McIlvaine "Hot Topic Hour"
June 30, 2011

Fuel Impacts on Design and Performance of SCR Catalysts

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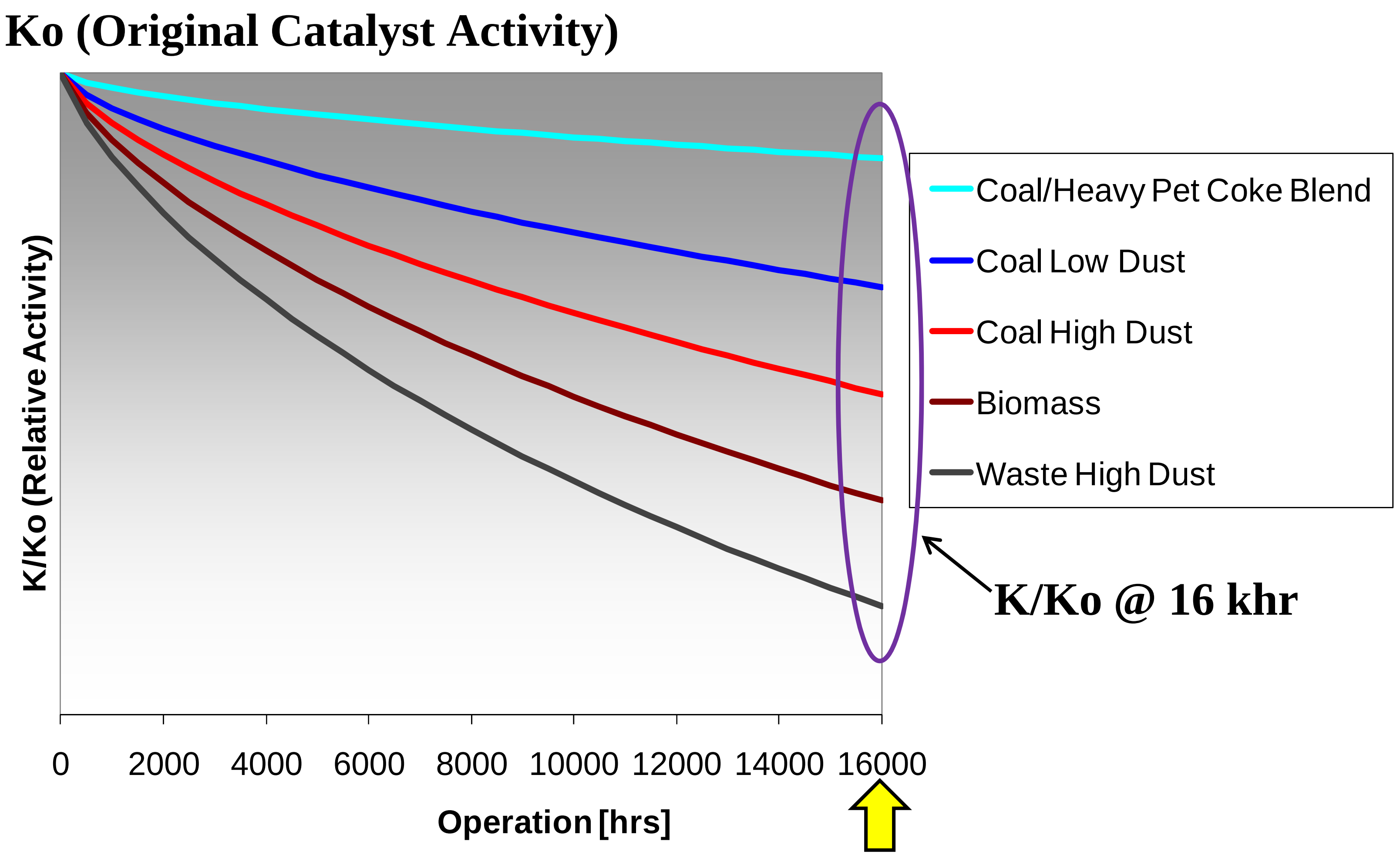
Catalyst Deactivates With Time of Exposure to Flue Gas



K/Ko @ 16 khr

Catalyst Design (at hour=0) Must Anticipate Deactivation to End of Guarantee Period (e.g., 16,000 hours) to Size Catalyst Properly

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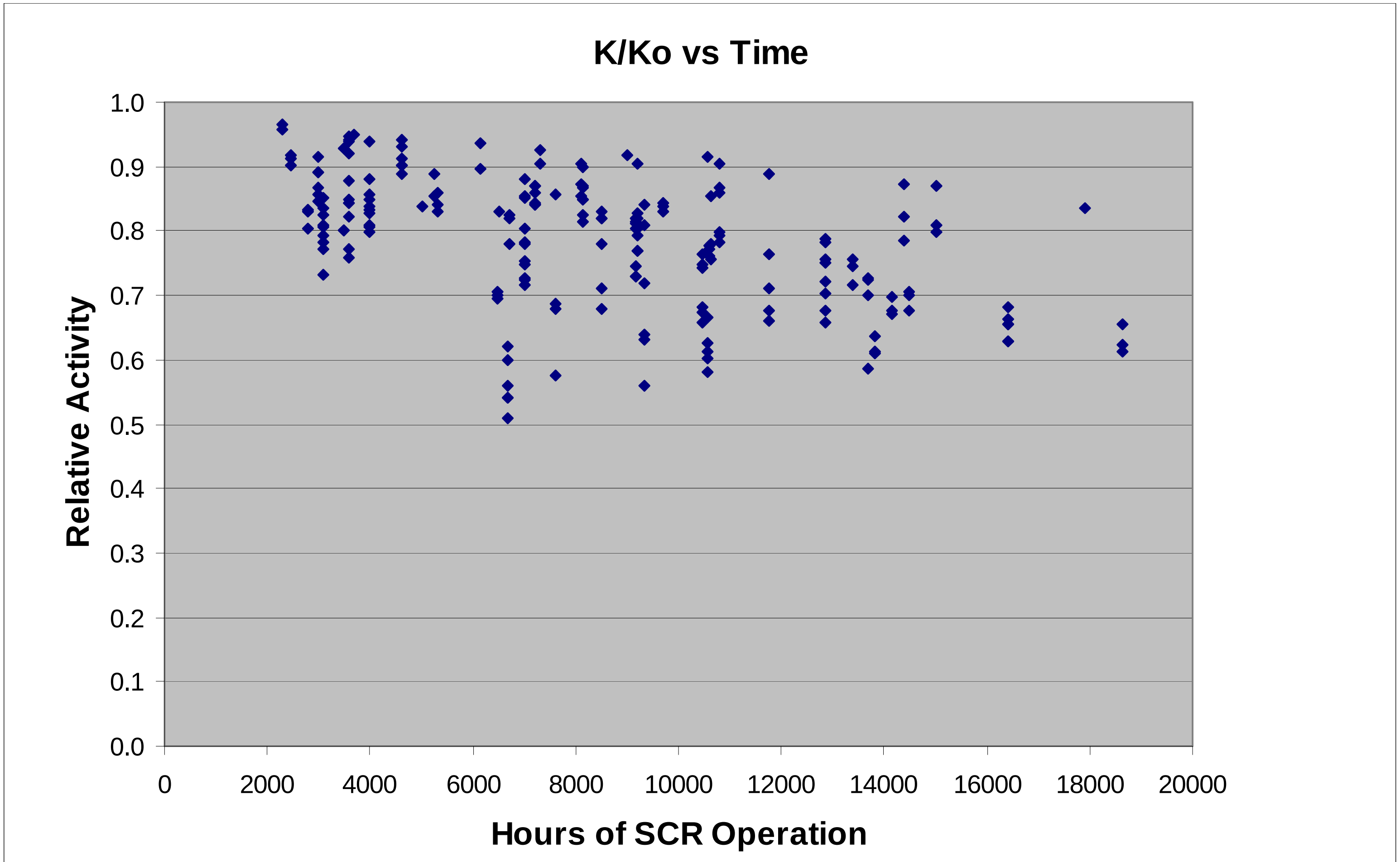
Catalyst Deactivation is Very Site Specific



