REINHOLD ENVIRONMENTAL Ltd.

2017 NOx-Combustion-CCR Round Table Presentation

February 27 & 28, 2017, in Cleveland, OH / Hosted by FirstEnergy

SCR: Troubleshooting SCR NOx Control in Gas Turbine Systems

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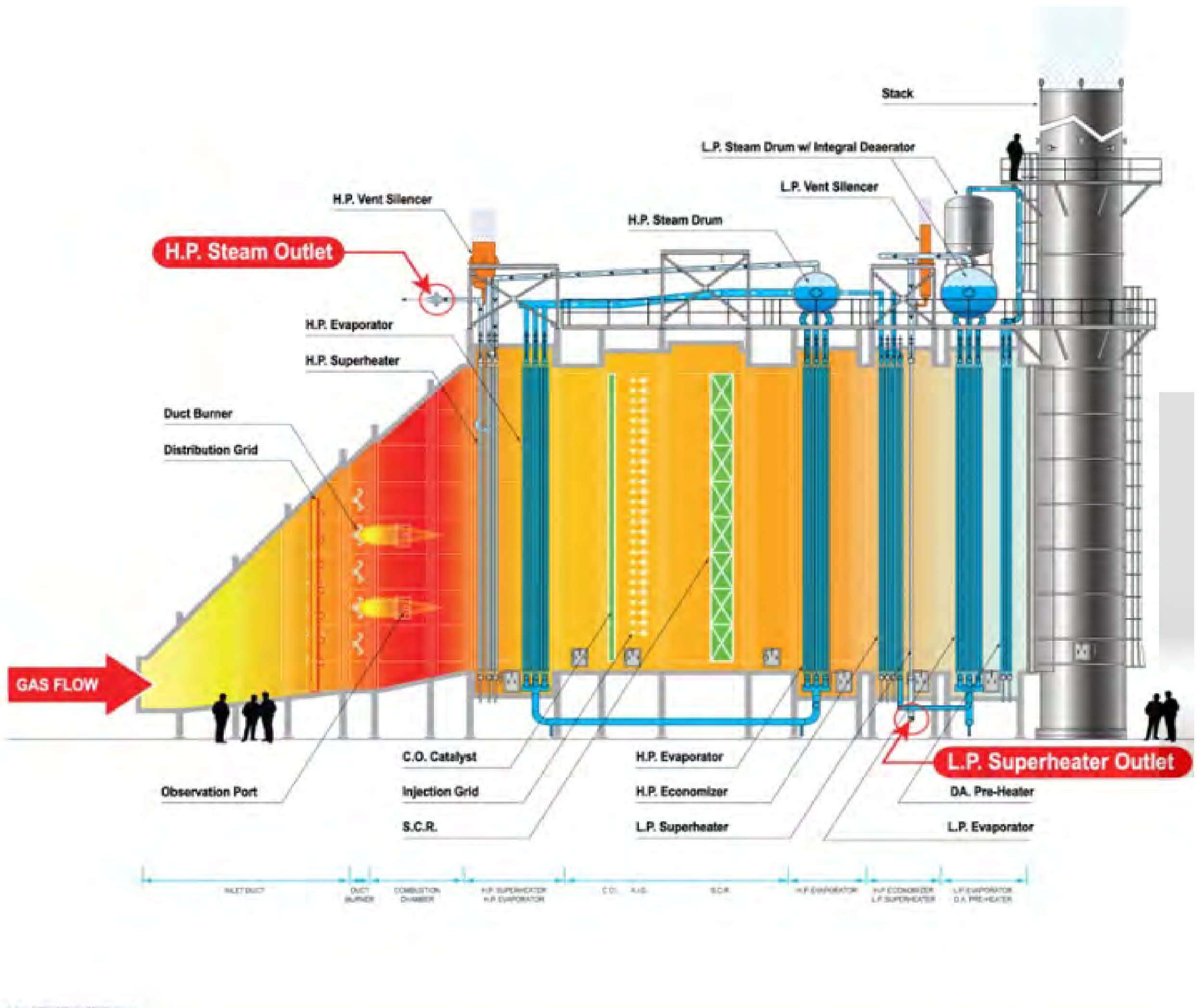
FERCo

Troubleshooting Gas Turbine SCR Performance

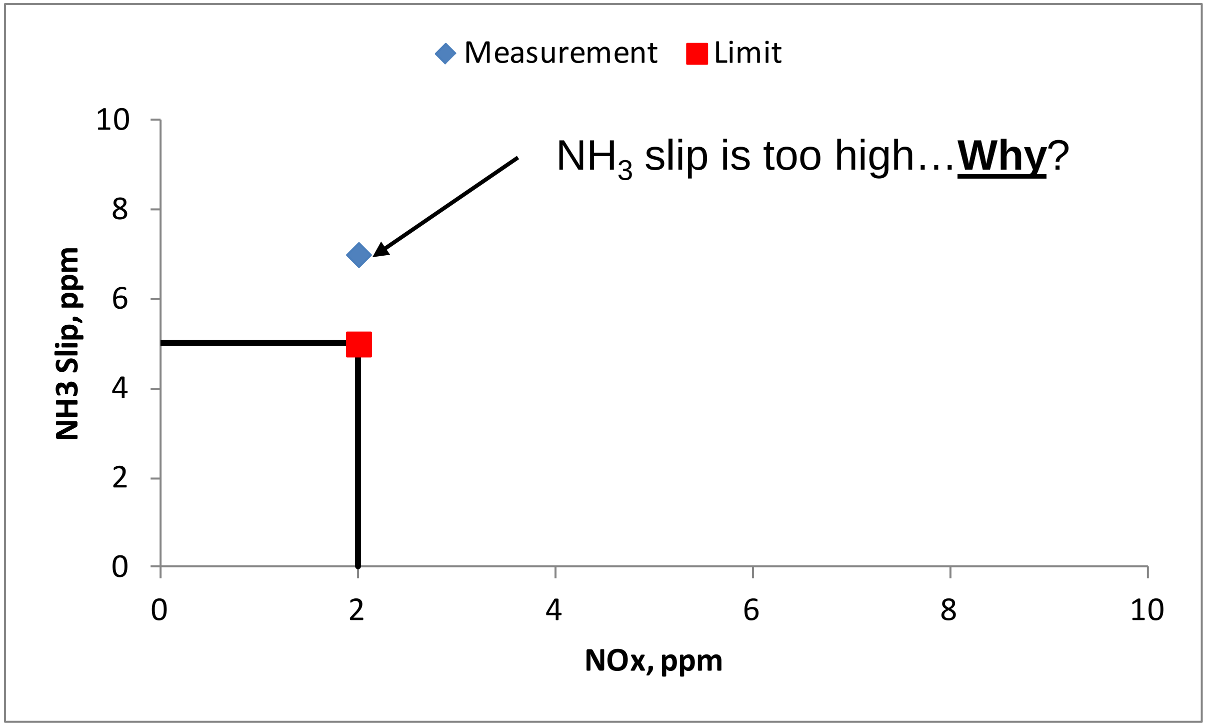
Topics

- Troubleshooting - How to Distinguish NH_3 Maldistribution from Bypass
- AIG Tuning - Catalyst Inlet NH_3/NO_x Distribution
- Identifying Flue Gas Bypass
- Measuring SCR Velocity

Combined Cycle Gas Turbine SCR



Troubleshooting



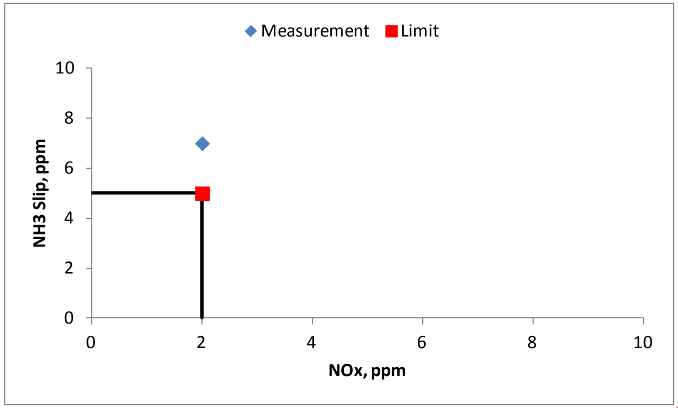
Why?

Catalyst Activity (K)?

- How active the material is in reducing NOx
- f(material, geometry)

Poor NH3/NOx Distribution?

- Want NH_3/NO_x uniform across the catalyst
- Local $NH_3/NO_x>1=NH_3$ slip
- ***Was the AIG designed properly?***
- ***Was the AIG tuned?***



Reactor Potential?

- Ability of the catalyst bed to reduce NO_x
- $RP= K*A_{sp}*V_{cat}/Q_{fg}$
- ***Was enough catalyst installed?***

Flue Gas Bypass?

- Any bypass by the catalyst increases stack NO_x & NH_3
- ***How can you tell if and where the bypass is?***

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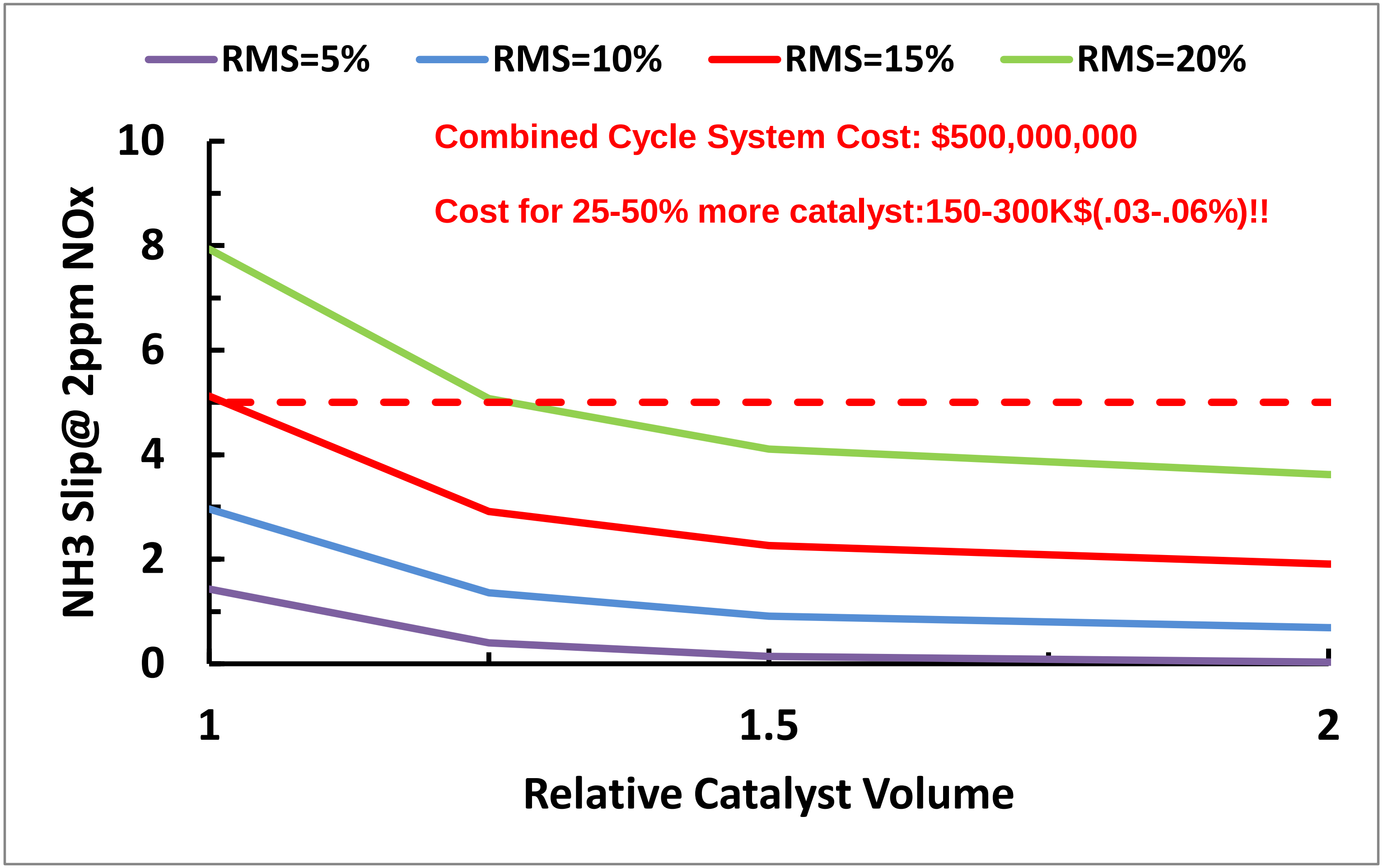
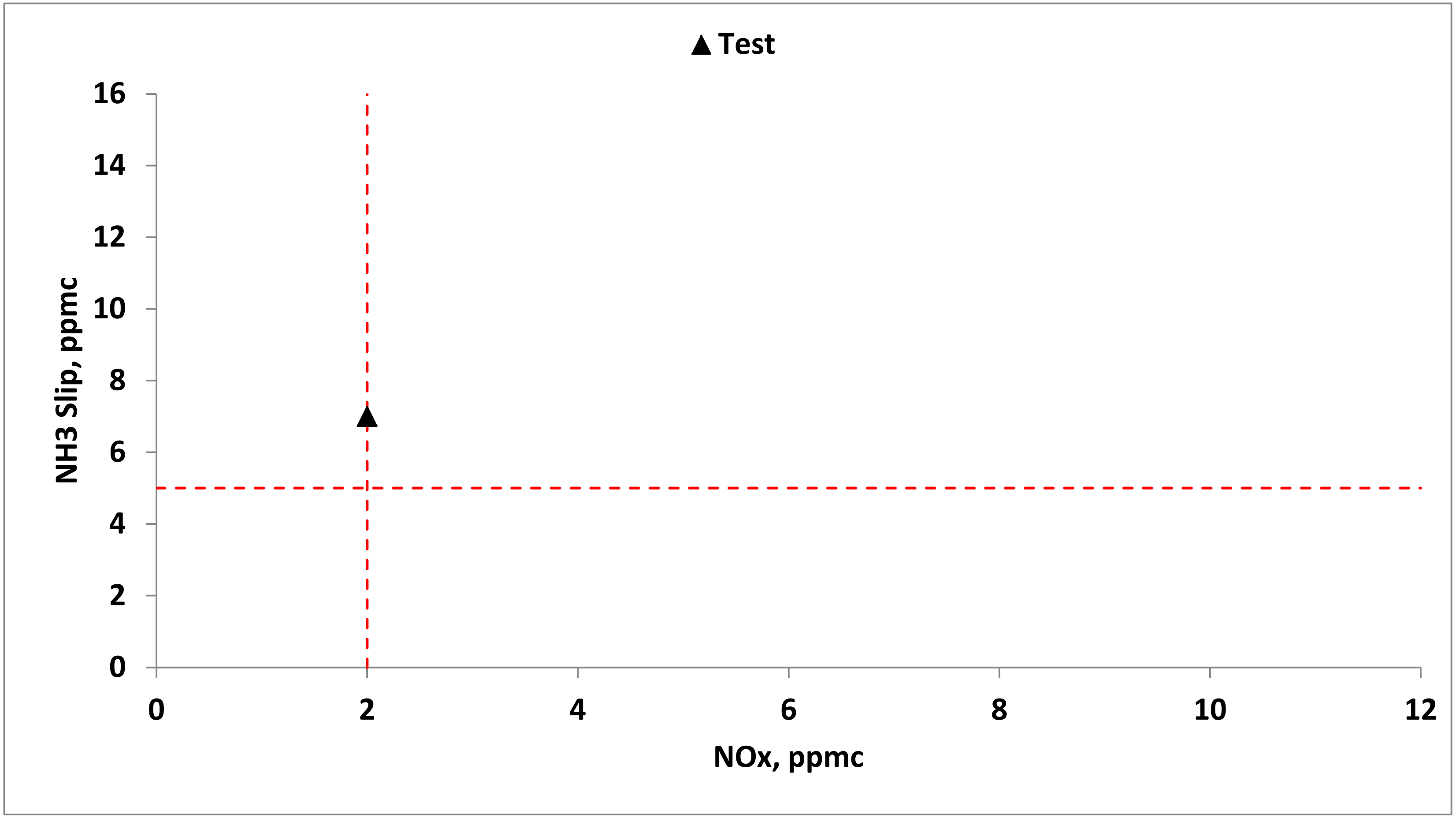
Was Enough Catalyst Installed?

