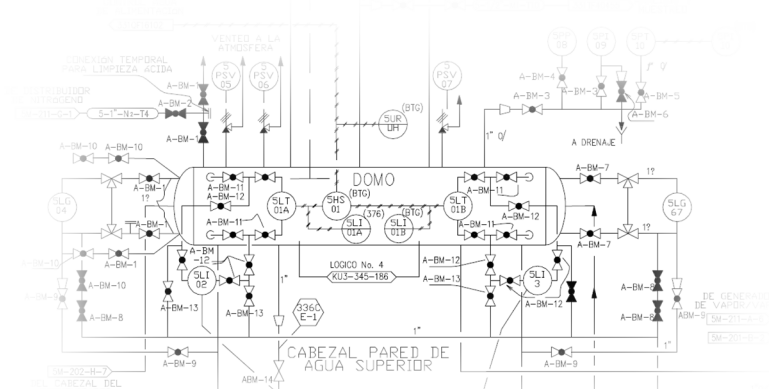
- Prevent Future Pressure Drop Events by Installing Pressure Control System

## From CFD Results

- Eliminate Hot Spots at Entrance of Convection Bank by Installing Burners with Better Mixing

## From Circulation Results

- Increase Circulation by Adding External Downcomers





# Thank you

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