

# REINHOLD ENVIRONMENTAL<sup>®</sup>



## **2024 Reinhold/PCUG Round Table Presentation**

Hosted by LG&E/KU and Co-hosted by Southern Co. and TVA  
in The Marriott Resort Lexington Griffin Gate Hotel, Lexington,  
KY on June 24-25, 2024

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# 2024 Reinhold Environmental® 6/25/2024 Buckeye Power - Cardinal Plant

Unit 3 Direct Urea Injection  
Project Update  
Bill Reinhart

## Credit to:

- CARDINAL OPERATING COMPANY
- ELECTRIC POWER RESEARCH INSTITUTE
- REACTION ENGINEERING INTERNATIONAL
- STEP COMBUSTION / EES
- ENERGY RESEARCH CONSULTANTS



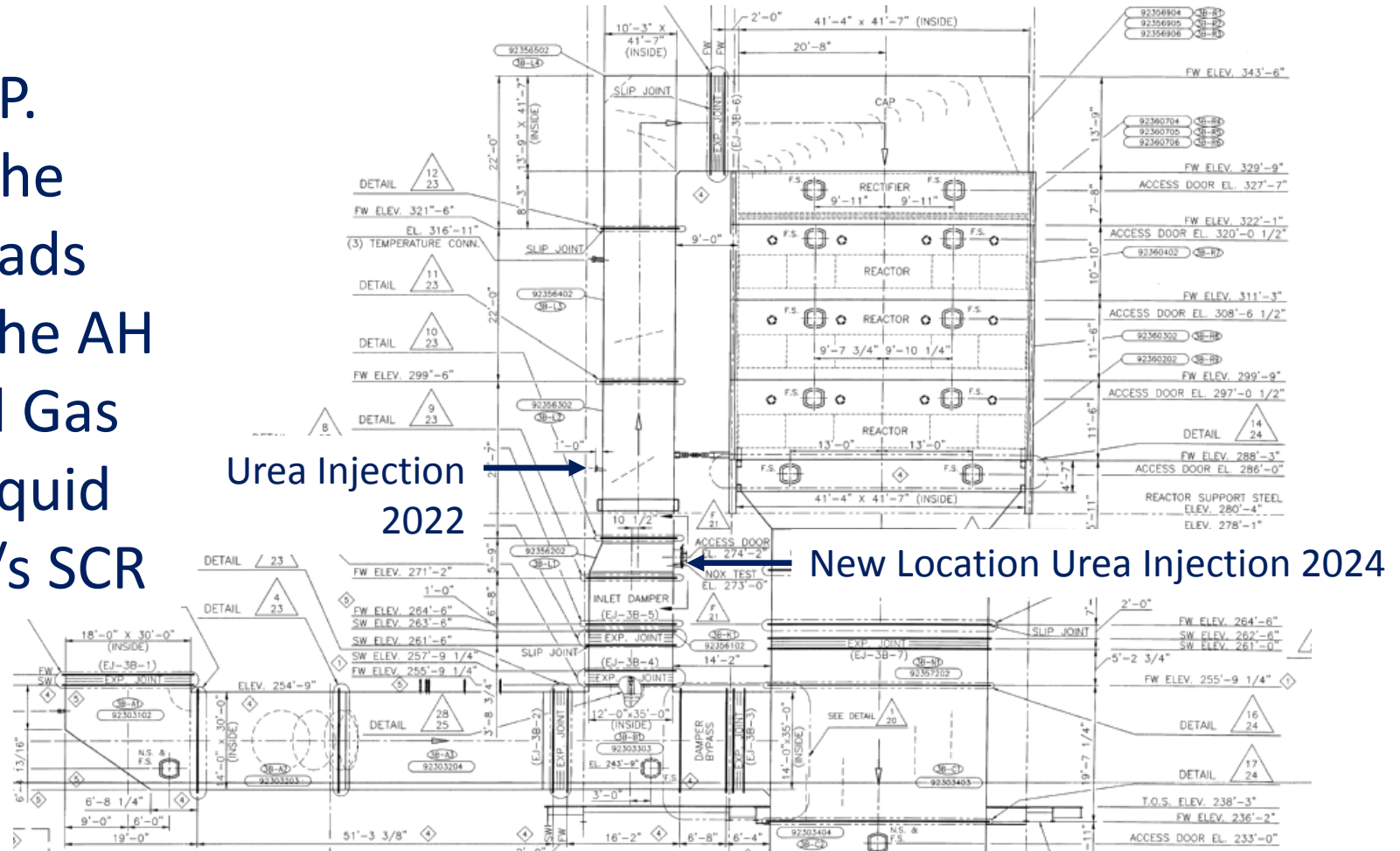
## Cardinal Power Plant

- Units 1 & 2  
590 MWN Supercritical  
On-Line 1967, Cold-Side ESP
- Unit 3  
620 MWN Supercritical  
On-Line 1977, Hot-Side ESP



# Unit 3 Urea Injection Location

Unit 3 has a Hot-ESP.  
Lime injection u/s the  
HESP only at low loads  
for MCOT and u/s the AH  
at all Loads for Acid Gas  
Mitigation. Urea Liquid  
solution injected u/s SCR



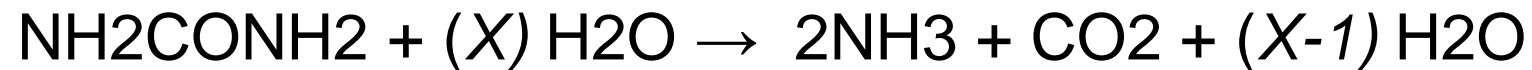
## CARDINAL UNIT 3 - Direct Urea Injection Commissioned May 2022, Upgraded April 2024

### ➤ Project Justification

- O&M Cost Savings - Hydrolyzer, Pumps, NH<sub>3</sub> Valves
- Improves Reliability – controls are simplified
- Reduces Potential for NH<sub>3</sub> Contamination into Condensate Reclaim
- Safety – reduces potential for NH<sub>3</sub> release

## CARDINAL UNIT 3 - Direct Urea Injection

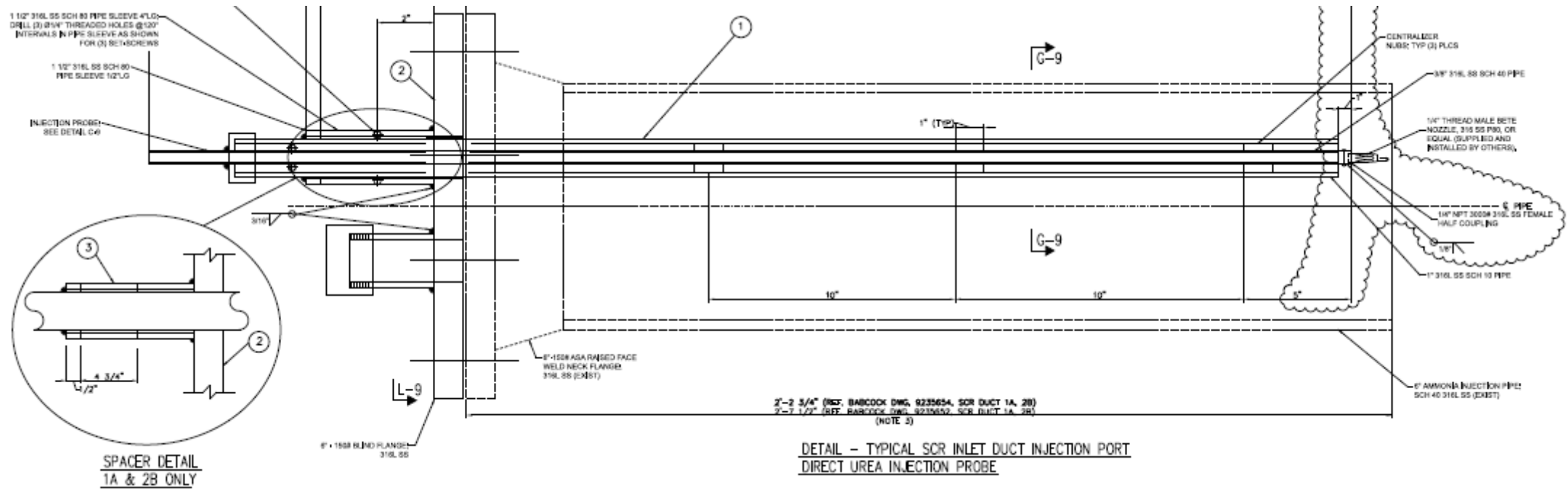
- Direct Urea Injection replaces the Ammonia-On-Demand (AOD) System
- Urea is mixed at 36% Solution
- Injected into Flue Gas upstream the SCR at 580-660°F
- Urea Solution decomposes to Ammonia, CO<sub>2</sub>, and Water Vapor

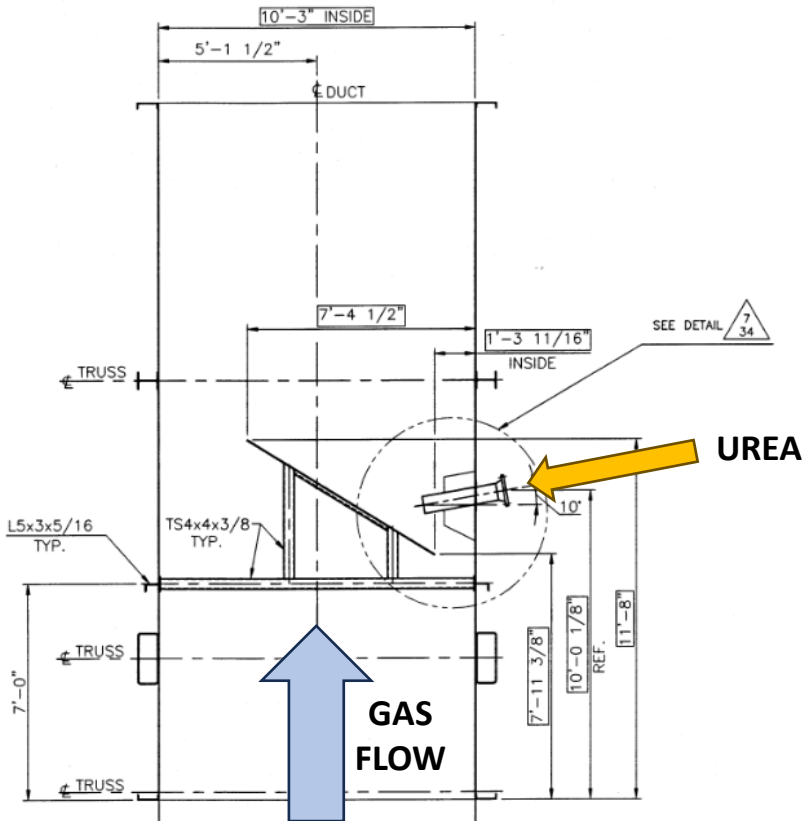


## Direct Urea Injection – Original 2022 Installation

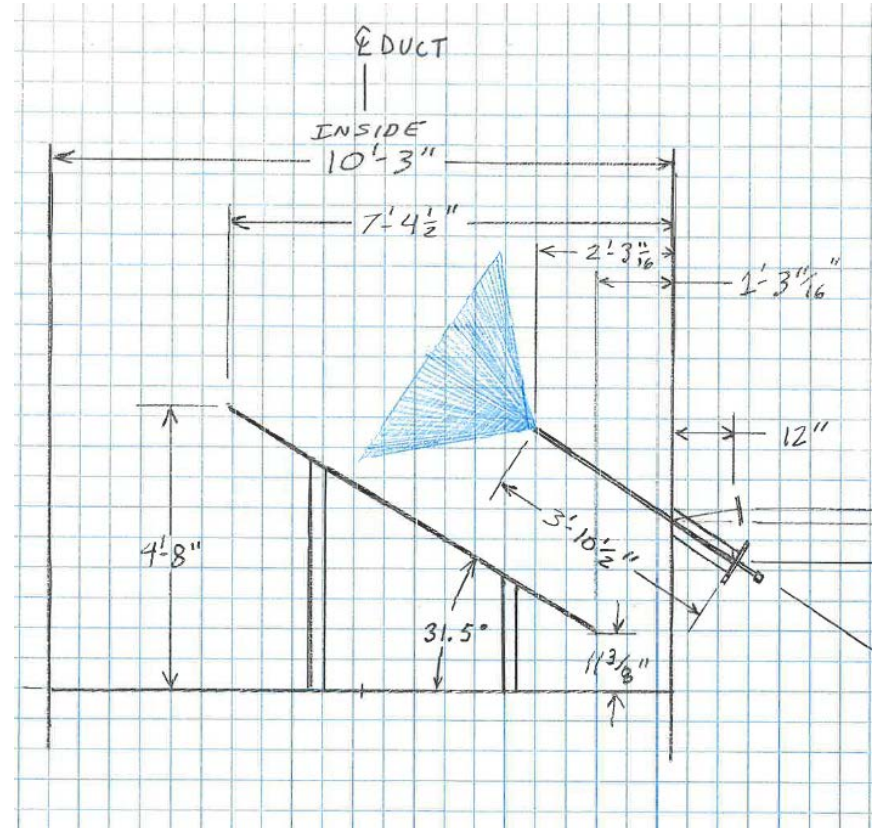


## UREA INJECTION LANCE – ORIGINAL DESIGN





Original Installation - Spring 2022



Spring 2023 modification

After initial installation, issues experienced:

- Clinker Formation
- SCR Plugging
- Corrosion of Mixing Discs

## FALL 2023 & SPRING 2024 OUTAGES

### CLINKER FORMATIONS AND CORROSION ON MIXING DISCS



## SCR PLUGGING



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## Issues attributed to:

- Large Droplet Sizes
- Evaporation Time
- Very Fine Ash Particles due to Hot ESP
- Injection Location – recirculation zone of Mixing Discs
- Droplet Deposition onto steel surfaces




## System Investigation / Redesign Efforts

- After multiple failed attempts to Resolve Issues in the field (we tried various nozzle tip designs, increased urea pressure, changed the angle of injection, replaced mixing discs with 316 SS), we decided that we need a CFD Model to assist in our investigation.
- We also funded a Supplemental EPRI Project to Assist in our redesign efforts.