Penny Wise and Pound Foolish!!

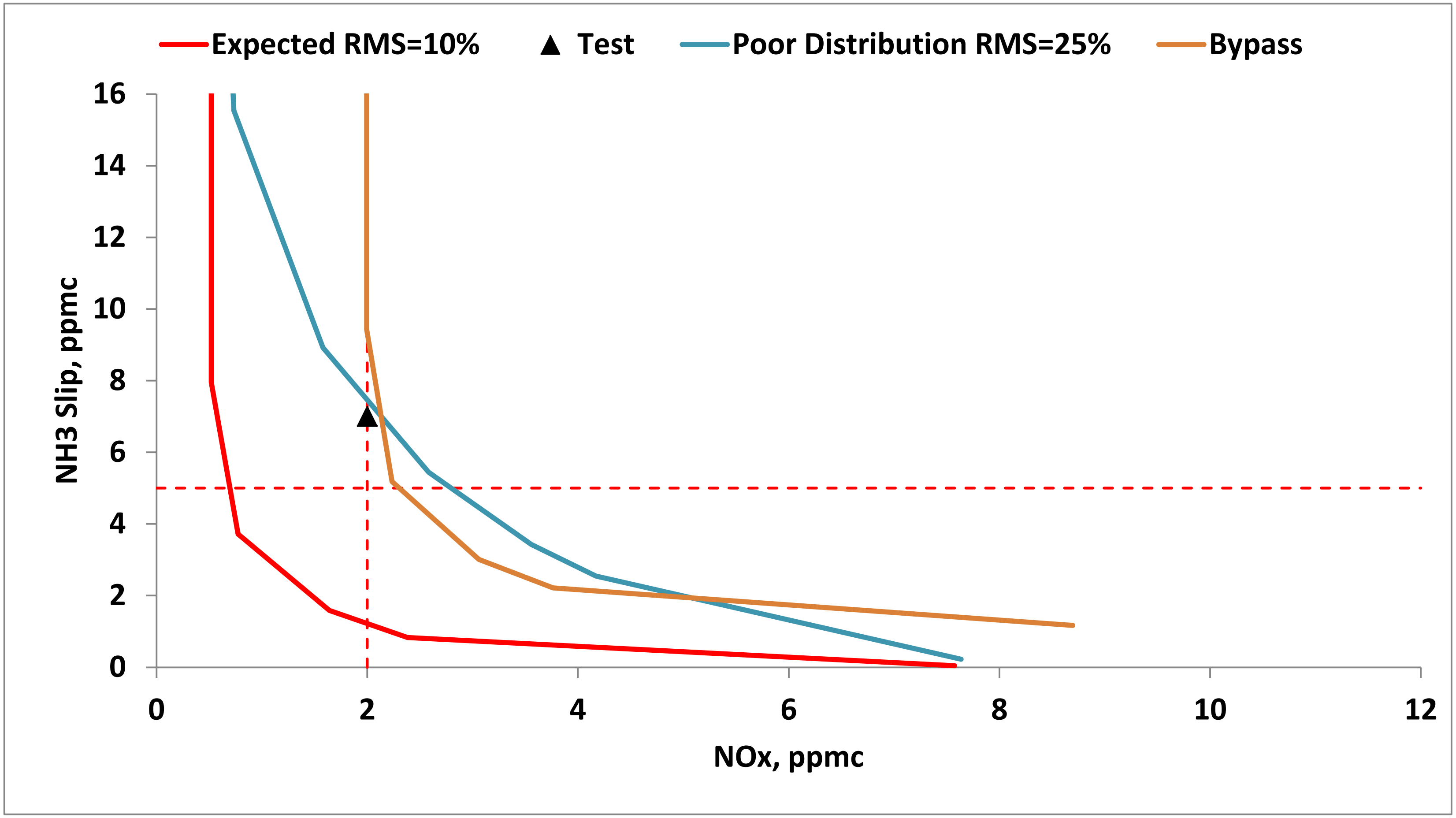


Is it a Poor NH3/NOx Distribution or Bypass?

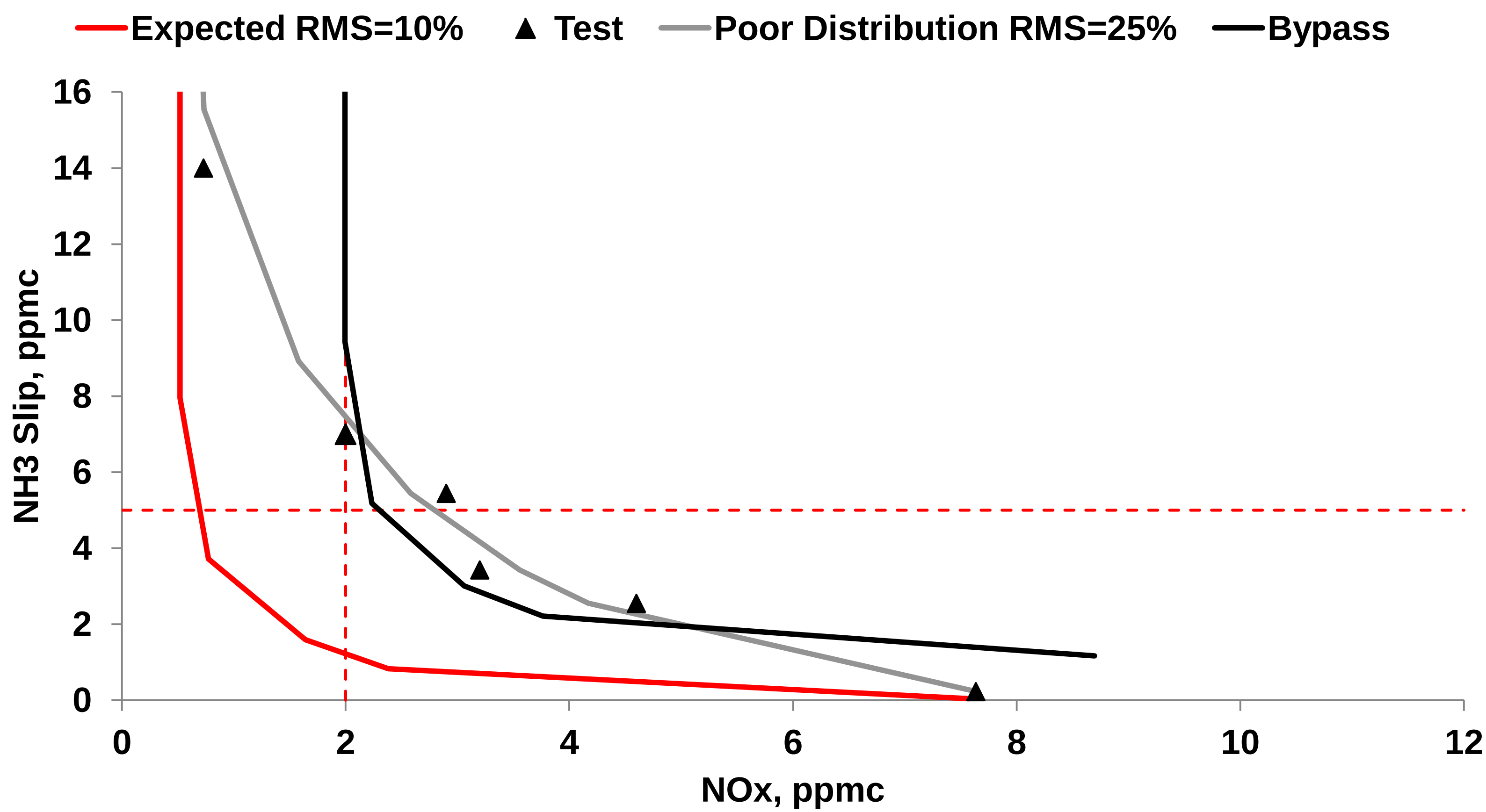


Is it a Poor NH_3/NOx Distribution or Bypass?

