Wet Stack Fine Particulate Method Development

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STAKEHOLDER PARTICIPATION

- This method development is a stakeholder participation program, supported by EPRI, NCASI, EPA (OAQPS), and DRI.

- *Stakeholders actively participate by receiving interim reports from EPA.*

- Periodic stakeholder telephone conference calls are held at report outs during the project.

METHOD DEVELOPMENT APPROACH

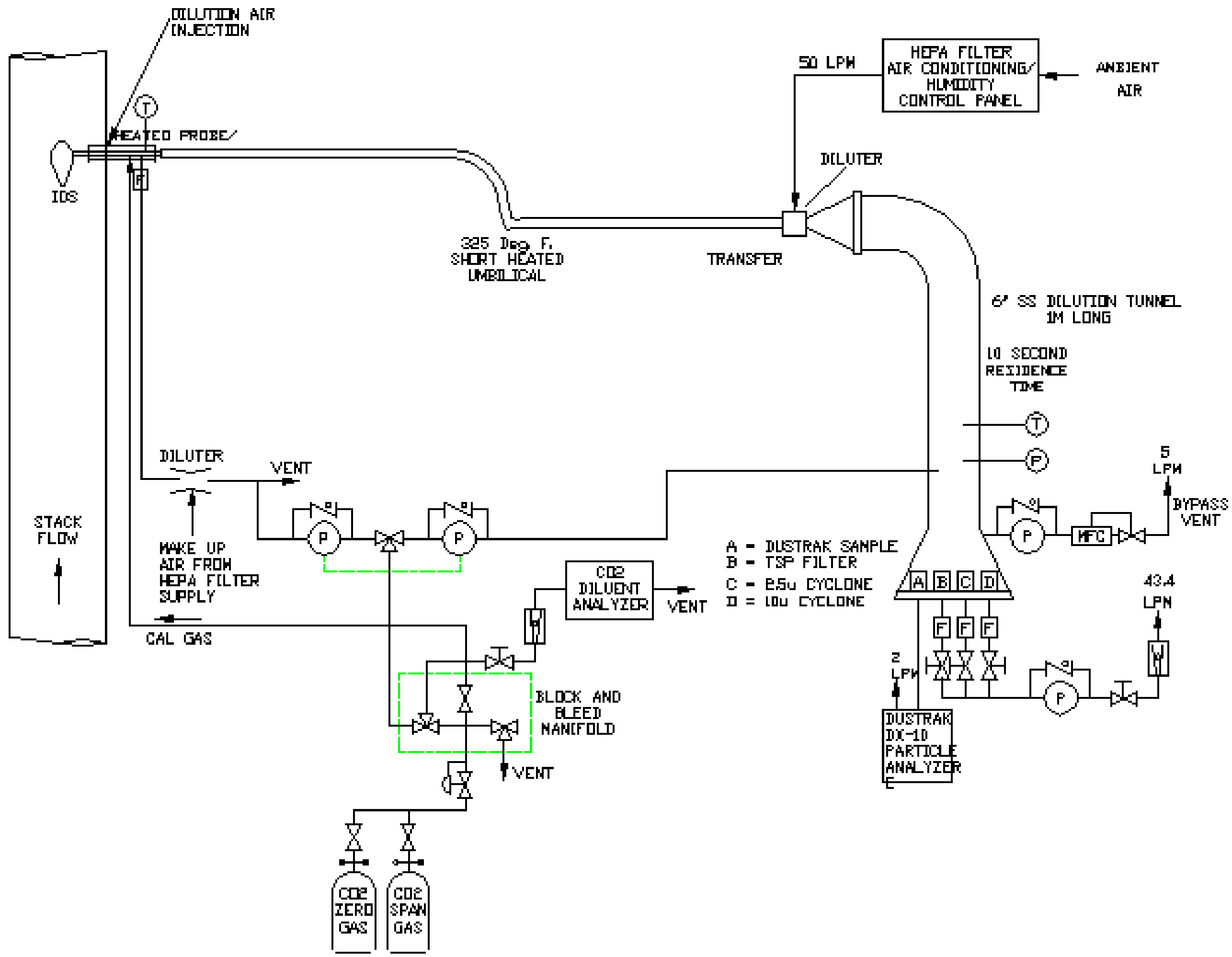
- Approach is to develop a protocol that has criteria for acceptance of a method and monitor, based on lab and field testing
- *The plan is to characterize a set of droplet generators within a wet test simulator for testing 20u or less droplet separators*
- Then challenge the INERTIAL DROPLET SEPARATOR (IDS) with known droplet matrices
- *We will integrate the IDS into a dilution sampling analysis system for wet testing*

DILUTION FINE PM SAMPLING TECHNOLOGY

- **FINE PM SAMPLER DESIGN** TO EMULATE ASTM COMMITTEE D22.03 WORKING GROUP RECOMMENDATIONS
- ***SAMPLE LIQUID DROPLETS LESS THAN 20u*** *IN A SATURATED STACK USING AN INERTIAL DROPLET SEPARATOR*
- **IMMEDIATE DILUTION** OF THE STACK GAS
- ***AGING*** *AT 85 F.*

- **PARTICLE FORMATION**
- ***CONDENSABLE PARTICLE FORMATION*** *WITH A 10 SECOND RESIDENCE TIME*
- **FRACTIONATION** OCCURS AFTER DILUTION WITH SHARP CUT CYCLONES
- ***FINAL PARTICULATE ANALYSIS*** *WITH AN AMBIENT BETA ATTENUATION MONITOR (BAM)*

