Catalytica
Combustion Systems

FIELD TEST OF A 1.5 MW INDUSTRIAL GAS TURBINE WITH A LOW EMISSIONS CATALYTIC COMBUSTION SYSTEM

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Program Objectives and Strategy

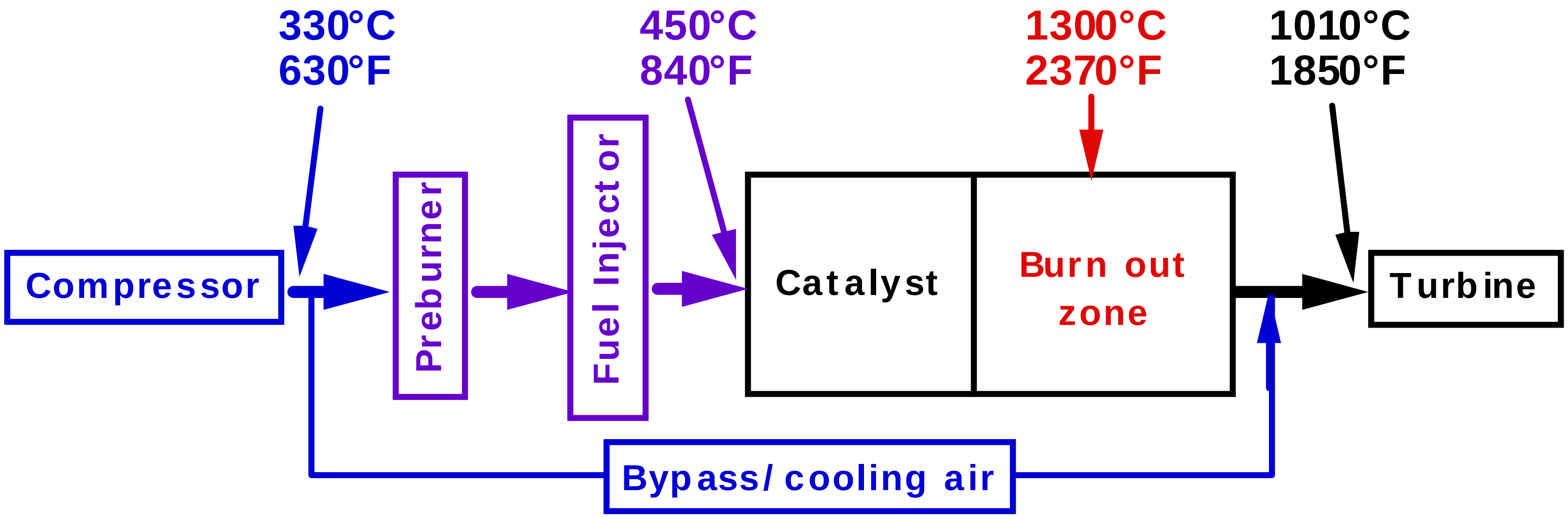
- Combustor to be a demonstrator of catalytic technology
  - Materials selected to minimize development time
  - No size limitations
- Basic engine/combustor approach
  - No modifications to gas turbine
  - Combustor change out at combustor flange
  - Natural gas fuel only
- Performance targets
  - Emissions over 90 to 100% load range and wide ambient

    NO_x < 3 ppm

    CO < 5 ppm

    UHC < 5 ppm
  - Minimal impact on turbine performance
- Combustor outlet temperature of 1300°C (2400°F) to demonstrate catalytic combustion technology for wide range of engines

