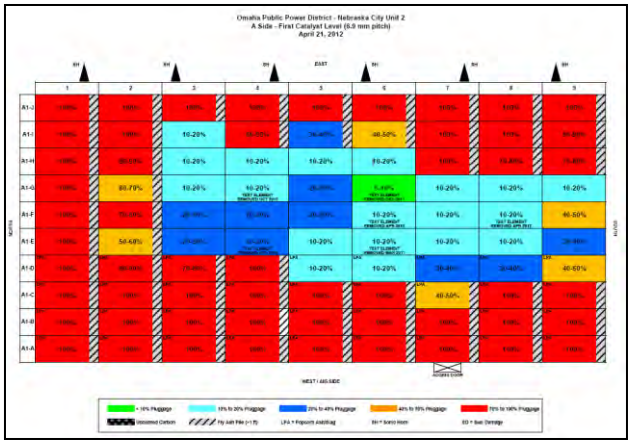
REINHOLD ENVIRONMENTAL Ltd.

2014 NOx-Combustion Round Table & Expo Presentations

February 10 & 11, 2014, in Charlotte, NC / Hosted by Duke Energy

Reinhold Environmental 2014 NOx-Combustion Round Table and Expo Presentation
February 11, 2014

"School of Hard NOx"



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IBIDEN

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Presentation Topics

- Nebraska Utility Case Example
  - Plant Operation and SCR Overview
  - SCR Performance and Initial Design
  - SCR Operation from 2011 - 2014
  - SCR Improvements
  - Current SCR Operation

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SCR Design and Operational Issues

- Nebraska Utility SCR System Problem Overview
  - Non-Universal Reactor Design
  - High Catalyst Pluggage (≈ 90%)
  - Step Change Drop in Catalyst Activity
  - LPA Deposition and Buildup
  - Catalyst Erosion and Mechanical Strength
  - High Ammonia Slip (≈ 10 - 14 ppm slip)
  - Premature Unscheduled Outage Needed to Support Catalyst Change Out Needs

Nebraska Utility Case Example

- 740 MW Commercial Operation 2009
- 100% PRB Coal Fired
- PC Boiler
- Low NOx Burners
- SCR
- Spray Dry Absorber/Fabric Filter
- Powder Activated Carbon-Injection

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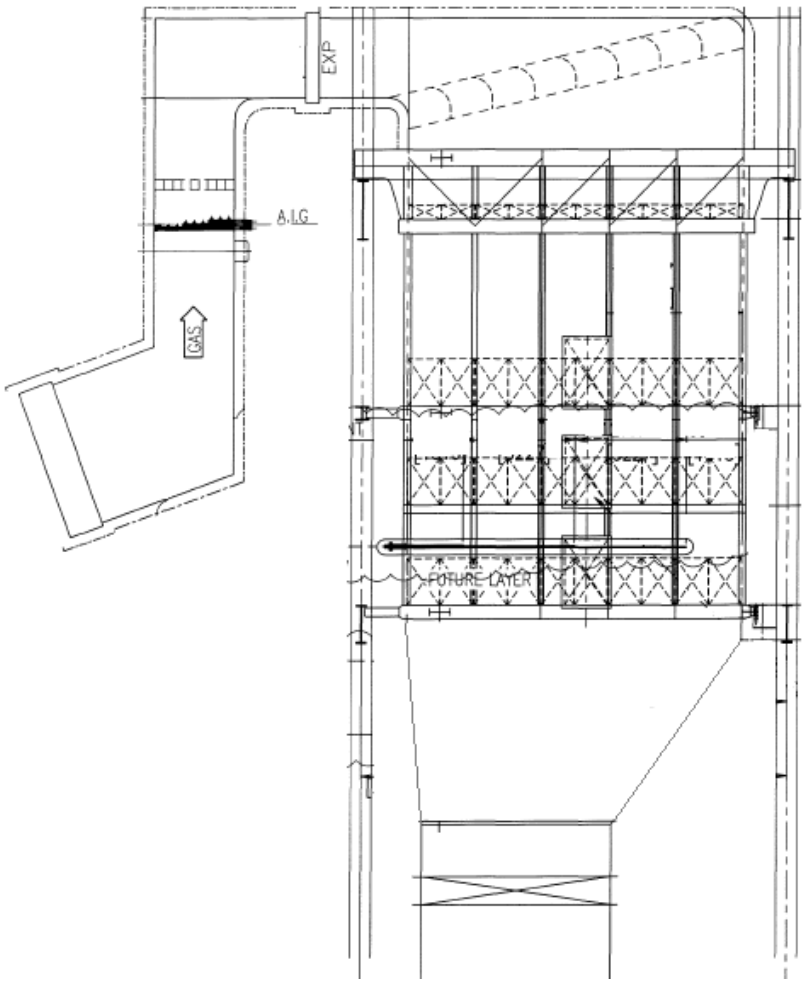
Nebraska Utility SCR Design



- High Dust
- 2+1 Layer Arrangement
- 2 Reactors
- Square Hood

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Original Catalyst Supply (By Others)

Catalyst Type	Honeycomb
NOx Reduction	71% (0.22 to 0.064 lb/MMBtu)
SO_2 to SO_3 Conversion Rate	1.0% per Layer (2% for 2 Layers)
Catalyst Pitch	6.9 mm (22 x 22 cell)
Catalyst Inner Wall Thickness	0.6 mm (Thin wall)
Catalyst Length	922 mm
Module Arrangement per Layer	9 x 10
Module Dimension	1889 x 946 x 1207 mm *Non-universal plan dimensions

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Catalyst RFQ For Spare Layer 2010

- Original Supplied Catalyst was Guaranteed for 16,000 hrs
- Fall 2010 RFQ for Spare Layer of Catalyst
- Installation of the Catalyst would occur during the Spring 2011
- Based on Modeling and Testing the Ammonia Slip was approximately 4 – 5 ppm at the time of the Spring Outage

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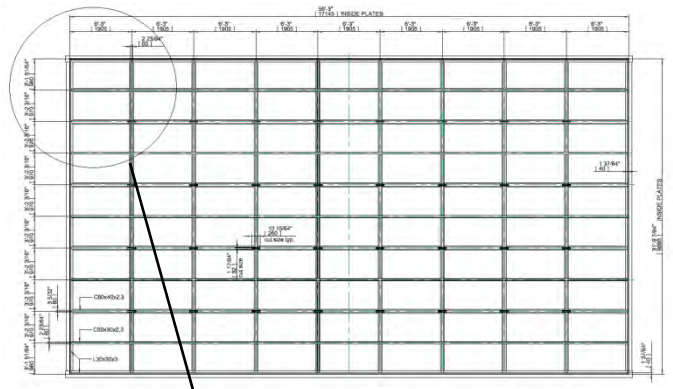
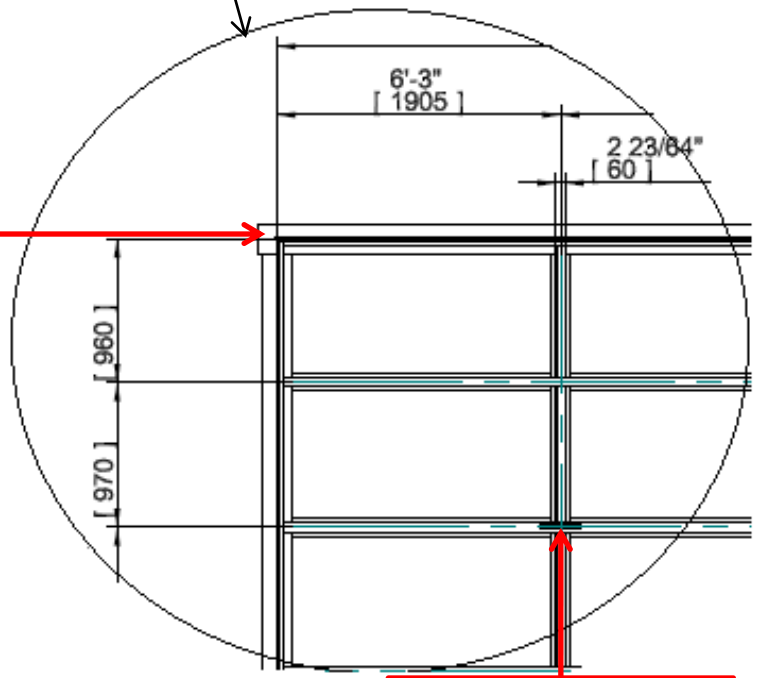
CERAM Spare Layer Catalyst Supply

- CERAM Wins Competitive Bid to Supply Spare Catalyst Layer
  - Catalyst to be Installed in Spring of 2011 (20,200 hrs)
  - Catalyst Installed into Third “Spare” Level
  - Larger Catalyst Pitch (7.4 mm) Selected by Utility
    - Based on Pluggage and DP Concerns
- At this Time, CERAM was not Fully Aware of all Potential Issues and Problems Related to the SCR Operations
- CERAM Discovers that Non-Universal Reactor Design Requires Slightly Smaller Catalyst Module Size for Limited Accessibility and Non-Universal Reactor Design

SCR Plan Arrangement

- Fixed Top Hung Design Catalyst Support Framing Required Special Sized Module Frames
- Design Does Not Utilize Reactor Wall Seals
- 32 mm Clearance Between Catalyst Modules for Seals





Reactor Wall

Hanger Straps

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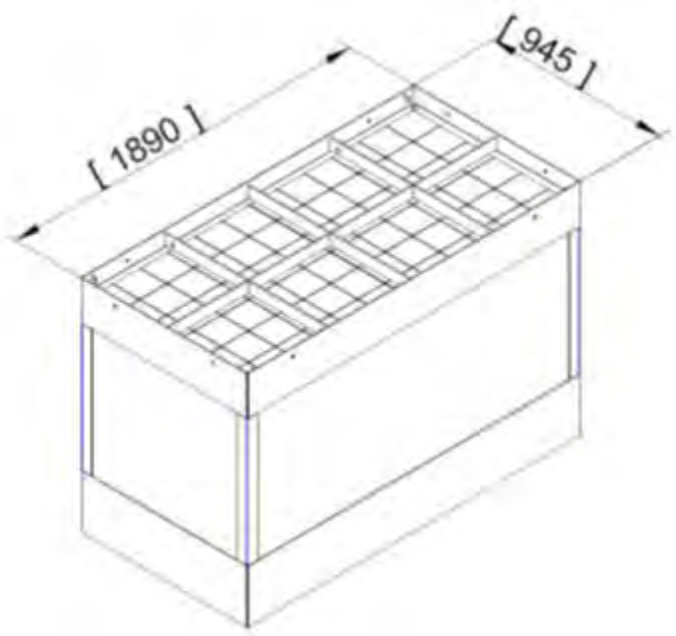
SCR Module Sizing

- Fixed Catalyst Support Framing
  Required Special Sized Module Frames
  - CERAM Standard Module Sizing
    (960 x 1900 x Height)
  - Nebraska Utility Module Size
    (945 x 1890 x Height)
- Limited Regeneration Options
  - Can Only Regenerate Their Own Catalyst Due to Size Constraints
- Limited Module Height
  - Loading Door Size



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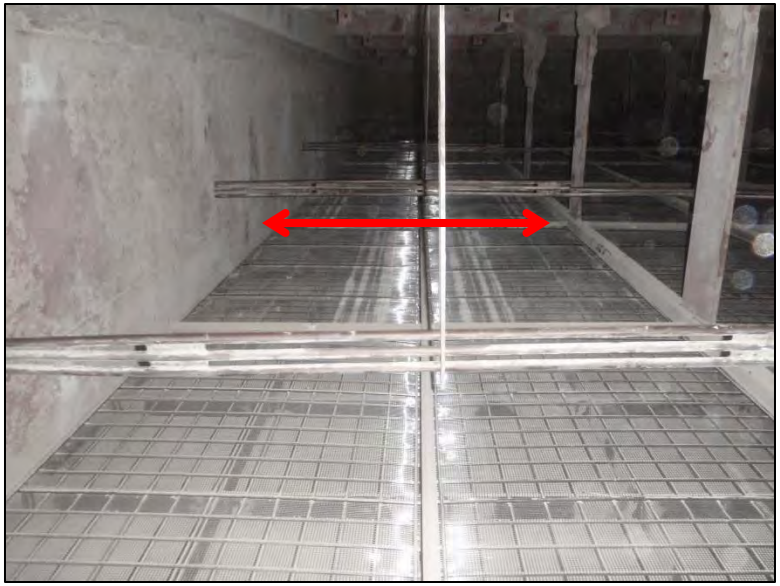
SCR Plan Arrangement & Module Sizing

- Fixed Catalyst Support Framing
  Required Smaller Sized Module Frames
- No Module Wall Seals



Limited Spacing Due to Support Structure

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SCR Module Sizing

- Limited Module Height
  - Loading Door Size

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CERAM Catalyst Management

- Shortly after Catalyst Purchase, Utility Sends RFQ for Catalyst Management Services
- CERAM Wins Competitive Bid
- Catalyst Management Begins with CERAM in Early 2011
  - Reactor Inspections
  - AIG Tuning
  - Data Surveillance and Trending
  - Catalyst Testing and Analysis
  - Manage CATLife® Modeling

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CERAM SCR Inspection 2011

- Moderate Catalyst Wall Thinning of Existing 6.9 mm pitch (22 cell) Catalyst (Supplied by Others) Observed in Levels 1 & 2
- Catalyst Pluggage Levels (20,200 hrs)
  - Level 1 Pluggage was 27%
  - Level 2 Pluggage was 21%
- CERAM 7.4 mm Pitch Catalyst Installed in Level 3
  - Larger Catalyst Pitch (7.4 mm Pitch 20 Cell Catalyst)
  - Increased Wall Thickness (0.60 → 0.80 mm)
  - Sloped Module Seals Instead of Flat Seals (Improved Ash Shear)
- Existing Catalyst Samples Removed for Testing

