Durability of Xonon™ Combustion Catalyst Modules

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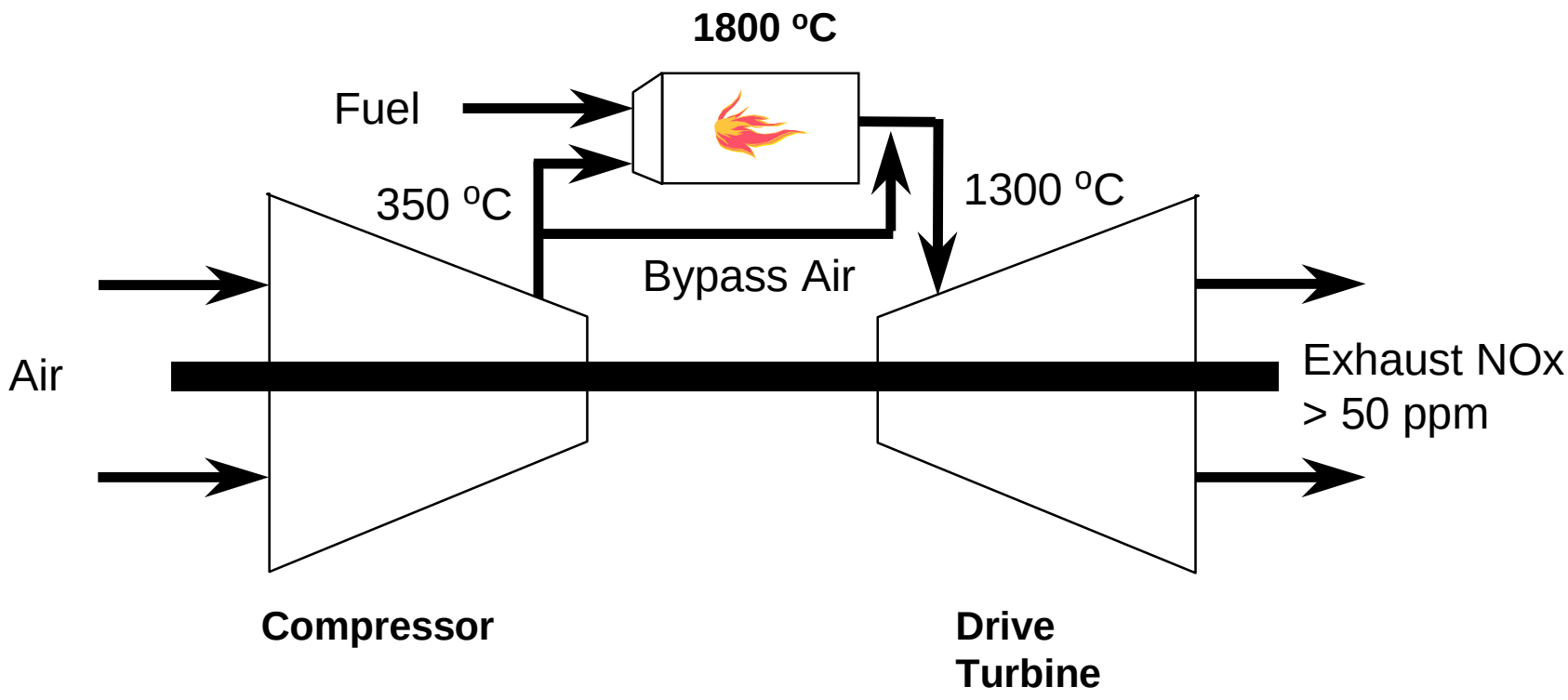
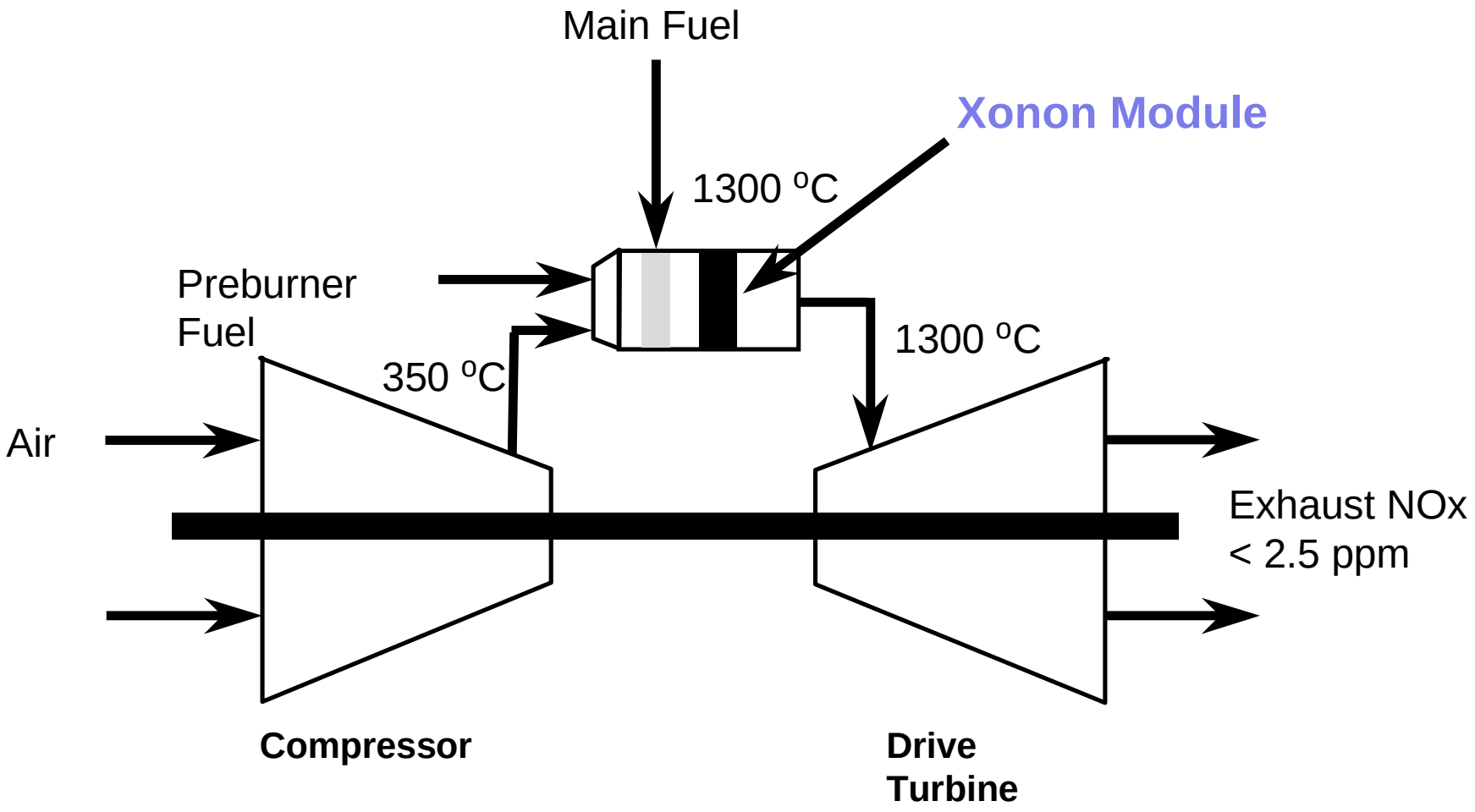
Topics