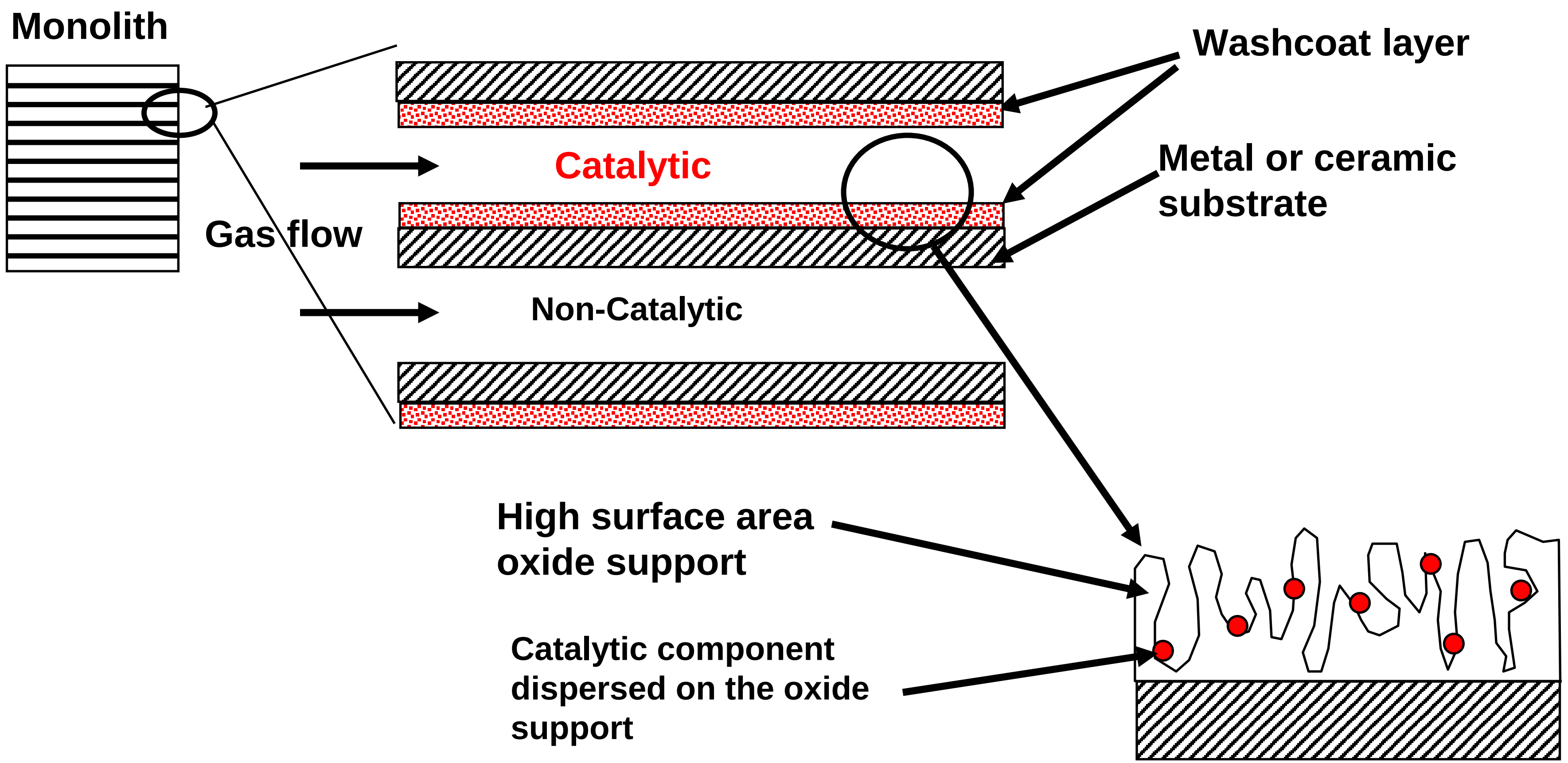
Schematic of combustor configuration



- Preburner provides required catalyst inlet temperature
- Catalyst fuel injector produces a uniform fuel/air mixture for the catalyst
- High post catalyst temperature oxidizes CO to < 10 ppm
- Bypass and cooling air provides required turbine inlet temperature

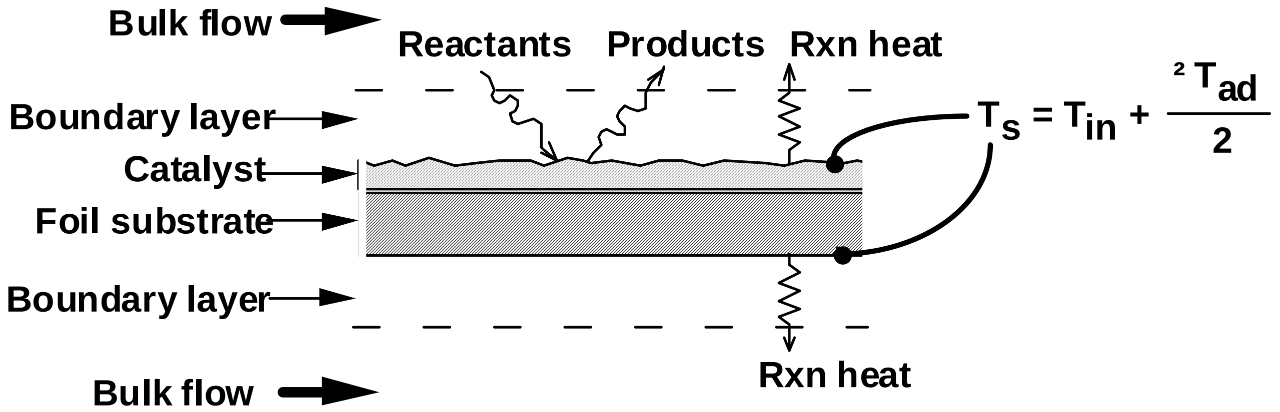
One Aspect of Catalyst System

Temperature controlled by "Integral Heat Exchange" structure that limits catalyst temperature below adiabatic combustion temperature



Integral Heat Exchange

Integral heat exchange (IHE) limits catalyst temperature

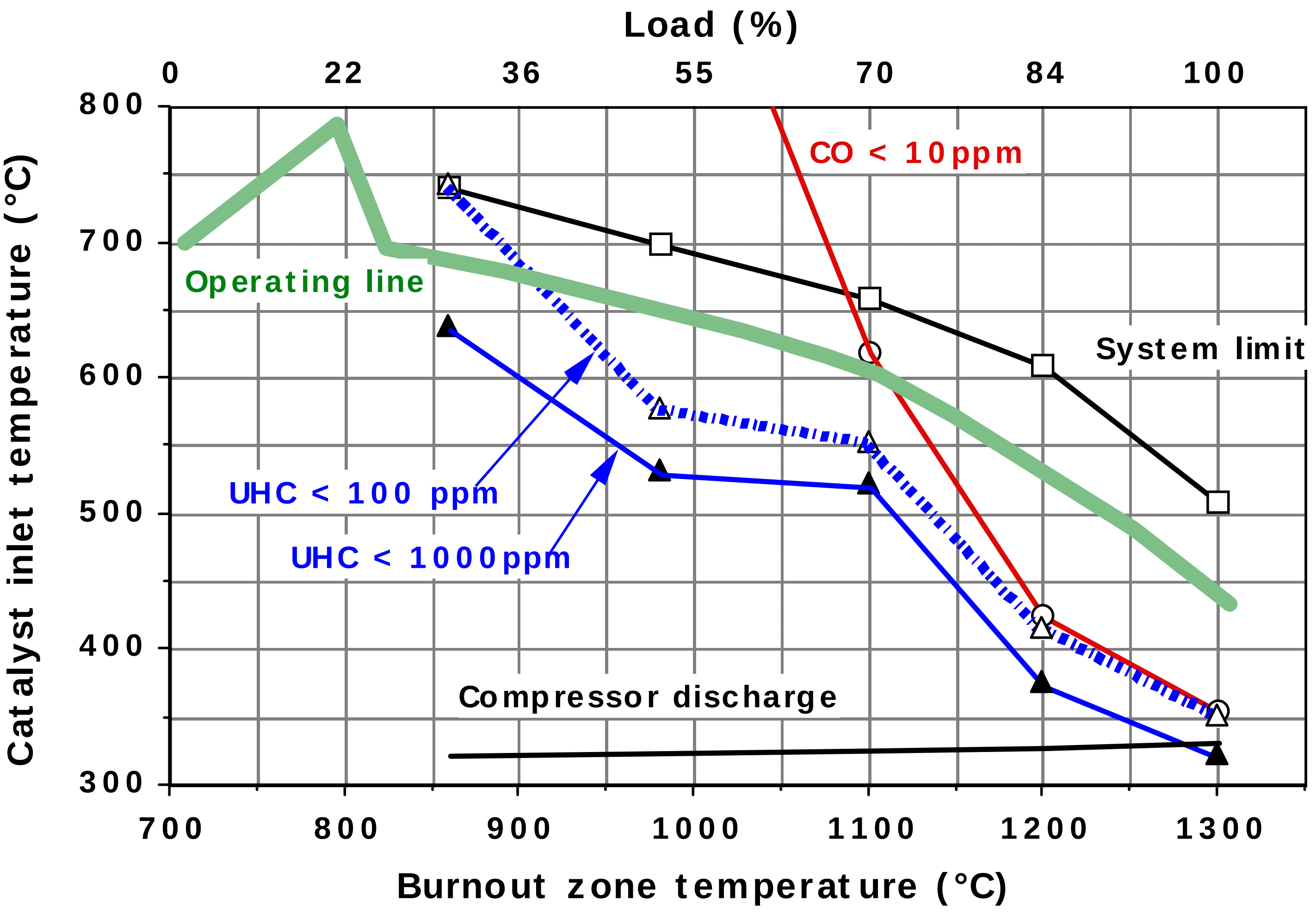


- Solid cross-section essentially isothermal
- Equal heat transferred to catalyzed and non-catalyzed channels
- Maximum conversion = 50%
- Maximum wall temperature = $T_{in} + \frac{1}{2}$ ² T_{ad}
- Example: Inlet gas T = 700°C (1290°F)
  Tad = 1300°C (2370°F)

