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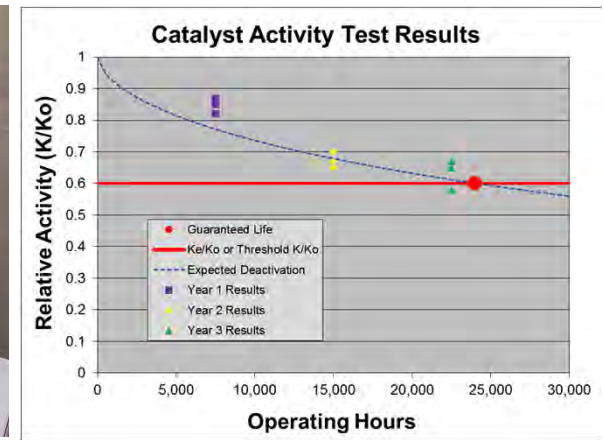
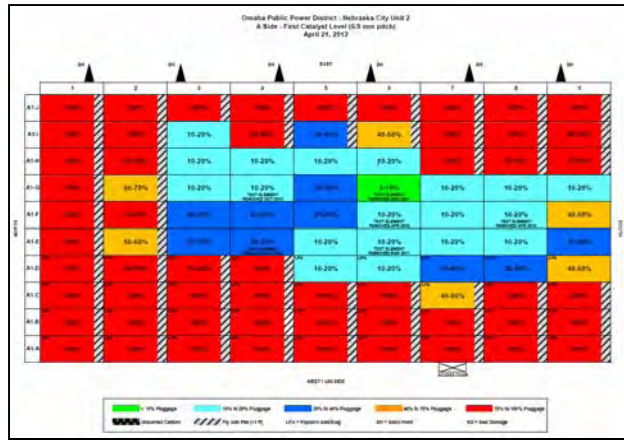
2016 NO_x-Combustion-CCR Round Table Presentation

February 1 & 2, 2016, in Orlando, FL / Hosted by OUC

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Reinhold Environmental 2016 NO_x-Combustion Round Table

SCR System Evaluation and Management Optimization



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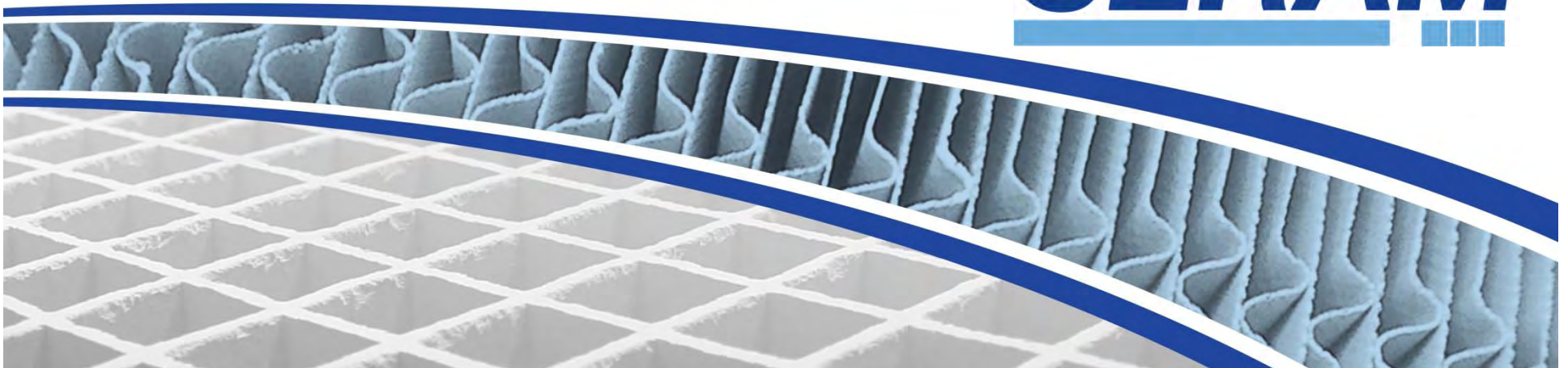
Presented by: Megan Winter & Noel Rosha
IBIDEN CERAM Environmental, Inc.
February 2, 2016

Presentation Topics

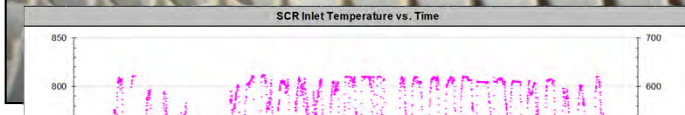
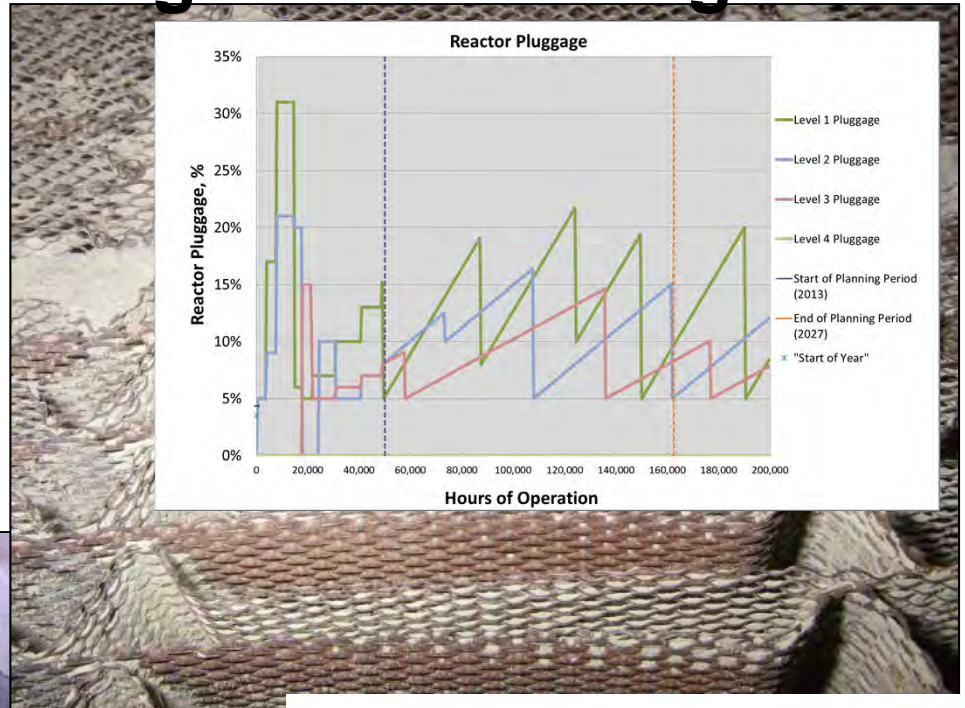
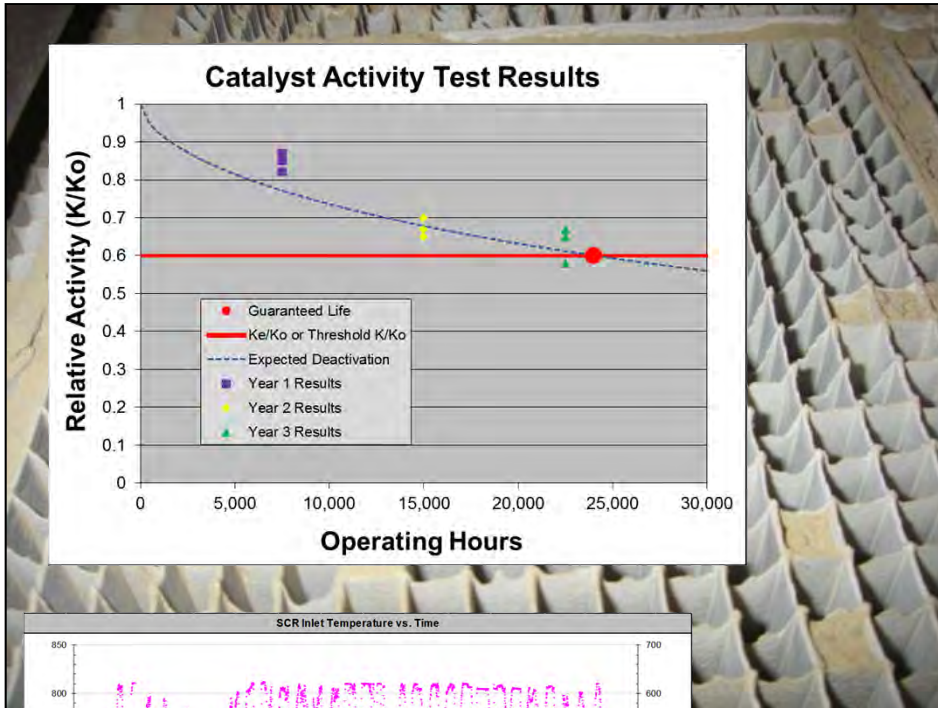
- DeNOx Demand & Reactor Potential
- Catalyst Design Assumptions
 - Pluggage, K/Ko, and Operating Condition Impacts to Catalyst Life
- SCR System Design Analysis
 - Reactor Arrangement
 - Catalyst Pitch Options
 - Range of Deactivation Rates
 - Range of Catalyst Pluggage Rates
- Long Term O&M Cost Analysis
- Industry Examples: The Good and Bad

DeNOx Demand and Reactor Potential

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All Aspects Affecting Catalyst Must Be Considered in SCR Design and Planning