- Background on technology
- ATS Program - *Issues for Commercialization*
  - Mechanical durability
  - Catalyst durability
    - High temperature transients
    - Fuel contaminants
  - Fuel variability
- Commercial field experience to date

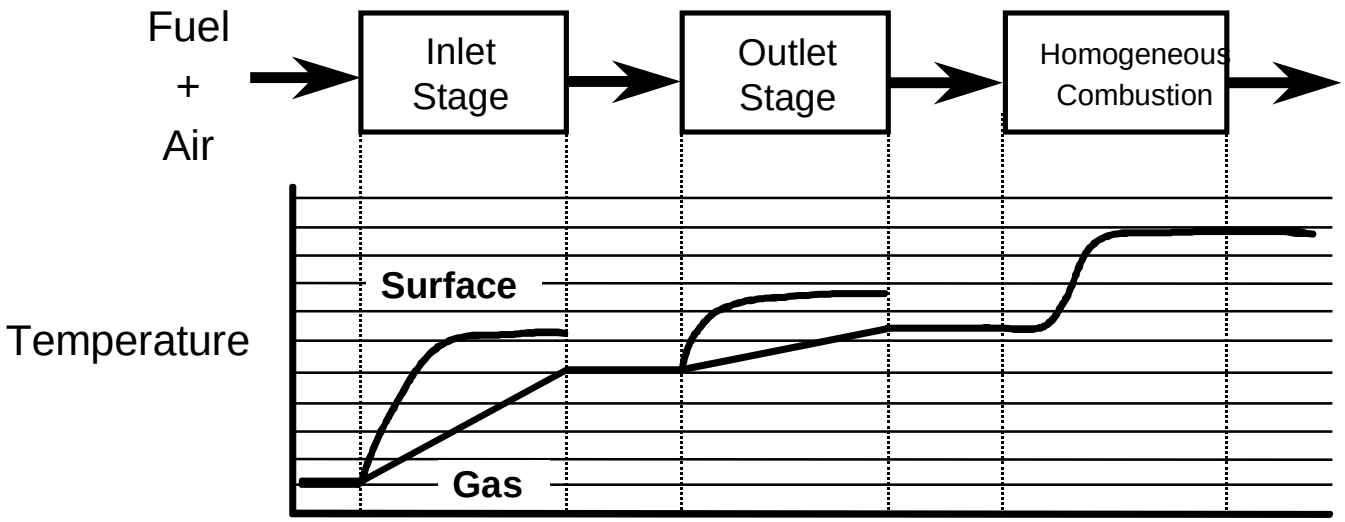
Traditional Combustor Flame Forms NO_x



Xonon - Gas Turbine Configuration



Xonon: A Breakthrough Technology



- High activity
- Low light off T
- Low wall T

- Higher wall T
- Over temperature protection
- High outlet gas T

Sufficient time to:

- Complete CH_4 combustion
- Complete CO and UHC burnout

- Staged catalyst system
- Low catalyst operating temperature
- Achieve high combustor outlet temperature

Xonon Catalyst Modules

Technical Status of Current ATS Program

Work completed for:

- Task 3.1: Dynamic Testing of Catalyst Bed (mechanical vibrations)
- Task 3.2: Catalyst High Temperature Thermal Stability (excursions)
- Task 3.3: Fuel Compositions
- Task 3.4: Fuel Contamination
- Task 3.5: Durability Testing

Ongoing work:

- Task 3.6: Catalyst Container Mechanical Testing
  - Materials (alloys) creep rate data
  - FE analysis

Task 3.1: Dynamic Testing of Catalyst Bed

Objective:

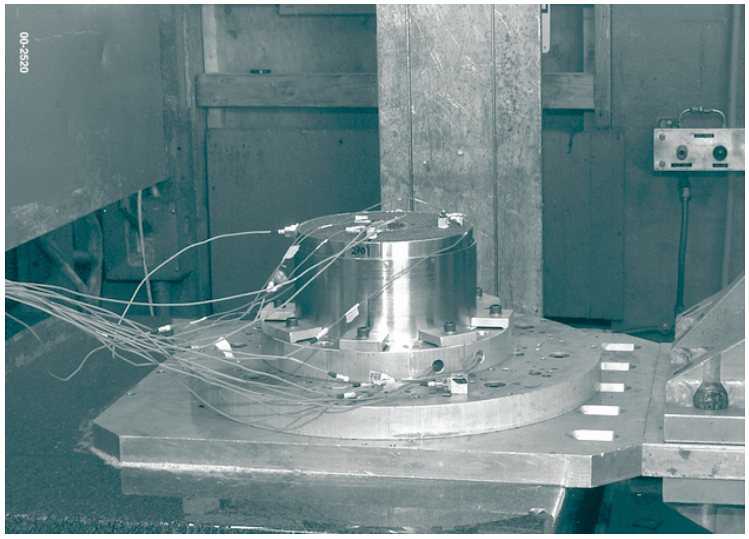
- Subject two catalyst module designs to mechanical vibration testing to assess durability

