Uncertainty in Ammonia Flux Measurement Systems

Cale Boriack

Sergio Capareda, Ronald Lacey,

Atilla Mutlu, Saqib Mukhtar,

Bryan Shaw, Calvin Parnell, Jr.

Biological and Agricultural Engineering Department

Texas A&M University

College Station, TX

Center for Agricultural Air Quality Engineering & Science

CAAQES

Objectives

- Develop an uncertainty budget for the ammonia measurement setup (instrumentation only)
- Define areas to reduce uncertainty in instrumentation

Center for Agricultural Air Quality Engineering & Science

CAAQES

Overview

- Uncertainty Background
- Ammonia Measurement System
- Application of Uncertainty to System
- Results
- Reducing Uncertainty
- Concluding Remarks

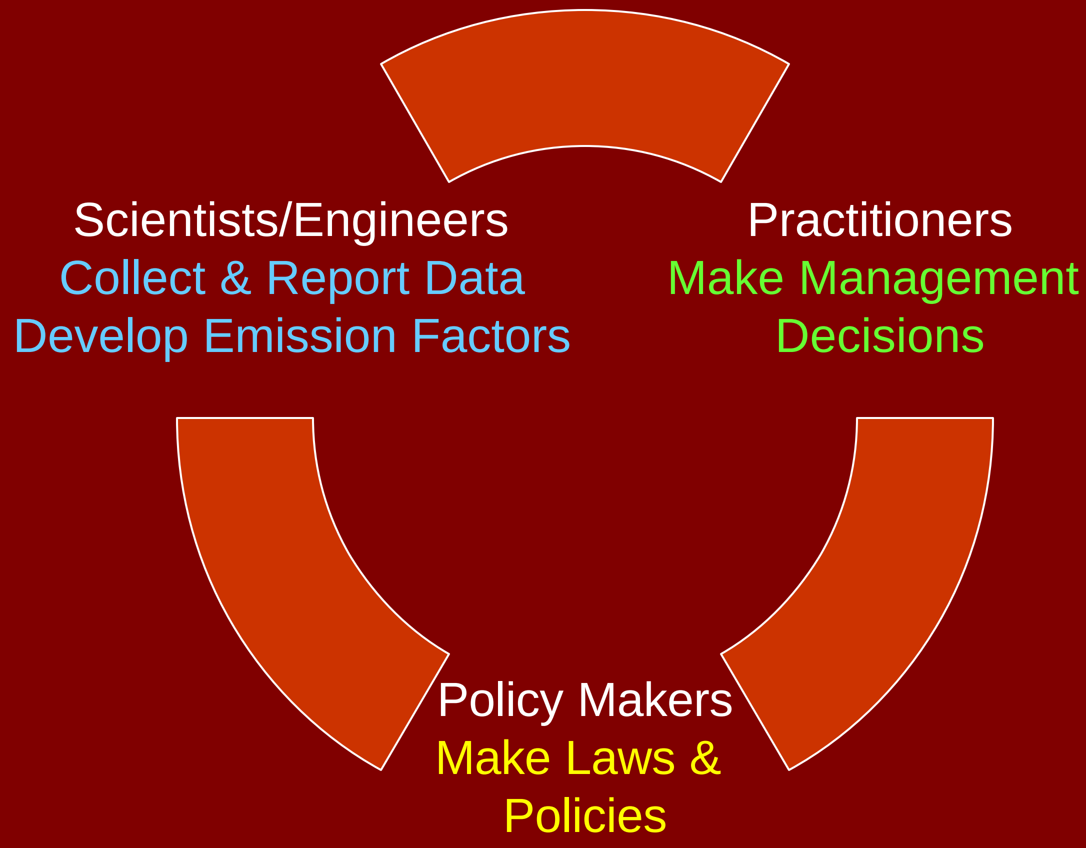
Center for Agricultural Air Quality Engineering & Science

CAAQES

Why Report Uncertainty?