## CFD Model (Fall/Winter 2023-24) Reveals:

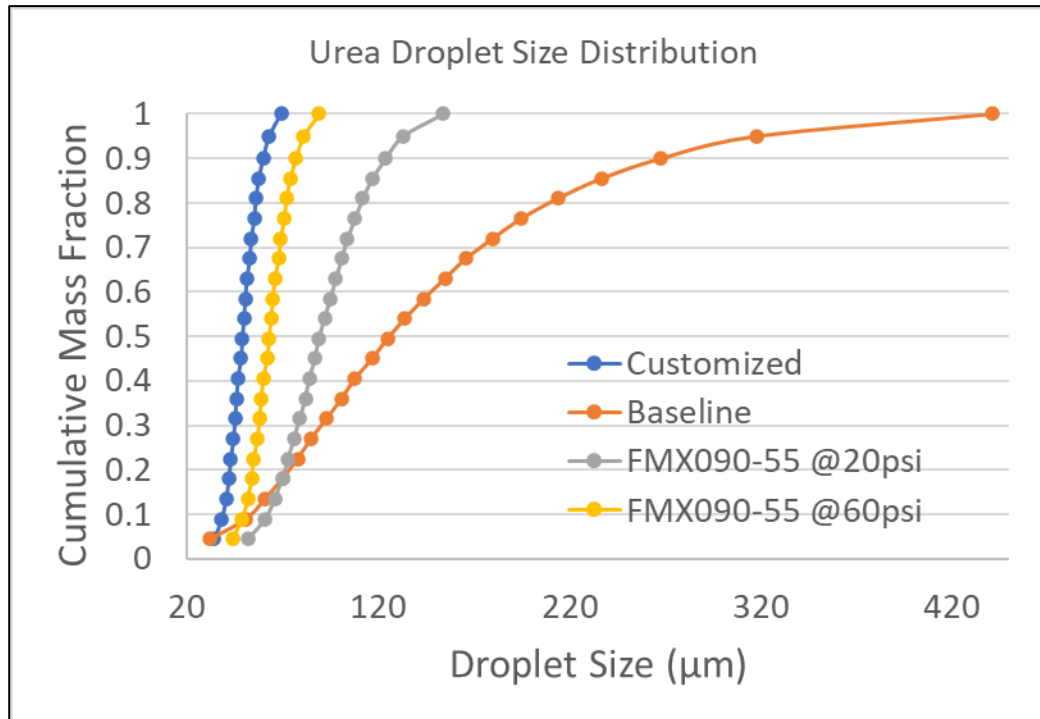
1. Need to Relocate Lances out of Recirculation Zone
2. Need Smaller Droplet Sizes
3. Reduce Droplet Deposition onto Steel Surfaces
4. Need to Improve NH<sub>3</sub> Distribution
5. This leads to Custom Lances w/ Atomizing Air

## CFD Model Cases:

Case 1. Baseline (BETE WL-0.75 nozzle). (Installation as of Spring 2023)		Case 5. Same as Case 3_1 except Custom Nozzle with $Dv_{90} = 60 \mu\text{m}$ . $55^\circ$ Spray Angle. Trim Injectors at 20% Flow.
Case 2. FMX-090 Nozzle (20 PSIG).		Case 6. Same as Case 5 except Min Load. $55^\circ$ Spray Angle.
Case 3. FMX-090 Nozzle (60 PSIG).		Case 7. Same as Case 5 except $90^\circ$ Spray Angle.
Case 4. Added 3 Trim Injectors between the 4 Primary Injectors.		Case 8. Same as Case 7 except Min Load. $90^\circ$ Spray Angle.
Case 4-1. Equal Flow through all 7 Injectors.		Case 9. Same as Case 7 except trim injectors inserted further into duct. $55^\circ$ Spray Angle.
Case 4-2. 80% Flow Primary / 20% Trim Injectors.		
Case 4-3. 90% Flow Primary / 10% Trim Injectors.		
Case 4-4. 95% Flow Primary / 5% Trim Injectors.		
Case 3_1. Same as Case 3 except added Inlet Damper.		Case 10. Same as Case 7 except trim injectors inserted further into duct. $90^\circ$ Spray Angle

## Urea Droplet Size Distribution

*Custom Lance (Parametric Cases #5 - #10)*



Dv90 Droplet Sizes:

Baseline (WL-0.75) = 280 µm

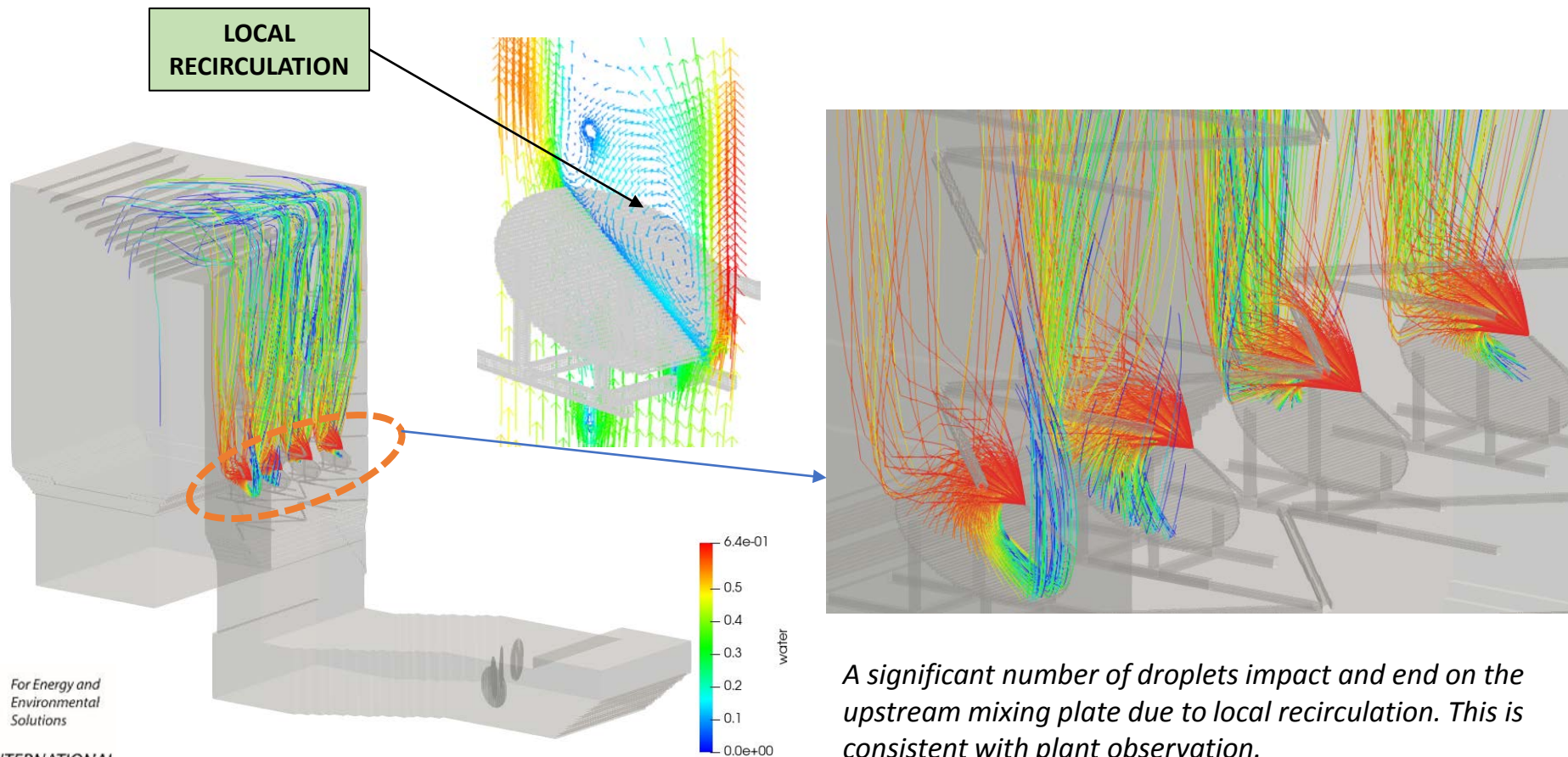
FMX-090-55 @ 20 PSI = 120 µm

FMX-090-55 @ 60 PSI = 80 µm

Custom Lance = 60 µm

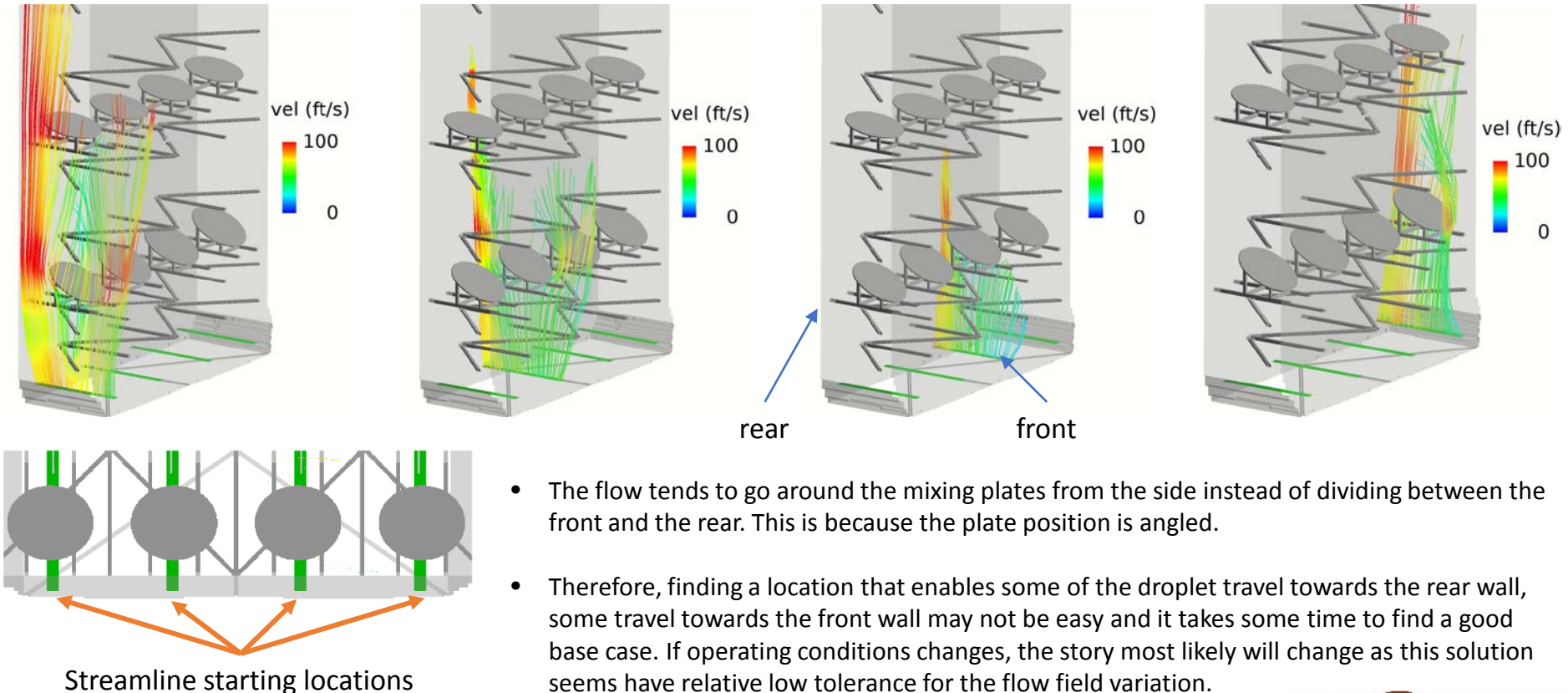
Note: The baseline nozzle tip has Dv90 Droplet Sizes of 430 µm at reduced flows.