Varying Based on Fuel Quality and Operations

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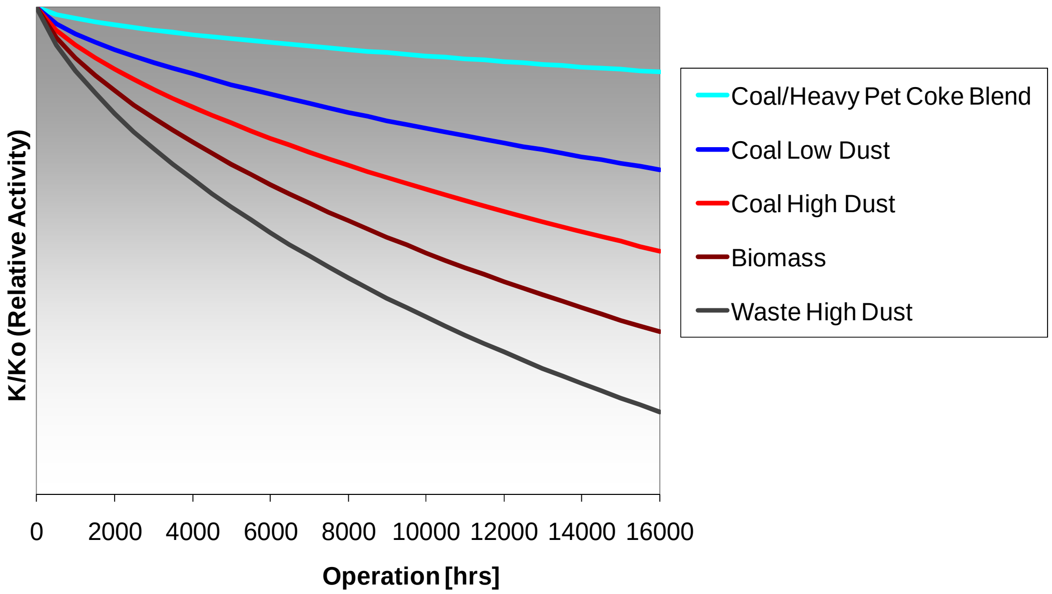
Catalyst Deactivation Mechanisms

- Gaseous Poisons:
  - Arsenic
  - Phosphorus
  - Potassium
  - Sodium
  - Cadmium
  - Lead
  - Copper
  - Other Elements



- Fouling by Solid Compounds
  - Gypsum (Calcium Sulfate) and Other Solid Compound Deposition
  - Ammonium Bisulfate (Avoided by Keeping Above Permissive Temperatures)
- Occurs During…
  - Normal SCR Operation
  - Startups and Shutdowns as Unit Goes Through Acid Dew Point

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Catalyst Deactivation

- Vanadium-Titania Based Catalyst Deactivates Based on Site Specifics
  - Fuel Quality – Arsenic, Phosphorus, Potassium, Sodium, Sulfur, Calcium, etc.
  - Combustion Quality – Increased Substoichiometric Staging Increases Quantity of Gaseous Poisons
  - # of Startups and Shutdowns
- Vanadium-Titania Based Catalyst Deactivates Independent of...
  - Catalyst Type – Plate, Honeycomb, Corrugated Fiber
  - Formulation – Different Activities and SO2:3 Conversion Rates
  - Reference Also "Comparison of Deactivation Rates of Different Catalyst Types" by Ed Healy, Southern Company and Hans Hartenstein, Evonik (now Steag) Presented February 9, 2009

http://www.reinholdenvironmental.com/public/47bc6d6a7e8f479388a20d66579738f8/Hans%20Hartenstein%20presentation%20Deactivation%202009.pdf

- Deactivation Resistance Comes From Providing Adequate Reactor Potential (RP=K/Av) – There Are No Magic Potions

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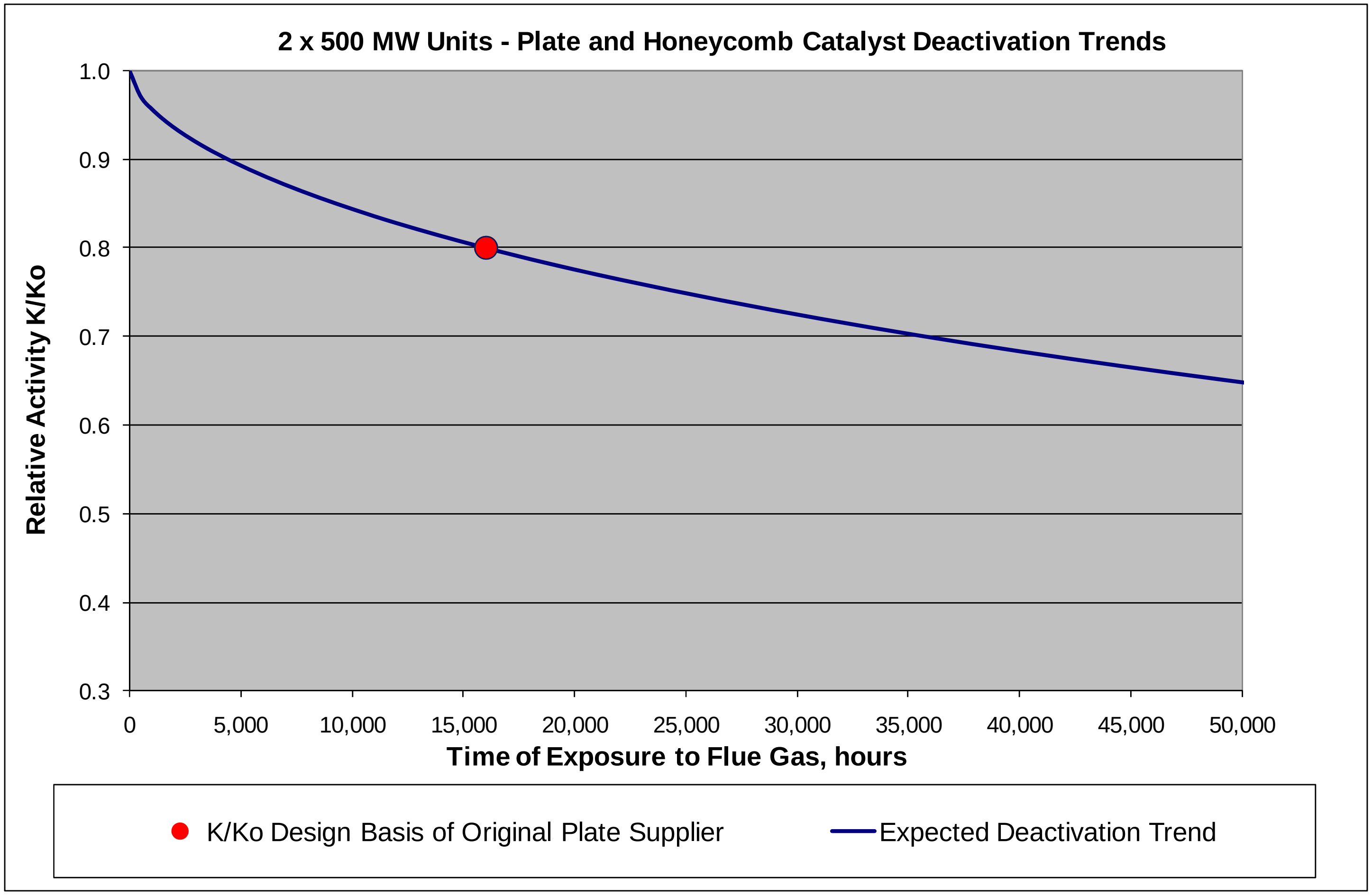
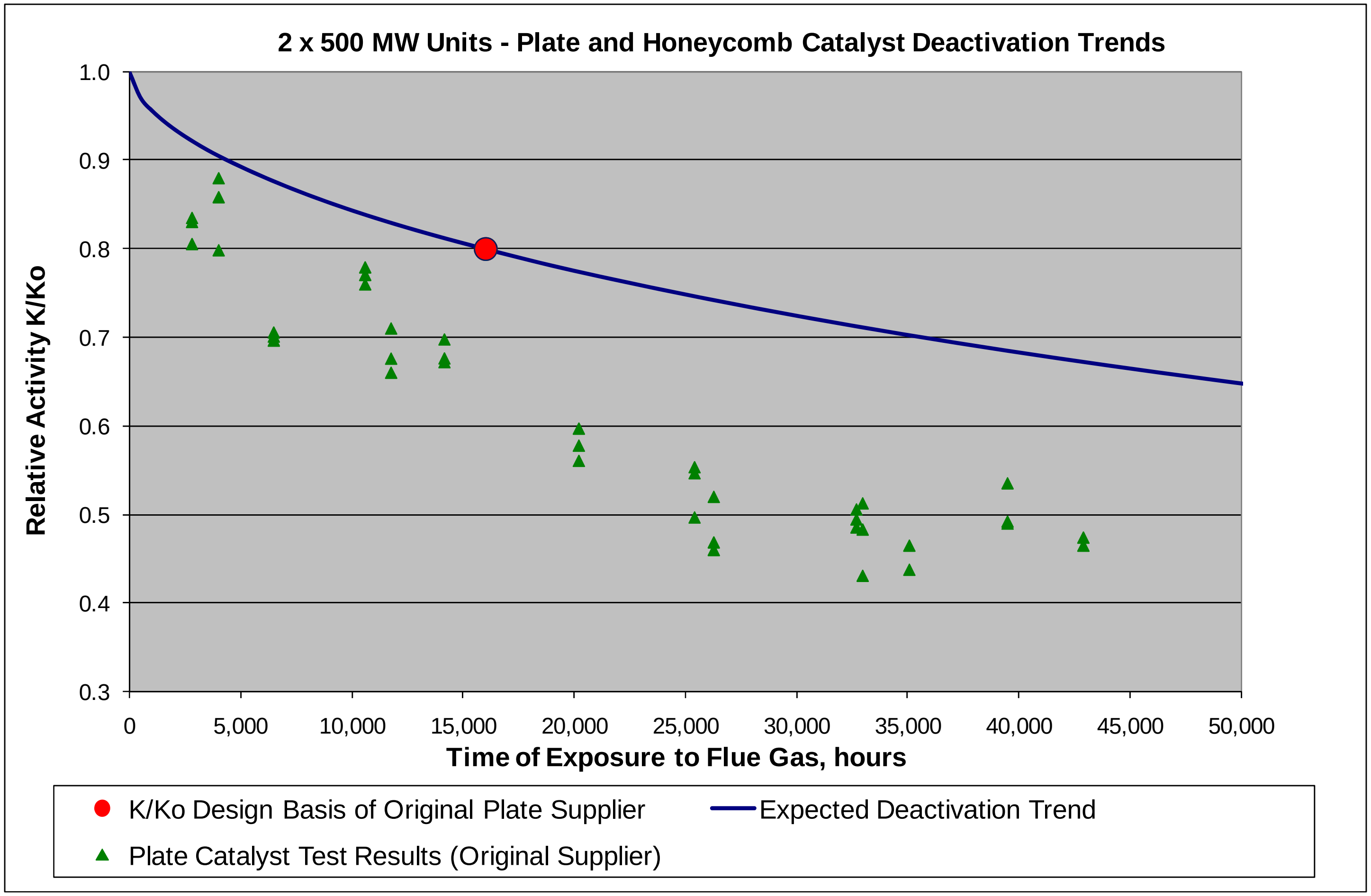
Case Example 1: Two x 500 MW Unit PRB Deactivation Rate History