Who uses Data: Air Pollution Engineering

- Shows the reliability of data
- Quality Control/Quality Assurance



Uncertainty

- Defined as the interval about the measurement or result that contains the true value for a given confidence interval (ASME, 1998)
- Arises as a result of random errors
- Every engineering system has uncertainty associated with it

Center for Agricultural Air Quality Engineering & Science
CAAQES

System Uncertainties

- Instrumentation
- Correction Factor Uncertainty
- Calibration Gases
- Data analysis and processing
- Presentation and Interpretation of results

Center for Agricultural Air Quality Engineering & Science
CAAQES

Errors

- Difference between individual result and true value
- Cannot be known exactly
- Three types of error
  - Random error
  - Systematic error
  - Spurious error

Center for Agricultural Air Quality Engineering & Science
CAAQES

Bias

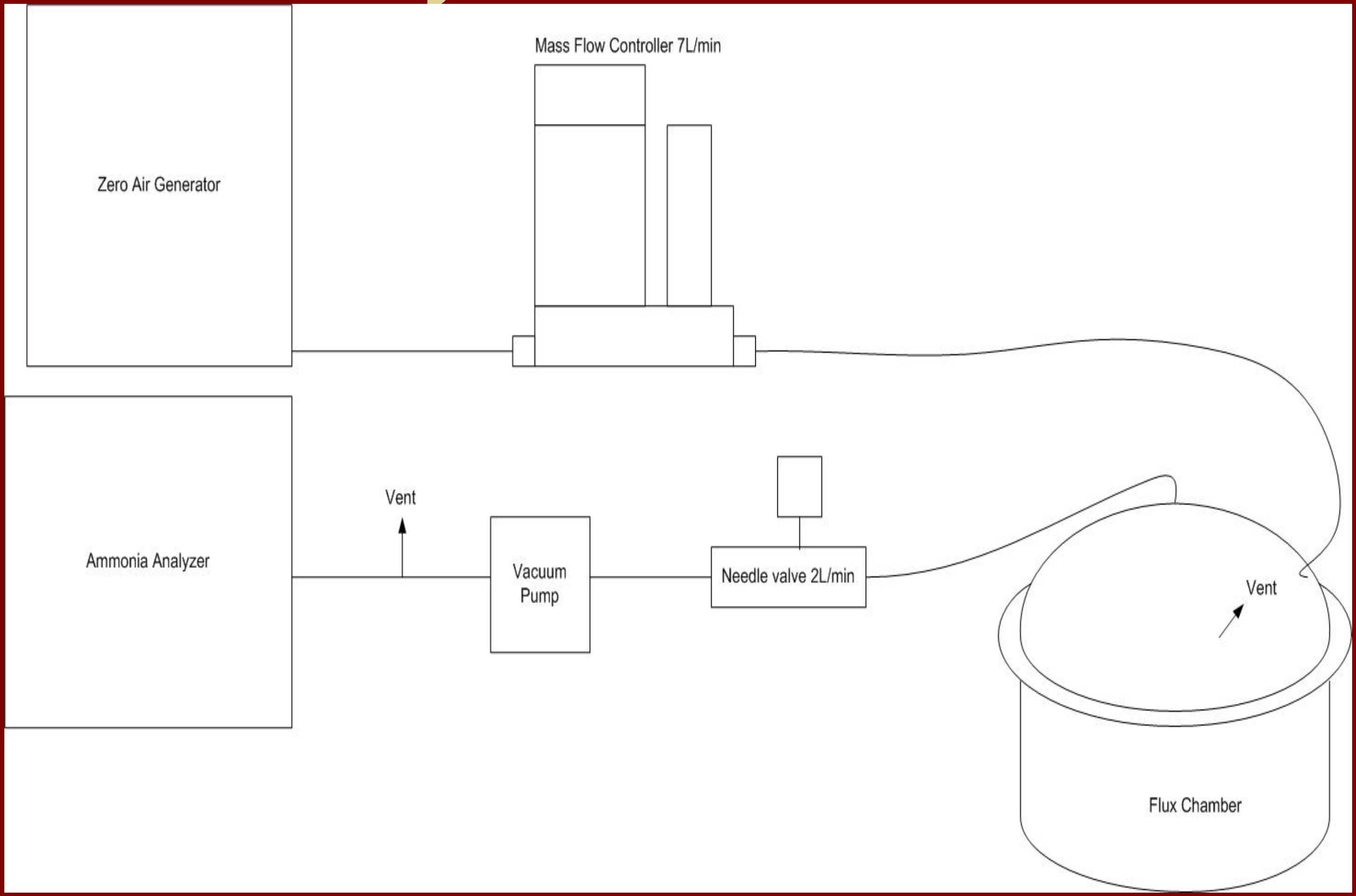
- Result of systematic error
- Often corrected through calibration
- Not included in uncertainty calculations