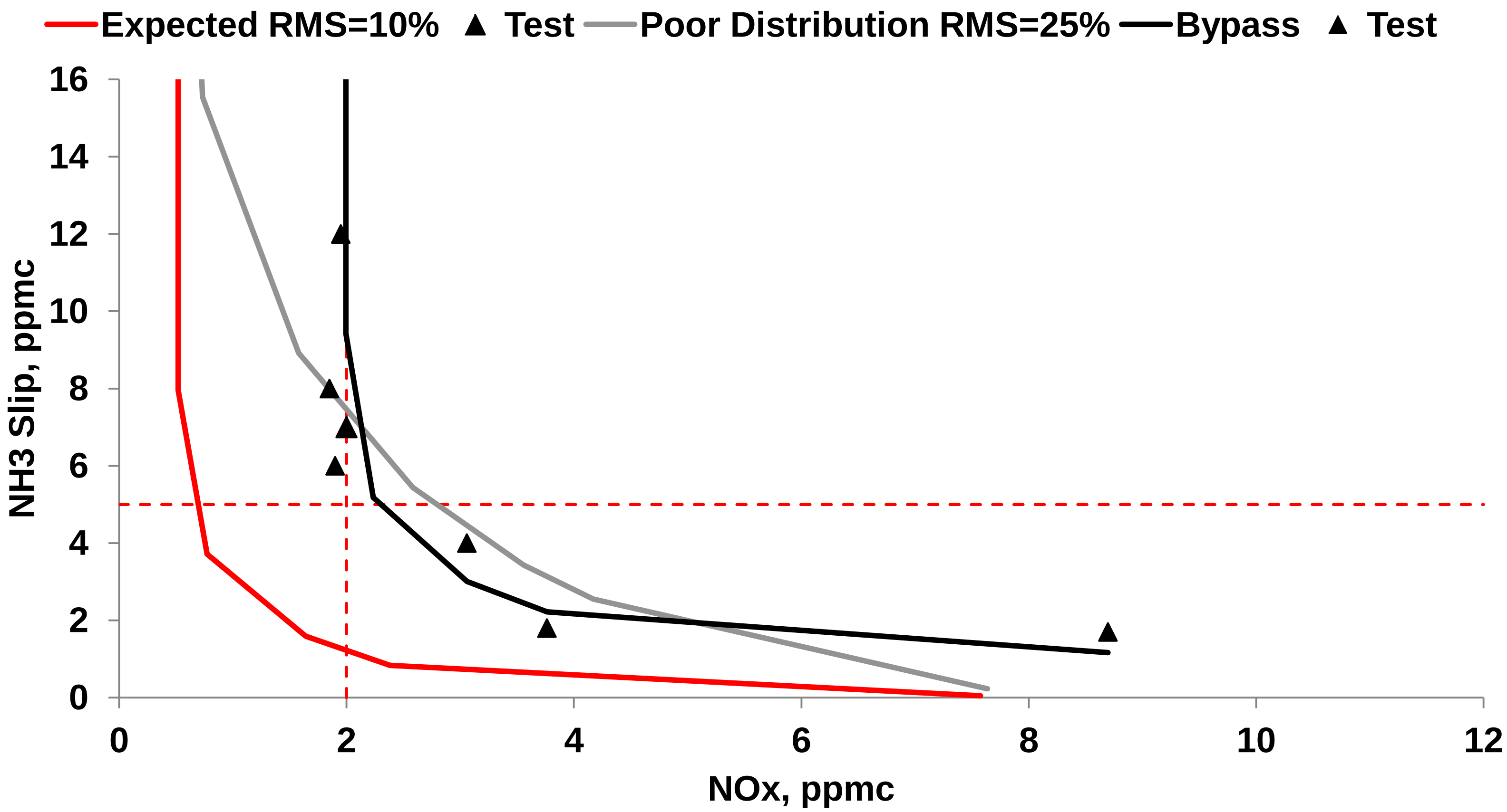
Difficult to tell with only one test



Conduct More Tests: Scenario 1



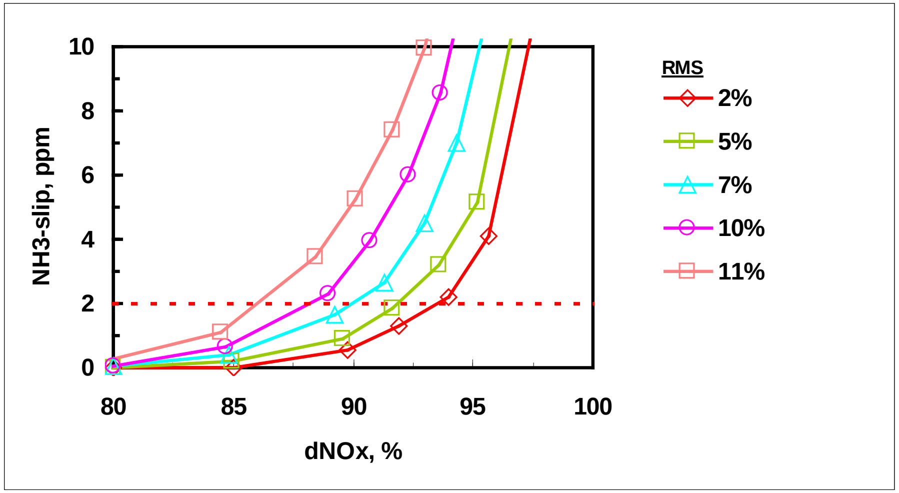
Conduct More Tests: Scenario 2



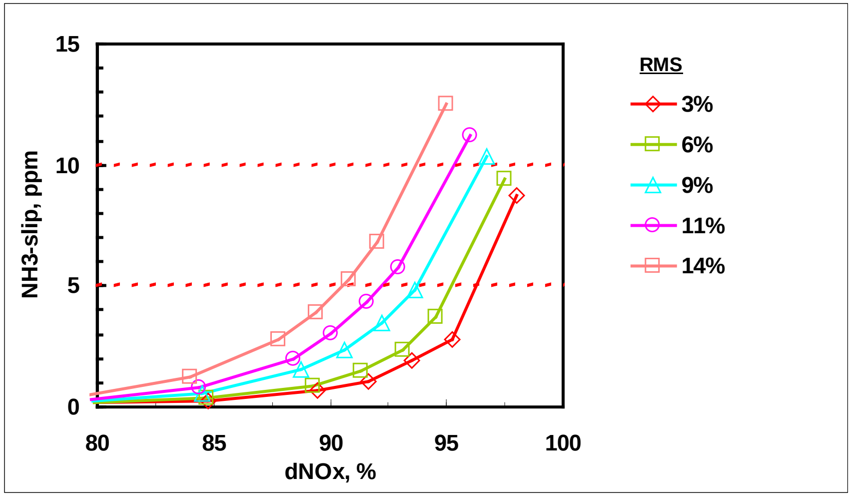
AIG Tuning

EFFECT OF NH_3/NO_X MALDISTRIBUTIONS ON SCR PERFORMANCE

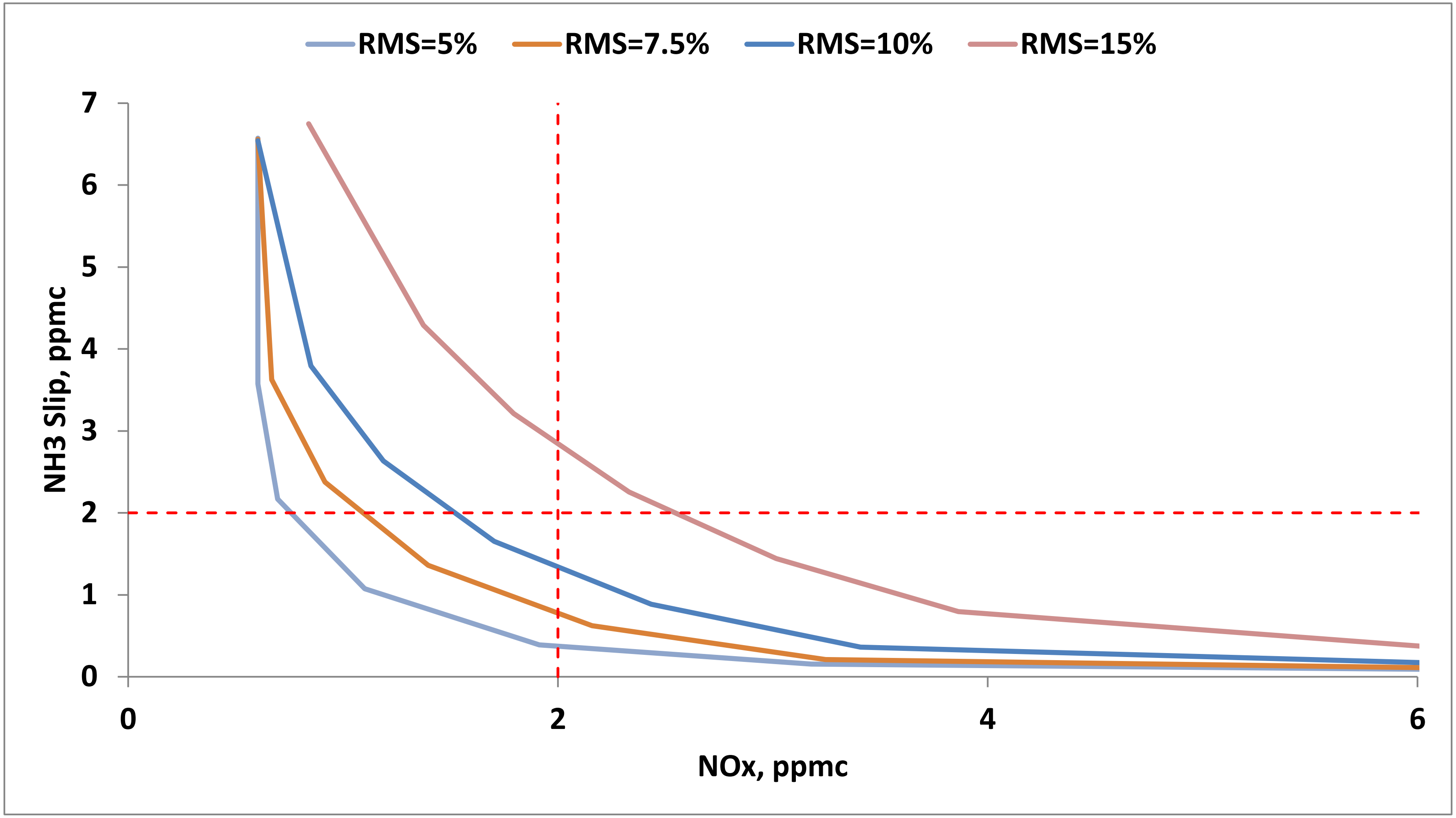
Coal-fired SCR (NOx_{in}=300 ppm)



Gas Turbine SCR (NOx_{in}=25 ppm)



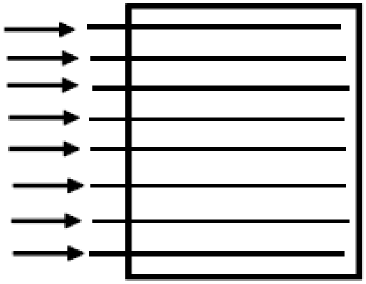
What Happens if (or when!) NH3 Slip Limits Reduced to 2ppm?



AIG Design Affects Tuning

- **No Adjustments:** Some systems have no adjustment valves- Bad Idea ! ! !

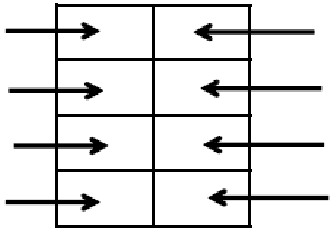
- **1-D:** Commonly used design



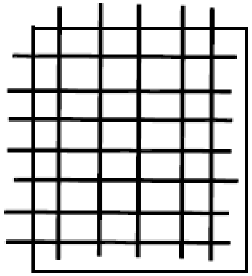
AIG Lance need to be properly designed to insure equal NH3 distribution along the lance:

$$AR=A_{lance}/A_{holes}>5$$

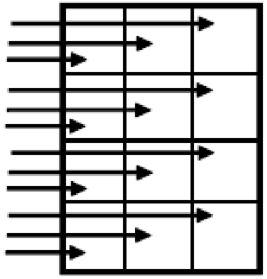
- **Multi Zone:** Better



Two Horizontal Zones



Horizontal and Vertical Lances



Three Horizontal Zones

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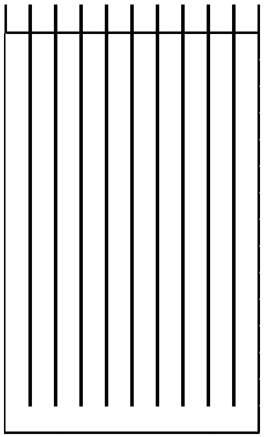
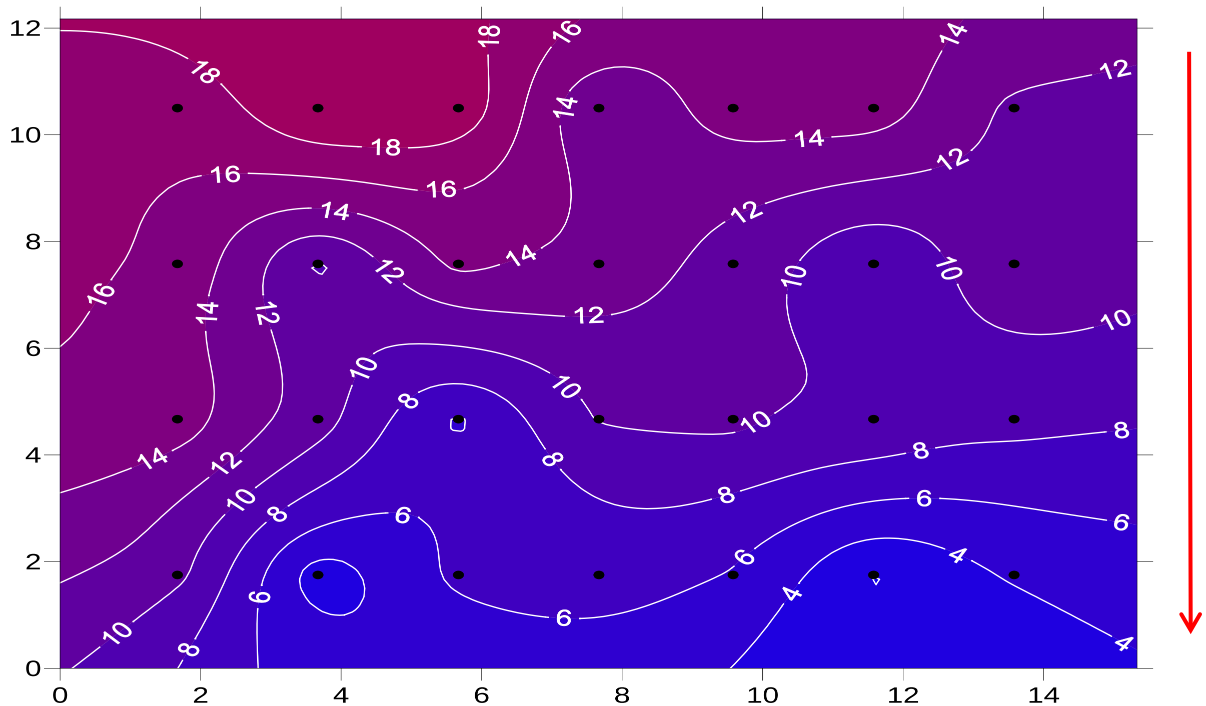
Case 1:AIG- Improper Design

NOx gradient due to NH3 bias from lances(injection hole area too large)





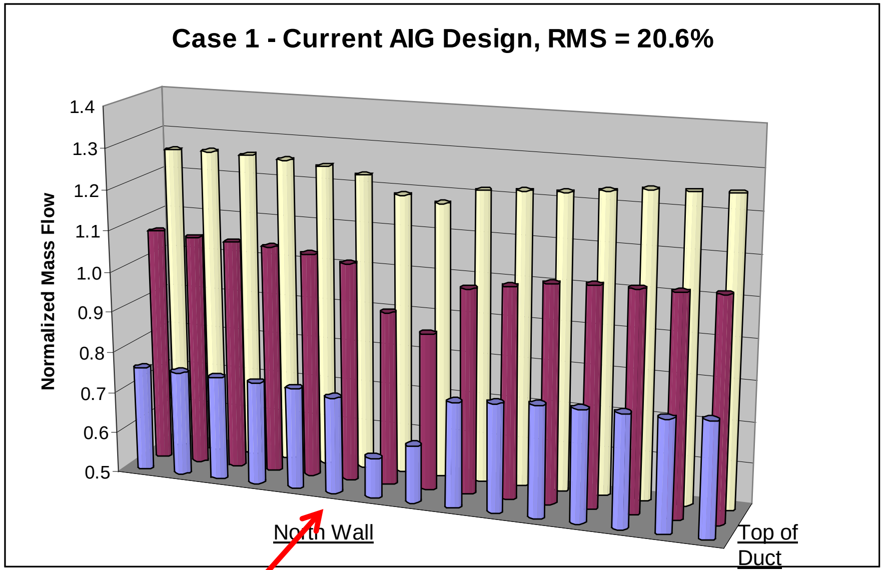
AR<5,

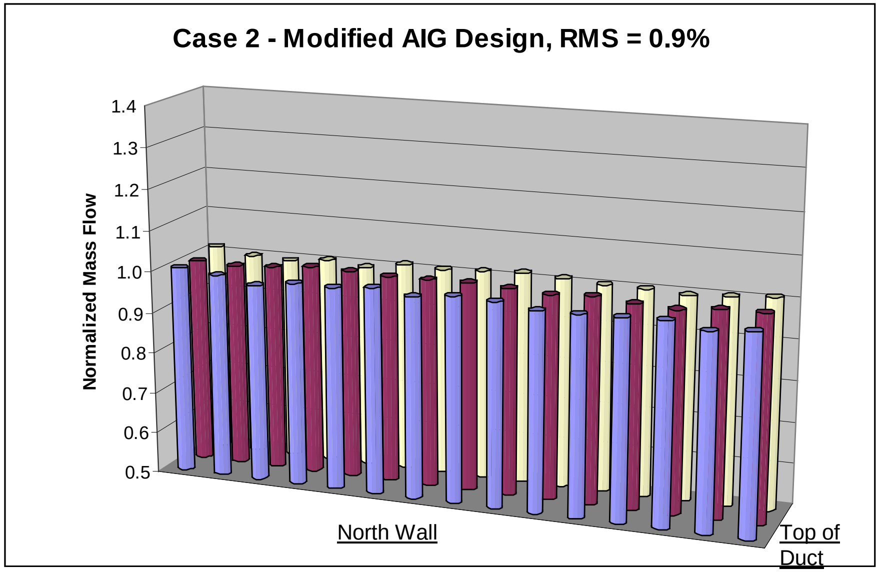
so NH_3 biased to bottom of the lance

<u>Want</u>

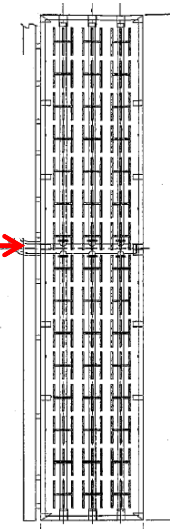
$AR=A_{lance}/A_{holes}>5$

Case 2:CFD RESULTS (AIG Holes Too Large)