PROTOTYPE WET STACK DILUTION SAMPLER FLOW DIAGRAM



NEW DROPLET SEPARATOR FOR SELECTING TARGET DROPLETS FOR ANALYSIS

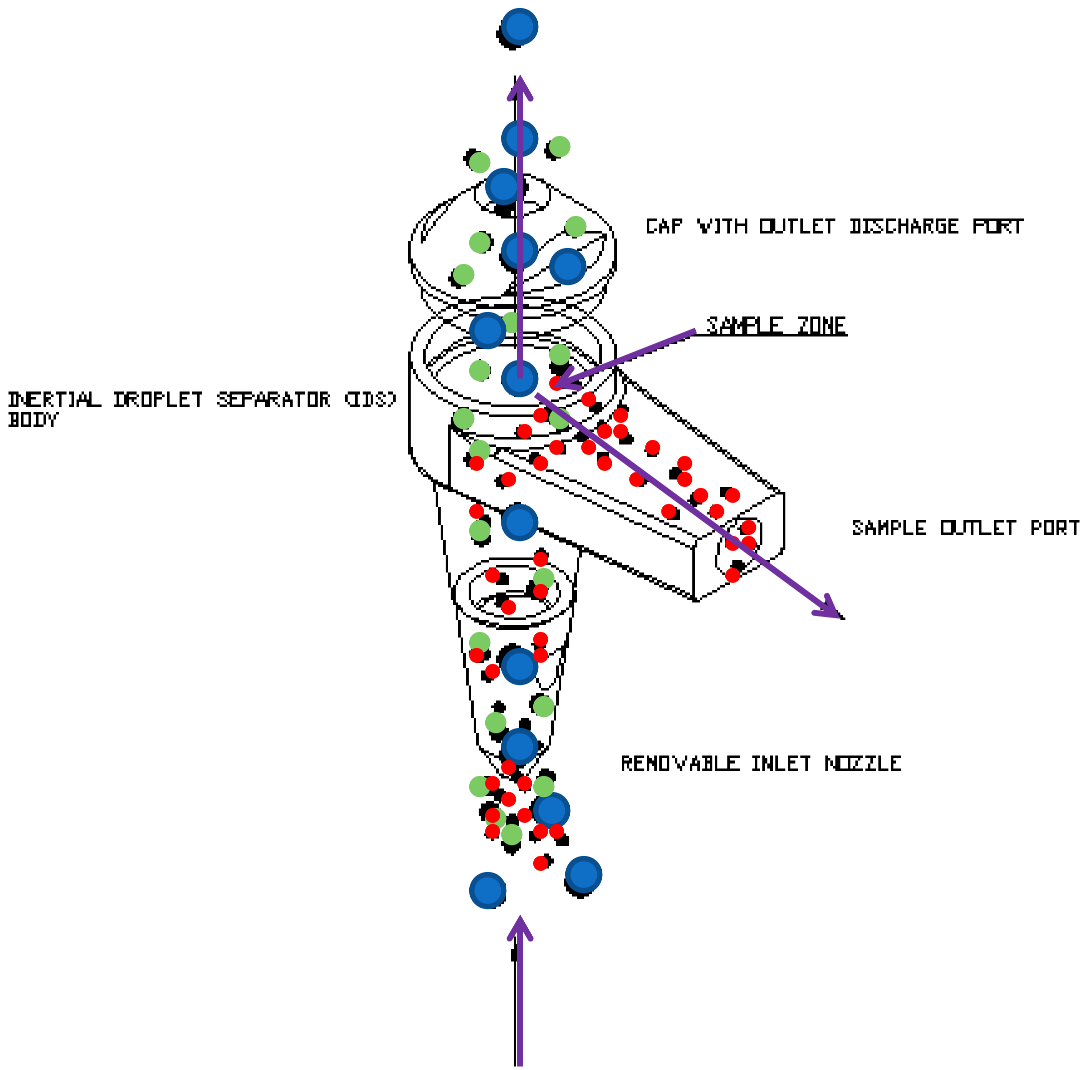
- INTRODUCTION OF AN INERTIAL DROPLET SEPARATOR (IDS)
- *DESIGNED TO SAMPLE WATER DROPLETS OF 20 MICRON OR SMALLER*
- TRANSFERS THE DROPLETS TO AN EVAPORATOR/DILUTION PROBE
- *RAPID WATER EVAPORATON TO YIELD DRY PARTICLE*

CURENT PROJECT HIGHLIGHTS

- Review results of dry test program
- *Conclusions from dry test program*
- Present Wet Stack Simulator Design
- *Wet Simulator Droplet Generating Performance*
- *IDS Performance in wet simulator*
- Next Steps

DRY TEST PROGRAM OVERVIEW

IDS DROPLET SEPARATION



IDS - DISASSEMBLED

DRY TEST PROGRAM OBJECTIVES

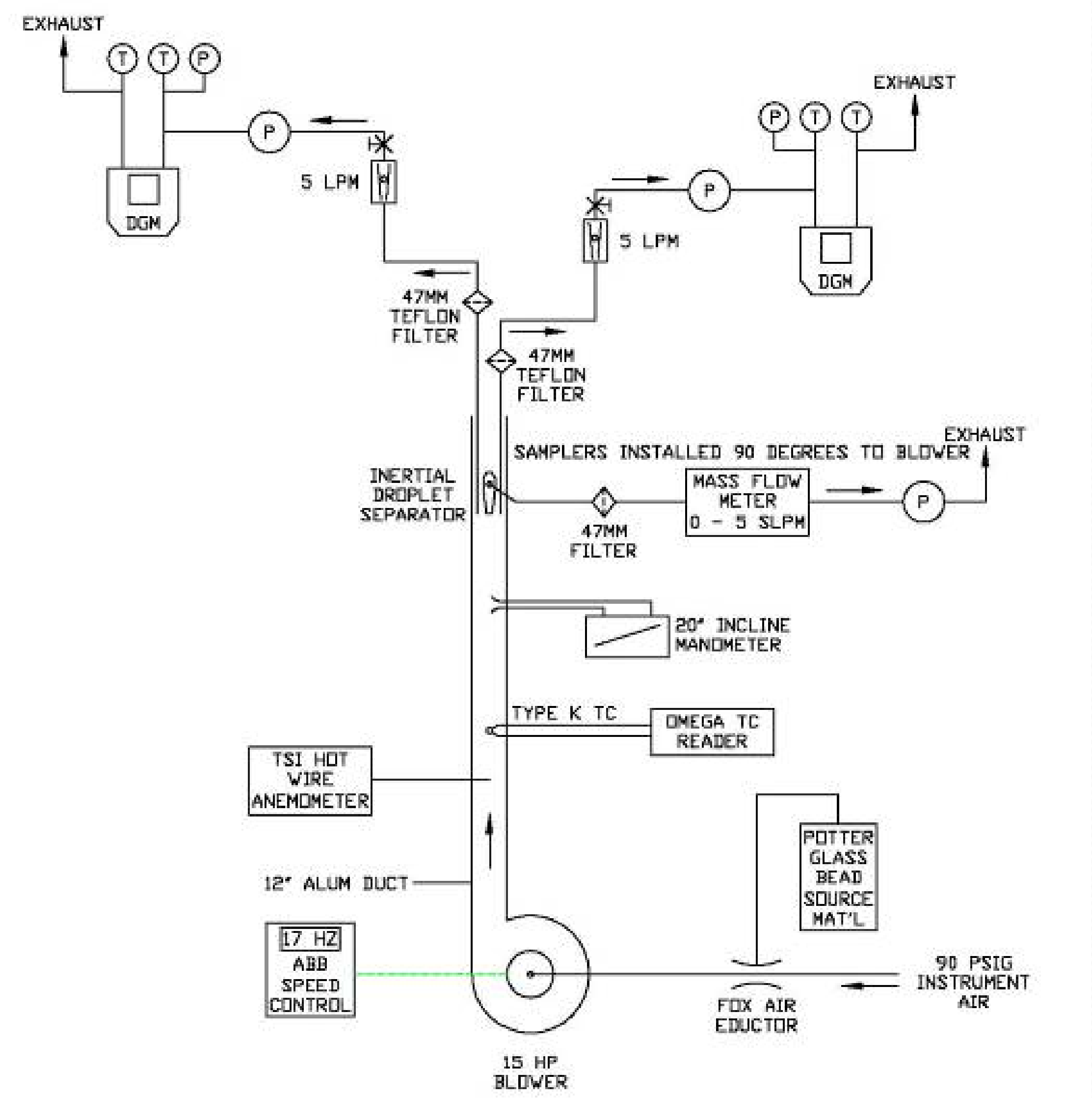
- **Construct prototype** Inertial Droplet Separator (IDS)
- ***Conduct laboratory tests*** *under dry stack conditions to demonstrate proof of concept*
  - Reject collection of particles above the 20-30 um diameter range

- **Test media:** glass beads, Arizona road dust
- ***Simultaneous Isokinetic tests*** *to measure concentration in stack and IDS tests to compare to Isokinetic results*
- **Evaluate the sample** effectiveness of the IDS against desired objectives
  - ***SAMPLE EFFECTIVENESS*** *is the % capture of the target particle size*