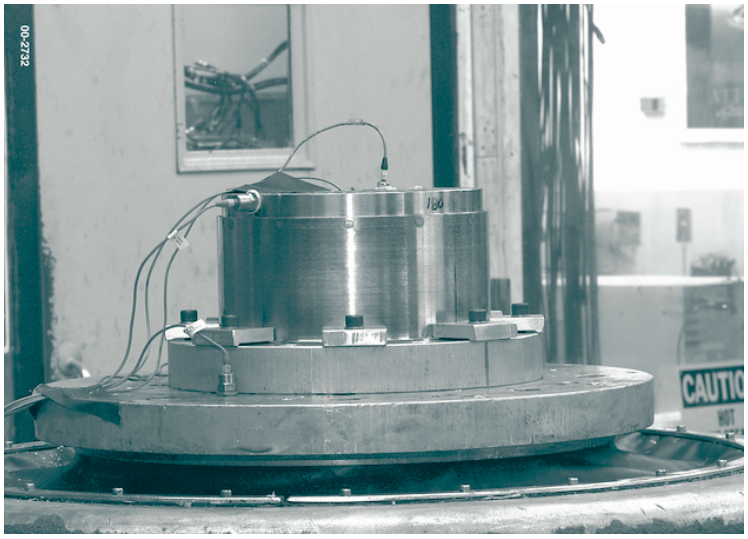
Approach:

- Employed modal finite element analyses to predetermine dynamic response
- Arranged accelerometers to detect expected response
- Conducted dynamic frequency surveys on shaker tables to locate resonant frequencies
- Conducted dwell tests at selected resonant conditions
- Disassembled and inspected catalyst modules

Dynamic Testing - Survey and Dwell Tests

- Dynamic frequency surveys and dwell testing were performed by Dayton T. Brown, Inc.
- Endevco model 2222C, 2224C 2226C and 2228C accelerometers with accuracy of ±5% at points of high amplitude were statigically located at 30 and 14 positions for the generic Rolls-Royce and Solar modules, respectively





Xonon Catalyst Modules

Dynamic Testing - Summary of Results

- Finite element modal analyses
  - Generic Rolls-Royce (16-inch) and Solar (8-in) catalyst modules
  - Natural frequencies and mode shapes computed
  - Results used to locate accelerometers for dynamic testing
- Frequency survey testing
  - Determined resonant frequencies at 1-G acceleration over 5- to 2000-Hz
  - Selected larger resonance responses for dynamic dwell testing
- Dwell testing at 2-G acceleration
  - Two hr (>11,000,000 cycles) at 4 axial and 4 radial resonant frequencies
  - No loss of mechanical durability detected for either module
- Catalyst modules disassembled
  - No signs of distress, wear, or fatigue.
  - Metallurgical examination deemed unnecessary

Task 3.2: Catalyst High Temperature Thermal Stability

Objective:

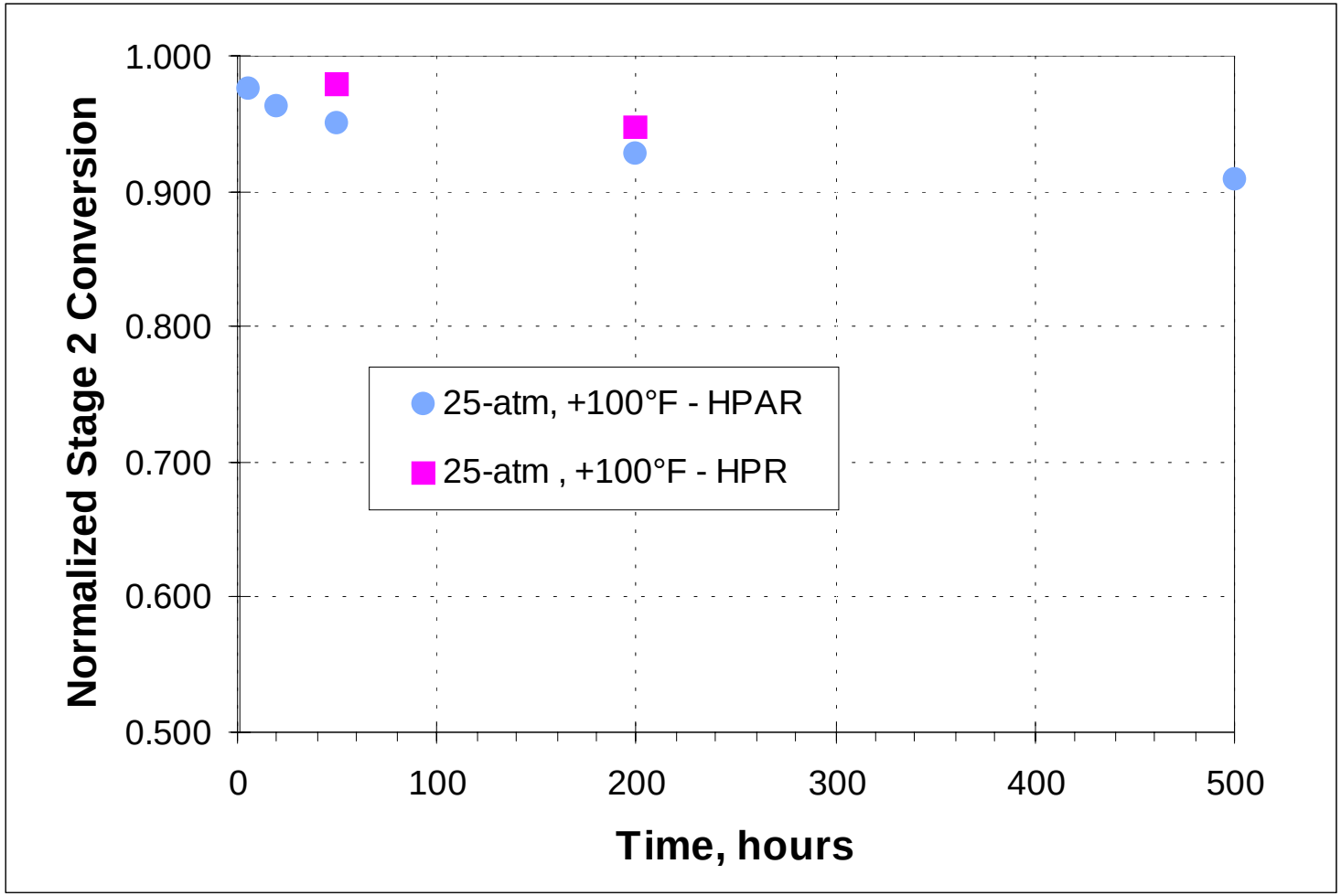
- Determine the effect on catalyst durability of high temperature excursions that may occur during start-up and load transients

Approach:

- Use commercial catalyst materials and preparation methods
- Exposure conditions chosen to simulate catalyst environment
- Age catalyst monoliths at 25- and 10-atm and two temperatures with sampling at progressive intervals from 5 to 2000 hours
- Analyze catalyst samples for total (BET) surface area and reduced active component surface area (via H_2 chemisorption)