## Droplet Trajectories – Upstream Mixing Plate



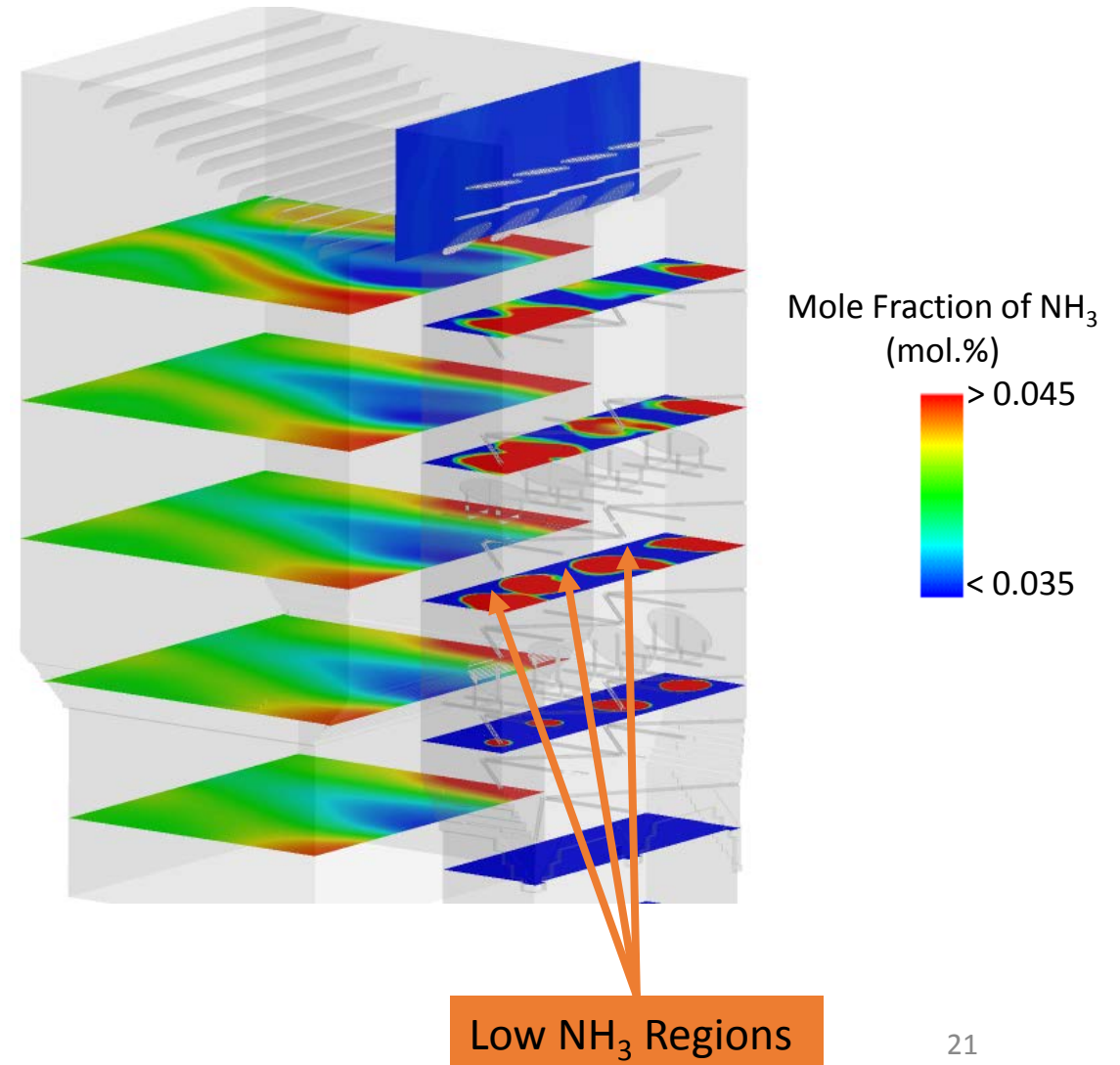
*A significant number of droplets impact and end on the upstream mixing plate due to local recirculation. This is consistent with plant observation.*

## Unit 3 - CFD Model - Streamlines Movies

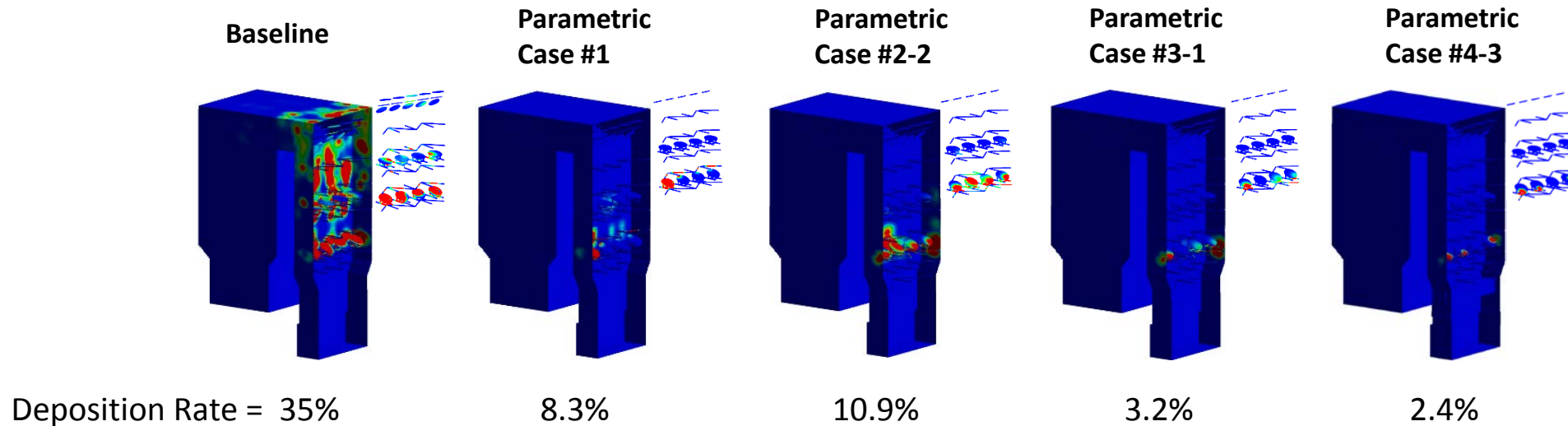


# Case Description – Parametric Case #4

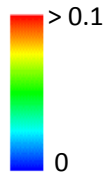
- Add 3 injectors in between the existing 4 injectors (center injectors) in the case #3-1. The idea is to fill the gaps where  $\text{NH}_3$  is low (see the figure on the right).
- The properties of the aqueous urea droplets are the same as in case #3-1.
- Four cases were carried out in this scenario:
  - Case 4-1: 57% urea injected through the center 4 injectors (uniform injection rates across the 7 injectors)
  - Case 4-2: 80% urea injected through the center 4 injectors
  - Case 4-3: 90% urea injected through the center 4 injectors
  - Case 4-4: 95% urea injected through the center 4 injectors



## Unit 3 - CFD Model - Deposition Rate



Deposition Flux  
(lb/(h·ft<sup>2</sup>))

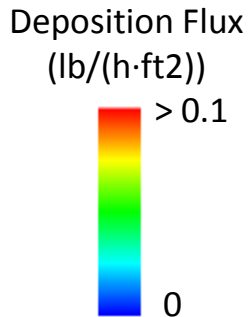


- *The parametric cases show significantly less deposition on the duct wall and the upstream mixing plates comparing to the baseline case.*
- *Parametric cases #3 & #4 show less deposition on the walls and internal surfaces comparing to parametric case #1 and #2.*

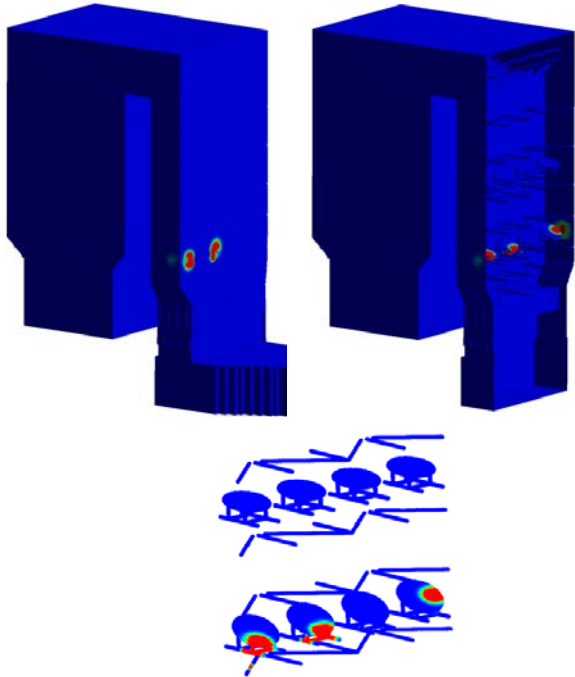


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Solutions

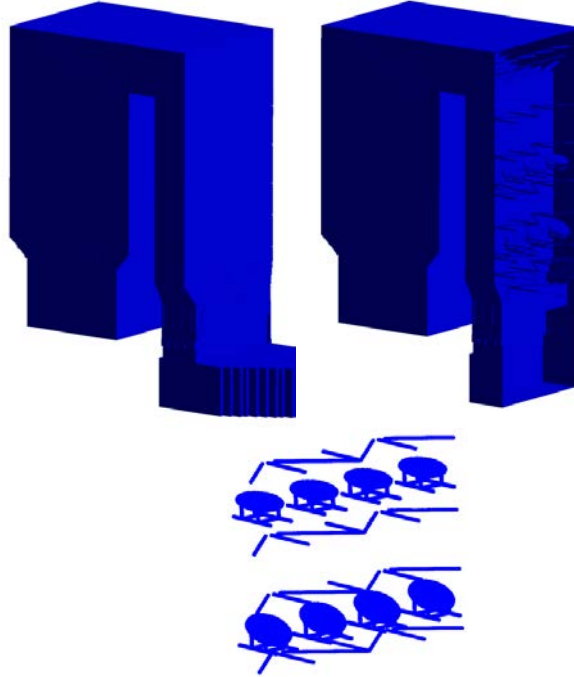
# Deposition Rate drops to Zero with Custom Lance, $Dv_{90} = 60 \mu\text{m}$



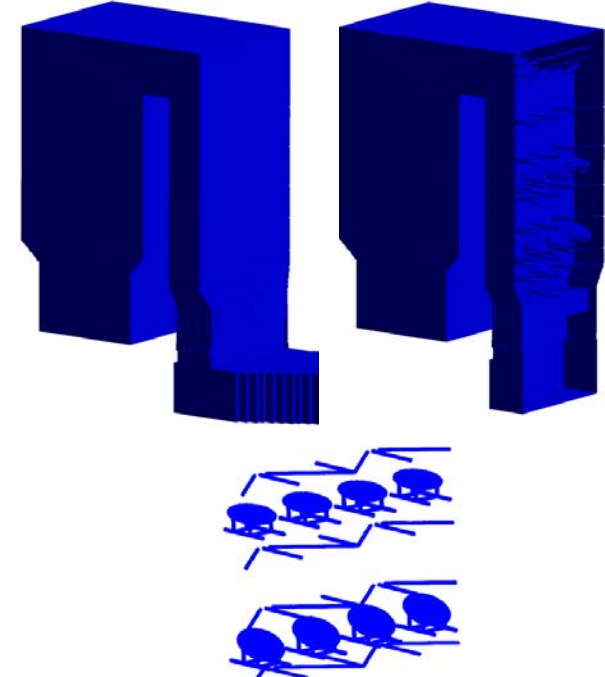
**Parametric Case #3\_1  
with Inlet Damper**