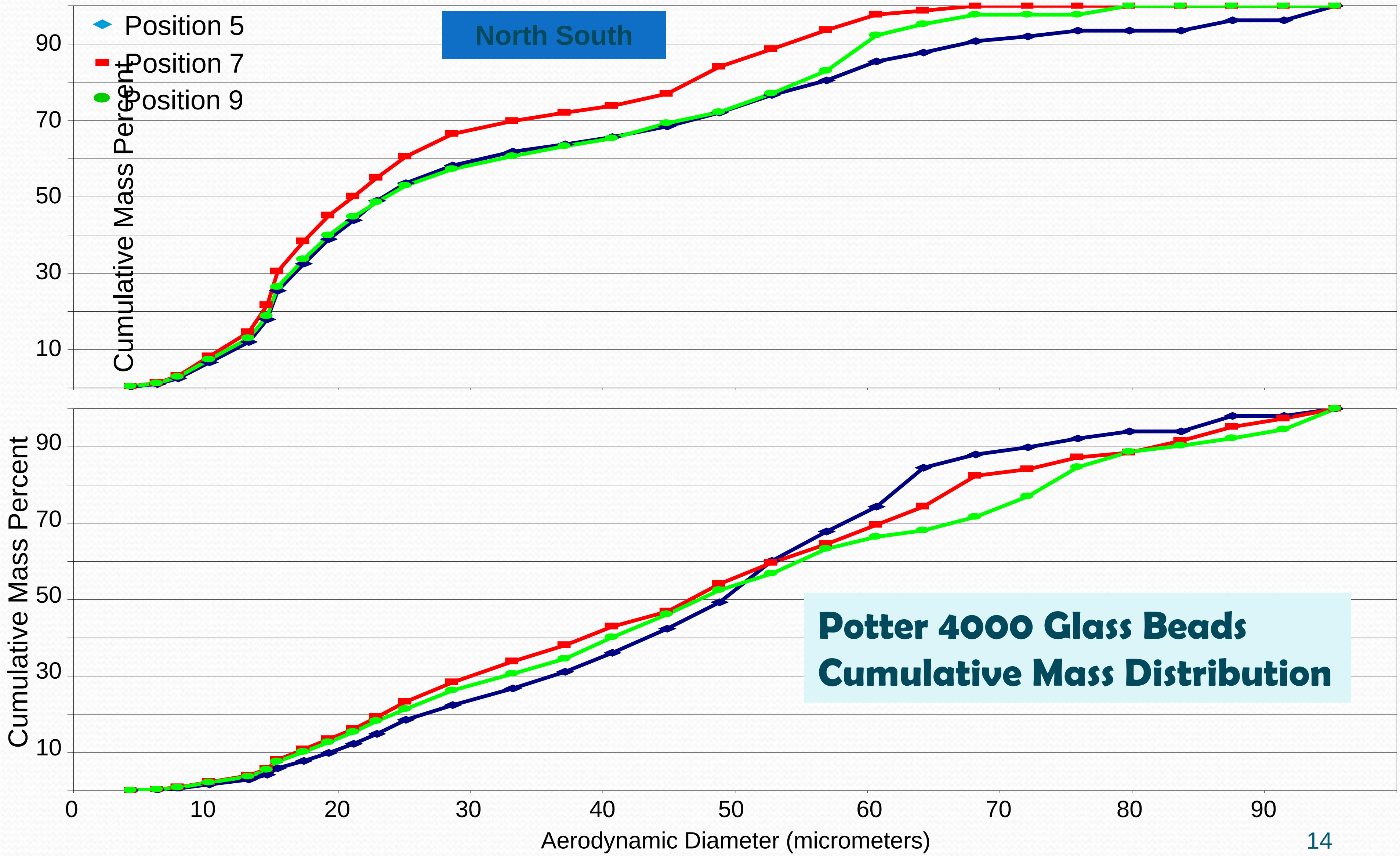
TEST PROTOCOLS

- Simultaneous Isokinetic & IDS
- *Cloud Droplet Probe (CDP)*
  - Characterization of Media Particle Size
- *CDP is calibrated with Potter 5000 Glass Beads from the factory*
- Sequential testing with CDP, Isokinetic, and Flow Through Cell CDP (FCDP)
- *Sequential CDP and IDS: Arizona Road Dust*

