Reinhold Environmental Ltd.

2009 NOx-Combustion Round Table & Expo Presentation

February 9 & 10, 2009, Cleveland, OH

Determining Reactor Potential *In situ*

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NOx Combustion Round Table & Expo

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Topics

- **Overview of Catalyst Management**
- **In situ Determination of Catalyst Activity or Reactor Potential***
  - **Why do it ?**
  - **How is it done ?**
  - **How does it compare to laboratory measurements?**
- **Low Load Operation**
- **Summary**

* Patent Pending

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Catalyst Management

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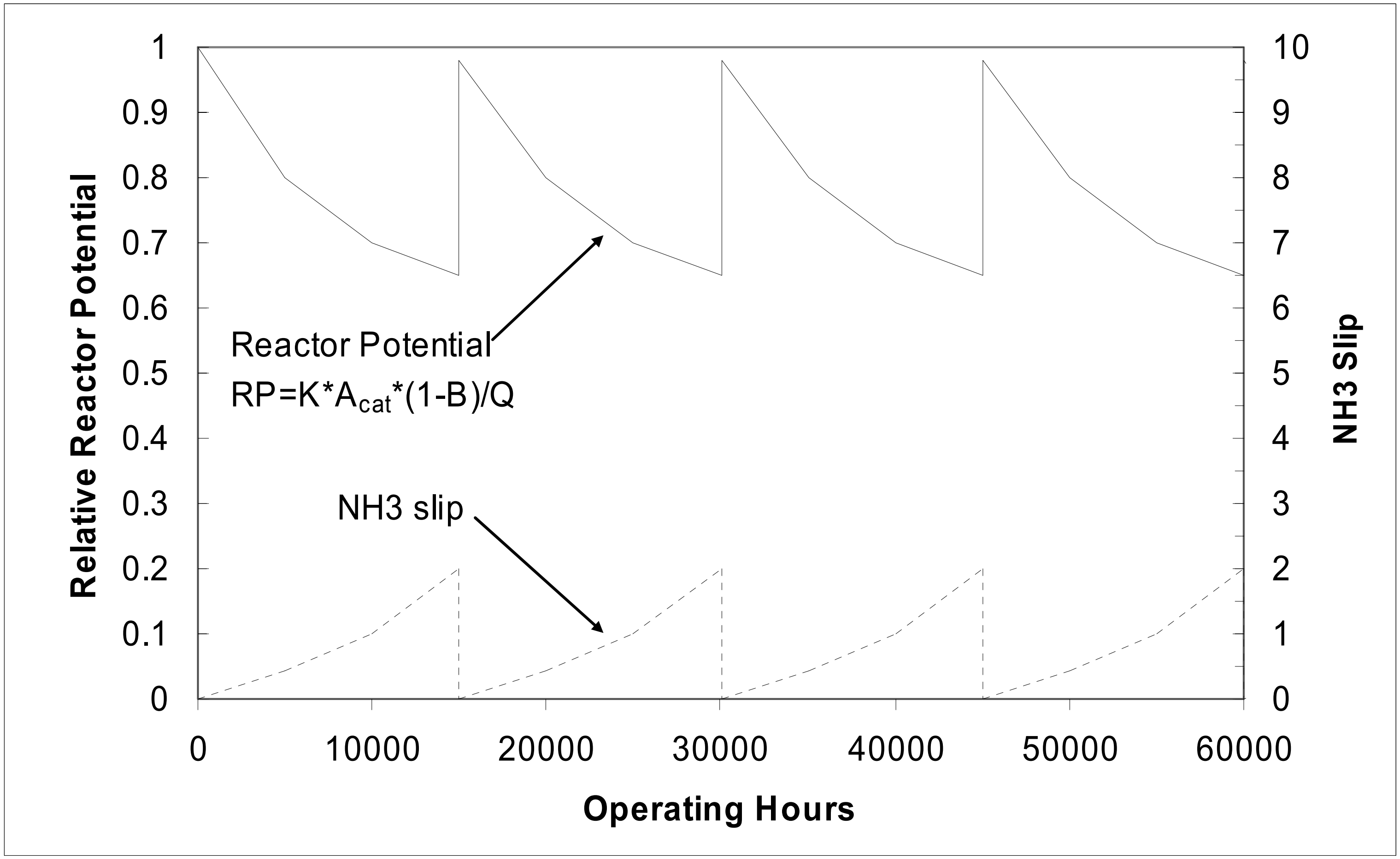
What is Catalyst Management?



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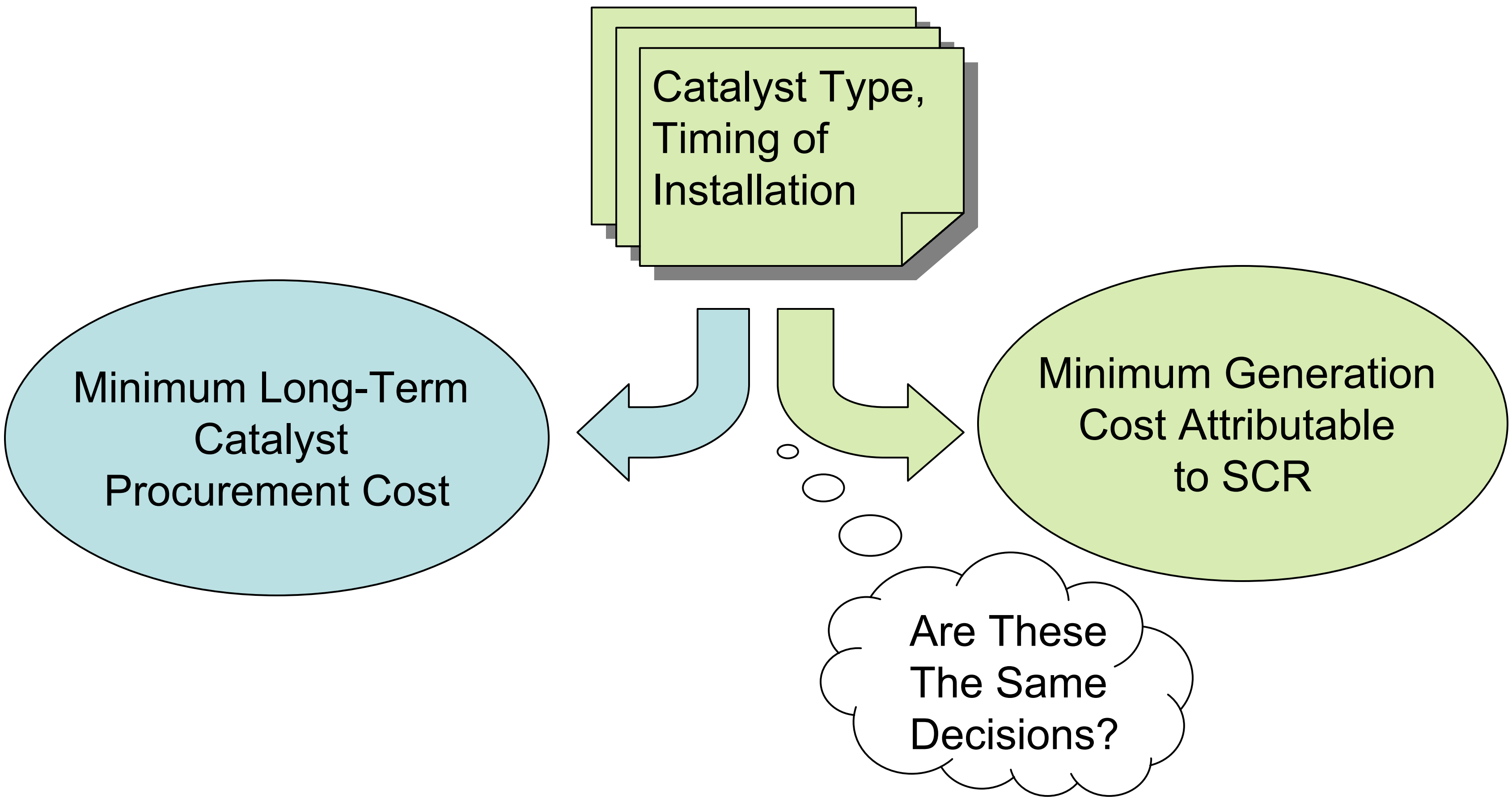
CATALYST MANAGEMENT DECISIONS