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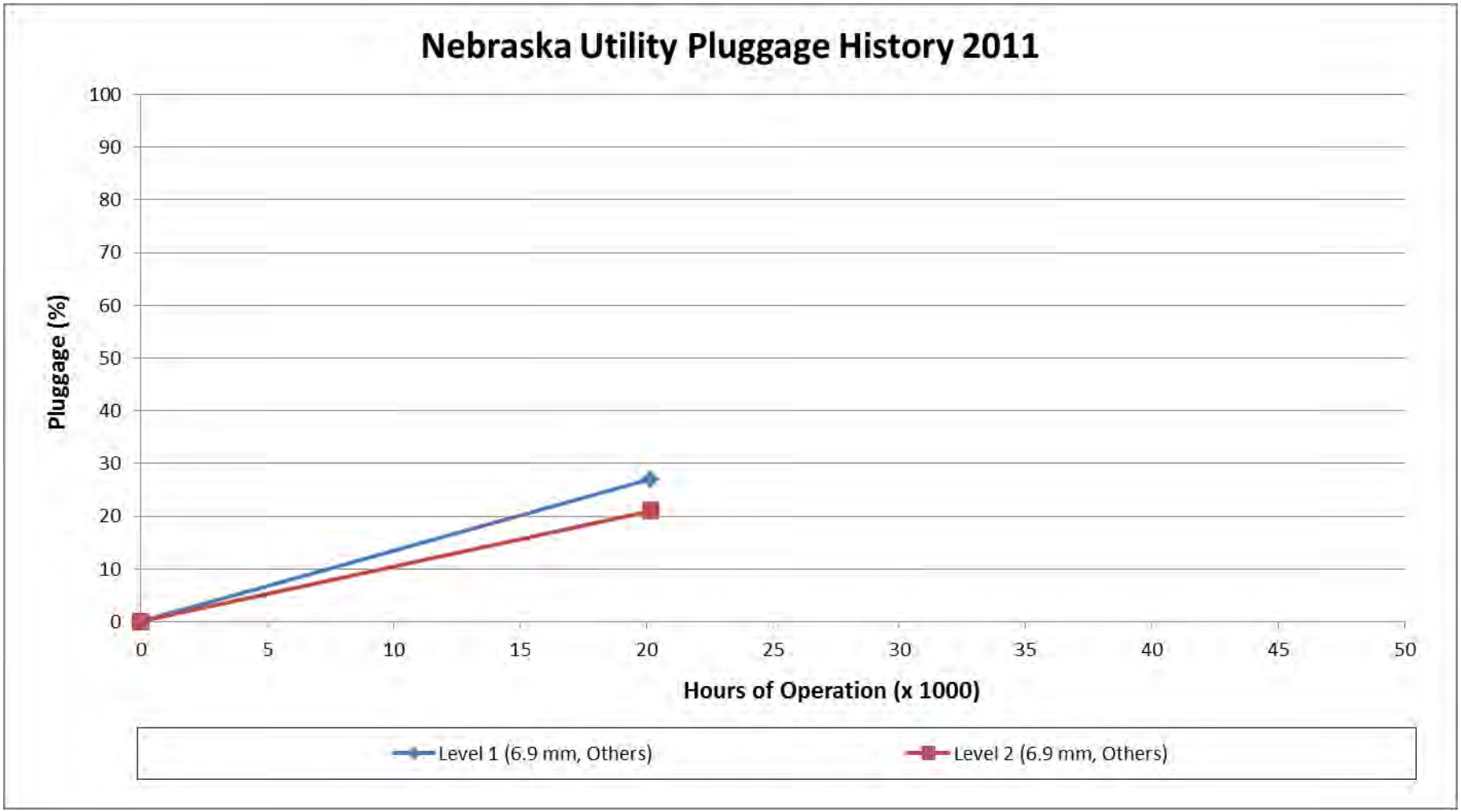
Catalyst Pluggage Tracker



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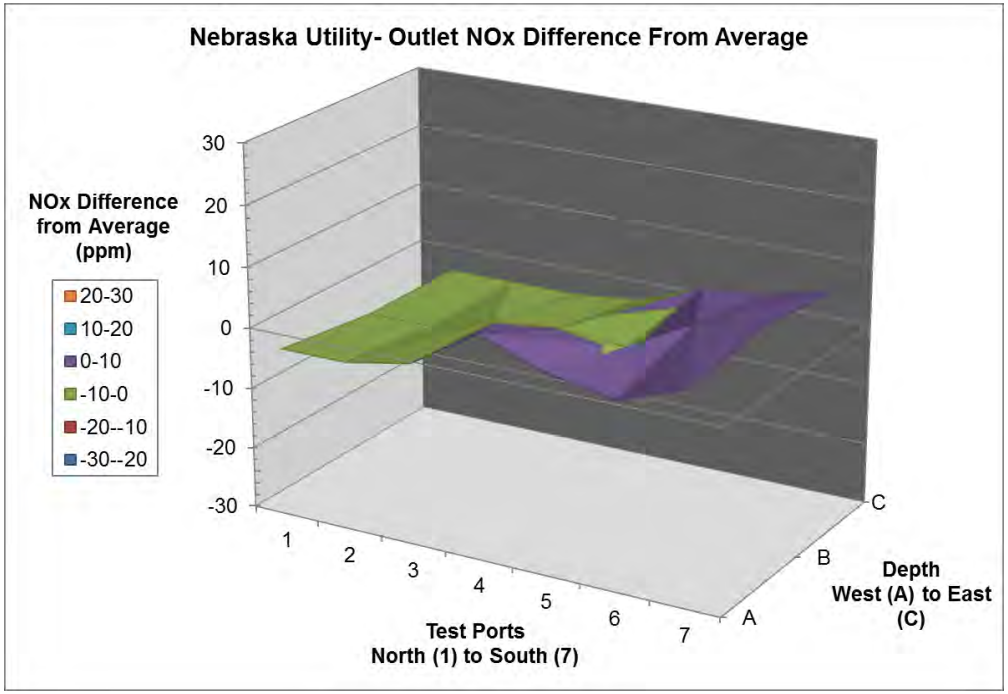
AIG Tuning 2011

- AIG tuning performed by CERAM
- Ammonia distribution found to be excellent
  - NOx Distribution +/- 10 ppm



Nebraska Utility Baseline AIG Tuning 2011 Summary			
	Units	**'A' Side Corrected Outlet NOx**	**'B' Side Corrected Outlet NOx**
Average Outlet NOx	ppm	53	45
Max Outlet NOx	ppm	60	48
Min Outlet NOx	ppm	49	38
Standard Deviation	ppm	4	3
Target Distribution:			
Points within ±10 ppm		21 of 21	21 of 21
Points within ±5 ppm		19 of 21	20 of 21

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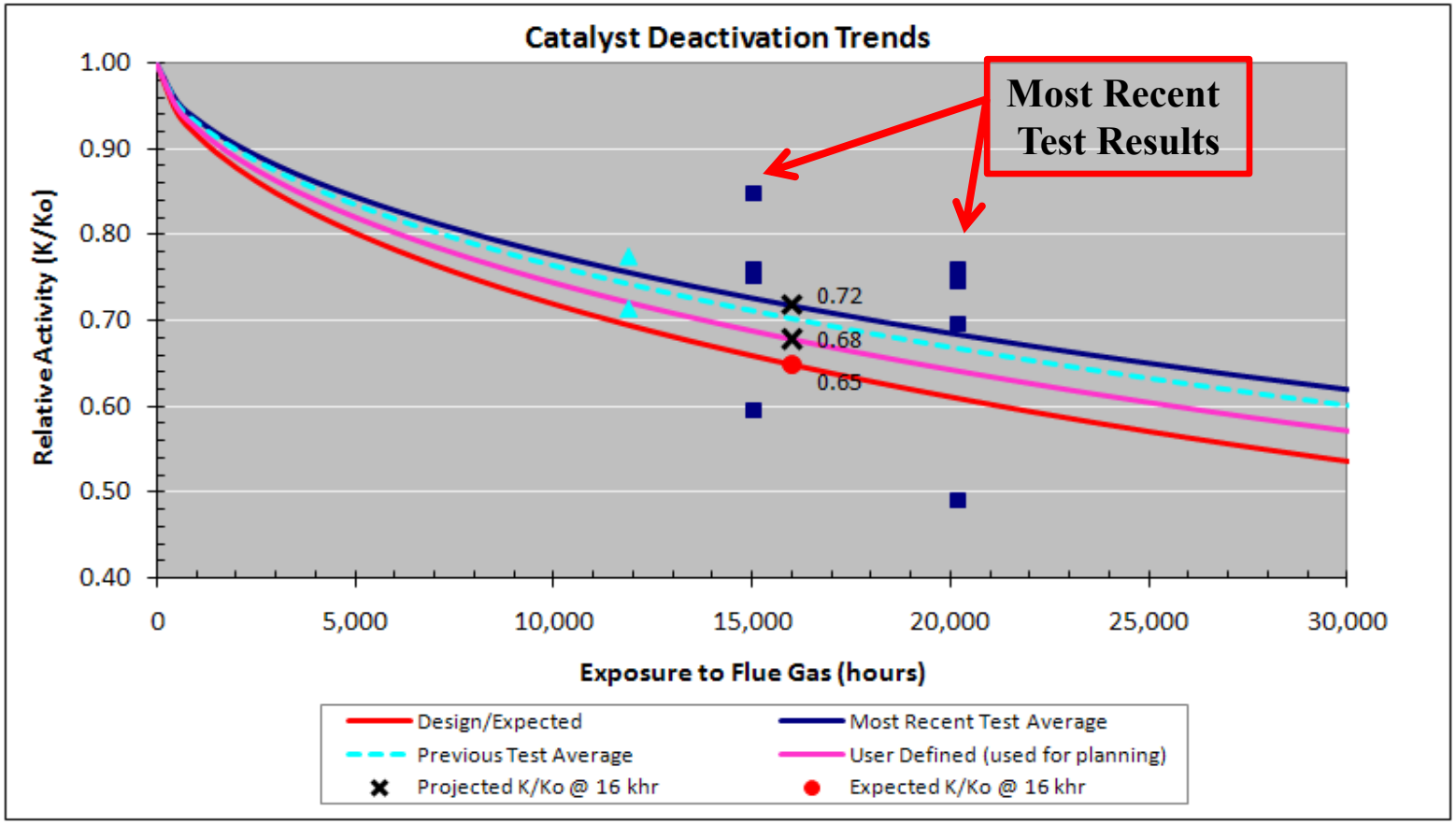
2011 Catalyst Testing Results



Test Average K/Ko at 16k hrs of 0.72

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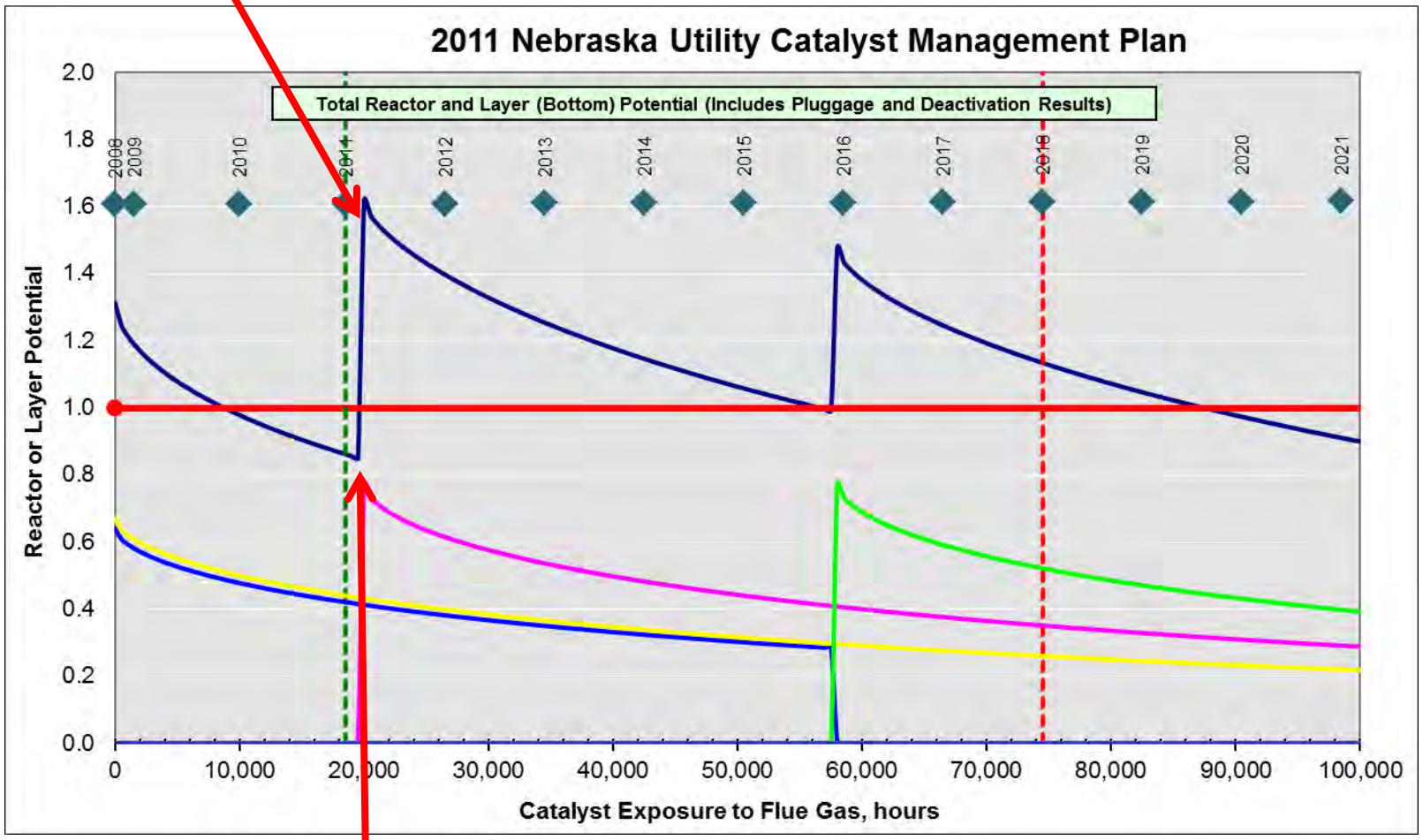
2011 Catalyst Management Planning

CERAM 7.4 mm Catalyst Addition



Modeling Predicted Ammonia Slip near 4 – 5 ppm

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2011 Design Conditions & Predictions

Nebraska Utility Catalyst Event Prediction	
Parameter	**Current Operations Basis**
Inlet NOx, lb/MBtu	0.20
Outlet NOx, lb/MBtu	**0.064**
Ammonia Slip, ppmvd @ 3% O_2	2.0
Fuel Burn Rate, MBtu/hr	6,298
Flue Gas Temperature, F	685
Gas Flow Rate, ACFM	3,434,564
Deactivation Basis	**Expected Replacement Timing and Season Year**
$K/Ko\,|_{16K} = 0.68$	**58,000 hours (Fall 2015)**