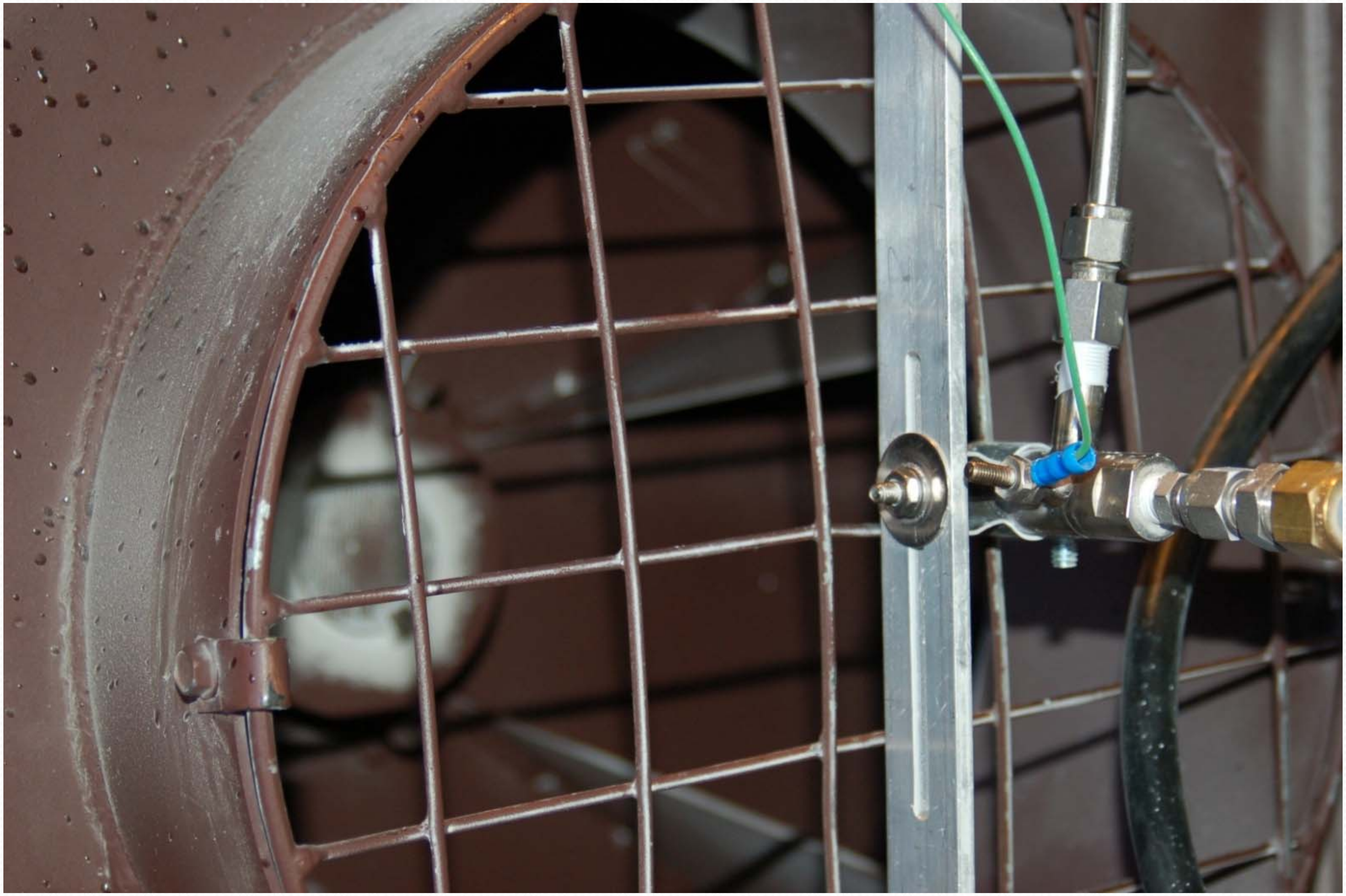
DRY TEST APPARATUS



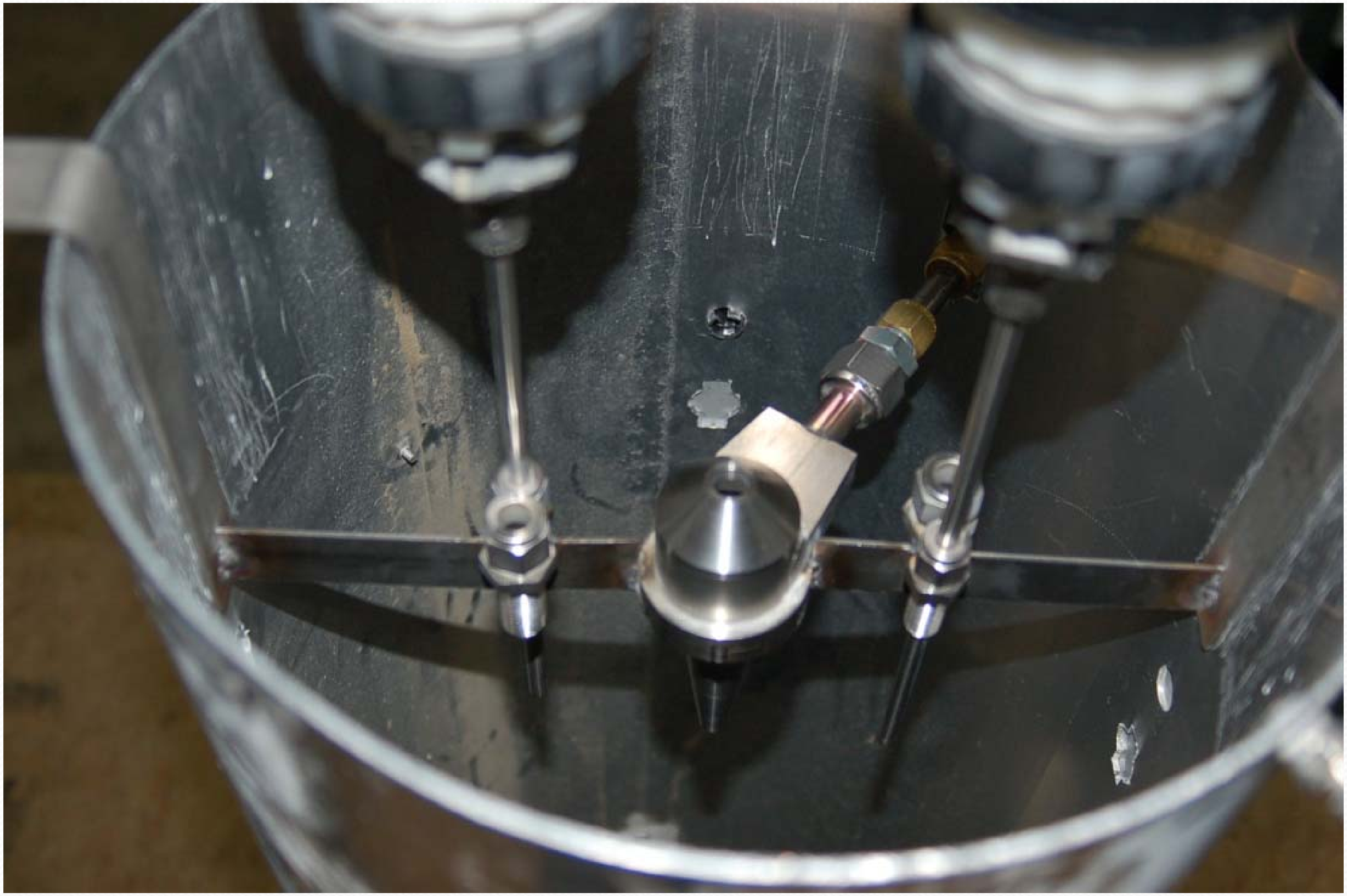
POTTER 5000 GLASS BEADS CUMULATIVE MASS DISTRIBUTION



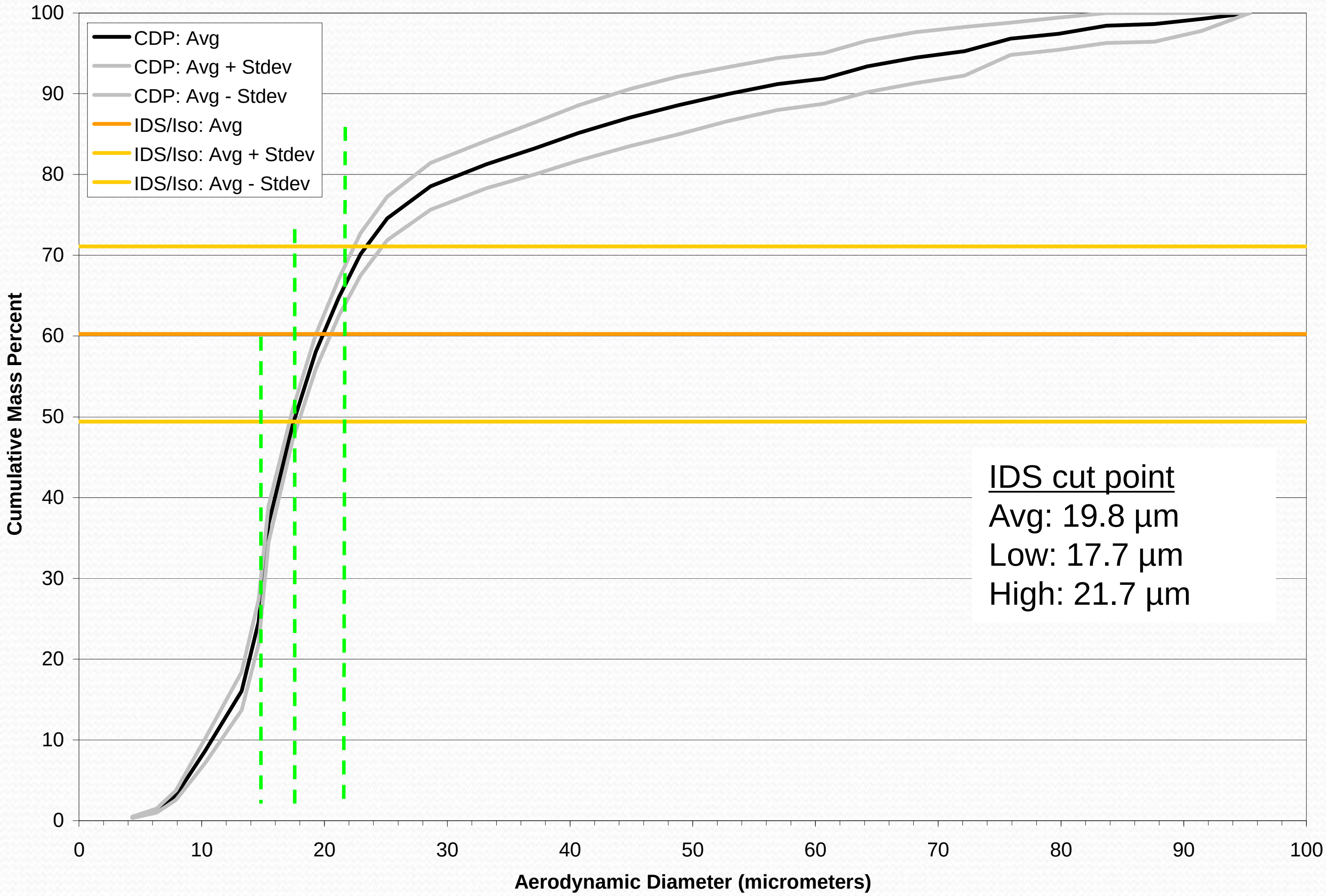
GLASS BEAD INJECTION @ FAN INLET



IDS and ISOKINETIC TRAINS IN STACK



IDS SIZE CUT ANALYSIS BASED ON THE IDS/ ISOKINETIC RATIO: ALL POTTER 5000 SAMPLES



ISO DRY TEST FINDINGS

- WASH RECOVERIES WERE >50% OF TOTAL RECOVERED MASS:
  - LARGE PARTICLES DROPPING OUT IN NOZZLE/TUBING
  - MICROSCOPIC ANALYSIS CONFIRMED

- A CONTINUOUS ANALYSIS METHOD WAS REQUIRED FOR EVALUATING THE IDS BEAD CAPTURE--CDP

SWITCH TO CDP
FOR
CONTINUOUS ANALYSIS

Use CDP to Characterize Test Media Particle and Mass Distribution in the Duct and downstream of the IDS

CDP OPERATING PRINCIPLE

- CLOUD DROPLET PROBE USED FOR SIZE AND MASS DISTRIBUTION OF WATER DROPLETS IN CLOUDS

- LASER LIGHT FORWARD SCATTER PRINCIPLE
  - The cone of photons that is forward scattered in the 4° to 12° range is collected and measured.