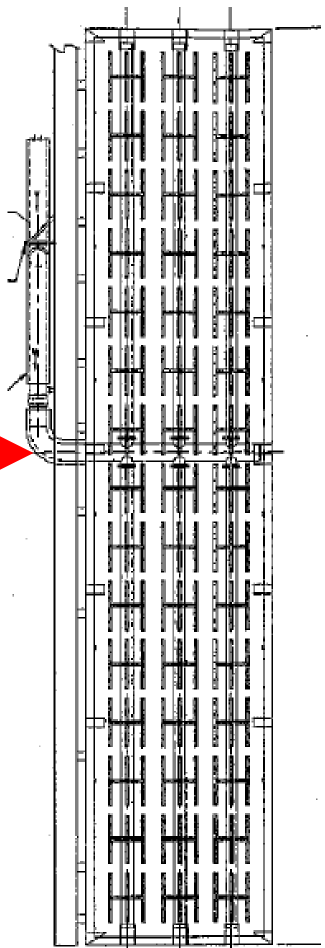


Ammonia Enters This Side



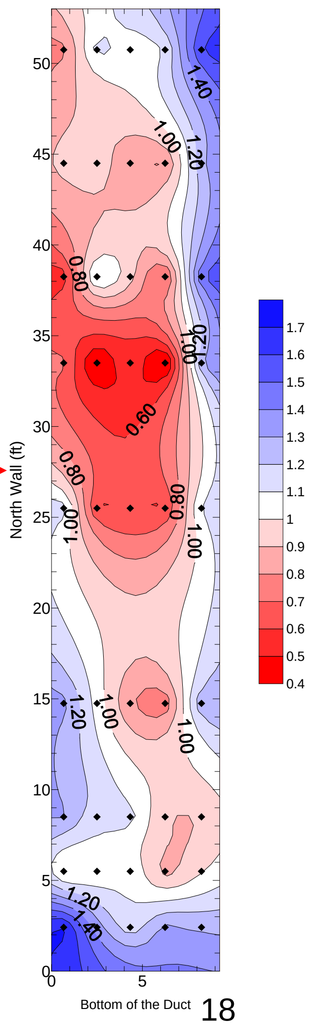
Case 2- Injection Holes Resized

NH_3



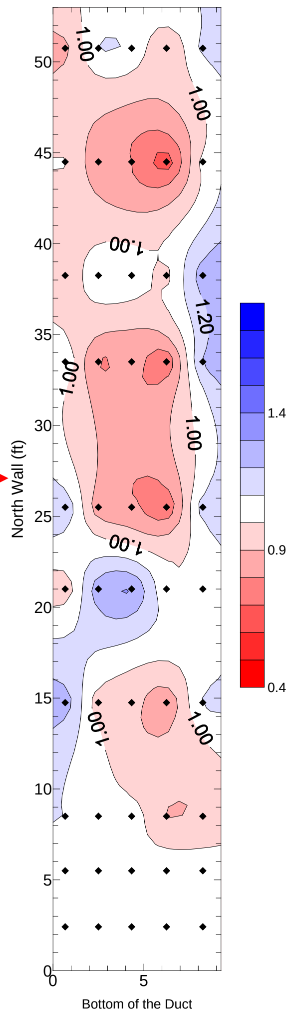
NH_3

Orig. AIG RMS = 35%



All Holes Resized RMS = 16%

NH_3



AIG Tuning

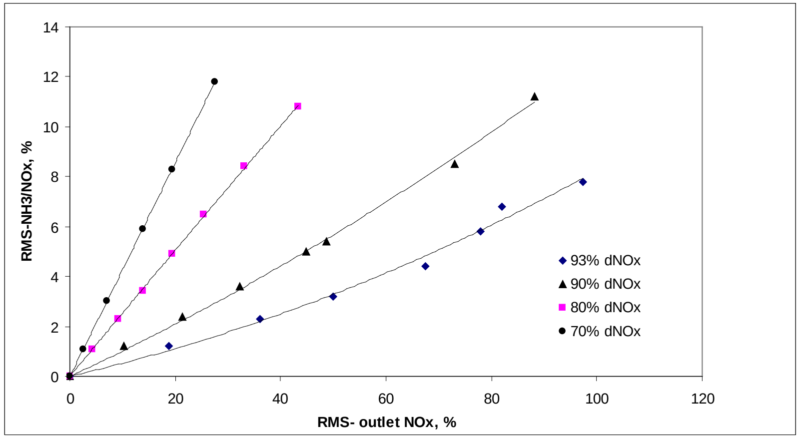
- **Measure and Adjust the NH_3/NO_x Ratio**
  - **Most precise**
  - **May require turning off the NH_3**
  - **Is done by just measuring NO_X**

$$NH_{3in_i} = (NO_{xin_i} - NO_{xout_i}) + NH_{3slip_i}$$

$$NH_{3in_i} = (NO_{xin_i} - NO_{xout_i})$$

$$\left(\frac{NH_3}{NO_x}\right)_i = \left(1 - \frac{NO_{x_{out_i}}}{NO_{x_{in_i}}}\right)$$

- **Adjust to a Uniform Outlet NO_x Distribution**
  - **Easier**
  - **Does not require that the NH_3 be turned off**
  - **However, there is not a unique relationship between outlet NO_x profile and NH_3/NO_x uniformity (if the inlet NOx varies)**



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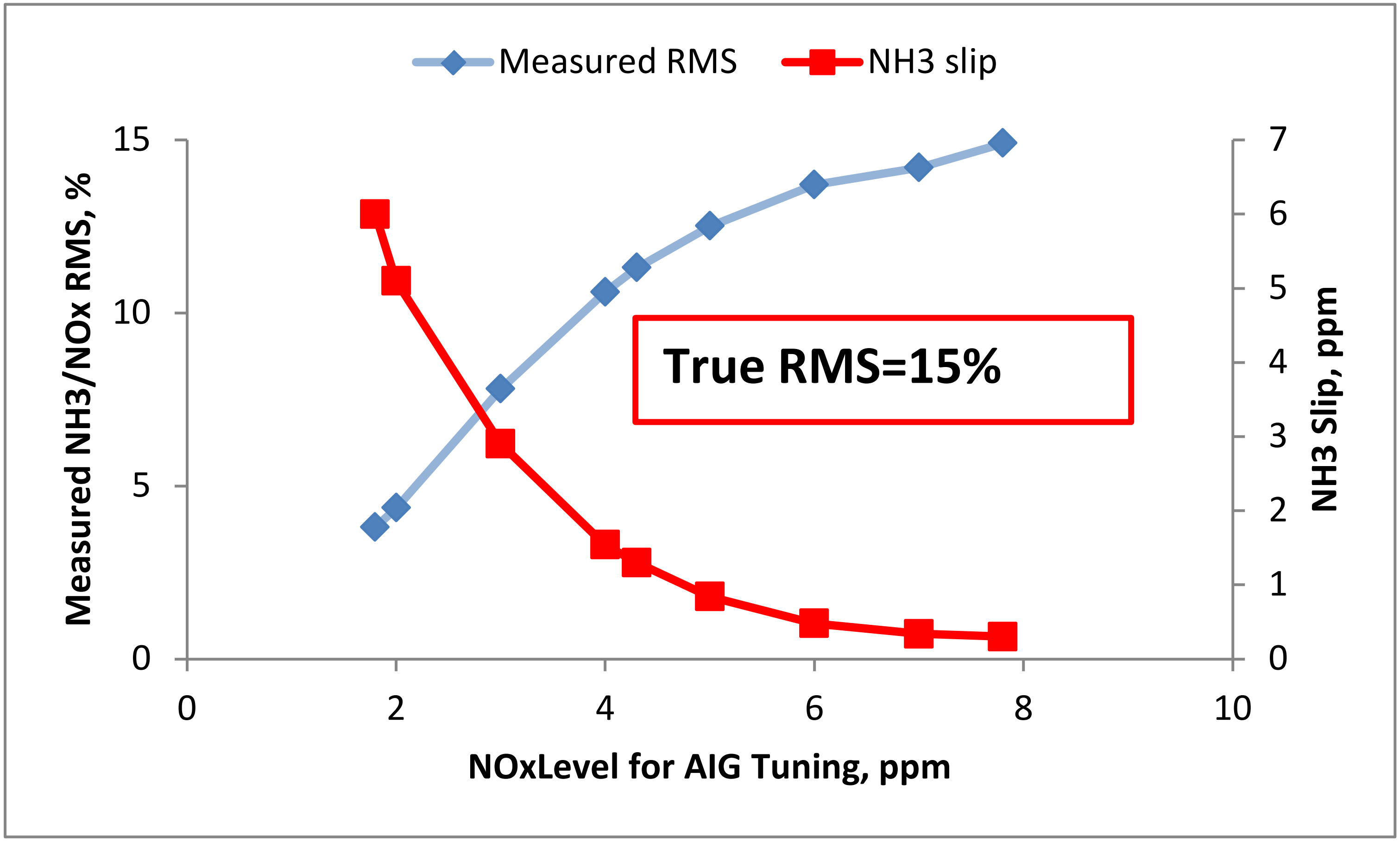
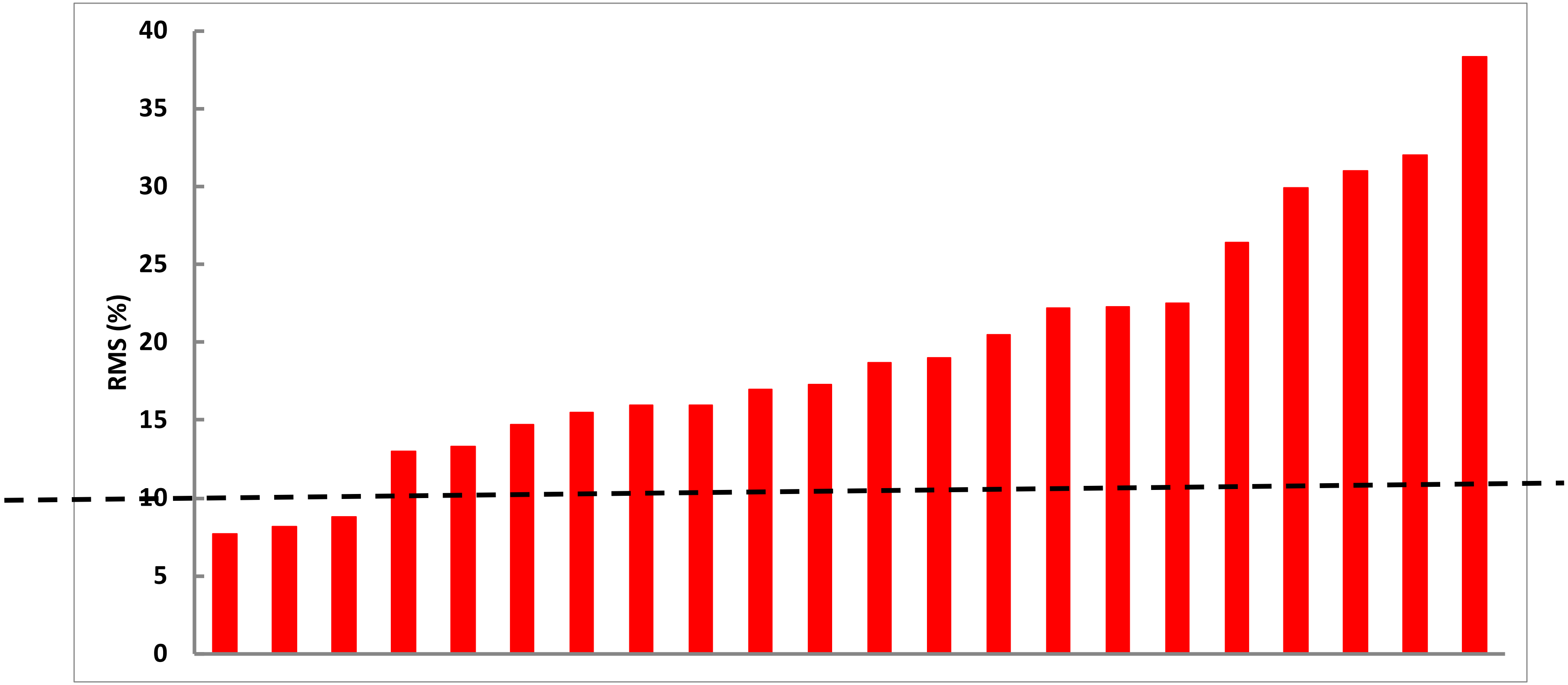
Tune at Too Low a NOx Level (Actual RMS=15%)



How Well is a GT AIG Tuned? (As Found RMS Values)

Most of the GT AIGs we encounter are not tuned very well!



