Pulverized Coal Extractive Testing Methods

Evaluation at the EPRI Coal Flow Loop

Robert Mudry, P.E.
Matthew Fleming
Airflow Sciences Corporation
Livonia, Michigan

Richard Brown
Jose Sanchez
The Electric Power Research Institute
Palo Alto, California

Why Measure Primary Air and Coal?

- Quantify Pipe to Pipe Balance
  - Burner Performance
    - Unburned Carbon
    - NOx Emissions
  - Overall Boiler Efficiency
  - Diagnose Burner Line Issues

- Assess Mill Performance
  - Fineness

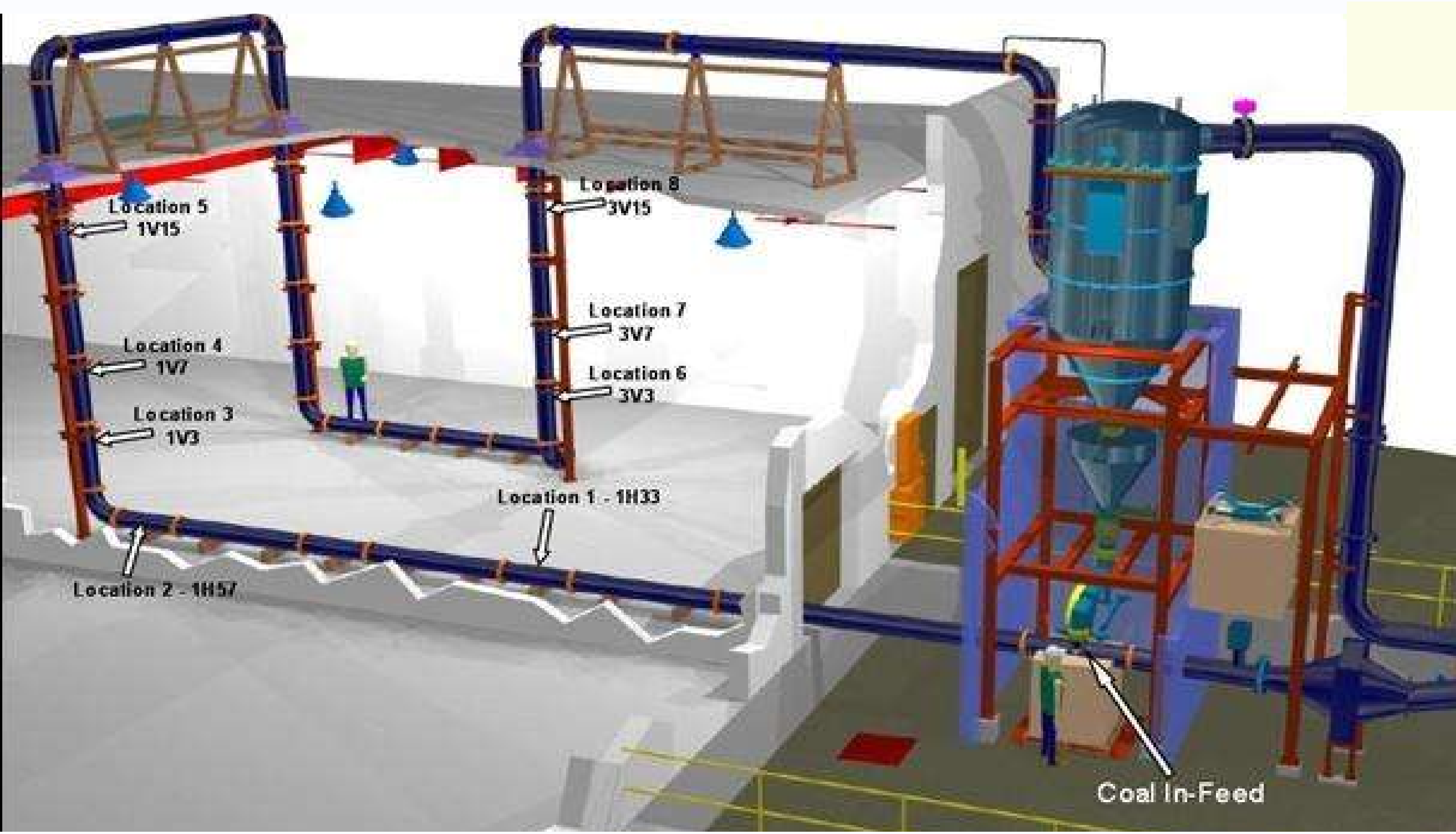
Coal Pipe Flow Measurement Methods

- Online, continuous measurement
  - Real-time coal balance information
  - Data over the load range
- Extractive measurement
  - Pipe to pipe air and coal flow balance
  - Data at select operating conditions
  - Pulverized coal samples

EPRI Coal Flow Loop Project Objectives

- Develop a Research Facility with Controlled and Known Conditions
  - Operate in full scale with coal
  - Precise control over air and coal flow rates
- Evaluate Online Coal Flow Instrumentation
  - Accuracy
  - Sensitivity to piping layout, flow rates, temperature, …
- Assess Extractive Testing Methods
  - Accuracy
  - Sensitivity to piping layout, flow rates, temperature, …

EPRI Coal Flow Loop

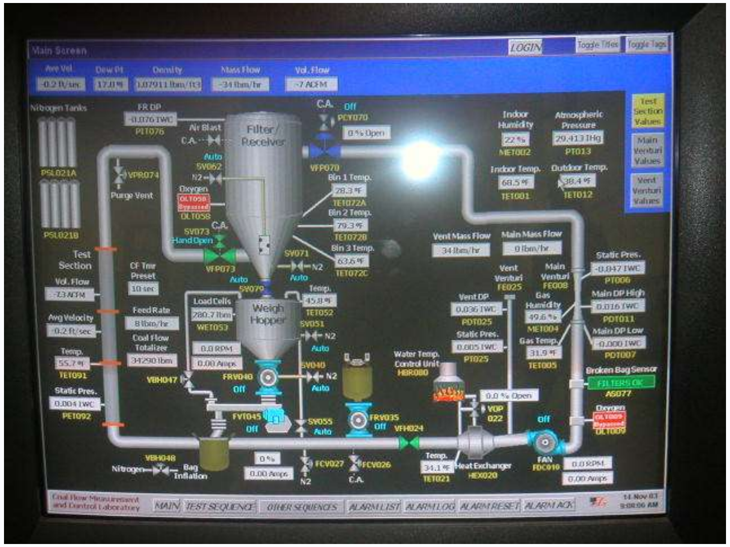


EPRI Coal Flow Loop

- Built in Livonia, Michigan
- Construction Completed 2003
  - 12” Schedule 40 Steel Pipe
  - Victaulic couplings
  - Reconfigurable pipe sections

EPRI Coal Flow Loop (cont.)

- Precise Control & Measurement of Air and Coal
  - < 0.5% air flow measurement
  - < 1.0% coal flow measurement
- 10-120 ft/sec in-pipe Velocity
  - 1400-5600 CFM
- 1 to 4 Air/Coal Ratio
  - 2,000-20,000 lbm/hr coal flow
- Ambient to 180 °F Air/Coal Temperature



Particulate Flow After Double Bend

Extractive Sampling Methods Evaluated

- Dirty Air Velocity Probe
- ASME PTC 4.2 (“The ASME Method”)
- ISO 9931 (“The Rotorprobe™ Method”)