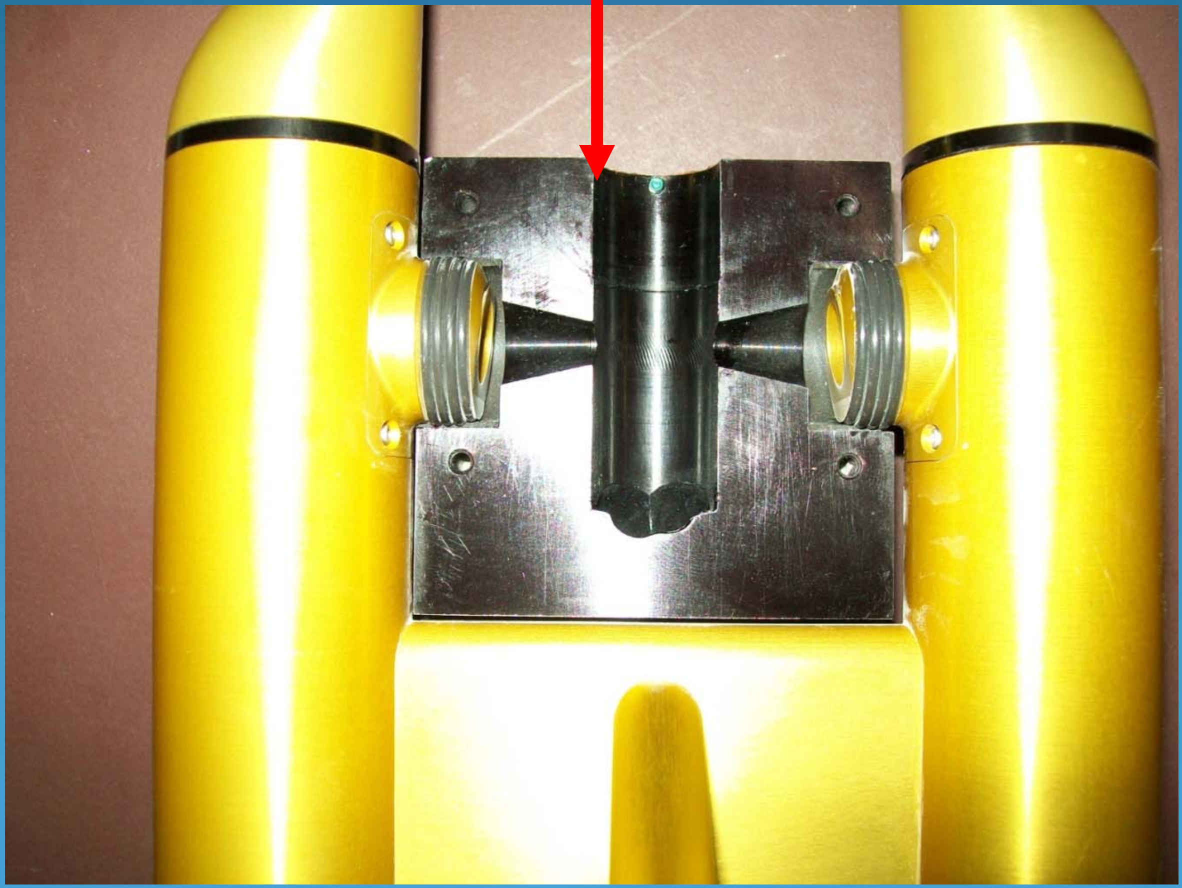
  - Intensity of scatter light is proportional to particle size.