Center for Agricultural Air Quality Engineering & Science
CAAQES

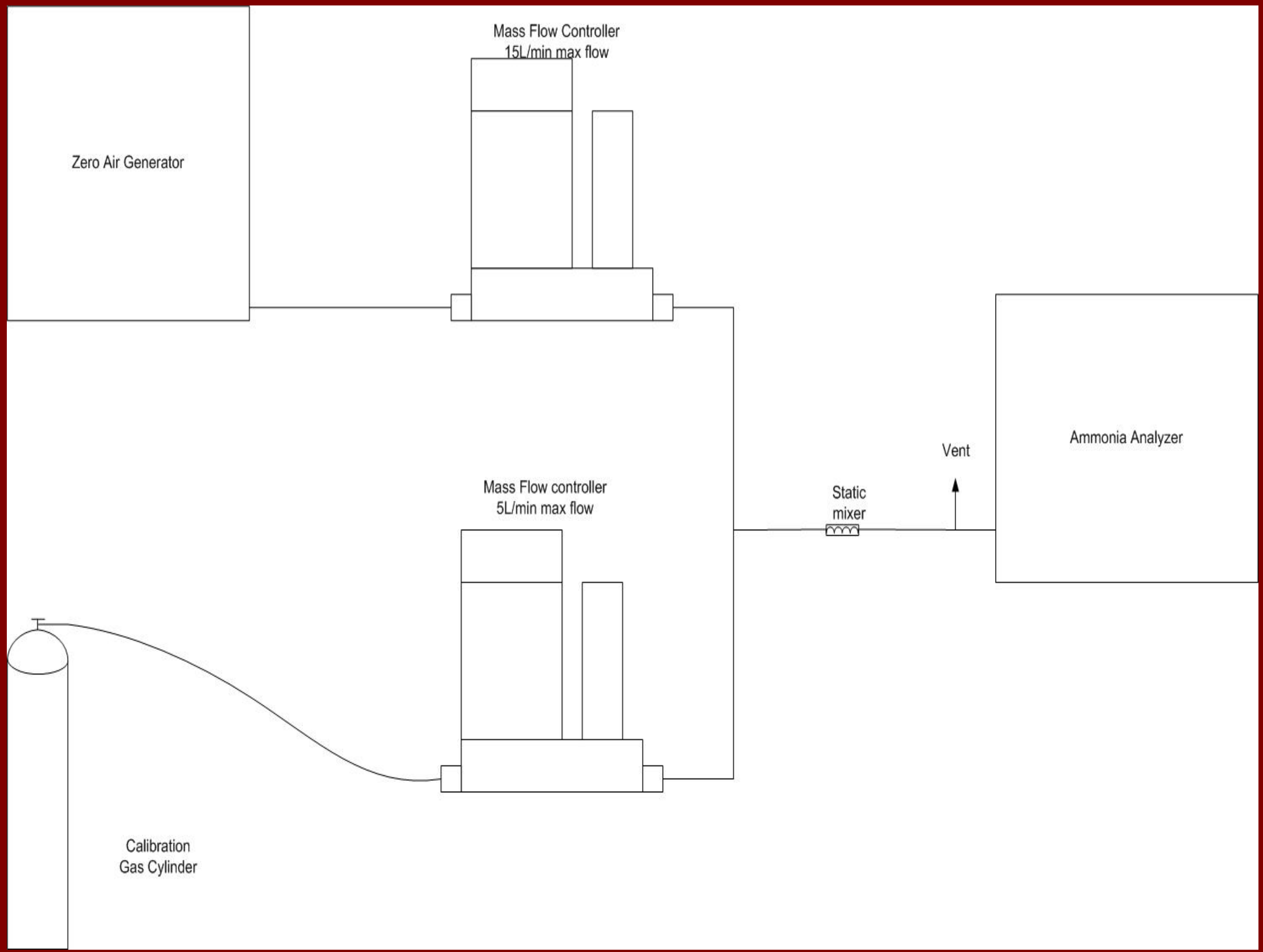
System Biases

- System Response
  - Chamber response
  - Instrument response
- Concentration biases
  - Ammonia emission suppression
  - Adsorption
  - Interferences

Ammonia Flux Measurement System



Calibration Setup



Center for Agricultural Air Quality Engineering & Science
CAAQES

Components

- Thermo 17C Chemiluminecsent analyzer
- Aalborg Mass flow Controllers
- Analog output FieldPoint (National Instruments) modules
- Analog input FieldPoint modules
- Calibration Gas cylinders