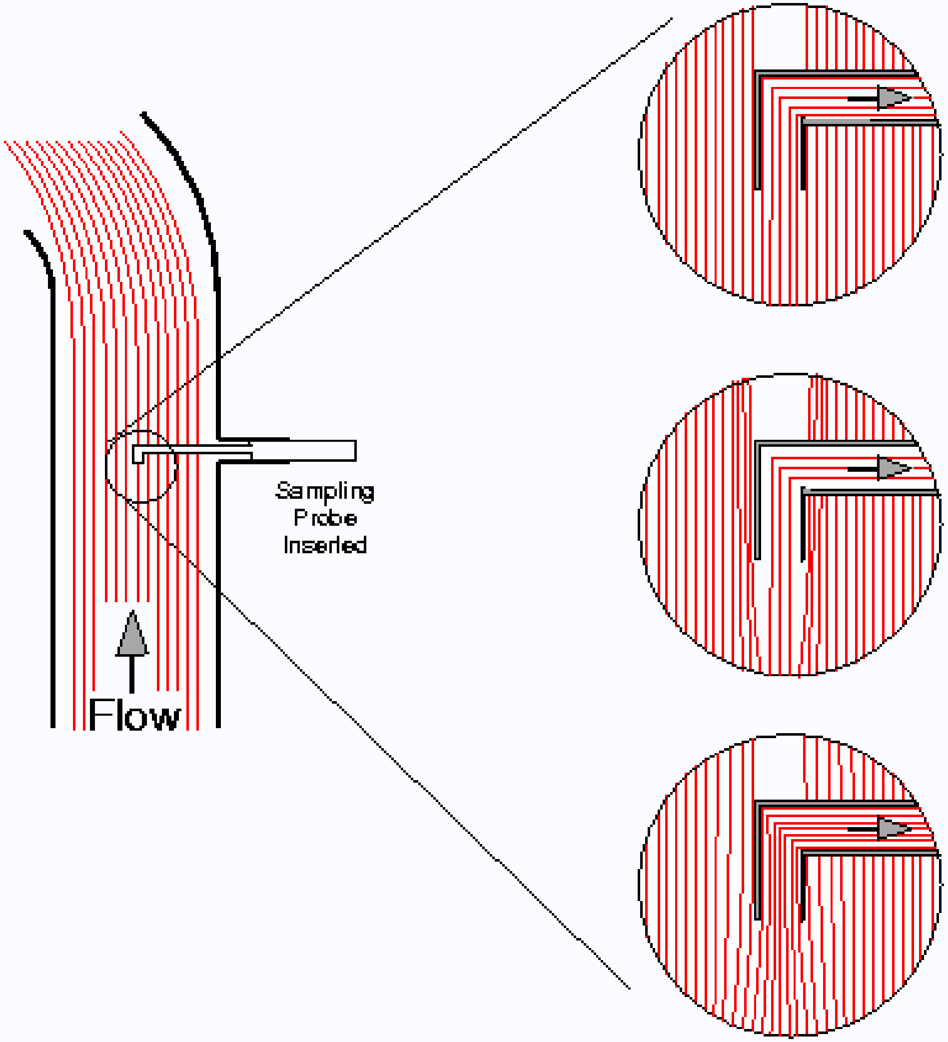
Extractive Sampling Methodology

- Primary Air Flow
  - Mill Inlet or Coal Pipe
  - Flow Rate
  - Velocity
  - Temperature
- "Clean Air" Testing
- "Dirty Air" Testing

Coal pipe testing with Advanced Coal Flow Measurement (ACFM) device

Extractive Sampling Methodology

- Coal Flow
  - Isokinetic sampling based on primary air velocity
  - Integrate coal flow rate based on sample weight and extraction time
  - Dry vs. wet coal comparison to feeder



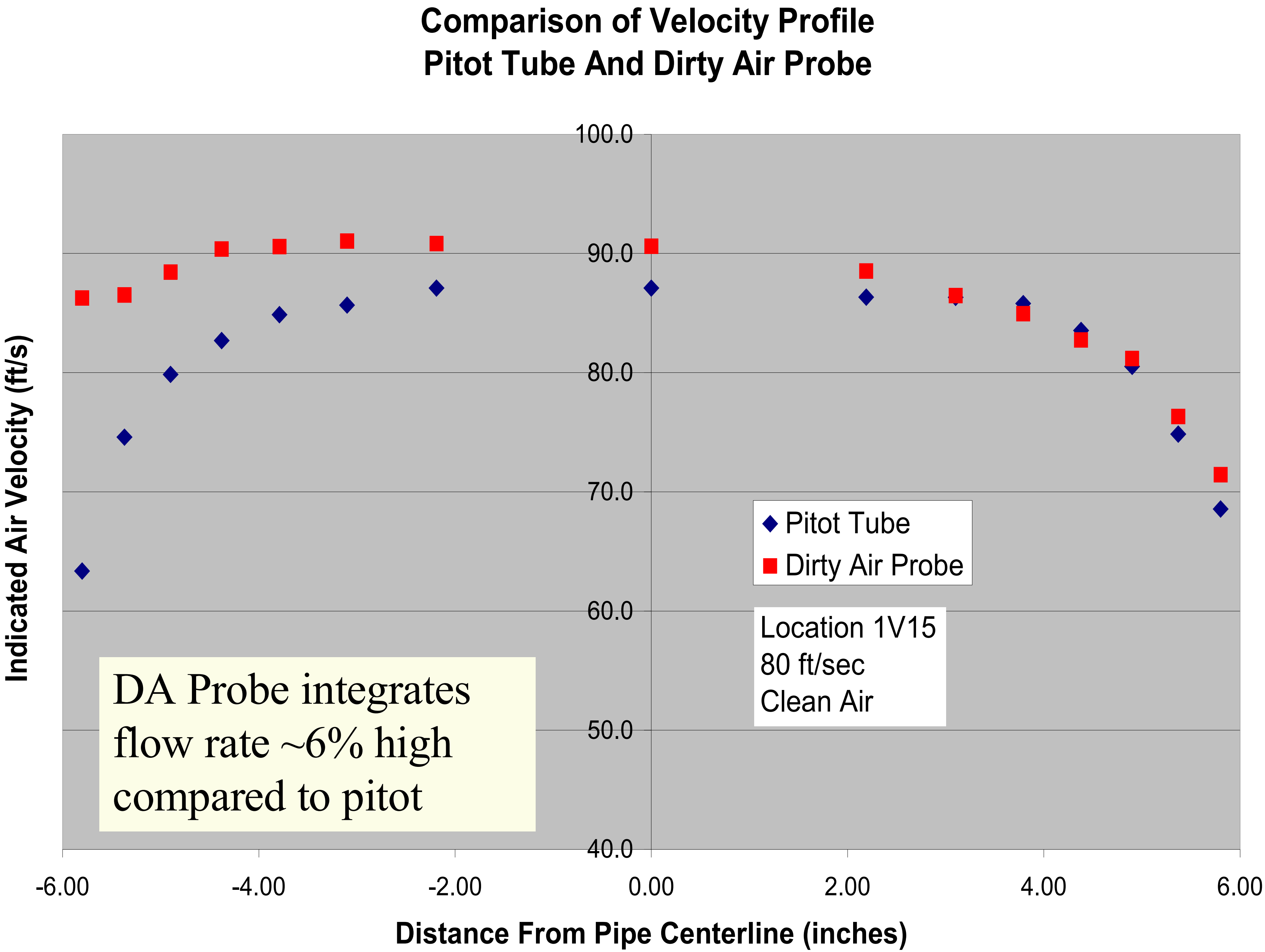
Extractive Test Matrix

- Examine effect of various parameters on accuracy
  - Probe / Method Type
  - Measurement Location
  - Air / Coal Ratio Conditions
  - Extraction Rate Sensitivity
  - Number of Test Ports Required
  - Number of Traverse Points Required

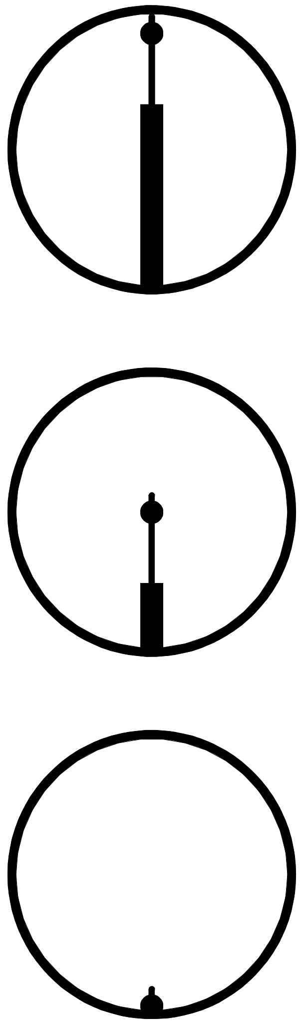
Clean Air Velocity Measurement

- The Dirty Air Velocity Probe traverse initially read ~6% high compared to the true pipe velocity profile measured with a pitot probe

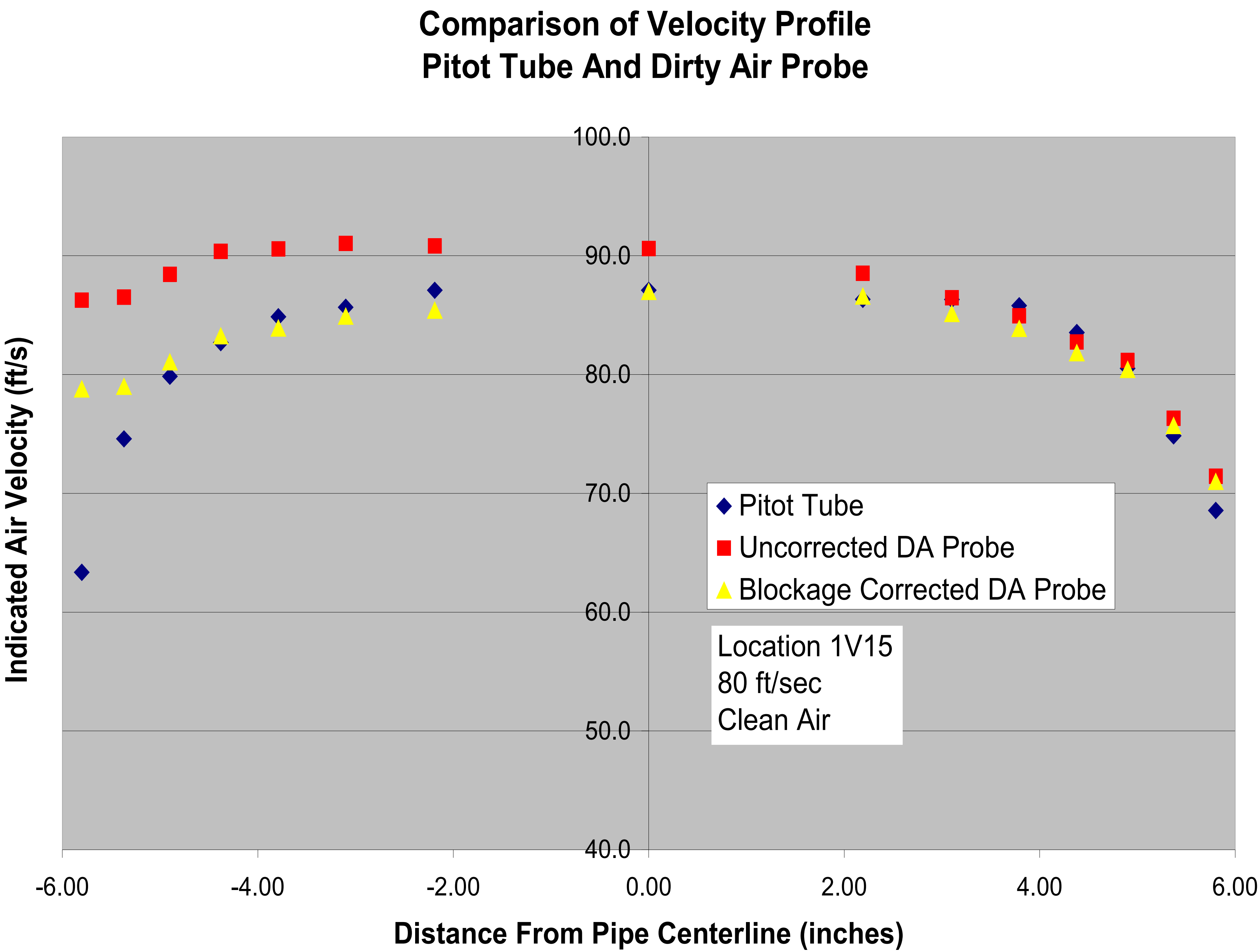
- The deviation was found to be caused by probe blockage of the pipe cross section and incomplete measurement at the far wall due to probe geometry
- With corrections for these two probe geometry influences, the Dirty Air Probe traverse correlated to within 0.5% of the true pipe velocity profile