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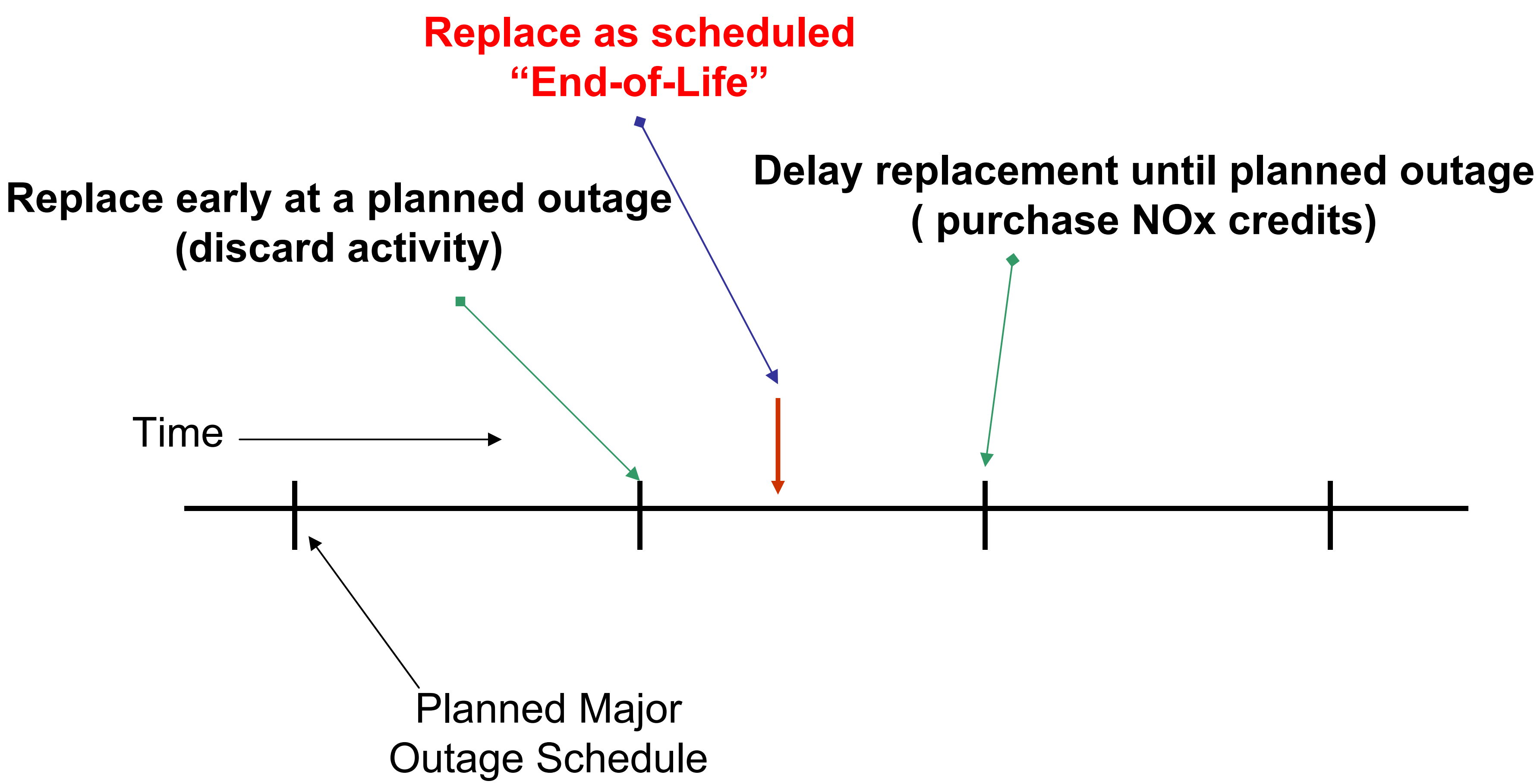
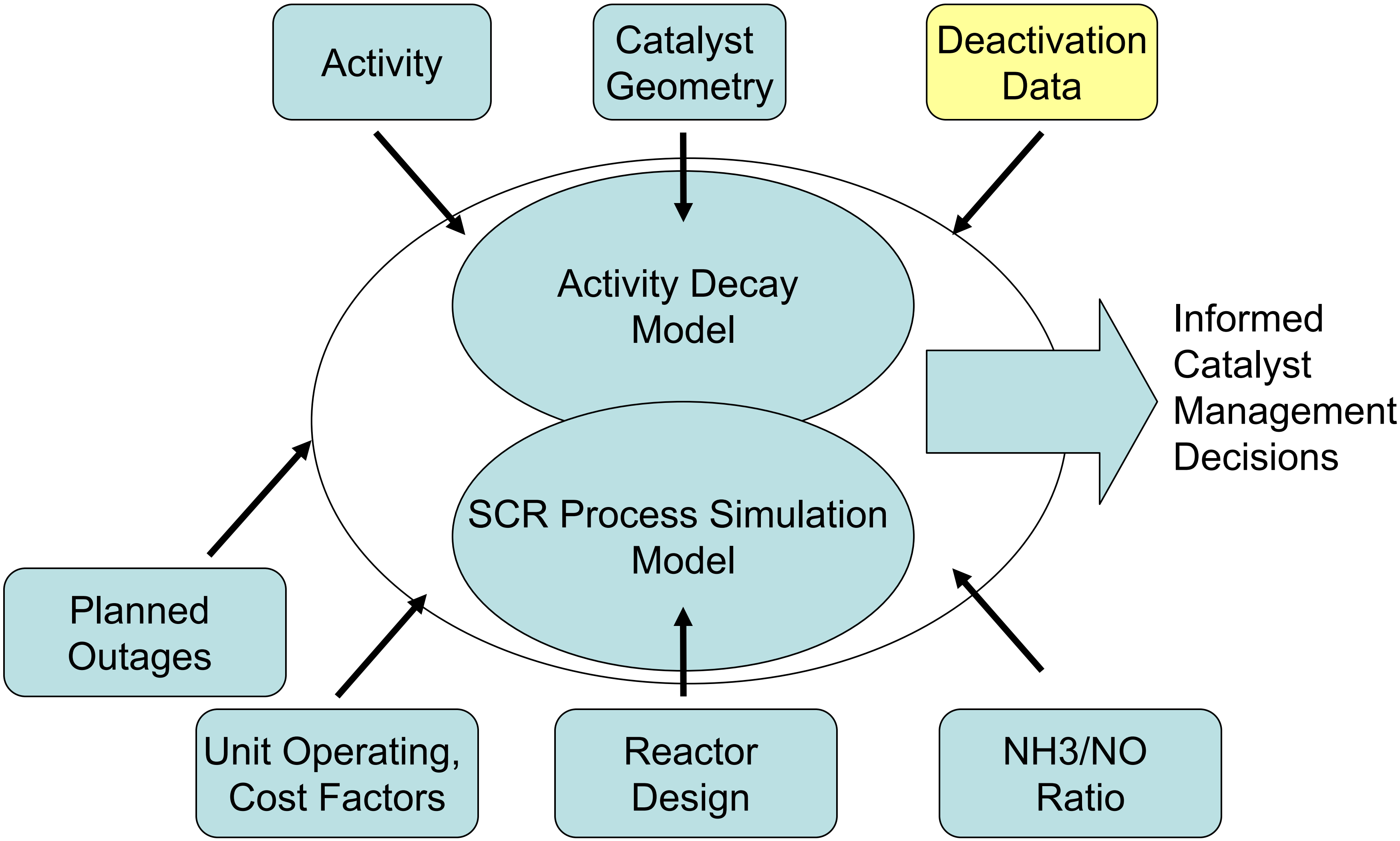
OBJECTIVE: ELIMINATE SPECIAL-PURPOSE OUTAGE FOR CATALYST



Comprehensive Catalyst Management Tools



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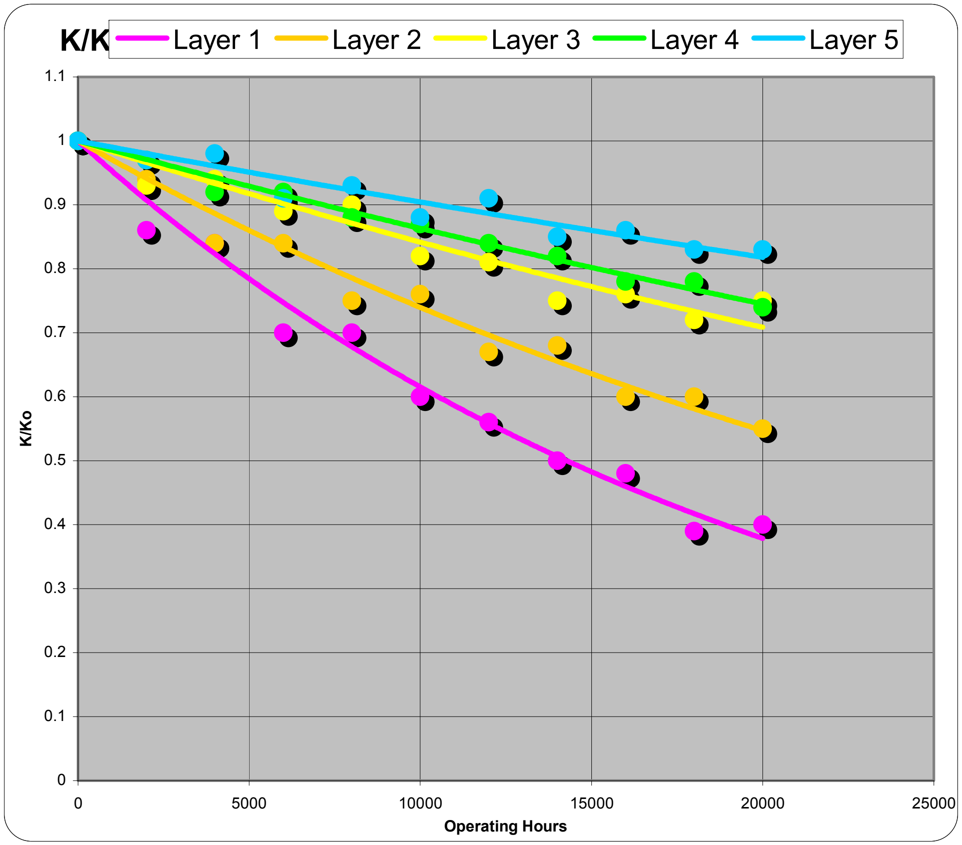
Deactivation Rates Key to Catalyst Management