CDP SAMPLING IN THE DUCT

ASSEMBLED FLOW THROUGH CDP (FCDP) CELL WITH IDS CONNECTED

CDP (IN YELLOW) AND BOTTOM HALF OF THE FLOW THROUGH CELL (CLAM SHELL DESIGN

From IDS

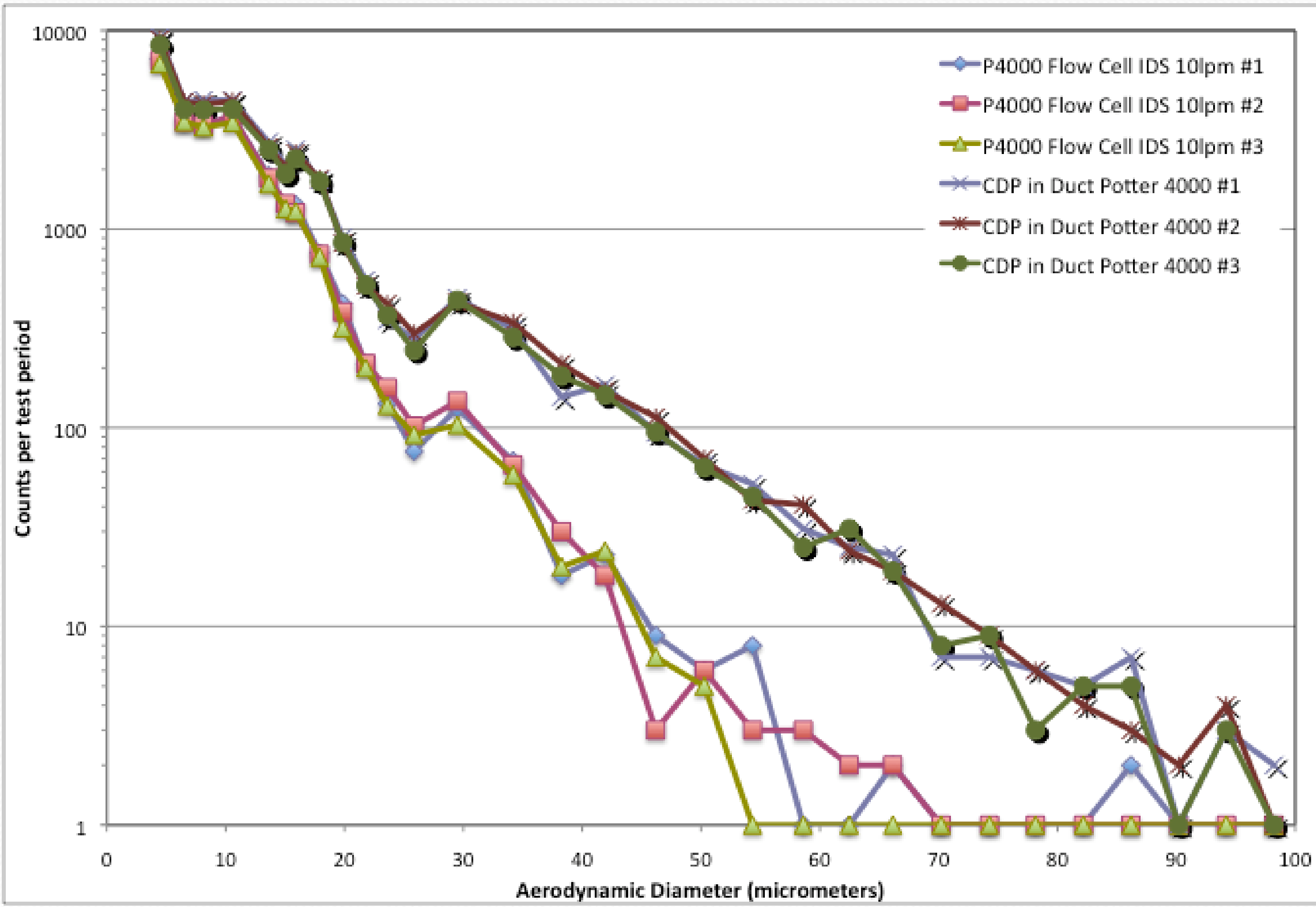


FLOW THROUGH CELL TESTING, WITHOUT ISOKINETIC SAMPLING

- **Test stack** with CDP in Open Path Mode
- ***Remove CDP and insert IDS*** *with Flow Through Cell CDP (FCDP) in-line*
- **Real time analysis** of the IDS sample fraction

- ***Compare*** *the in stack particle distribution to the IDS sample cut downstream of the IDS*
- We were looking for a better way to determine the percent transmission cut point for the IDS

INDIVIDUAL RUNS: CDP RAW COUNTS OF POTTER 4000 IN DUCT AND AFTER IDS WITH IDS AT 10 LPM



IDS & FLOW THROUGH CDP OBSERVATIONS

- At sample flow rates of 10 and 5 lpm IDS is collecting majority of particles smaller than 20 to 30 um.

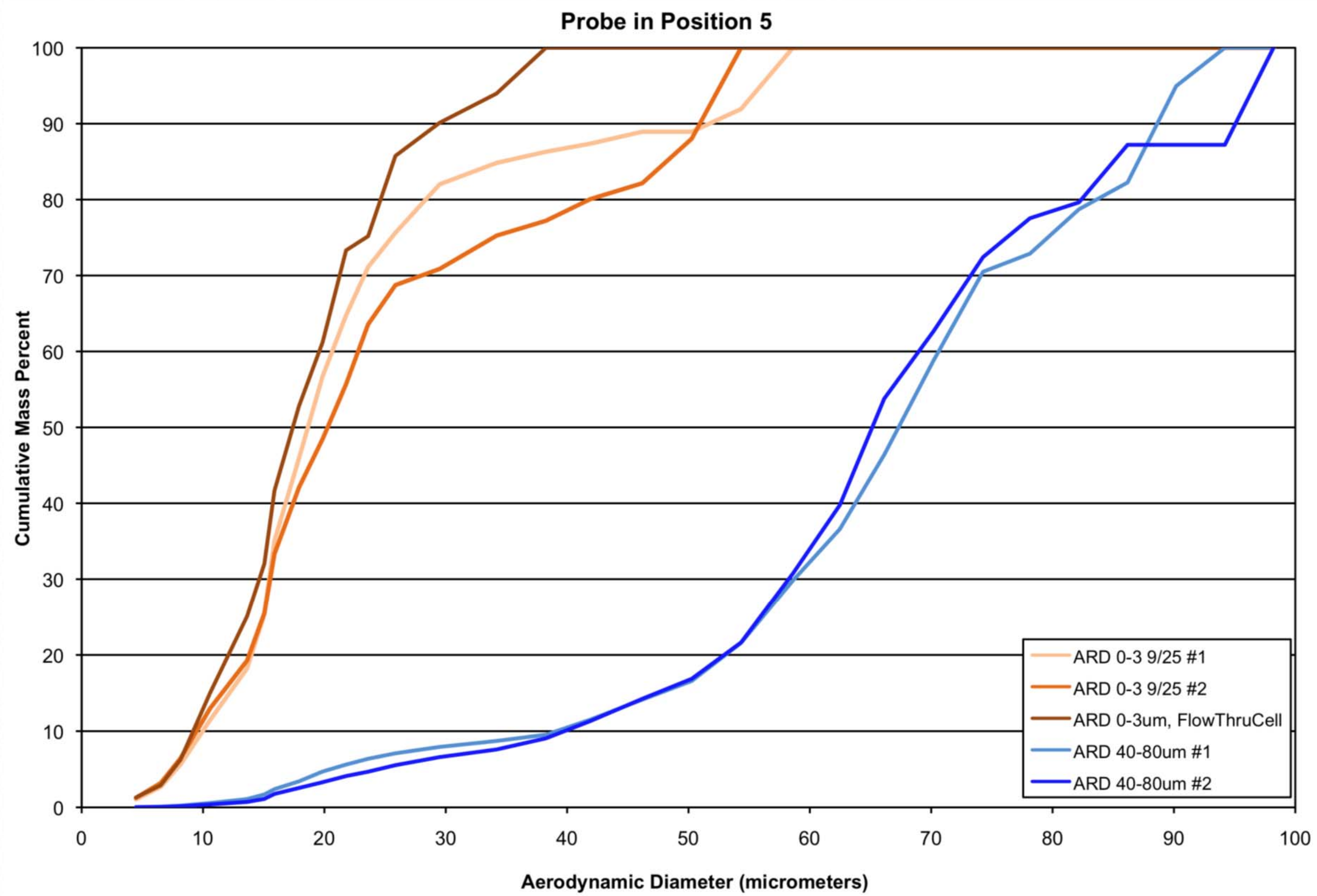
- *Performance is consistent for both Potter 5000, 4000, and Arizona Road Dust with respect to each other.*

- One issue with the CDP data reporting is low counts for larger particles.

ARIZONA ROAD DUST (ARD)

- Conduct additional dry testing using different sample media to better determine separation performance of IDS
- *Fine distribution ARD; 0-3 um (Physical)*
  - IDS should collect all
- *Medium distribution ARD: 40-80 um (physical)*
  - IDS should not collect most

CDP SIZE DISTRIBUTION: ARIZONA ROAD DUST



Arizona Road Dust

Test ID	ARD	Iso or IDS	Raw Filter mass (µg)	Raw Wash mass (µg)	Sample Duration	Stnd Vol (m^3)	Stnd Conc[a] (µg / m^3)	Theoretical (µg / m^3)	Filter&Wash to Theor (%)
141	0-3	Iso	149	74	35m 23s	0.2579	865	8,196	10.6
142	0-3	Iso	2222	680	30m 27s	0.2231	13,007	9,512	136.7[b]
145	0-3	Iso	2107	479	26m 28s	0.2000	12,930	10,712	120.7[b]
143	0-3	IDS	1360	471	28m 25s	0.1200	15,261	10,211	149.5[b]
144	0-3	IDS	1197	475	26m 20s	0.1150	14,537	10,613	137.0[b]
146	0-3	IDS	1227	373	27m 57s	0.1201	13,319	10,353	128.6[b]
147	40-80	Iso	61	513	16m 50s	0.1312	4,375	8,523	51.3
151	40-80	Iso	40	702	13m 2s	0.1059	7,004	11,077	63.2
148	40-80	IDS	15	399	14m 4s	0.0627	6,606	10,134	65.2
149	40-80	IDS	23	461	12m 59s	0.0549	8,819	11,118	79.3
150	40-80	IDS	20	380	12m 37s	0.0548	7,309	11,462	63.7

[a] Not corrected (i.e. no background subtraction)
[b] Reentrainment of media with intake air to blower