- Original Supplier’s (Plate by Others) Estimate of Deactivation Rate
- Used as Basis for Catalyst Design

Case Example 1: Two x 500 MW Unit PRB Deactivation Rate History



- Deactivation Rate Assumed by Original Plate Catalyst Supplier Proven to be Overly Optimistic

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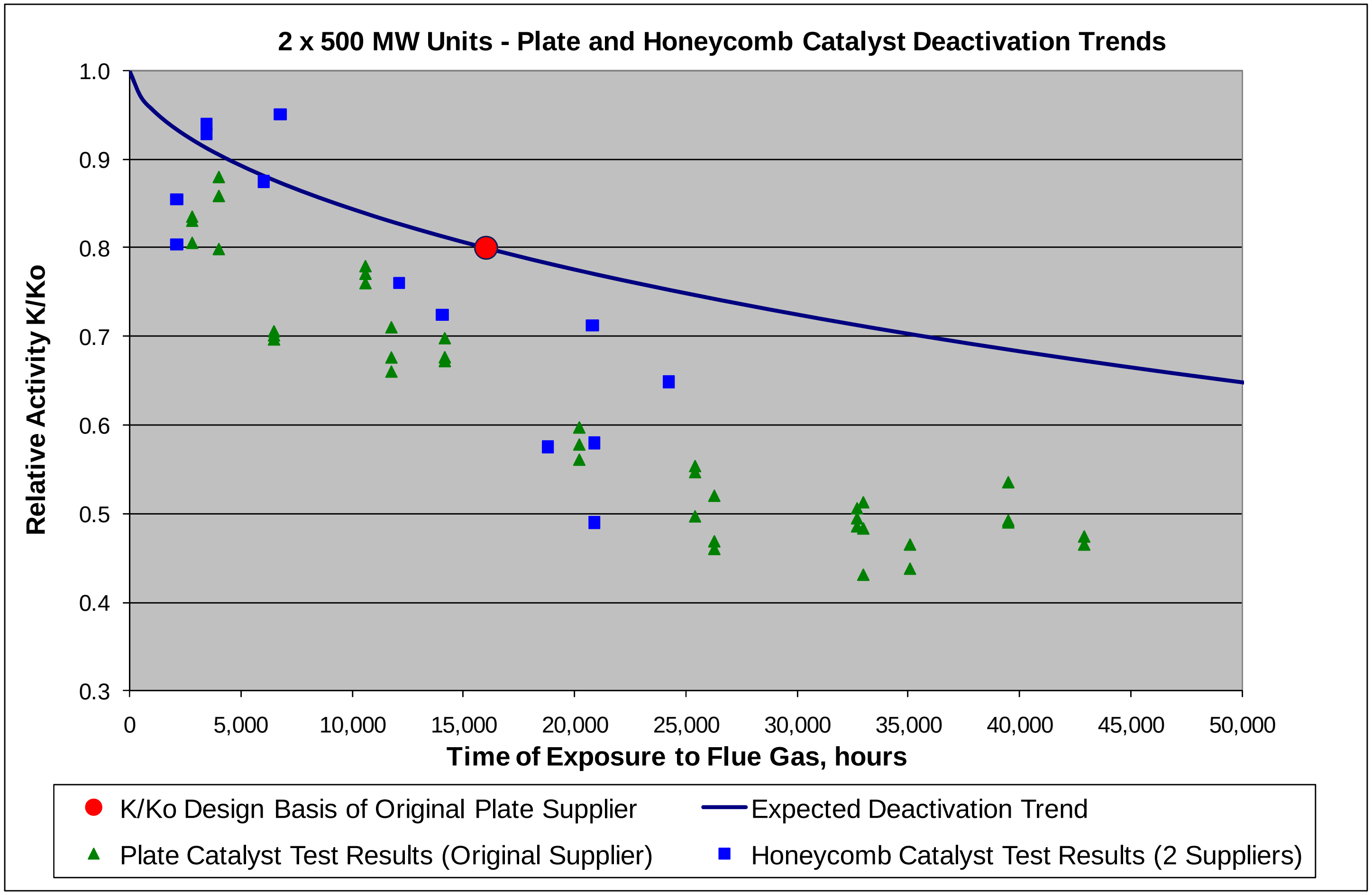
Case Example 1: Two x 500 MW Unit PRB Deactivation Rate History



- Deactivation Rate Assumed by Original Plate Catalyst Supplier Proven to be Overly Optimistic
- Subsequent Replacements With Honeycomb Catalyst From 2 Different Suppliers Confirms Both Types Deactivate Based on The Same Trend

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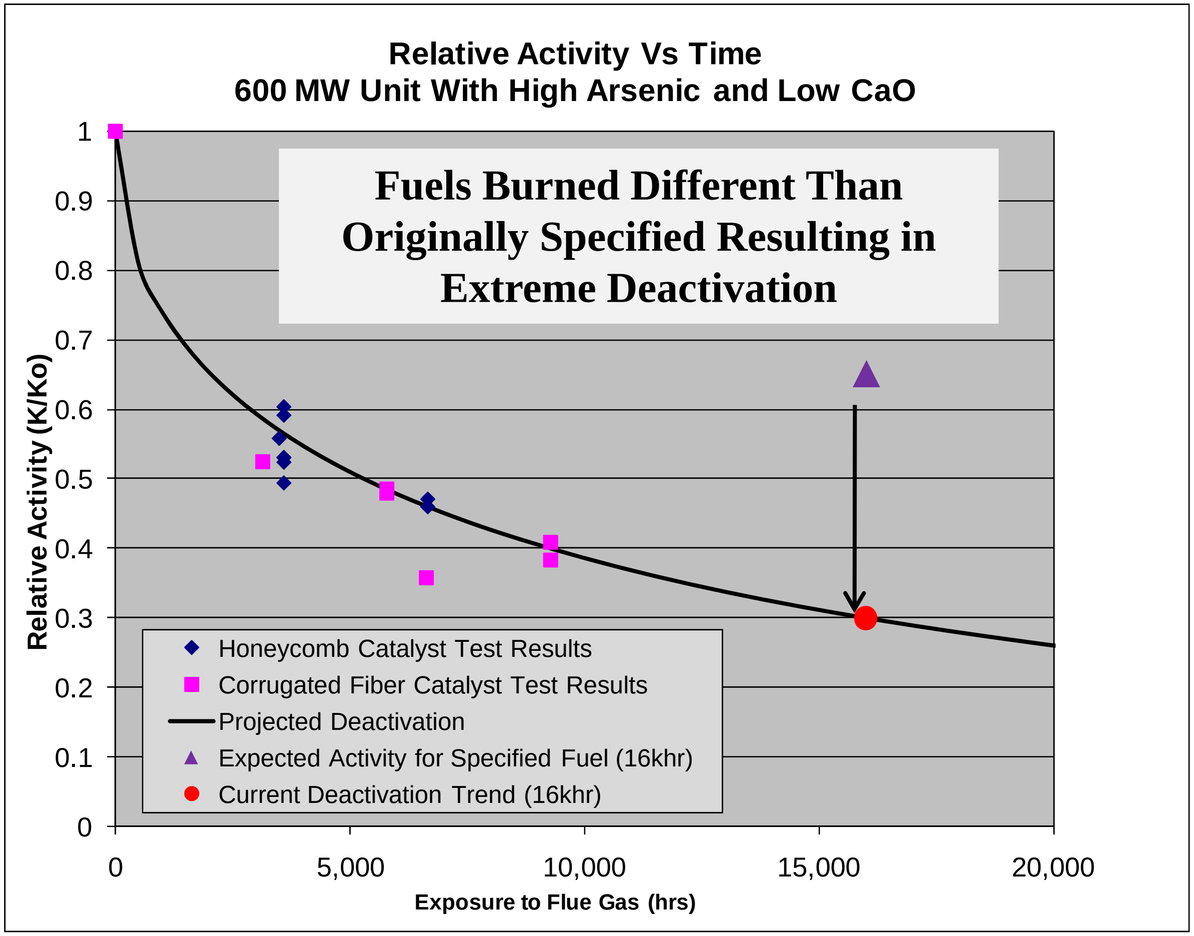
Case Example 2: 600 MW Unit Burning Eastern Bituminous High Arsenic/Low Calcium Coal