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2011 Ammonia Slip Testing

- Ammonia Slip Testing Conducted in Fall 2011
  - Modeling Predicted 0.5 ppm Slip with New Catalyst Installed in Spring 2011
  - Test Results Showed Slip was near 2 ppm
- First Indication that the Model Result did Not Agree With Reality, but why?
- Catalyst Testing to be Performed during the Next Available Outage in 2012 to Confirm Slip Test Results

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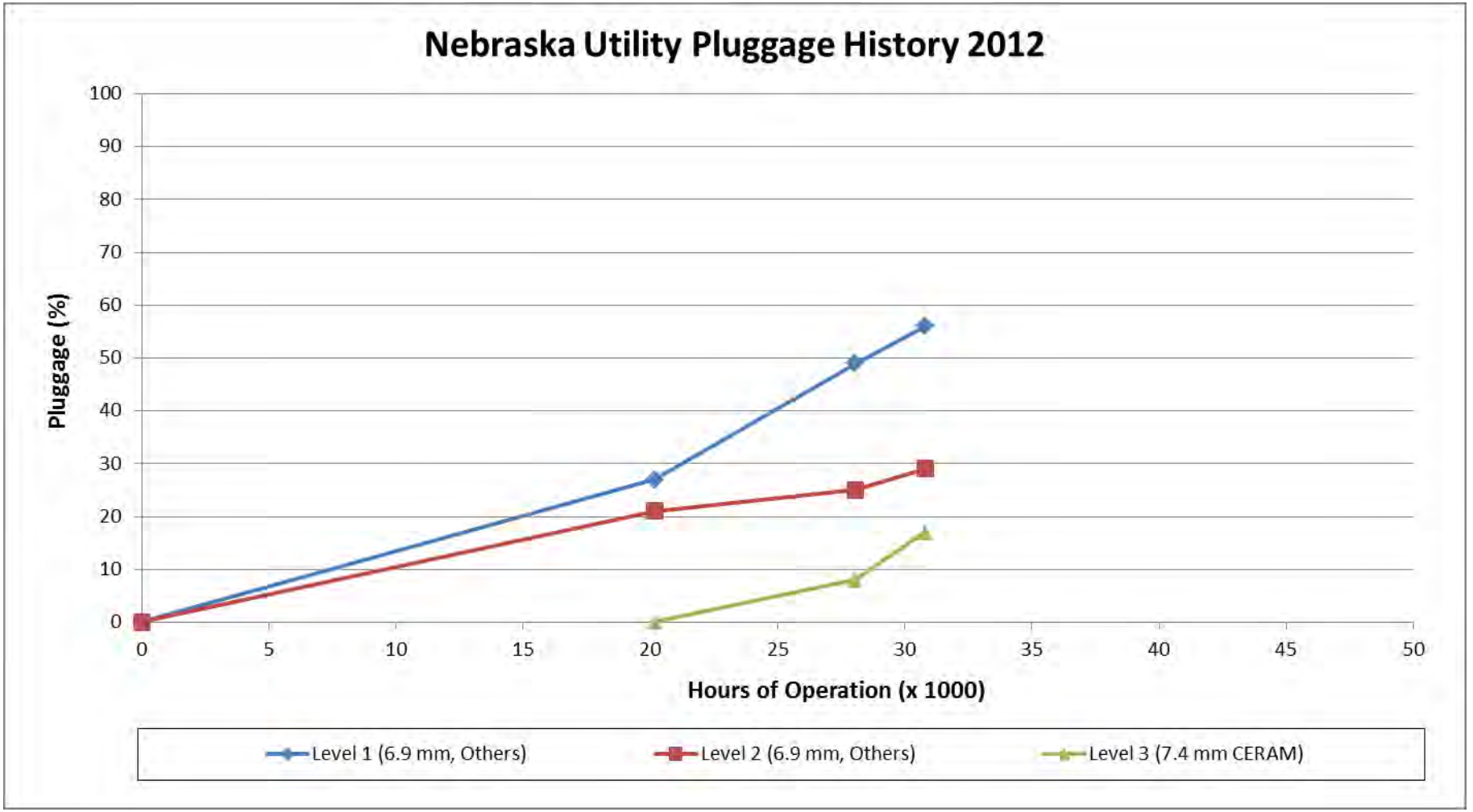
Catalyst Pluggage Tracker



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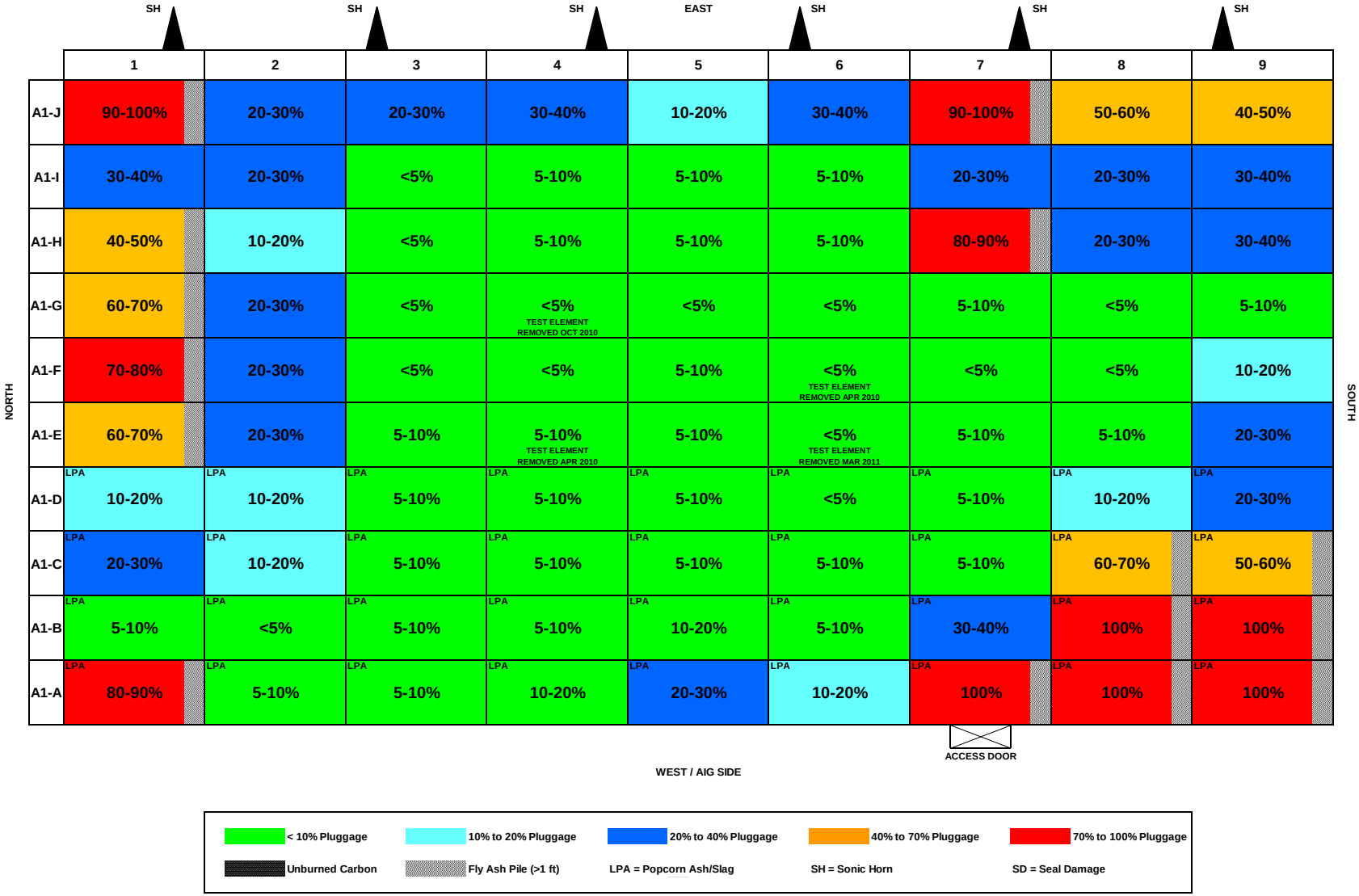
2011 Level 1: A Side



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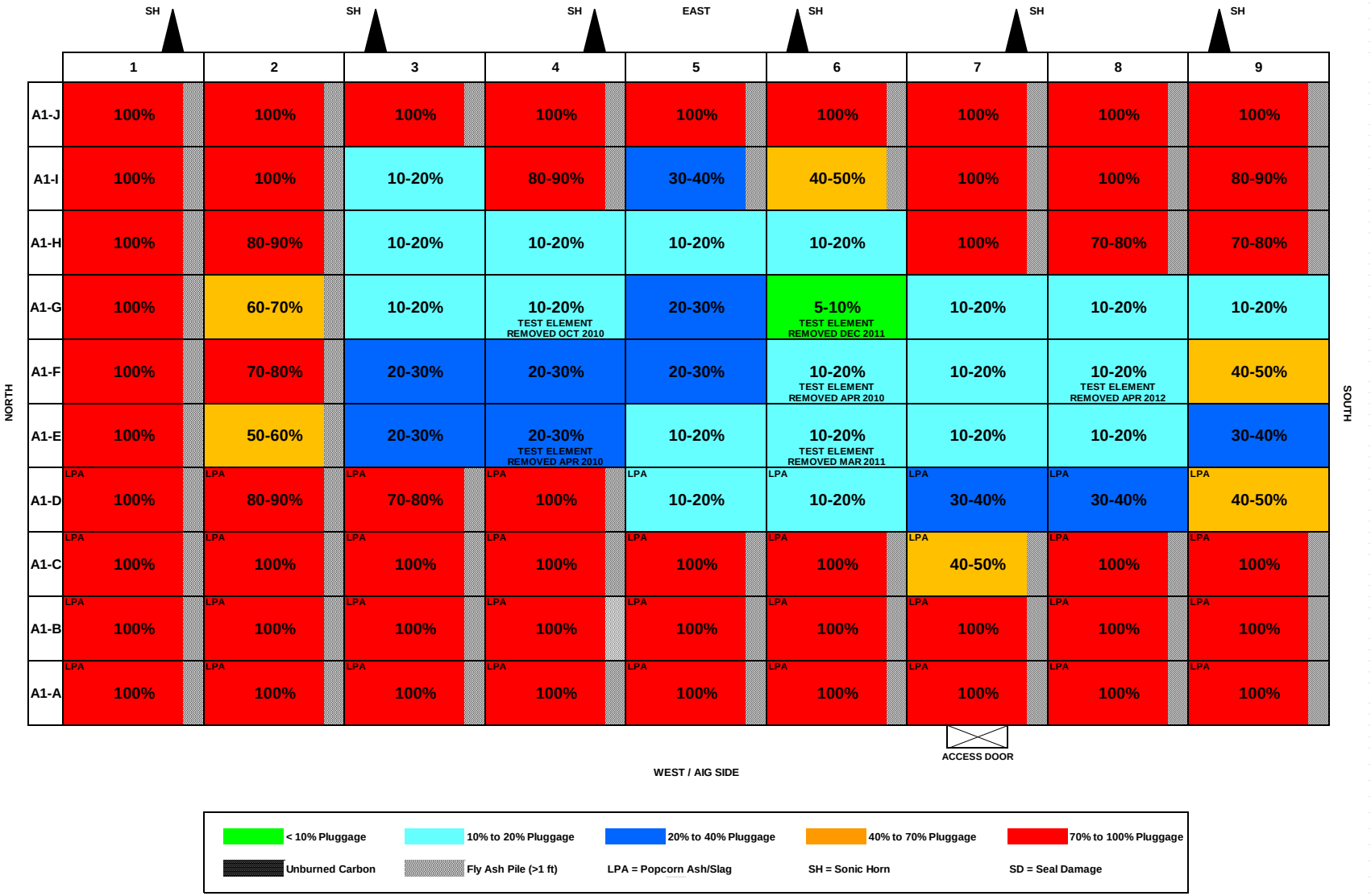
2012 Level 1: A Side



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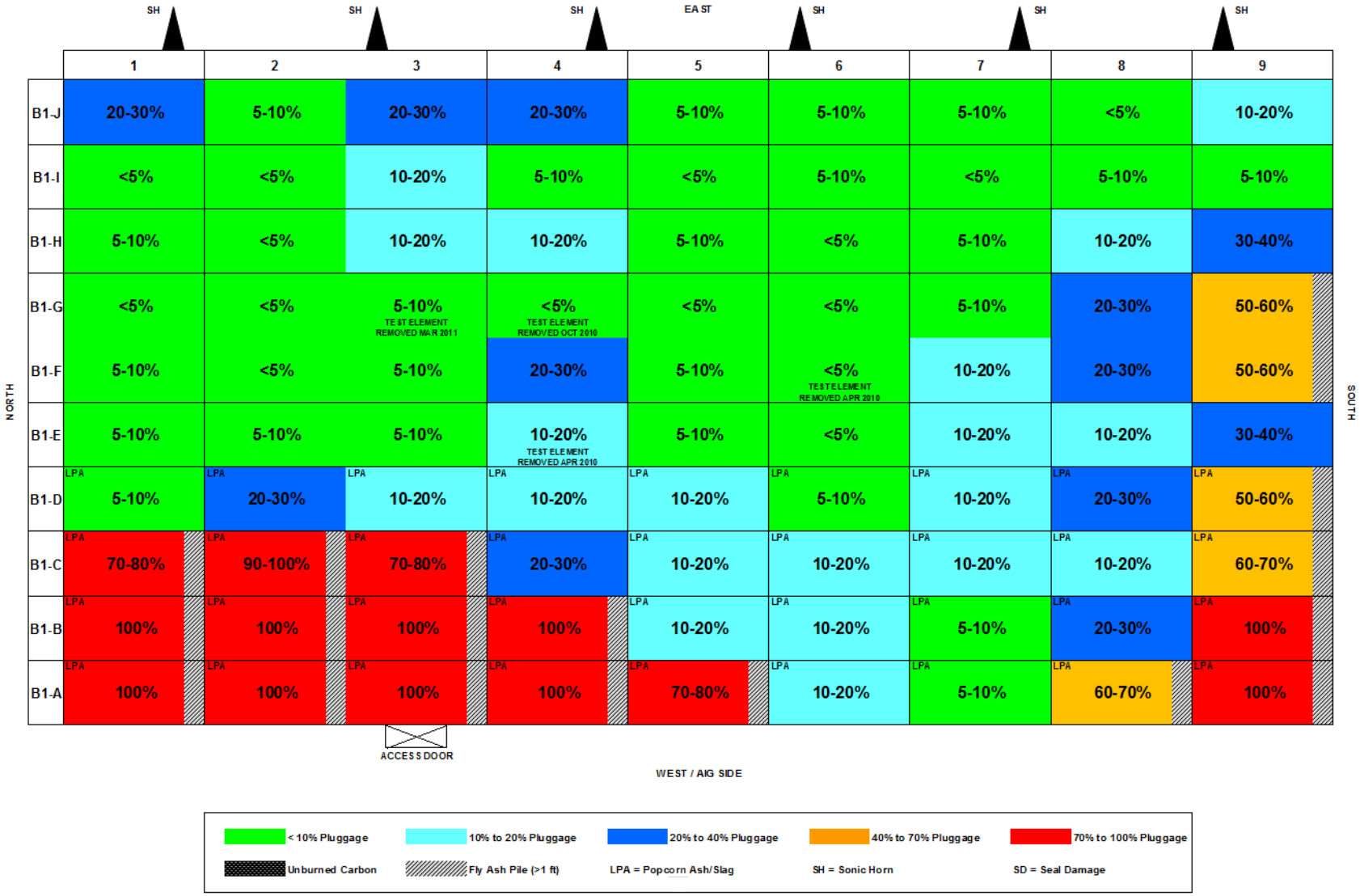
2011 Level 1: B Side