Reactor Potential

$$P = K / Av$$

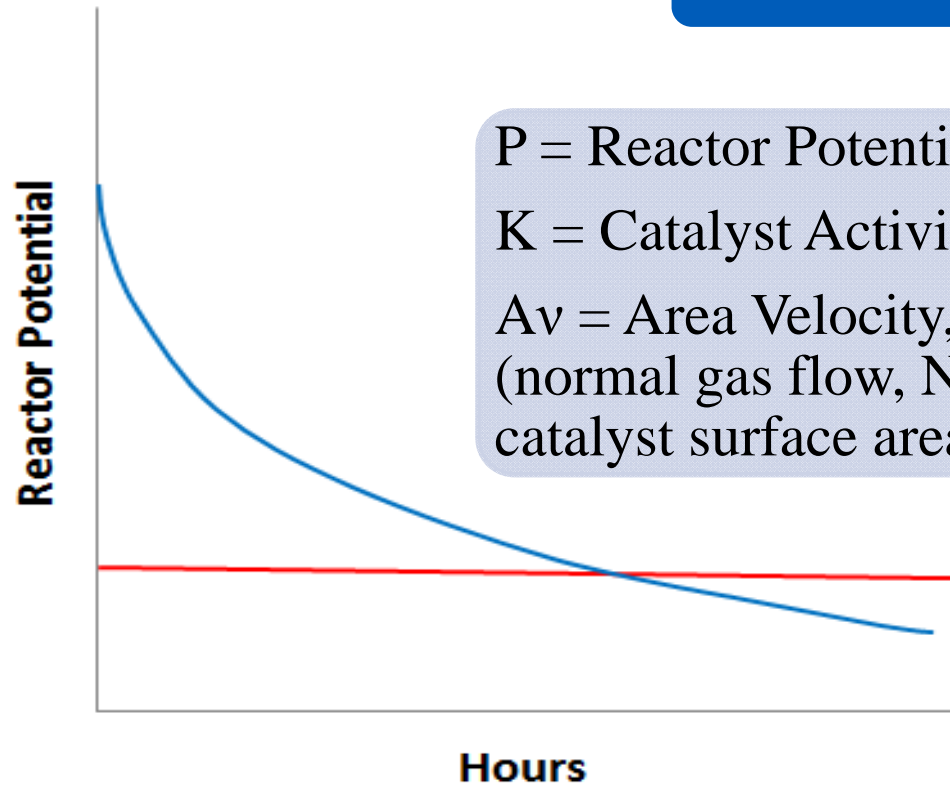


P = Reactor Potential

K = Catalyst Activity, $\text{Nm}^3/\text{m}^2\text{h}$ or Nm/h

Av = Area Velocity, Nm/h

(normal gas flow, Nm^3/h divided by total installed catalyst surface area, m^2)



The Magnitude of Reactor Potential Determines the Amount of SCR System Performance Possible (DeNO_x & Ammonia Slip Control)

Operating Reactor Potential

$$P_o = \sum K_1 / Av_1$$



P_o = Sum of Layer Based Reactor Potentials Considering Design Variables

K_1

Operating Temperature

Flue Gas Composition
(H₂O, O₂, etc.)

Av_1

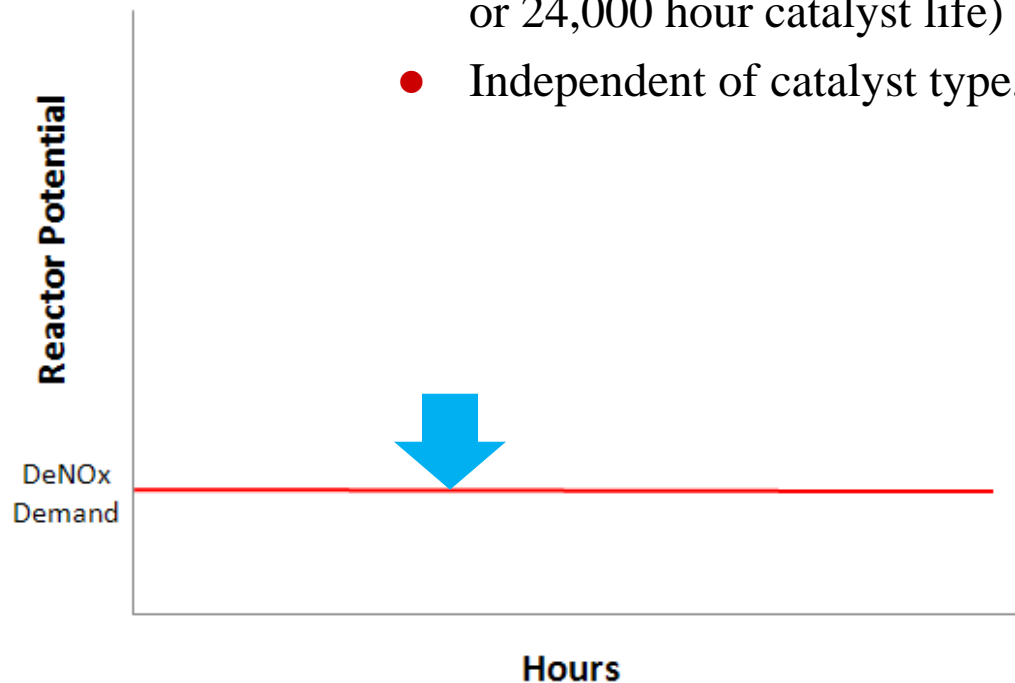
Operating Flow Rate

Catalytic Surface Area

- Pluggage
- Erosion
- Geometry

DeNOx Demand

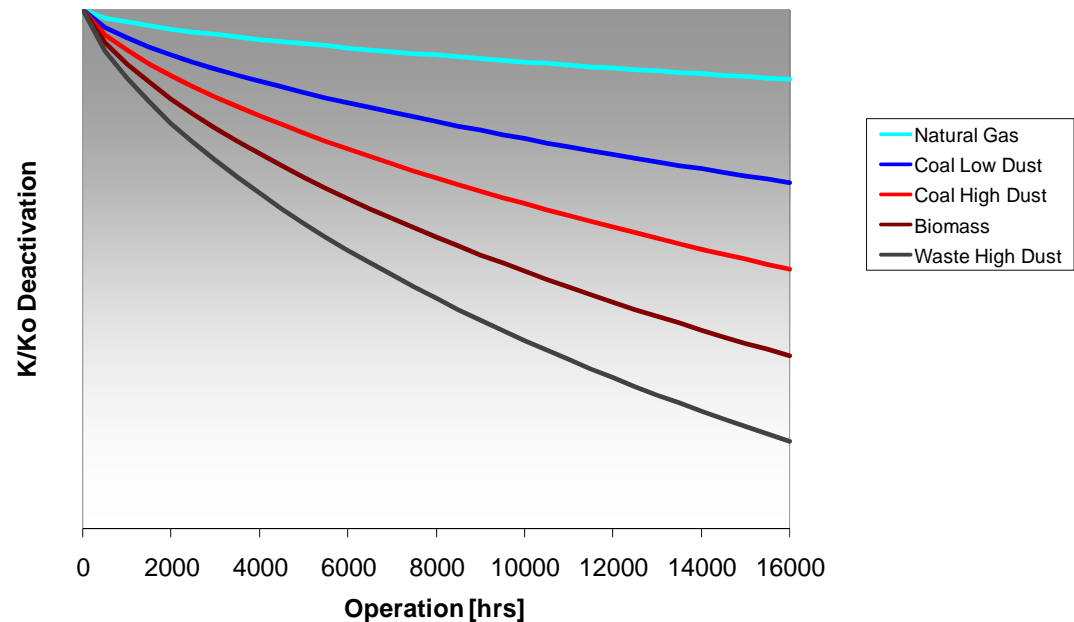
- DeNOx Demand (P_{req}) = The reactor potential required to meet NOx removal and ammonia slip requirements
- Calculated based on NO_x removal requirements, NH₃ slip and *distributions (velocity, NH₃/NO_x, temperature)*
- Independent of catalyst design life (i.e. same value for 16,000 or 24,000 hour catalyst life)
- Independent of catalyst type, formulation or manufacturer



$$P_{req} = K_{req} / Av$$

Catalyst Deactivation

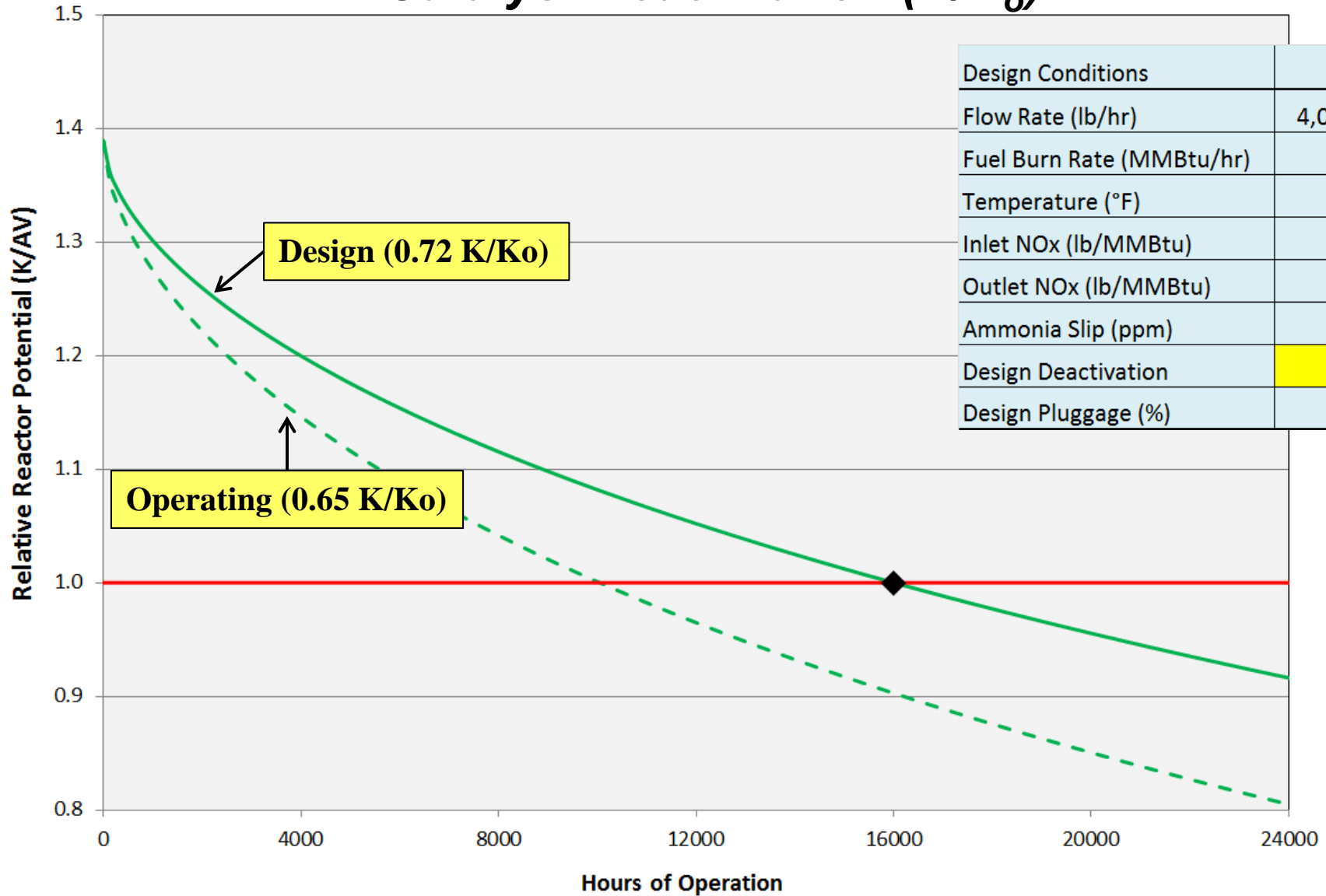
- Catalyst activity relative to initial activity (K/K_0)
- *Determined* based on coal constituents, combustion and experience
- Does not affect DeNO_x demand
- Dependent on catalyst design life
- Independent of SCR Catalyst Type and Composition