Catalyst Management depends on accurately measuring catalyst deactivation for each layer



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Example: EPRI's CatReact

Case 1

- **Input Buttons**
- Unit Data
- SCR Data
- Catalyst Data
- Time Factors
- Economic Factors
- Planned Outages
- Capacity Factors
- Catalyst Deactivation
- Output Data
- Reset All Forms

CATREACT

Initiate Calculaton

Calculate

☐ *Check for Changes*

1	1+1	1+2
2	2+1	2+2
3	3+1	3+2
4	4+1	

Calculation Scenario

	Layer 1	*Layer 2*	*Layer 3*	*Layer 4*	*Layer 5*
Startup	1	1	1		
Event 1				1	
Event 2	1				
Event 3		1			
Event 4			1		
Event 5				1	
Event 6	1				
Event 7		1			
Event 8			1		
Event 9				1	
Event 10	1				
Event 11		1			
Event 12			1		
Event 13				1	
Event 14	1				
Event 15		1			
Event 16			1		
Event 17				1	
Event 18	1				
Event 19		1			
Event 20			1		

Note: Numbers signify Catalyst Type

NPV COST SUMMARY: END-OF-LIFE AND "SYNCHRONIZED" TO SCHEDULED OUTAGES

Summary Report	Ideal		Nearest	
As of Date	1/1/17		1/1/17	
Total Cost NPV	**$**	**36,083,516**	**$**	**29,953,064**
Catalyst NPV	$	8,085,640	$	9,539,199
Reagent NPV	$	19,354,327	$	19,725,846
Labor NPV	$	92,938	$	109,646
Electricity NPV	$	7,989,975	$	-
NOx Credit NPV	$	-	$	-
dP NPV	$	560,635	$	578,374
Catalyst Layers Installed	6		7	

Ideal: EOL Determines Replacement Schedule

Nearest: Replacement Schedule Synchronized to Planned Outages

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In Situ Determination of Catalyst Activity and Reactor Potential

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In Situ Measurement of Catalyst Deactivation – Why?

- For year-round operation there are limited opportunities for physical catalyst sampling and laboratory analysis
- Extended maintenance outage schedules further reduce the frequency of physical catalyst sampling opportunities
- The *in situ* technique allows the measurement of catalyst activity <u>any time</u> the SCR is in operation
- The *in situ* measurements supplement laboratory analysis by providing a larger and more complete set of deactivation data from which to base catalyst management decisions
- The *in situ* measurement technique is similar to the traditional laboratory analysis

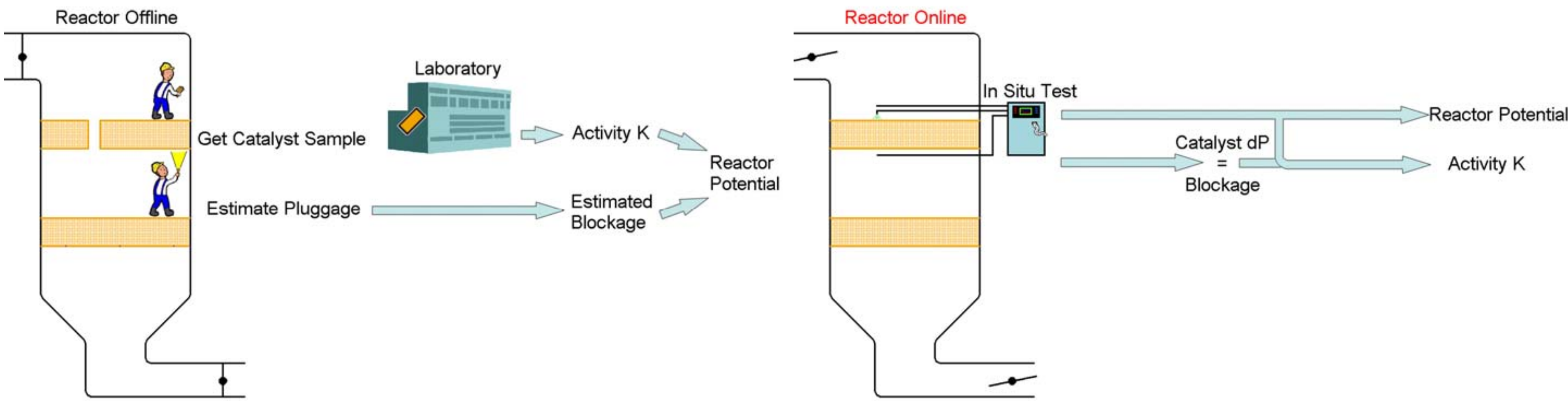
In Situ Measurement Technique*

Laboratory:

- **Test Conditions**:
  - A_{Vd} = Design Area Velocity
  - $NH_3/NO_x = 1$
- **Measure:**
  - ΔNO_x
- **Calculate:**
  - $K = -A_{Vd} \ln(1-\Delta NO_x)$
  - $RP = \frac{K}{A_{Vd}}(1-B)$

***In Situ*:**

- **Test Conditions**:
  - $A_{V,FS}$ = Full-Scale Area Velocity
  - $NH_3/NO_x > 1$
  - (NH_3 added only in test sections)
- **Measure:**
  - ΔNO_x
- **Calculate:**
  - $RP = K/A_{V,FS} = -\ln(1-\Delta NO_x)$



*** Patent Pending**

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Insitu vs Laboratory

- **By design, the in situ method measures the true Reactor Potential at any point in time**
  - **Based only on ΔNO_x measurement**
  - **Actual operating conditions of SCR system (i.e. at the real A_V conditions accounting for catalyst blockage)**
- **Laboratory analysis of K combined with an A_V adjustment to account for the blockage effects in the full-scale reactor, should result in a similar RP value**

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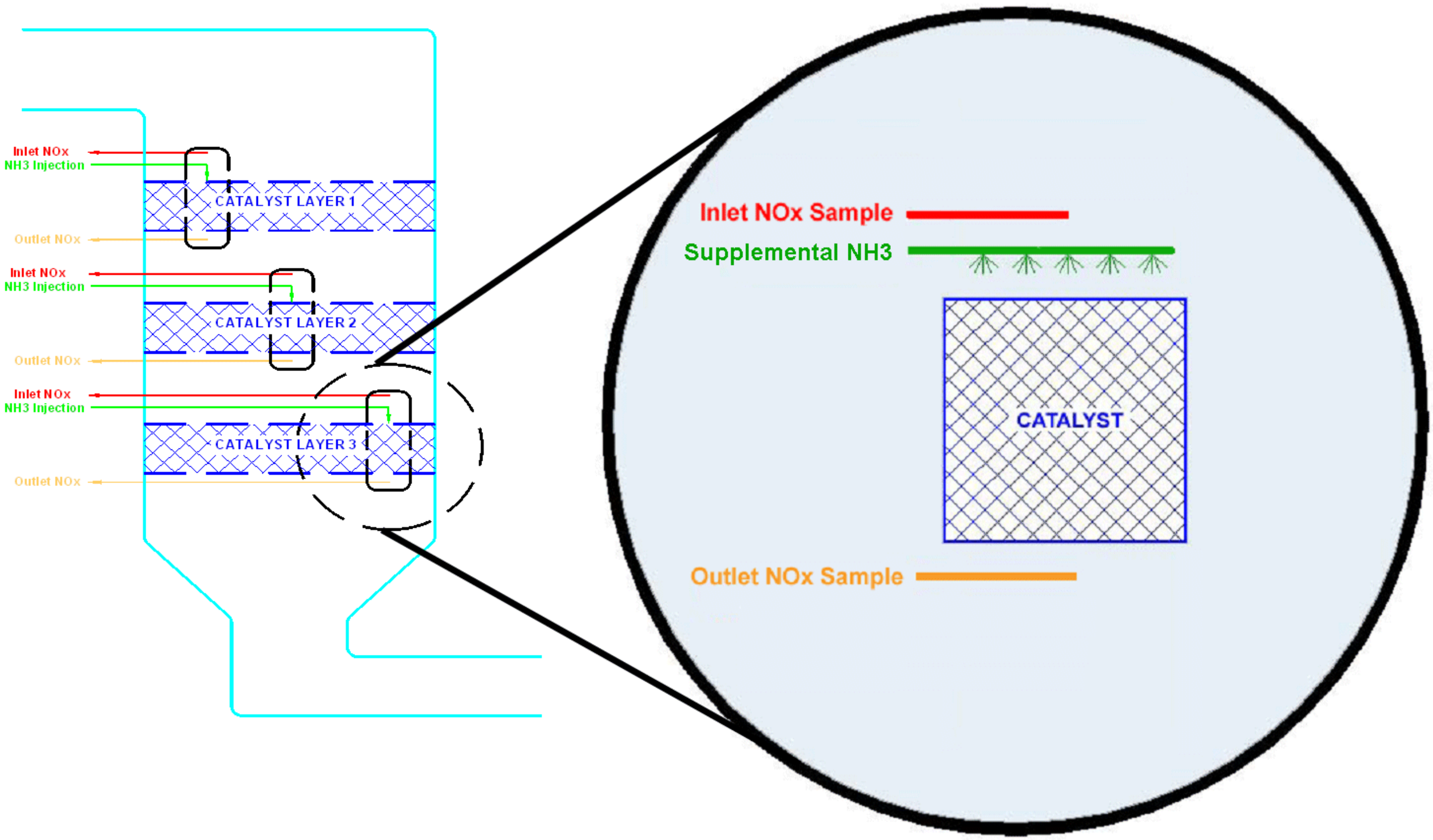
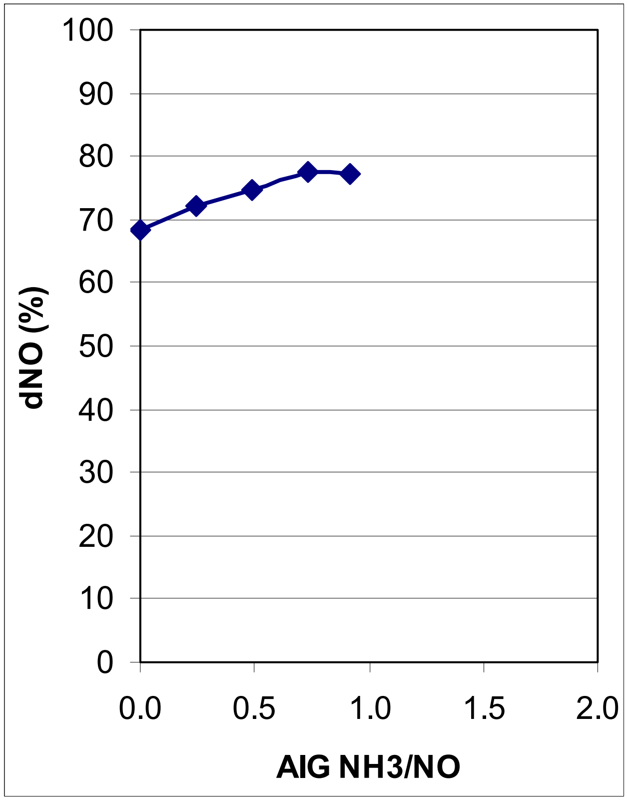
KnoxCheck™ *In Situ* Test Modules