Predicted Performance of Catalysts

From Results of HPAR and HPR Isothermal Excursion Tests



Thermal Stability - Summary of Results

- Measured extent of sintering for commercial catalyst
  - At 25- and at 10-atm with +100 and +200°F excursions
  - Examined 26 samples at 5- to 2000-h in a bench-scale aging system (HPAR)
  - Examined at 50- and 200-h in a sub-scale test rig (HPR)
- Aging system and subscale rig tests show similar results
- Conclusions
  - Short-term (100s hours) excursions of 100 to 200°F small effect on long-term catalyst performance
  - Results used to extend CESI's 16,000-h predictive catalyst performance & life model

Task 3.4: Fuel Contamination

Objective:

- Determine effect of fuel contaminants on catalyst performance

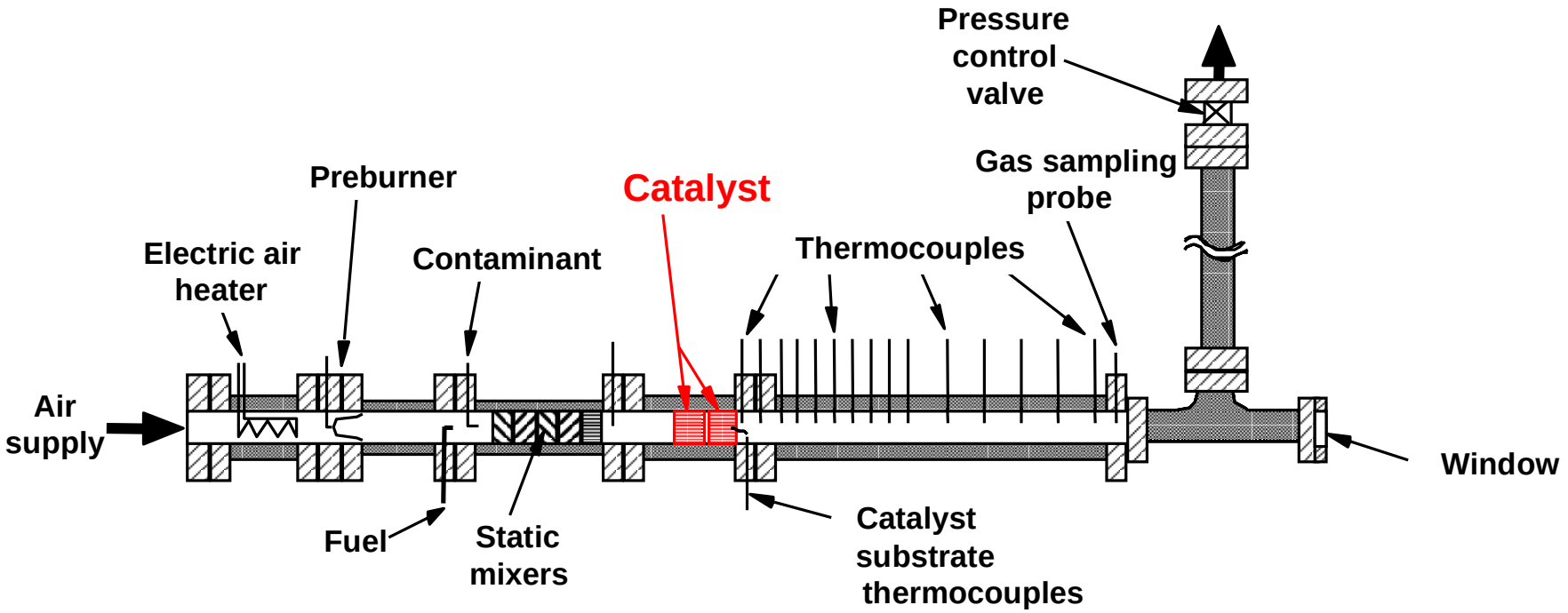
Approach:

- Use sub-scale catalyst test facility under commercial conditions
- Run steady-state (2-hr) perform ignition test then introduce fuel contaminant for specified duration
- Run steady-state without contaminant (20-min) then perform ignition test
- Repeat contaminant exposure until loss in performance (stage conversion & ignition temperature) observed