**Parametric Case #5  
Custom Lance (Full Load)**



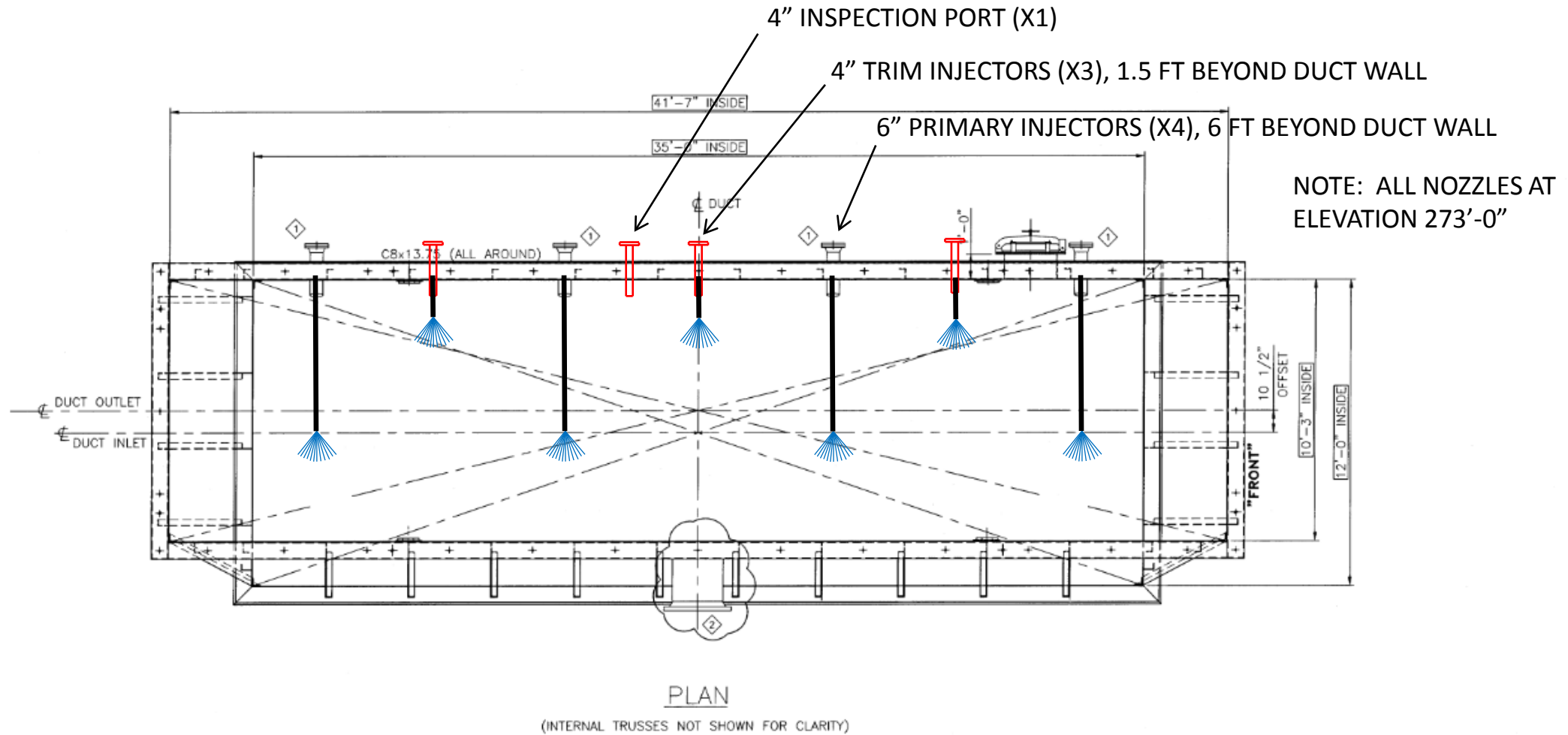
**Parametric Case #6  
Custom Lance (Min Load)**



- *The total aqueous urea deposition rate in Parametric Case #3-1\_ with Inlet Damper is 112.9 lb/h (3.4% of Total Urea Flow), of which 91.3% occurs on the upstream mixing plates, 8.4% occurs on duct walls, and 0.3% occurs on structure members.*
- *No deposition occurs in Parametric Case #5 or Parametric Case #6. (Custom Lance, w/ Trim Injectors)*

# CARDINAL UNIT 3

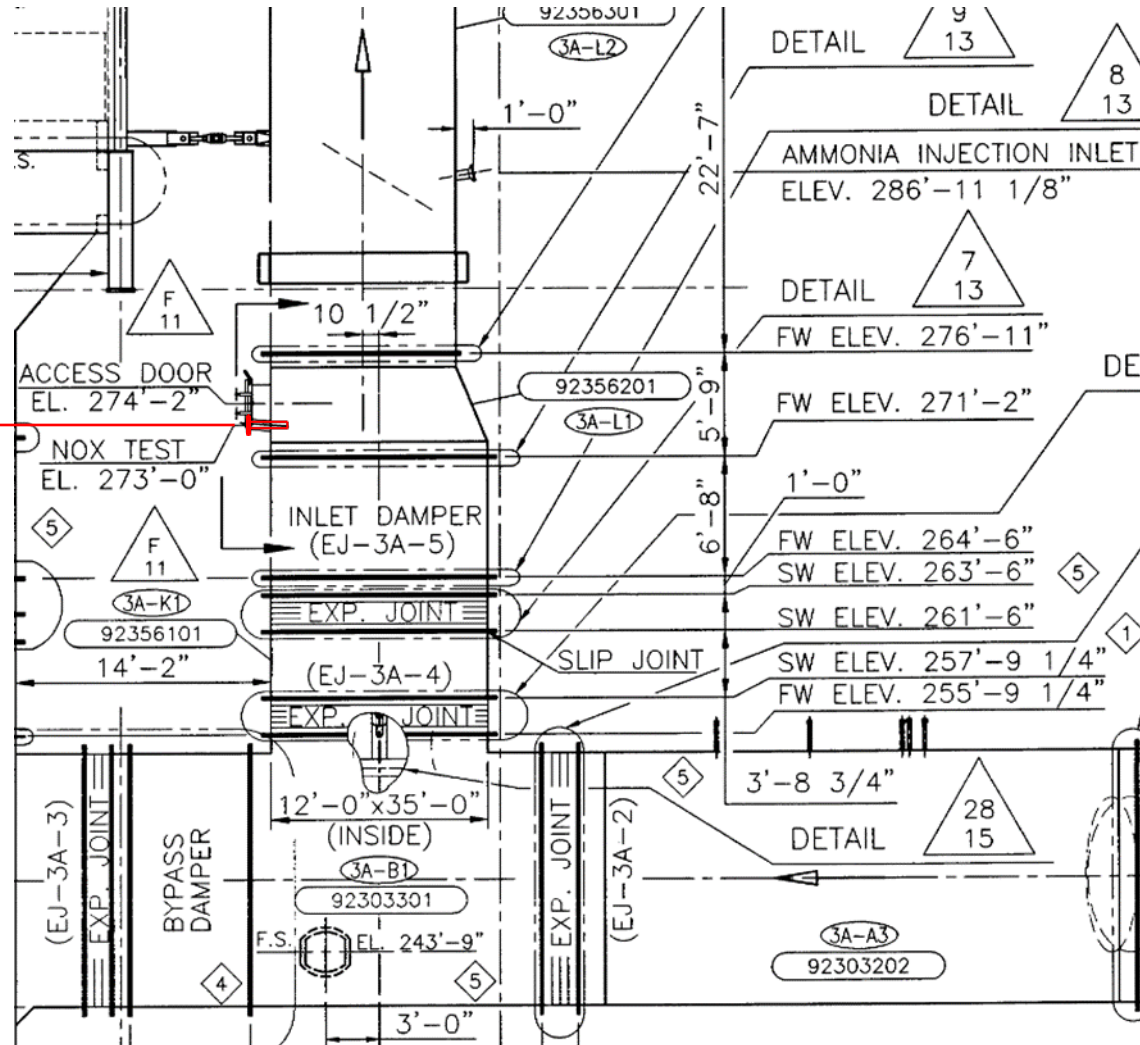
## PRIMARY AND TRIM INJECTORS SPRAY PATTERN, PLAN VIEW



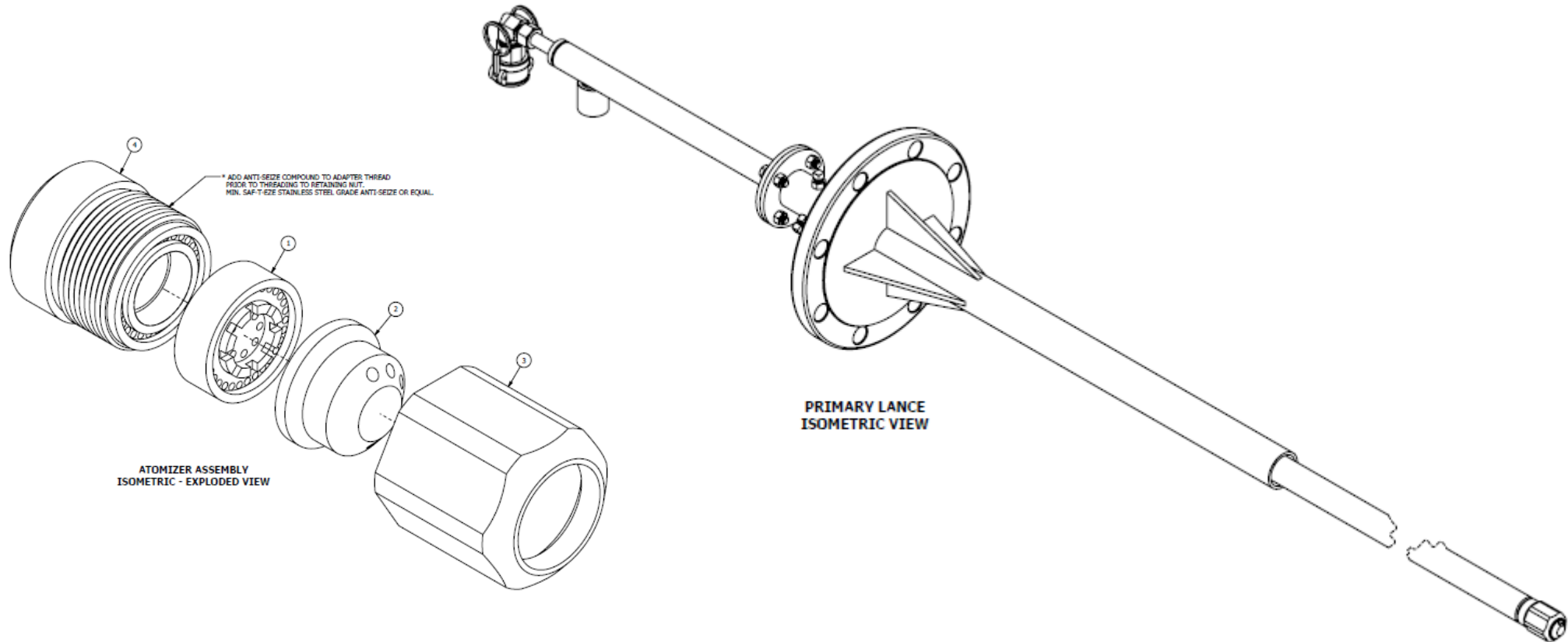
# CARDINAL UNIT 3

NEW PORTS ELEVATION 273'-0", PRIMARY INJECTORS (X4), TRIM INJECTORS (X3), INSPECTION PORT (X1)

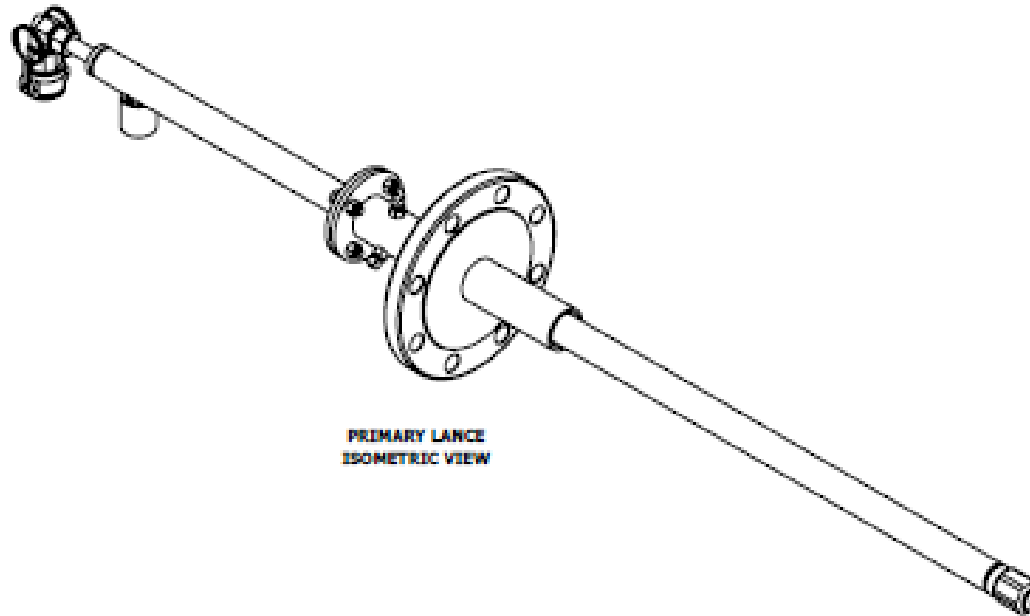
NEW INJECTORS  
ELEV. 273'-0"