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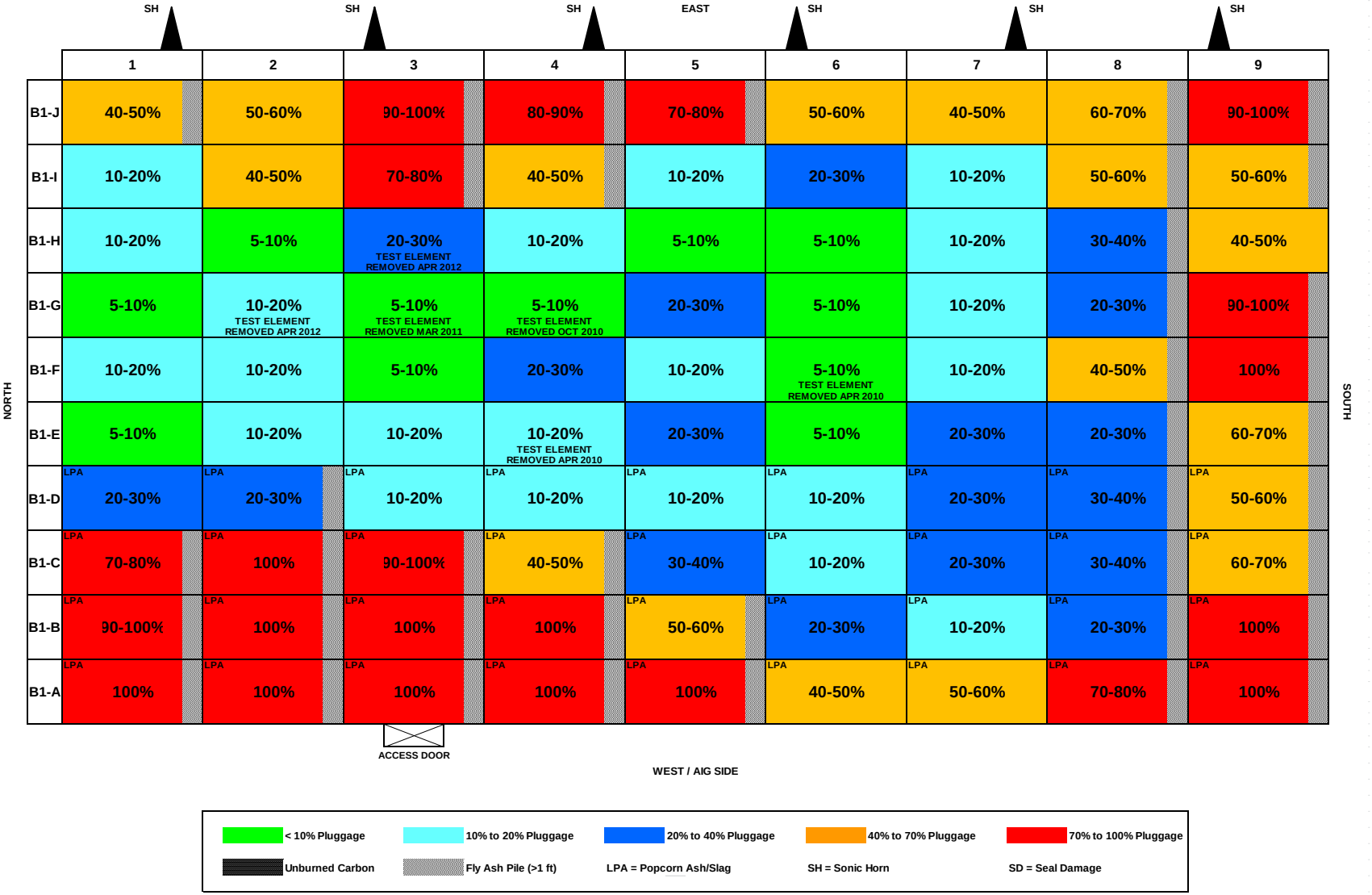
2012 Level 1: B Side



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2012 Inspection Results

- LPA and Fly Ash Buildup on Covergrates (Small Opening)
- Ash Piles 2 - 5 ft
- Ash Accumulation on Flat Module Seals (Supplied by Others)

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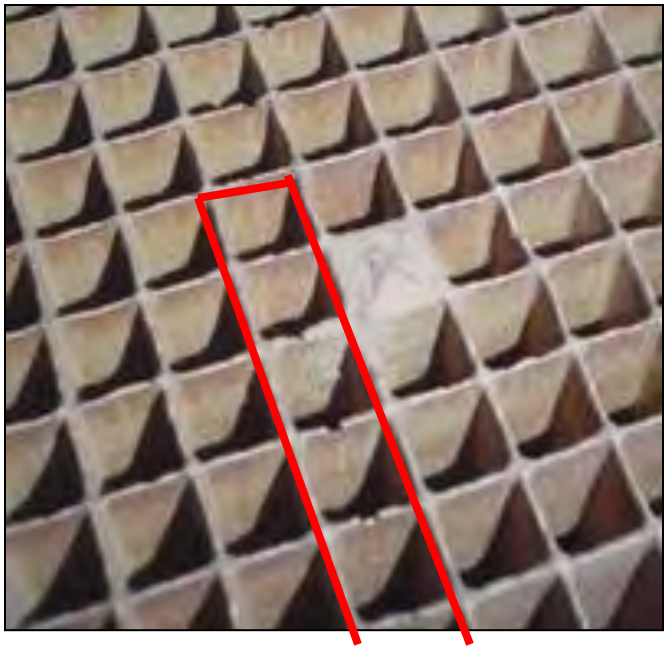
2012 Inspection Results

- Severe Catalyst Wall Thinning (Levels 1 & 2)
  - Small Fissures and Cracks at the Inlet Face of the Catalyst
  - Internal Cracks Observed with Test Elements
  - Regeneration was not an Option due to Mechanical Condition and Thin Wall Construction of Original Catalyst



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2012 Inspection and Cleaning

- Not Possible to Clean Thin Walled Honeycomb Catalyst by Other's
  - Air Lance Cleaning Damaged 4 Modules
    - Cleaning Halted Due to Damage
  - Affected Modules were Covered with a Steel Plate to Prevent Further Damage

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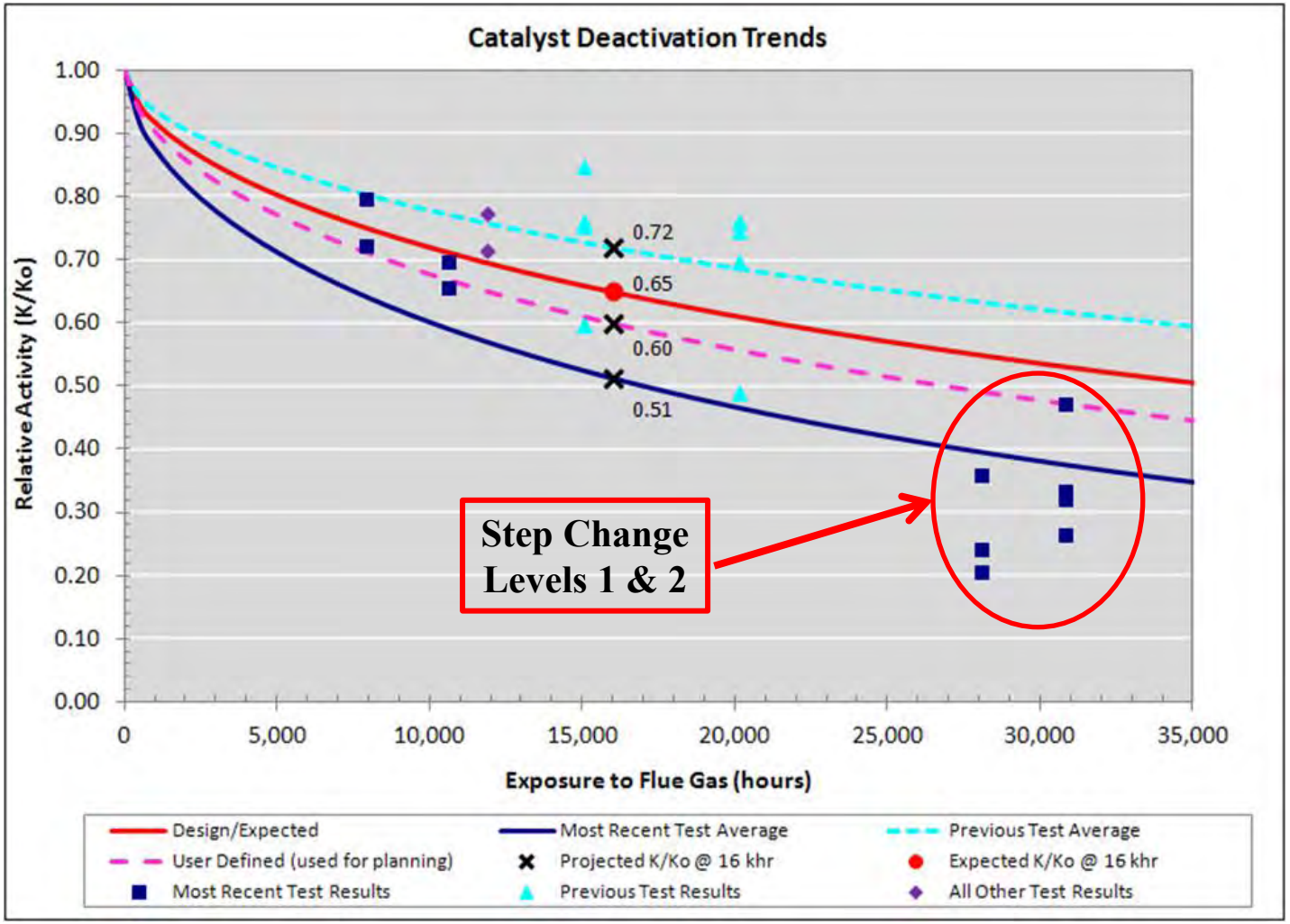
2012 Catalyst Testing Results



Test Average K/Ko at 16k hrs of 0.51
(2011 was K/Ko at 16k hrs 0.72)

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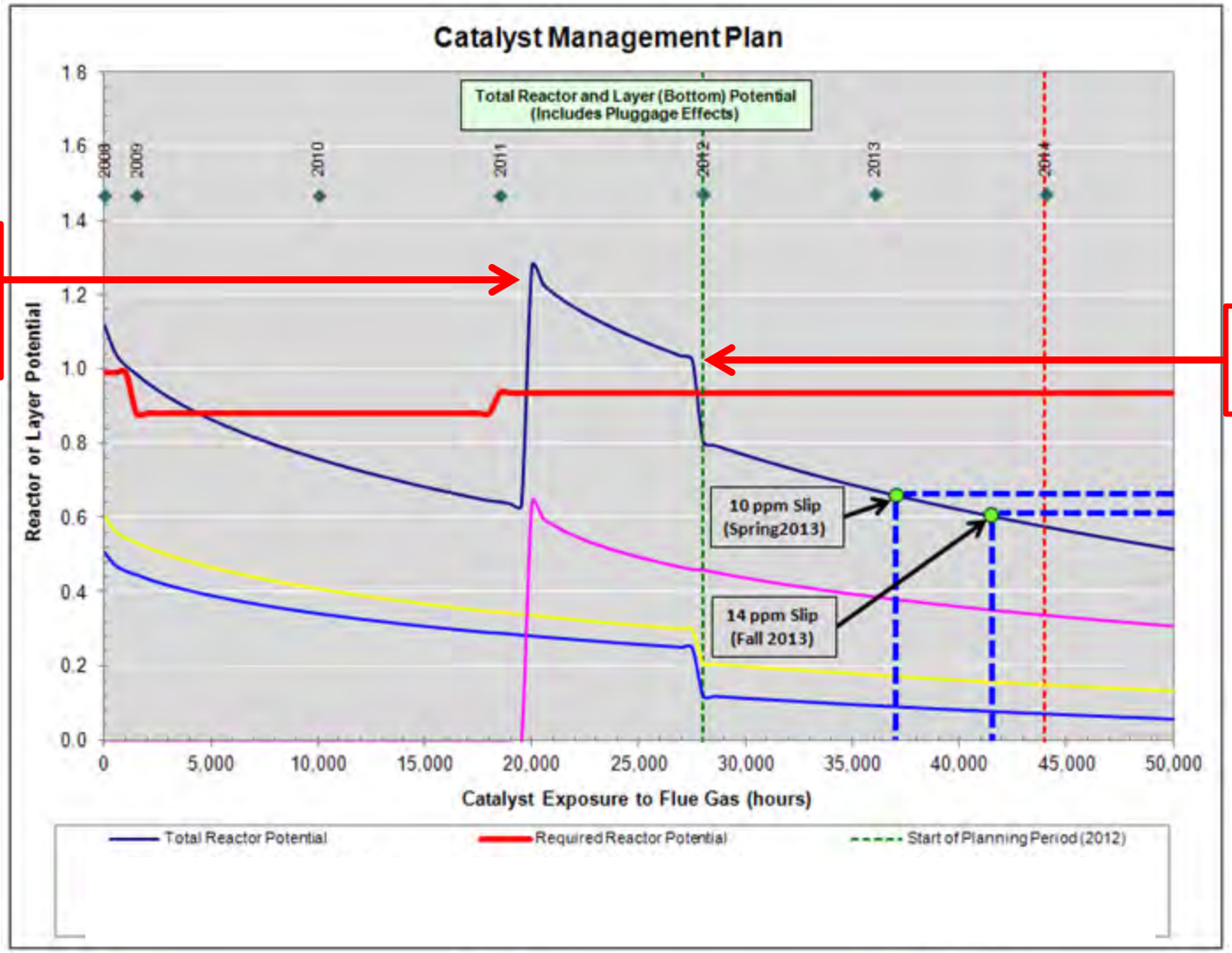
2012 Catalyst Management Plan