Center for Agricultural Air Quality Engineering & Science

CAAQES

Analyzer

- Thermo 17C
- Chemiluminescent type analyzer

Center for Agricultural Air Quality Engineering & Science
CAAQES

Chemiluminescent Analyzer Operation Principle

$$NO + O_3 \rightarrow NO_2 + O_2 + h\nu$$

$$NO_x + O_2 + \text{Heat}\,(325°C) \rightarrow NO + \text{by products}$$

$$N_t + O_2 + \text{Heat}\,(750°C) \rightarrow NO + \text{by products}$$

$$NO_2 = NO_x - NO$$

$$NH_3 = N_t - NO_x$$

Center for Agricultural Air Quality Engineering & Science
CAAQES

Analyzer Calibration

- Single-point performed on a weekly basis
- Multipoint calibration performed monthly
- Calibration Gas (50 ppm or 100 ppm) Uncertainty of 2%
  - NO
  - NO_2
  - NH_3

Center for Agricultural Air Quality Engineering & Science
CAAQES

Mass Flow Controllers

- Aalborg GFC-17
  - 0-5 L/min Calibration gas
  - 0-15 L/min Zero air
- Calibrated at least every year

Center for Agricultural Air Quality Engineering & Science
CAAQES

Fieldpoint Modules

- AO-210
- 12 bit output

Center for Agricultural Air Quality Engineering & Science
CAAQES

Uncertainty Calculation

- First order Taylor Series
  - Assumes all input variables are independent
    - Likely to overestimate analyzer uncertainty

$$u_c(y(x_1, x_2, \ldots)) = \sqrt{\sum_{i=1}^{n} c_i^{\,2} u(x_i)^2} \qquad c_i = \frac{\delta y}{\delta x_i}$$

u_c = combined uncertainty

$y(x_1, x_2, \ldots)$ = function with several input variables x_n

c_i = sensitivity coeffecient

$u(x_i)$ = uncertainty of input variable (standard)

System Uncertainty

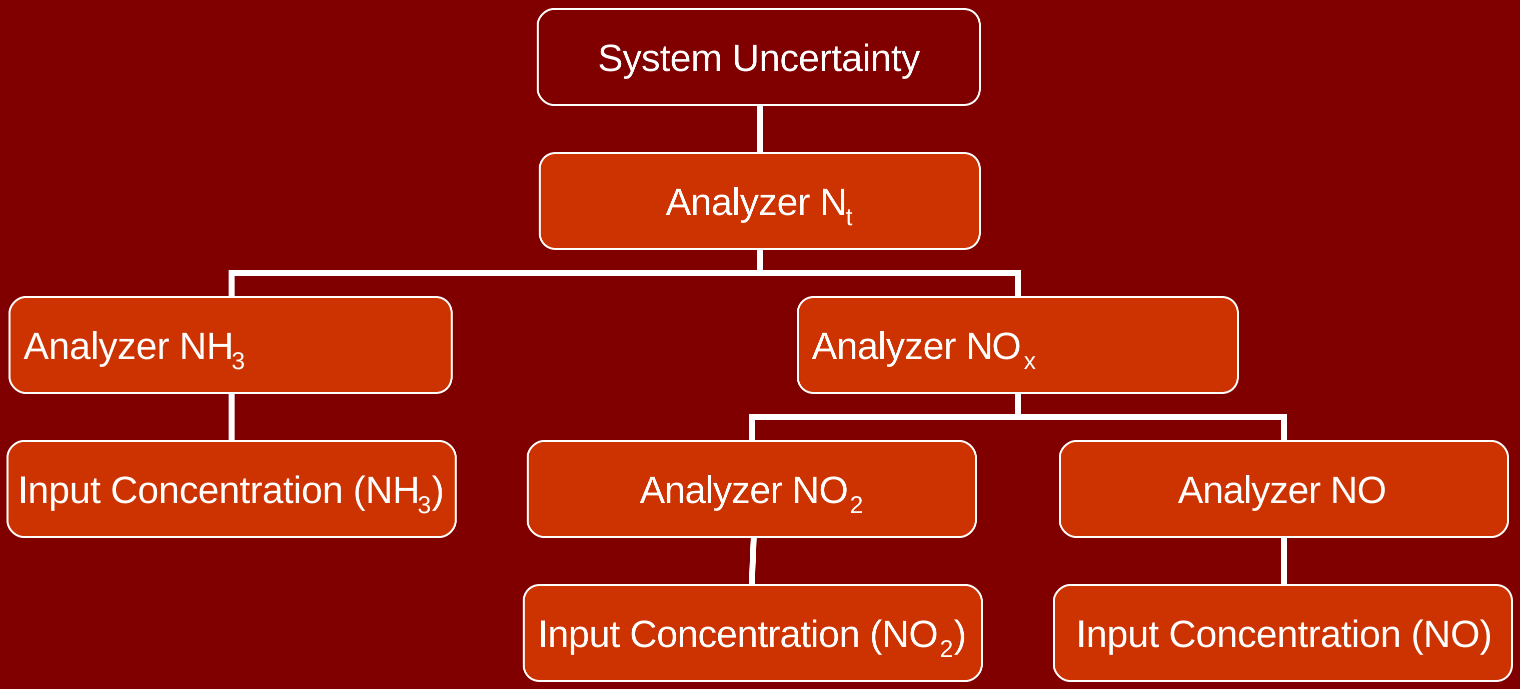
Manufacturer	Component	Model	Uncertainty type	Reported uncertainty	Uncertainty distribution	Standard Uncertainty
National Instruments	Field point module	FP-AO-210	Gain	0.40%	normal	0.20%
			Offset	14mV	normal	7mV
Aalborg	Mass flow controller	GFC-17	Accuracy	0.5% FS	normal	0.25% FS
			Repeatability	1.5% FS	normal	0.75% FS
Thermo	Ammonia analyzer	17C	Linearity	1% FS	normal	0.5% FS
			Span drift	1%FS	normal	0.5% FS
			Zero drift	1 ppb	normal	0.5 ppb
			Zero noise	0.5 ppb	normal	0.25 ppb
			Lower detectable limit	1 ppb	normal	0.5 ppb