*** Patent Pending**

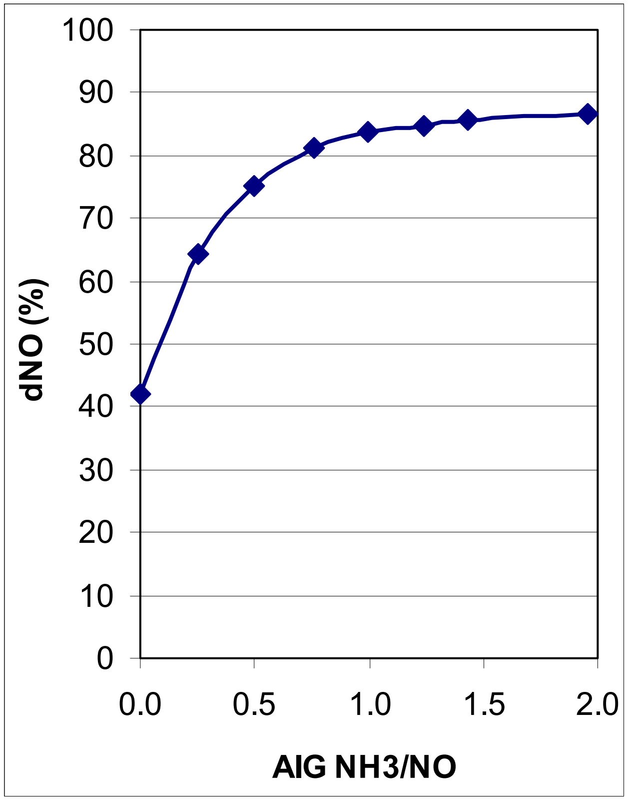
Typical KNOxCheck™ Test Results

Catalyst Layer 1



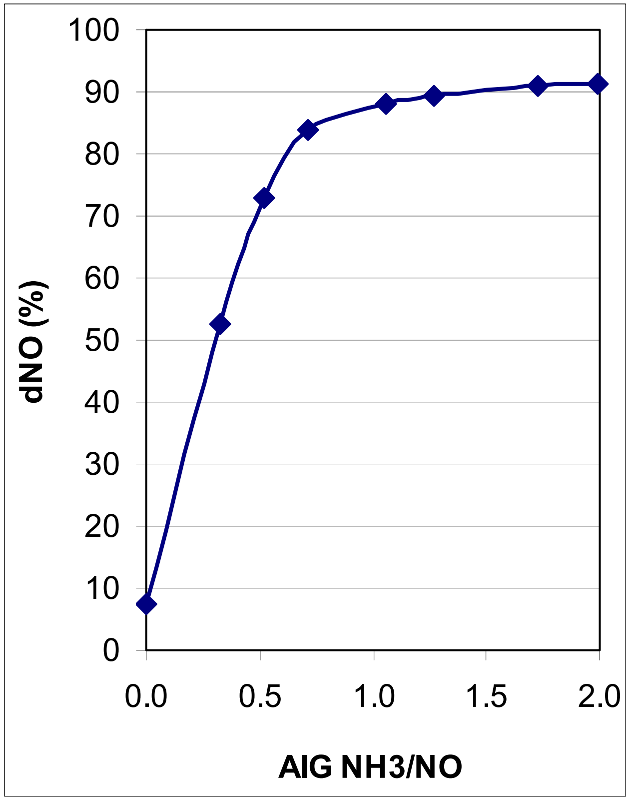
- dNO maximum = 77.3%

Catalyst Layer 2



- dNO maximum = 86.6%

Catalyst Layer 3



- dNO maximum = 91.3%

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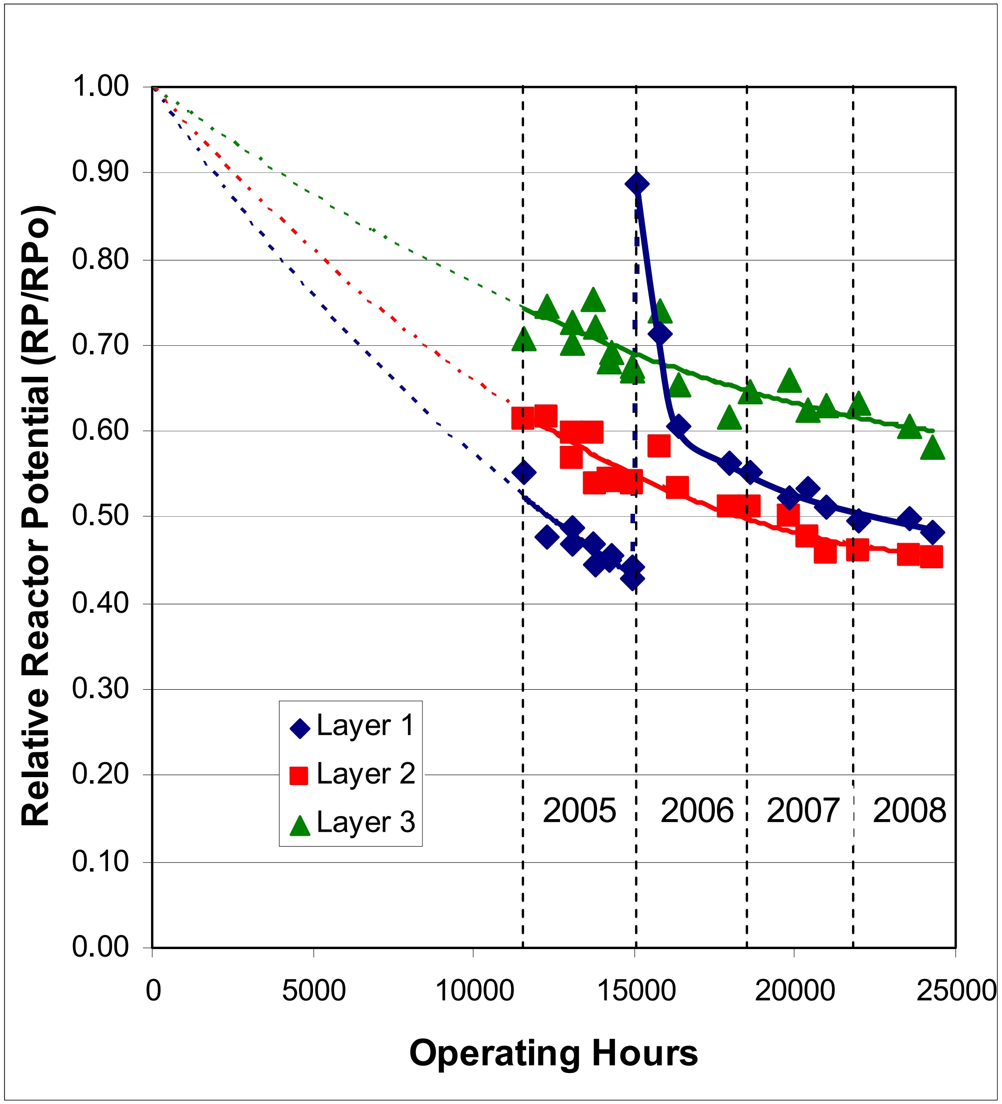
In Situ KnoxCheck™ Measurements: Individual Layers



- **4-years of operation beginning in 2005**
  - **700 MW unit**
  - **E. bituminous coal**
- **SCR on-line May 2002**
  - **Seasonal operation**
  - **Two reactors**
  - **3 + 1 configuration**
  - **Initial load: 3 layers honeycomb catalyst**
  - **Layer 1 replaced with plate catalyst prior to 2006 ozone season**