- Original Deactivation Rate Underestimated Based on Change in Fuel Specification
- Catalyst Test Results For Honeycomb and Corrugated Fiber Catalyst Confirms Both Types Deactivate Based on The Same Trend

Why is Estimating Catalyst Deactivation So Important

- If Deactivation is Underestimated
  - Catalyst is Undersized
  - Incapable of Meeting NOx Removal and Ammonia Slip Performance at Some Point During the Guarantee Period
  - Deficient Performance is Either Tolerated or an Early Outage (Unscheduled) is Required for Catalyst Addition
  - Catalyst Management Costs are Underestimated
- Understanding and Managing Reactor Potential Critical to Minimize Risk
- Examples Help to Illustrate Risk

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Reactor Potential

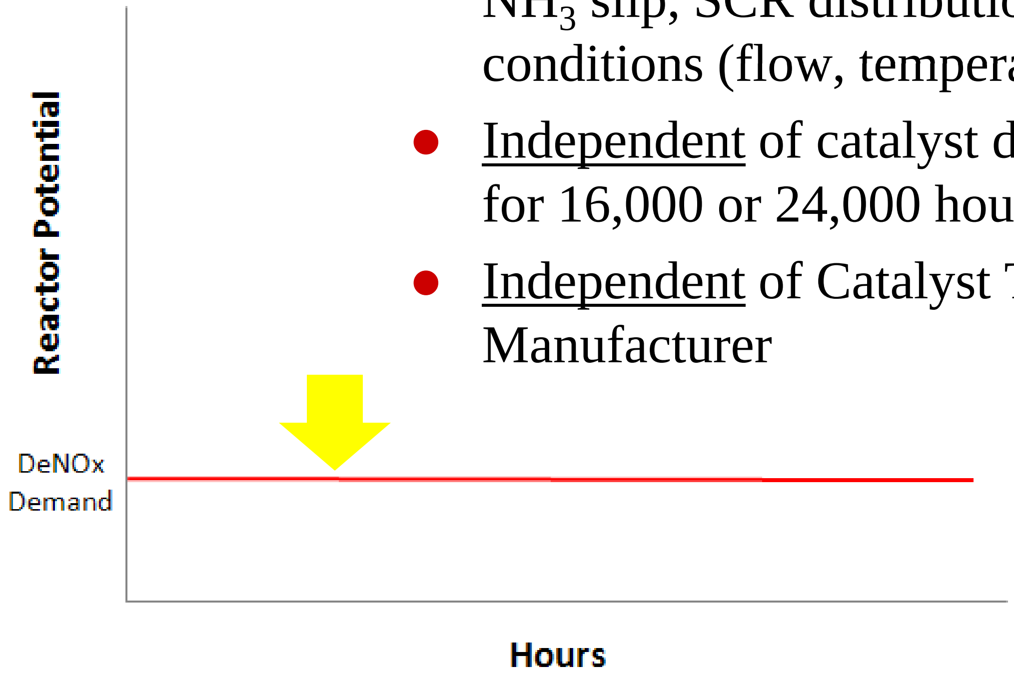
$$P = K/AV$$

K = catalyst activity, Nm^3/m^2h or Nm/h

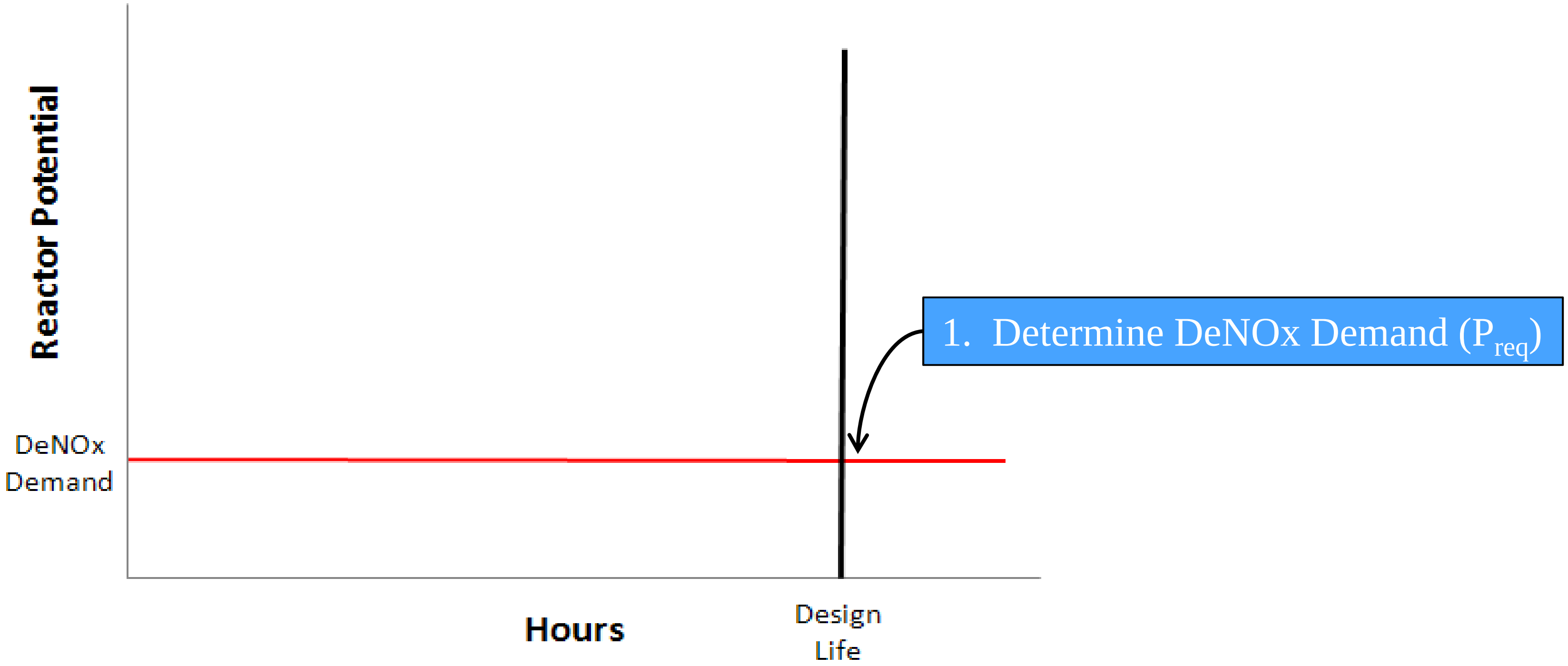
AV = catalyst area velocity, Nm/h (normalized operating gas flow, Nm^3/h divided by total installed catalyst surface area, m^2)

DeNOx Demand Reactor Potential

- DeNOx Demand = The reactor potential required to meet NOx removal and ammonia slip requirements at the specified operating conditions
- *Calculated* based on NO_X removal requirements, NH_3 slip, SCR distributions, and boiler operating conditions (flow, temperature, pressure, etc.)
- Independent of catalyst design life (i.e. same value for 16,000 or 24,000 hour catalyst life)
- Independent of Catalyst Type, Formulation, or Manufacturer