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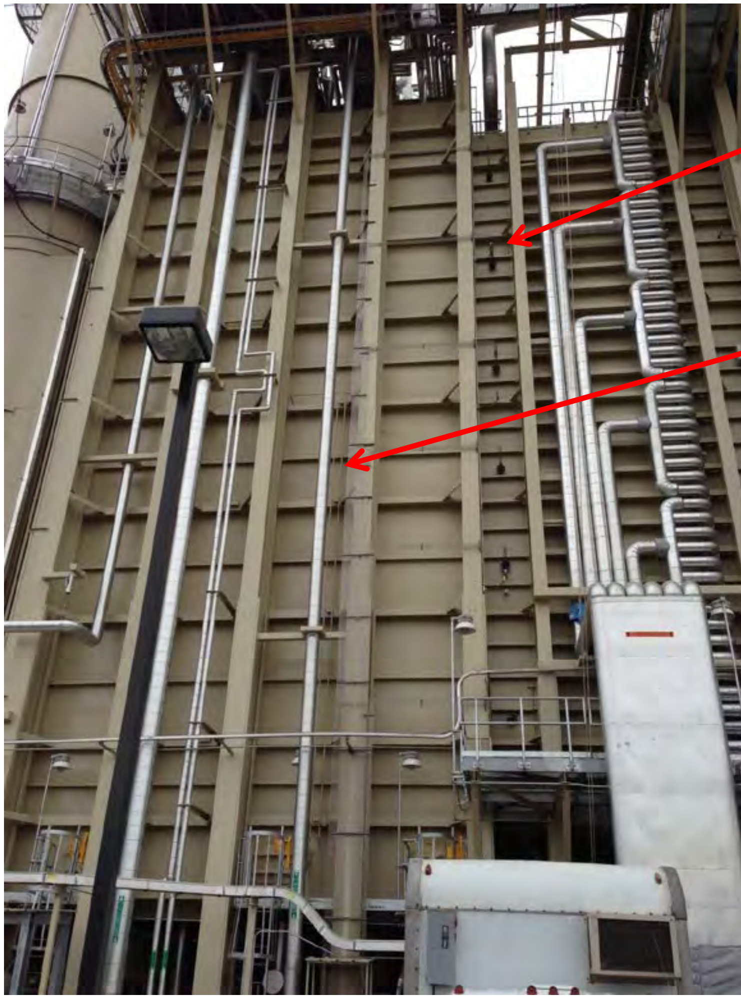
Gas Turbine SCR AIG Tuning

- **Tuning is Facilitated by Installing a Permanent Sample Grid at the Catalyst Exit:**
  - **Typically done on coal units but not Gas Turbines**
  - **Not feasible to manually traverse a large combined cycle system for AIG tuning**
  - **Typically need 36 to 60 probes depending on AIG design**

- **With Permanent Probes Tuning can Typically be done in <u>One Day</u>**

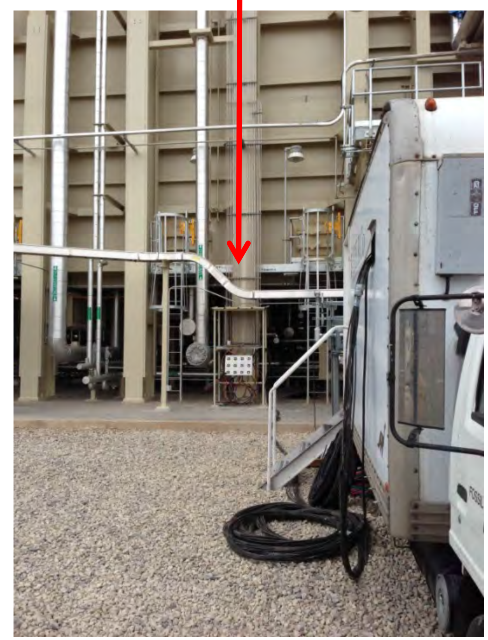
- **The NO_x Profiles at the Exit of the Catalyst can also Help Identify Bypass**

Outside View of a Permanent Sample Grid on a Large Combined Cycle



Sample probe exit ports

Sample probe lines brought down to grade



Sample Probes Supported from Catalyst Frame

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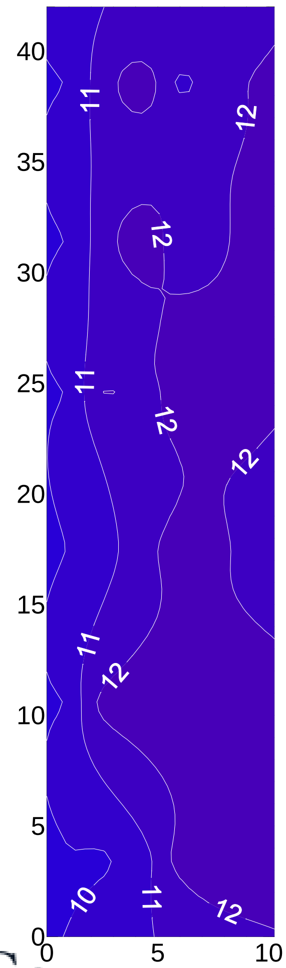
FERCo's Multipoint Instrumentation

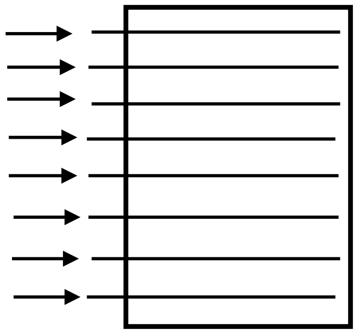
- Samples 48 points in 12-15 minutes (4 groups of 12)
- NO_x and O_2

Duct Burners Impact AIG Tuning

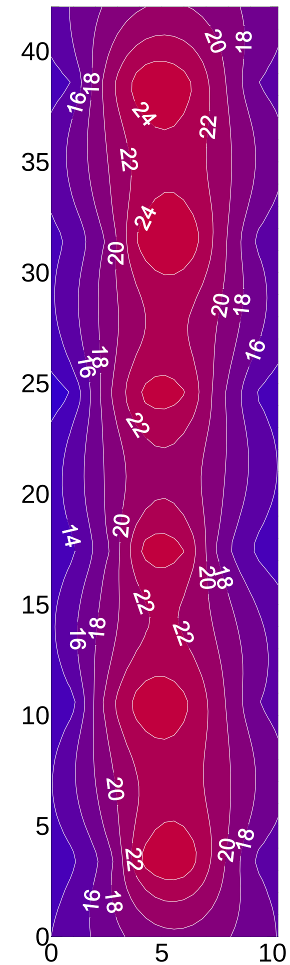
Duct Burners Off
(Inlet NO_x ppm)



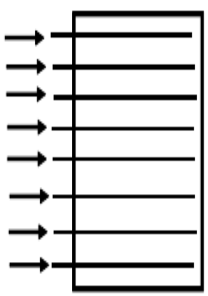
AIG Difficult to Tune



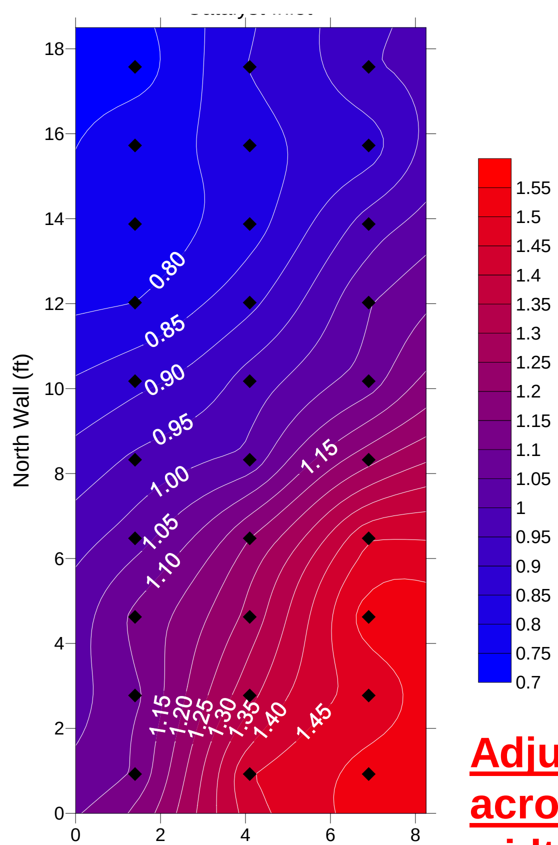
Duct Burners On
(Inlet NO_x ppm)



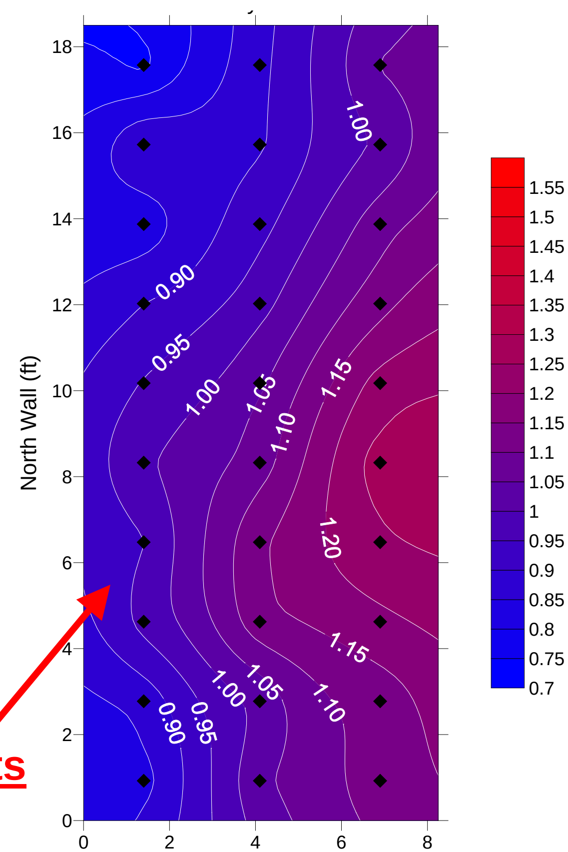
AIG Tuning, 1-D AIG Design; NH_3/NO_x



<u>As Found, RMS = 22%</u>



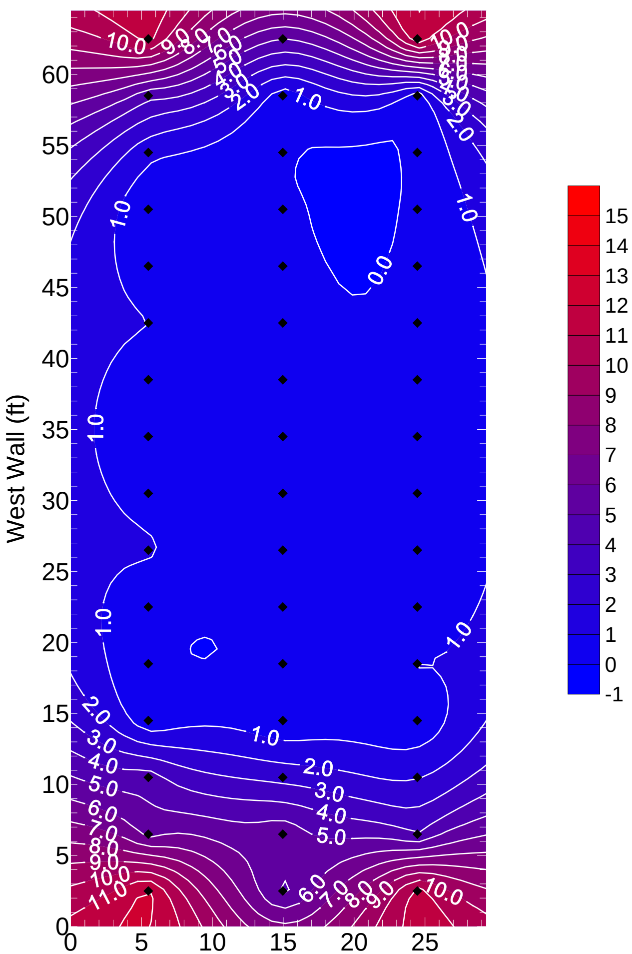
<u>Tuned, RMS = 13%</u>



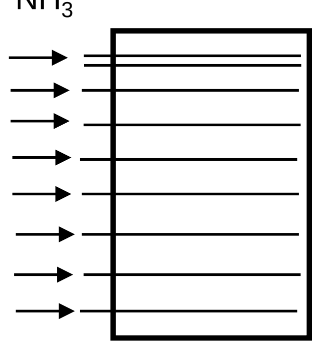
<u>Adjustments across the width not possible</u>