Install CERAM 7.4 mm



Step Change Levels 1 & 2

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2012 Catalyst Testing

- Severe Step Change Deactivation Observed in the 1st and 2nd Level ($K/Ko|_{16khr} = 0.51$)
  - Calcium Sulfate Fouling and Phosphorus Poisoning
  - Low Tungsten Content in Catalyst
  - Thinning of the Catalyst Walls (Pore Structure)
- Step Change was not Observed in the 3rd Level of CERAM Catalyst

	Model 2011	Model 2012
Relative Activity (K/Ko)	0.71	0.46
Normalized Relative Activity ($K/Ko|_{16khr}$)	0.72	0.51
Expected Replacement Timing and Season Year	Fall 2017 (2 ppm slip)	Spring 2013 (10 ppm slip)

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2012 Catalyst Management Planning

- Catalyst Types (Replacing Layer 1 and 2 with Larger Pitch)
  - Catalyst Types
    - Install 7.4 mm Pitch Honeycomb Catalyst
    - Install 8.2 mm Pitch Honeycomb Catalyst
    - Install 5.6 mm Pitch Plate Catalyst
  - Catalyst Install Schedules
    - Remove both 6.9 mm Pitch Catalyst, Install 1 Layer
    - Remove both 6.9 mm Pitch Catalyst, Install 2 layers
  - Modified Operating Conditions
    - Higher Slip
    - Lower Inlet NOx

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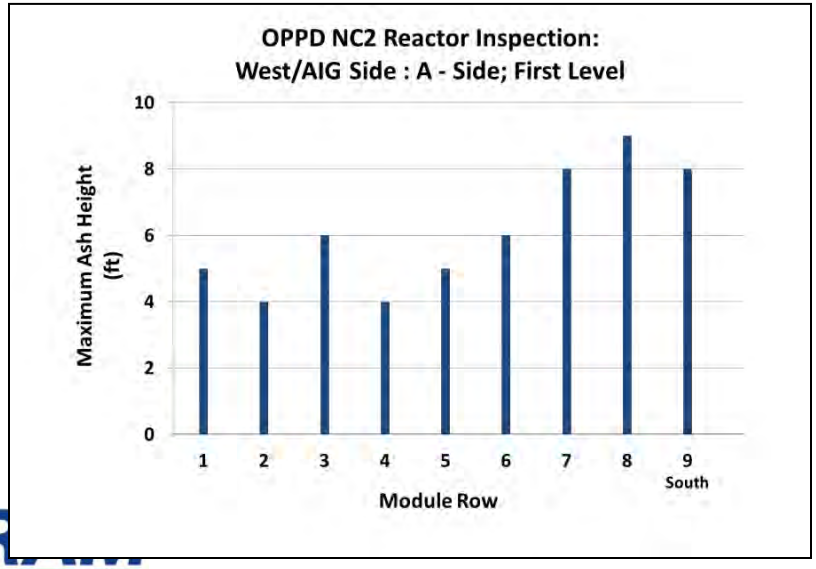
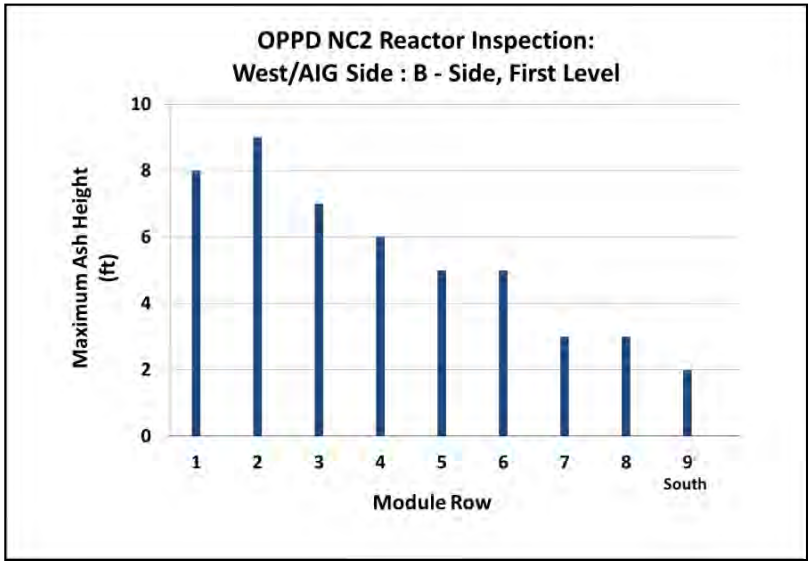
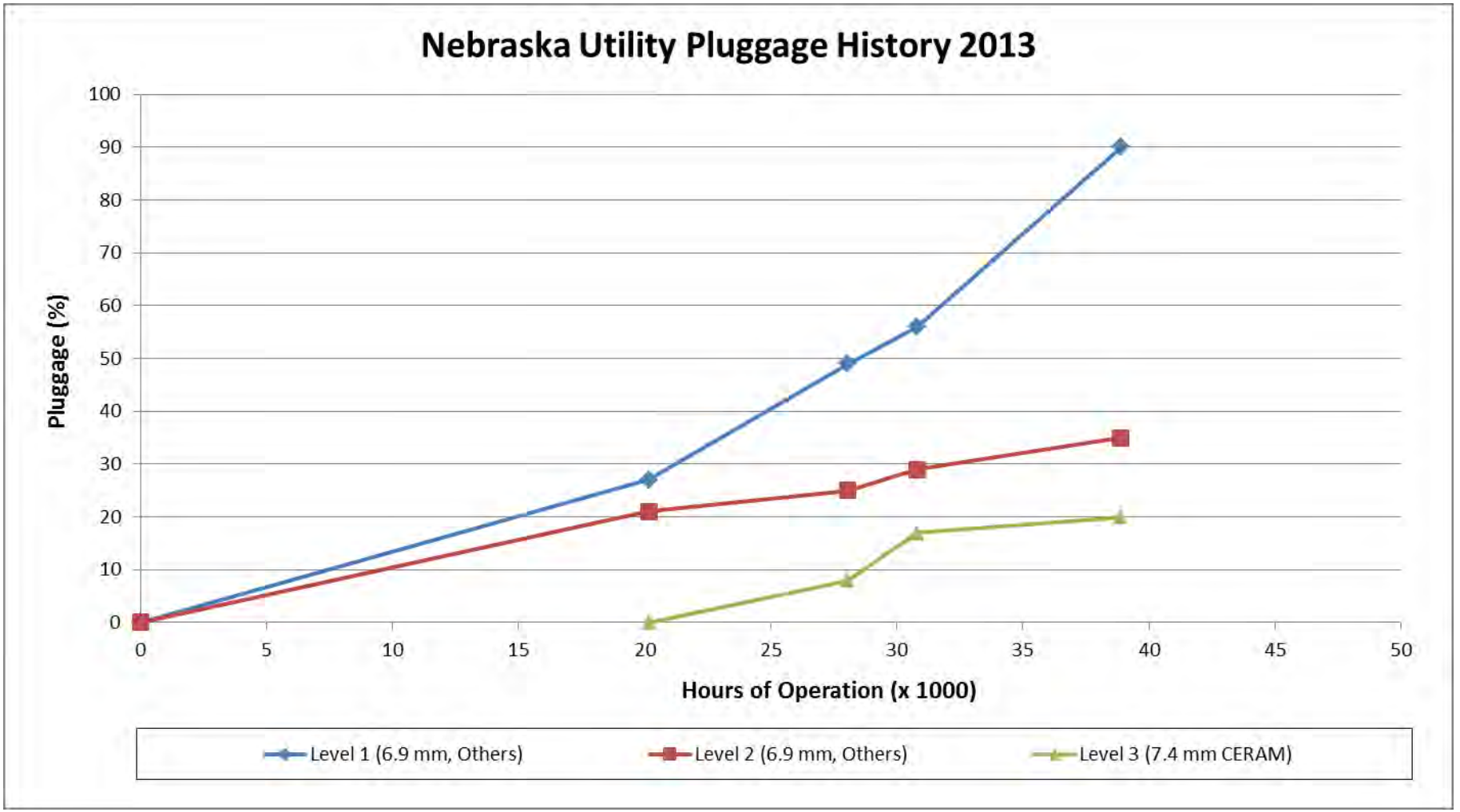
SCR Conditions as of Spring 2013

- CERAM Conducted a Reactor Inspection After 38,800 hrs
  - Level 1 Pluggage: **90% !!!**
    - Mechanical Damage/Erosion Contributed to Pluggage Rates
  - Level 2 Pluggage: 35%
  - Level 3 Pluggage: 20% (Consequence of Layer 1 and 2 Pluggage)
- Ash Piles Ranging from 4 to 9 ft Tall Along AIG Side of the Reactor
- LPA Accumulation on Cover Grates in Level 1





Catalyst Pluggage Tracker



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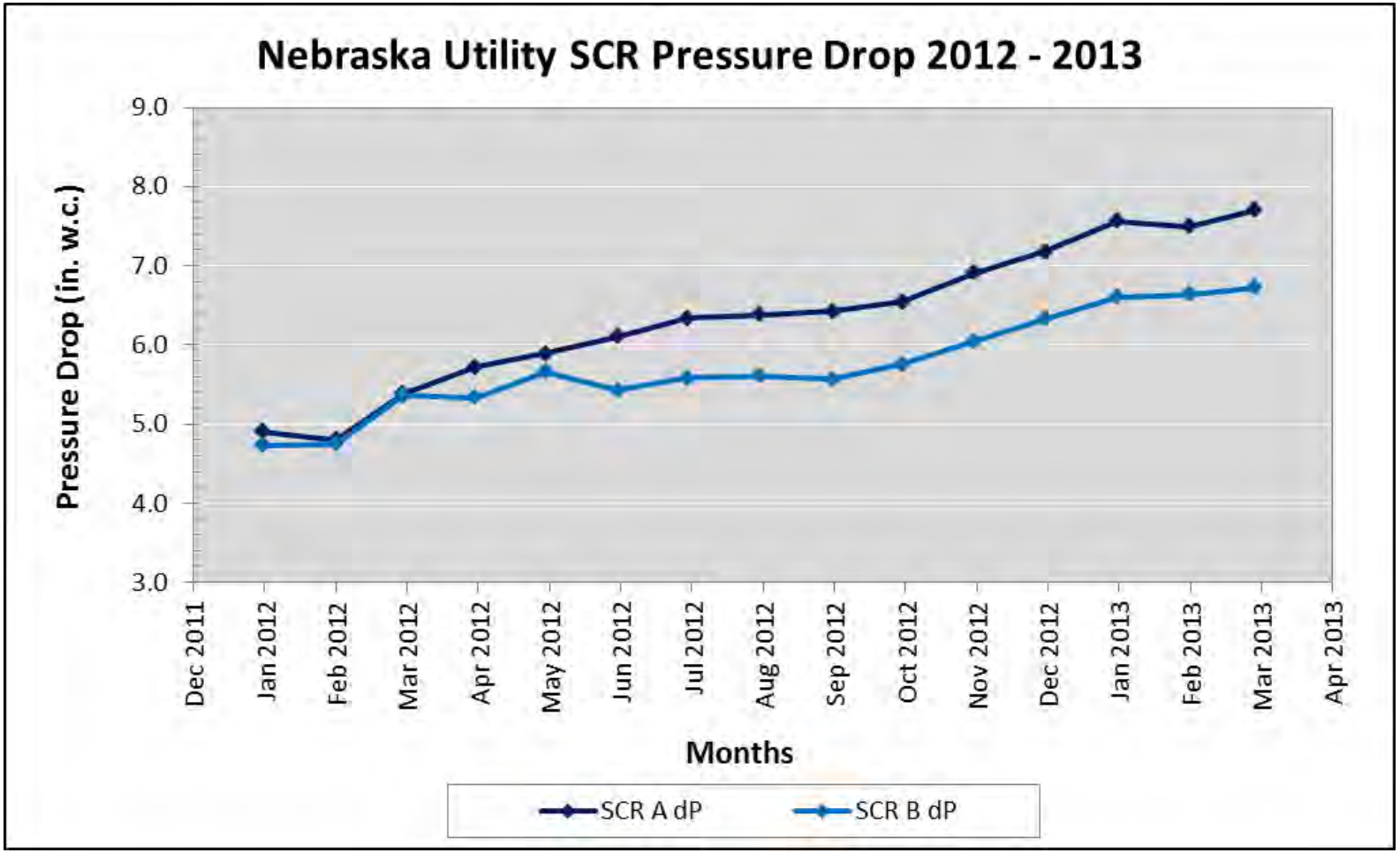
2012 - 2013 Catalyst SCR Pressure Drop



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Nebraska Utility SCR

What Went Wrong?