Comparison of Velocity Profile
Pitot Tube And Dirty Air Probe
Indicated Air Velocity (ft/s)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
Distance From Pipe Centerline (inches)
Pitot Tube
Dirty Air Probe
Location 1V15
80 ft/sec
Clean Air
DA Probe integrates
flow rate ~6% high
compared to pitot

Pipe Blockage Correction Factor



Note: The larger the pipe diameter, the less impact the probe blockage has on the velocity measurement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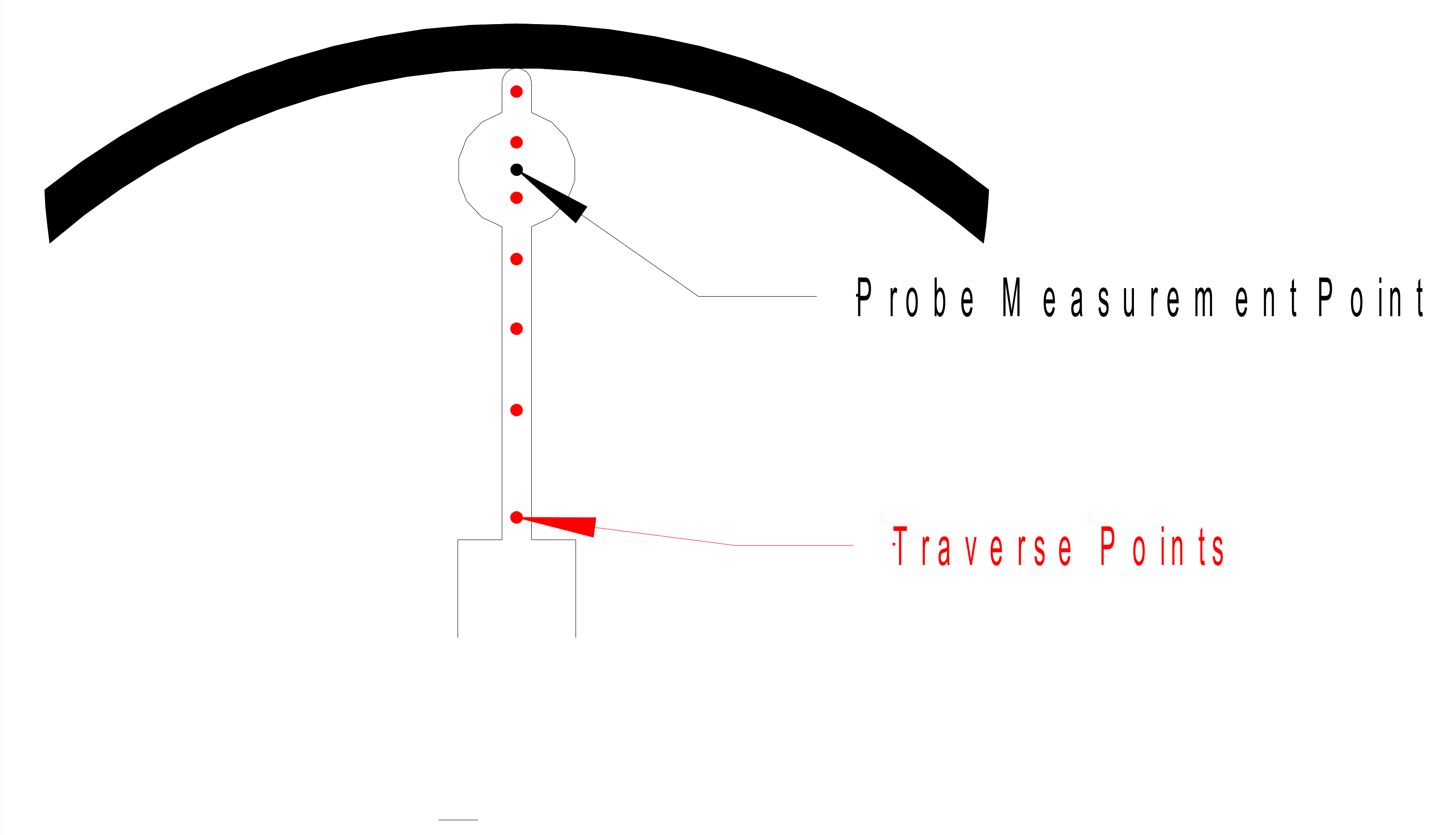
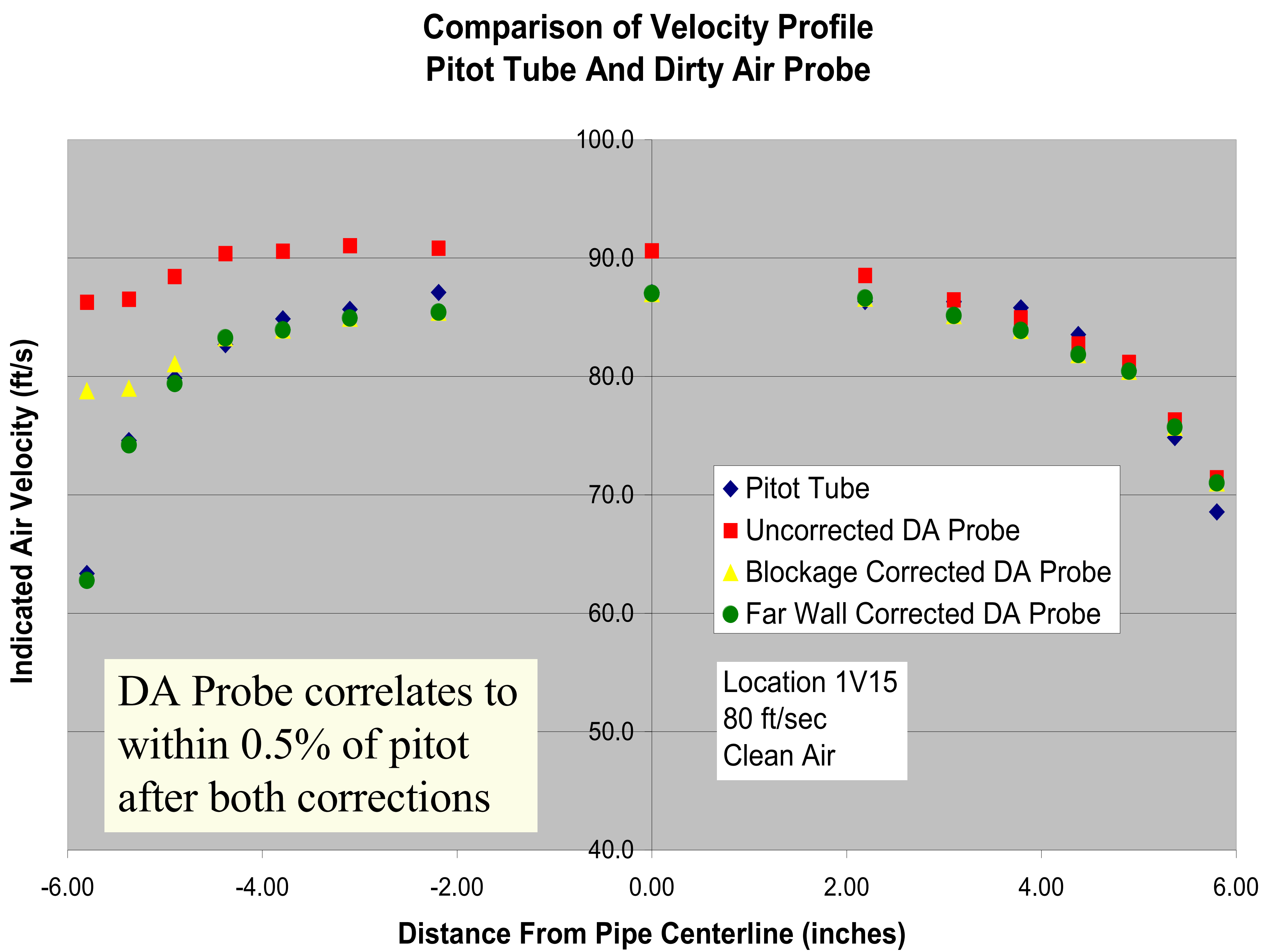
60.0
50.0
40.0
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
Distance From Pipe Centerline (inches)
Pitot Tube
Uncorrected DA Probe
Blockage Corrected DA Probe
Location 1V15
80 ft/sec
Clean Air