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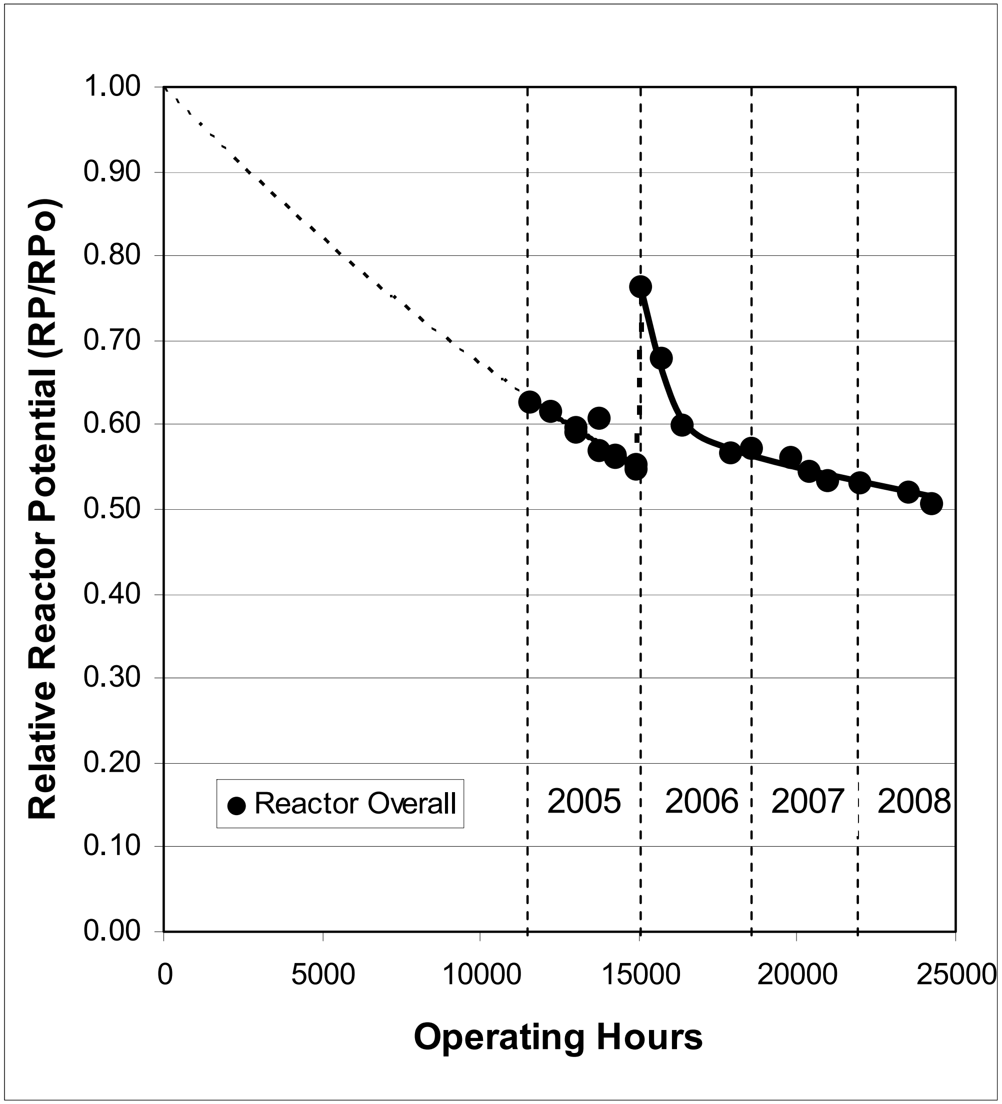
In Situ KnoxCheck™ Measurements: Reactor Overall



- **4 to 6-week test interval**
- **Nominally 20 data points over four ozone seasons**
- **Equivalent to nominally "2 years" of annual SCR operation**

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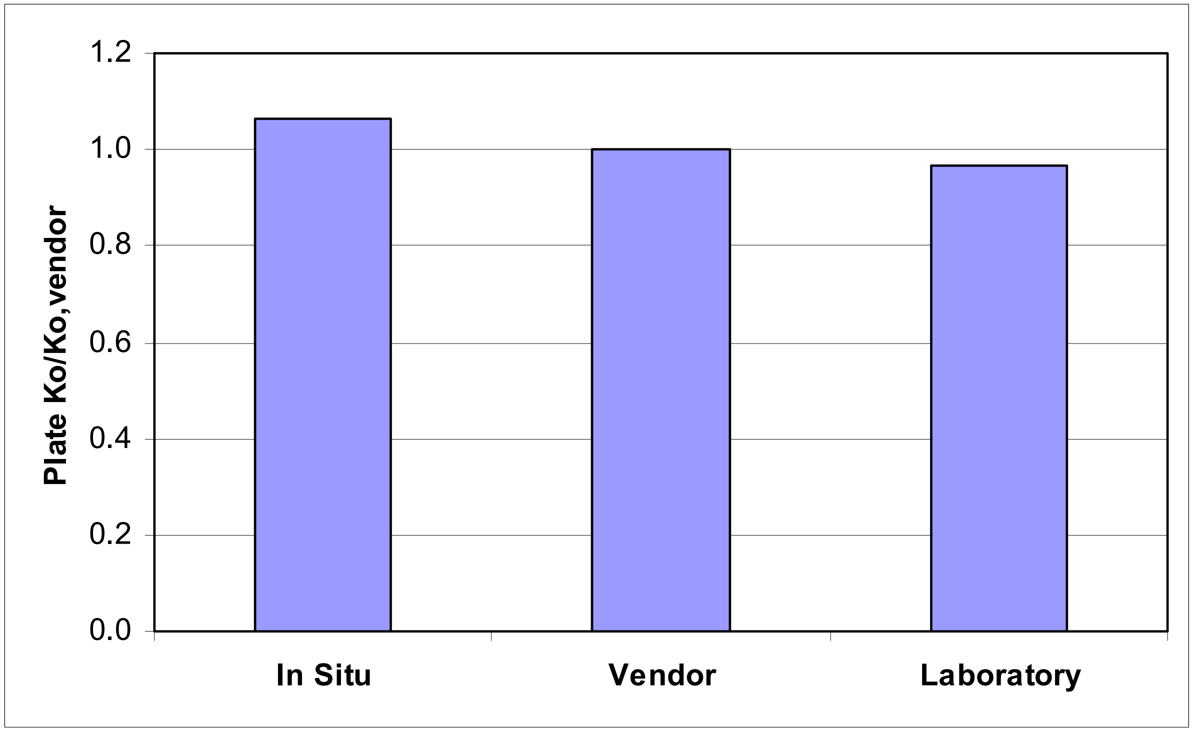
Insitu vs Laboratory Activity

Insitu Activity was **measured upon start up of the new layer of plate catalyst and compared to the Vendor value and a 3rd Party Laboratory measurement**



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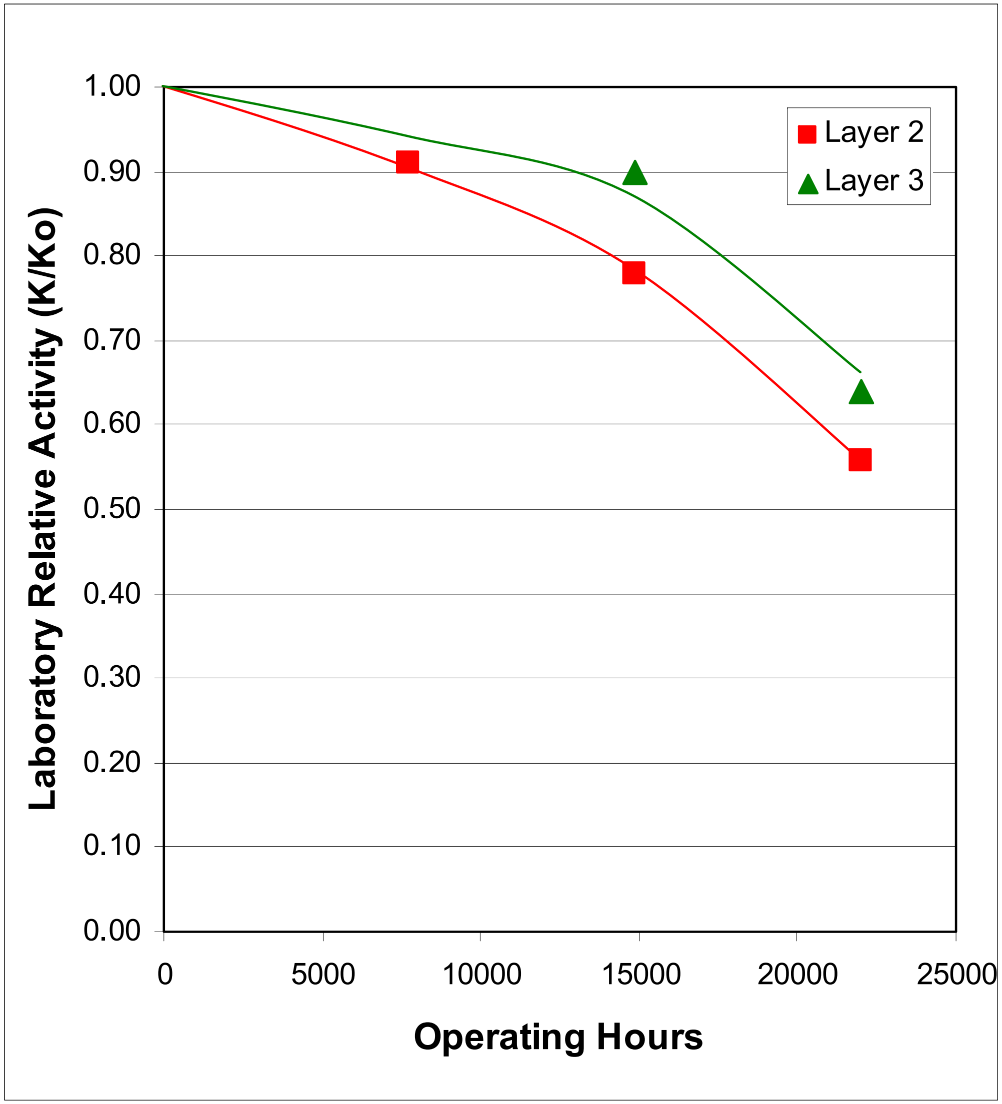
"Annual" Laboratory Activity Results: Layers 1 & 2