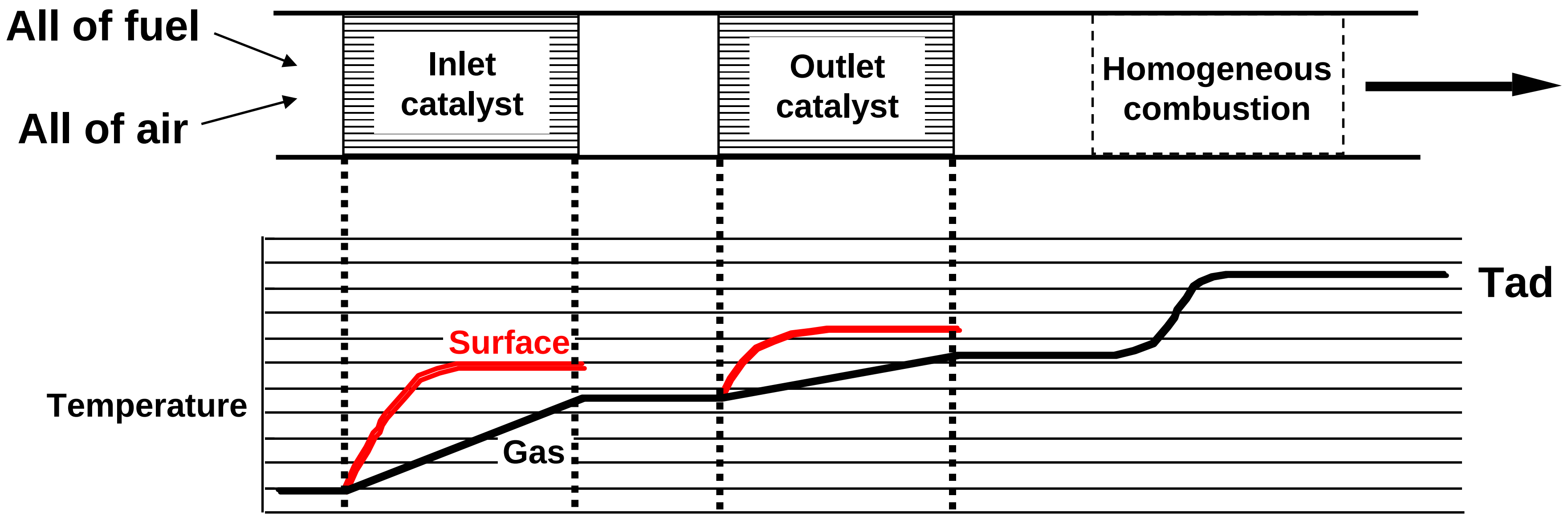
non-IHE wall T = 1300°C(2370°F)
IHE wall T = 1000°C (1830°F)