Far Wall Correction Factor





Comparison of Velocity Profile
Pitot Tube And Dirty Air Probe
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80.0
70.0
60.0
50.0
40.0
-6.00
-4.00
-2.00
0.00
2.00
4.00
6.00
Distance From Pipe Centerline (inches)
Pitot Tube
Uncorrected DA Probe
Blockage Corrected DA Probe
Far Wall Corrected DA Probe
DA Probe correlates to within 0.5% of pitot after both corrections
Location 1V15
80 ft/sec
Clean Air

Dirty Air Velocity Measurement

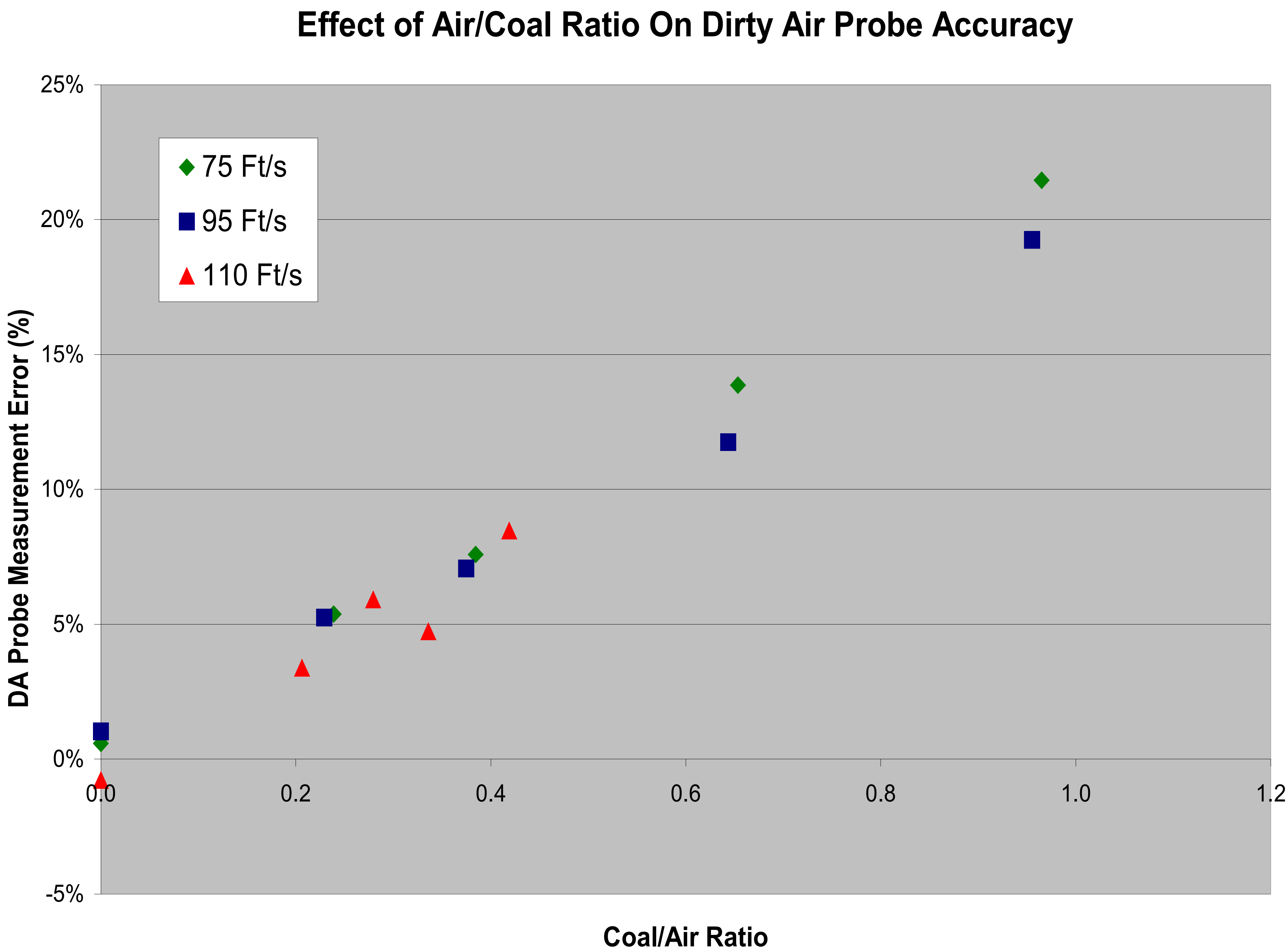
- Dirty Air Velocity Probe has now been calibrated in clean air flow

- How accurately does it measure air velocity in the presence of coal?
- Test matrix:

Air Velocity	Air/Coal Ratio									
(ft/sec)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	Clean
75	X	X		X			X			X
95	X	X		X				X		X
110				X	X	X			X	X

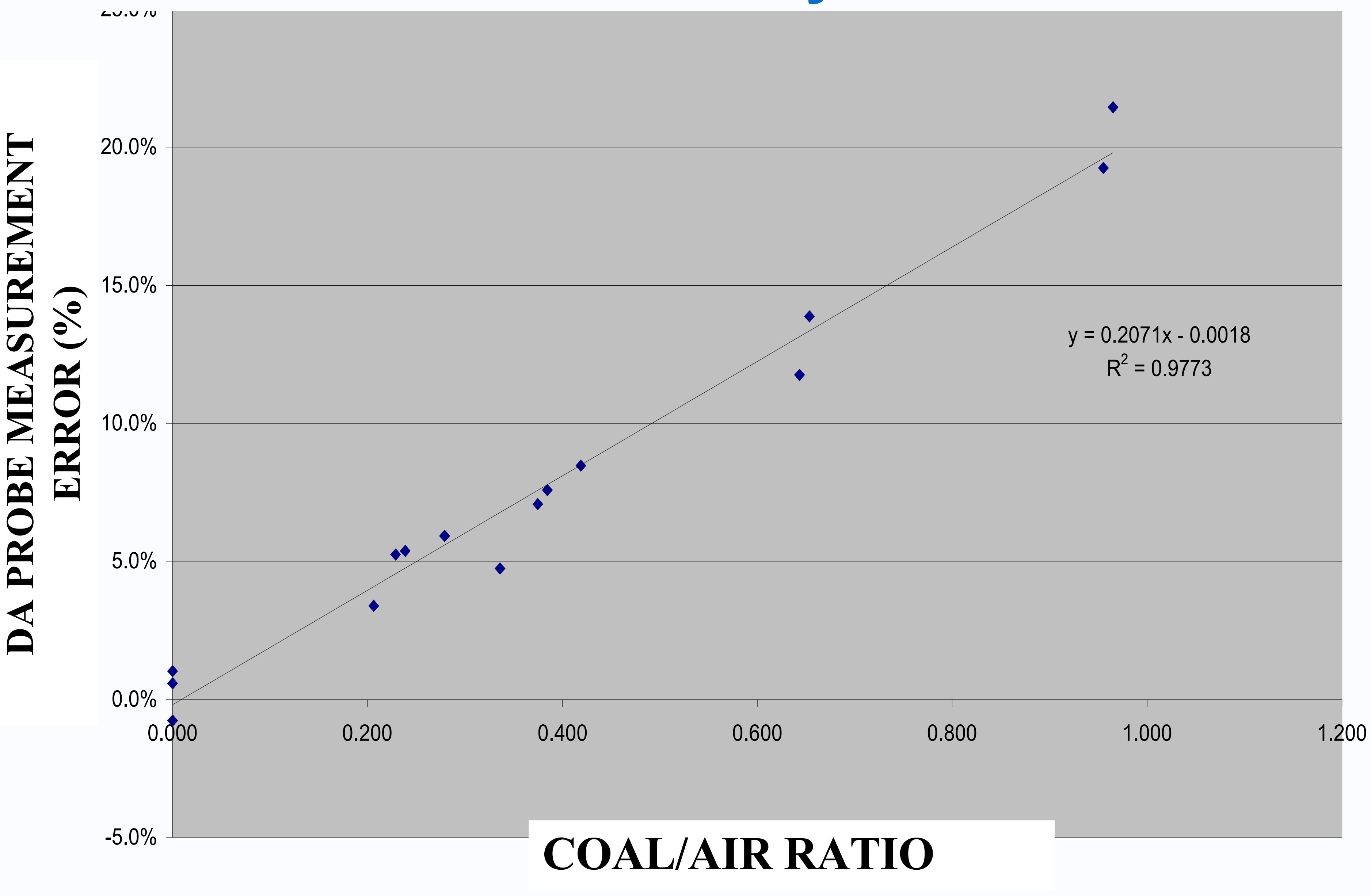
Dirty Air Velocity Measurement

- Results indicate that the velocity reading **is**, in fact, influenced by the amount of coal flowing in the pipe
- It is hypothesized that the coal affects the pressure reading on each side of the probe's disc
- This causes the Dirty Air Probe to read <u>high</u> compared to the true air flow rate
- A correction factor can be developed based on the coal mass flow rate to restore accuracy to within 2%
- This creates a bit of a dilemma in setting the extraction rate for isokinetic coal sampling, but corrections can be made post-test

