NOxStar™ Plant Demonstration

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October 30, 2003

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NOxStar™ Process

- NOxStar™ is an auto-catalytic reduction process whereby controlled quantities of an NH_3 based reagent and a minute amount of hydrocarbon are continuously injected into the hot flue gas stream.

- Hydrocarbon auto-ignites to form a plasma of free radicals which auto-catalyzes the reaction of NH_3 and NO_x to nitrogen and water vapor.

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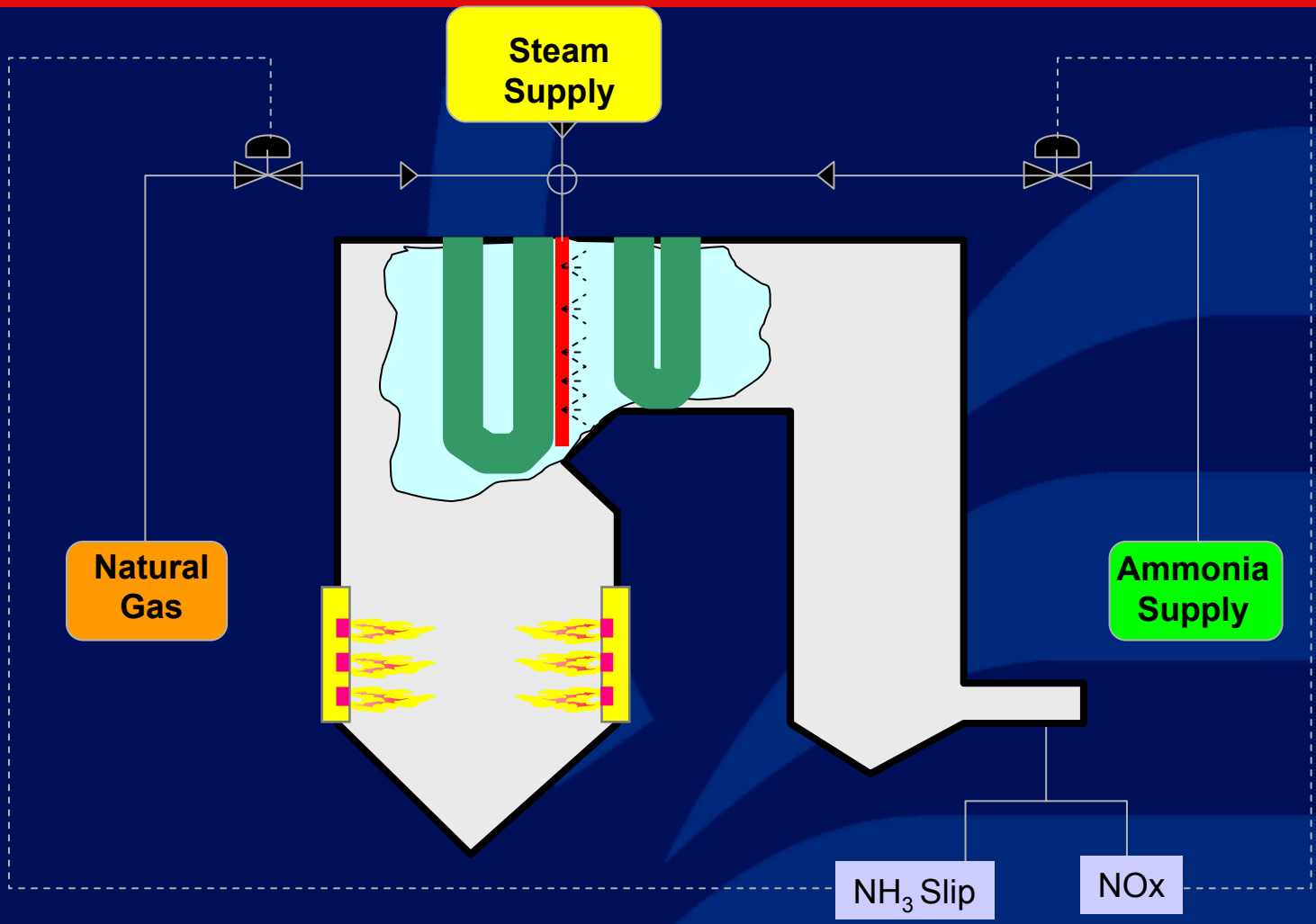
NOxStar™ Application to Plant



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NOxStar™ Development

- NOxStar™ process developed for pulverised coal combustion
  - Small scale – 0.55 mmBtu/h (160kW_t)
  - Large scale – 135 mmBtu/h (40MW_t)
  - Plant scale – 200 MW_e

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NOxStar™ Development – Small Scale

- Small scale – 0.55 mmBtu/h (160 kW_t)
- Aims
  - Demonstrate process for coal firing
  - Demonstrate process for conditions appropriate to large boiler plants
  - Acquisition of parametric data for process design

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NOxStar™ Development – Small Scale

- Parametric Testing
  - NH_3:NO_X molar ratio
  - Hydrocarbon type
  - Hydrocarbon heat input
  - Injector arrangement
  - Flue gas temperature
  - Residence time
  - Inlet NO_X level
  - Coal
  - Cooling surface
- Performance
  - Input parameters
  - Outlet NO_X / NO_X reduction
  - NH_3 slip
  - CO

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NOxStar™ Development – Small Scale

- High NO_X reduction achieved
  - Less than 0.10 lb/mmBtu from inlet of 0.45 lb/mmBtu (80% to 90% reduction)
- Low ammonia slip
  - < 5ppm
  - Ammonia continues to reduce downstream of reaction zone
- Wide temperature window
  - Better reduction at higher temperature

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NOxStar™ Development – Small Scale

- Low hydrocarbon input
  - Sufficient to create plasma
  - Natural gas and propane equally effective
- Insensitive to coal type
  - USA, UK, world traded bituminous coals tested
- Unaffected by presence of heating surfaces
  - Can locate system in boiler cavity

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NOxStar™ Development – Large Scale