## Primary Injectors



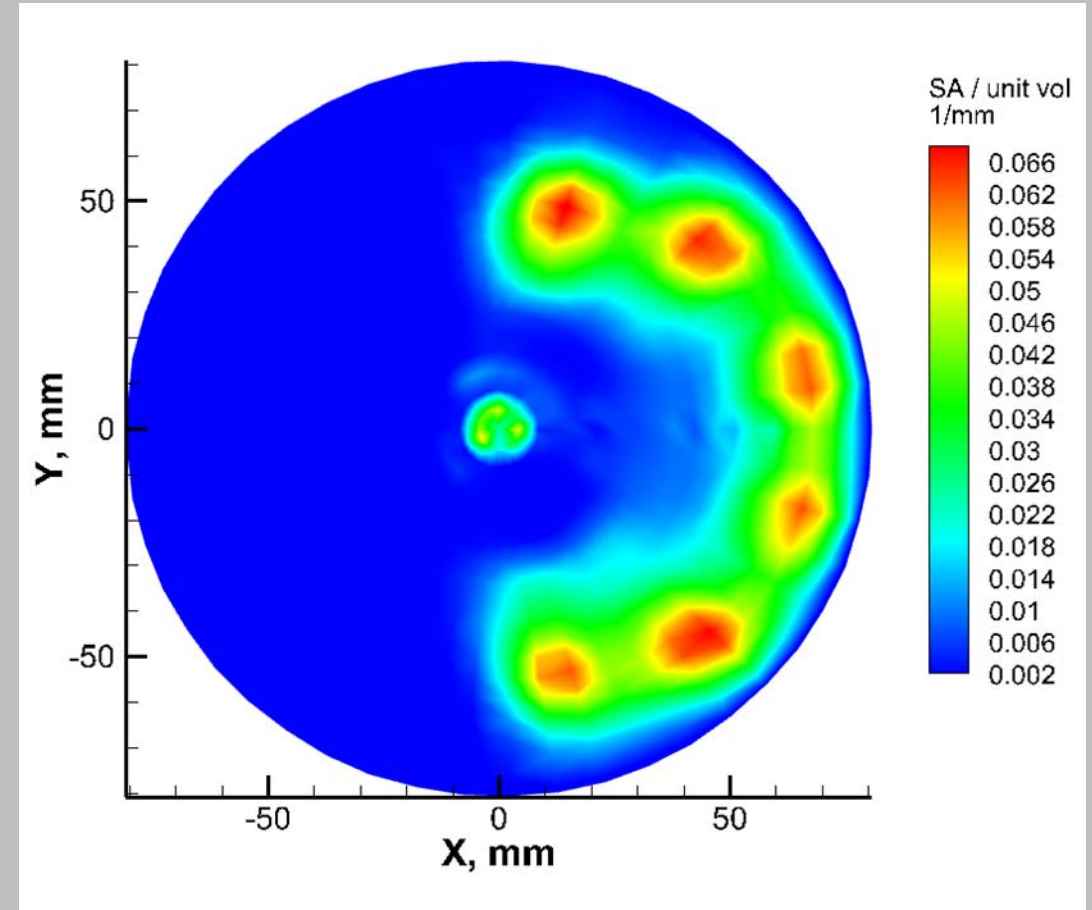
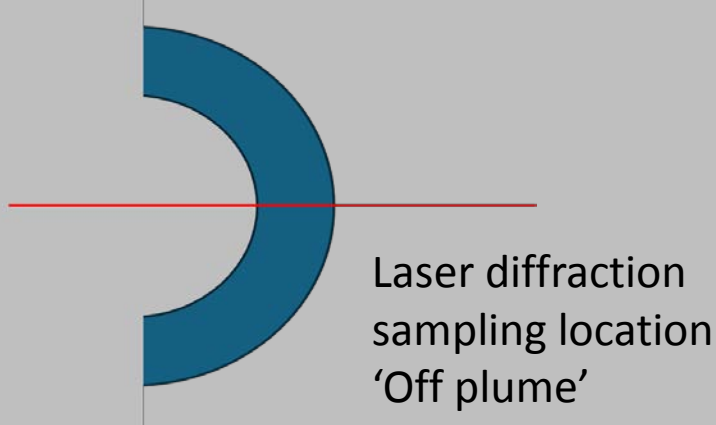
# Trim Injectors



PRIMARY LANCE  
ISOMETRIC VIEW

# Spray Optical Patternation Flow Mapping Example:

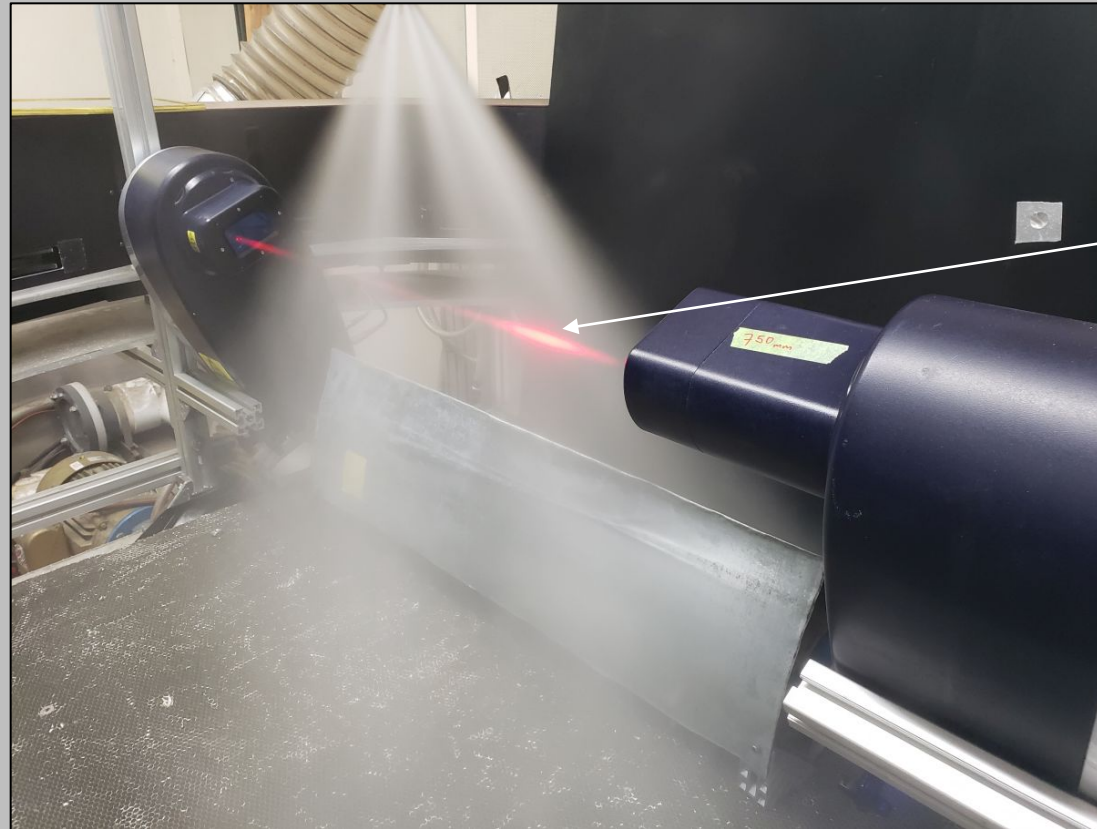
$Z = 3$  inches,  $P_{\text{air}} = 70$  psig,  $Q_{\text{flow}} = 1.25$  gpm



# Spray Droplet Size Distribution Measurement

- Primary, first set

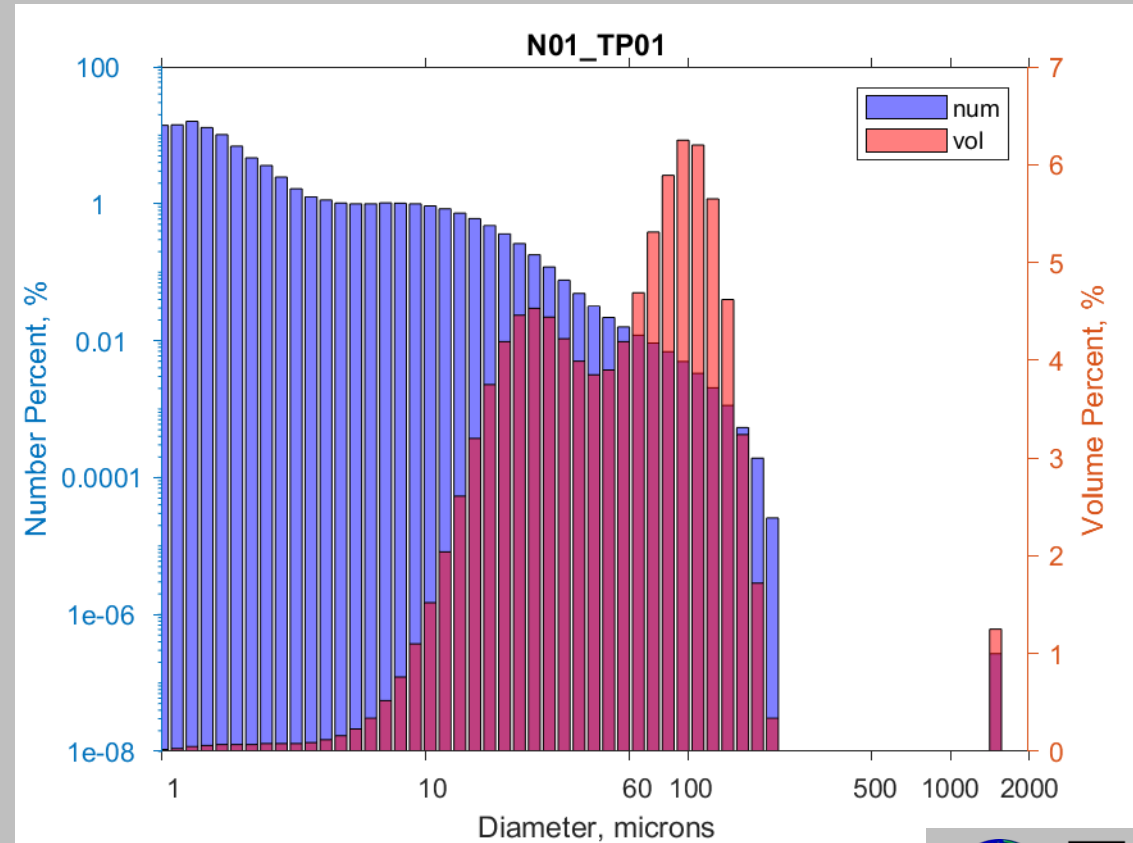
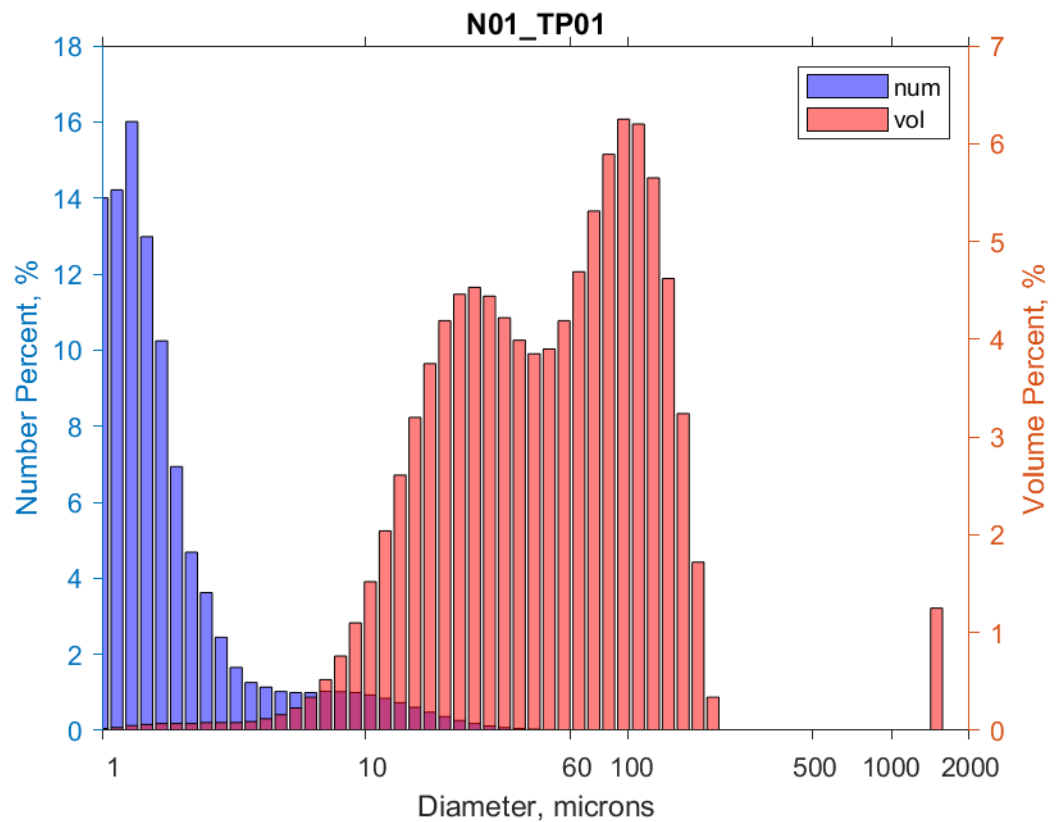
- $D[3,2]$
- $Dv10$
- $Dv50$
- $Dv90$