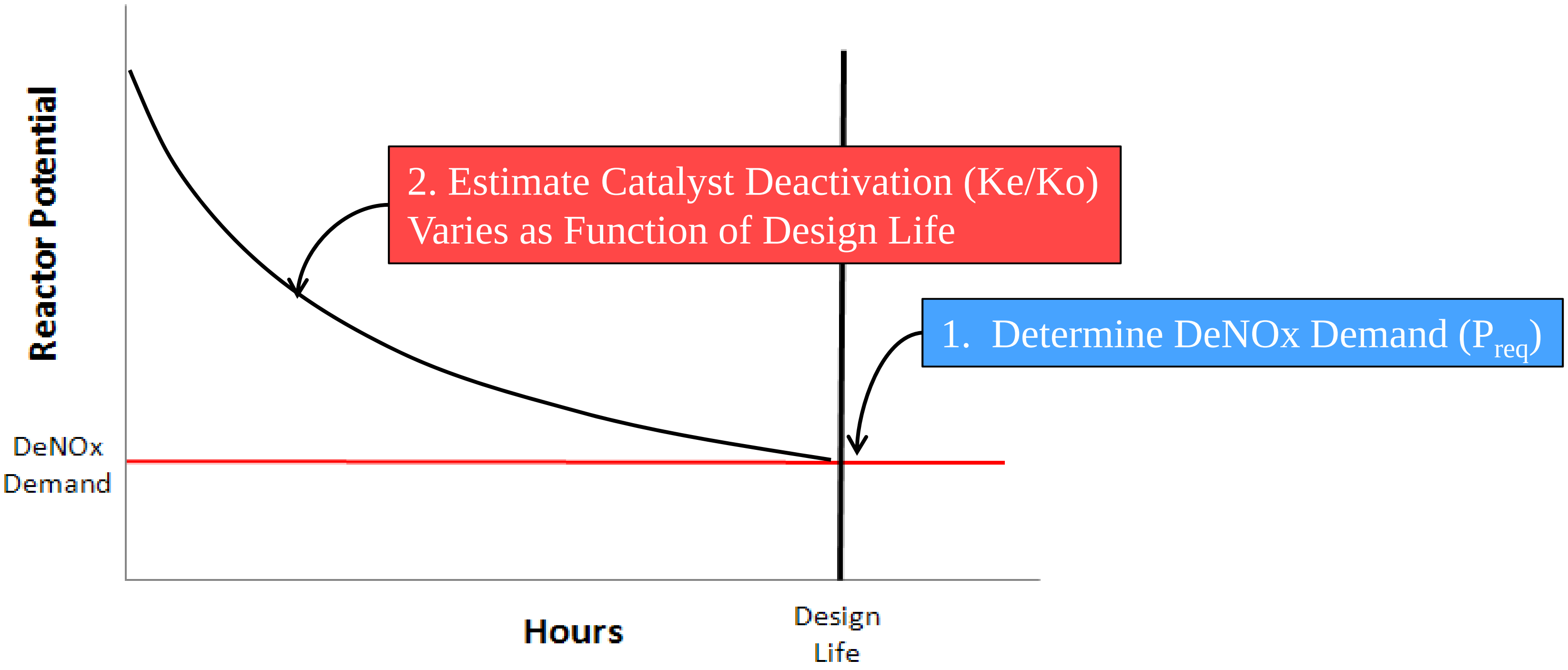
DeNOx Demand, Reactor Potential, & Catalyst Design



1. Determine DeNOx Demand (P_{req})

1. DeNOx demand (P_{req}) is the amount of reactor potential necessary to achieve NOx removal and ammonia slip performance based on fixed operating conditions (flows, temp, etc.)

DeNOx Demand, Reactor Potential, & Catalyst Design



2. Estimate Catalyst Deactivation (Ke/Ko) Varies as Function of Design Life

1. Determine DeNOx Demand (P_{req})

1. DeNOx demand (P_{req}) is the amount of reactor potential necessary to achieve NOx removal and ammonia slip performance based on fixed operating conditions (flows, temp, etc.)
2. Catalyst deactivation is estimated based on fuel quality, combustion parameters, and design life

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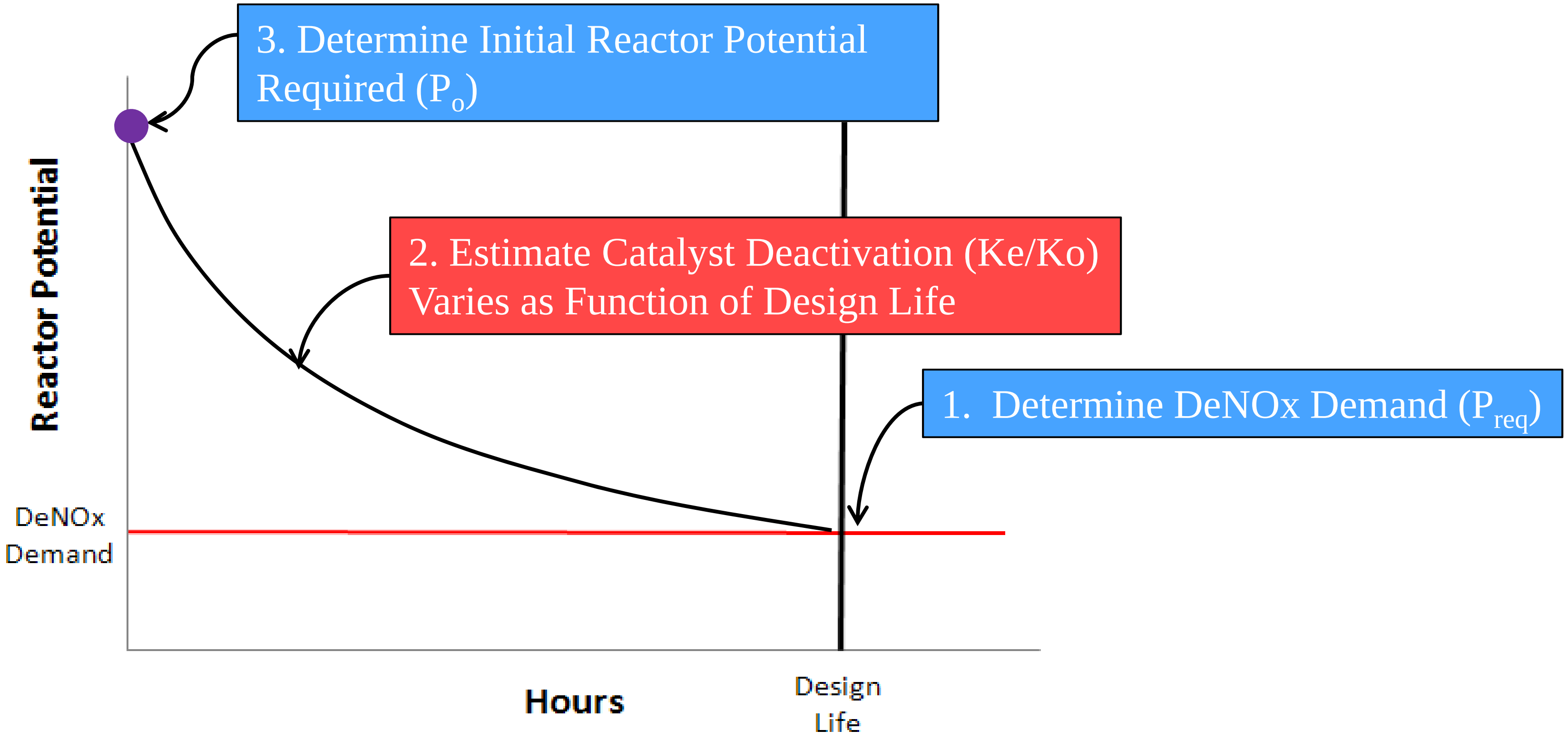
DeNOx Demand, Reactor Potential, & Catalyst Design



3. Determine Initial Reactor Potential Required (P_o)

2. Estimate Catalyst Deactivation (Ke/Ko) Varies as Function of Design Life

1. Determine DeNOx Demand (P_{req})

1. DeNOx demand (P_{req}) is the amount of reactor potential necessary to achieve NOx removal and ammonia slip performance based on fixed operating conditions (flows, temp, etc.)
2. Catalyst deactivation is estimated based on fuel quality, combustion parameters, and design life
3. Based on DeNOx demand and deactivation the initial reactor potential (Po) is determined

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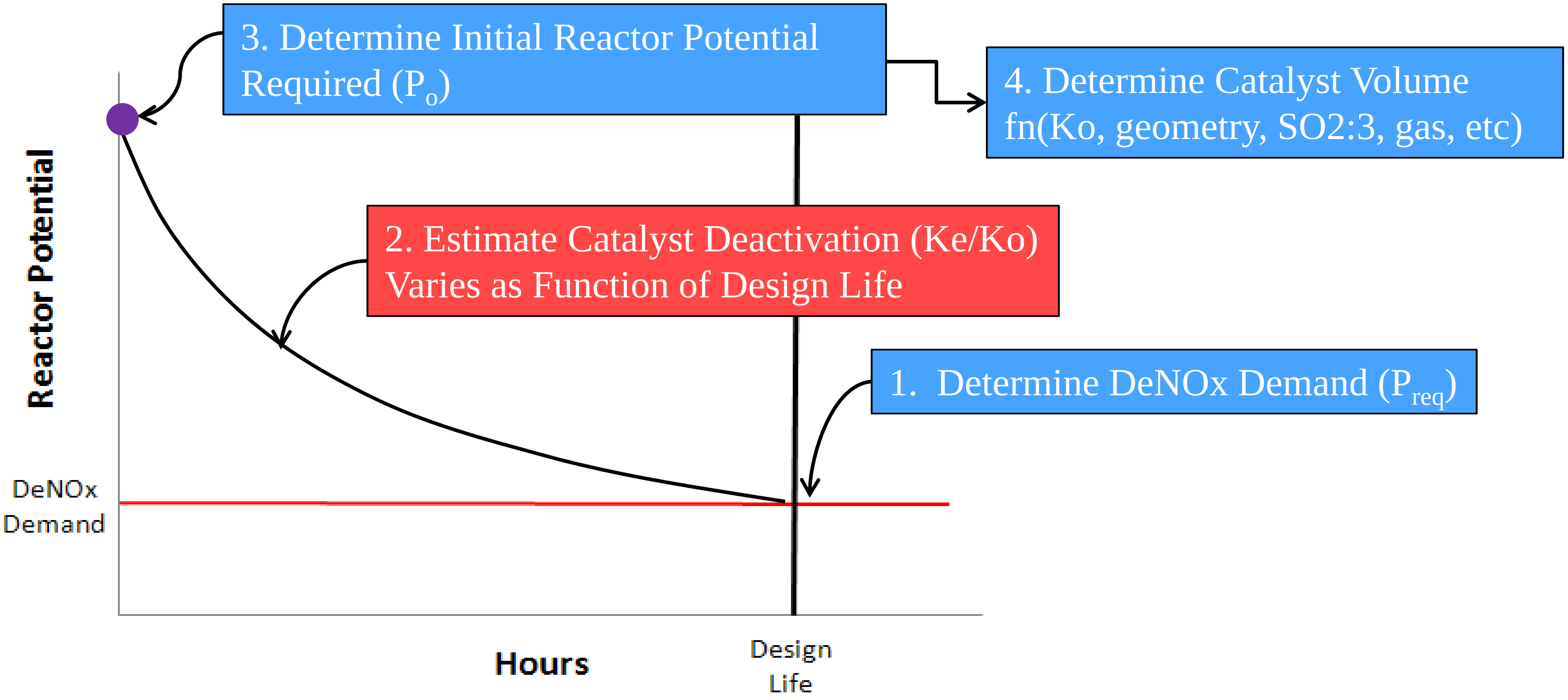
DeNOx Demand, Reactor Potential, & Catalyst Design