- Large scale – 135 mmBtu/h (40 MW_t)
  - Rig capacity 310 mmBtu/h (90 MW_t)
  - Injection lances physically similar to full scale
- Aims
  - Demonstrate scale up
  - Demonstrate injection lance design
  - Demonstrate multi-nozzle arrangement
  - Demonstrate process control

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310 mmBtu/h (90 MW_t) Test Facility

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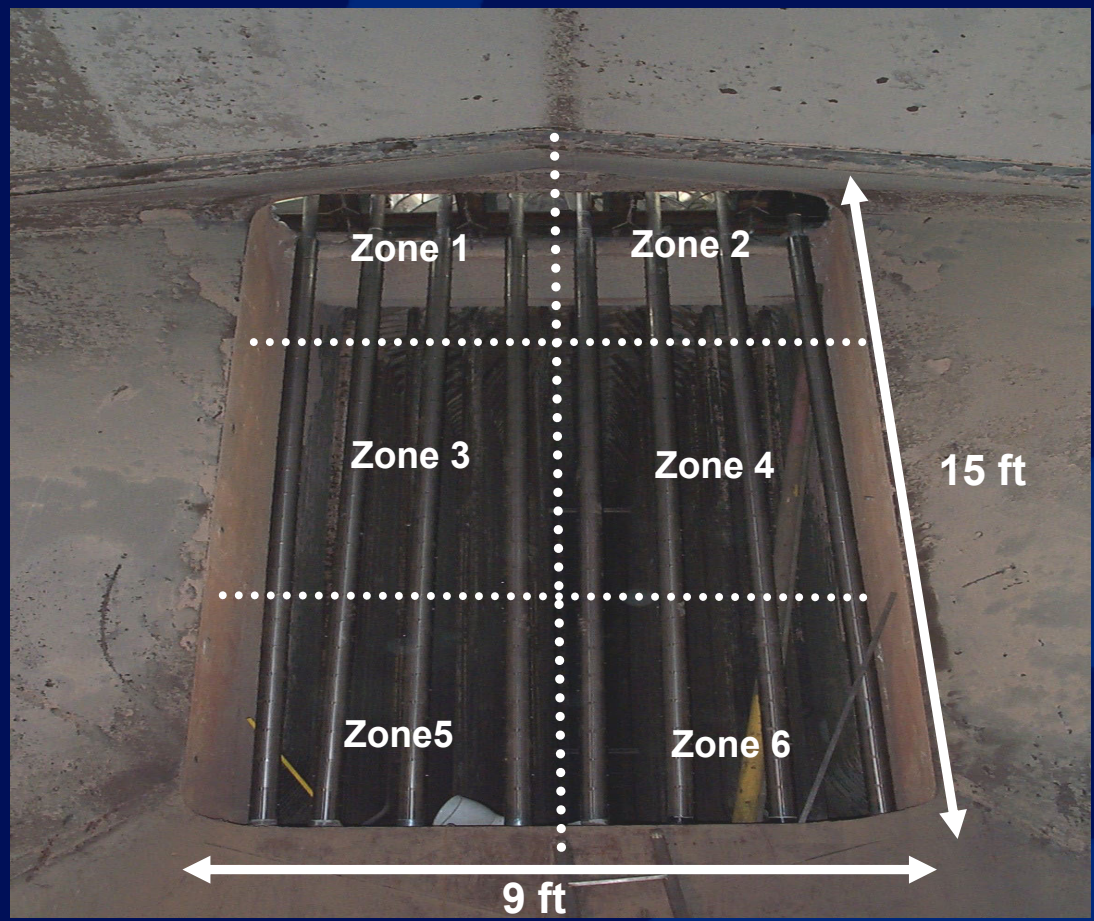
NOxStar™ Injection Grid



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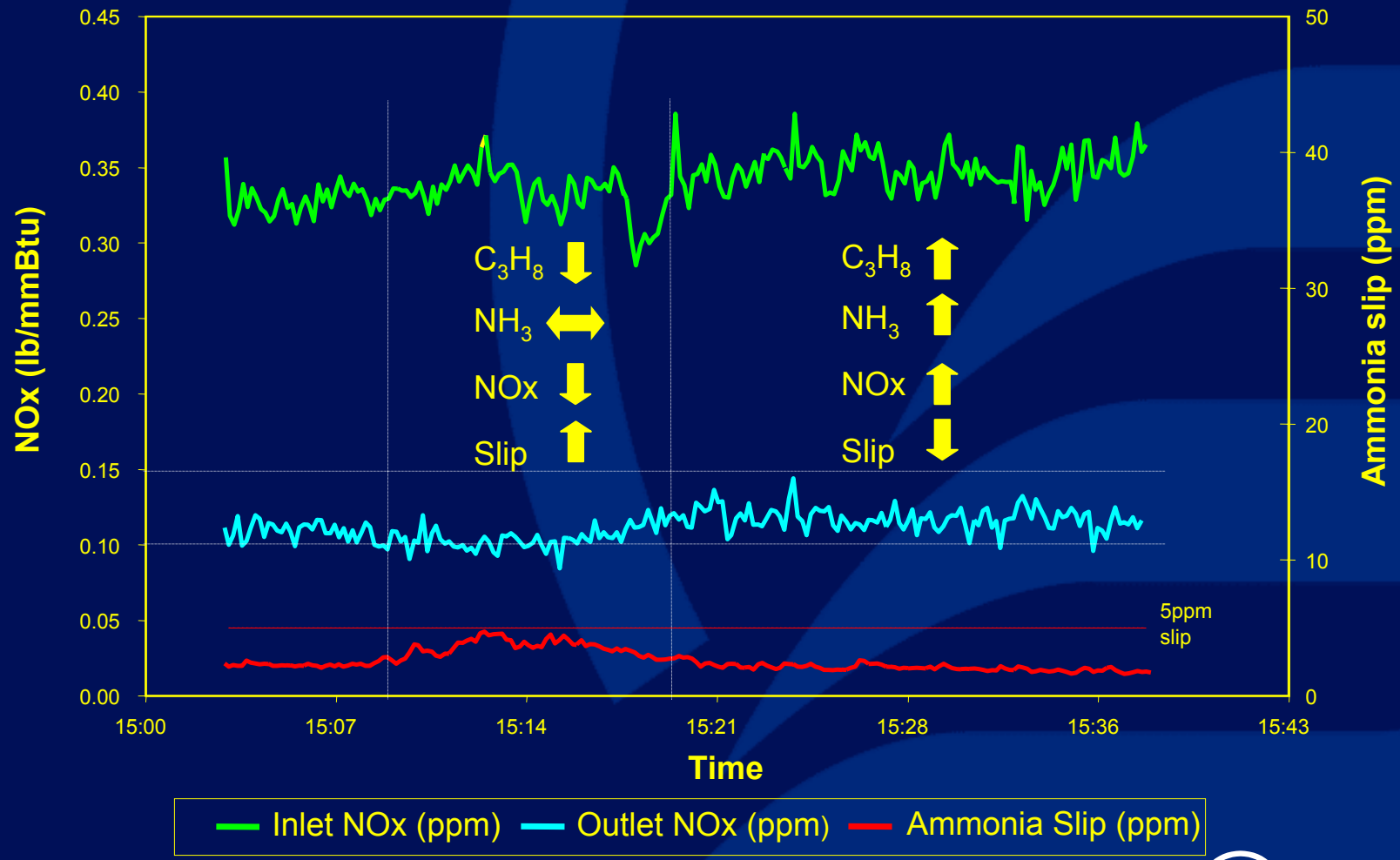
NOxStar™ Process Control