- For seasonal operation, data every 5 months
- For year-round operation, one sample per year?
- Nominal sample interval of 8000 hours?
- Only 3 data points per layer over approximately 24,000 operating hours

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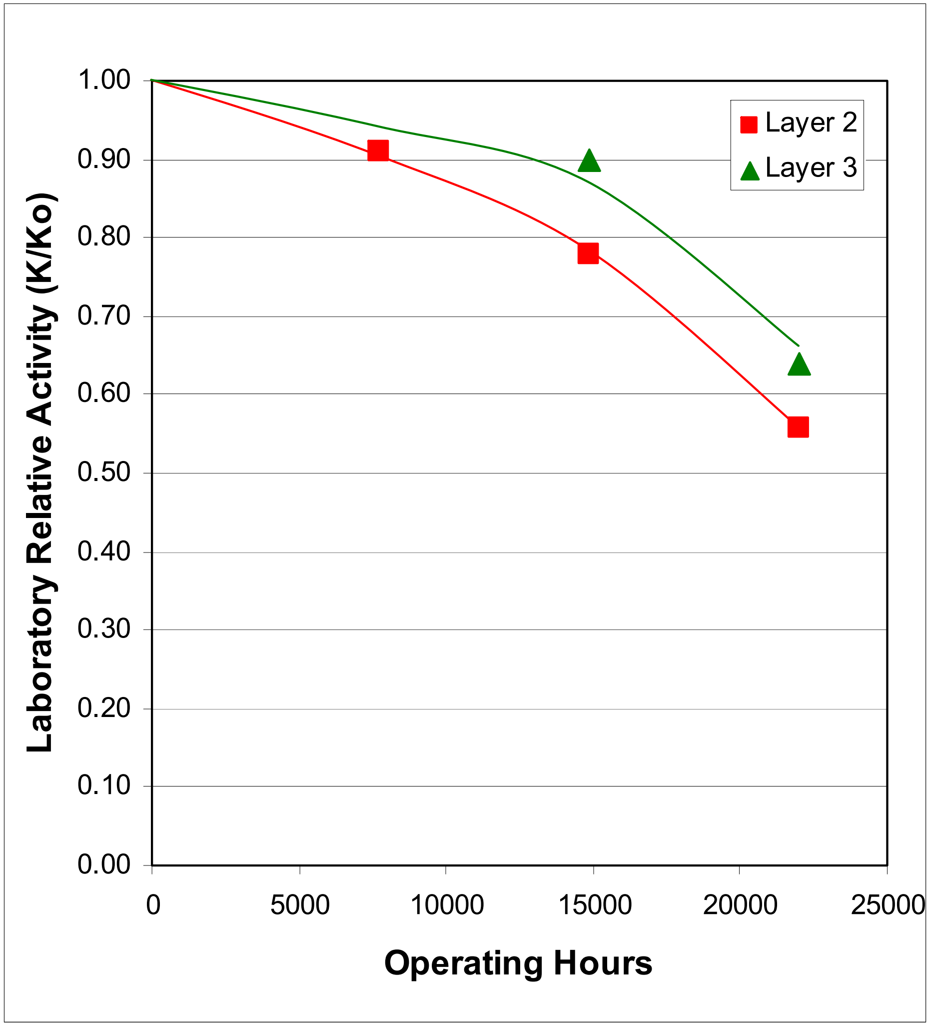
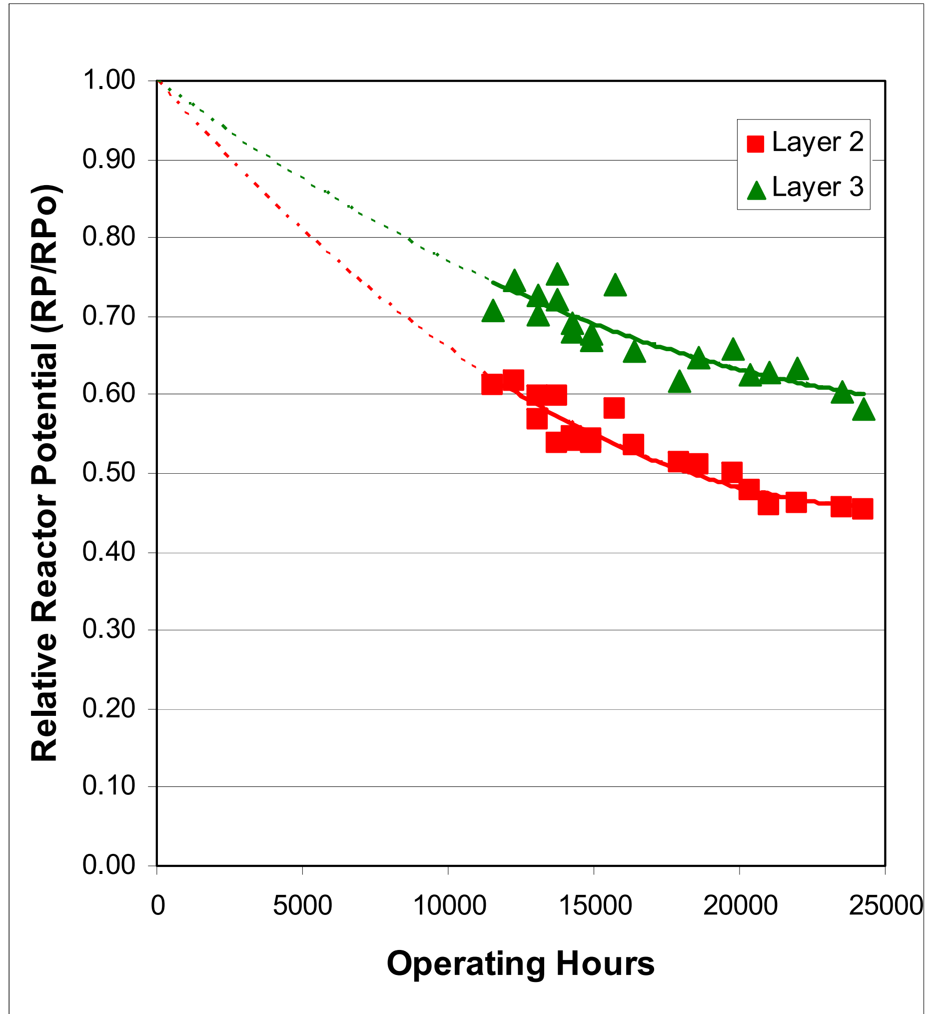
Volume of Data: Laboratory vs. *In Situ*

Annual Laboratory Analysis



On-Demand KnoxCheck™ Measurements



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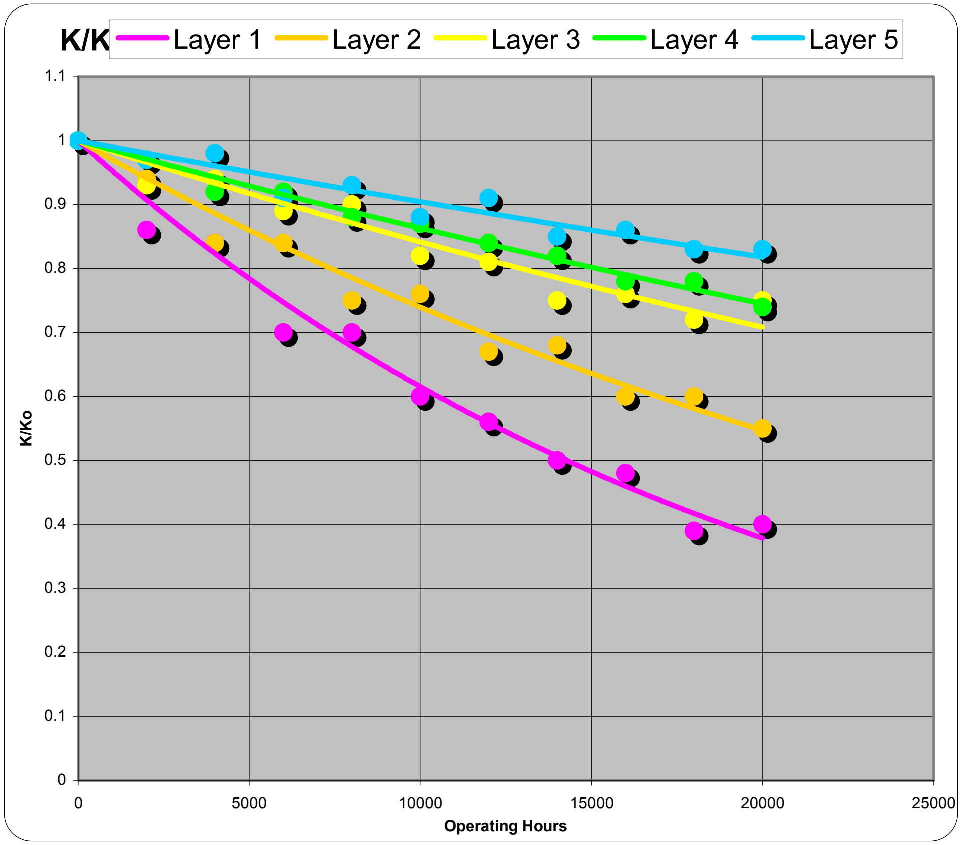
Importance of Frequent Catalyst Activity Measurements