3. Determine Initial Reactor Potential Required (P_o)

4. Determine Catalyst Volume fn(Ko, geometry, SO2:3, gas, etc)

2. Estimate Catalyst Deactivation (Ke/Ko) Varies as Function of Design Life

1. Determine DeNOx Demand (P_{req})

1. DeNOx demand (P_{req}) is the amount of reactor potential necessary to achieve NOx removal and ammonia slip performance based on fixed operating conditions (flows, temp, etc.)
2. Catalyst deactivation is estimated based on fuel quality, combustion parameters, and design life
3. Based on DeNOx demand and deactivation the initial reactor potential (Po) is determined
4. Catalyst volume is determined based on Po, catalyst activity, geometry, SO_2 to SO_3 conversion rate, and various gas conditions and constituents

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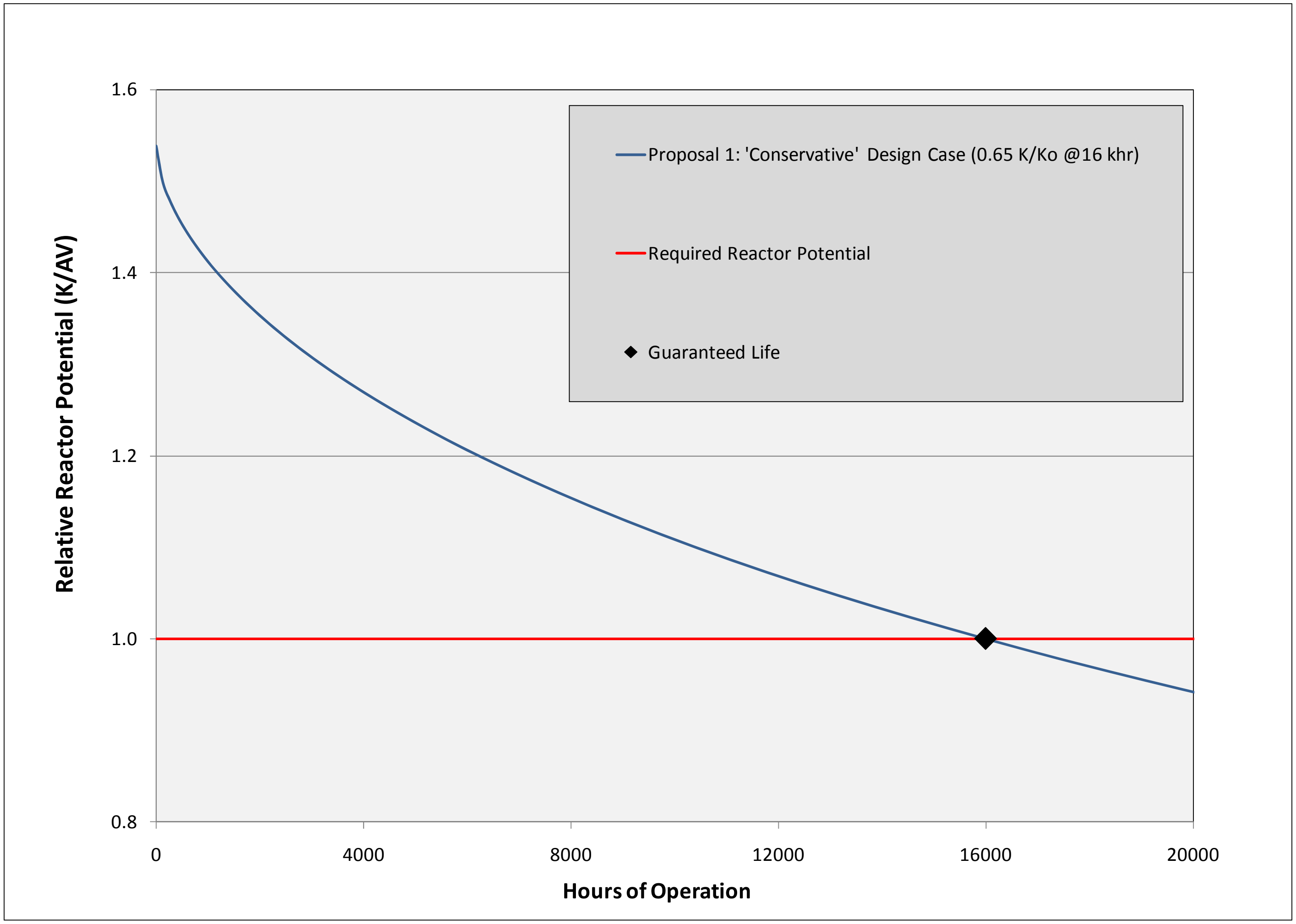
Comparison of Catalyst Design Cases



- Proposal 1 Has the Most Conservative K/Ko Basis (0.65 @ 16,000 hr)