Laser diffraction  
red laser sheet

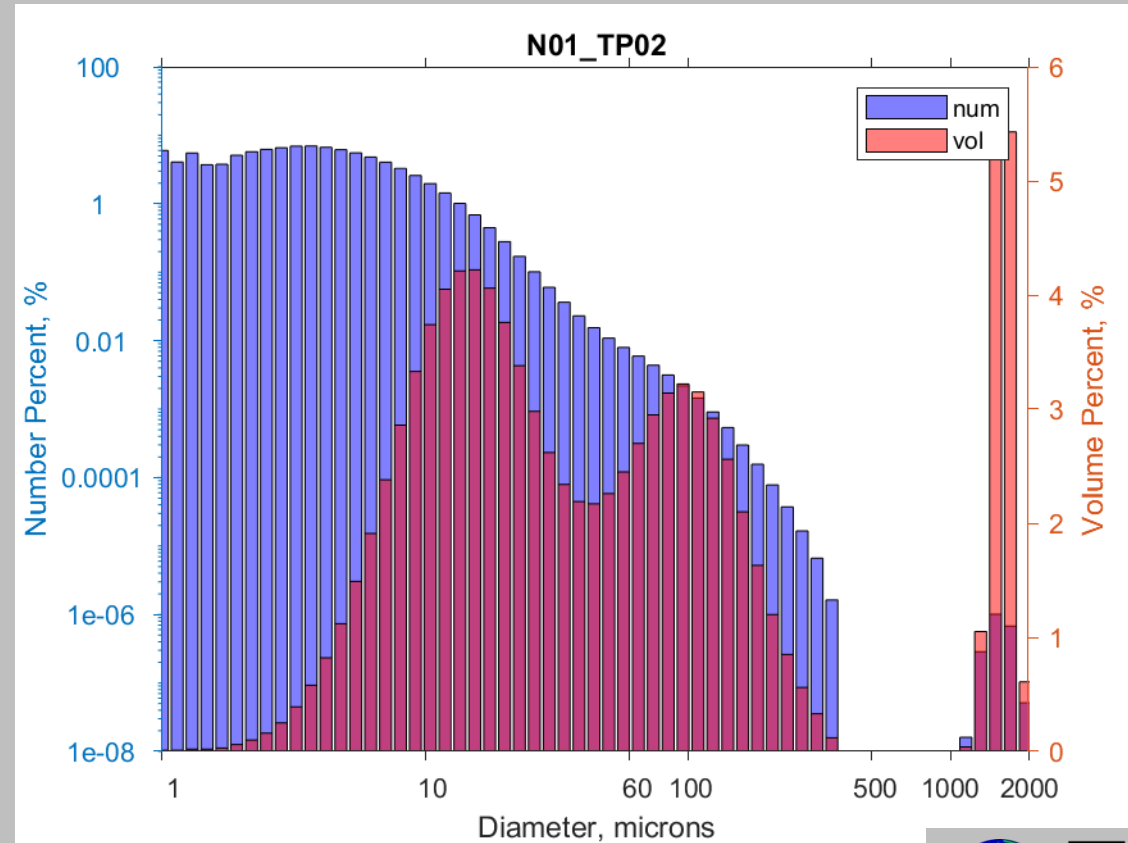
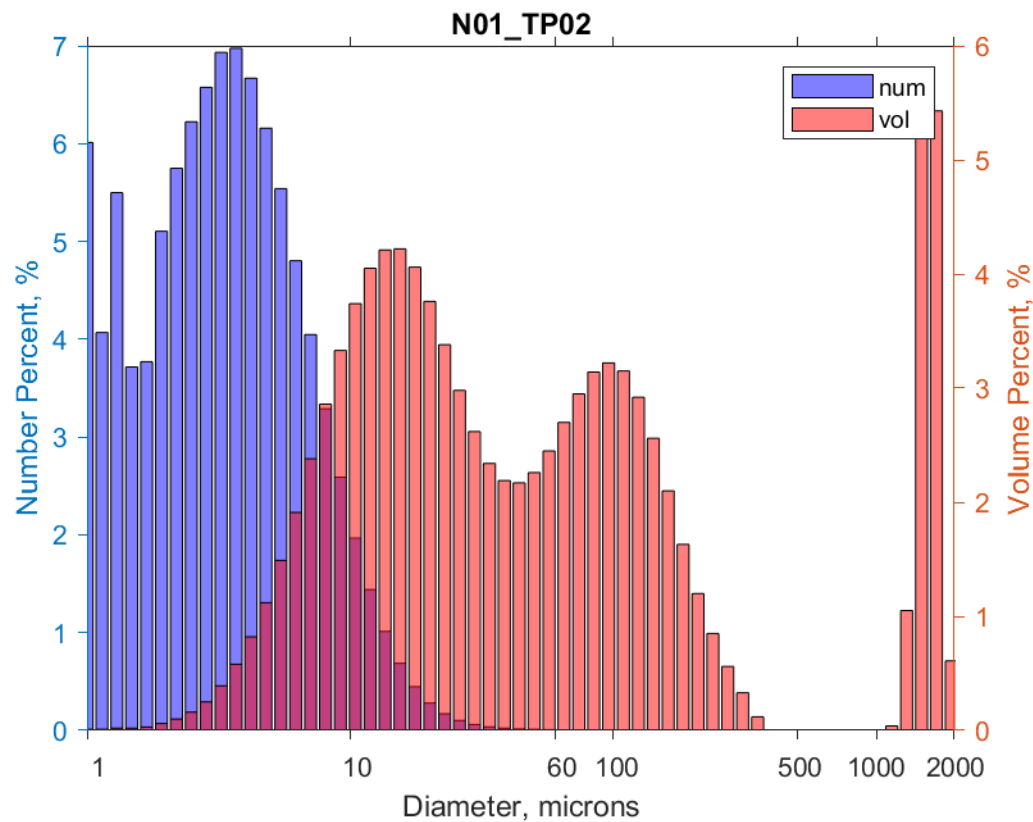
# Laser Diffraction – Volume and Number Distributions

- Primary Injector
  - 80 PSIG Atomization Air, 1.2 GPM



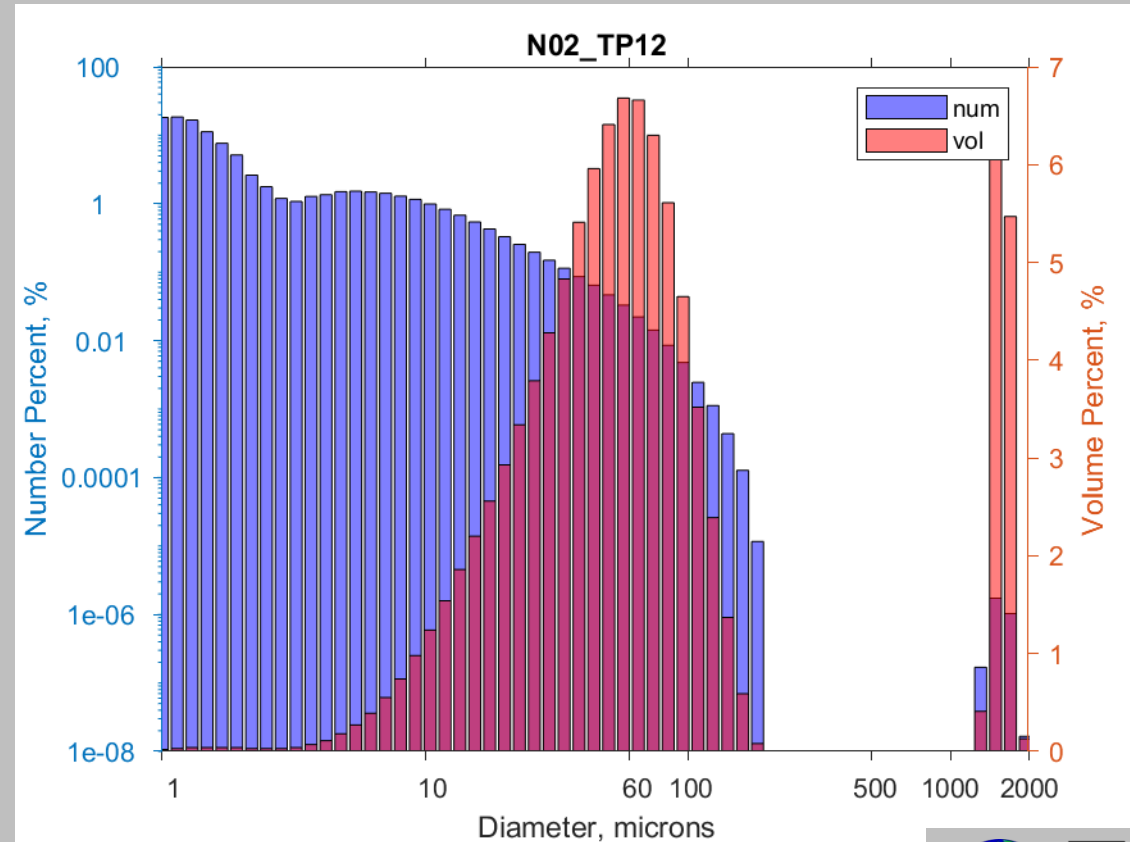
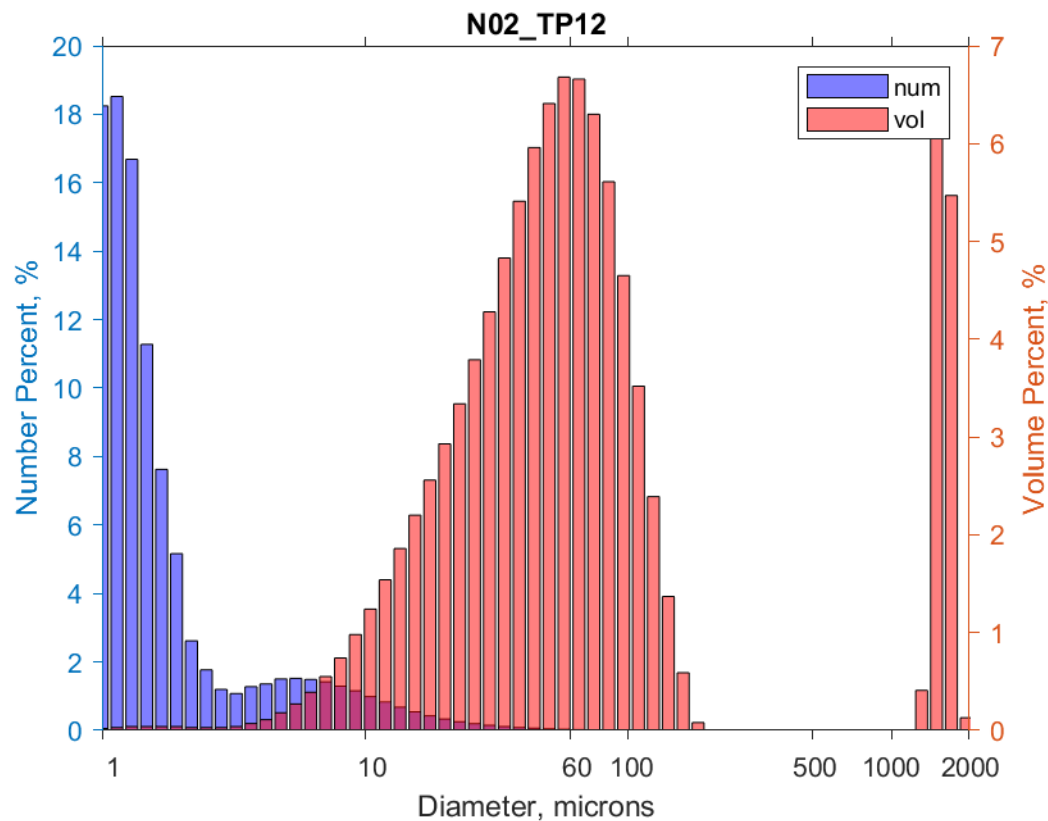
# Laser Diffraction – Volume and Number Distributions