Example Case

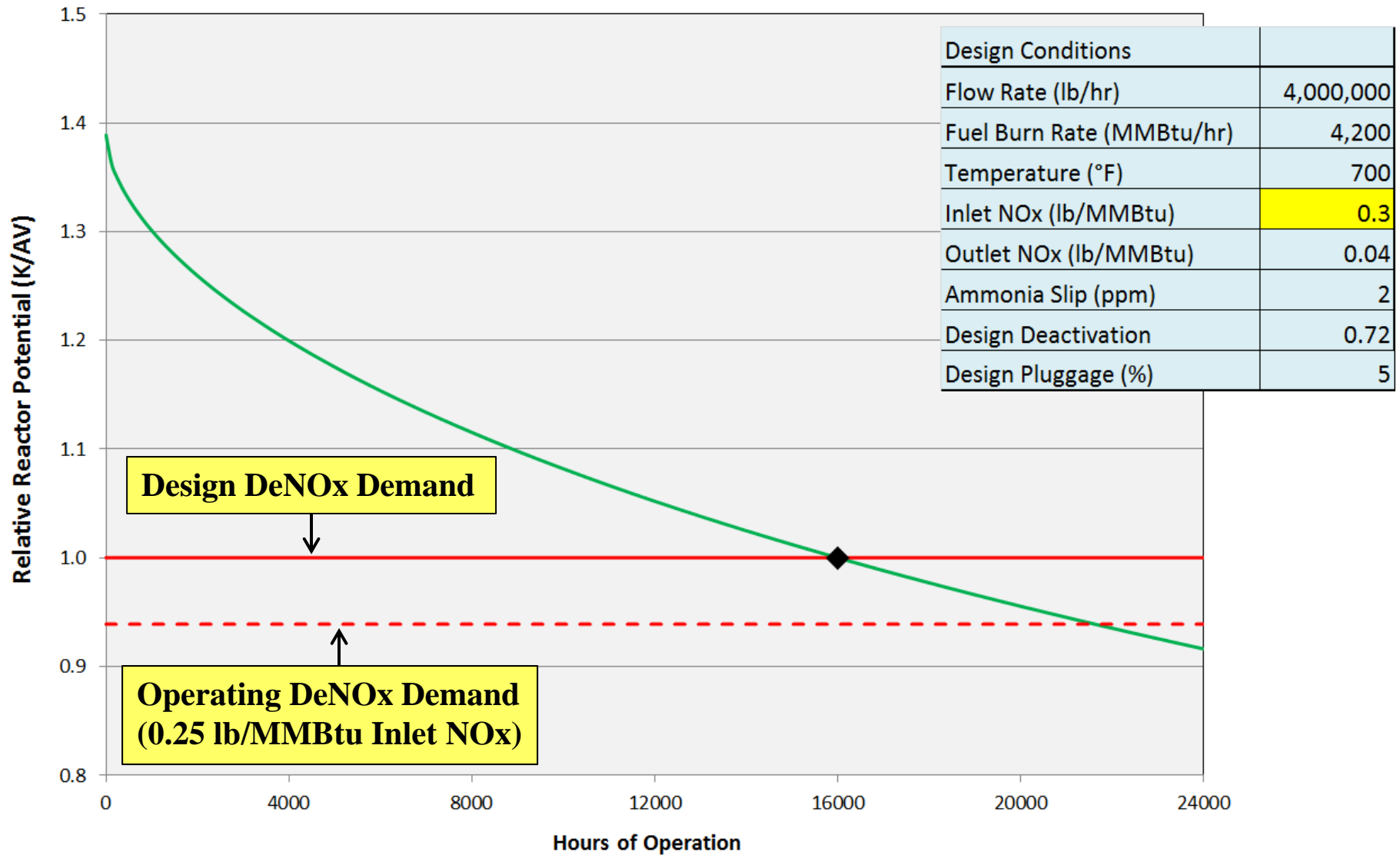
Design Conditions	
Flow Rate (lb/hr)	4,000,000
Fuel Burn Rate (MMBtu/hr)	4,200
Temperature (°F)	700
Inlet NOx (lb/MMBtu)	0.3
Outlet NOx (lb/MMBtu)	0.04
Ammonia Slip (ppm)	2
Design Deactivation	0.72
Design Pluggage (%)	5

Design vs. Operating Catalyst Deactivation (K/K_0)

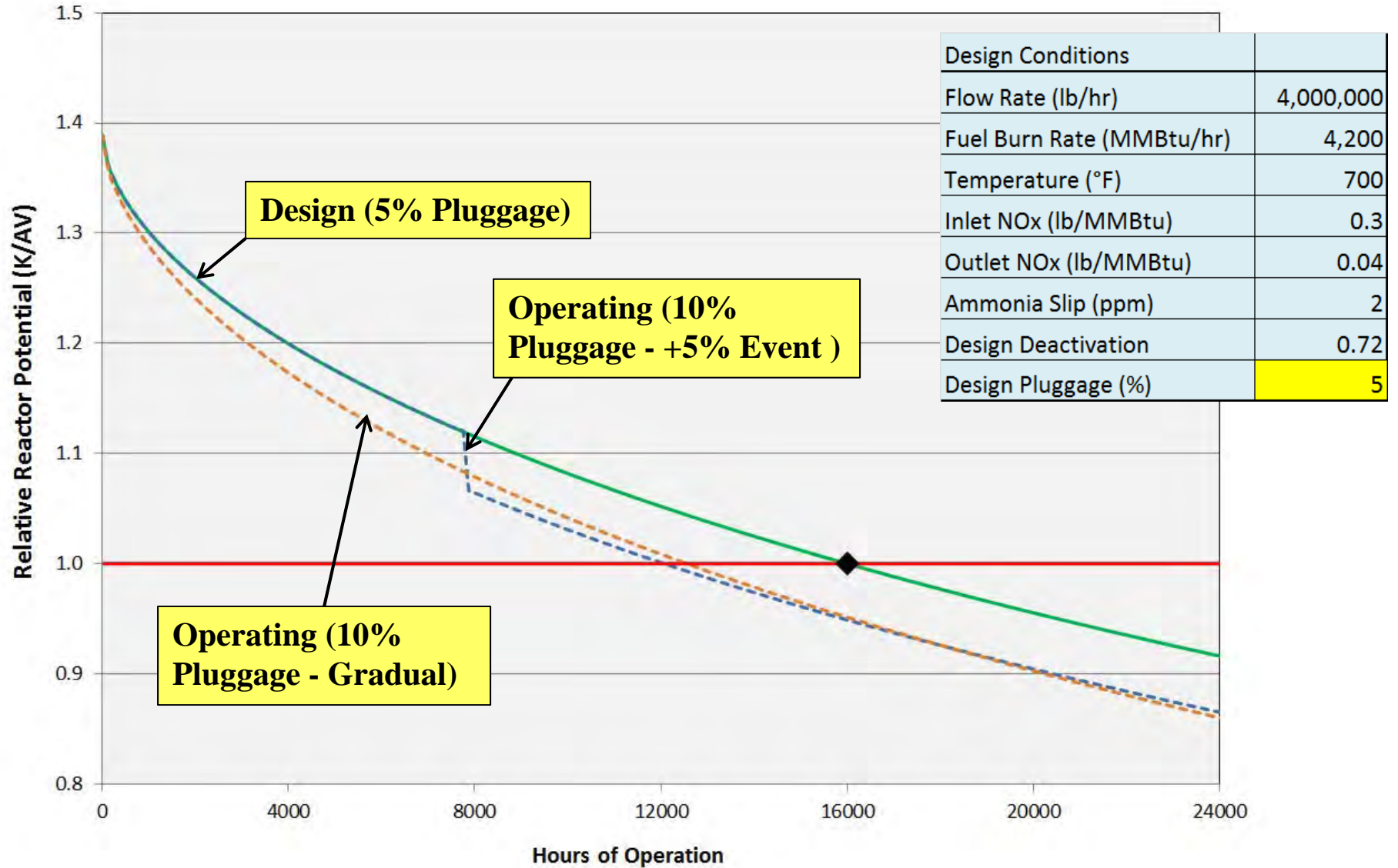


Reduced Catalyst Life (Approx. 6,000 hours)