AIG Tuning, 1-D AIG Design; Outlet NO_x

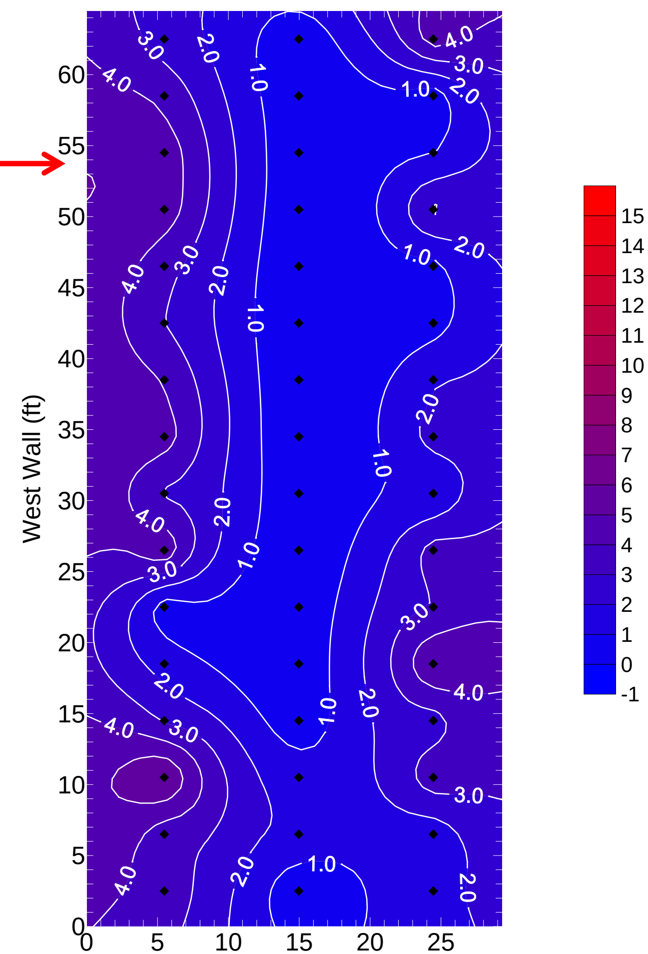
As Found



Reagent consumption reduced 5%



Tuned



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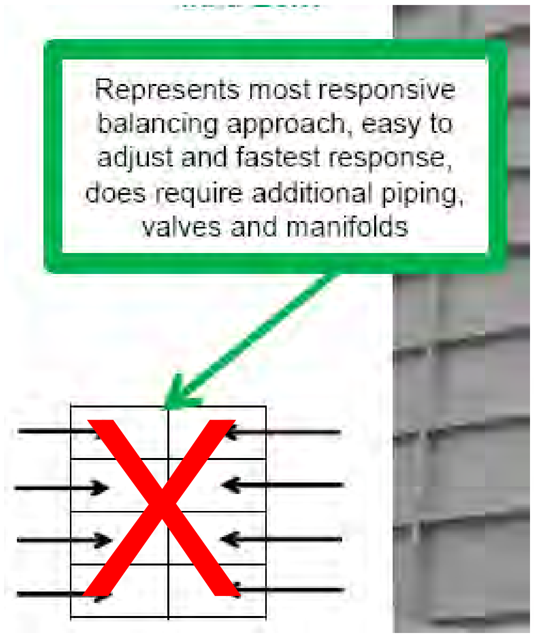
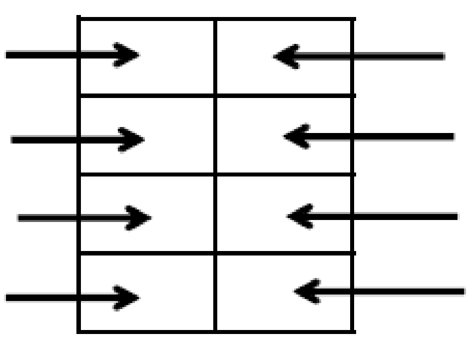
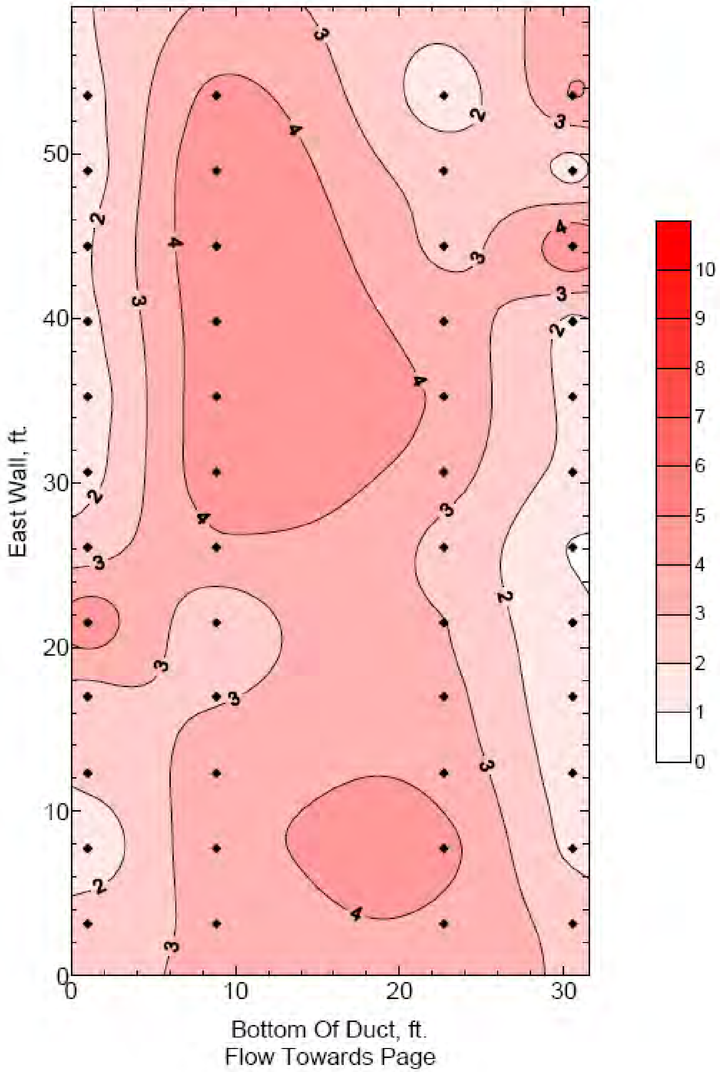
AIG Tuning, 2-D AIG Design; Outlet NO_x



AIG Design:2-Zones Horizontally





In most Gas turbine SCR reactors you need to make an adjustment in the center. This two zone design does not allow this

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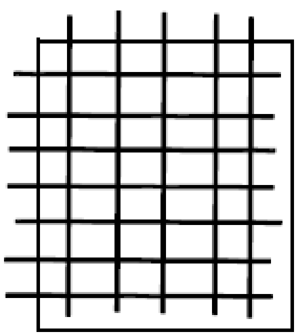
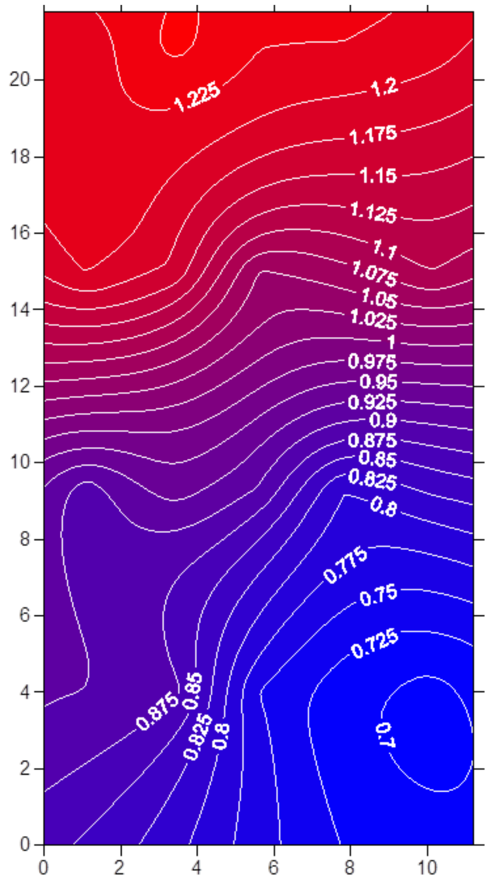
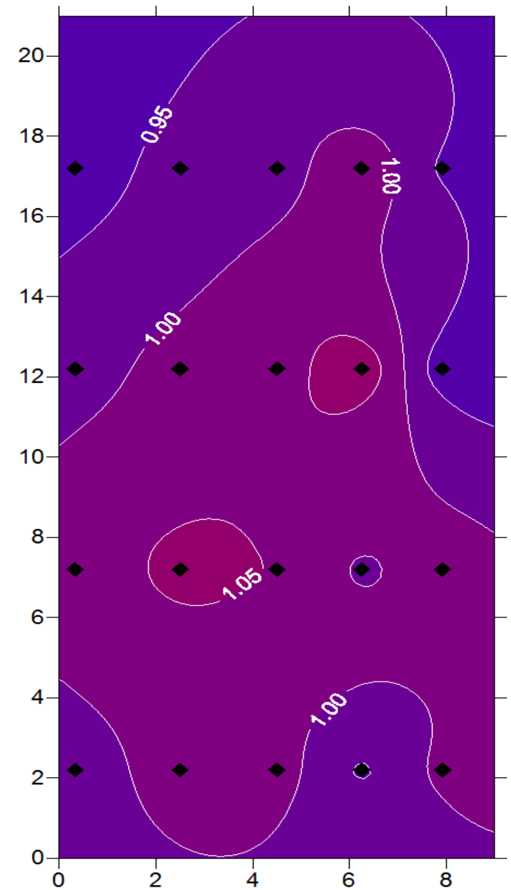
AIG Tuning, Multi Zone AIG Design; NH_3/NO_x



