Flow Measurement Uncertainty Using Tracer Gas Dilution Method

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Comparative Flare Gas Flow Measurement Study

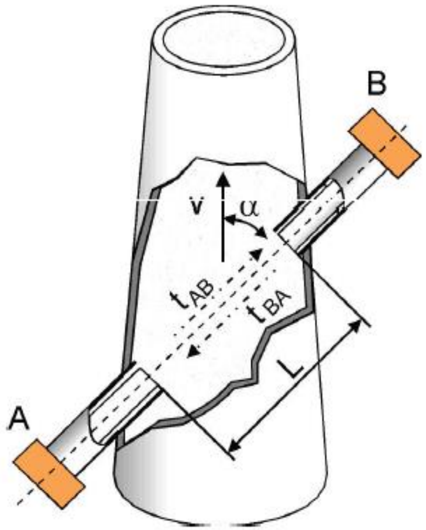
- In 2011, Chevron contracted a blinded study to test various flow meters used in flare gas measurement.
- The goal was to shed some light on different flare gas flow measurement technologies.
- Improve:
  - API-14.10 (Measurement of Flow to Flares)
  - API-22.3 (Testing Protocol for Flare Gas Metering)
- Data presented at the GPA (Gas Producers Association), April, 2013, San Antonio, Texas.

Thank you:
Steve Baldwin, Chevron
Houston, Texas, U.S.A.

Thank you:
Eric Estrada, Targa Resources
Houston, Texas U.S.A.

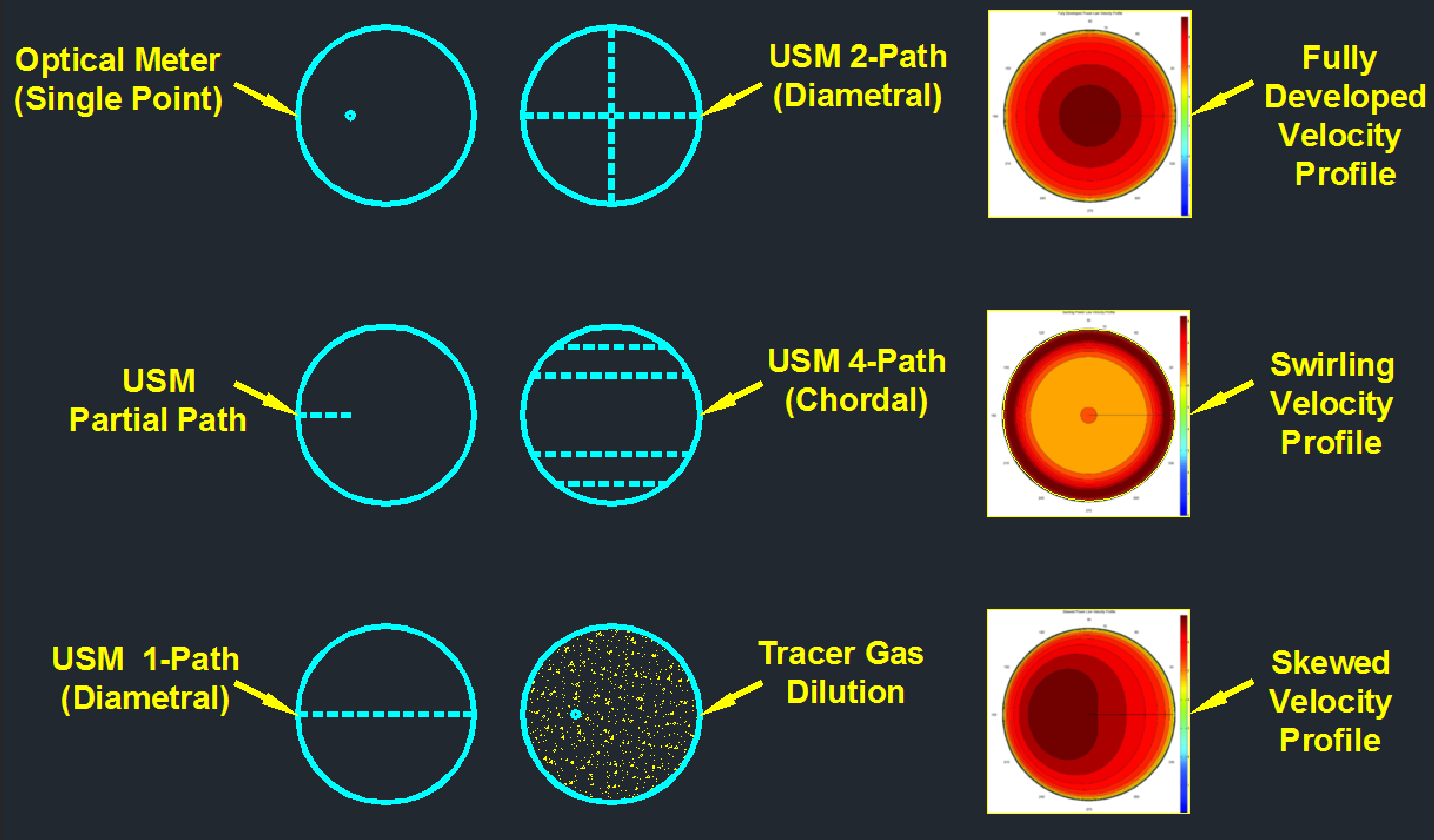
The comparative blinded study ran from 2011 to 2013 and included the following meters:

- USM (4-path Chordal)
- USM (2-path, Diametral)
- USM (1-path, Diametral)
- USM (1-path, Partial Insertion)
- Optical Flow Meter
- Tracer Gas Dilution Methodology



Wanted to test Pitot Tube Technology but time & money didn't allow it.