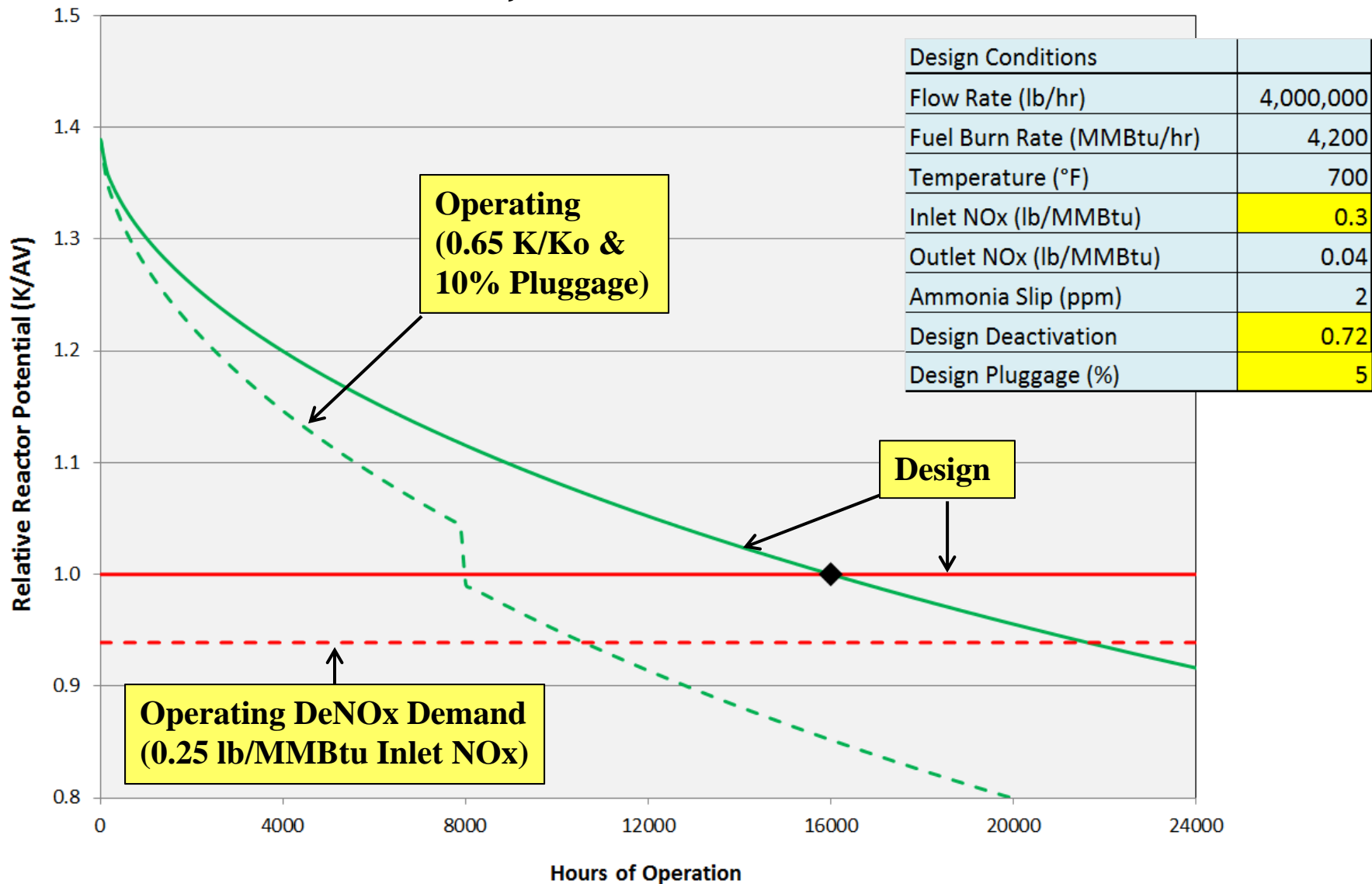
Design vs. Operating DeNOx Demand



Design vs. Operating Reactor Potential (Pluggage)

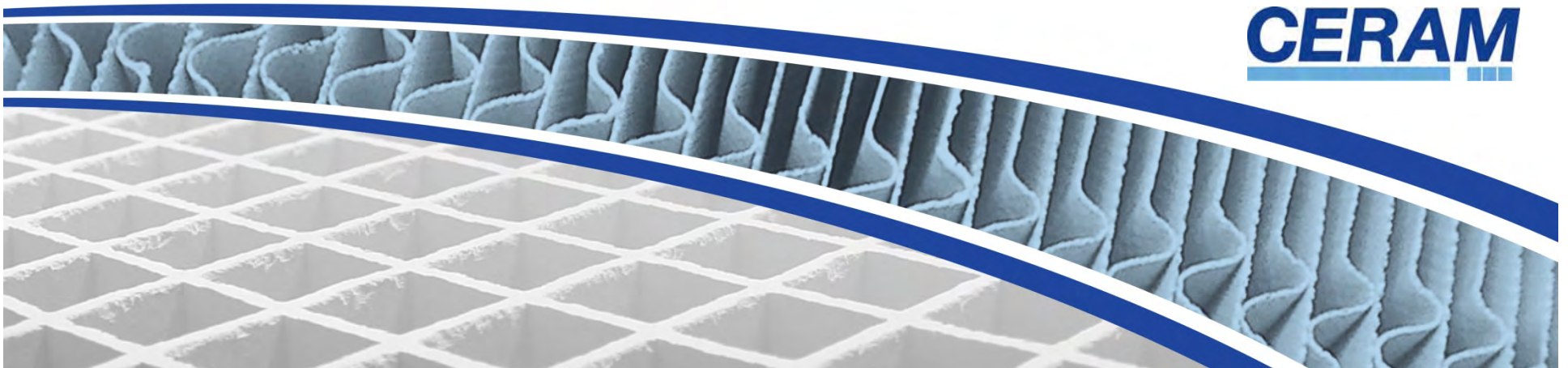


Design vs. Operating Reactor Potential, DeNOx Demand and Deactivation



SCR System Design Analysis

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SCR System Design Challenges

- Minimize initial capital cost
- Minimize long term O&M costs
- Limit Operating Risks
- Current SCR market is very competitive
 - Aggressive SCR (and Catalyst) design approach to reduce initial capital
 - Can lead to high operating risk and high long term costs due to repeated catalyst events

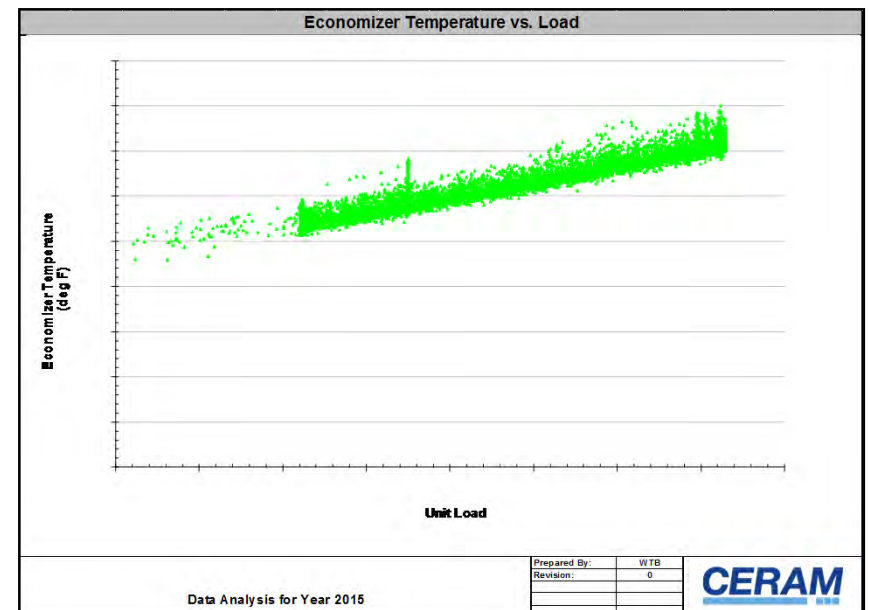


Project Risk Management

- Performance Guarantee Administration
 - Test A Performance Can Be Achieved Even with Aggressive Catalyst Design (Plenty of Excess Reactor Potential)
 - Test B Guarantee Difficult to Administer
 - ◆ Fuel Specifications Change
 - ◆ Boiler Operations Change
 - ◆ Personnel Change
 - ◆ Intermittent Sonic Horn and Sootblower Failures
 - ◆ Catalyst Pluggage Events Occur
 - ◆ Comprehensive Documentation Required of Owner
- Owner, OEM, or AE can be proactive to minimize project risk and costs!