Catalyst Management depends on accurately determining the Activity History of each layer



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Low Load Operation

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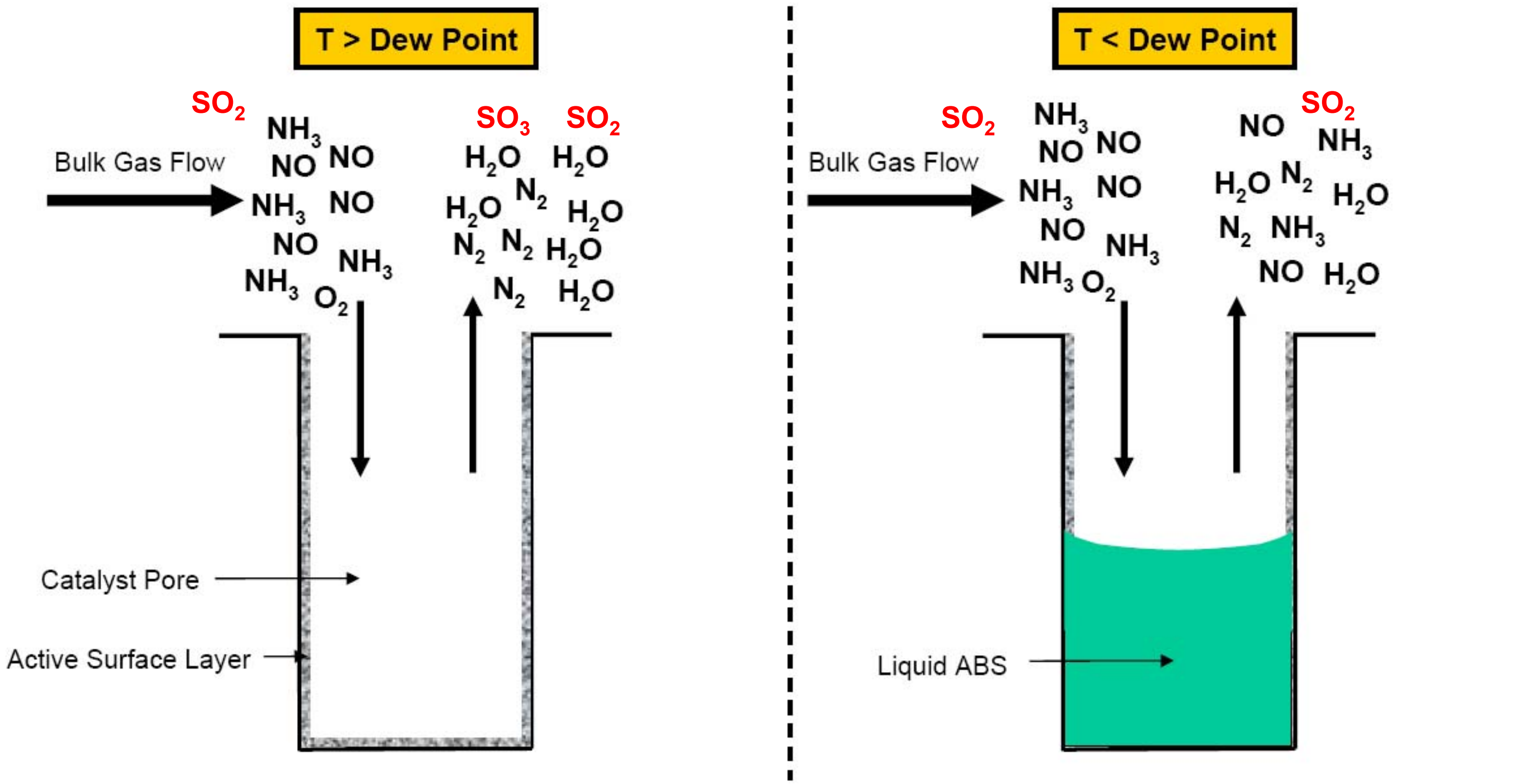
Additional Benefit: Low-Load SCR Operation

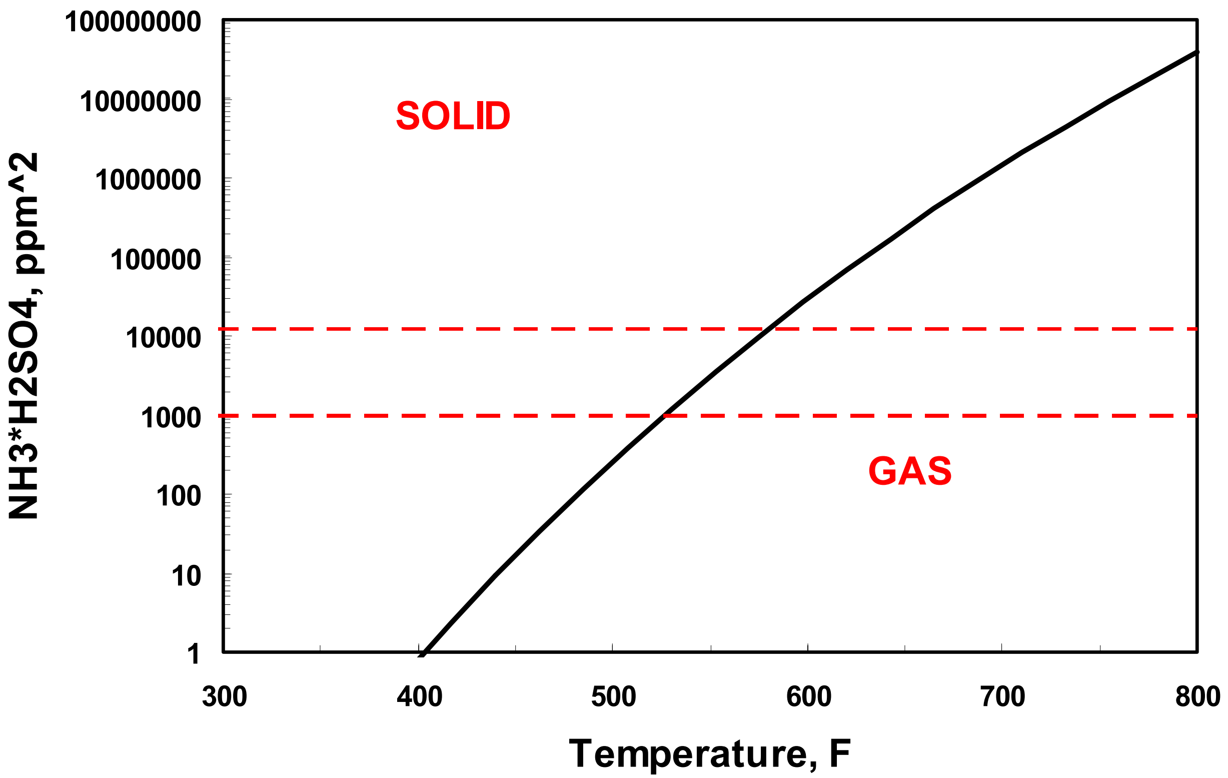
- **At temperatures below Minimum Operating Temperature (MOT) recommended by the catalyst vendor:**
  - **ABS formation**
  - **Loss of catalyst surface area**
  - **Reduction in catalyst activity**
- **At full-load operating conditions, ABS will sublime, leading to a restoration of catalyst activity**
- **The extent of catalyst activity recovery will be a function of temperature and cycle duration**
- ***In Situ* measurement technique can be used for real-time tracking of catalyst activity reduction and restoration**