Microscopic Analysis

Summary of Computer Controlled SEM (CCSEM) Results
IDS TEST SAMPLES

Size Distribution by Average Diameter (microns)

Sample ID	Bead Type	Description	0.5 - 1	1 - 2.5	2.5 - 5	5 - 10	10 - 20	20 - 50
9/16/2009	5000	Acetone Rinse	18.4	42.3	23.2	13.5	2.44	0.09
W222	4000	Acetone Rinse	14.5	40.8	29.4	10.9	3.57	0.8
W223	4000	Acetone Rinse	12.5	36.6	25.9	17.3	6.27	1.5
W224	4000	Acetone Rinse	27.3	41.5	15.0	10.2	4.63	1.3
SBU222	4000	PC Filter	38.8	49.4	10.3	1.4	0.07	0.000
SBU223	4000	PC Filter	36.6	49.6	12.0	1.7	0.06	0.004
SBU224	4000	PC Filter	41.3	48.3	9.2	1.0	0.05	0.002

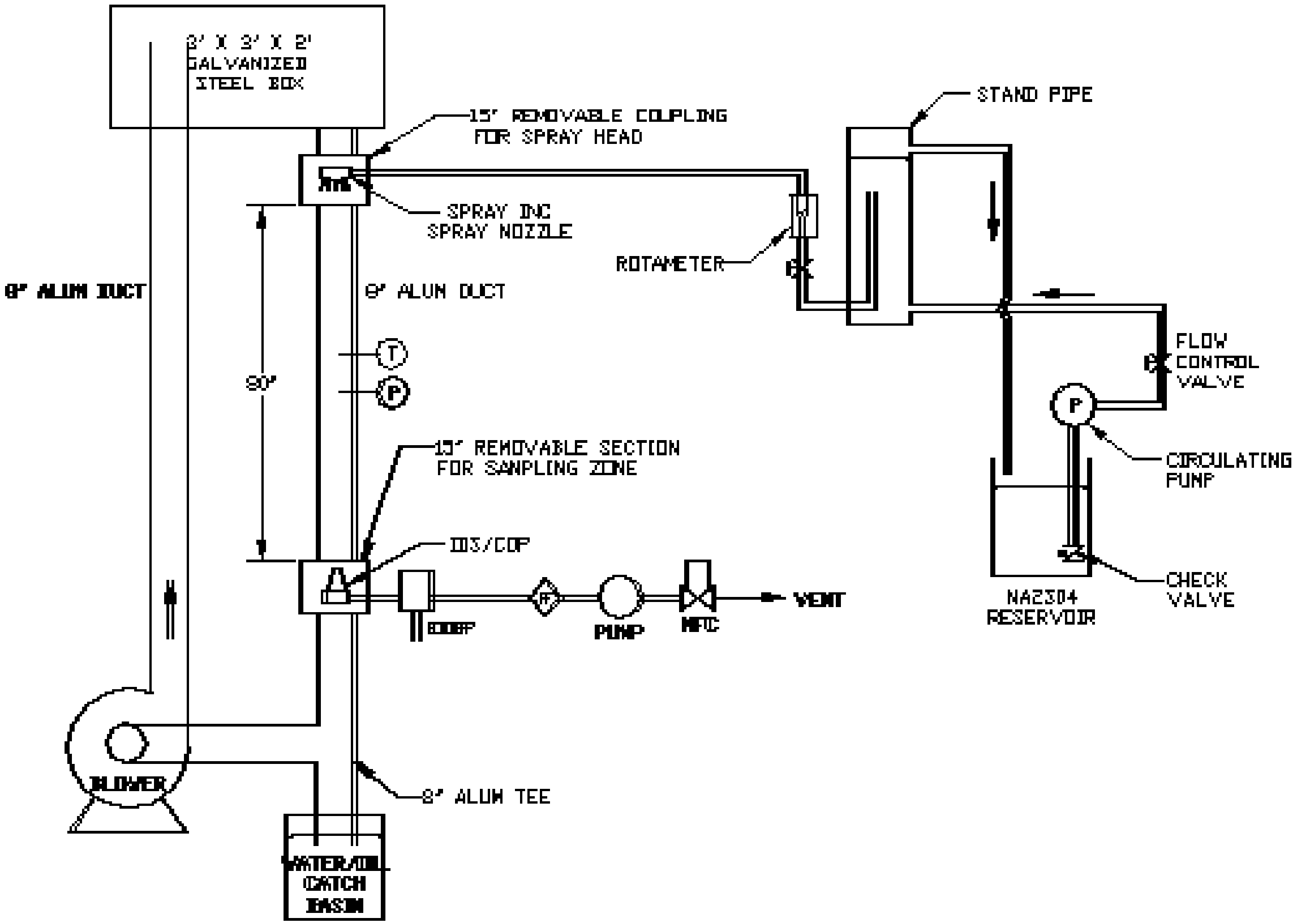
Volume Distribution by Average Diameter (microns)

Sample ID	Bead Type	Description	0.5 - 1	1 - 2.5	2.5 - 5	5 - 10	10 - 20	20 - 50
9/16/2009	5000	Acetone Rinse	0.1	1.6	9.7	40.8	33.1	14.8
W222	4000	Acetone Rinse	0.02	0.8	5.2	14.0	36.7	43.3
W223	4000	Acetone Rinse	0.01	0.3	2.7	13.1	35.2	48.7
W224	4000	Acetone Rinse	0.03	0.4	2.0	9.5	31.7	56.4
SBU222	4000	PC Filter	1.4	18.3	39.2	31.9	9.1	0.0
SBU223	4000	PC Filter	1.1	15.8	39.3	35.1	6.1	2.6
SBU224	4000	PC Filter	1.7	20.9	40.9	27.3	7.5	1.8