SCR System Design Study

- SCR design studies performed in cooperation with Owner to reduce project risk.
- Establish “Design Basis” based on operating data analysis
- Evaluate impacts of key design parameters
 - Reactor Arrangements
 - Catalyst Pitch Options
 - Range of Deactivation Rates
 - Range of Catalyst Pluggage Rates



SCR Design Study Objectives

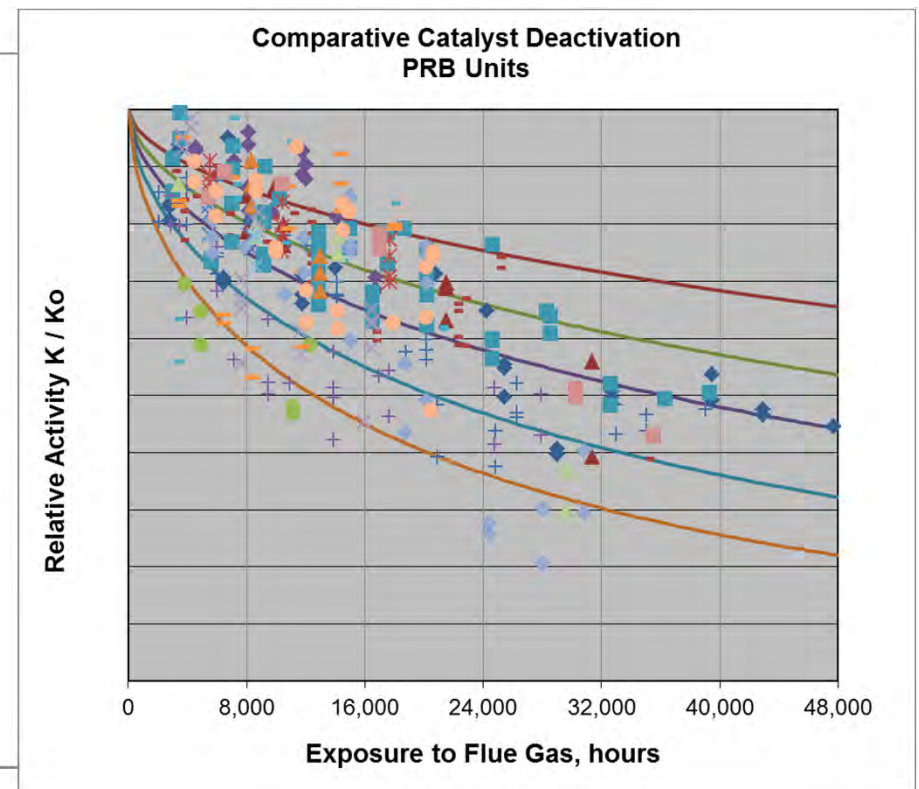
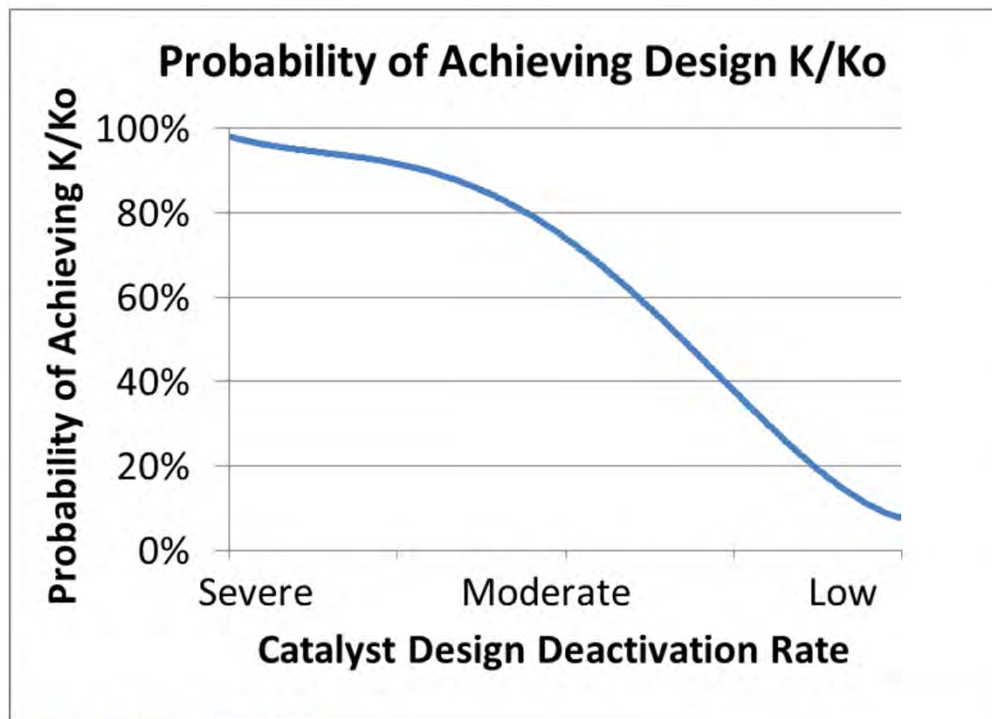
- Determine reactor footprint (target face velocity)
 - Keep ash fluidized but reduce erosion potential
 - Consider range of temperature and excess air
- Analyze key design parameters
 - Initial number of layers
 - Catalyst pitch options
 - Various pluggage rates
 - Various deactivation rates
- Provide NPV analysis of a matrix of alternatives
- Include sensitivity analysis of results
- Matrix of results allows determination of final design parameters based on probability considerations

Reactor and Catalyst Design Cases

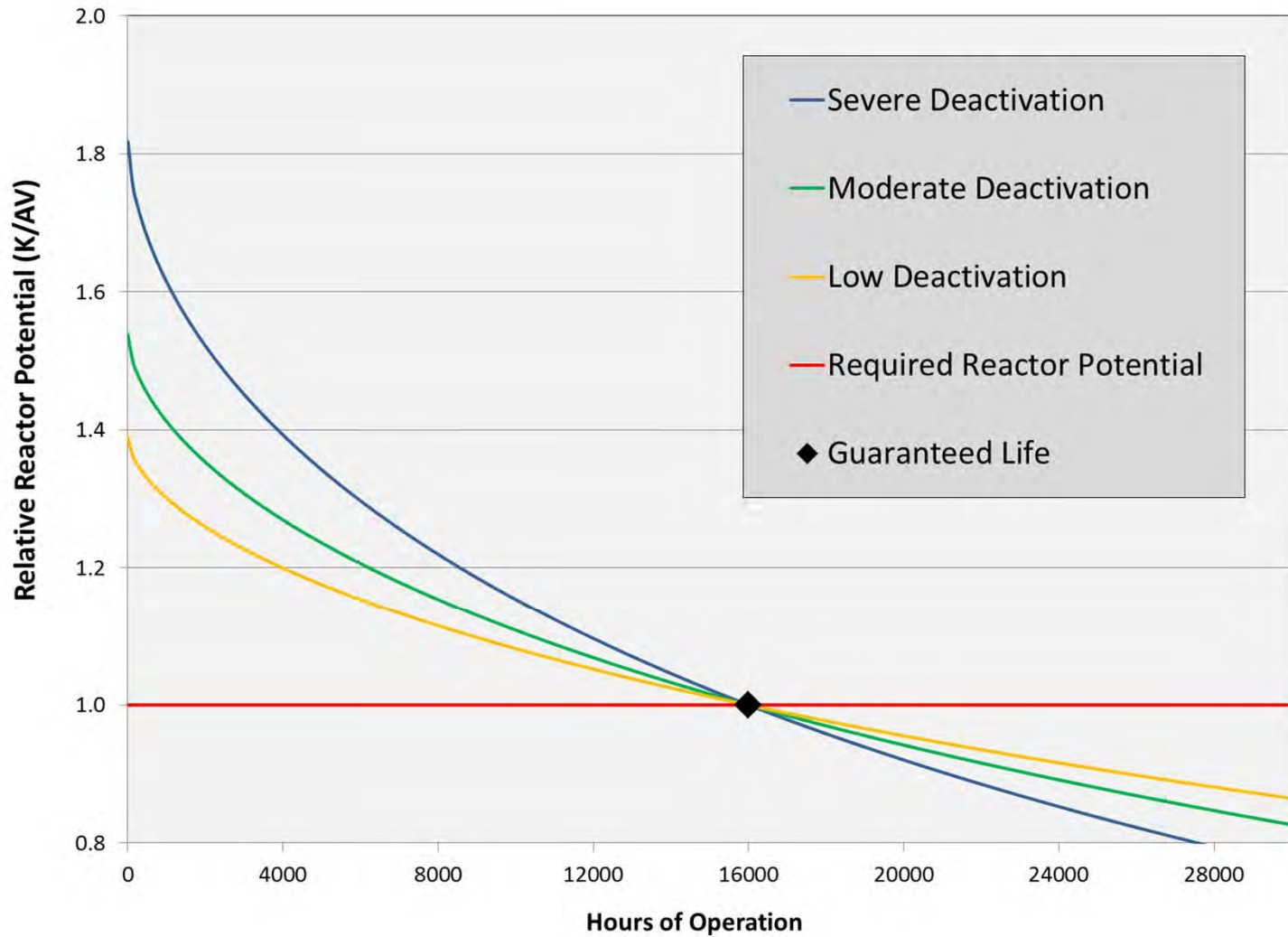
- Example reactor design cases:
 - Case 1: 2+1 Reactor, Aggressive Pitch
 - Case 2: 2+1 Reactor, Moderate Pitch
 - Case 3: 3+1 Reactor, Moderate Pitch
 - Case 4: 2+1 Reactor, Moderate Pitch, Increased Outlet NO_x
- Catalyst pitch options
 - Consider coal and ash characteristics (PRB vs. Bituminous)
 - Consider range of pitch from small (aggressive) to large (conservative)

Deactivation Rate Statistical Analysis

- PRB & Bit. coal catalyst deactivation rates vary greatly
- An optimistic assumption will result in an undersized SCR
- A pessimistic assumption may result in higher than needed capital costs