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NOxStar™ Large Scale Performance

- Process scale-up demonstrated
  - NO_X < 0.10lb/mmBtu
  - NH_3 slip < 5ppm
  - Ability to control NH_3 slip
  - Ability to deal with non-uniform flow and temperature profiles

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NOxStar™ Plant Scale Demonstration

- Full scale plant demonstration
  - TVA's Kingston Power Station
  - 200 MW_e
  - Tangentially fired
  - Twin furnace design
  - Baseline NO_X 0.55 lb/mmBtu
  - "Difficult" temperature & velocity profiles
  - Boosted OFA & NOxStar™ installed

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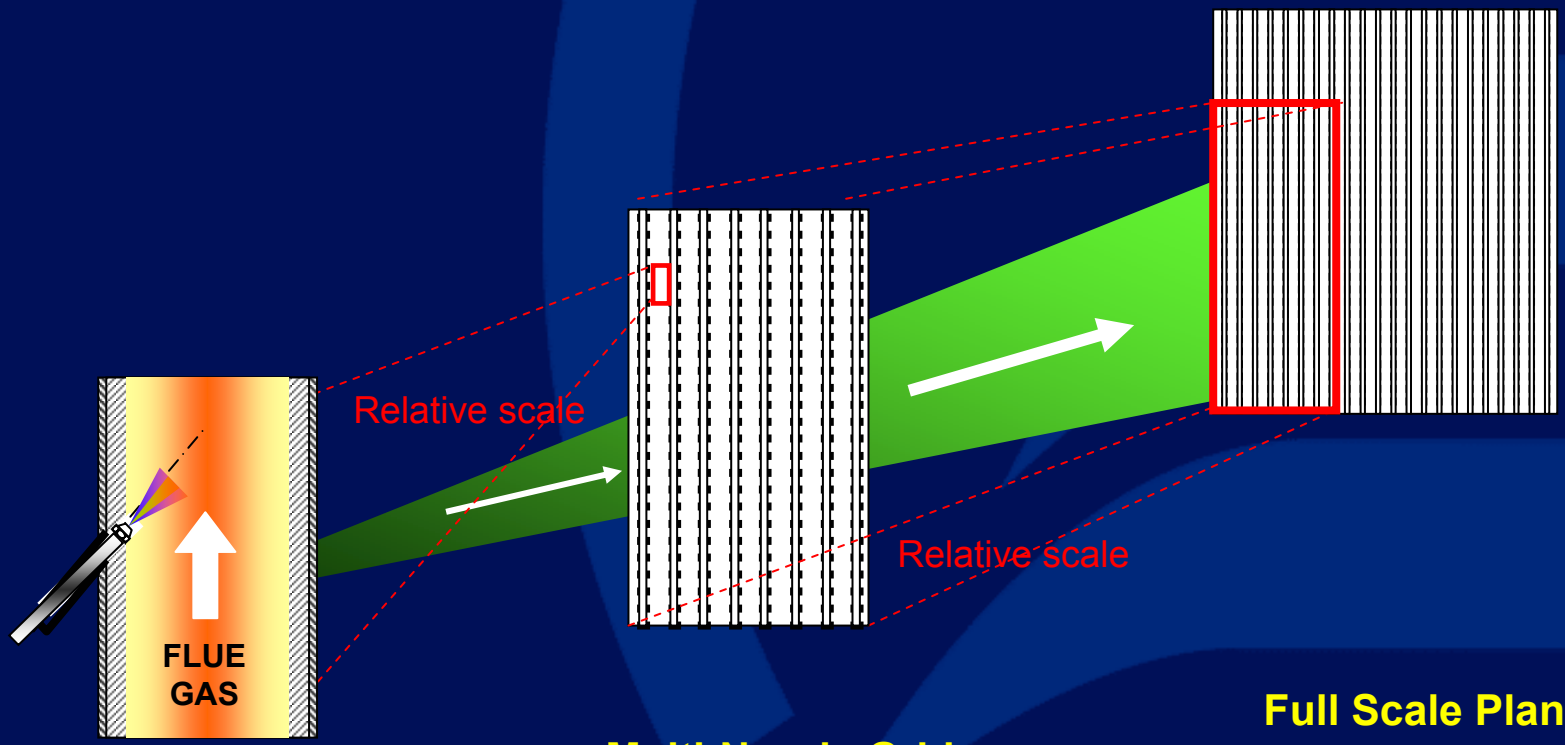
Scale-up : Test Facilities to Plant