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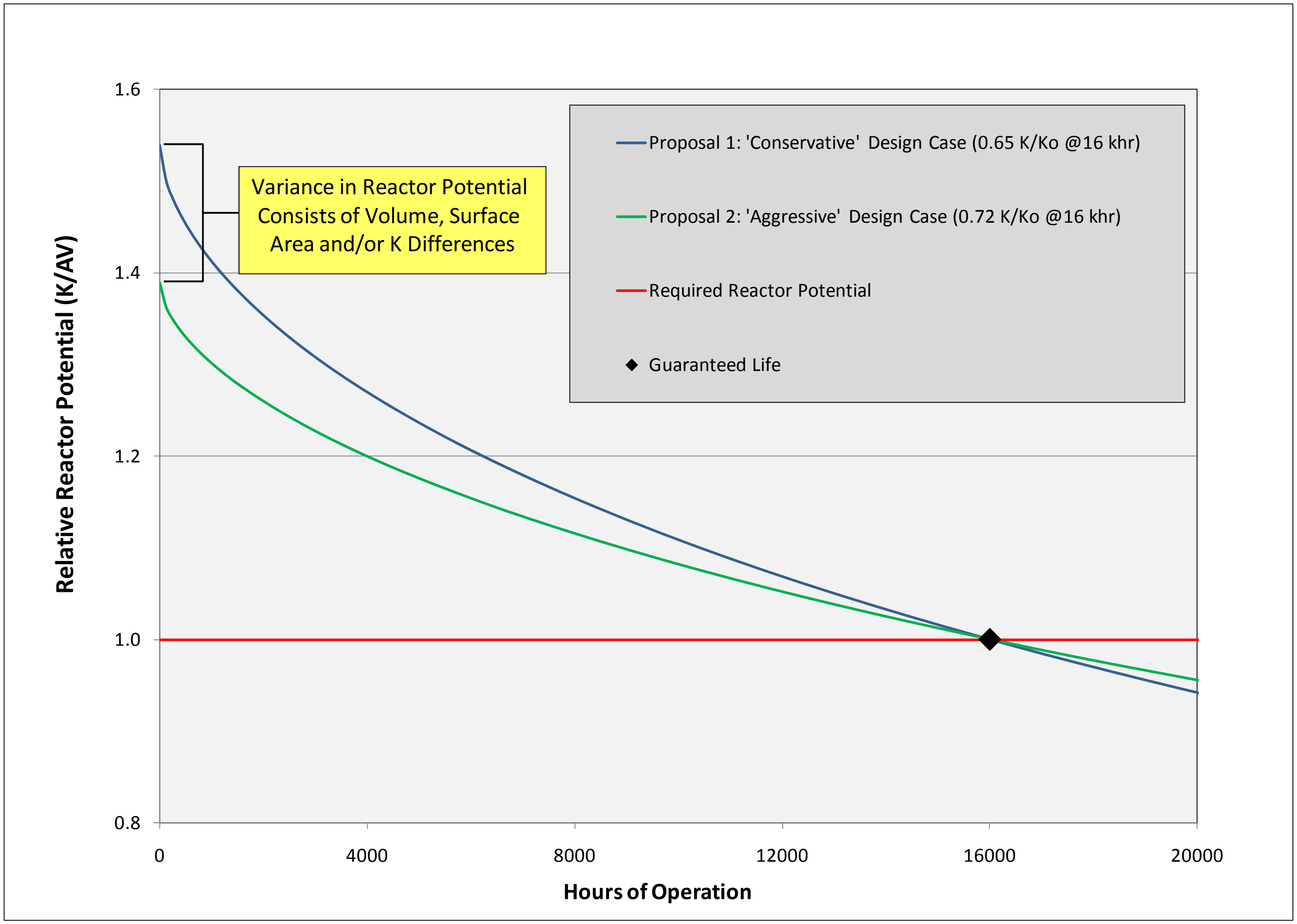
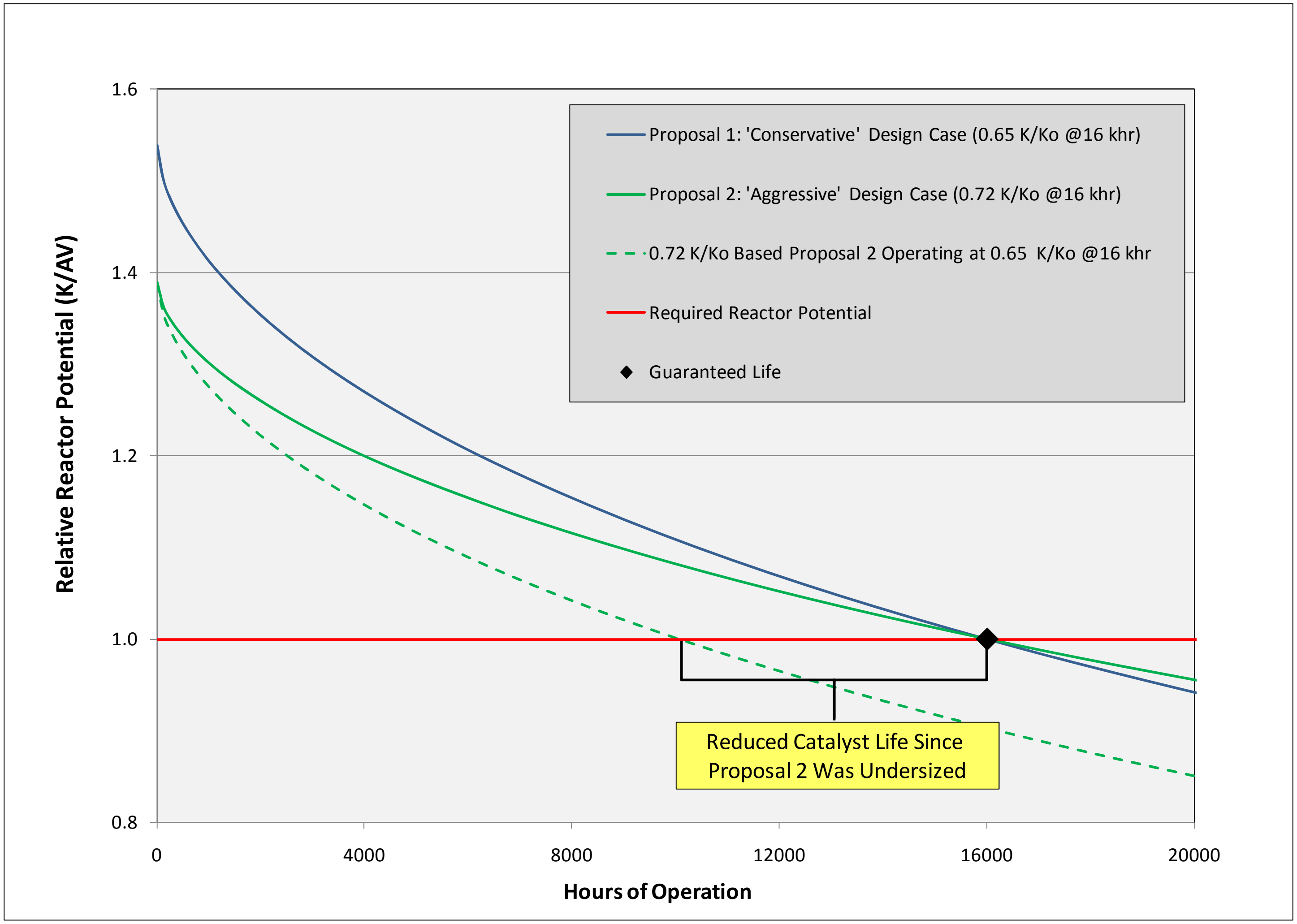
Comparison of Catalyst Design Cases



- Proposal 2 is Based on a More Aggressive Deactivation Rate (0.72 K/Ko)
- Approximately 10% Difference in Catalyst Volume
- Who is Right?

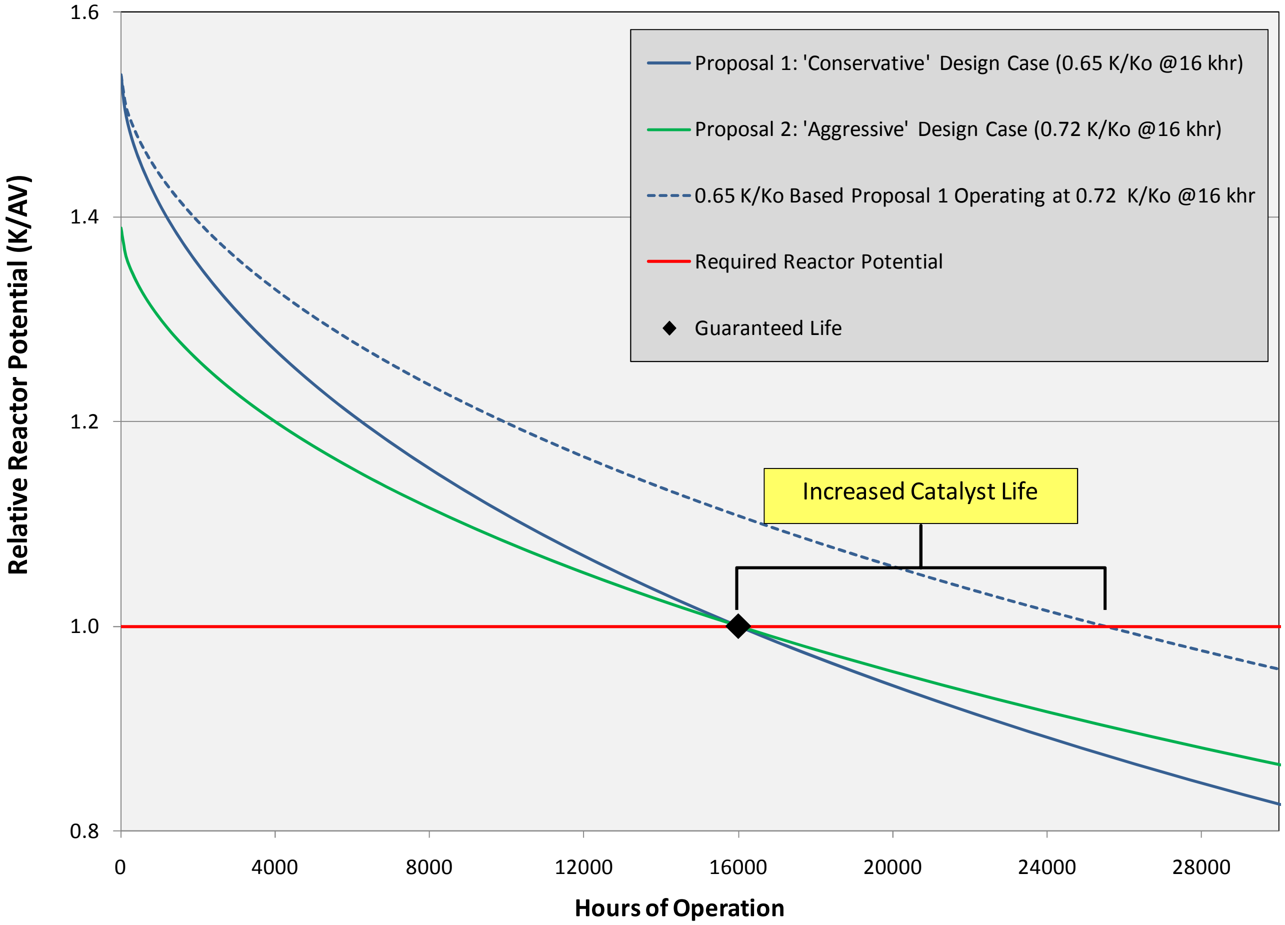
Case A: Proposal 1 Deactivation Rate Correct