- Primary Injector
  - 80 PSIG Atomization Air, 0.4 GPM



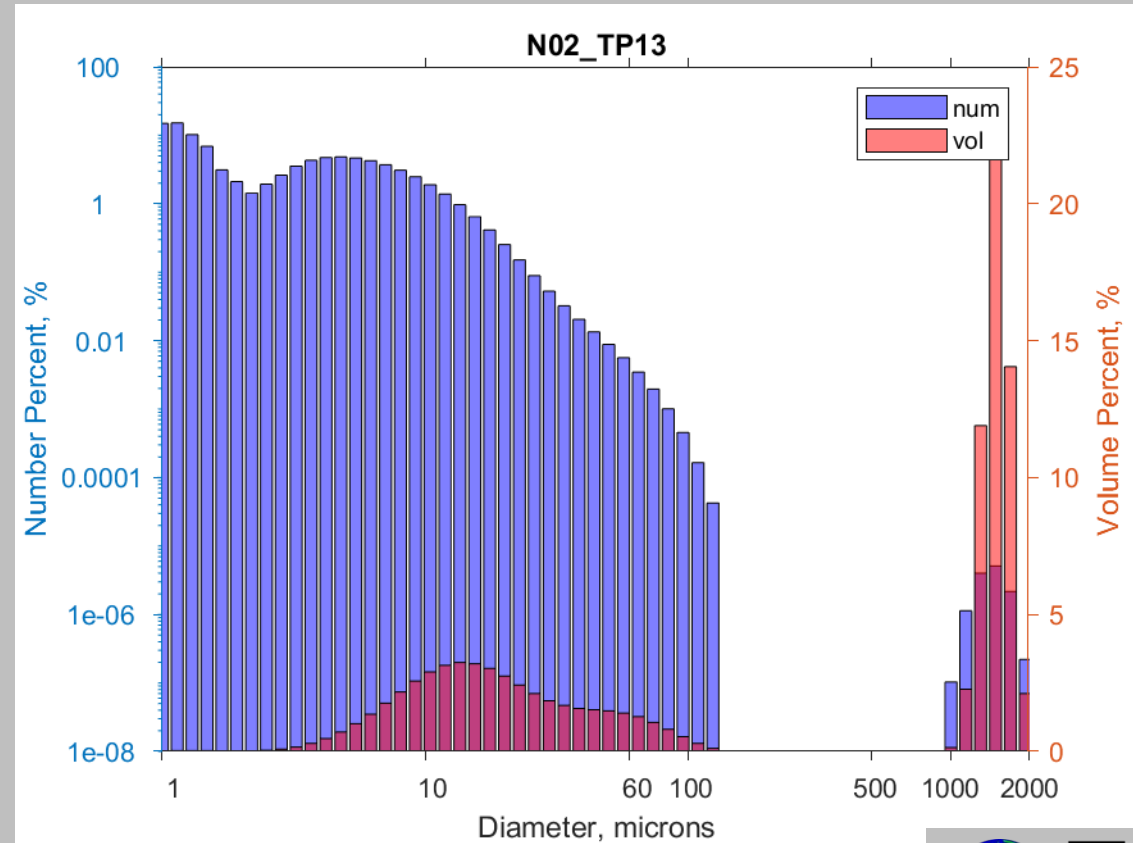
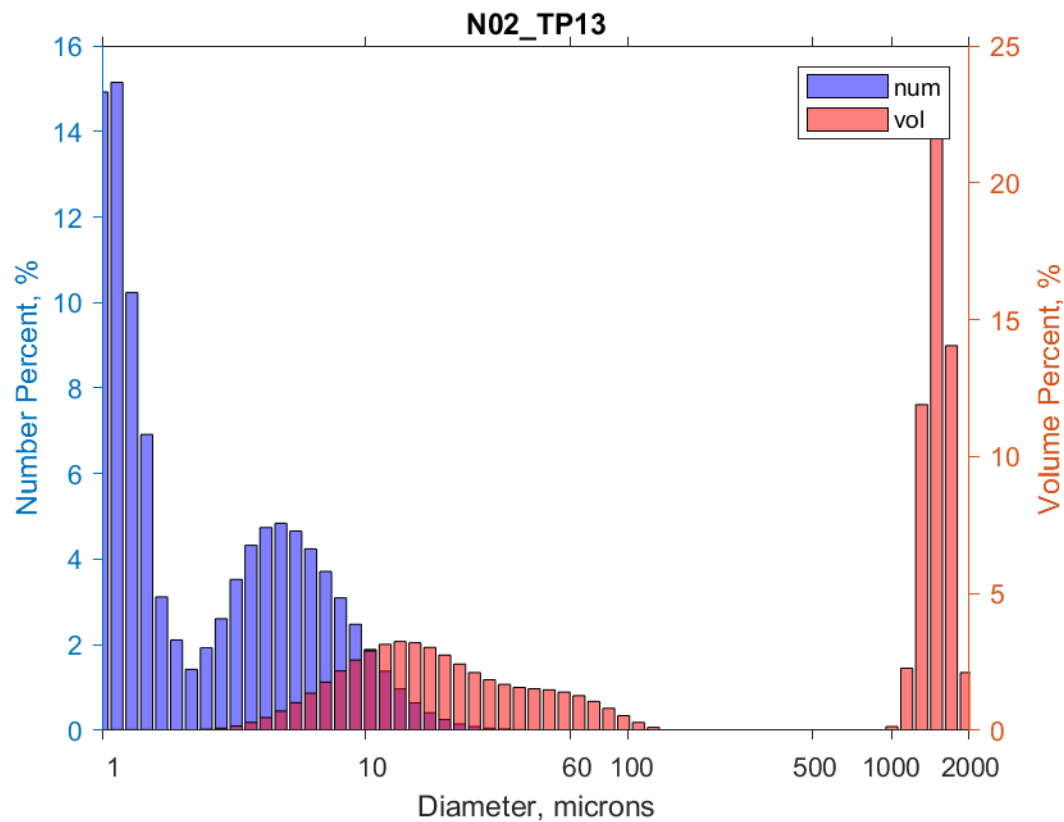
# Laser Diffraction – Volume and Number Distributions

- Trim Injector
  - 80 PSIG Atomization Air, 0.4 GPM



# Laser Diffraction – Volume and Number Distributions

- Trim Injector
  - 80 PSIG Atomization Air, 0.13 GPM



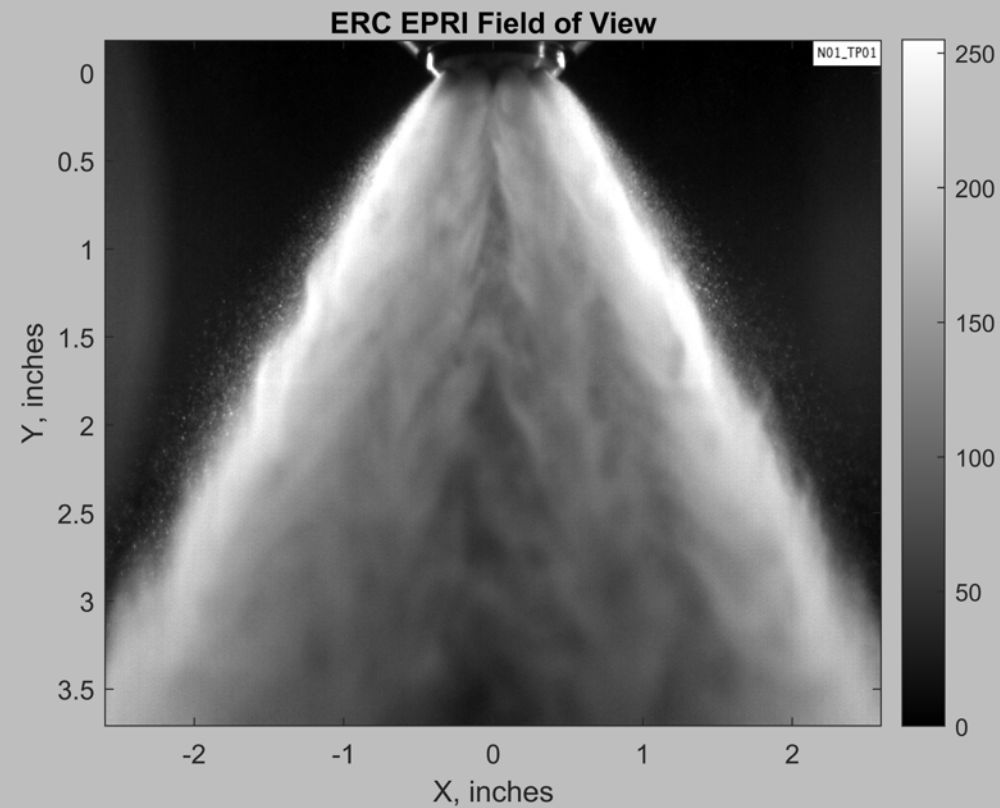
# High Speed Video

- Settings

- Exposure 5 microseconds
- Frame rate 6,600 frames per second
- Display rate 5 frames per second
- Field of view about 5 inches wide x 3.5 inches tall, see image below
- Frames saved 1,000
- Frames shown herein 20
- Elapsed Time in Video 0.003 Seconds

# High Speed Video

- Field of view
  - Still image to indicate horizontal and vertical scale



# High Speed Video

- Primary First Set, Trim, External (Full Flow)
  - 80 PSIG Atomizing Air, 1.2 GPM, 0.4 GPM, 1.2 GPM

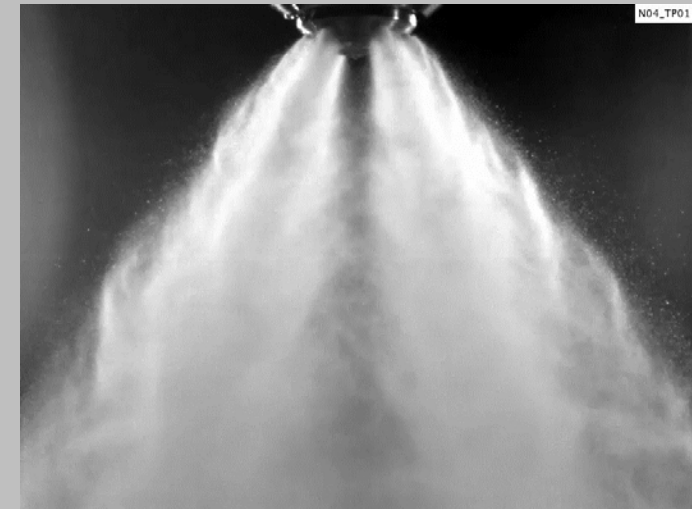
Primary First Set



Trim



External



# High Speed Video

- Primary First Set, Trim, External (Low Flow)
  - 80 PSIG Atomizing Air, 0.4 GPM, 0.13 GPM, 0.4 GPM

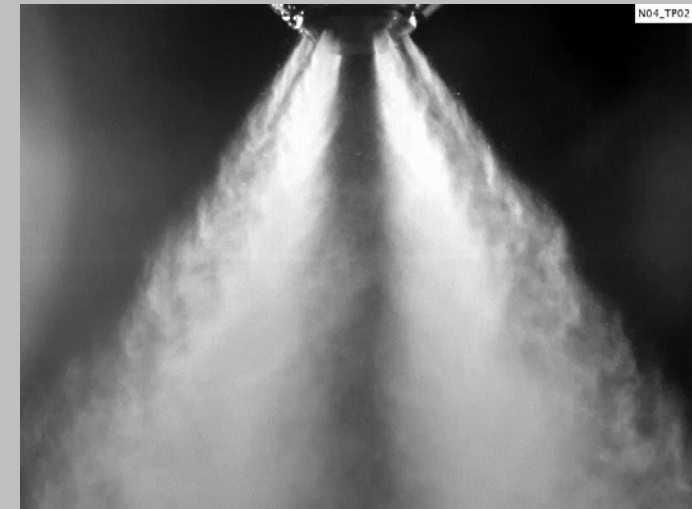
Primary First Set



Trim



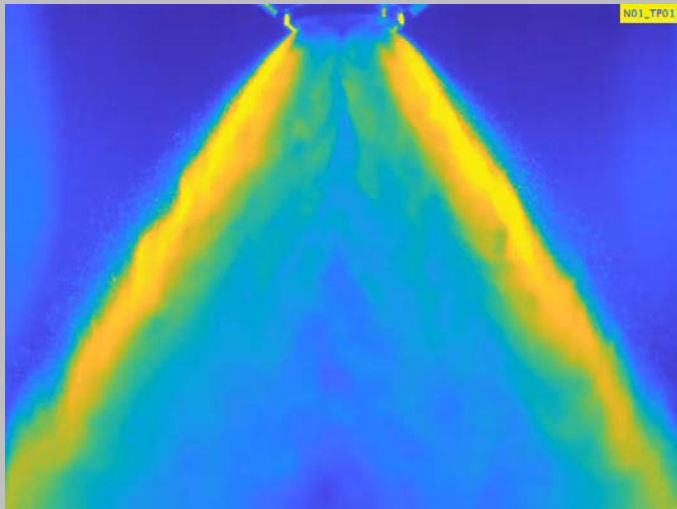
External



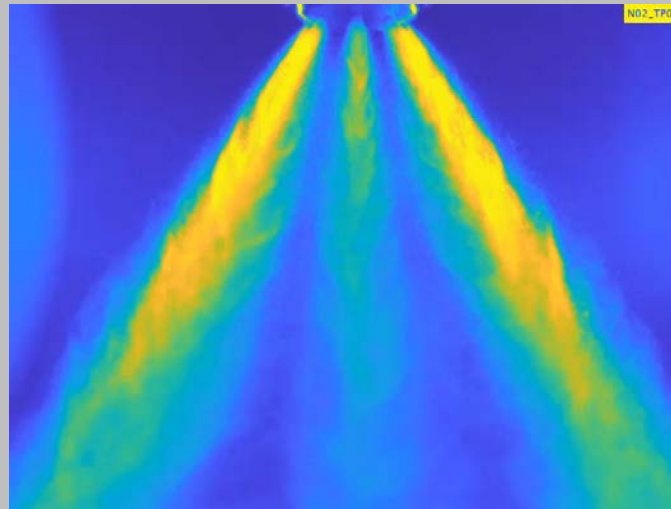
# High Speed Video

- Primary First Set, Trim, External (Full Flow)
  - 80 PSIG Atomizing Air, 1.2 GPM, 0.4 GPM, 1.2 GPM