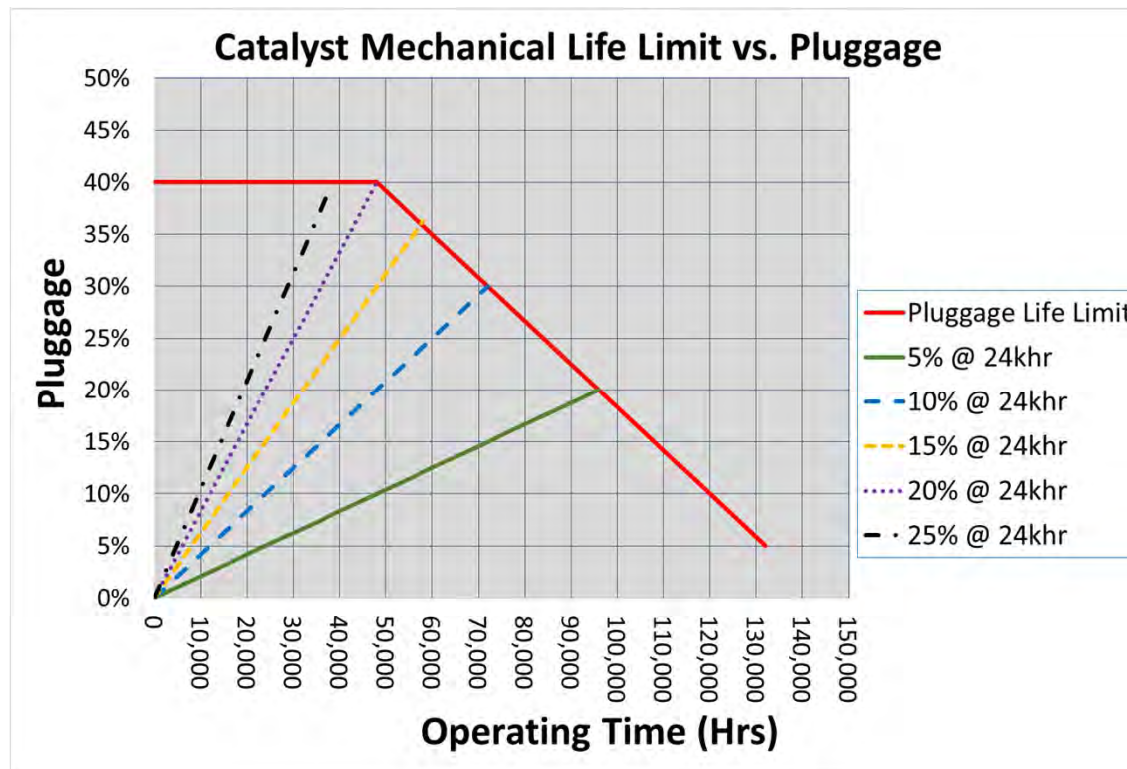


Deactivation Assumption - Impact on Initial Catalyst Potential



Catalyst Pluggage & Mechanical Life

Range of Catalyst Pluggage Rates			
	Pluggage Percentage at End of Life		
Catalyst Pitch	Low	Moderate	High
Small pitch	10%	15%	20%
Moderate pitch	5%	10%	15%
Large pitch	3%	5%	10%



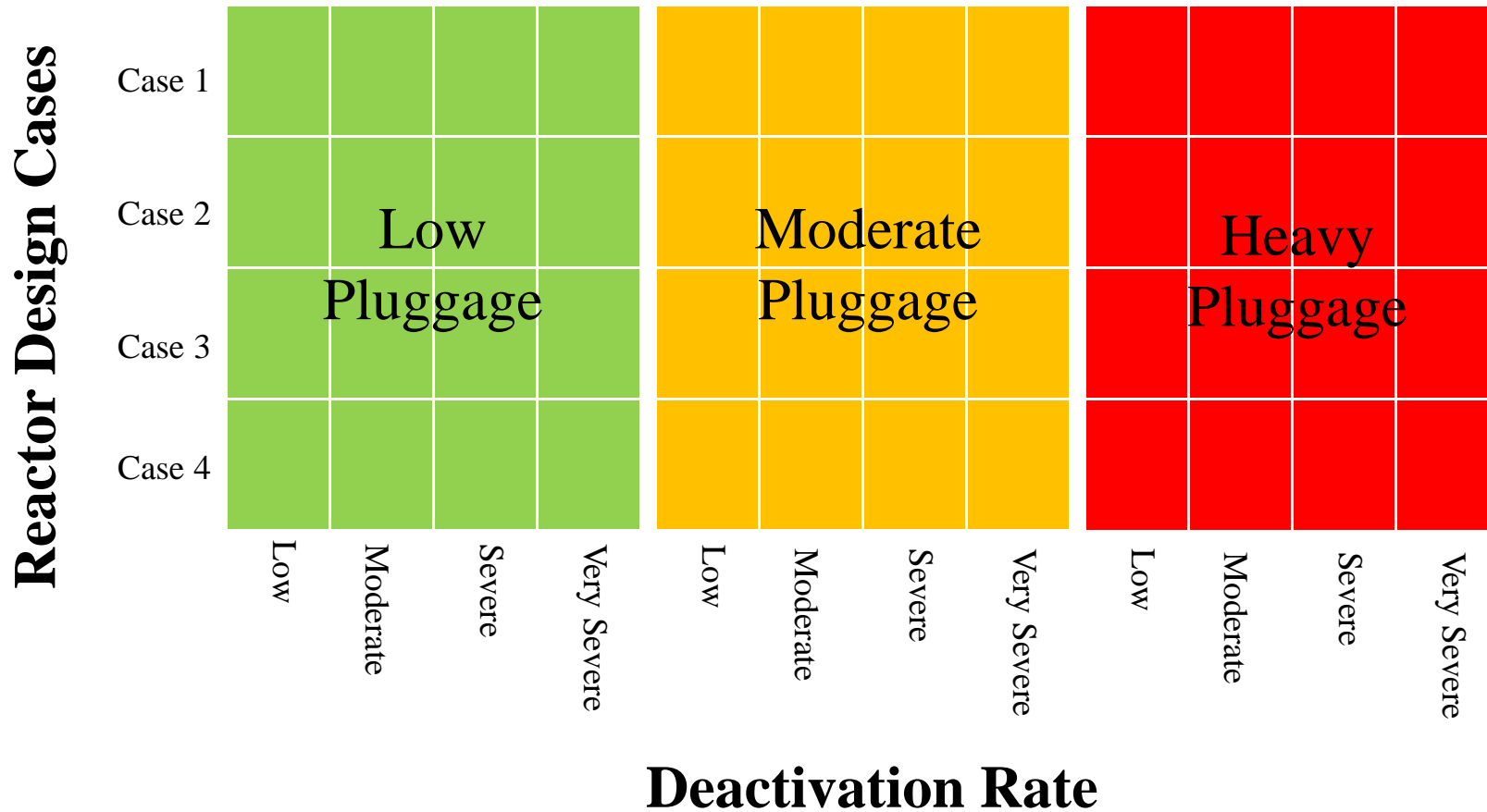
SCR Design Scenario Analysis

- Develop 20-Year model for each plan
 - Determine number of catalyst events
 - Catalyst replacement timing (consider outage interval)
 - Economic analysis including:
 - ◆ Catalyst capital costs
 - ◆ Catalyst disposal/salvage value
 - ◆ Catalyst in and out costs
 - ◆ Ammonia costs
 - ◆ Aux power costs due to catalyst DP

Matrix of 20-Year Plan Results

Catalyst Management Cases Summary				
	Case 1	Case 2	Case 3	Case 4
Case Description	No. of Layers Small Pitch	No. of Layers Moderate Pitch	No. of Layers Moderate Pitch	No. of Layers Large Pitch
Catalyst Pluggage Rate @ 24,000 Hours	Low (10%) Moderate (15%) High (20%)	Low (5%) Moderate (10%) High (15%)	Low (5%) Moderate (10%) High (15%)	Low (3%) Moderate (5%) High (10%)
Deactivation Rates				
Very Low				
Low		Outputs Include: <ul style="list-style-type: none"> • Number of Catalyst Events • Timing of Catalyst Events • Maximum Catalyst DP • 20 Year Plan NPV • Ammonia Costs 		
Moderate				
Severe				

Matrix of Results Analysis



Total of 48 SCR Design Scenarios!

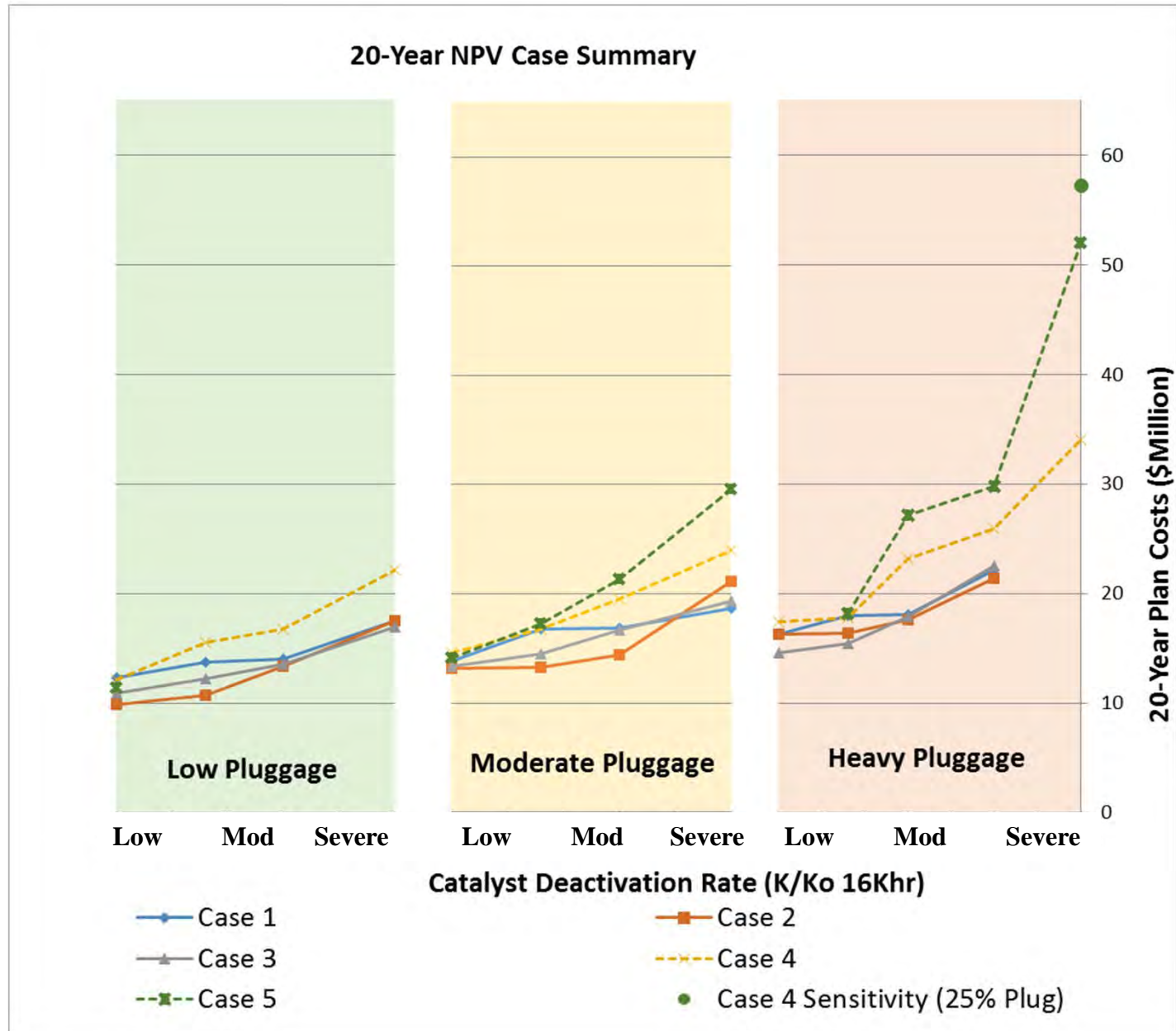
Elimination of Deficient Scenarios

Deactivation Rate	Reactor Design Cases												
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4	
Low	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙
Moderate	⊙	⊙	⊙	⊙	⊙	⊗			⊙	⊗			
Severe	⊙	⊗	⊙	⊗	⊗	⊗		⊗	⊗	⊗		⊗	⊗
Very Severe	⊗	⊗	⊙	⊗	⊗	⊗		⊗	⊗	⊗		⊗	⊗