Reduced Catalyst Life Since Proposal 2 Was Undersized

- Should a K/Ko of 0.65 Actually Occur Proposal 2 Would be Undersized and Meet Performance for Less Than 11,000 Hours
- Early Outage Required or Reduced Performance Must be Accepted

Case B: Proposal 2 Deactivation Rate Correct



- Should a K/Ko of 0.72 Actually Occur Proposal 1 Would be Oversized and Meet Performance for More Than 24,000 Hours (>3 Years)
- Catalyst Management Costs Greatly Reduced

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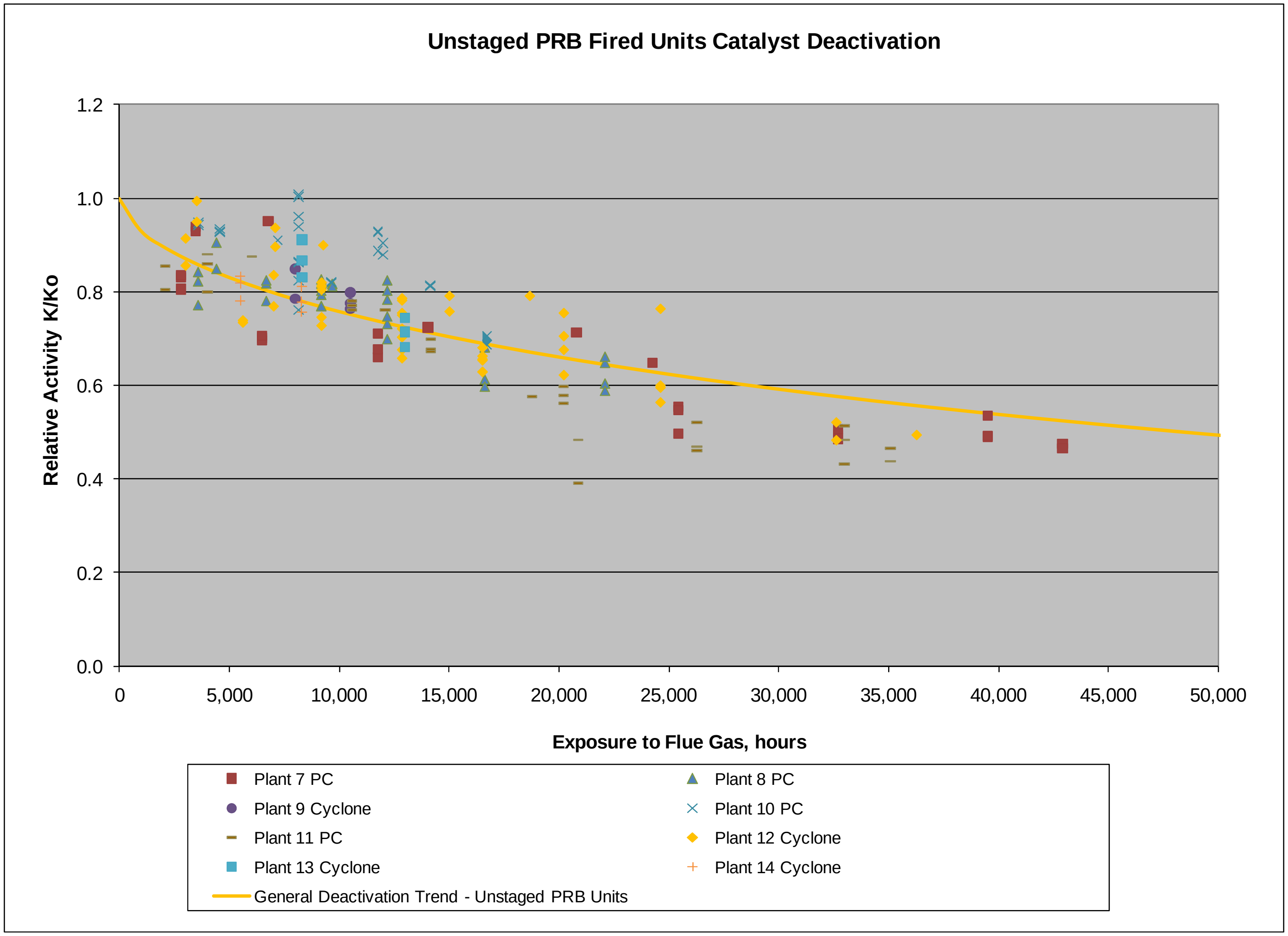
Group 1: PRB Unit Catalyst Activity Test Results



- “Unstaged” PRB Units Indicate a K/Ko @ 16,000 hours of 0.6 to 0.8
- Wide Variation of Results Dependent on Many Operations and Fuel Variables

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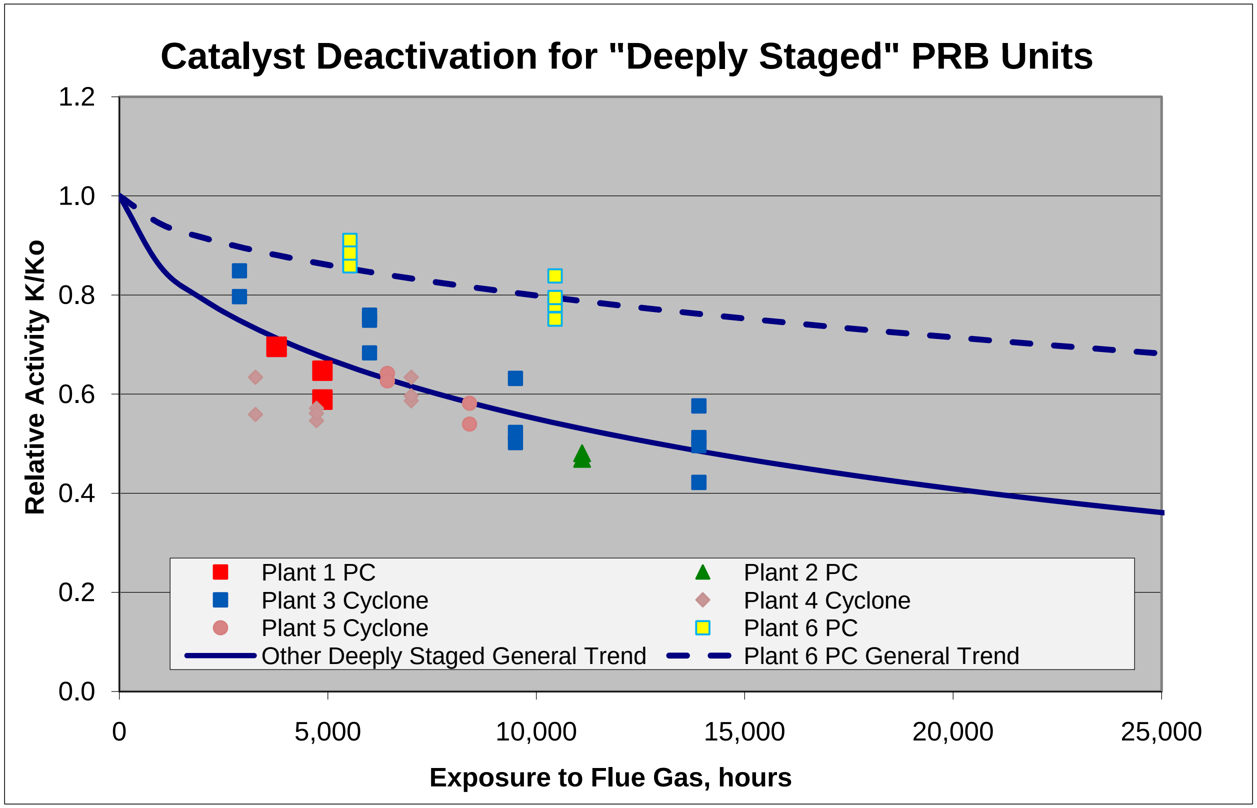
Group 2: PRB Unit Catalyst Activity Test Results



- Combustion Conditions Greatly Affect PRB Application Deactivation Rates
- Broad Consensus of Results for “Deeply Staged” Units Confirm Severe Deactivation
- Highly Risky if Plant 6 Alone Was Selected as a Reference Unit to Support Proposal Sizing
- A Plant 6 Based Catalyst Design Will Last Less Than One Year on a 24,000 Hour Guarantee With Deep Deactivation Seen for Broader Experience

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Summary

- Deactivation Rates Vary Widely Dependent on Site Specifics
  - Fuel Quality, Combustion Parameters, and Boiler Duty Cycle Greatly Affect Catalyst Deactivation Rates
- Vanadium-Titania Based Catalysts All Deactivate at the Same Rate Based on Site Specifics
- Underestimating or Aggressive Sizing Compromises SCR Performance and Effective Catalyst Management
  - Risk of Early Outage for Catalyst Additions
  - Risk of Deficient Performance
- Initial SCR Project Design Should Carefully Consider Reactor Potential to Determine the Risk Profile of Various Proposals
  - Aggressive Catalyst Designs Can Result in Operations Difficulties and Increased Cost