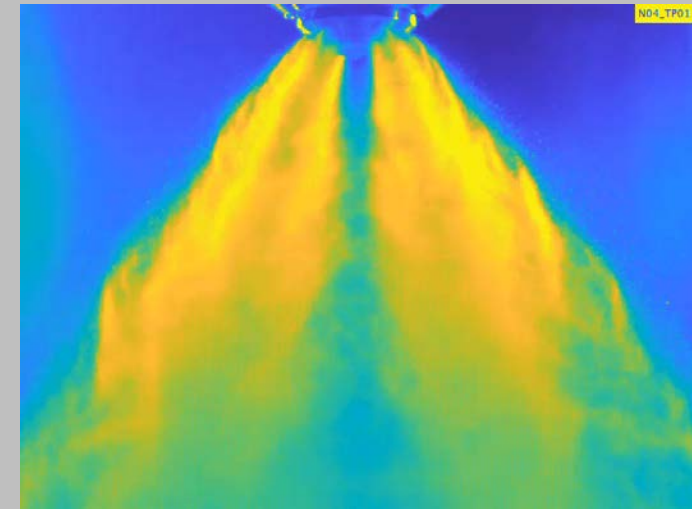
Primary First Set



Trim



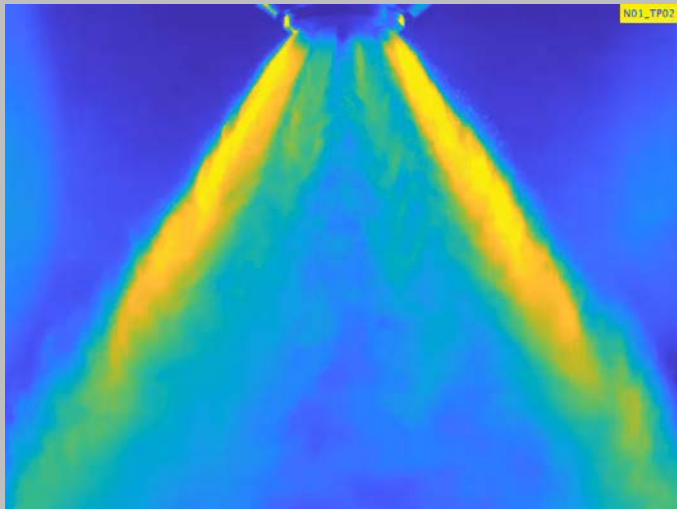
External



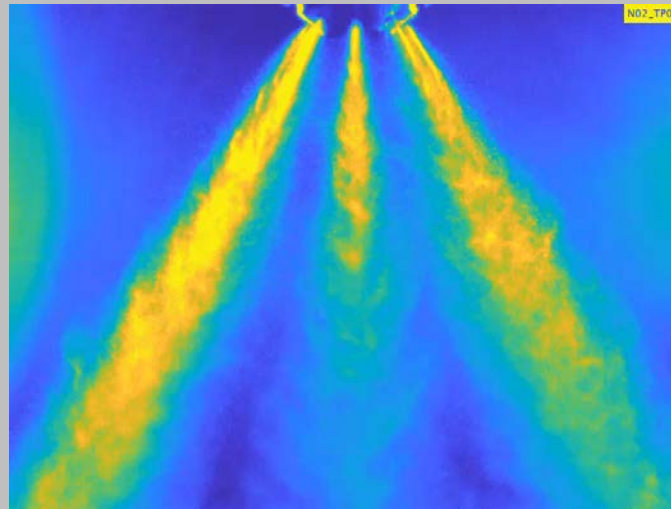
# High Speed Video

- Primary First Set, Trim, External (Low Flow)
  - 80 PSIG Atomizing Air, 0.4 GPM, 0.13 GPM, 0.4 GPM

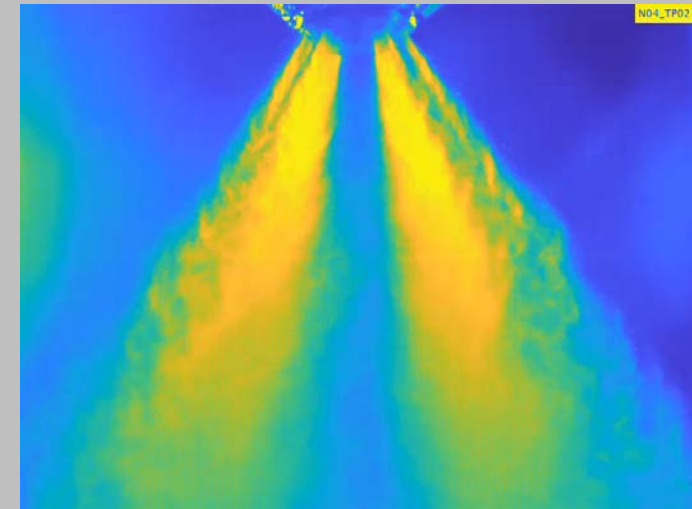
Primary First Set



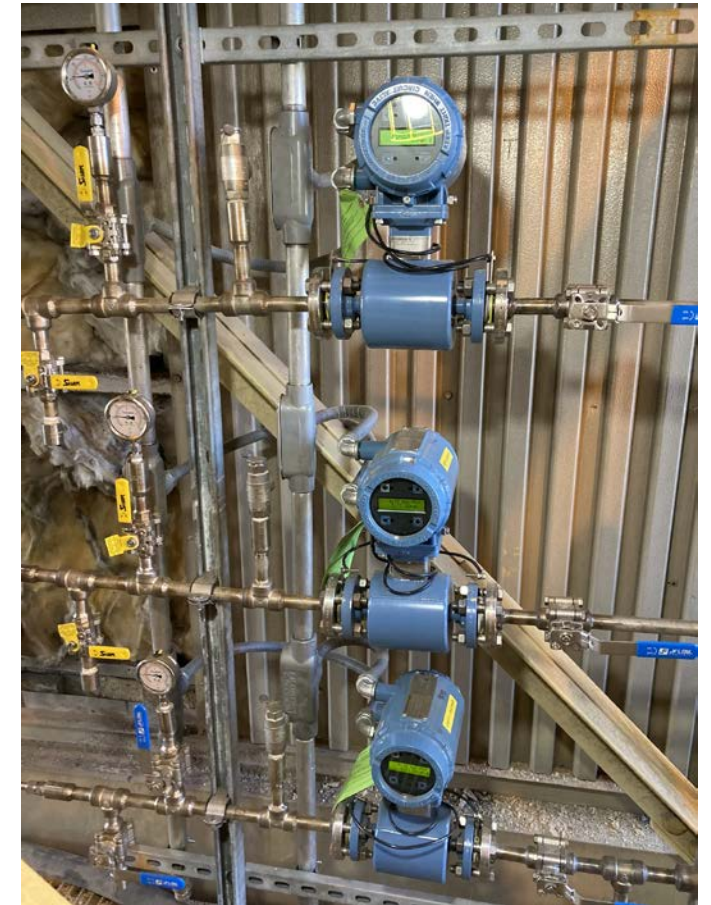
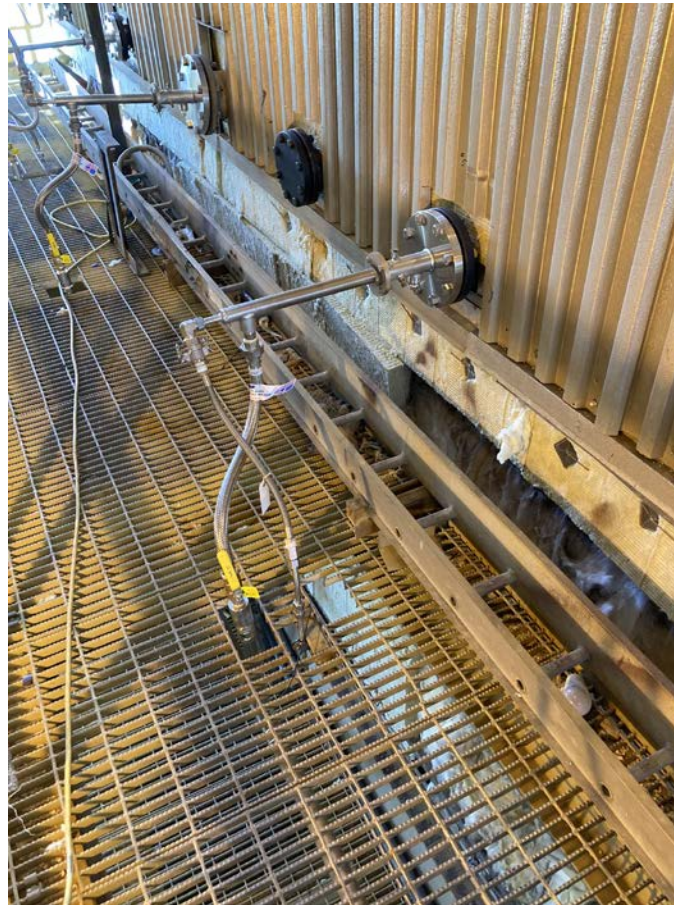
Trim



External

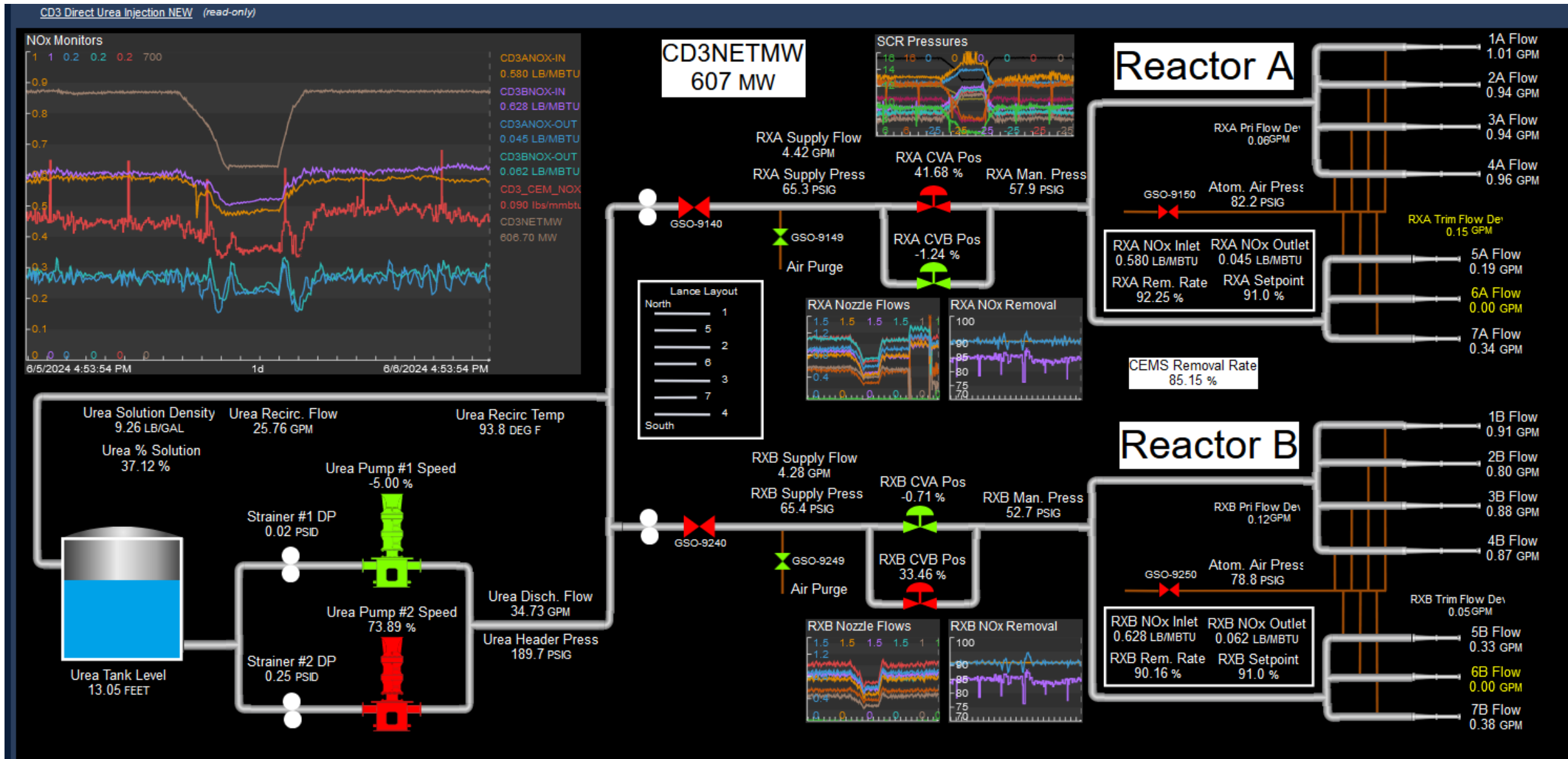


## Direct Urea Injection – 2024 Installation





# PI Vision Display of System Upgrade



# OHIO'S ELECTRIC COOPERATIVES

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## QUESTIONS?

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