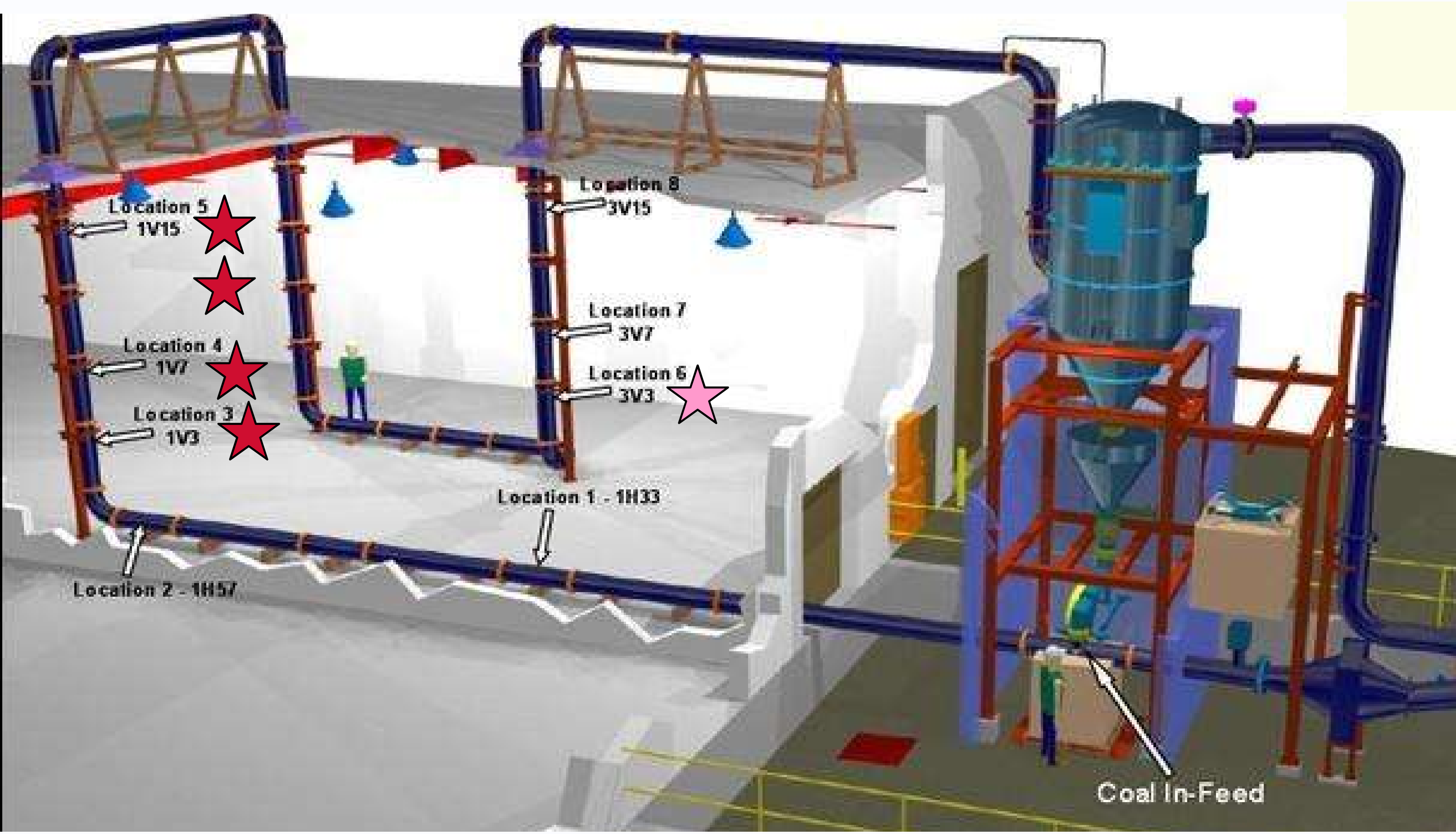


Effect of Air/Coal Ratio On Dirty Air Probe Accuracy
25%
20%
15%
10%
5%
0%
-5%
0.0
0.2
0.4
0.6
0.8
1.0
1.2
75 Ft/s
95 Ft/s
110 Ft/s
DA Probe Measurement Error (%)
Coal/Air Ratio

Effect of Air/Coal Ratio on Dirty Air Probe Accuracy



Coal Flow Rate Measurement

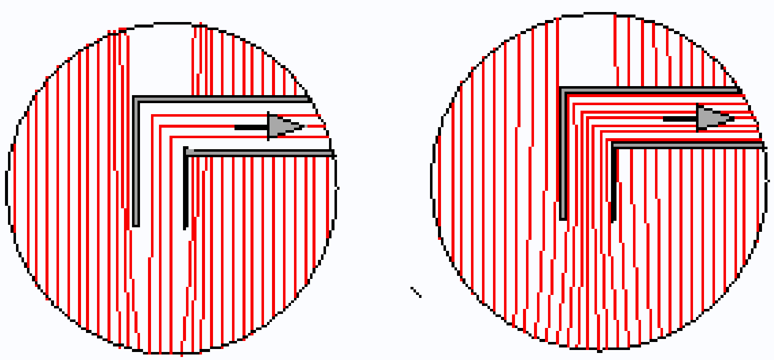


Coal Flow Rate Measurement

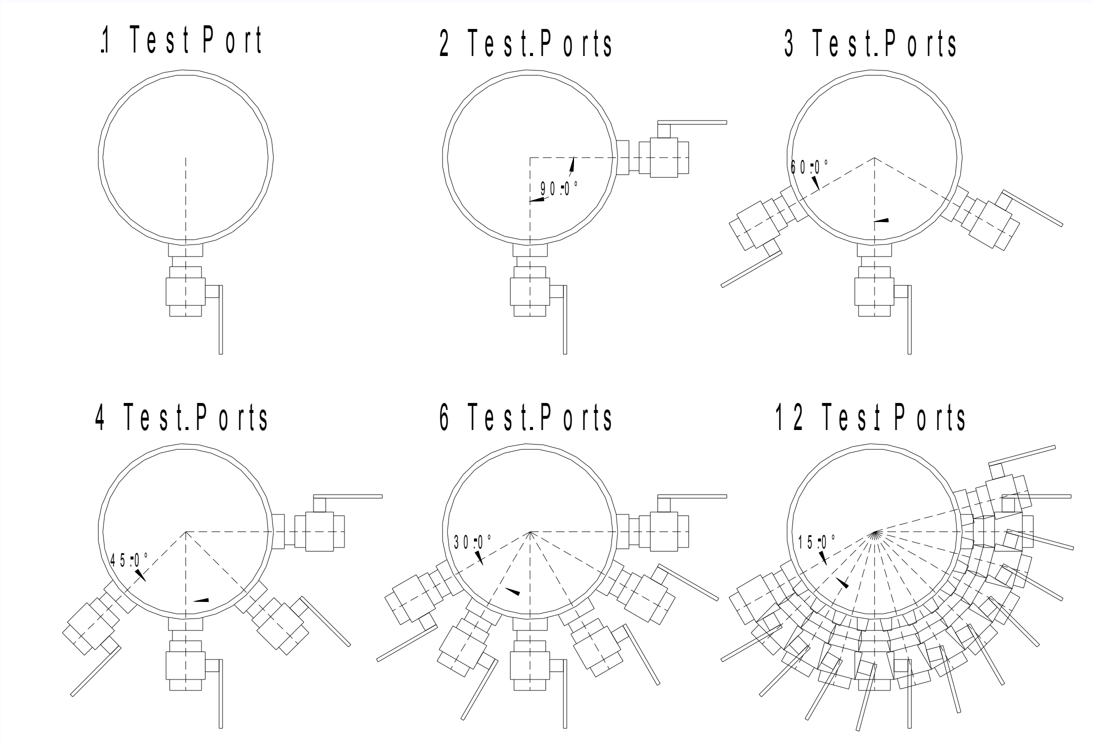
- For the ASME method, the accuracy (random error) of the coal flow measurement can be influenced by the proximity to the upstream elbow
  - Accuracy ±9% at 15 diameters, 2 test ports
  - Accuracy ±35% at 3 diameters, 2 test ports
  - Accuracy ±13% at 3 diameters, 4 test ports
- ISO 9931 method accuracy (random error) is fairly consistent at all test locations
  - Accuracy ±8%, 2 test ports