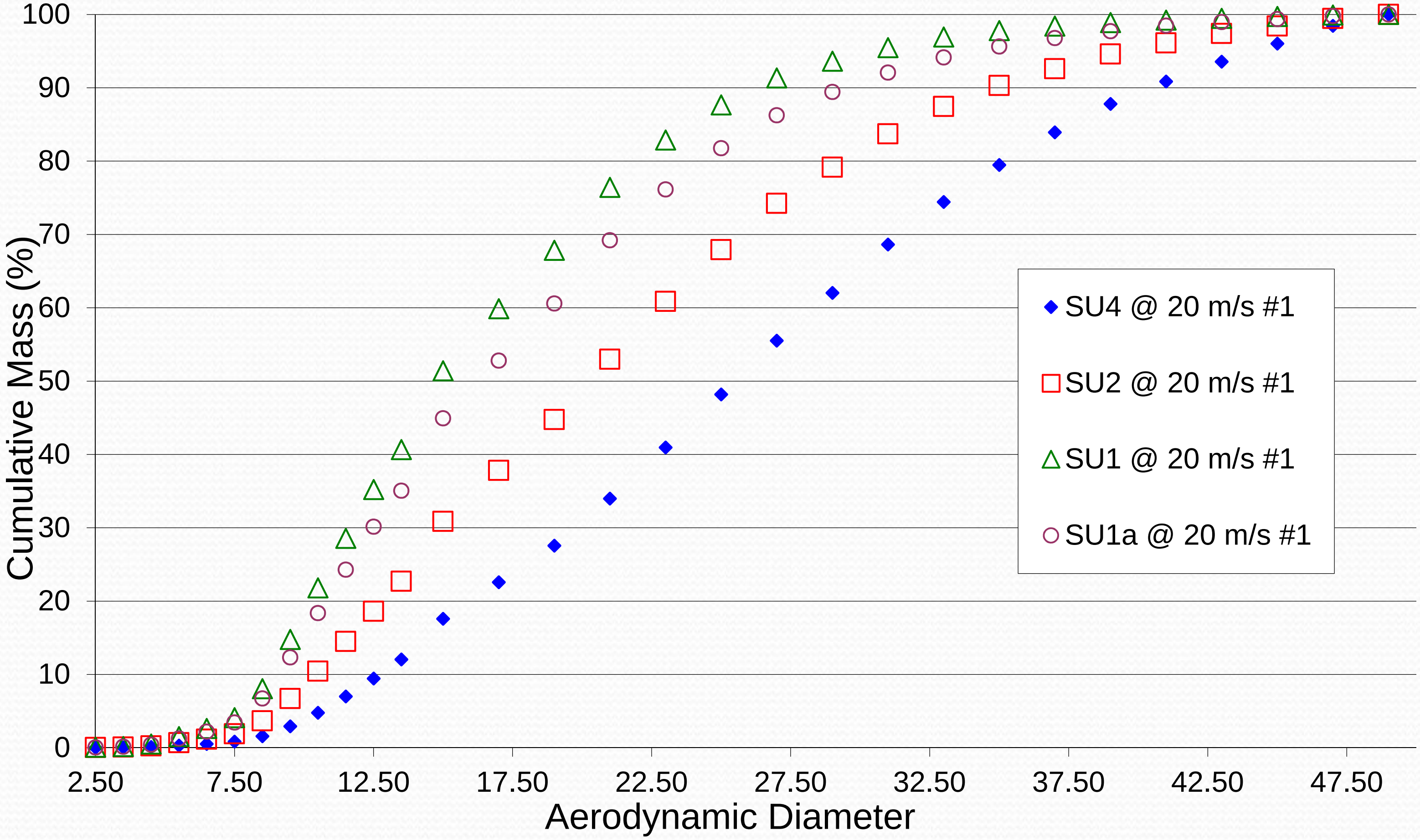
ARIZONA ROAD DUST CONCLUSIONS

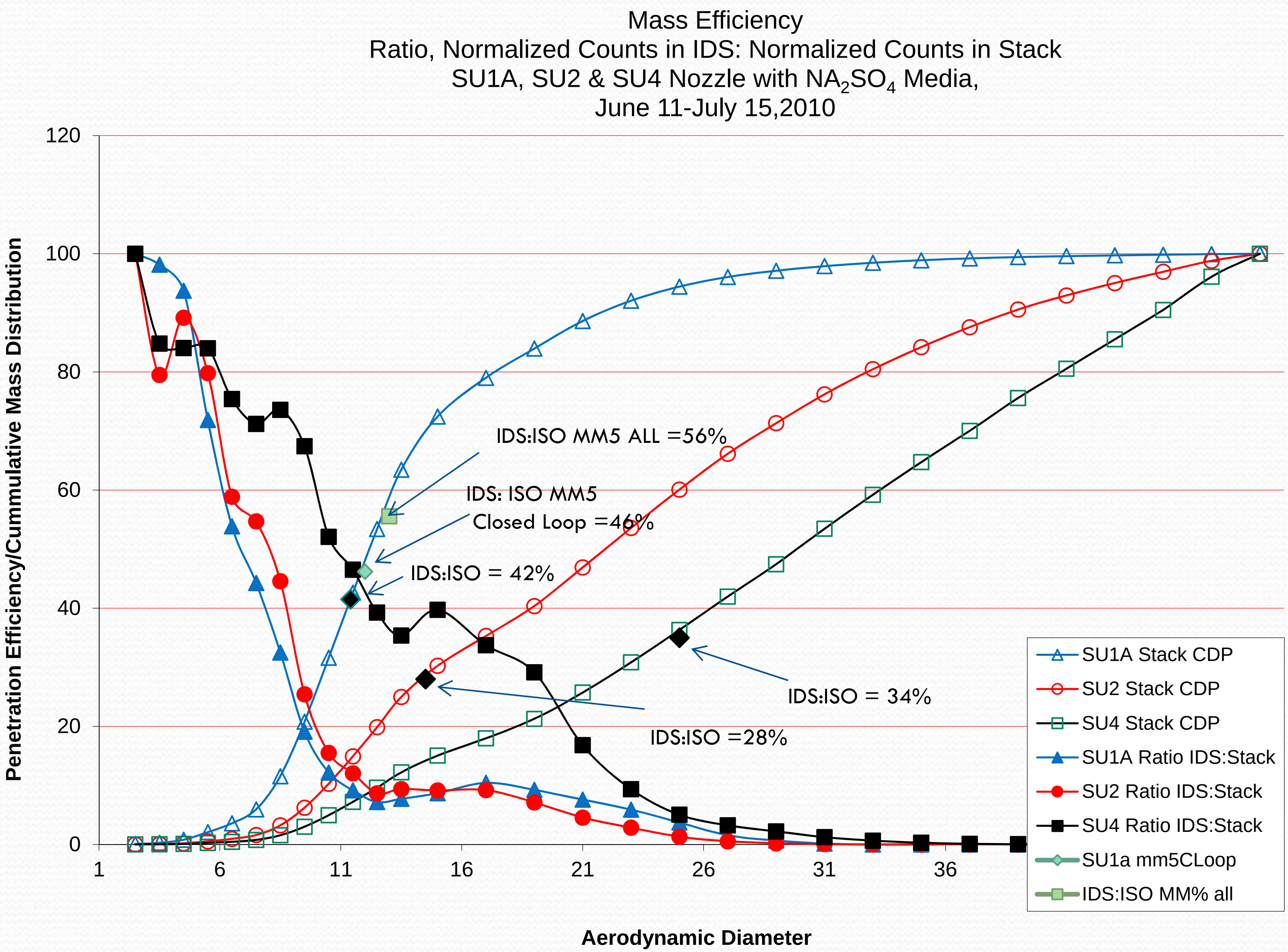
- IDS collected all of fine ARD
- *For larger ARD, results consistent with Potter 5000 glass beads. Indicated IDS is collecting some of the larger particles in the 40-80 um ARD sample.*

WET STACK DROPLET SIMULATOR



WET DROPLET SIMULATOR
SPRAY HEAD PERFORMANCE CURVES FOR WATER





Mass Efficiency
Ratio, Normalized Counts in IDS: Normalized Counts in Stack
SU1A, SU2 & SU4 Nozzle with NA_2SO_4 Media,
June 11-July 15,2010
Penetration Efficiency/Cummulative Mass Distribution
Aerodynamic Diameter
IDS:ISO MM5 ALL =56%
IDS: ISO MM5
Closed Loop =46%
IDS:ISO = 42%
IDS:ISO = 34%
IDS:ISO =28%
SU1A Stack CDP
SU2 Stack CDP
SU4 Stack CDP
SU1A Ratio IDS:Stack
SU2 Ratio IDS:Stack
SU4 Ratio IDS:Stack
SU1a mm5CLoop
IDS:ISO MM% all

Results/Conclusions

- Based on ratio of IDS:Isokinetic mass collected and CDP in-stack particle size distribution:
- Dry tests
  - IDS is transmitting (collecting) greater than 90% of fine particles < 10 µm
  - IDS is cutting (not transmitting) particles greater than 20 to 50 µm aerodynamic; (results varied depending upon media)
- Wet tests:
  - IDS is cutting in the range of 10 to 25 µm aerodynamic
- IDS is effective at cutting large droplets, but cut point is uncertain; want to better quantify

NEXT STEPS

- Test IDS/dilution train in simulator stack under wet conditions
  - Objective: Proof of concept that IDS/dilution train system will sufficiently eliminate large droplets and transport sample to $PM_{2.5}$ cyclone/filter system
- Field Test IDS/dilution train
  - Objective: Proof of concept under actual field conditions
- Laboratory evaluation of IDS with monodisperse aerosol
  - Objective: Better quantify d_{50} of IDS