Consider How a Meter Senses the Flow:

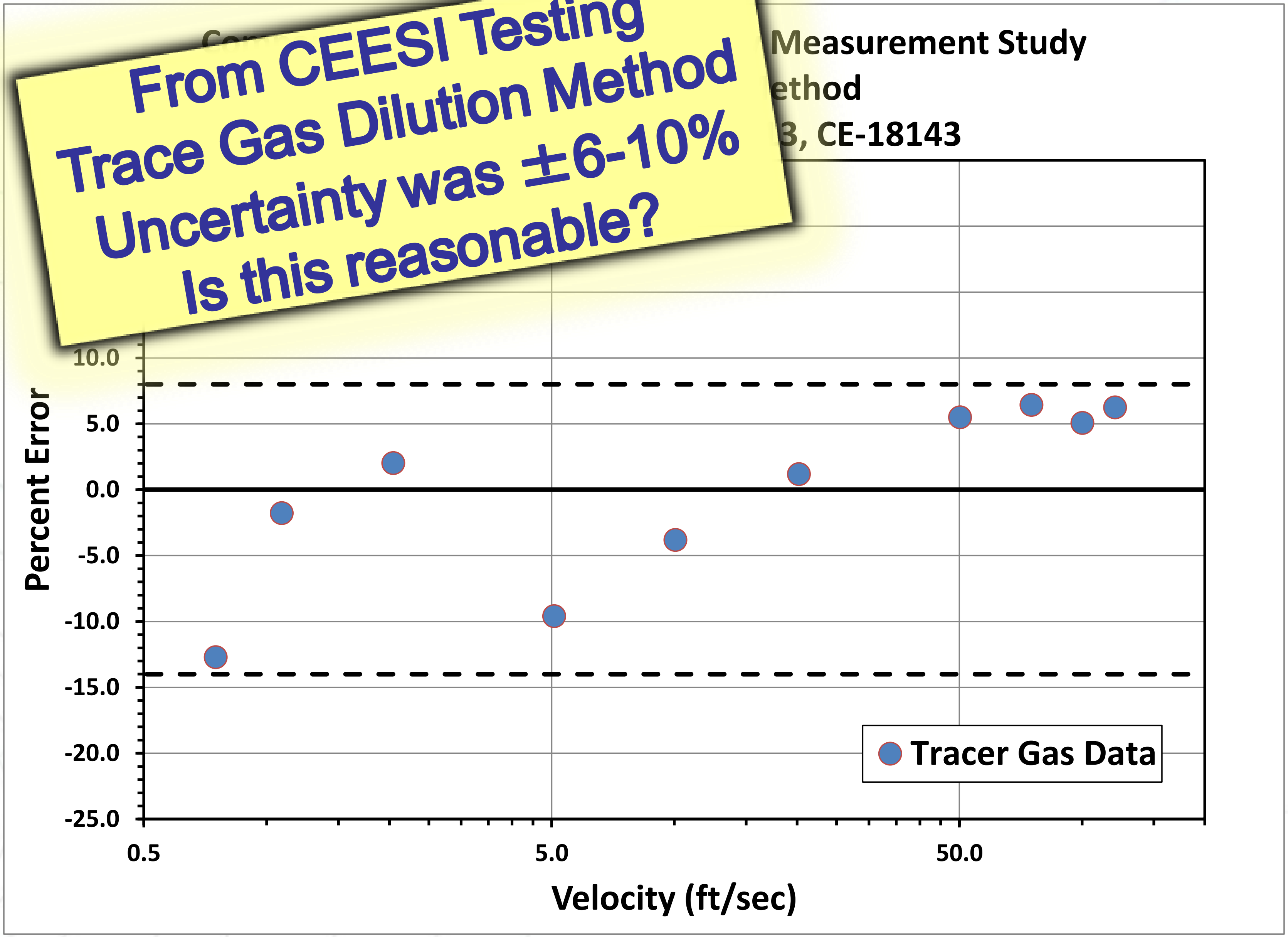


Rules of the Game:

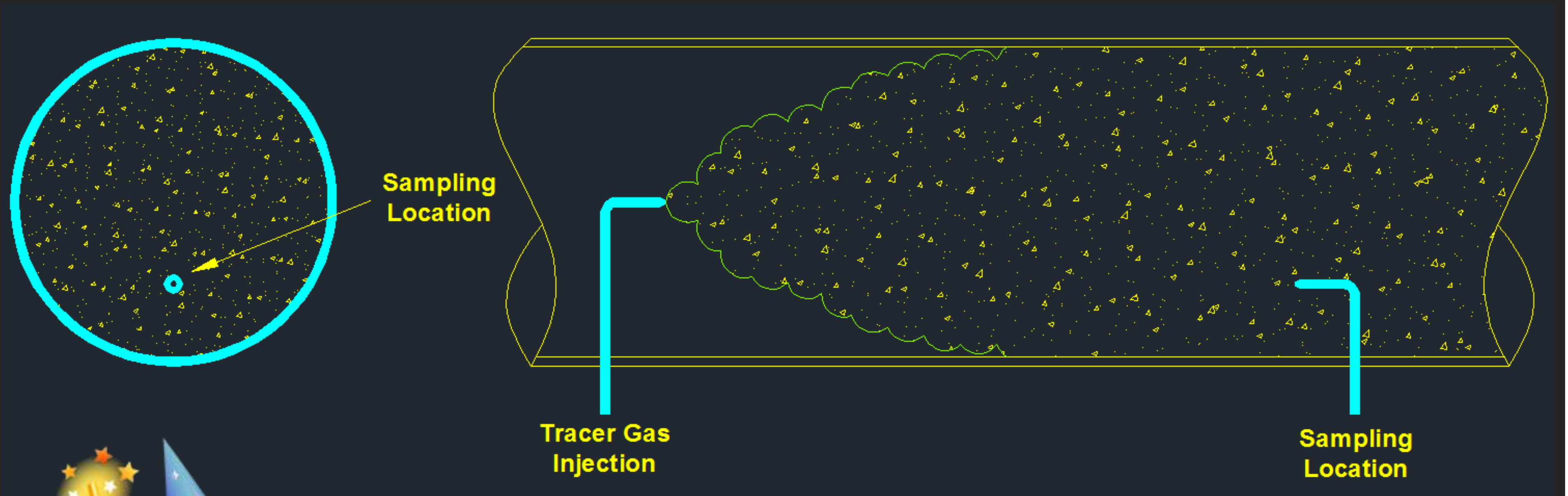
Fluid:	Air
Temperature:	70°F (Ambient)
Pressure:	12 PSIA (Ambient)
Velocity:	1 to 150 FPS (feet/second)
Pipe size:	10” (6” pipe for 4-path chordal USM)
Pipe orient:	Horizontal
Piping Config:	Ideal straight-run
	Swirling flow after an elbow
	In-Plane & Out-of-Plane

Uncertainty Using Tracer Gas Dilution Method

From CEESI Testing
Trace Gas Dilution Method
Uncertainty was ±6-10%
Is this reasonable?

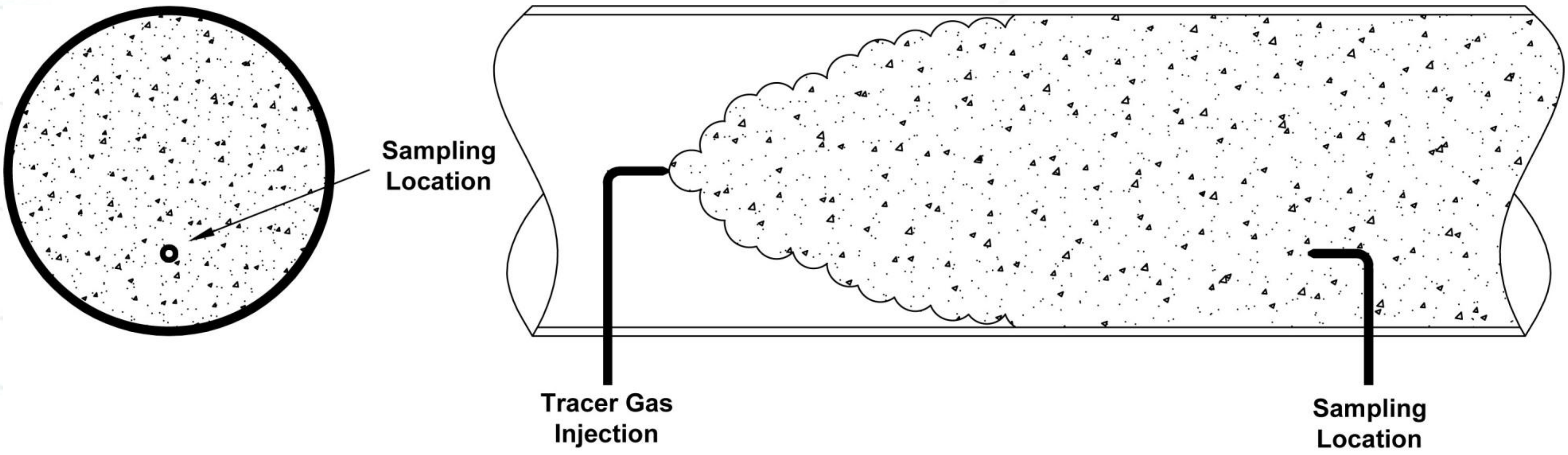


Consider How Tracer Gas Dilution Measures Flowrate:



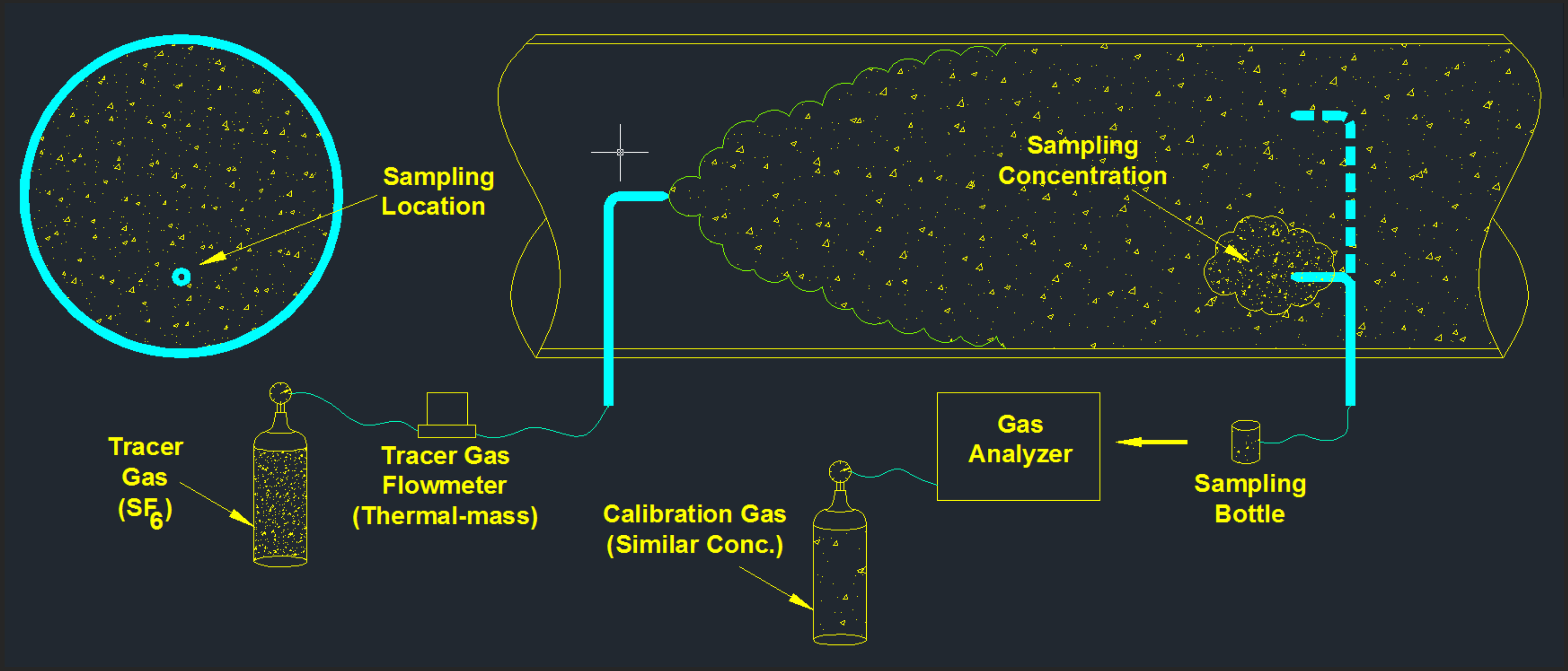
It's Magic!

Consider How Tracer Gas Dilution Measures Flowrate:

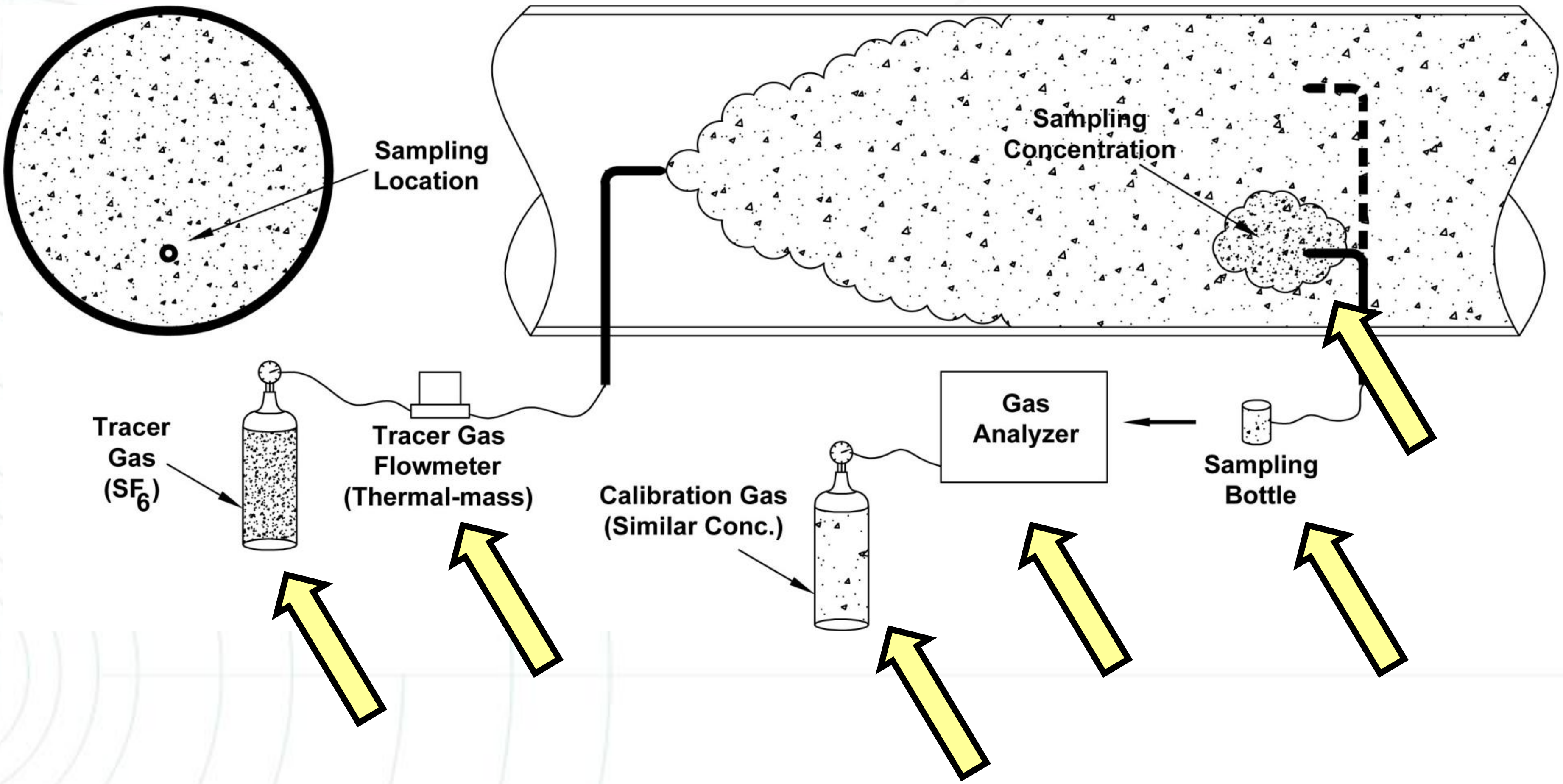


It's Magic!

How Tracer Gas Dilution Method Really works:



How Tracer Gas Dilution Method Really Works:



Flow Rate Equation:

From ASTM E2029:

$$F_U = \frac{(C_I - C_D)}{(C_D - C_U)} F_I$$

Where:

F_U = Upstream mass flow rate

C_I = Injection stream concentration of tracer gas†

C_D = Downstream concentration of tracer gas†

C_U = Upstream concentration of tracer gas†

F_I = Injection mass flow rate

† All concentrations are mass concentrations

Uncertainty Equation:

$$\frac{\partial_T F}{F} = \sqrt{\left[\left(\frac{\Delta C_I}{C_I}\right)^2 + \left(\frac{\Delta F_I}{F_I}\right)^2 + \left(\frac{(\Delta C_D)^2 + (\Delta C_U)^2}{C_D - C_I}\right)\right] + \cdots}$$

$$\ldots + 2\left[\frac{\sum_{i=1}^{N}\left(F_I^i - F_I\right)^2}{(N-1){F_I}^2} + \frac{\sum_{i=1}^{N}\left(C_D^i - C_U^i - C_D + C_U\right)^2}{(N-1)(C_D - C_U)^2}\right]$$

More Uncertainty Calculations:

Bias Errors:

SF_6 toxicity threshold = 1000 ppm,

ACGIH recommends 1/10th toxicity threshold, therefore $C_I$max.= 0.0001

$F_{min.}$ = min. flowrate = 1 ft/sec in a 10” pipe = 0.034 lbs/sec.

At $F_{min.}$ & a max. SF_6 conc. of 0.0001, F_I = 0.012 lbs/hr

This extremely small flow rate can be achieved by diluting the tracer gas which adds to uncertainty of F_I alternately an extremely small thermal mass meter could be used with pure SF_6.

The term $\left[\left(\frac{\Delta C_I}{C_I}\right)^2 + \left(\frac{\Delta F_I}{F_I}\right)^2\right]$ is estimated to be $(0.04)^2$

More Uncertainty Calculations:

The term $\left(\frac{(\Delta C_D)^2+(\Delta C_U)^2}{C_D-C_I}\right)$ is related to the gas analyzer uncertainty which depends on the calibration gas and the analyzer's ability to match the calibration gas value. Typical calibration gas uncertainty for SF_6 concentrations of 1ppm to 100 ppt = 2%. Estimated analyzer uncertainty to match calibration gas = 0.5%

The term $\left(\frac{(\Delta C_D)^2+(\Delta C_U)^2}{C_D-C_I}\right)$ is estimated to be $(0.02)^2$