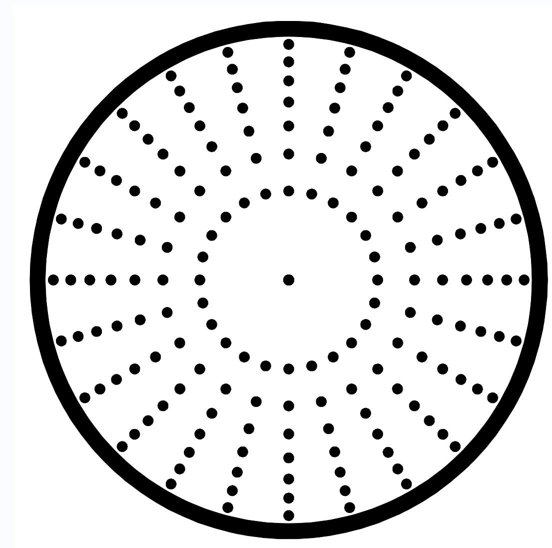
Isokinetic Extraction Rate Sensitivity

- Accuracy of the coal flow measurement is degraded for both methods if the isokinetic extraction rate is incorrect
- The ASME method is more sensitive to extraction rate
  - For every 10% change in the extraction rate, coal flow measurement changes by ~7%
- The ISO 9931 method is less sensitive to extraction rate
  - For every 10% change in the extraction rate, coal flow measurement changes by ~2.5%



Number of Test Ports and Traverse Points





Equivalent Port Location: up to

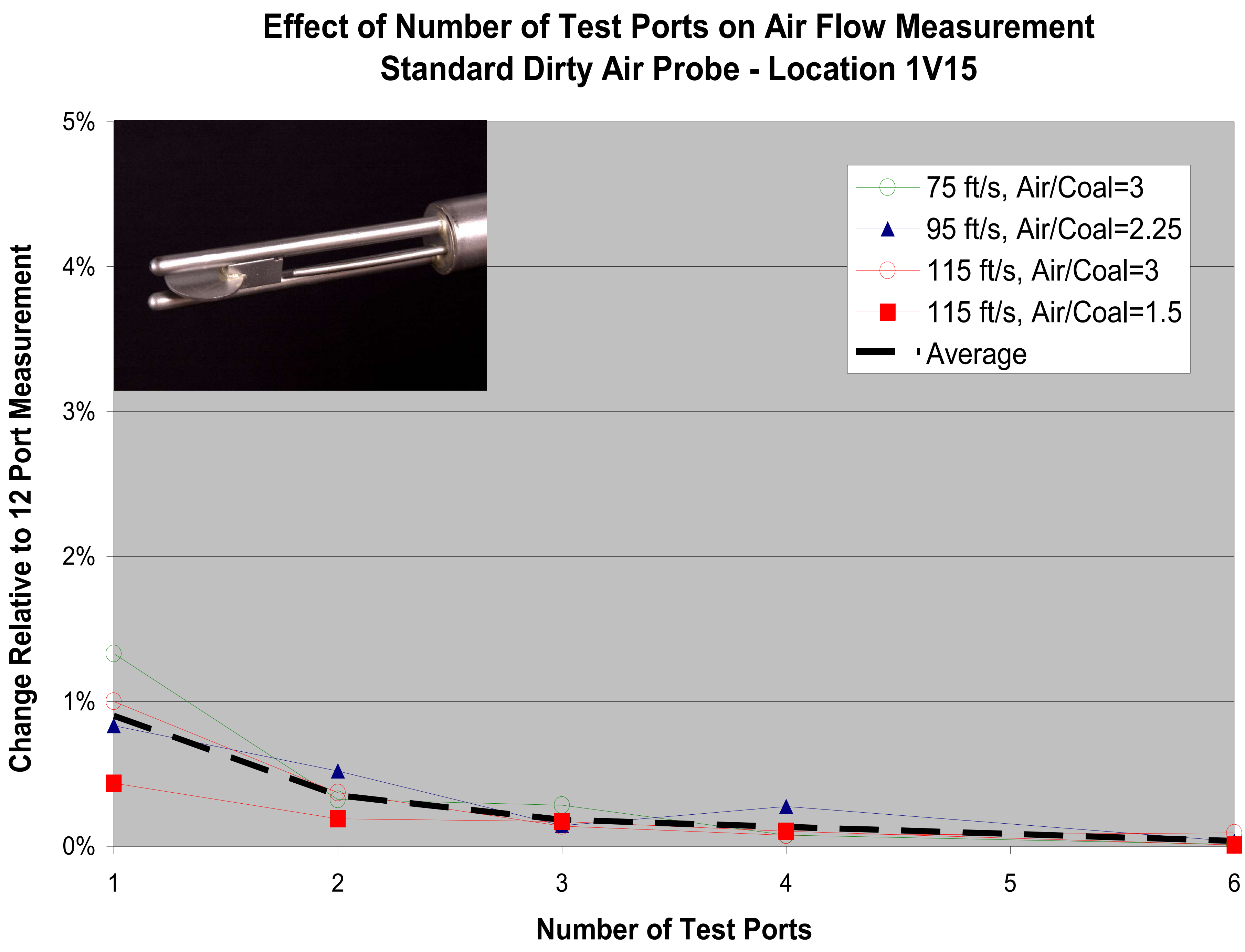
12 Traverses were performed spaced 15 degrees apart

15 Points were sampled

in each traverse

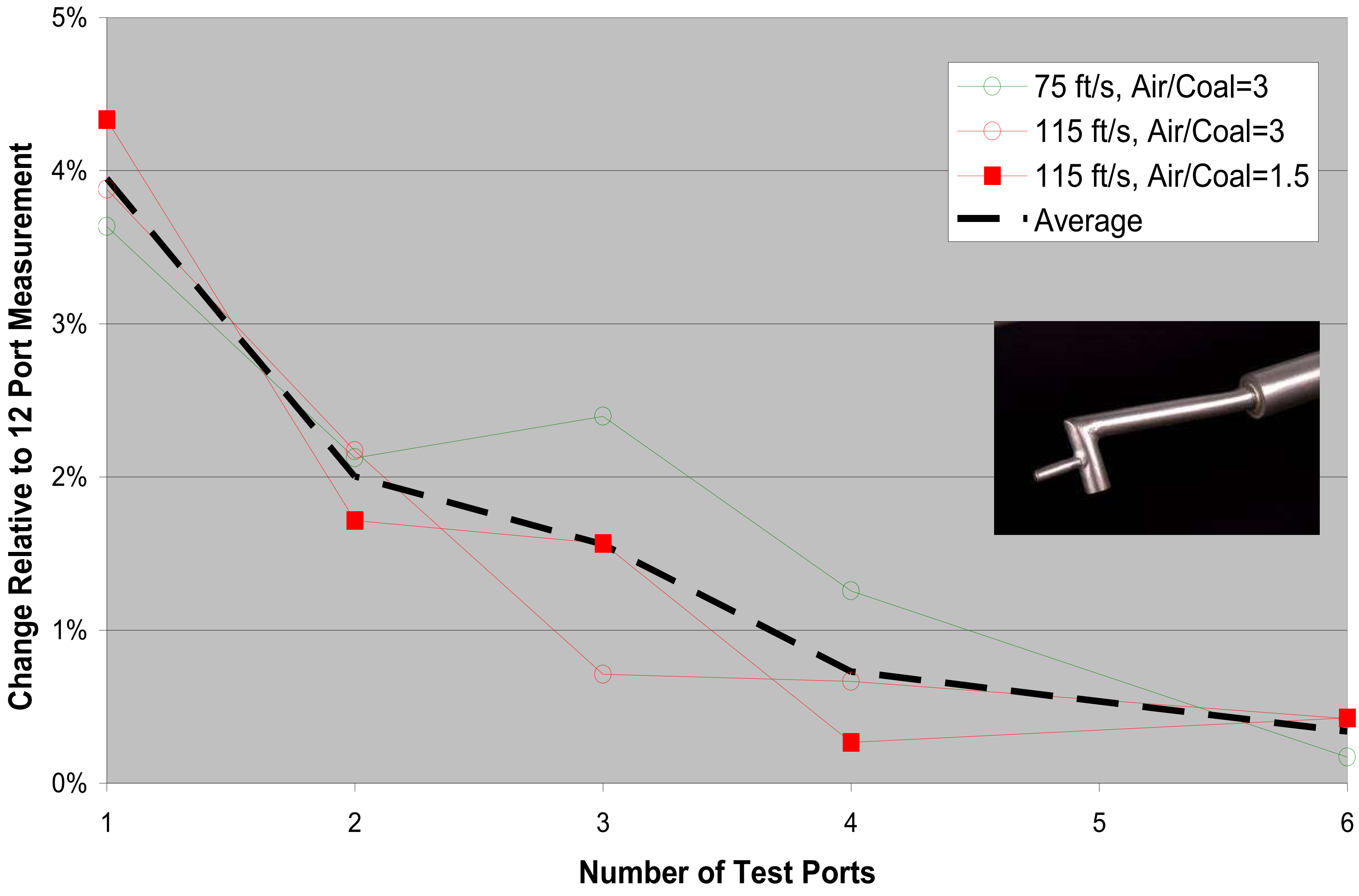
Rotating Test Port for Extractive Testing