⊗ Does Not Achieve Initial Guarantee Life

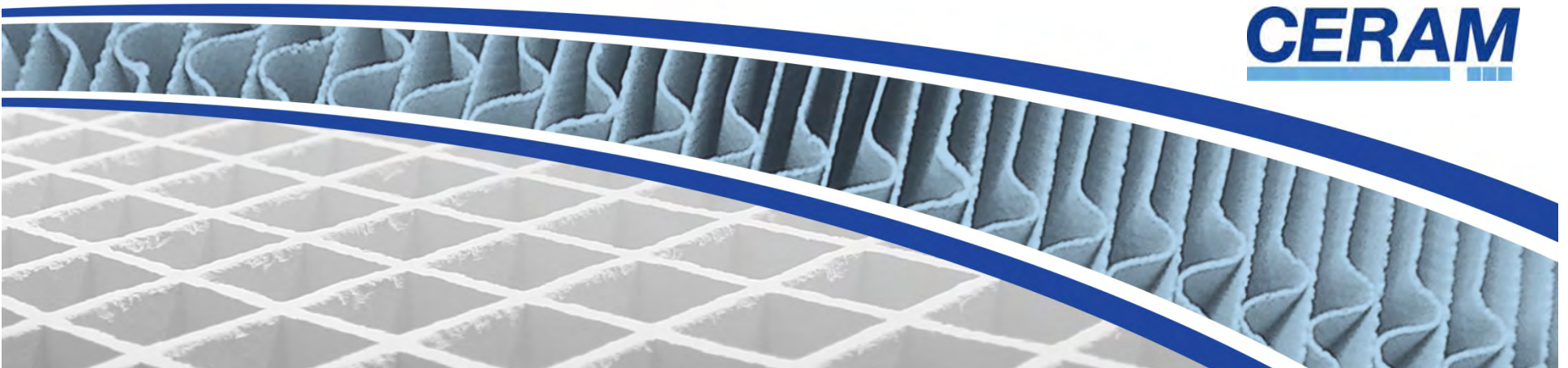
⊙ Low Probability Based on Experience

20 Year Economic Comparison



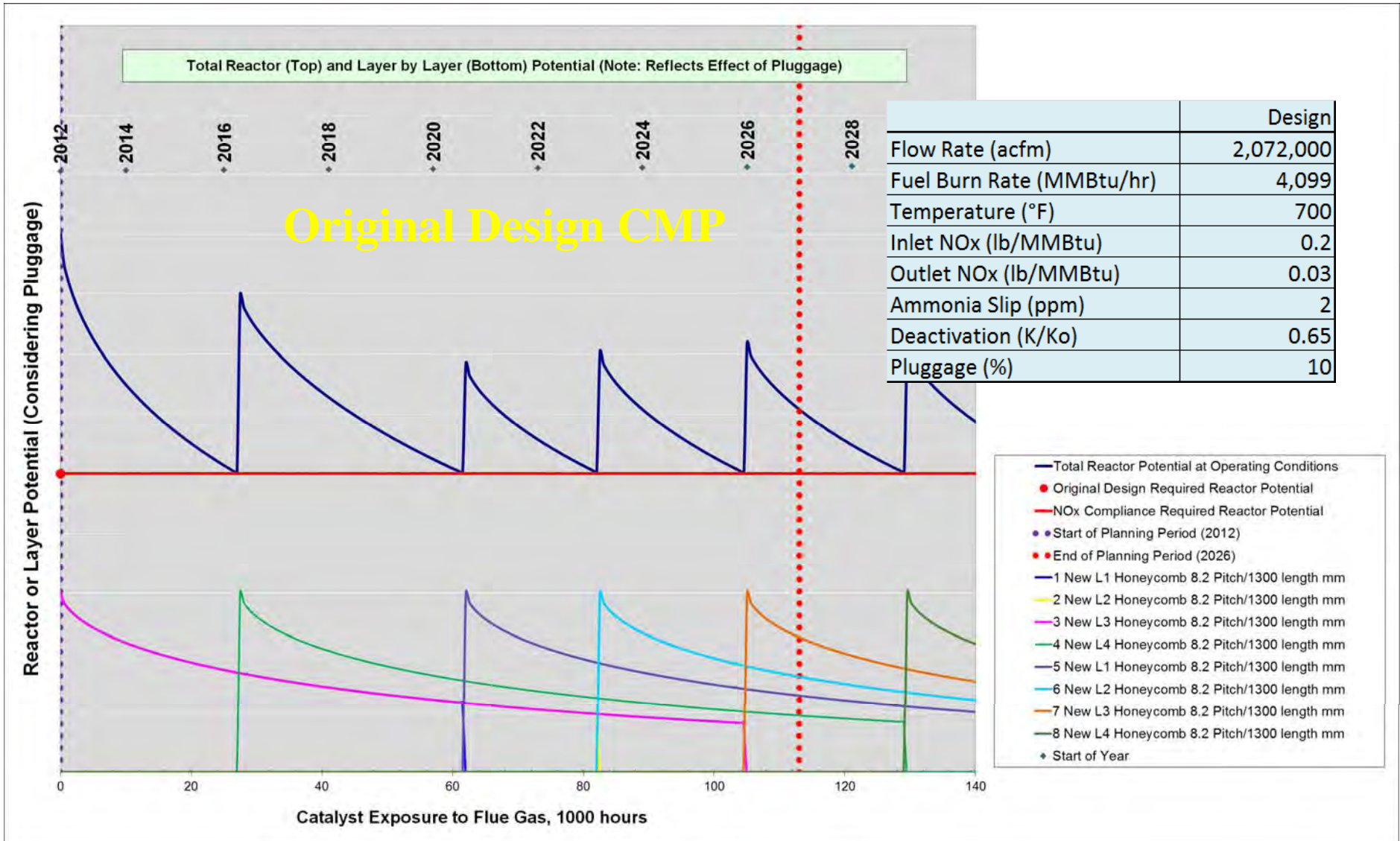
Industry Examples: The Good & Bad

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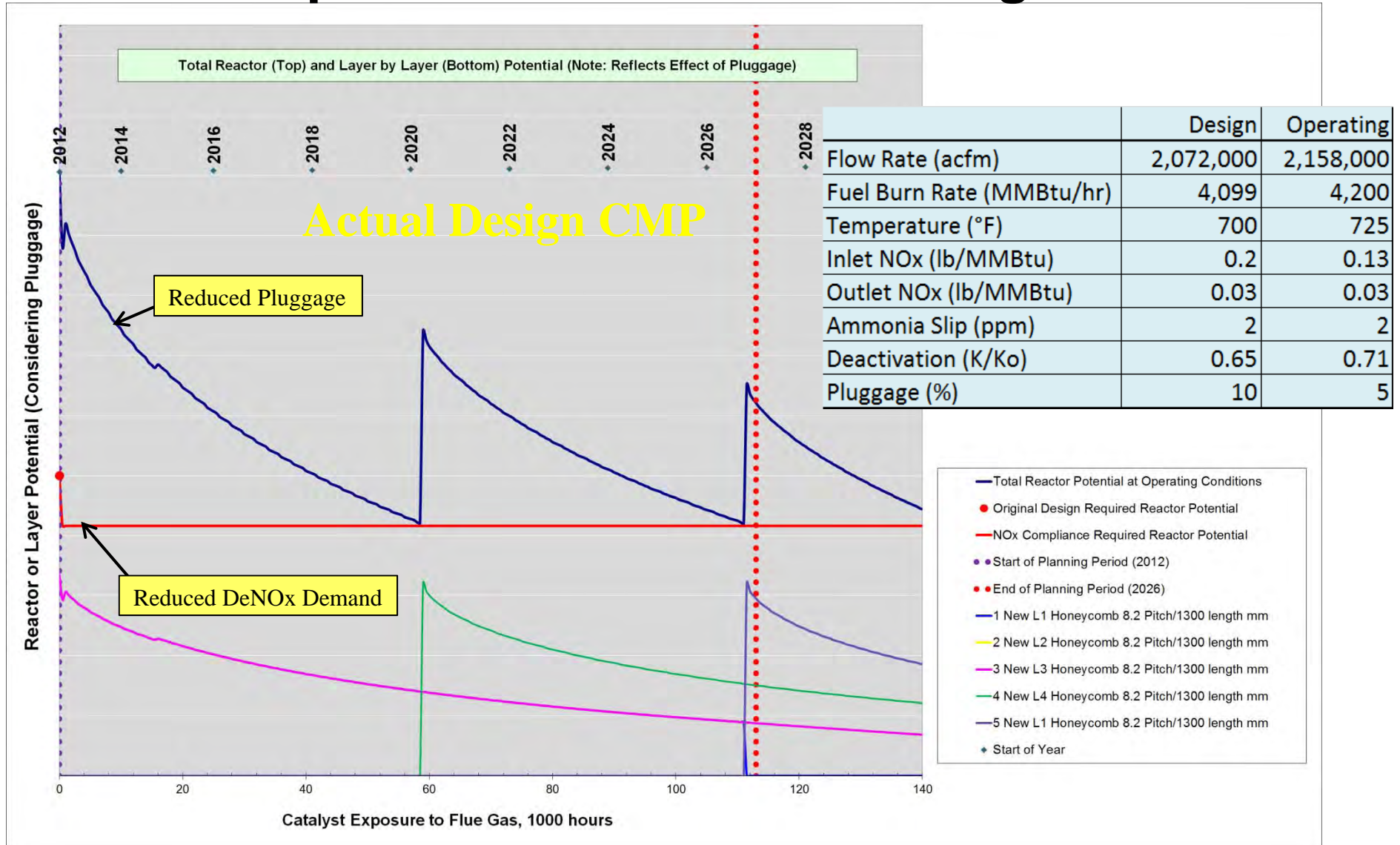