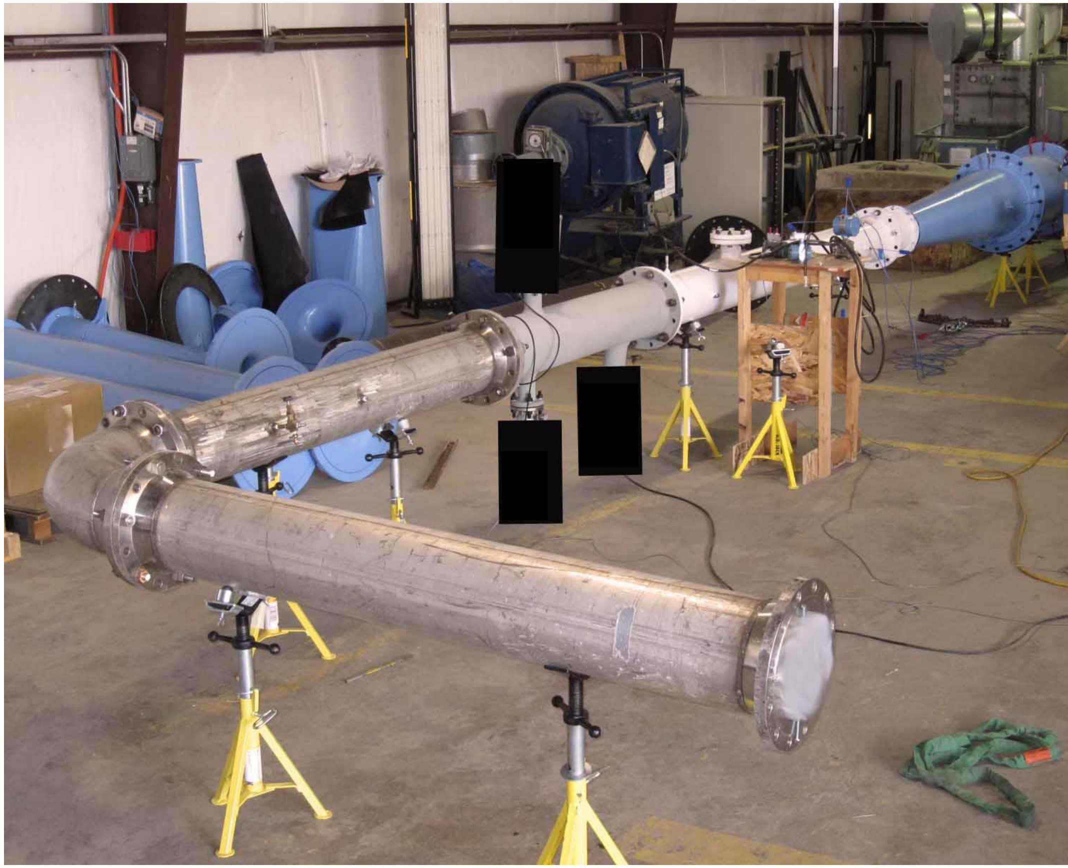
More Uncertainty Calculations:

Random error due to the thermal mass meter & the analyzer is $\left[\frac{\sum_{i=1}^{N}\left(F_I^i - F_I\right)^2}{(N-1){F_I}^2} + \frac{\sum_{i=1}^{N}\left(C_D^i - C_U^i - C_D + C_U\right)^2}{(N-1)(C_D - C_U)^2}\right]$

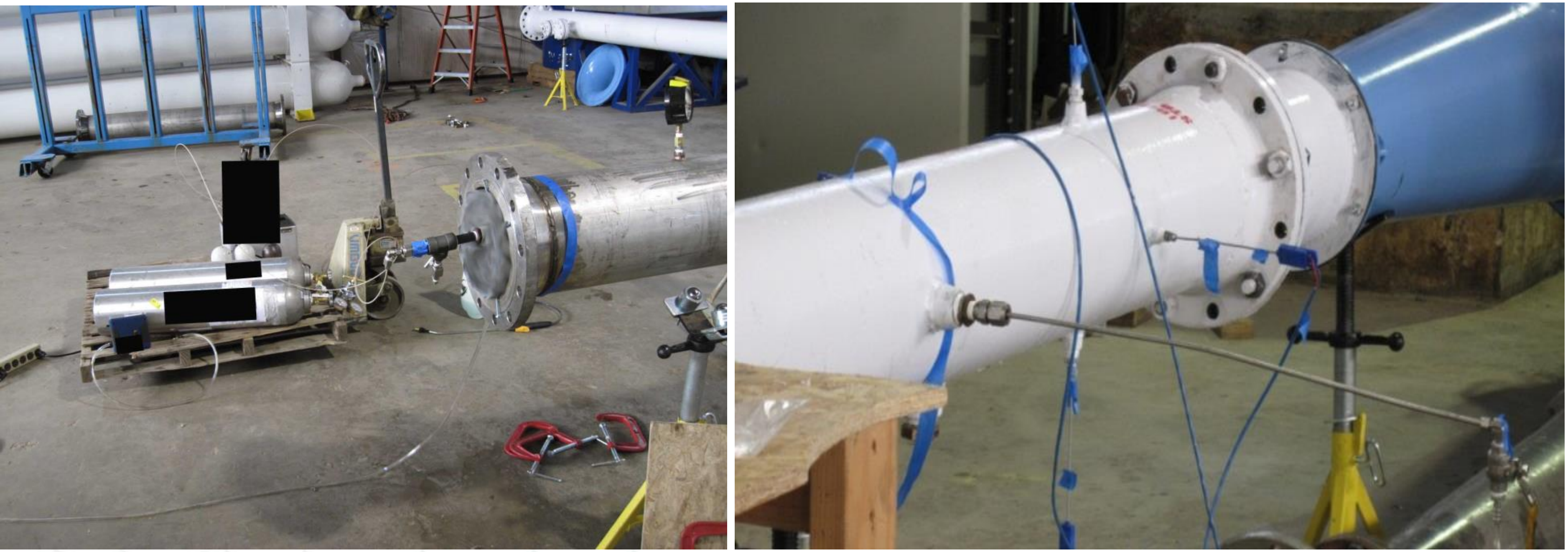
Multiple samples were taken to characterize the random error in the thermal-mass meter & the analyzer, the 2σ uncertainty was 5.06%.