Single Nozzle
0.55 mmBtu/h
Single Zone

Multi-Nozzle Grid
135 mmBtu/h
6 Control Zones
8 Lances (15 ft)

Full Scale Plant
200 MW_e T-Fired
2 x 9 Control Zones
2 x 22 Lances (21 ft)

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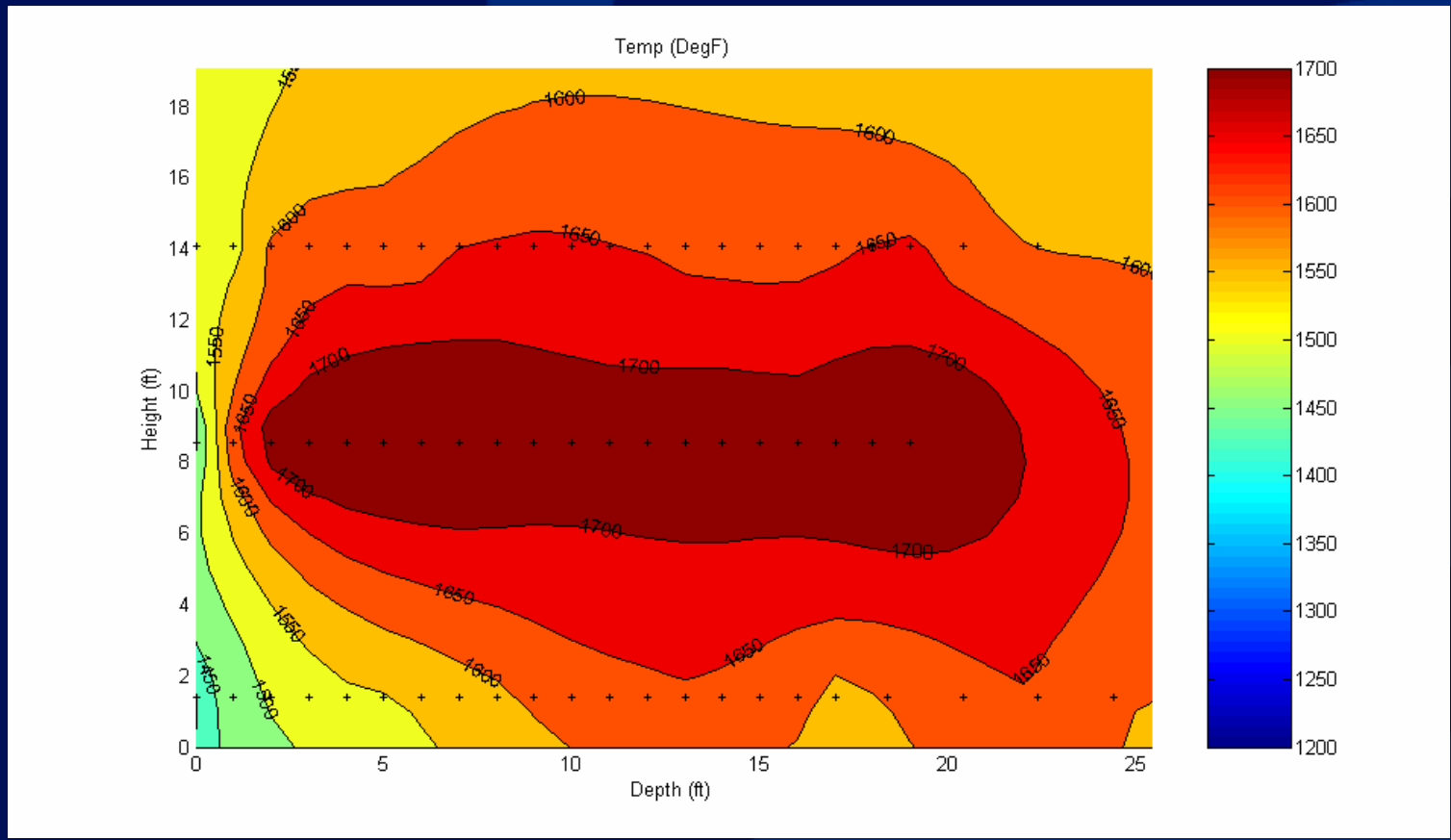
RH Flue Gas Temperatures (Calculated at Injection Grid) based on HVT Testing