XONON 1 Catalyst performance and operating line

- Measured on Sub-scale rig at operating conditions



XONON design flexibility

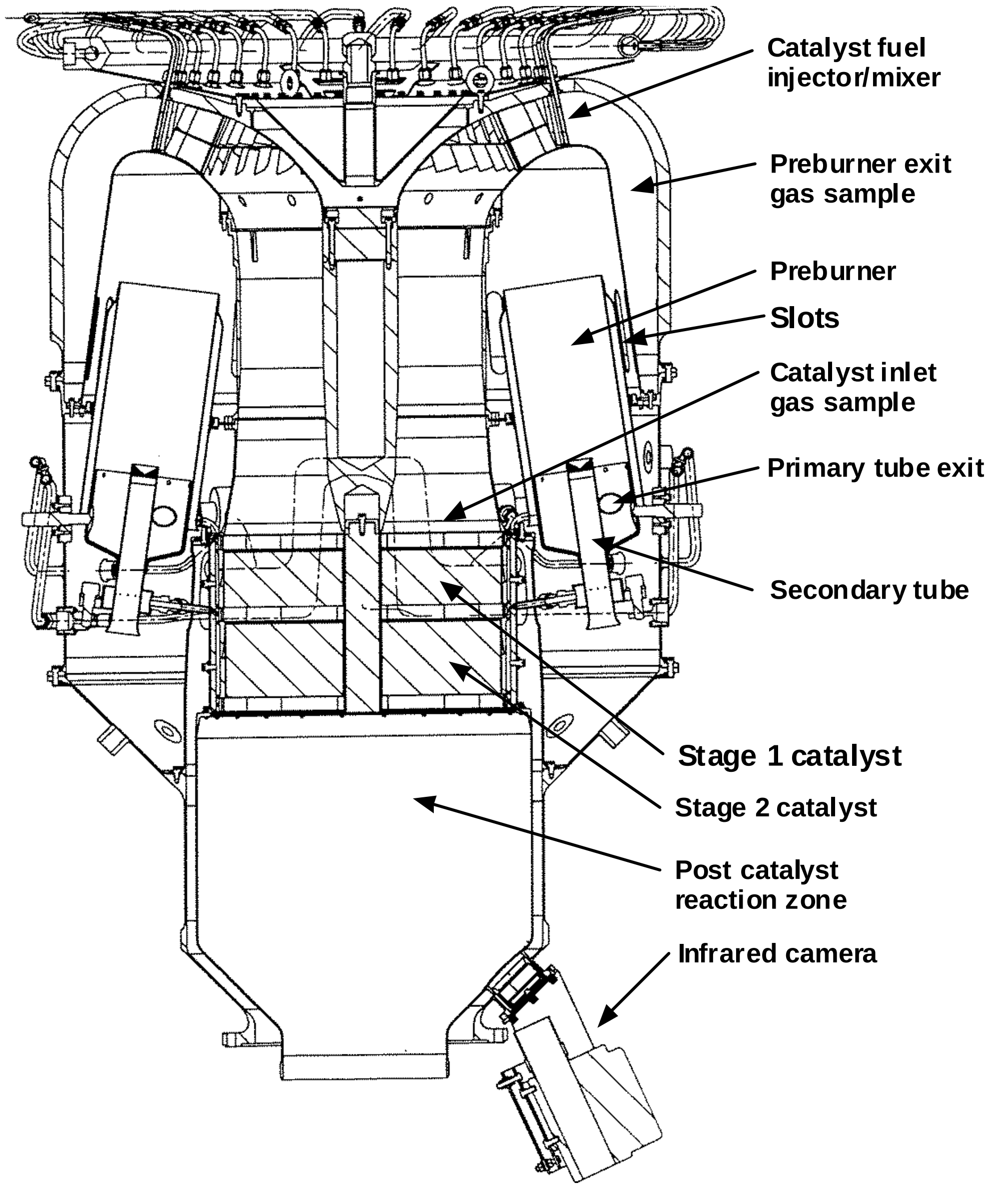


- High activity
- Low lightoff T
- Designed for low wall T

- Higher wall T (design limits max wall T)
- High outlet gas T

Sufficient time to:

- Complete CH4 combustion
- Complete UHC and CO burnout



Combustor cross section

Preburner Design

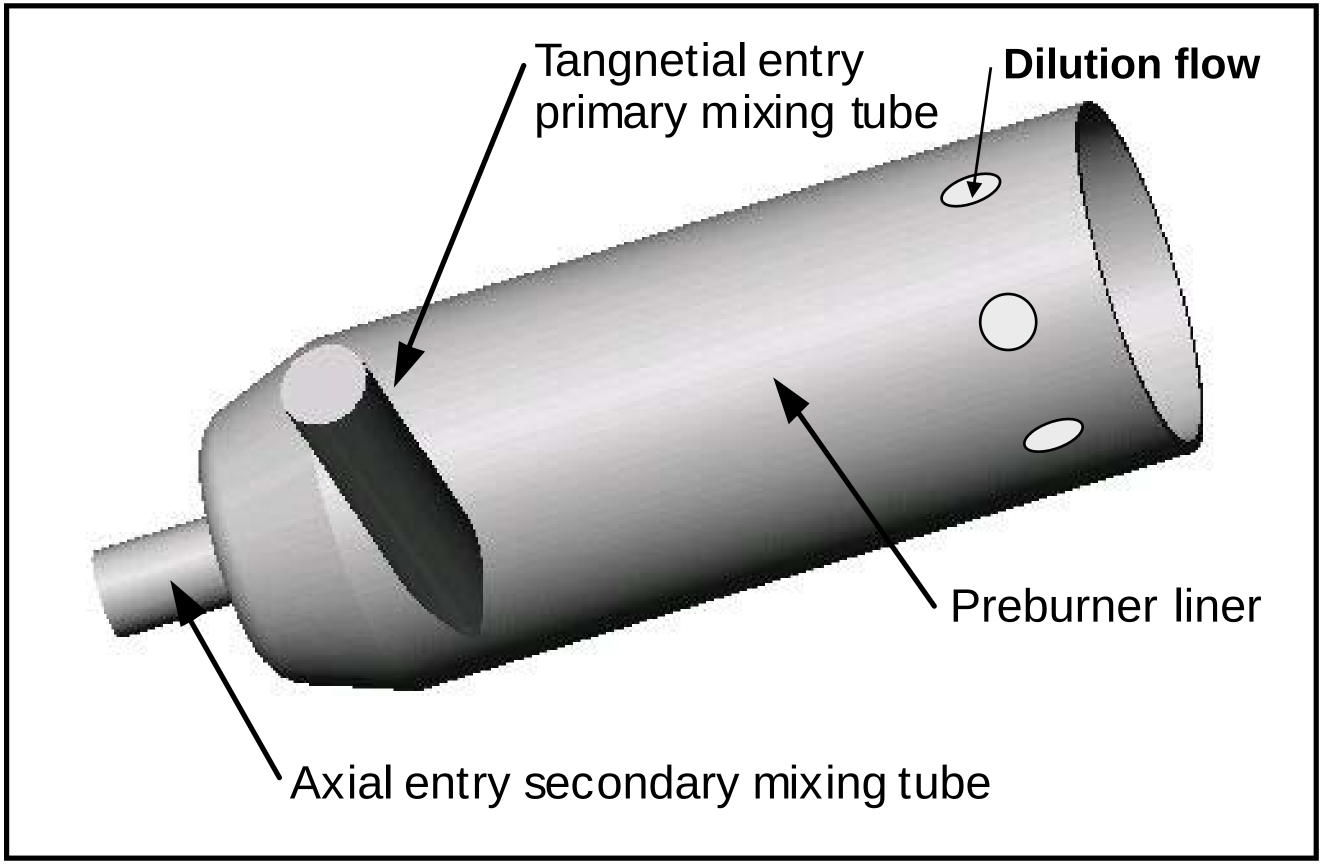
Requirements

- **Temperature rise of 700°C (1200°F) during starting and acceleration**
- **Low emissions load range requires 80 to 150°C(150 to 270°F) temperature rise**
- **NOx contribution at engine exhaust < 2 ppm over low emissions load range**

Design

- **Lean premix swirl stabilized primary**
  - **Operates from LBO+20% to NOx limit**
- **Lean premixed parallel secondary ignited by primary**
- **More then 50% of combustor air flow is added downstream of the primary and secondary prior to catalyst inlet**

Preburner: Perspective View



Catalyst Fuel-Air Mixing System

Requirements

- **Fuel-air mixture uniformity < ± 3% of mean at catalyst inlet**
- **No recirculation or stagnation zones that would hold flame downstream of fuel injection**