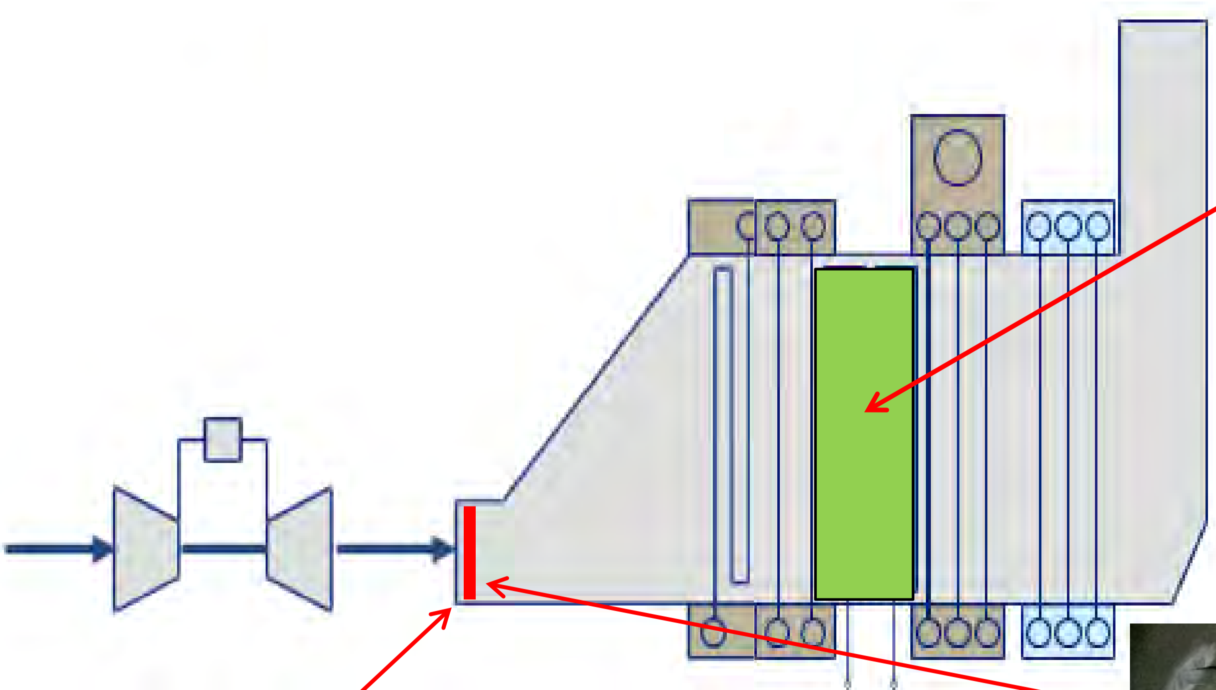
As Found, RMS = 19%



Tuned, RMS = 5%



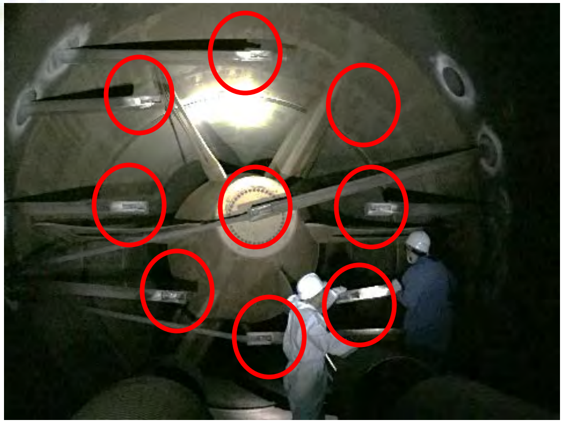
Direct Injection/Dual Function Catalyst



Dual Function or a combination of SCR and Dual Function Catalyst

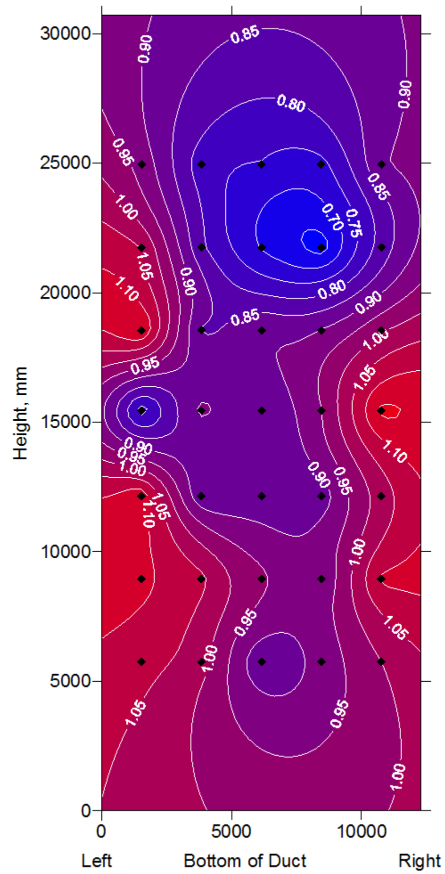
NOx and CO Removal

Direct Injection of Ammonium Hydroxide or Urea

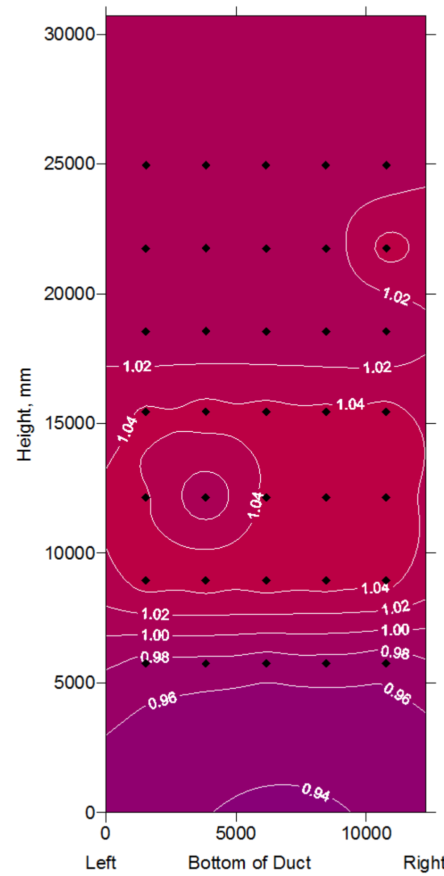


Direct Injection of Aqueous Ammonia@ Turbine exhaust

As Found, RMS = 14%



Tuned, RMS = 3%

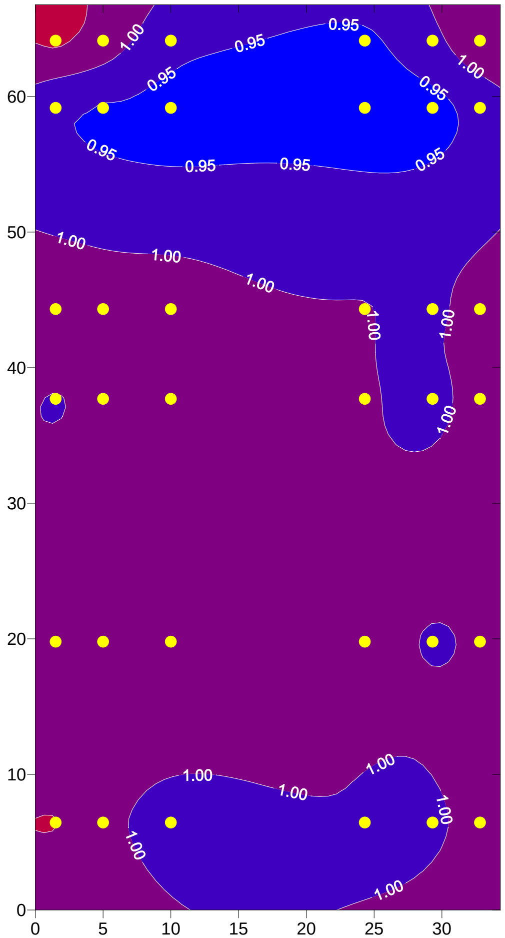


Probe Grid Does Not Always Tell The Entire Story

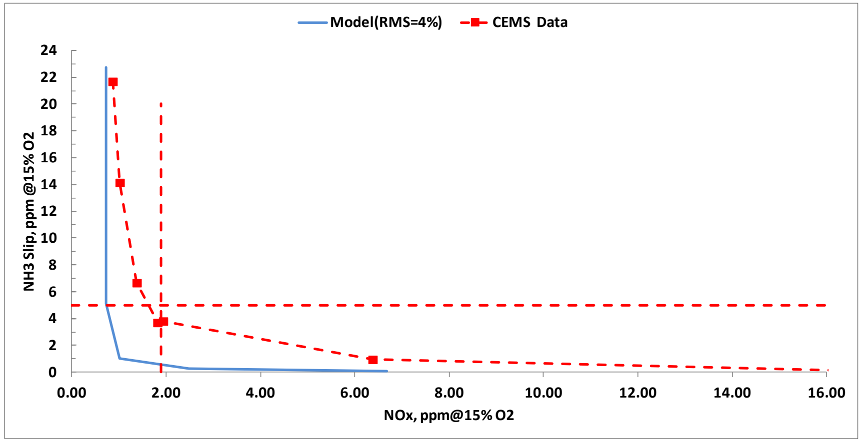
- **May not be able to tune at a reduced ammonia injection rate (RMS not accurately determined)**
- **Probe locations may not sample problem areas**

Probe Grid Does Not Always Tell The Entire Story

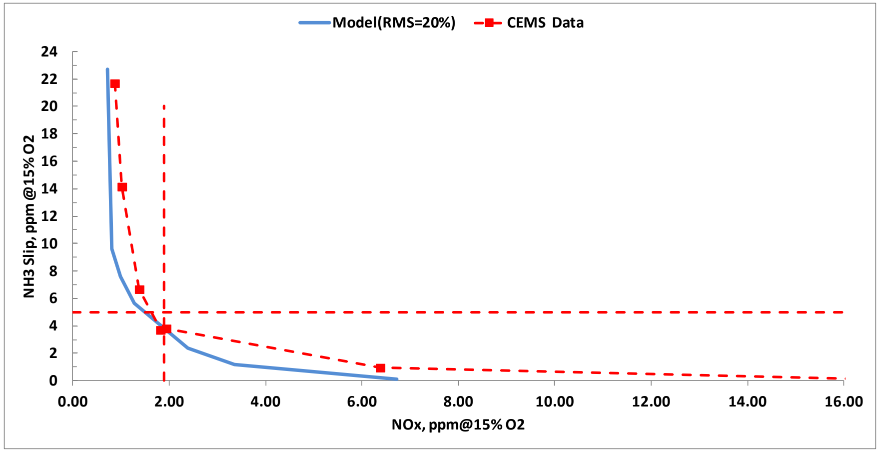
Tuned, RMS = 4%



Blue: Process Model: 4% RMS **Red: CEMs Data**



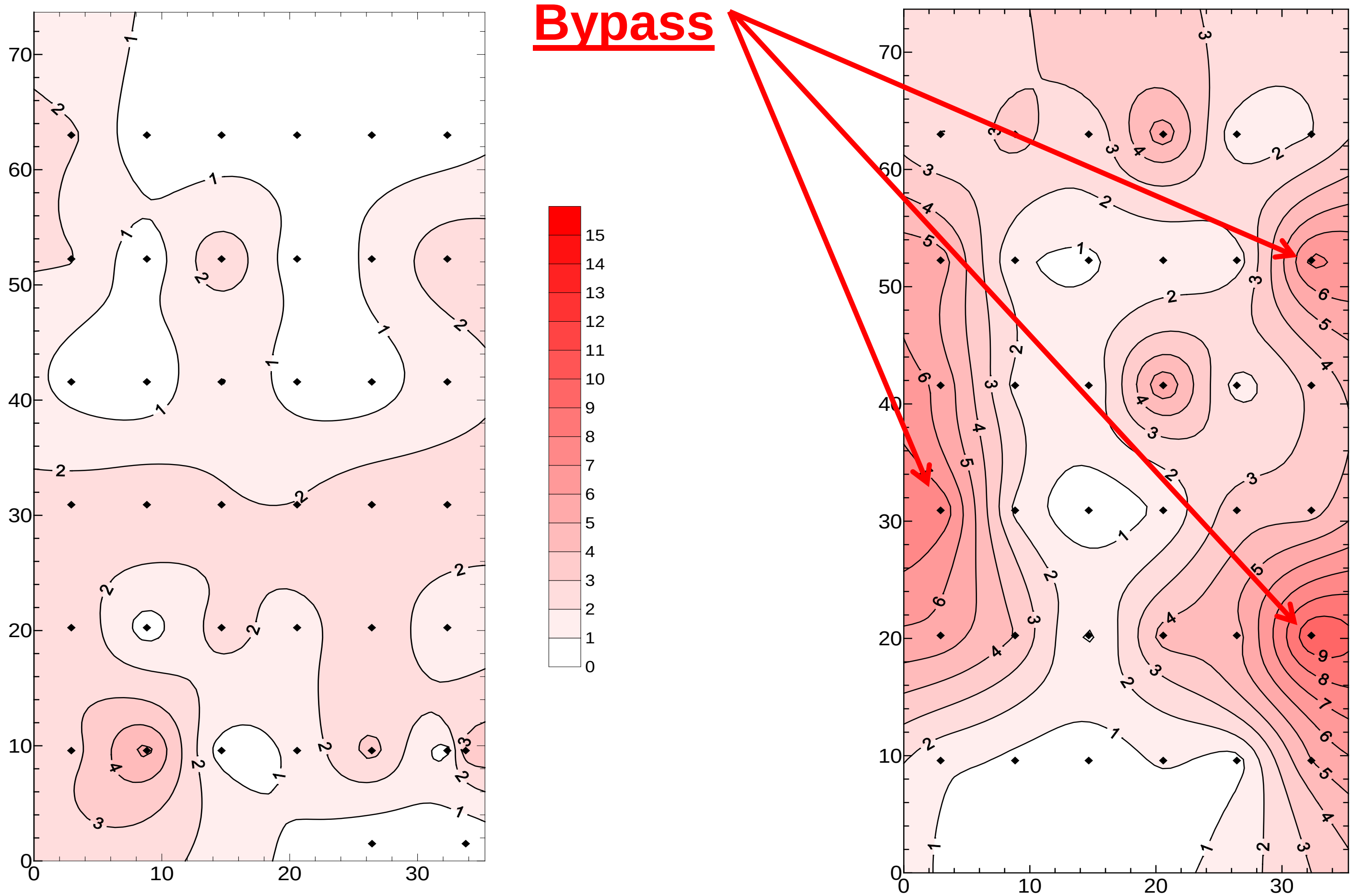
Blue: Process Model: 20% RMS **Red: CEMs Data**



Bypass

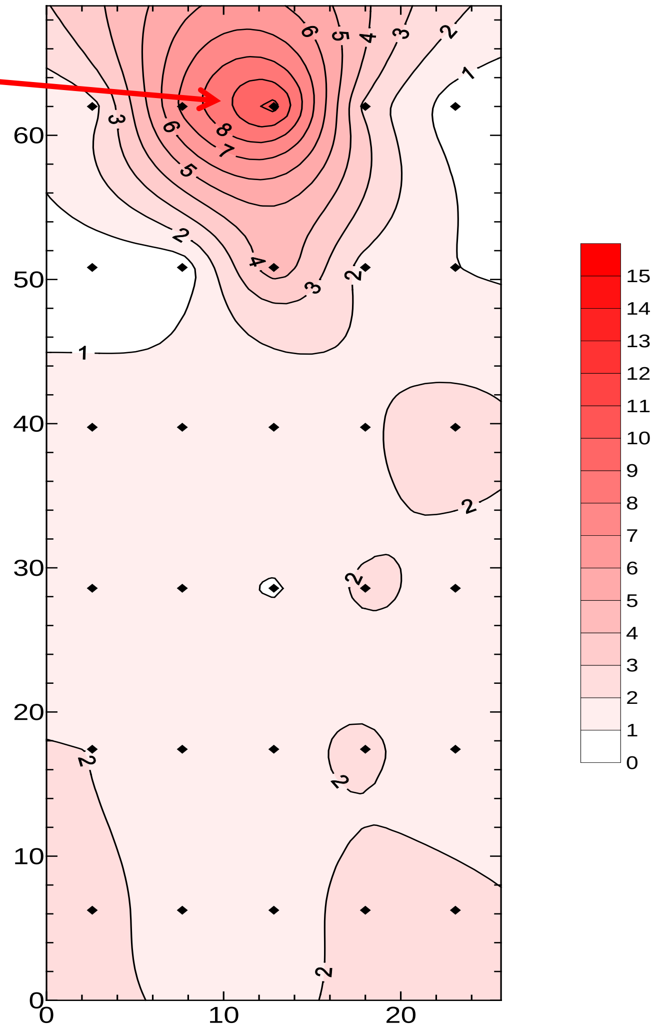
NO_x Profiles Can Also Help Detect Bypass

Base Year | **Possible Bypass** | **Two Years later**



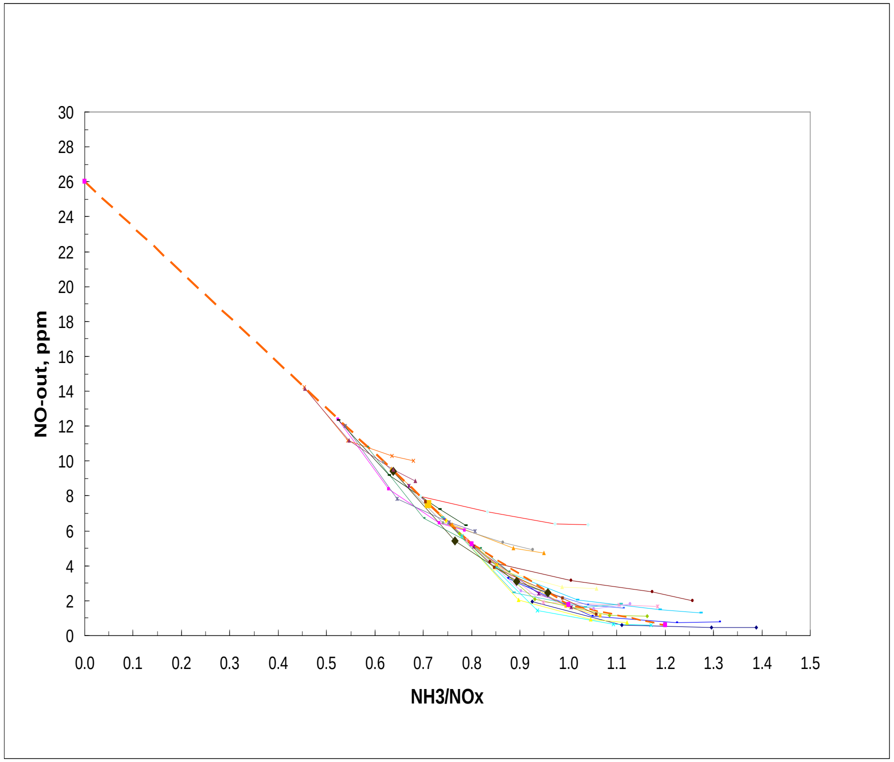
NO_x Profiles Can Also Help Detect Bypass

Possible Bypass

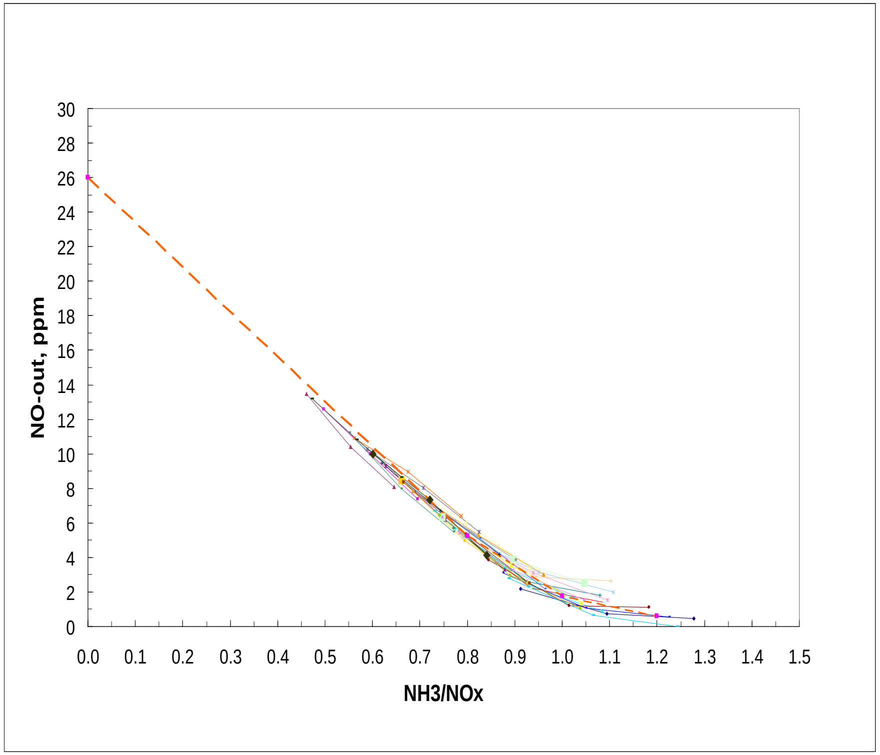


Gas Bypass

As-Found



Repaired



SCR Velocity Measurements

APPROACHES TO MEASURING VELOCITY MALDISTRIBUTIONS

Traditional

- Rely on Physical Cold Flow, or CFD Model Results
  > May not be totally representative
  > Doesn't test full scale operational issues