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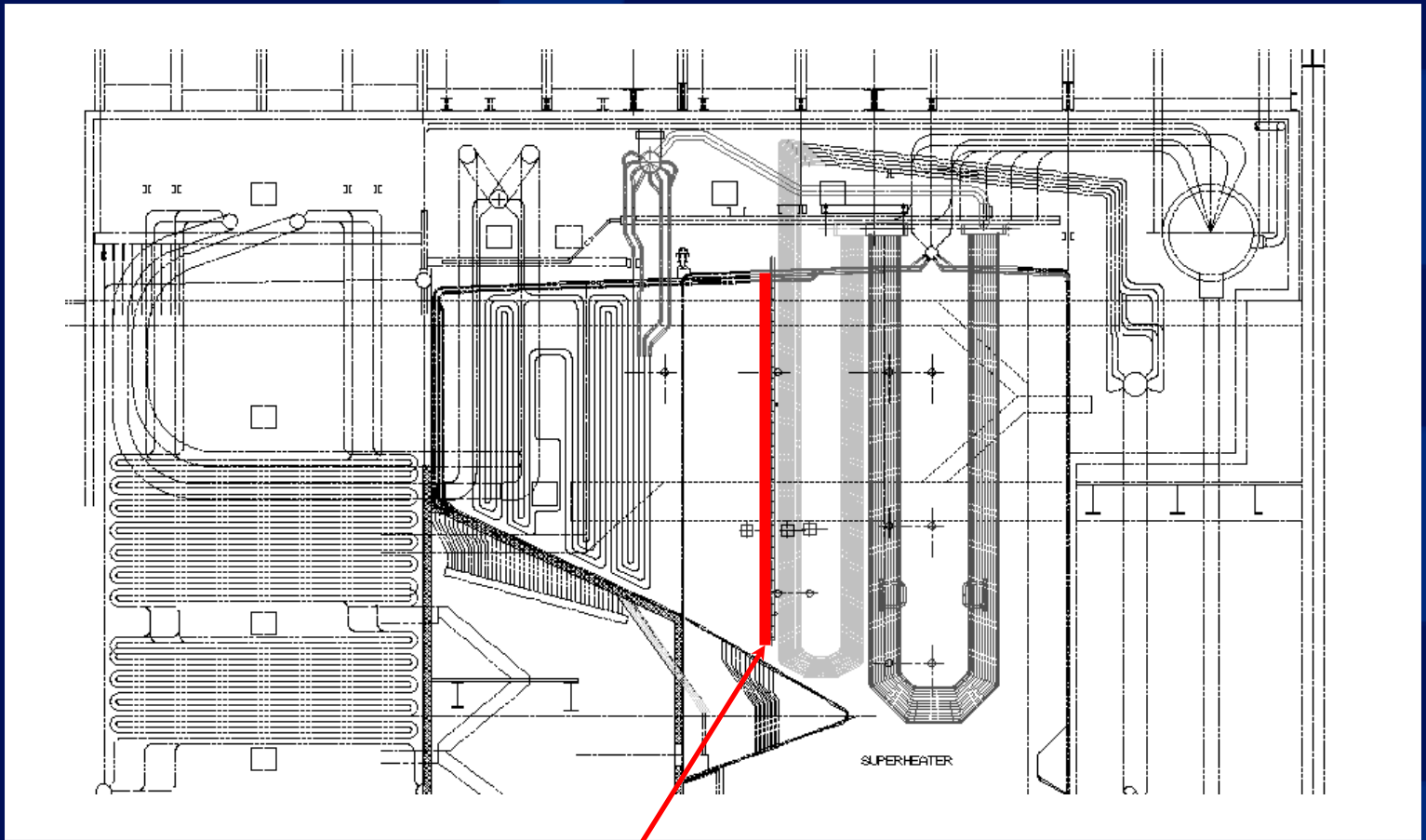
SH Injection Lance Location



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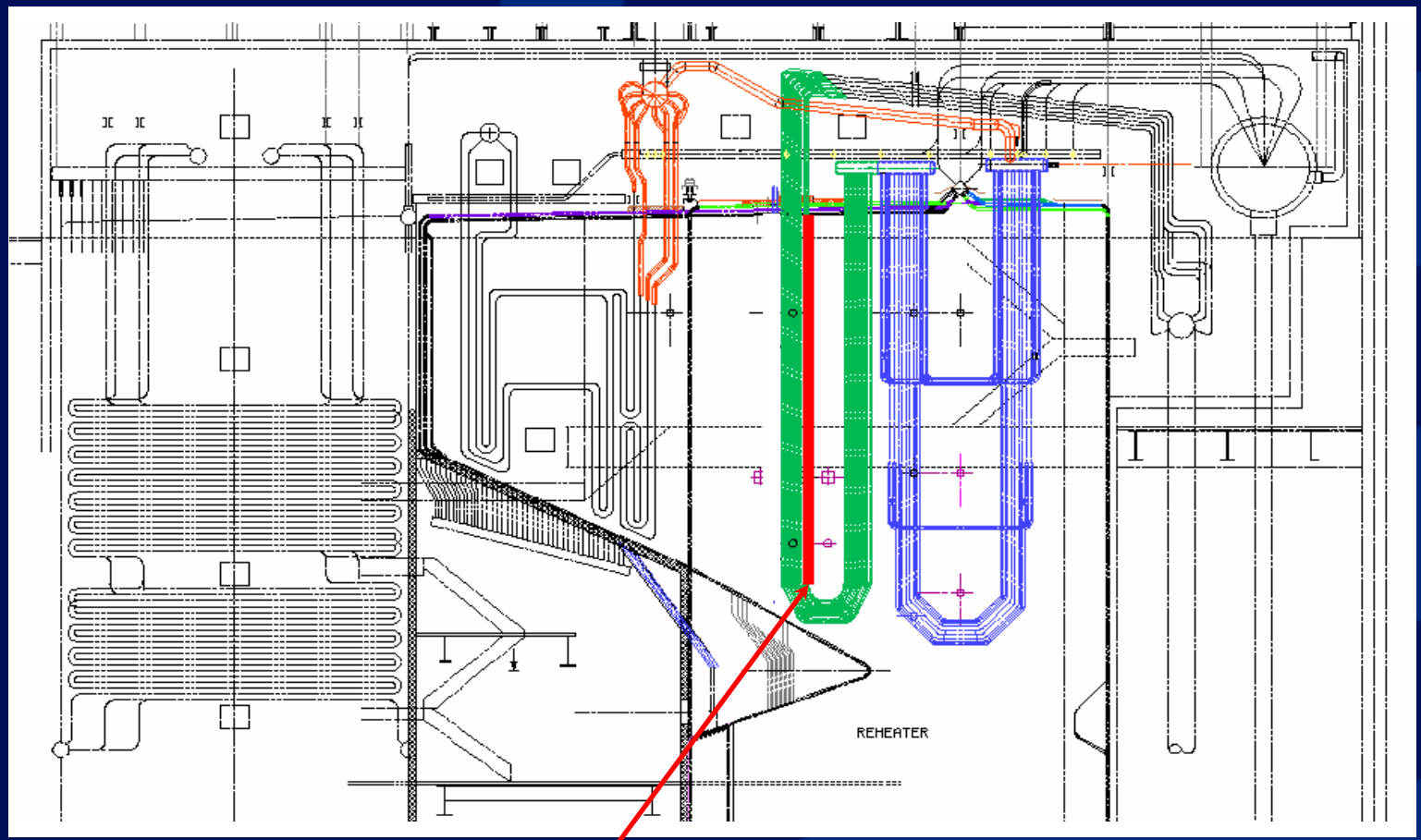
RH Injection Lance Location



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Injection Lance Installation

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NOxStar™ Plant Scale Demonstration