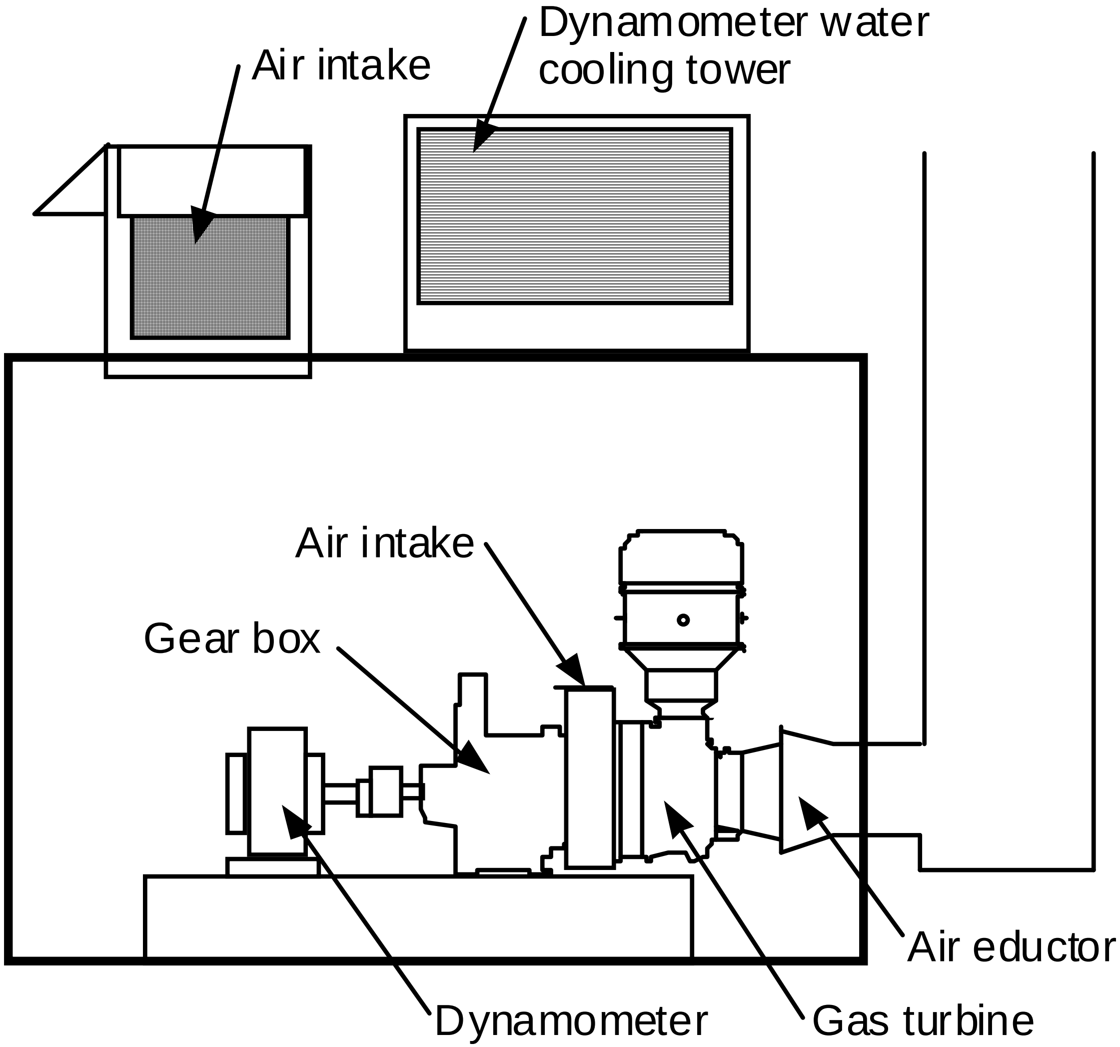
Design

- **Preburner exhaust flow is reversed to enhance temperature uniformity upstream of the fuel injector**
- **Fuel is injected upstream of counter rotating swirlers**
  - **36 swirl vanes and 36 fuel injection pegs**
  - **Counter rotating flows promote mixing with low tangential velocity just upstream of the catalyst**

Catalytic Module

- ~95% open area for low pressure drop
- All metal structure for thermal shock resistance

Engine Test Cell Layout

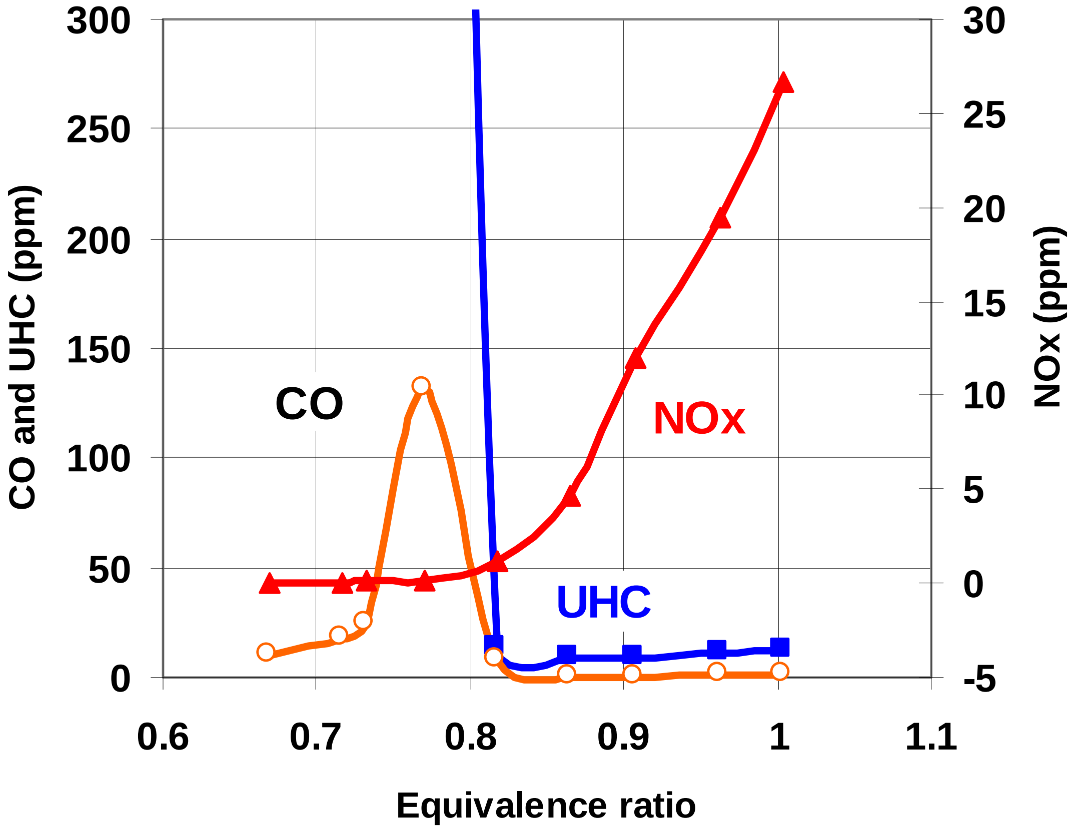


On Engine Preburner Testing

- Static pressure tap downstream of mixed preburner exhaust used to measure gas composition
- Engine operated at part load
- Fuel to preburner primary and secondary could be varied over a reasonable range
  - Must stay within catalyst operating zone
  - Engine was operated in speed control mode with set dynamometer load