Results:

- Use to define fuel contaminant (Pb, V, S) specifications

Schematic of Contaminant Subscale Test Facility



ATS Program Accomplishments

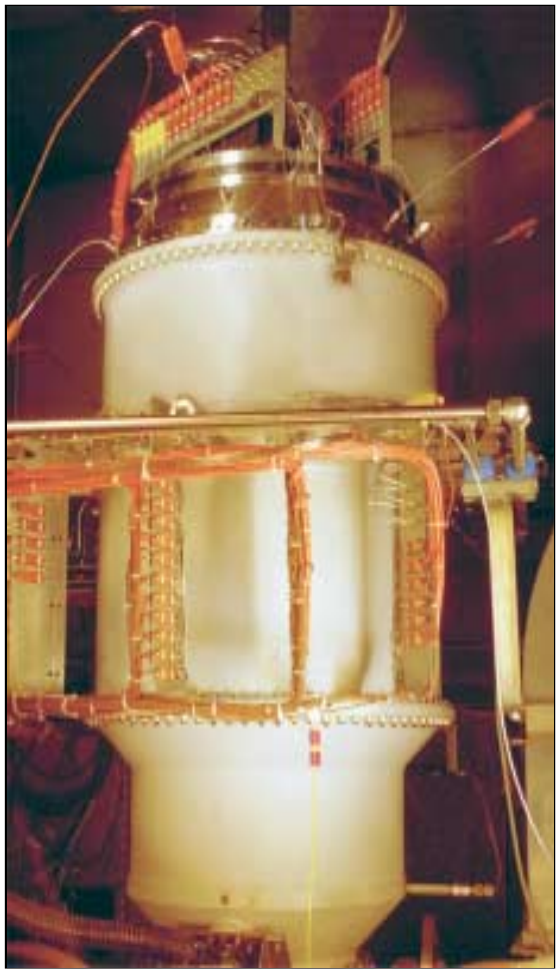
- Developed tests to examine issues of commercial interest
  - ATS advanced turbine cycle conditions
  - Fuel variability
  - Catalyst module life
    - Durability of mechanical supporting structures
      - Mechanical vibration tests
      - Analysis of creep
    - Catalyst durability
      - High temperature excursions
      - Air-borne and fuel-borne contaminants
- Results assist commercialization of catalytic technology
  - Define fuel and air specifications
  - Develop methods to predict and test module life

Field Tests - Xonon at Silicon Valley Power

- 1.5 MW Kawasaki M1A-13A turbine equipped with Xonon Catalyst Module
- Field operating conditions - connected to the grid
- Used for extended durability (RAMD) testing under commercial conditions (permitted)
  - Confirmed combustor performance
  - Established reliable connection to utility grid
  - Developed control system for unattended operation
  - Incorporate design improvements for operability and reliability

Xonon on the Public Electrical Grid

Xonon (at SVP) Instrumented for RAMD



RAMD at Silicon Valley Power

Objective

- Reliability, availability, maintainability, and durability (RAMD) operation to 8,000+ total hours

Status (as of 8/31/00)

- Duration - 4,100 (Phase I), 3,300 (Phase II) cumulative hours
- Availability - 90.7% uptime, 98.6% reliability
- Average emissions (full load):
  - NOx < 2 ppm
  - CO < 1 ppm
  - UHC < 1 ppm

Acknowledgements

- **ATS Program for 2000**
  - Solar Turbines, Inc.
  - Rolls-Royce - Allison Engine Company
  - CESI Team:
    - David Yee - Project Leader
    - John Barnes - Dynamics & creep of supporting structures
    - Scott Magno - Thermal stability of catalysts
    - David Ginter - Fuel variability & fuel contaminants
    - Mark Spencer - Catalyst durability (sub-scale test facility)
- **RAMD Project at SVP**
  - US Department of Energy, California Energy Commission, California Air Resources Board, and Gas Research Institute