- Total NO_X reduction of 68% to 0.17 lb/mmBtu
  - NOxStar™ reduction was 53%
  - Ideal process temperature not obtained
    - Below ~1700°F at injection location
    - Ideally >1825°F desired
- NH_3 slip < 5ppm
- Repeatable
  - Repeatability confirms good controllability

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Ammonia Slip
On-Line vs. Wet Chemistry

1. Laser NH_3 analysers located downstream of air heater, wet chemistry measurement is upstream

2. Generally good agreement between wet chemistry measurement and on-line analysers when full duct covered

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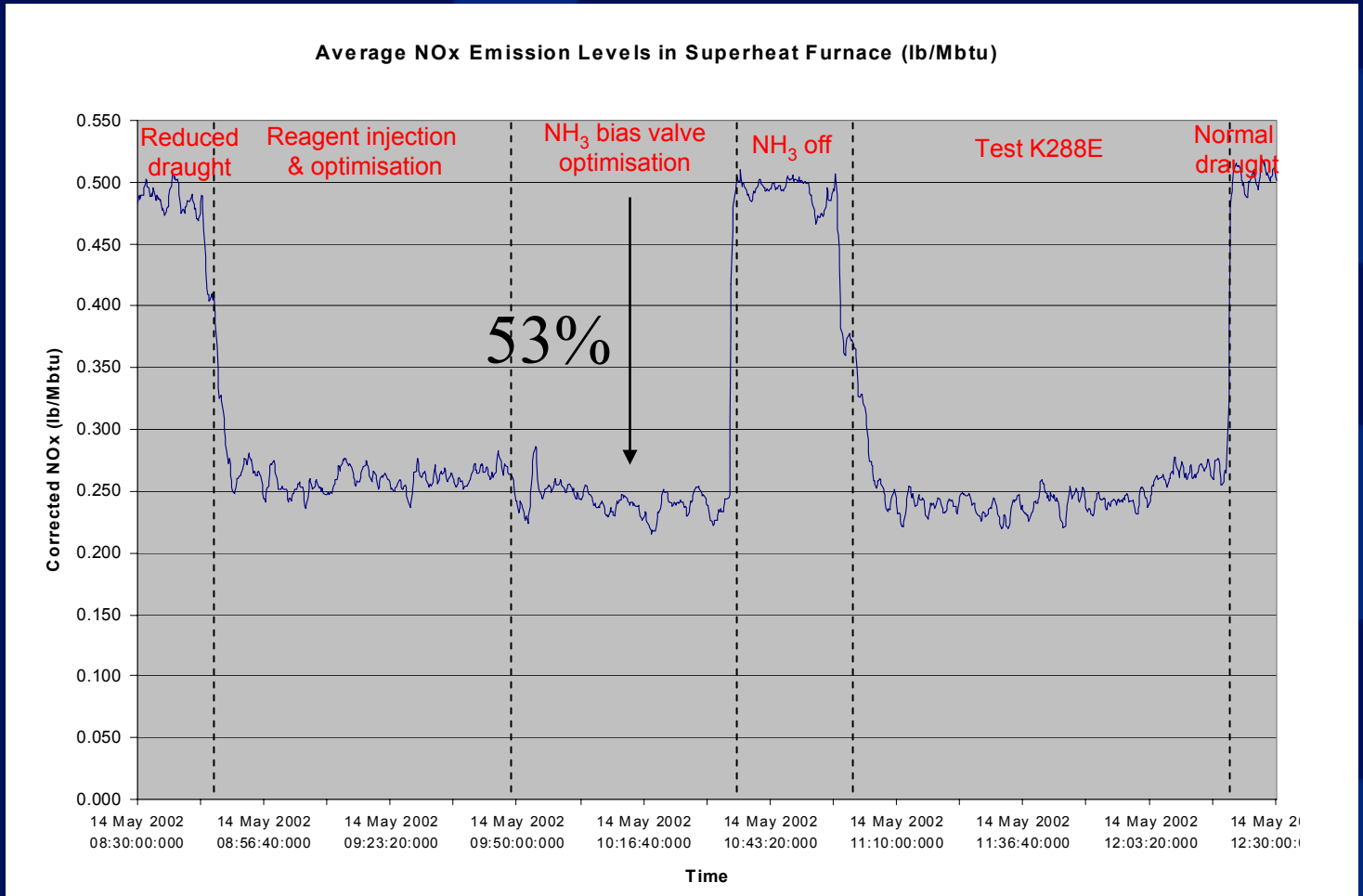
Kingston 9 Results 14 May 2002



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Effect of grid location

- Locating the grid further upstream will result in increased temperature and increased time at temperature
- The increased temperature will result in an improvement of 10 percentage points in NO_x reduction
- The increased residence time will result in a further 4 to 5 percentage points in NO_x reduction