1) Poor flow Distribution Through the Reactor, LPA Accumulation on Covergrates
2) Aggressive Catalyst Design by Other Honeycomb Supplier
   - 6.9 mm Pitch Catalyst (Aggressive for PRB)
   - 43% Catalyst Pluggage (Levels 1 & 2)
3) Thin Wall Catalyst (<0.6 mm), Pluggage, and Erosion did not Allow for Regeneration
4) Step Change Drop in Catalyst Activity
5) 2 Initial Catalyst Layers (2+1 Reactor)
   - Operates as 3+0 With More Frequent Change Outs

Result is Very High Ammonia Slip and Frequent Catalyst Change Outs

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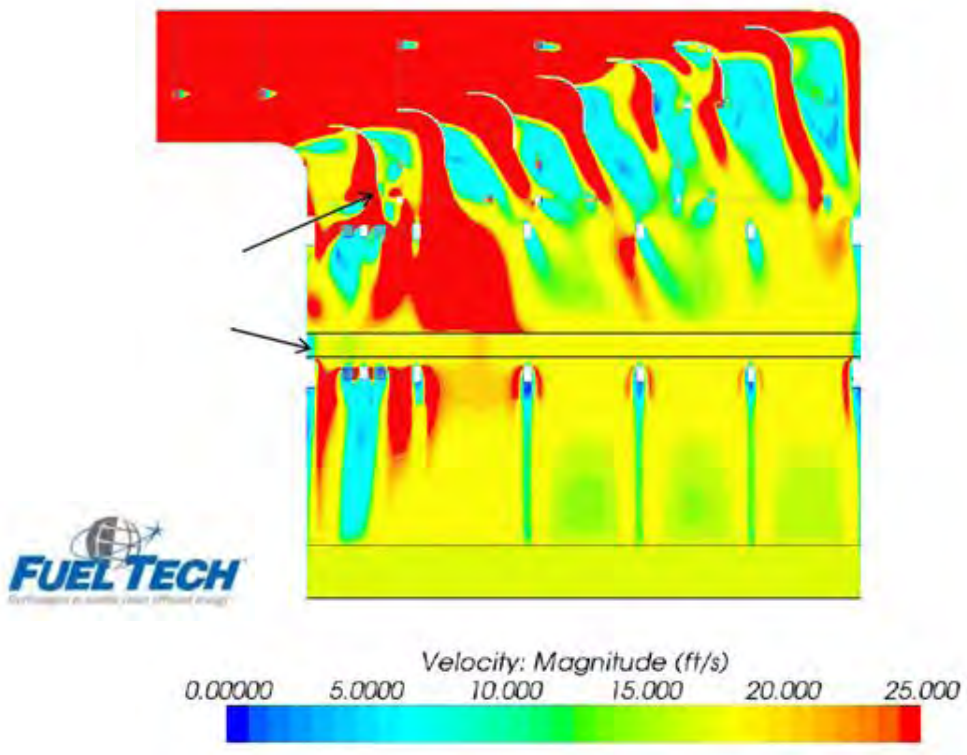
SCR Improvements & Solutions

- CERAM Recommended Utility Perform Flow Modeling of the SCR
  - Confirm Areas of Poor Flow in the Reactor
  - Identify Possible Solutions to Reduce Pluggage



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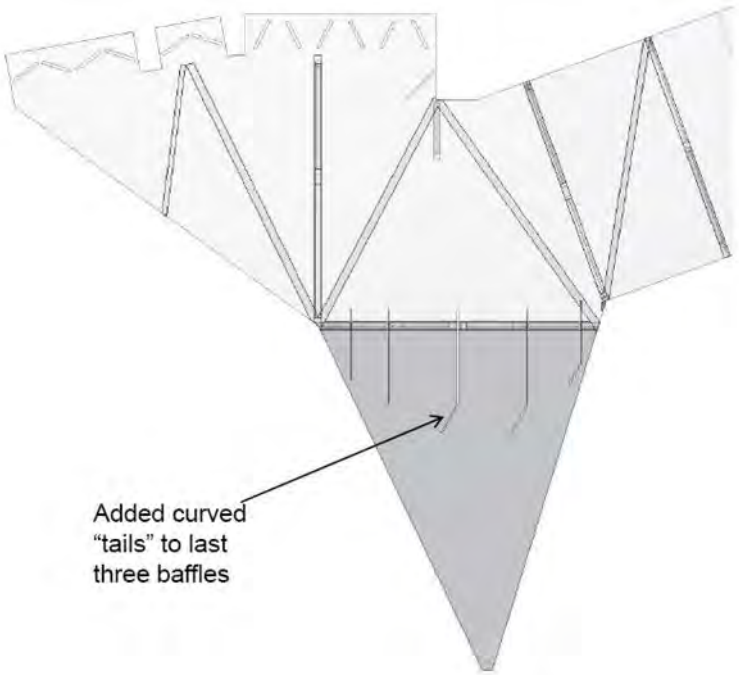
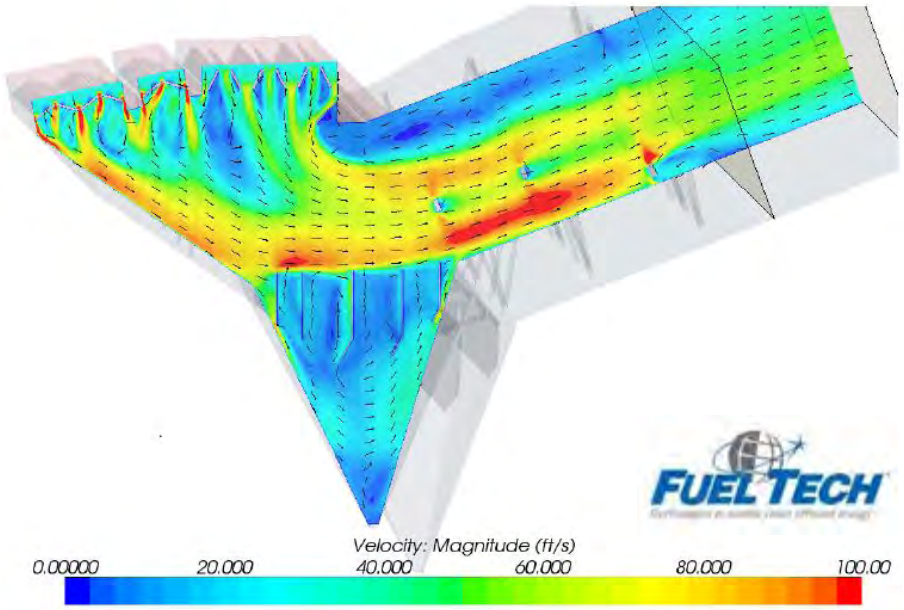
SCR Improvements & Solutions

- Reduce LPA Accumulation within the SCR
  - Baffle Plates Installed at the Economizer Hopper
  - Modeling Predicts 89% LPA Removal (Baseline 54%)
  - Negligible Increase to System Pressure Drop (≤0.1 in. w.c.)





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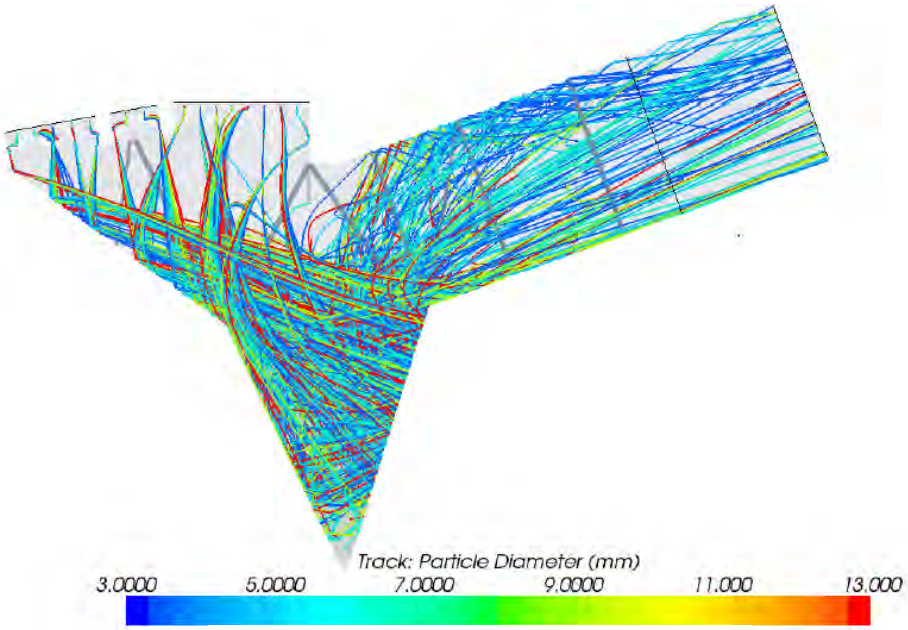
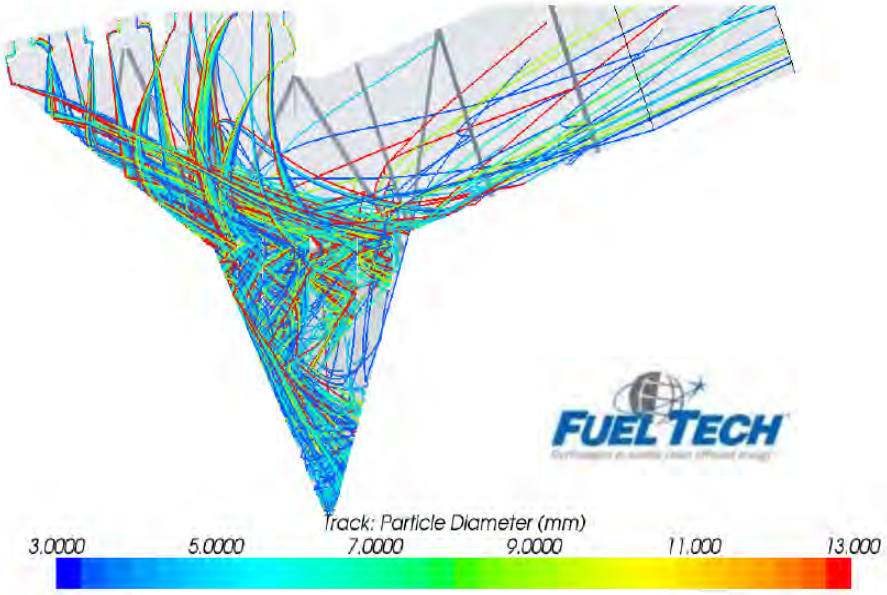
SCR Improvements & Solutions

- Particle Modeling Performed
  - Baseline Yielded 54% Particle Removal
  - Baffle Plate Option 5 Yielded 89% Particle Removal



Baseline



Baffle Plate Option 5

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SCR Improvements & Solutions

- Catalyst Cleaning Planning Guide and Procedure developed by CERAM for the Utility
- Objectives of the Catalyst Cleaning and Procedure Guide:
  - Assist in Determining the Frequency and Magnitude of Catalyst Cleaning Efforts
  - Provide an Efficient Cleaning Procedure to Follow When Cleaning Does Occur
- Cleaning Guide can be Used to Evaluate Short Term Outages (3 – 7 days) and Extended Outages (Planned or Unplanned)

SCR Improvements & Solutions

- Catalyst Cleaning Guidelines
  - **Outage Duration** – Calculate Expected Time Available for Cleaning
  - **Cleaning Frequency** – Determine Time since Last Thorough Cleaning
  - **Catalyst Cleanliness** – Estimate Catalyst Pluggage based on Pressure Drop
  - **Cleaning Effectiveness** – Estimate Catalyst Pluggage Recovery
  - **Cleaning Costs** – Calculate Catalyst Cleaning Cost
  - **Fan Energy Cost** – Calculate Energy Cost Based on Pluggage / Reactor Pressure Drop

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SCR Improvements & Solutions

- Utility Installed Additional Catalyst Cleaning Devices in 2013
  - Installed Air Cannons / Ash Sweepers in Level 1 (A & B Reactors)
  - Operation Planned to Begin Spring 2014 (if needed)

From Martin Engineering Website

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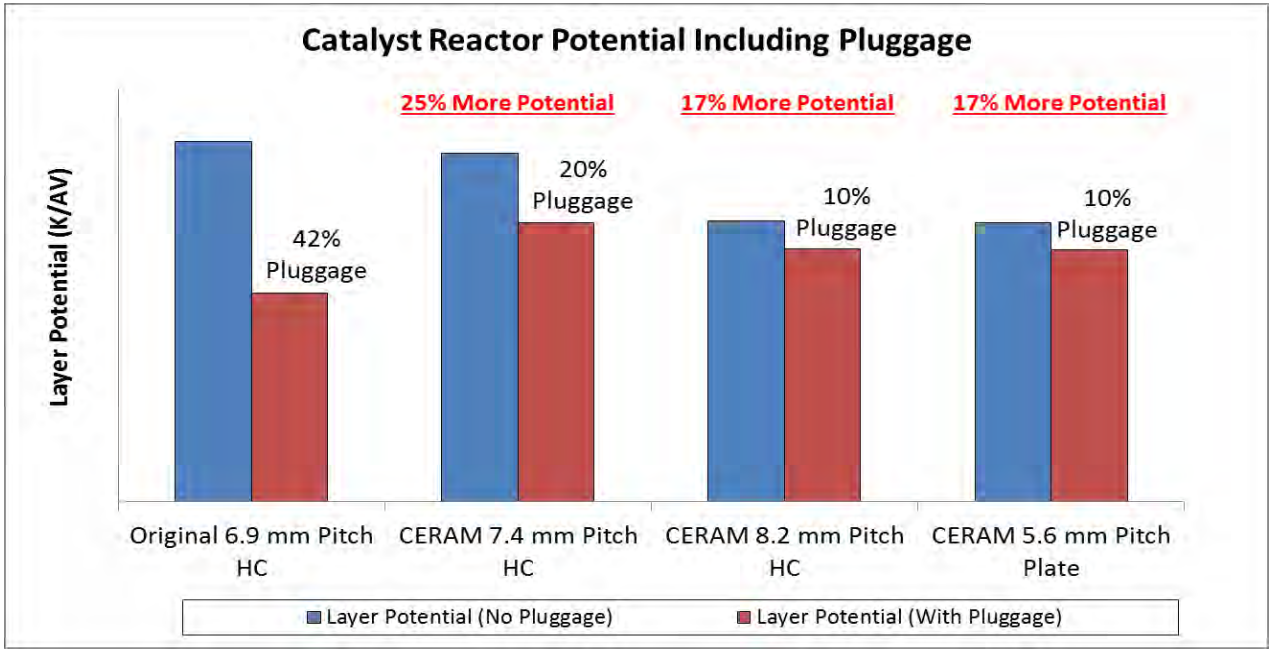
Catalyst Selection – Geometry and Chemistry

- Catalyst Pitch Evaluation
  - Transitioning to Larger Pitch – Reduced Surface Area must be Offset by Reduction in Catalyst Pluggage
  - 8.2 mm Pitch Honeycomb has 22% Less Specific Surface Area Compared to 6.9 mm
  - 7.4 mm Pitch Honeycomb has 13% Less Specific Surface Area Compared to 6.9 mm
  - 5.6 mm Pitch Plate has 36% Less Specific Surface Area Compared to 6.9 mm