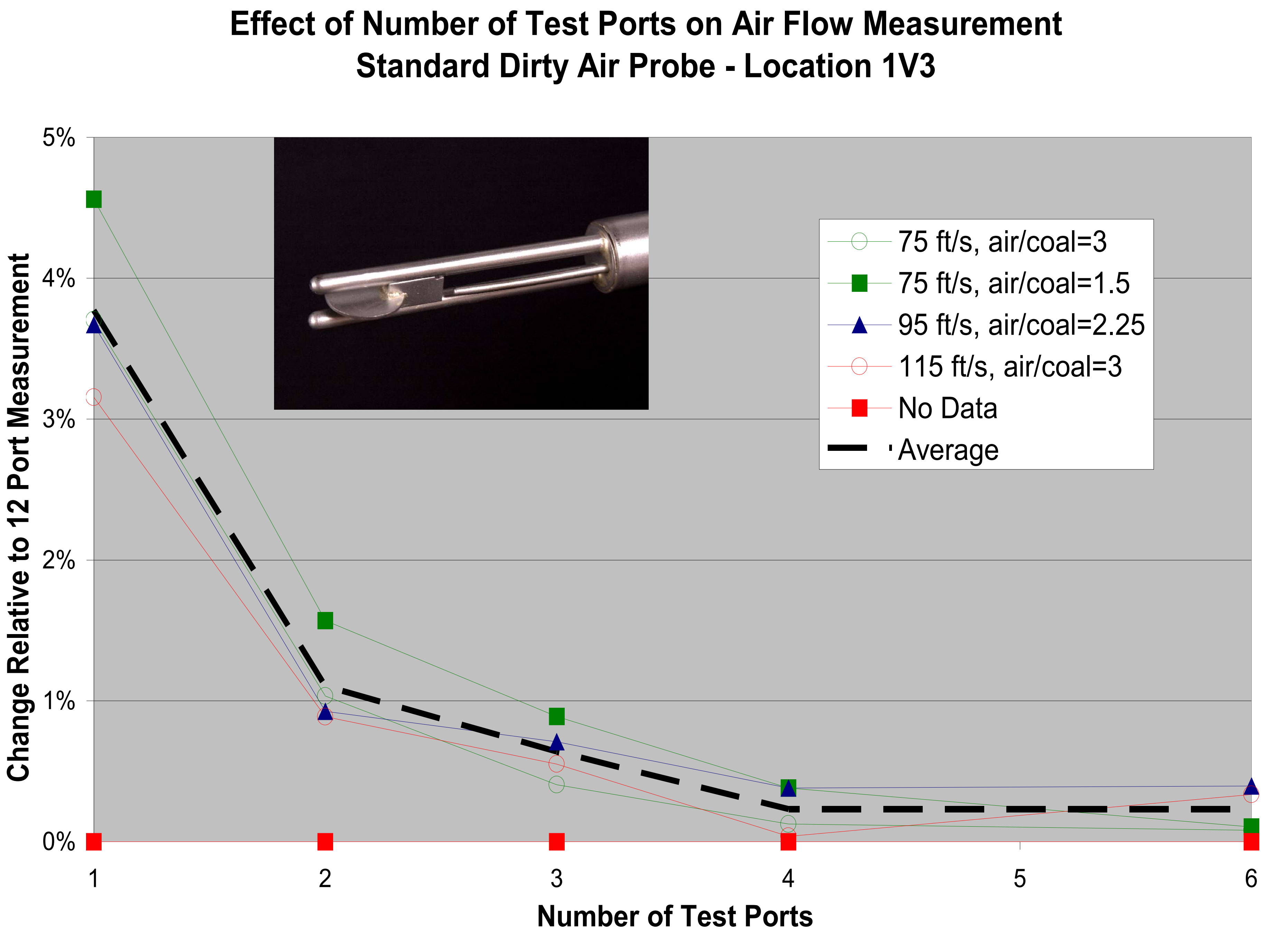
- 180° Swivel
- String Potentiometer for Angle Alignment
- 180 Point Grid
  - 15 ° intervals = 12 traverses
- Linear Probe Actuator
  - 15 sampling points/traverse