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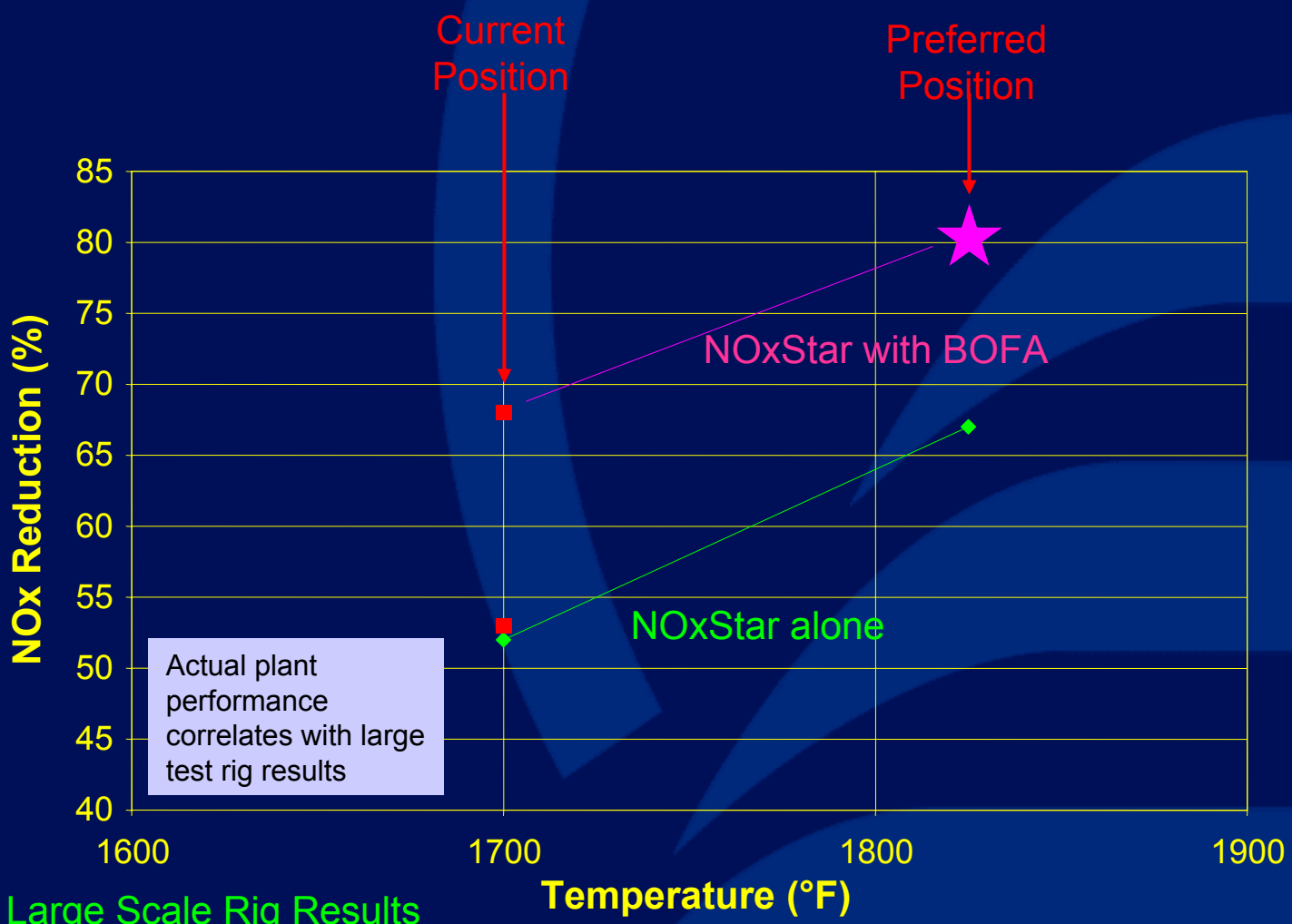
NOxStar™ Rig and Plant Performance



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Effect of Inlet NO_X

- Reduced NO_X at the inlet to the NOxStar™ reaction zone leads to
  - Significant reduction in outlet NO_X
  - Minor impact on %age NO_X reduction

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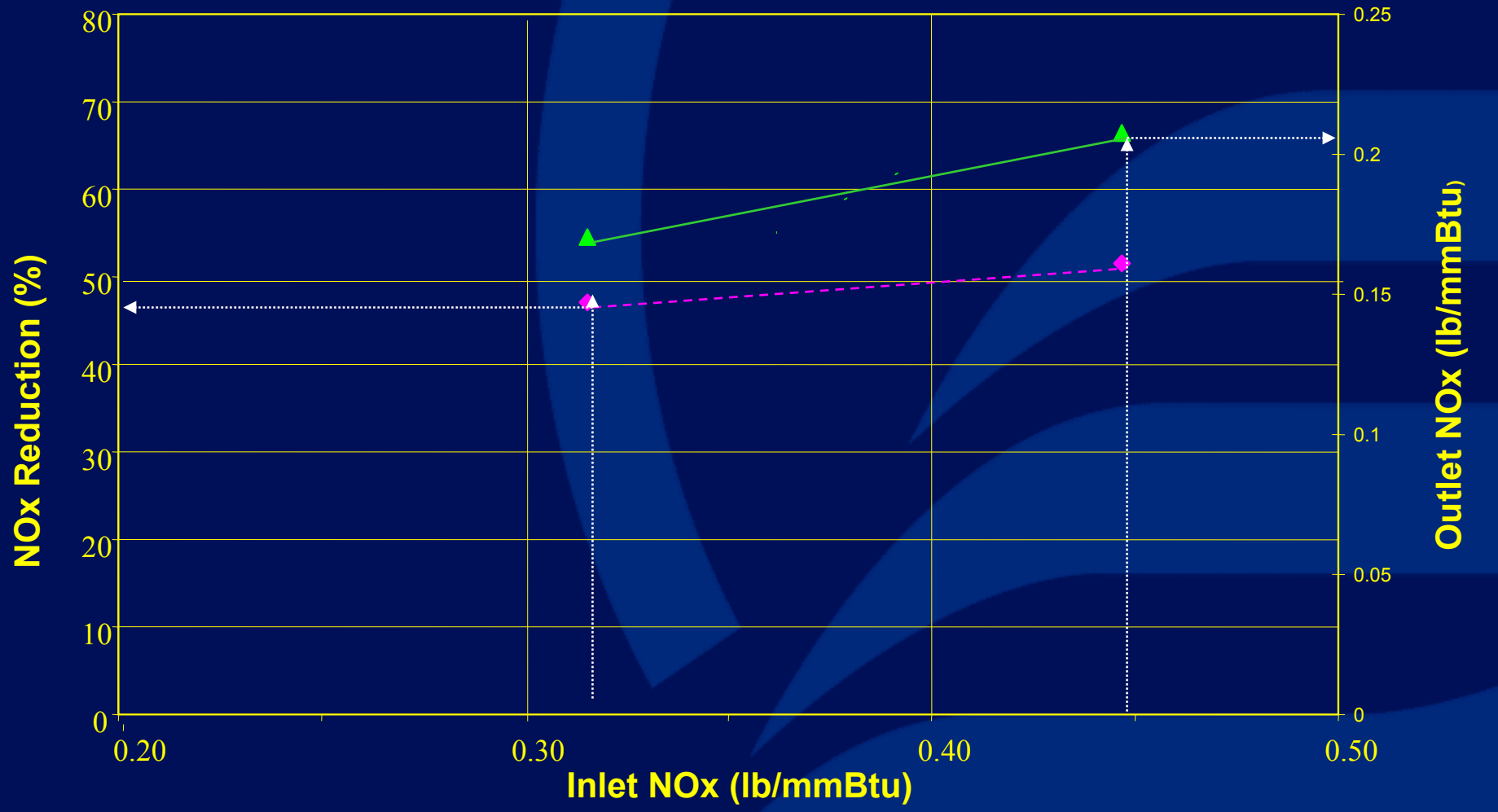
Kingston 9 Effect of Inlet NO_x