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Catalyst Replacement in 2013

- CERAM Wins Competitive Bid to Replace Catalyst in 1st and 2nd Levels of the SCR
  - CERAM Proposed both 8.2 mm Honeycomb and 5.6 mm Plate
  - Utility Selected 8.2 mm Pitch Honeycomb
  - Catalyst Selection Allows for:
    - Reduced Pluggage and DP Concerns
    - Optimized Catalyst Management Modeling
    - Multiple Regenerations (Wall Thickness $\geq$ 0.9 mm)
    - Reduced Fan Energy Costs

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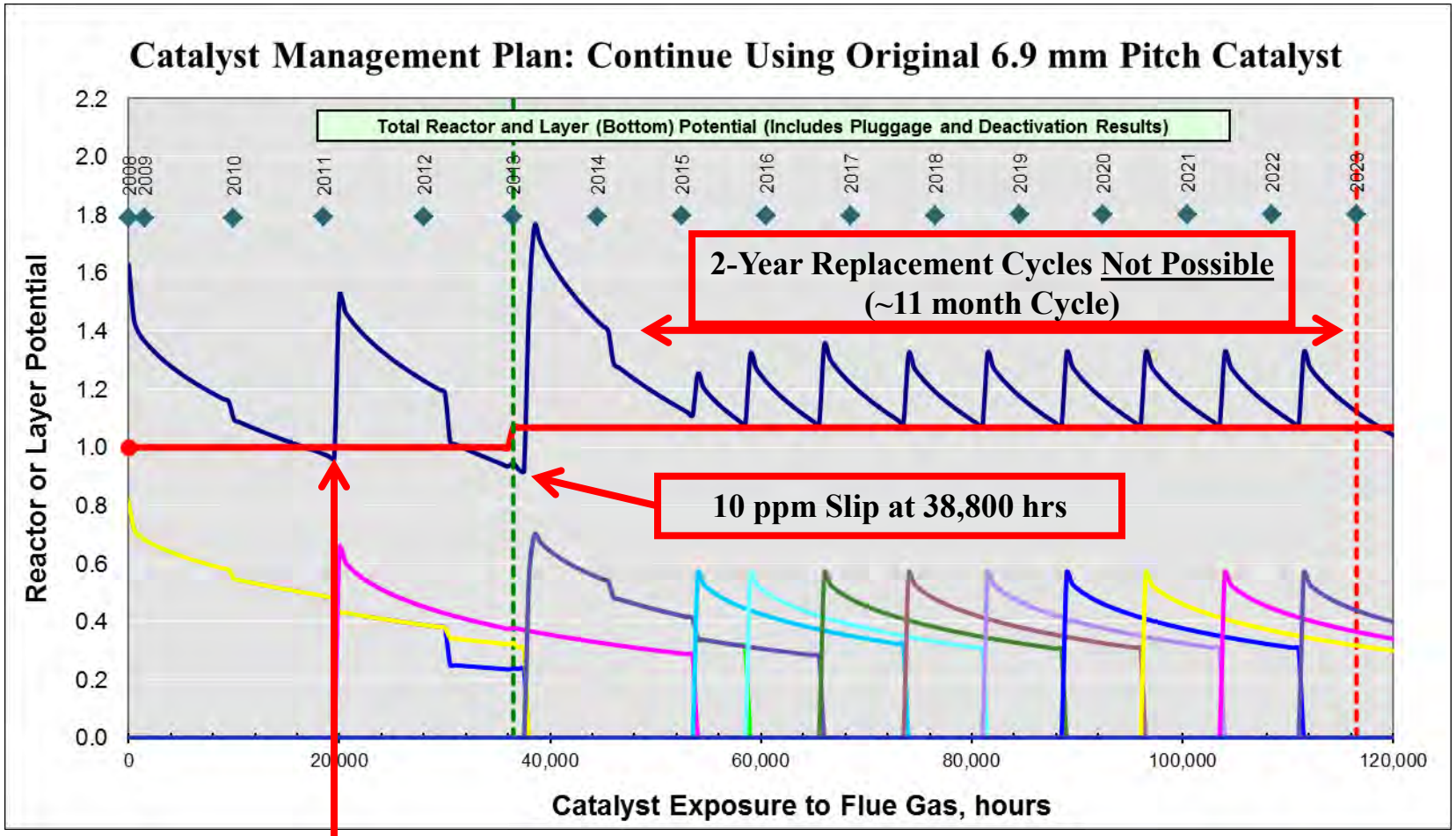
CERAM Working with Nebraska Utility to Optimize CMP

- Goal was to Develop Long Term Catalyst Management Plan to fit Desired Outage Schedule
  - Replace One Layer Every 2 Years
- Transition to Larger Catalyst Pitch
  - 8.2 mm CERAM Replaced Original 6.9 mm First Layer in Spring 2013
  - 8.2 mm CERAM Replaced Original 6.9 mm Second Layer in Spring 2013
  - Replace Third Layer in Spring 2015
- Future 2 Year Replacement Cycle is Achievable

Status Quo CMP – Using Original Catalyst Design



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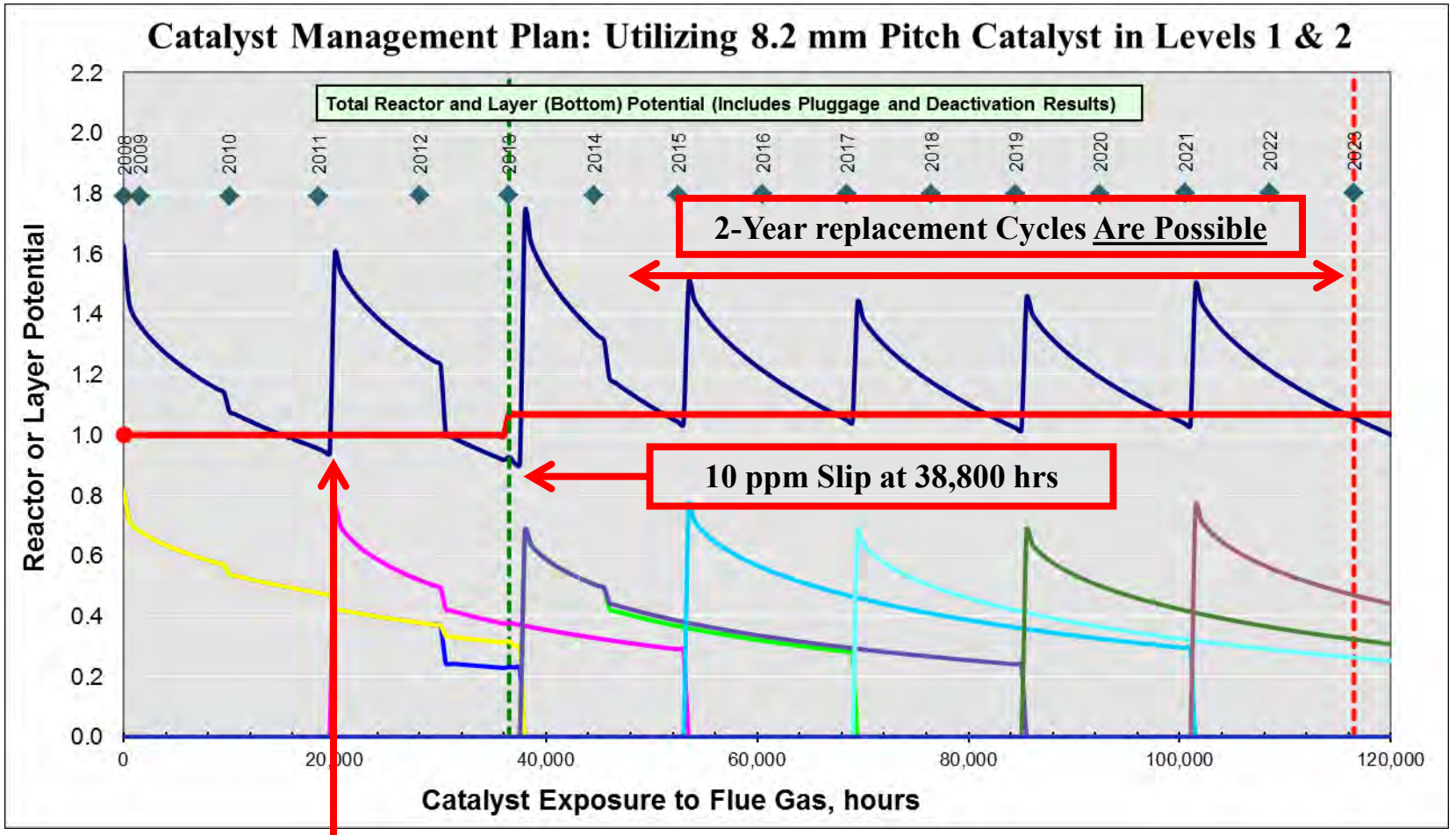
Optimized CMP – 2 Year Replacement Cycles



4 - 5 ppm Slip at 20,200 hrs

Utilizing 8.2 mm Pitch Catalyst Allows for 2 Year Replacement Cycle

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Catalyst Management NPV

- Economic Comparison Between Installing 6.9 or 8.2 mm Pitch Honeycomb Catalyst
- 10-Year NPV Analysis
  - NPV Cost Savings of $8.9 Million dollars (39%)
  - $2.2 Million in Fan Energy Costs Savings (Lower Pressure Drop)
  - $6.8 Million in Catalyst Related Expenditures Savings (Includes In / Out Costs)

Catalyst Economic Comparison: Nebraska Utility		
	Install 6.9 mm pitch catalyst in Levels 1 & 2	**Install 8.2 mm pitch catalyst in Levels 1 & 2**
Catalyst Related Expenditures	$16.54 Million	$ 9.79 Million
Fan Energy Costs for Reactor Pressure Drop	$ 6.46 Million	$ 4.28 Million
Total Net Present Value of Plan (2013 to 2022)	$ 23 Million	$ 14.07 Million

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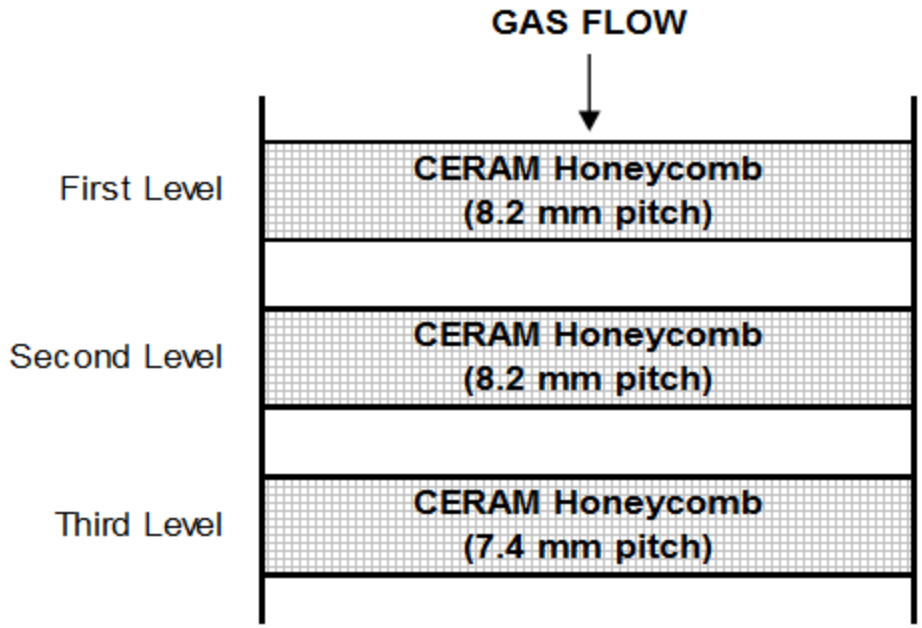
Current SCR Operation

- Reactor Inspection Performed in January 2014
  - Level 1 Pluggage: 6%, 6,000 hrs
  - Level 2 Pluggage: 7%, 6,000 hrs
  - Level 3 Pluggage: 20%, 25,000 hrs
    - Residual from Shadowing Effects of Old Catalyst
- Minor Popcorn Ash Accumulation Found (Baffles Effective)



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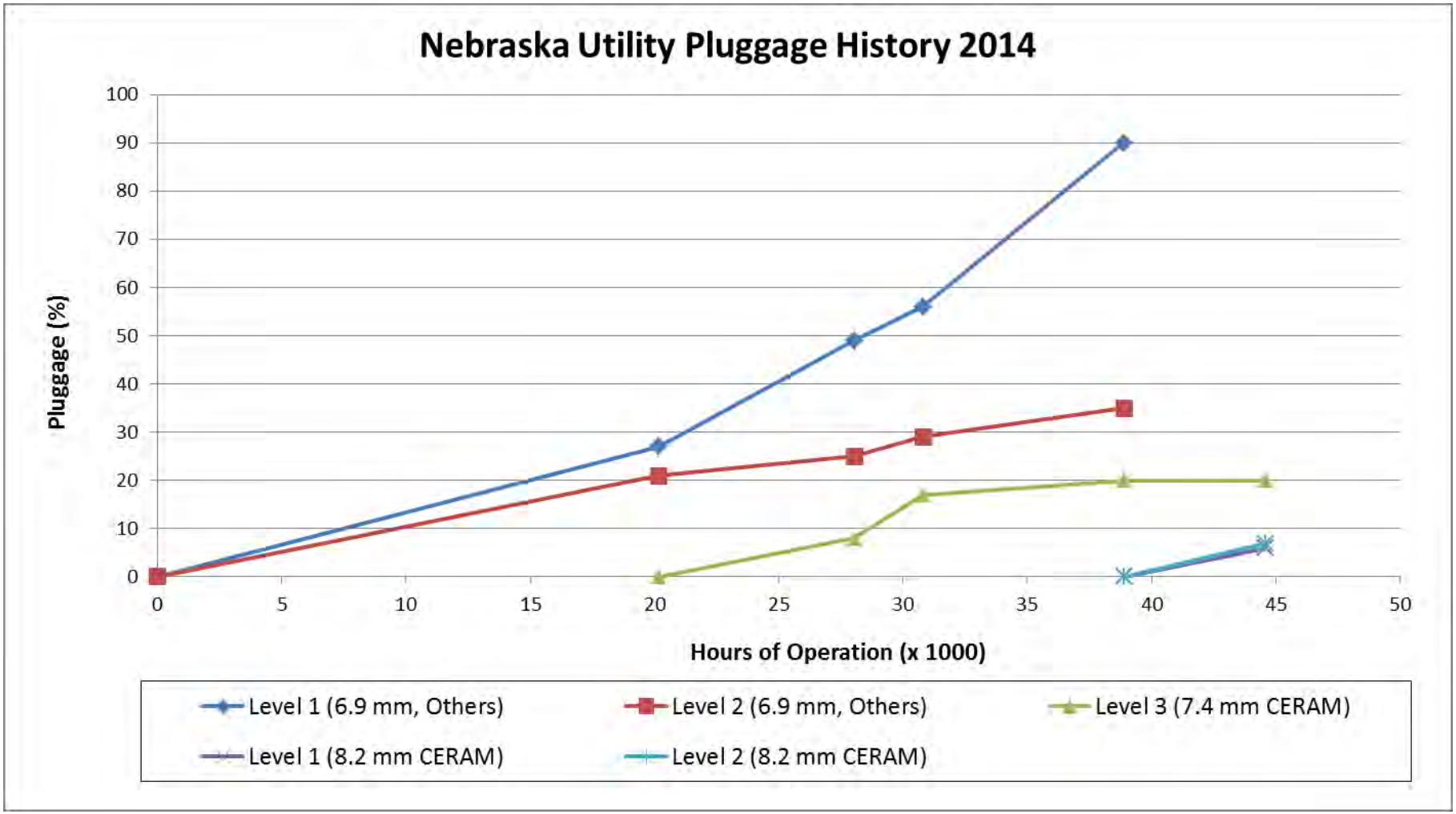
2014 Catalyst Pluggage Tracker