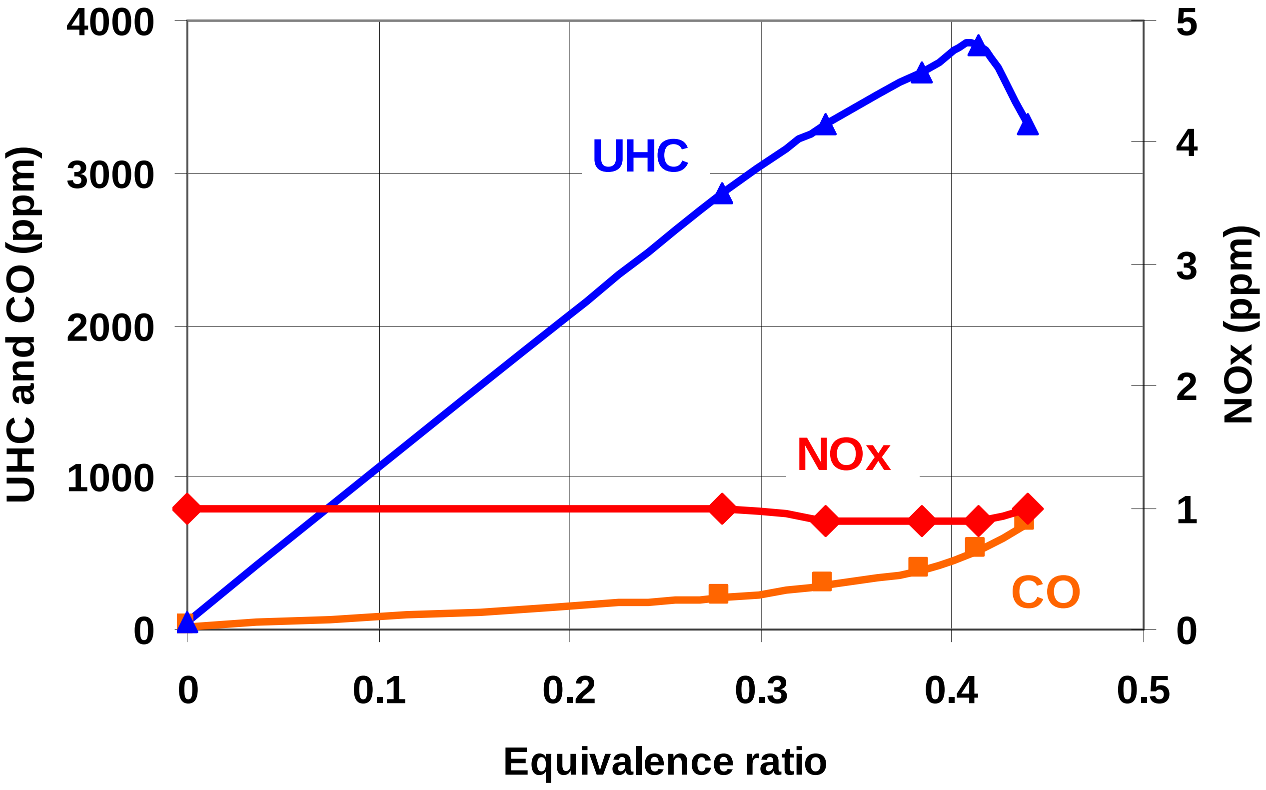
Primary Zone Performance

- Measured at preburner exit
- No secondary fuel



Secondary Performance

- **Primary Ø=0.86**
- **Measured at preburner exit**



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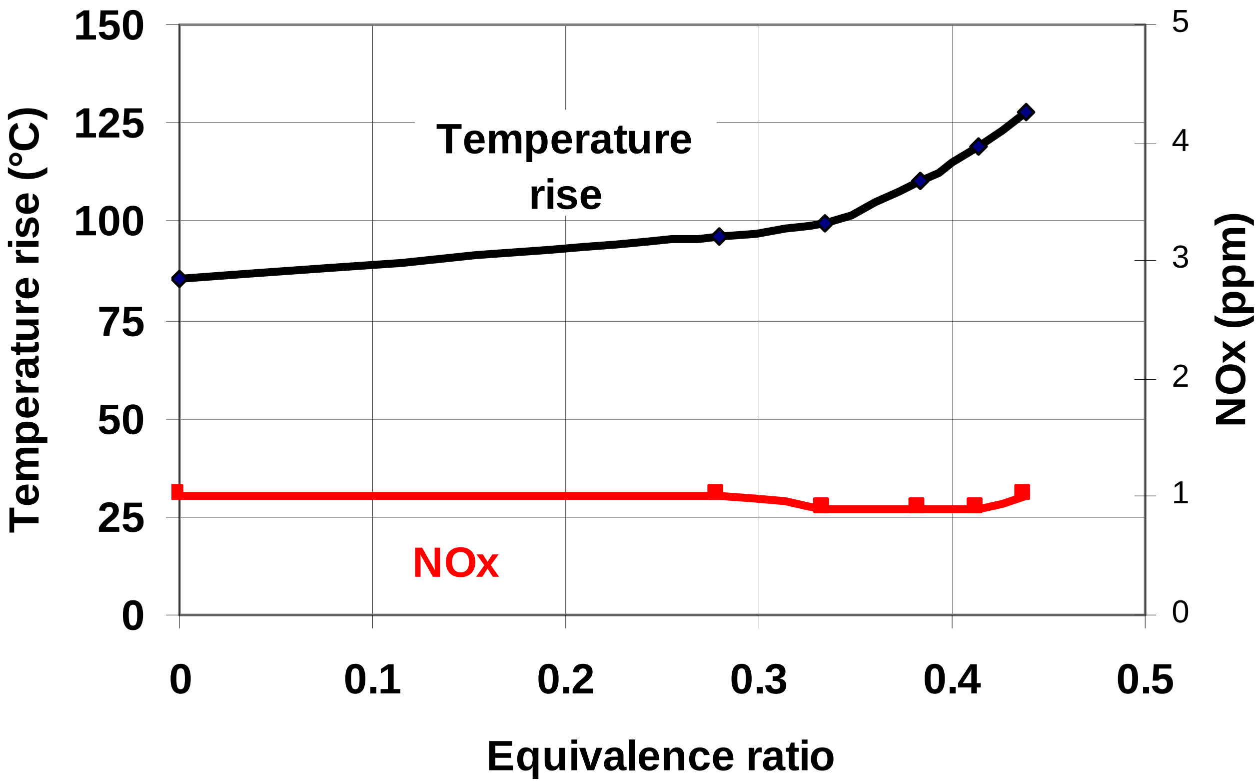
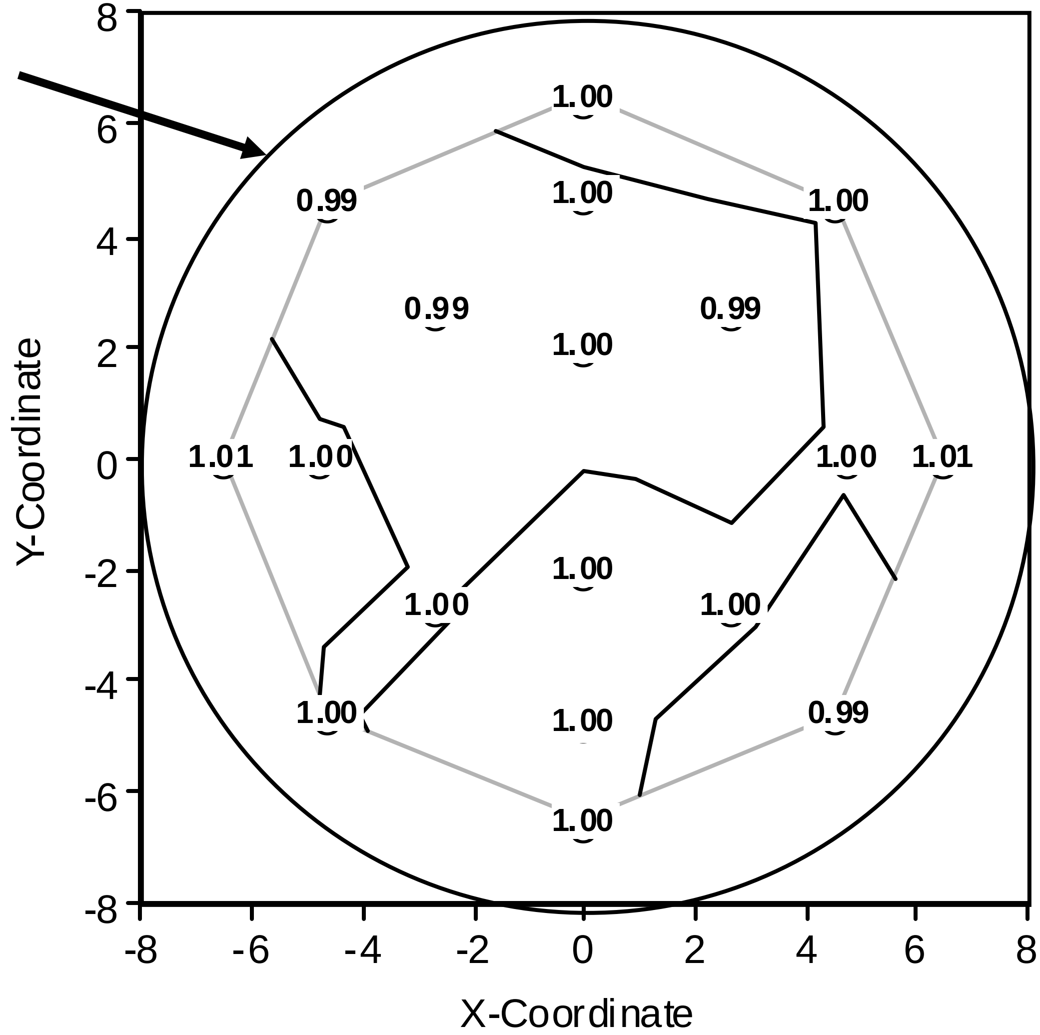


Fuel-Air Mixer Performance

- 18 sampling tubes at the catalyst inlet face used to extract mixture for analysis by FID hydrocarbon analyzer
- Measurement done under constant dynamometer load with engine in speed control mode
- Measurement time was ~20 minutes
- Some measurement variation may arise from total fuel variation required for engine control
  - Especially large at low catalyst fuel flow