- Use High Temperature Thermal Anemometer or Pitot Probe

Issues

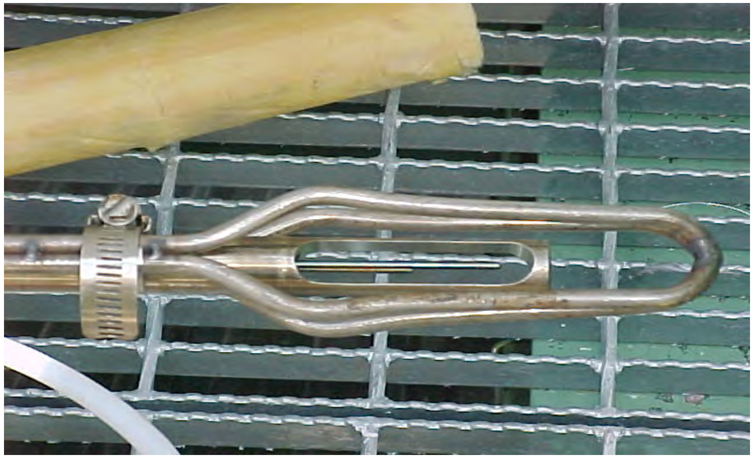
- Long Probes
- Pitot Probes: Low ΔP readings (0.01 – 0.04 "H_2O)
- Flow Disturbances (support structure, etc)

Alternate Approach

- Based on NO_x Measurements at the Catalyst Exit

APPROACHES TO MEASURING VELOCITY MALDISTRIBUTIONS

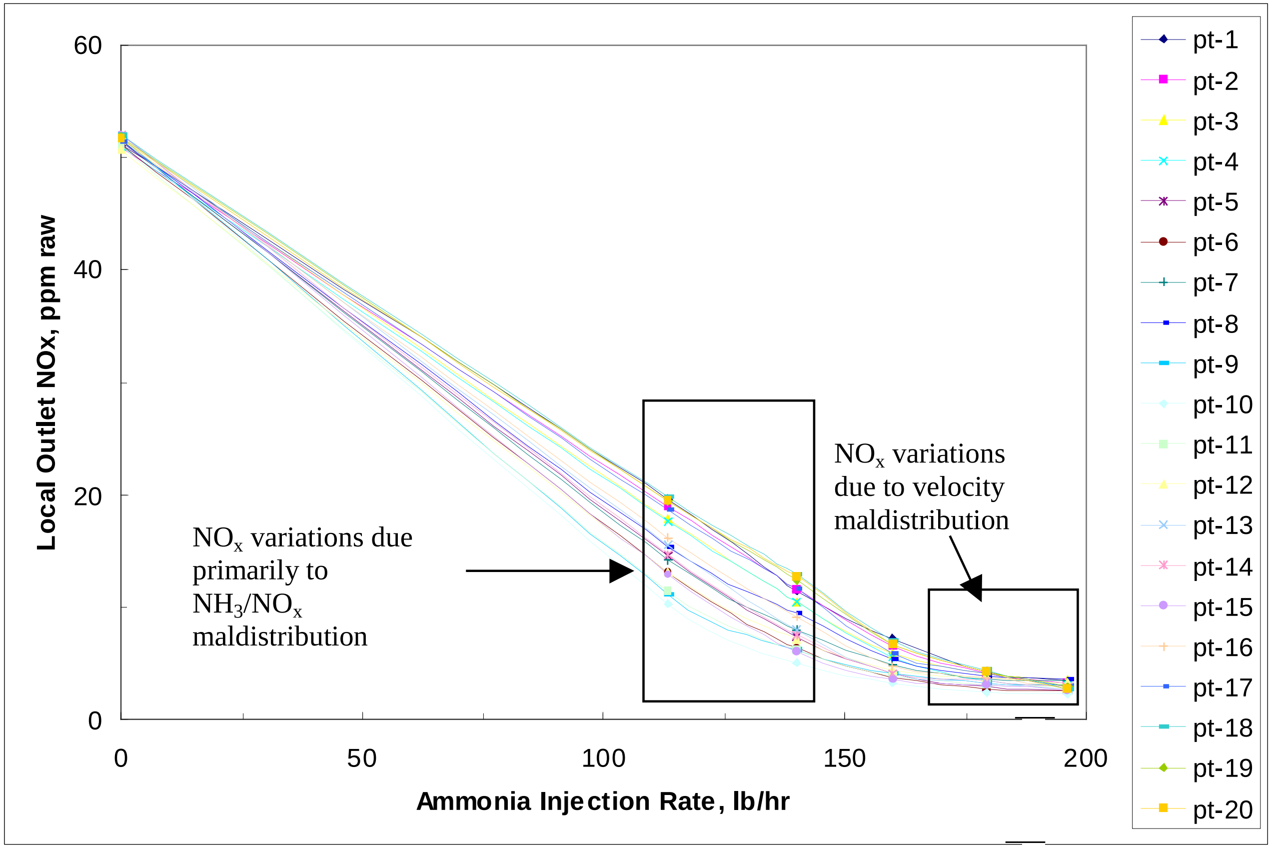
High Temperature Thermal Anemometer



S-Type Pitot Probe

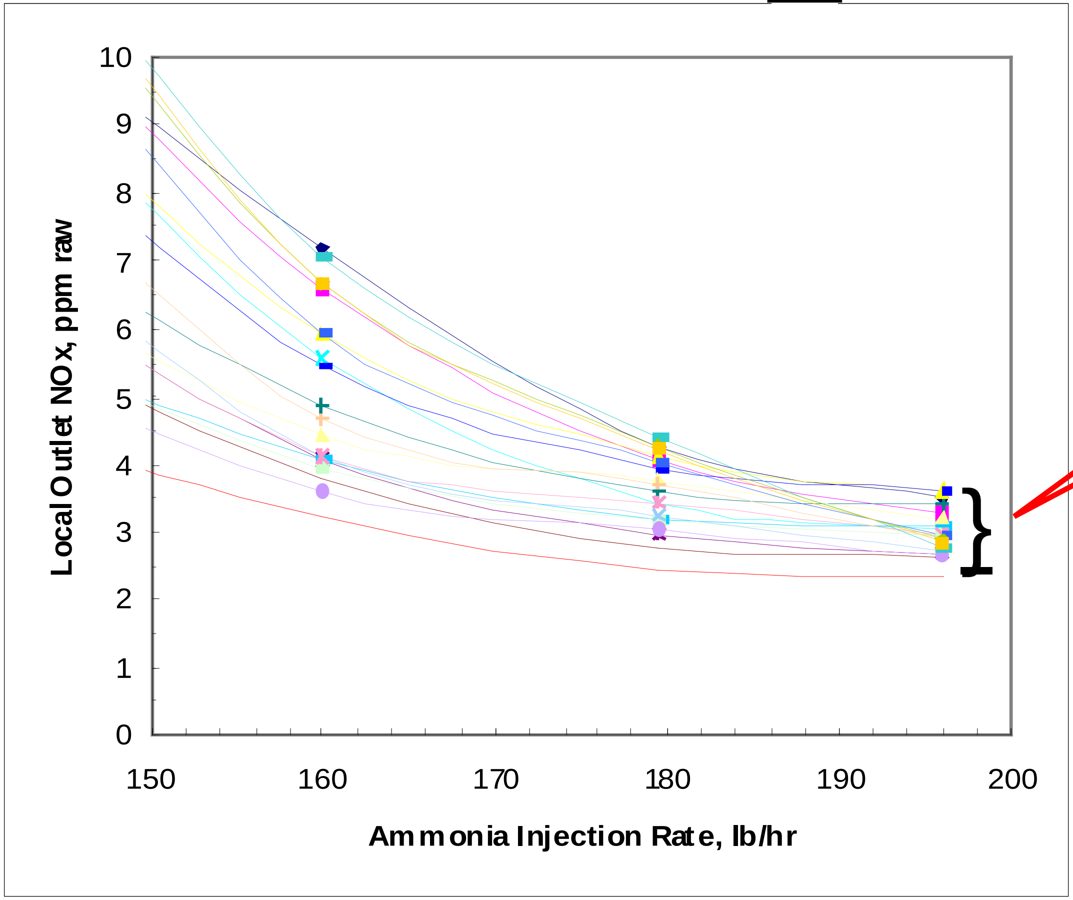
	N.G. SCR (30' x 45')	Coal SCR (45' x 47')
	Velocity RMS, %	
Cold Flow Model	13	6
Anemometer	30	32
S-Type Pitot	20	26

LOCAL OUTLET NO_x VS. NH_3 INJECTION RATE



LOCAL NO_x VS. NH_3 INJECTION RATE

High NH_3/NO_x Ratio



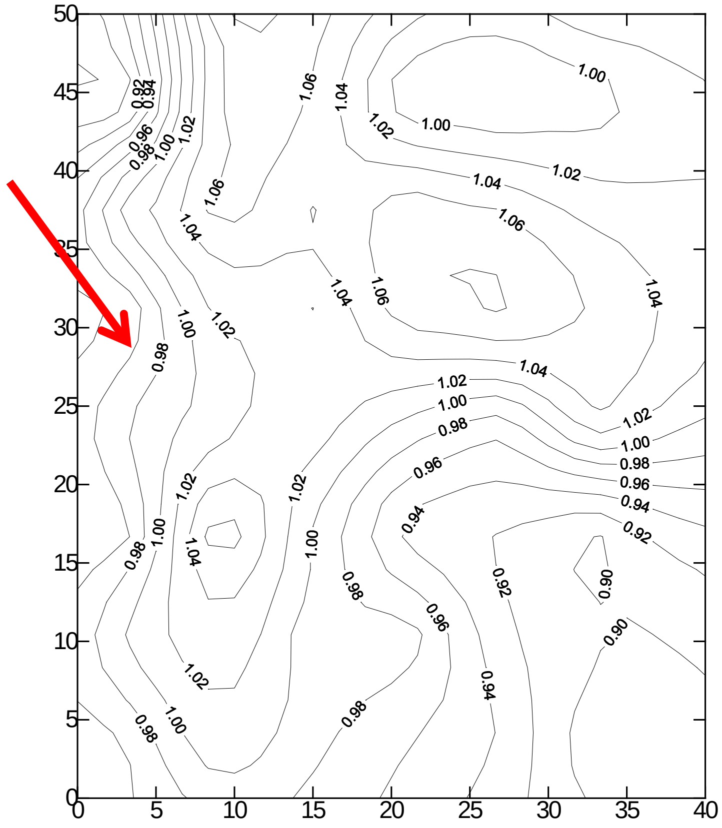
Variation=f(K/Av)

$K=-A_V \ln(1-\Delta NO_x)$

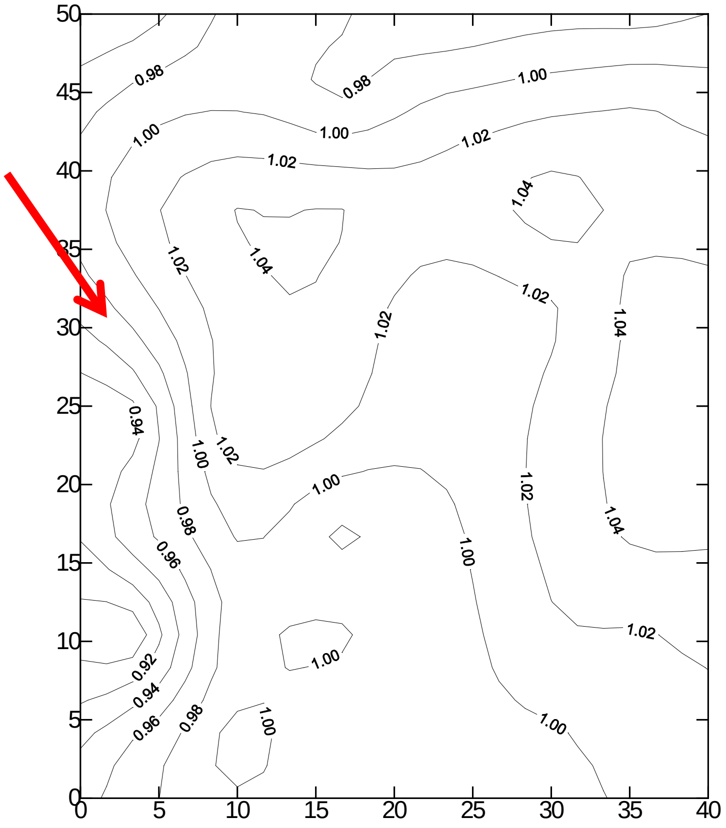
$Vel_i \sim Q_i = K\, A_{sp} V_{cat} / \ln(1-\Delta NO_x)$

VELOCITY PROFILE FOR A COAL-FIRED SCR

Cold Flow (RMS = 5.8%)



Full Scale (RMS = 3.6%)



Summary

- Simple stack measurements (NH_3 vs NO_x) can distinguish Gas Bypass from NH_3/NO_x maldistribution
    - Facilitated by using a continuous TDL analyzer to make the NH_3 measurements
- AIG tuning facilitated using a permanent probe grid at the catalyst exit
    - With a probe grid and multipoint sampling, AIG tuning completed in one day
- AIG Design affects how well a unit can be tuned
- NO_x profiles at the SCR outlet can also help diagnose areas of Gas Bypass
- Velocity Profiles
    - Difficult to measure directly at full scale
    - SCR outlet NOx measurements can be used to infer velocity profiles