430 MW PRB Unit

Original Design Plan (3+1 Reactor/8.2 mm HC)



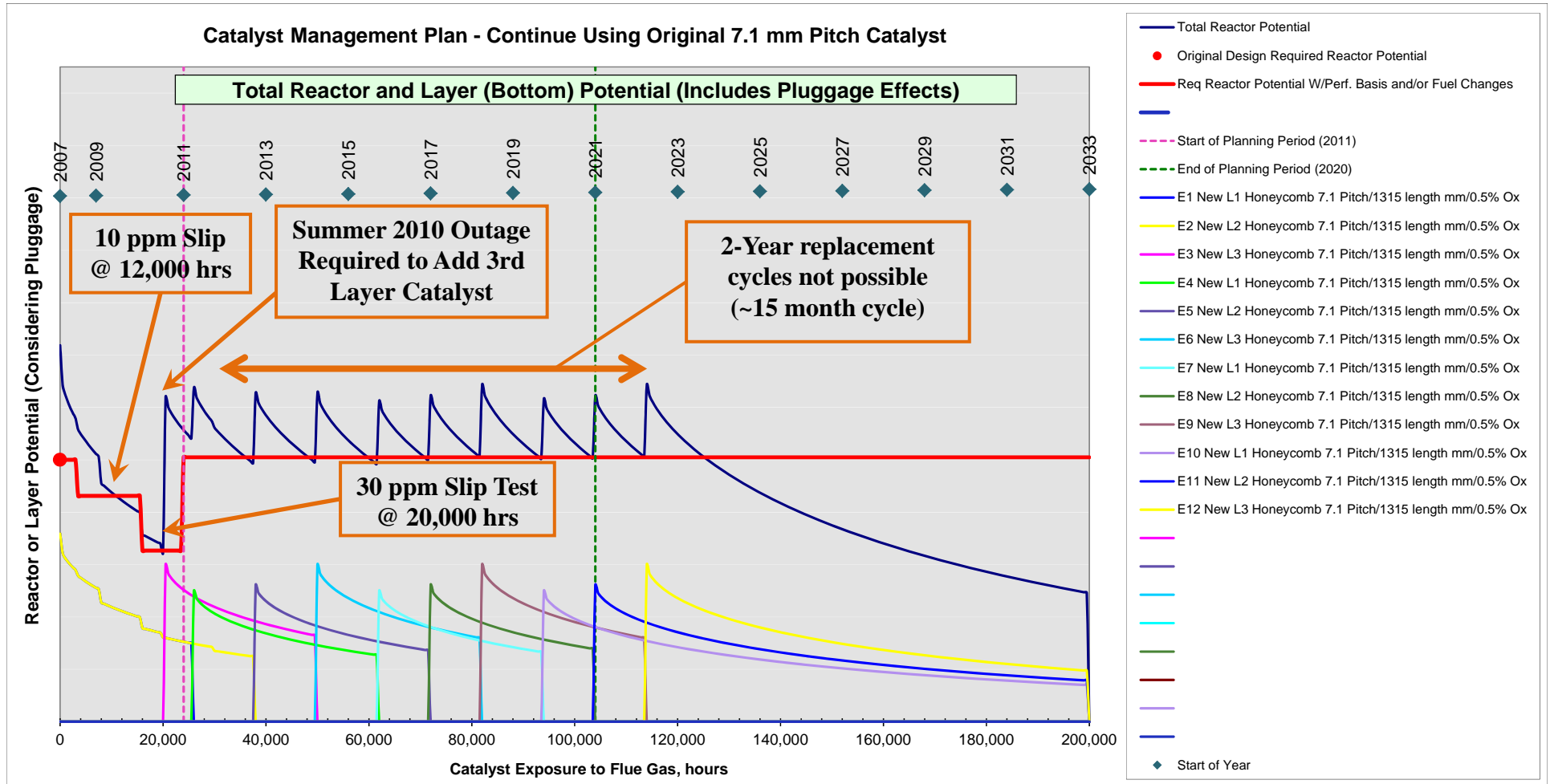
430 MW PRB Unit Operations Better than Designed



700 MW PRB Unit

Aggressive Initial Design by Others

(2+1 Reactor / 7.1 mm HC)



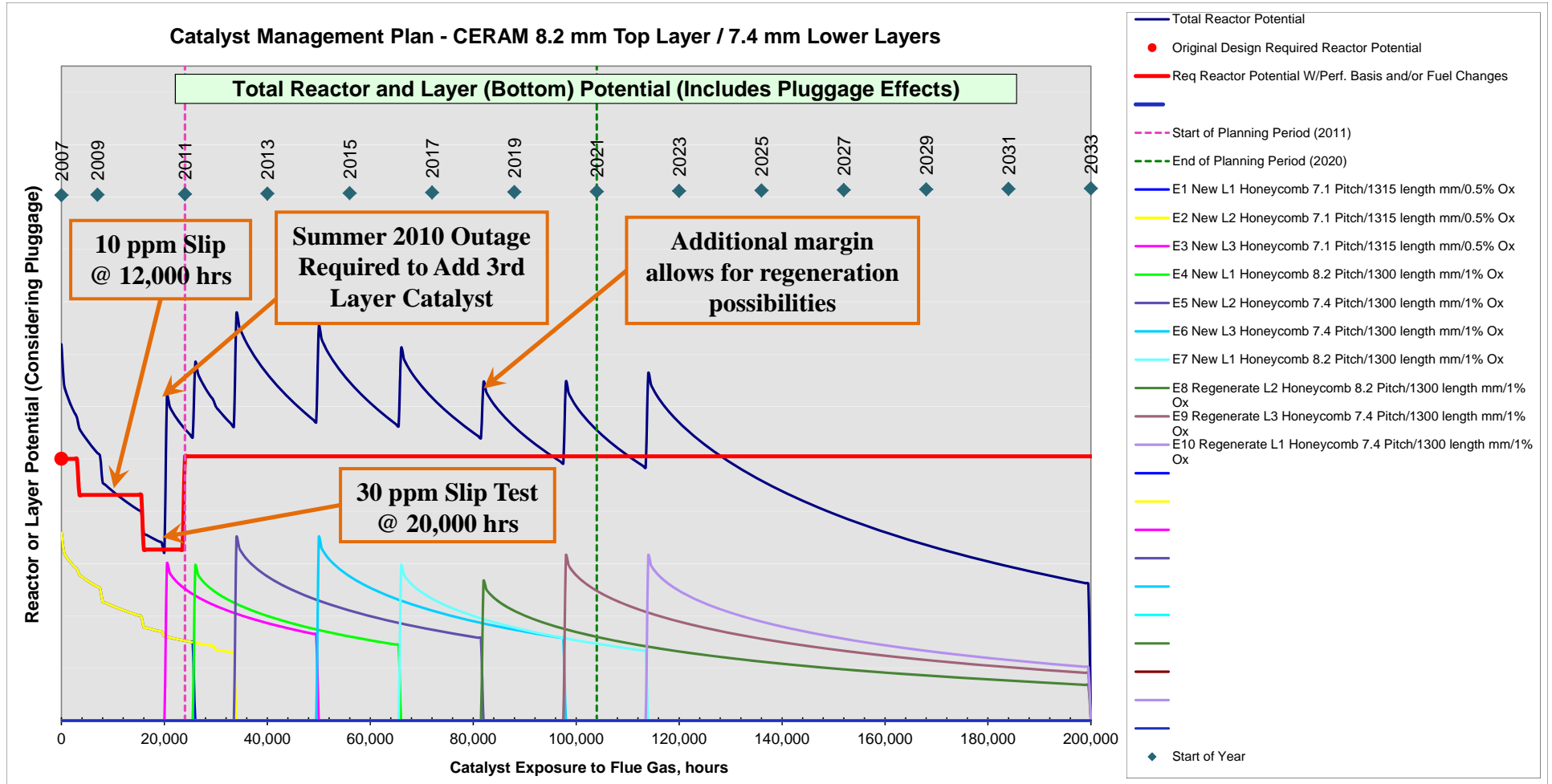
● **Aggressive (small) 7.1 mm Pitch**

● **Only 5% Design Pluggage (30% Actual)**

● **Aggressive Design $K/K_{o16_{\text{hr}}}$ 0.78 (0.72 Actual)**



CERAM Optimized CMP – 2 Year Replacement Cycles



• **Transition to Larger Pitch**

• **Reduced Pluggage Rates Significantly**

• **Optimized for Operating Conditions**



Presentation Summary

- Develop SCR Design Basis from Operating Data Statistical Analysis
- Consider Impacts of Design Deactivation and Pluggage Assumptions
- Consider Operating DeNO_x Demand and Reactor Potential
 - Impacts of Operating Conditions (Temp, O₂, Flow, etc.)
- Competitive Market Leads to Aggressive SCR System Design
 - Test A Easily Achieved by OEM
 - Test B Difficult to Administer by Owner
- Proactive SCR Design Analysis Limits SCR Operating Risks

Thank You!

Questions?

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