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NOxStar™ Plant Scale Demonstration

- Performance of NOxStar™ process demonstrated
- Control of reagent supply to individual zones demonstrated
- Optimisation of reagent supply to account for gross mal-distributions in flow and temperature demonstrated
- Nozzle blockage not a problem
- NOxStar™ process is readily retrofitable to utility boilers

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K9 Lance Operational History

- Lances brought into NOxStar™ operation in January 2002
- NOxStar™ testing carried out on Reheat furnace through January and February 2002 with limited testing on Superheat furnace
- NOxStar™ testing carried out on Superheat furnace through April and May 2002

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K9 SH Lance Condition

- Superheater lances and nozzles remain in relatively good condition
- Nozzle flow paths in good condition
- No lance distortion
- Insulation and cladding in good condition

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K9 RH Lance Condition

- Reheater lances experienced problems
- Cooling water leaks led to nozzle blockage and lance distortion
- Cooling water leak is attributed to interrupted flow of cooling water
- All lances removed

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Latest Lance Improvements

- Reagent/Hydrocarbon/Steam now pre-mixed before entering lance
- Lances steam cooled
- Lance comprises 3 concentric pipes to achieve 3 zone control
- Nozzles are now larger diameter, drilled holes

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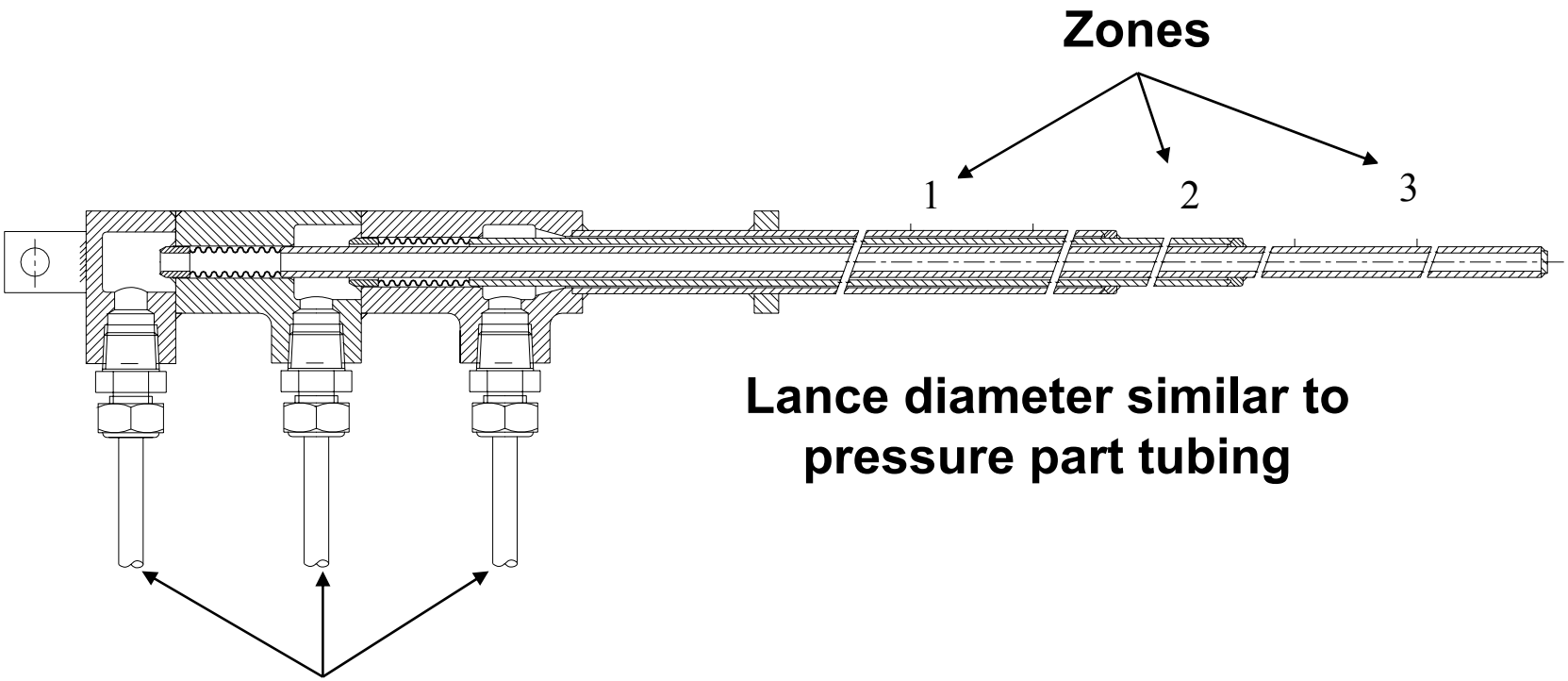
NOxStar™ Steam-Cooled Lance



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Next NOxStar™ Commercial Installation

Location:	TVA Colbert Station Unit 4
Boiler Capacity:	200 MW_e
Schedule:	-Installation Q4 2003
	-Commissioning Q1 2004

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Conclusions

- The NOxStar™ technology is performing as predicted
- Performance goals can be achieved with lances located in the correct temperature zone
  - Achieve overall NOx reductions of 65-75%
  - Manage the ammonia slip to < 5 ppm
  - Minimize the impact on plant heat rate
  - Minimize auxiliary fuel consumption

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