ABS Plugging at Low Load Operation

$[NH_3(g) + SO_3(g) + H_2O(g) \leftrightarrow NH_4HSO_4(l)]$



ABS Formation Temperature



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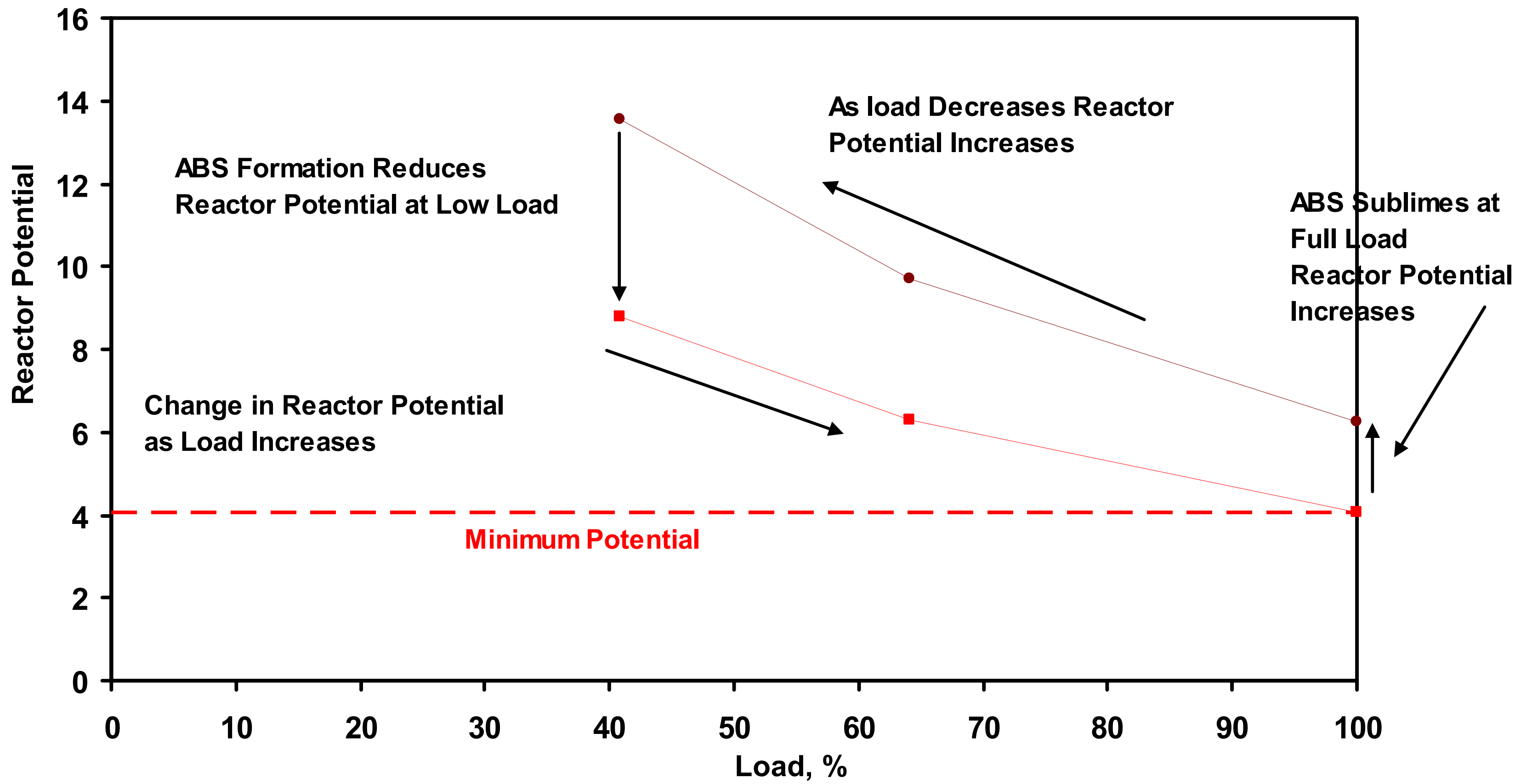
ABS Accumulation Decreases Reactor Potential



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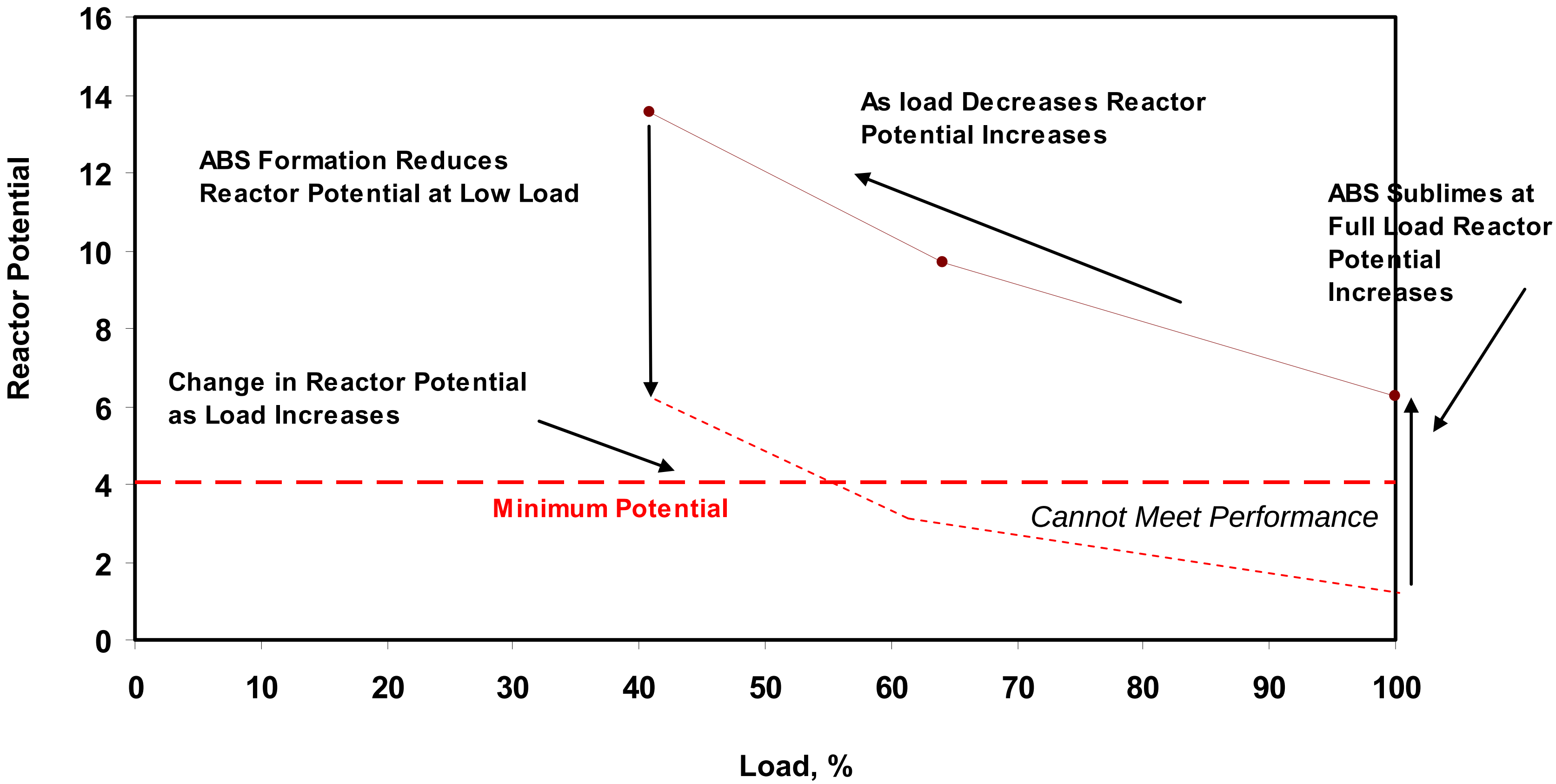
ABS Accumulation Decreases Reactor Potential



Recovery at Full Load

- **Catalyst Activity Recovery: a Function of Temperature and Cycle duration**
- **ABS Sublimation: Potential for Increased SO_3 and Residual NH_3 Emissions**
  - **Minimize Residual NH_3 by Reducing Reagent Injection Rate, and NH_3 / SO_3 By Temperature Ramp Rate**
  - **SO_3 Appears To Condense In Air Heater Minimizing SO_3 Spike**
  - **Control Residual NH_3 to Avoid Fouling**
- **Insitu Activity Measurement can document Recovery**

Summary

Summary

- The *in situ* technique directly measures the true reactor potential of the SCR system. The reactor potential is the parameter that determines the overall performance of the SCR reactor. With the laboratory catalyst activity measurement, an estimate of the catalyst blockage and Area Velocity is needed to determine reactor potential.

- *In Situ* measurements can be made on a layer-by-layer basis within the reactor anytime the SCR system is in operation. This provides a much larger data set upon which to quantify deactivation rates compared to once-a-year physical sampling.

- There was good quantitative agreement between the *in situ* and laboratory catalyst activity measurements of a new layer of plate catalyst installed at the start of the 2006 ozone season.

- The In Situ measurement technique can be used for real-time tracking of Reactor potential reduction and restoration during low-load operation

Comparison of Measurement Techniques

Laboratory	*In Situ* KnoxCheck™
<u>Benefits</u> • Accurate K determination • Physical sample can be analyzed for physical and chemical properties	**<u>Benefits</u>** • Larger data set (trend) • Can test immediately after unit "upset" (e.g., coal change, tube leak, etc.) • Direct measurement of RP
<u>Limitation</u> • Limited data set, especially for year-round operation	**<u>Limitation</u>** • Does not provide physical and chemical property analyses

The *in situ* technique should not be thought of as a replacement for laboratory analysis of catalyst samples, but as a companion measurement

Cost Benefit Analysis

Example:
- 500 MW
- 0.31 lb/MMBtu Inlet NOx
- 90% NOx Reduction
- Annual Operation

Scenario 1:Activity decrease requires NOx reduction be reduced to 85% for 5 months until a planned outage is reached. The 5% is made up by purchasing NOx Credits

Credit Cost ($/ton)	Cost($)
1500	$186,000
2000	$248,000
2500	$310,000

Scenario 2: APH plugging requires a weekend outage for washing

Electric Sales Price ($/MW-hr)	Lost Revenue ($)
$ 70	$1,680,000
$ 100	$ 2,400,000

KNOxCheck™: Retail Price of a Commercial System is $175,000-200,000

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Questions?

Knox✓ *Online Catalyst Activity Test System*

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