F/A Map at Catalyst Inlet--1065 kW

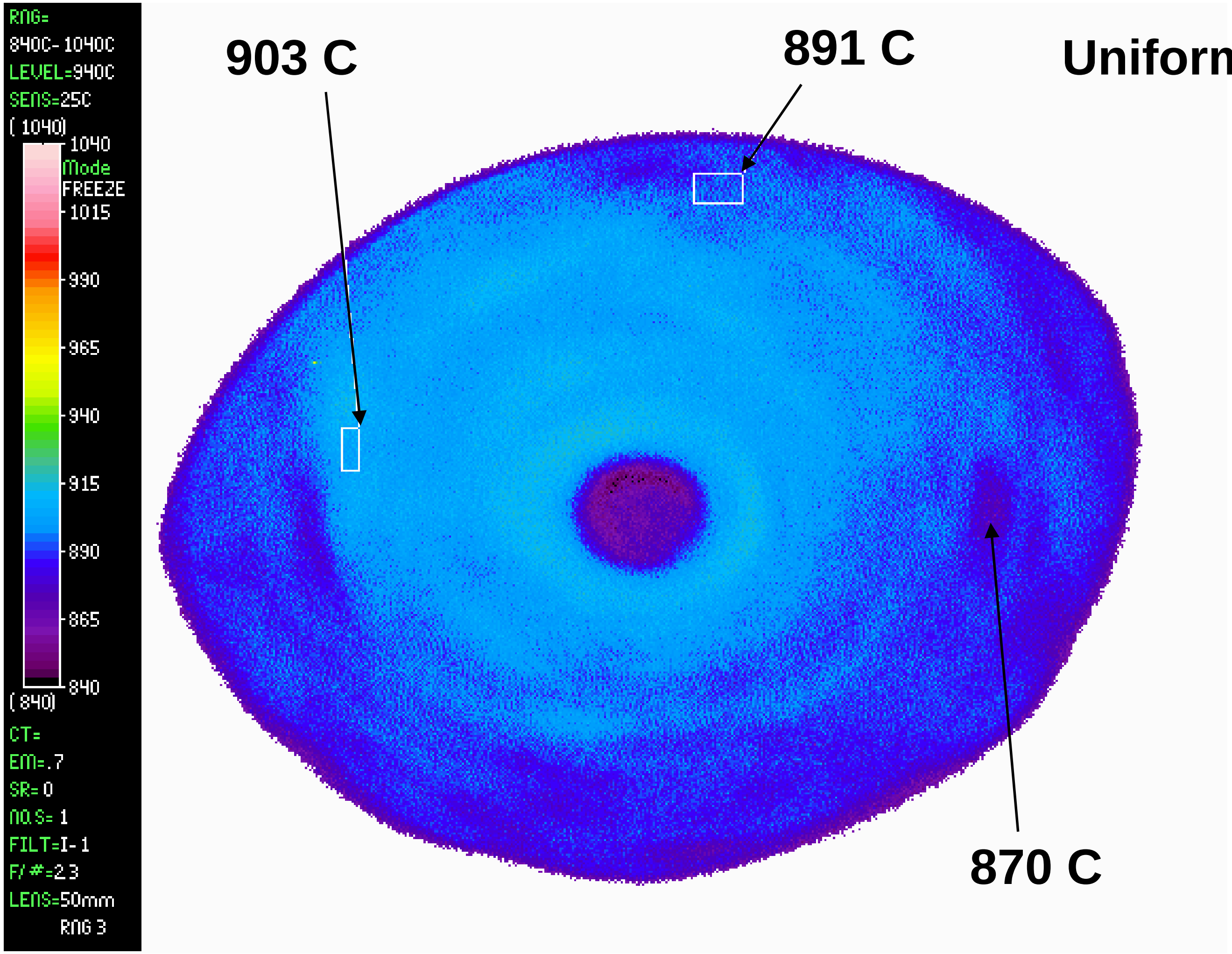


<u>Results</u>

Relative F/A ratio

Min	**0.991**
Max	**1.008**
Range	**± 0.9%**

Infrared Image at Full Load (EGT limit)

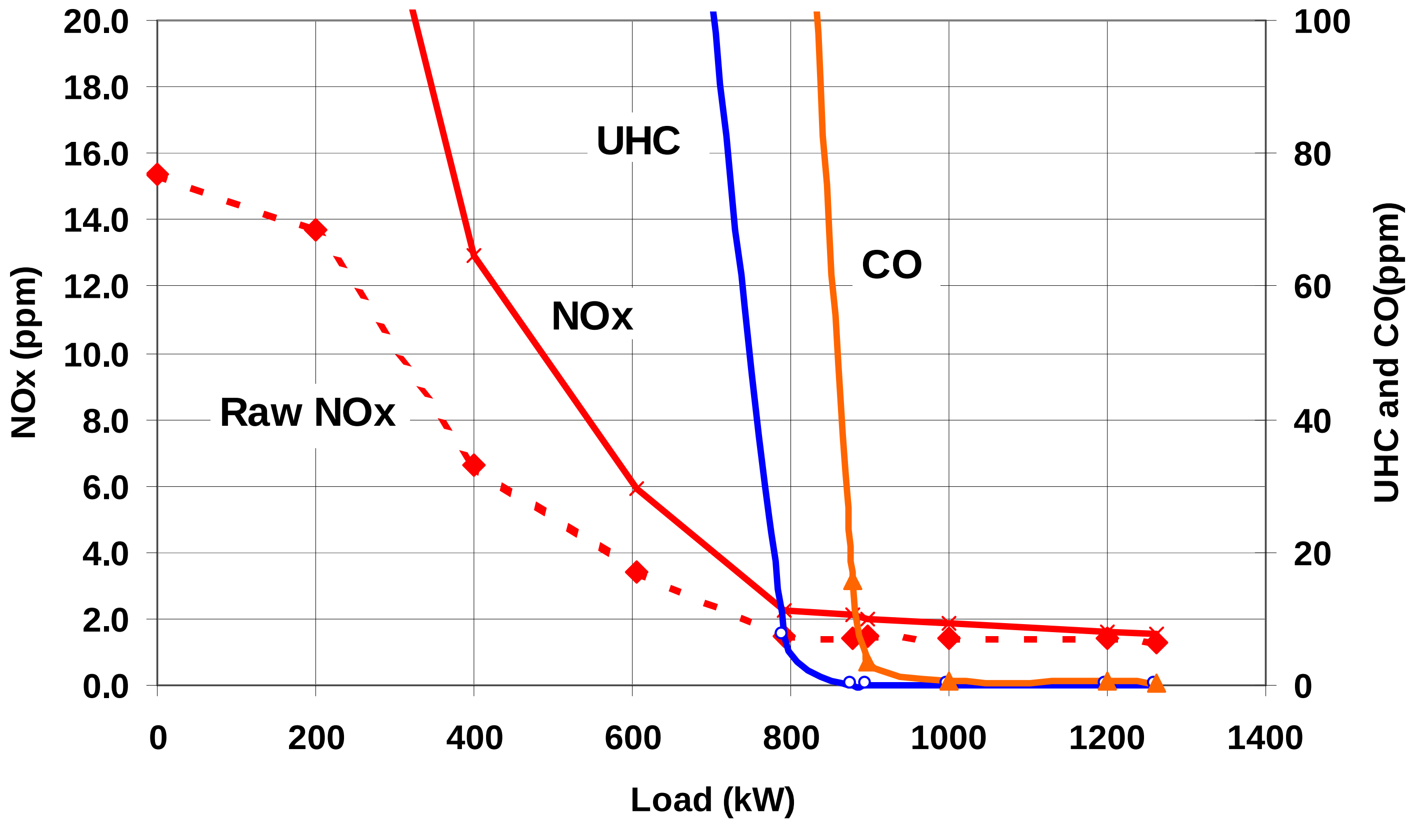


Uniformity = ~ 75 C

994125c4

Engine Performance

- **Measured at engine exhaust**
- **Corrected to 15% O_2**



Summary

- Combustor designed and fabricated to demonstrate catalytic combustion on a 1.5 MW industrial gas turbine
- System operated at base load for 1000 hours
- System provides emissions levels of:

NOx	< 3 ppm
CO	< 1 ppm
UHC	< 1 ppm

- Catalyst shows good durability to high loading of air contaminants
- Combustor dynamics were very low