$\frac{\partial_T F}{F} = \sqrt{(.04)^2 + (.02)^2 + 2(.05)^2}$ = 8.3%

A Few Pictures:

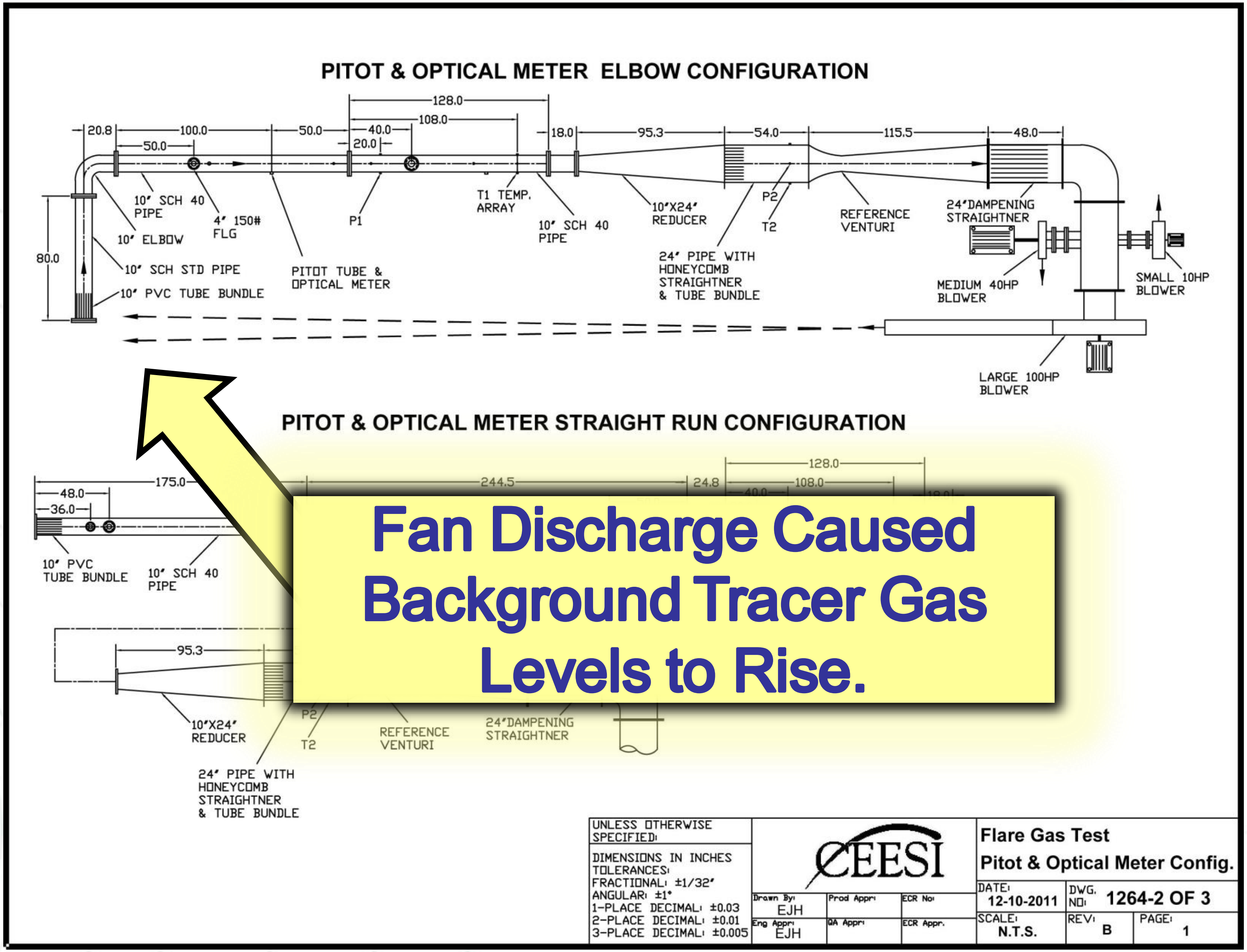


Test Facility & Test Piping



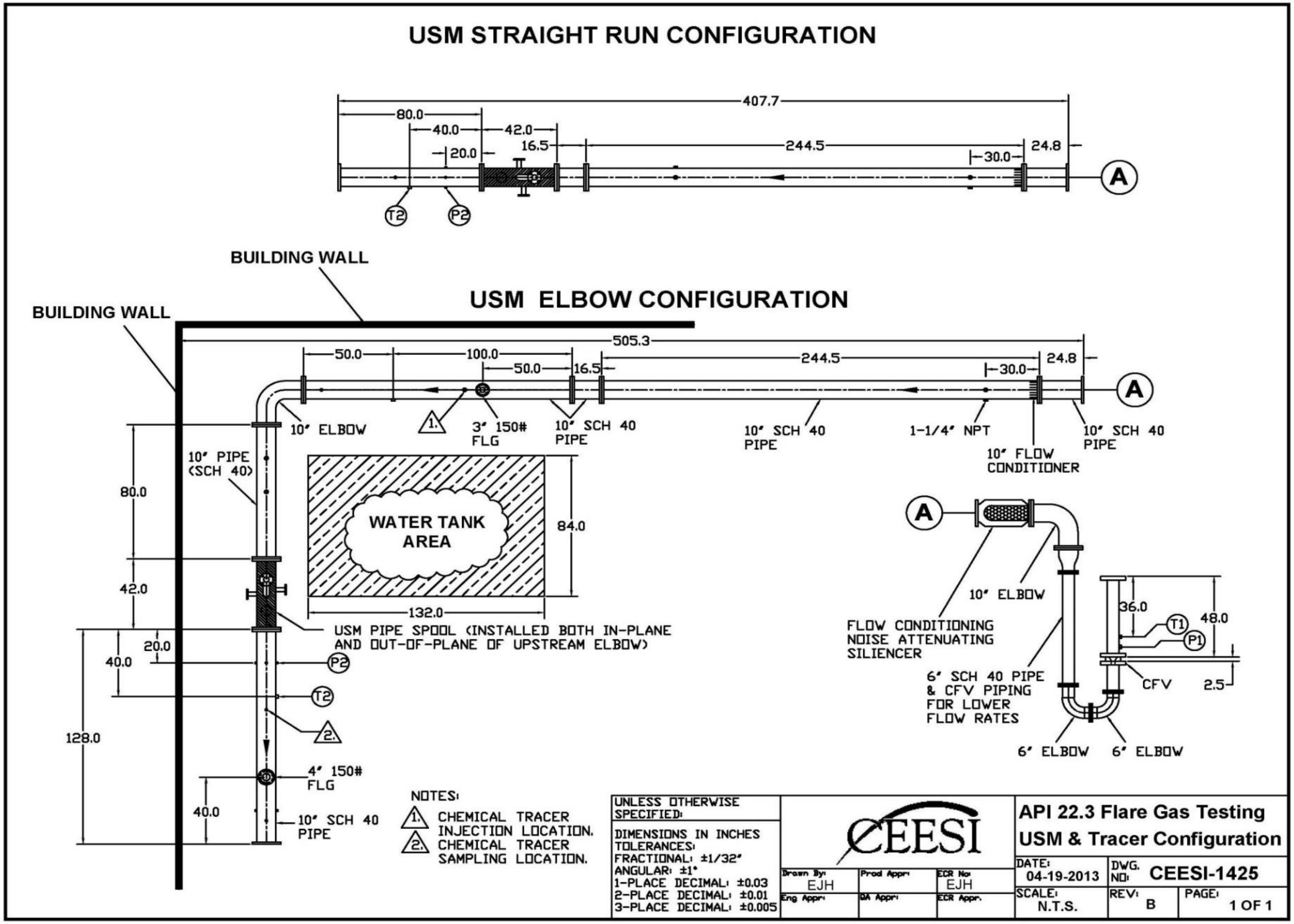
Tracer Gas Dilution Installation

Comparative Flare Gas Flow Measurement Study



Fan Discharge Caused Background Tracer Gas Levels to Rise.

Comparative Flare Gas Flow Measurement Study



Results:

<u>Question:</u>

From CEESI Testing, Trace Gas Dilution Method Uncertainty was ±6-10%. Is this reasonable?

<u>Answer:</u>

Yes, uncertainty calculation revealed an 8.3% uncertainty at 2-sigma.

Uncertainty Using Tracer Gas Dilution Method

Trace Gas Dilution Observations:

- **The worse the straight-run, the better the mixing.**
- **A large error due to the injection flow rate is possible.**
- **Consider the calibration gas uncertainty in the uncertainty calculations.**
- **Because concentration sampling is a discrete single point measurement, large random errors are likely, so many samples are required to reduce random error.**
- **How well the tracer gas mixes is hard to characterize.**

Tracer Gas Dilution is labor intensive but may be a viable alternative when other methods are not possible.

Comments & Questions?

Thank you!