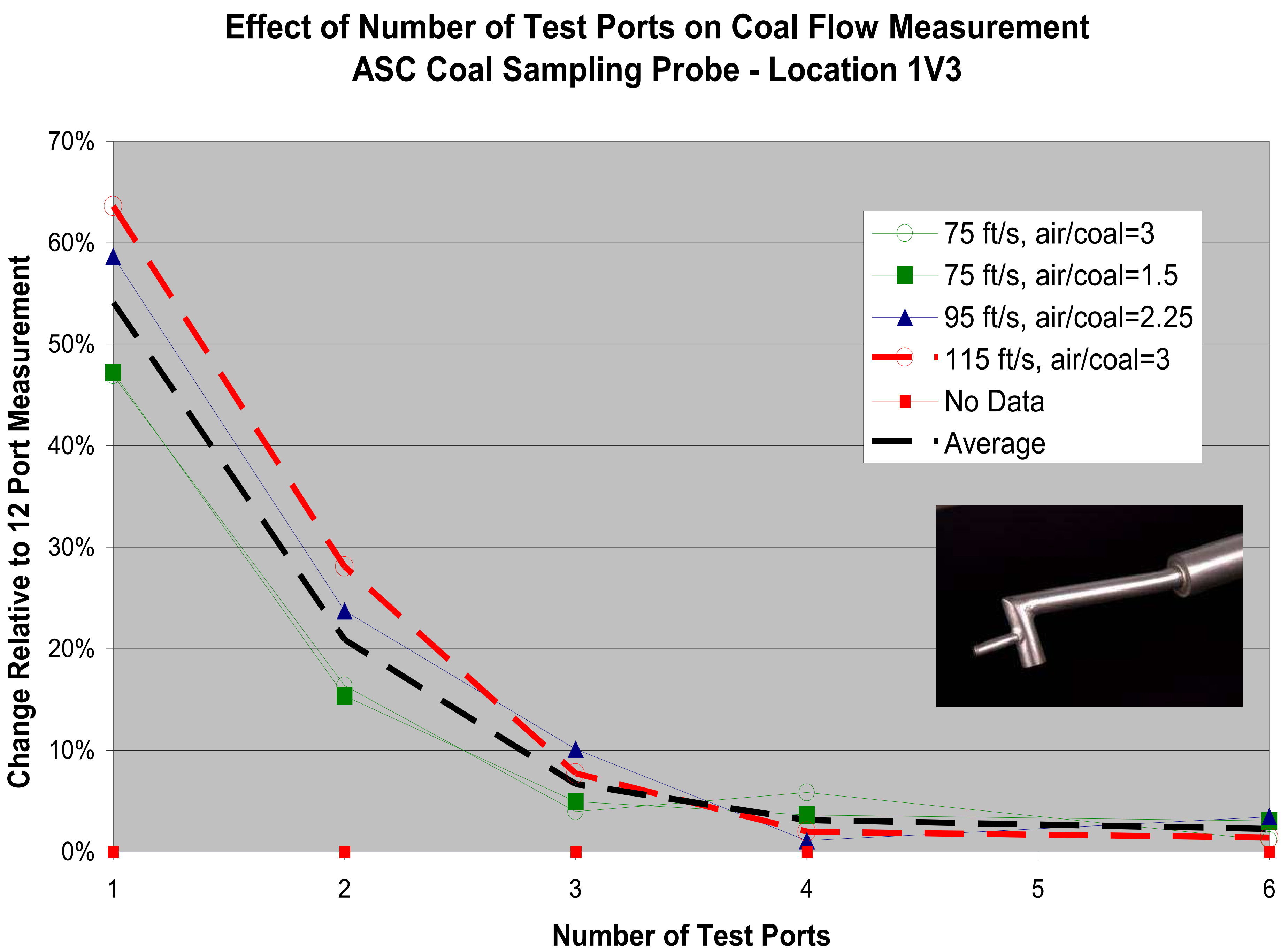


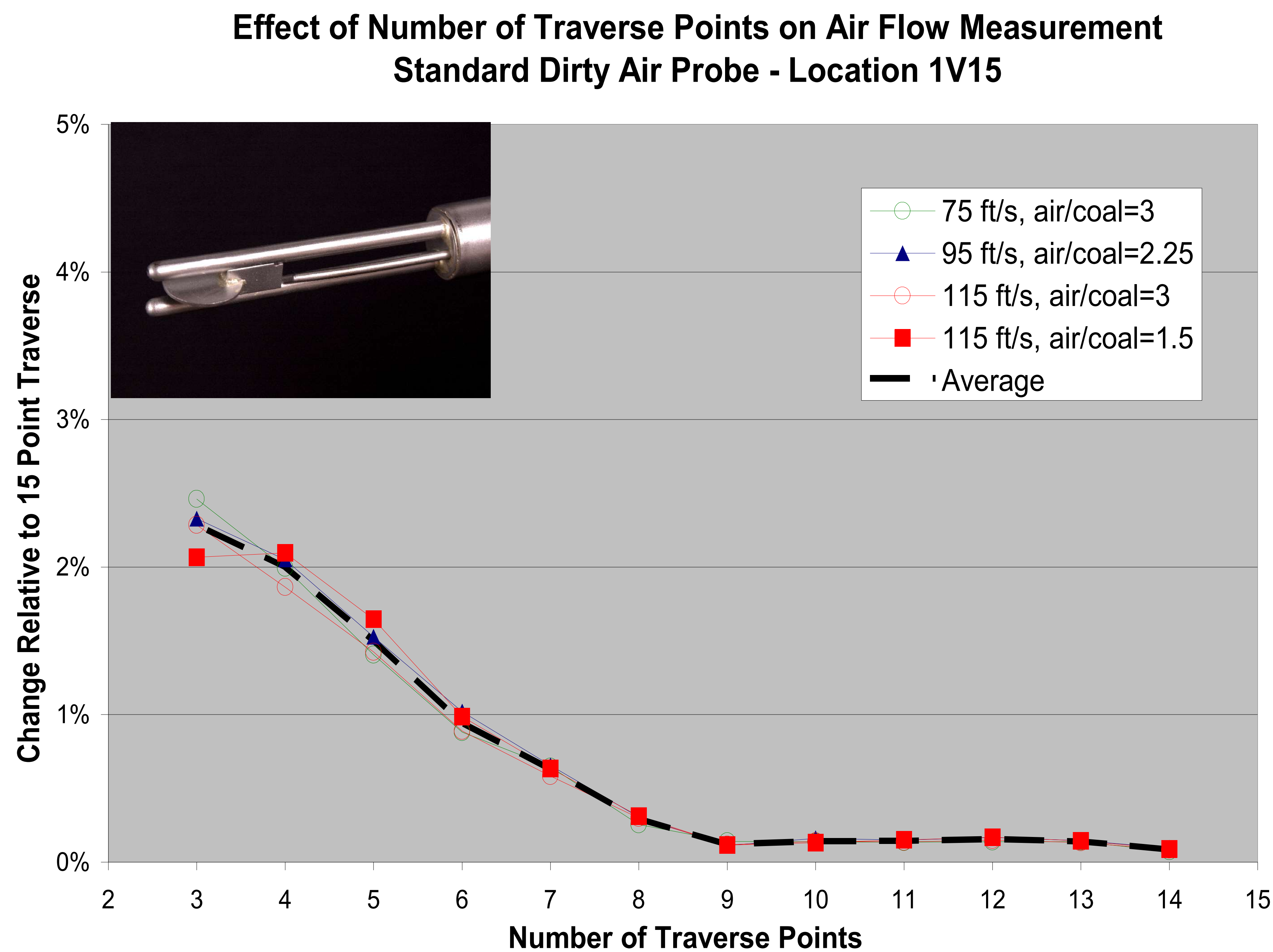
Effect of Number of Test Ports on Air Flow Measurement
Standard Dirty Air Probe - Location 1V15
75 ft/s, Air/Coal=3
95 ft/s, Air/Coal=2.25
115 ft/s, Air/Coal=3
115 ft/s, Air/Coal=1.5
Average
Change Relative to 12 Port Measurement
0%
1%
2%
3%
4%
5%
1
2
3
4
5
6
Number of Test Ports

Effect of Number of Test Ports on Coal Flow Measurement
ASC Coal Sampling Probe - Location 1V15

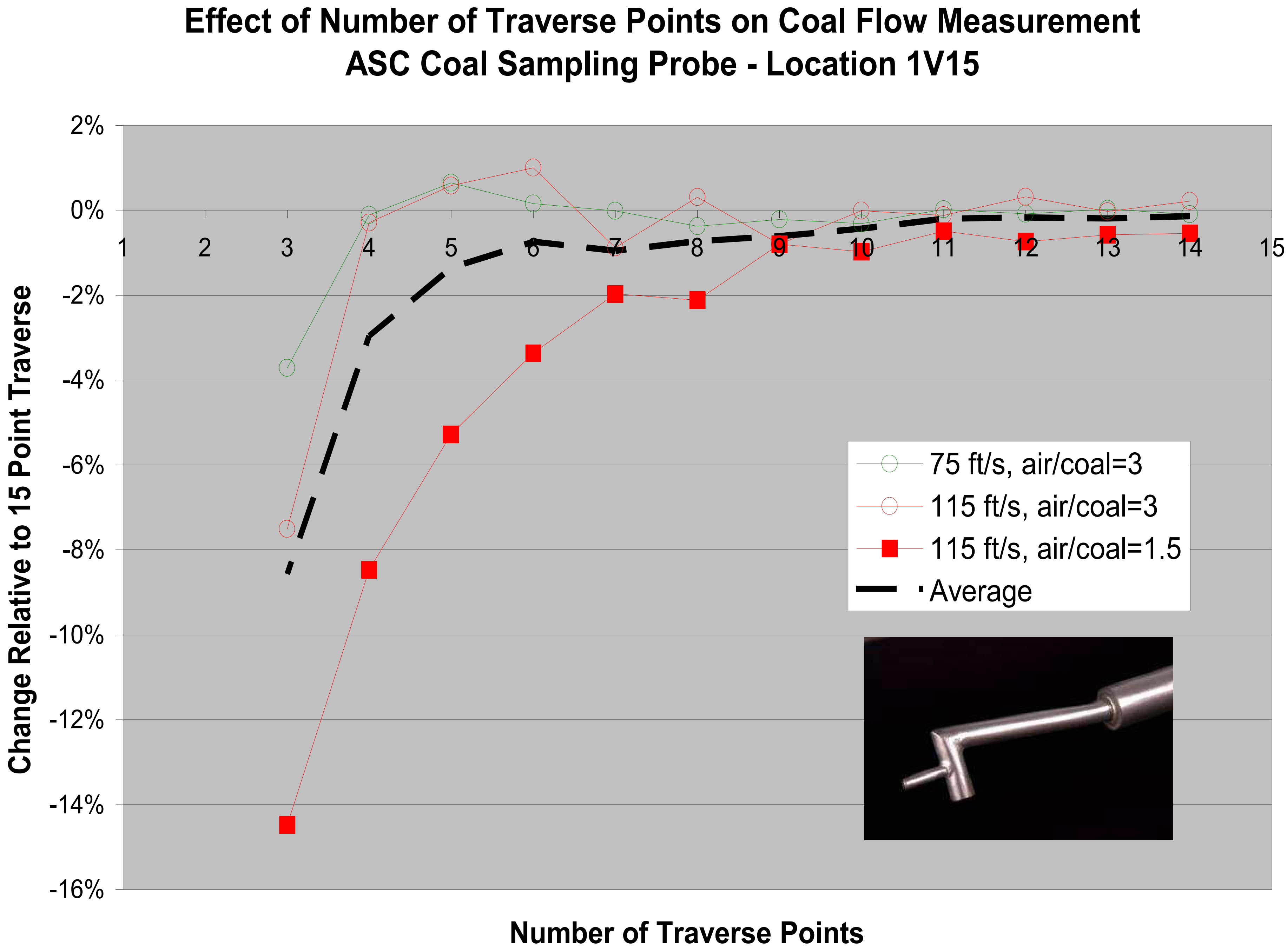



Effect of Number of Test Ports on Air Flow Measurement
Standard Dirty Air Probe - Location 1V3
5%
4%
3%
2%
1%
0%
Change Relative to 12 Port Measurement
1
2
3
4
5
6
Number of Test Ports
75 ft/s, air/coal=3
75 ft/s, air/coal=1.5
95 ft/s, air/coal=2.25
115 ft/s, air/coal=3
No Data
Average


Effect of Number of Test Ports on Coal Flow Measurement
ASC Coal Sampling Probe - Location 1V3
Change Relative to 12 Port Measurement
70%
60%
50%
40%
30%
20%
10%
0%
1
2
3
4
5
6
Number of Test Ports
75 ft/s, air/coal=3
75 ft/s, air/coal=1.5
95 ft/s, air/coal=2.25
115 ft/s, air/coal=3
No Data
Average



Effect of Number of Traverse Points on Air Flow Measurement
Standard Dirty Air Probe - Location 1V15
Change Relative to 15 Point Traverse
0%
1%
2%
3%
4%
5%
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Number of Traverse Points
75 ft/s, air/coal=3
95 ft/s, air/coal=2.25
115 ft/s, air/coal=3
115 ft/s, air/coal=1.5
Average



Effect of Number of Traverse Points on Coal Flow Measurement
ASC Coal Sampling Probe - Location 1V15
2%
0%
-2%
-4%
-6%
-8%
-10%
-12%
-14%
-16%
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Change Relative to 15 Point Traverse
Number of Traverse Points
75 ft/s, air/coal=3
115 ft/s, air/coal=3
115 ft/s, air/coal=1.5
Average

Number of Test Ports and Traverse Points

- Results to date have been summarized
- Additional testing is still planned
- For acceptable accuracy (within 2% on air, 5% on coal):

Location	Number of Test Ports Required	Number of Traverse Points Required
1V15	2	9
1V11	2	9
1V7	3-4	9
1V3	4	9
3V3	6	15

In Summary, Results to Date Suggest…

- Dirty Air Probe can achieve dirty air flow measurement accuracy to within 2%
  - Proper correction factors are required
  - Velocity reading is dependent on air-to-coal ratio, complicating calculation of isokinetic extraction rate
- For a single upstream bend
  - ASME method can achieve coal measurement accuracy within 10-13%
  - More test ports are required as test plane moves closer to an elbow
  - ISO 9931 method can achieve coal measurement accuracy to within 8%
- Accuracy of both methods is influenced by geometry of upstream elbows (degree of roping)
- Rotorprobe is less sensitive to extraction rate than ASME method
- Need to perform additional testing to complete the data analysis and create generalized correction factors

Acknowledgements

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  - Oglethrope Power Corp.– Kerry Faulkner
  - TXU – Mark Smith
- EPRI Program 71 Members

Questions?

- For More Information Contact:
  - Rob Mudry (734) 525-0300 rmudry@airflowsciences.com
  - Matt Fleming (734) 525-0300 mfleming@airflowsciences.com
  - Jose Sanchez (650) 855-2580 josanche@epri.com
  - Rich Brown (650) 855-2216 ricbrown@epri.com