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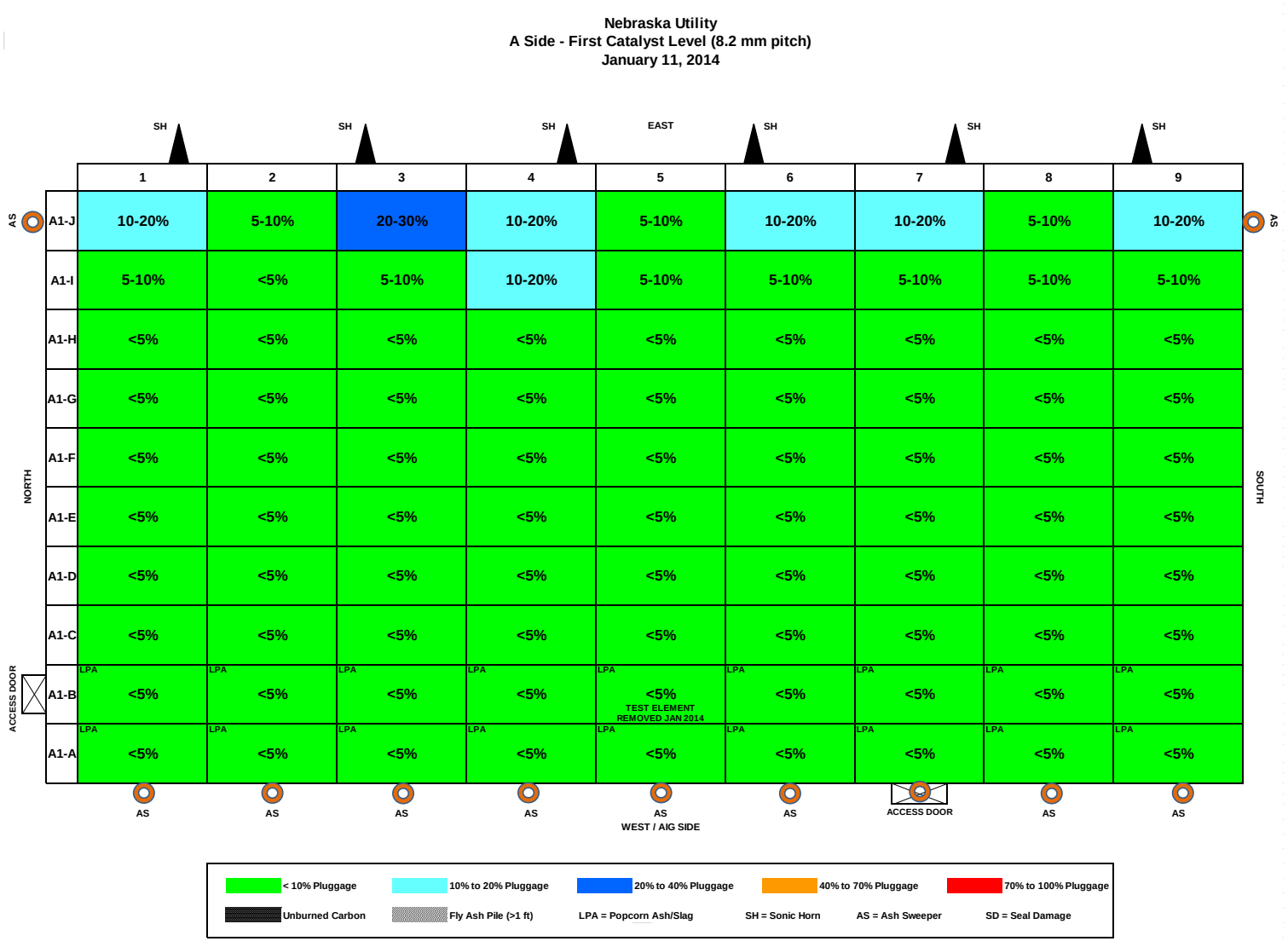
2014 Reactor Inspection: Level 1 (A Side)



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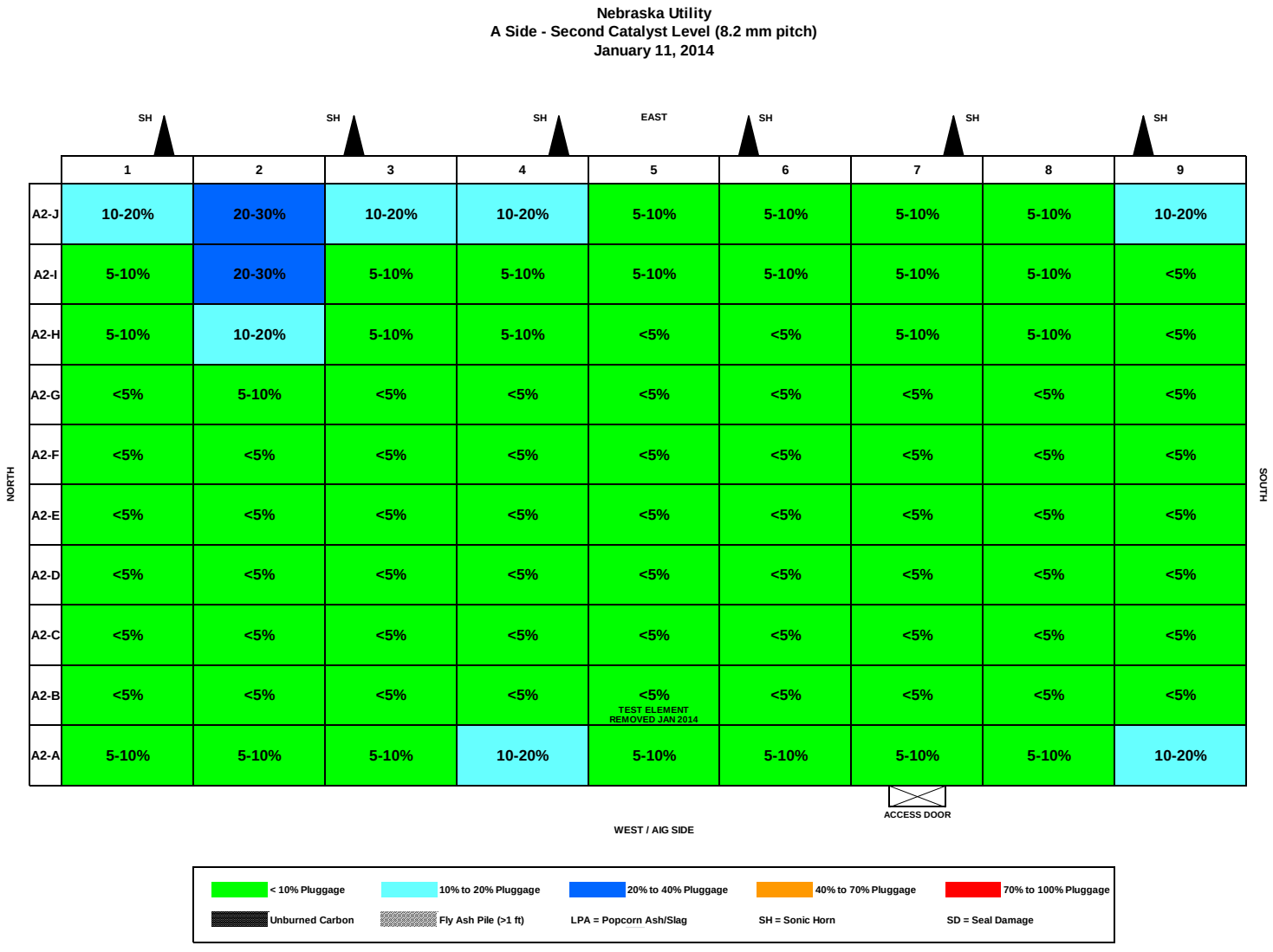
2014 Reactor Inspection: Level 2 (A Side)



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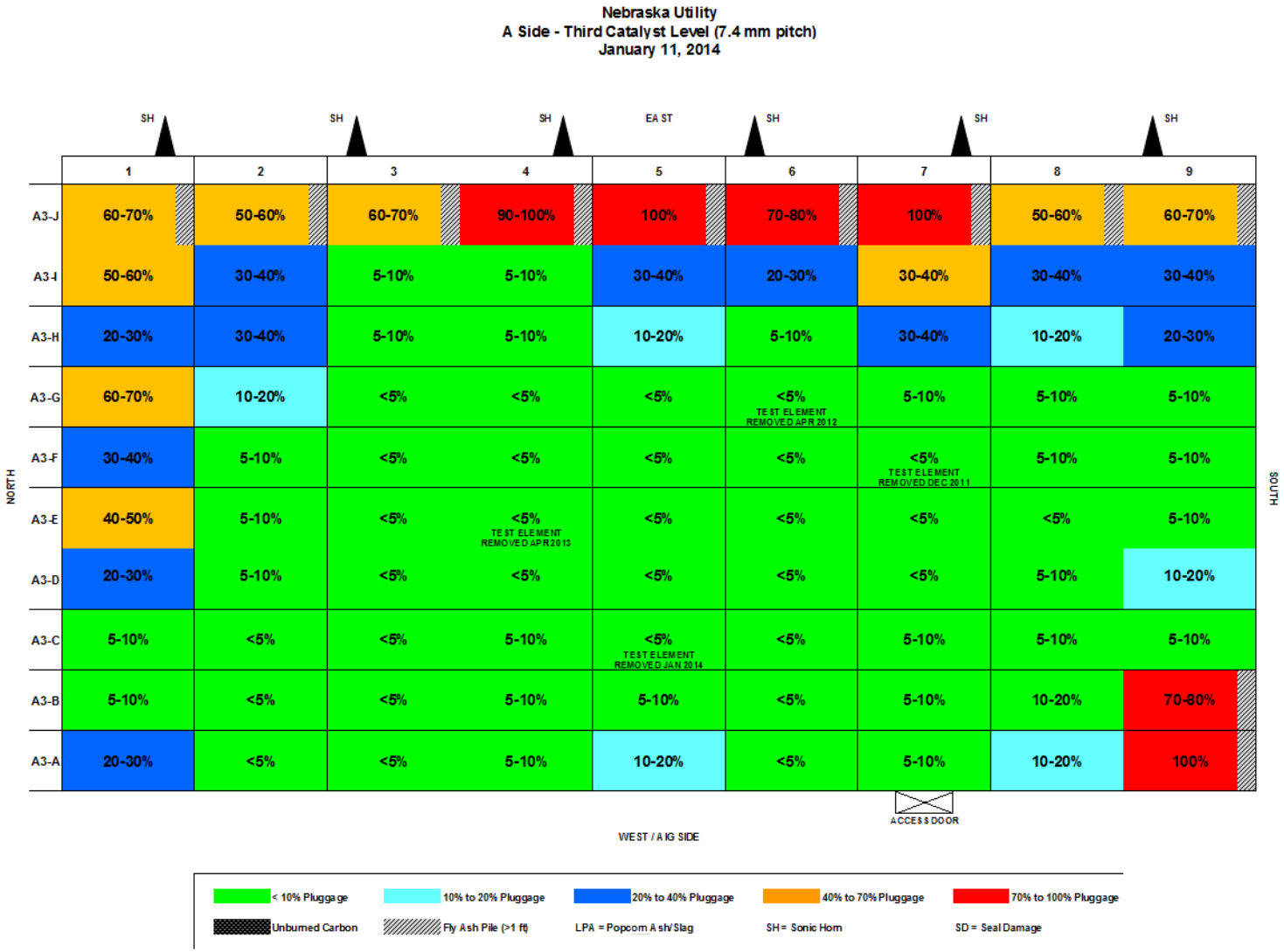
2014 Reactor Inspection: Level 3 (A Side)



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2014 SCR Reactor Inspection

Potential Further SCR Improvements

- Air Cannons/Ash Sweepers May Not be Needed if Ash Piles do Not Develop
- Reviewing Options to Upgrade Sonic Horns
  - Mega/Magnum Horns
- Review Plans to Mount the Sonic Horns Flush with the Internal Reactor Wall
- Investigate Dry Ice Cleaning Procedures During Long Outages to Remove Residual 3rd Level Pluggage
- Monitor and Assess Pluggage during Short Outages to Determine if Further Modifications are Needed

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Summary

- Even the Worst SCR Issues can be Overcome
- Pitch Selection, Catalyst Quality, and Outage Cleaning Procedures can Help to Reduce Ash Accumulation and Pluggage
- Catalyst Management Plans Change Continuously and Are Based on the Following:
  - Unit and SCR Operations
  - Catalyst Deactivation Results and Trends
  - Reactor Inspection Results
- Thin Walled Catalyst Limits Long Term Use and Regeneration Options
- CERAM's Catalyst Management Program is Effective in Reducing Risk, Avoiding Surprises, and Limiting SCR Related Costs

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Thank You!

Questions?

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