Uncertainty of Analyzer assumed to be the uncertainty of the sensor.

Center for Agricultural Air Quality Engineering & Science

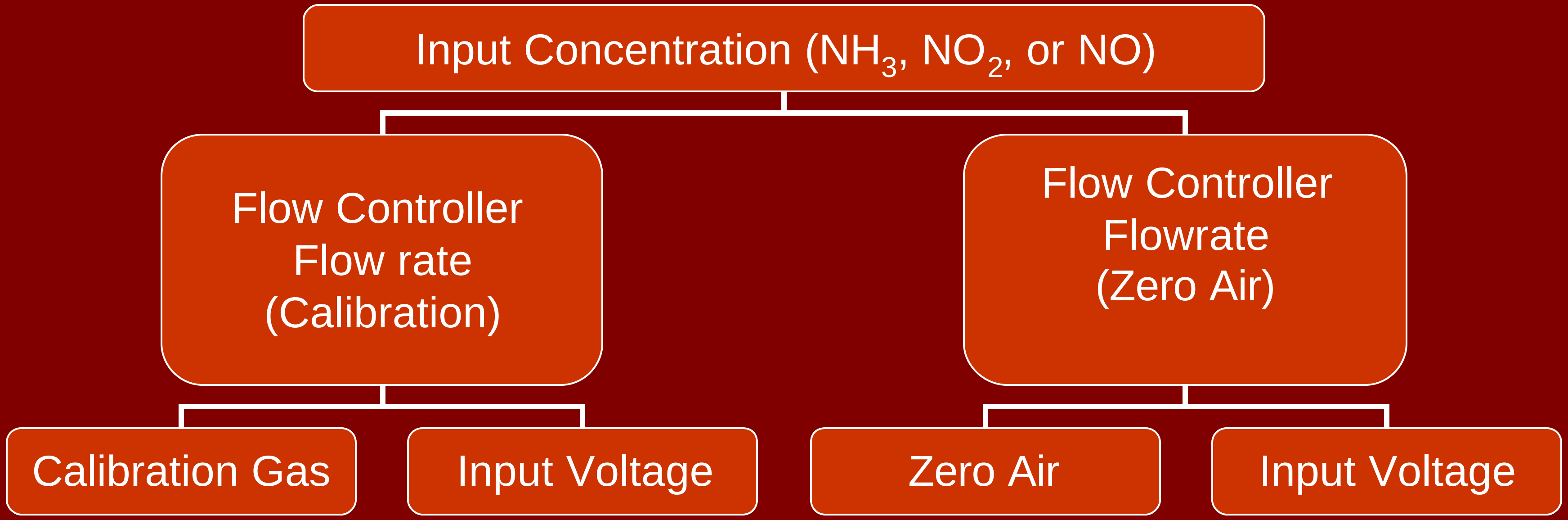
CAAQES

Uncertainty Budget



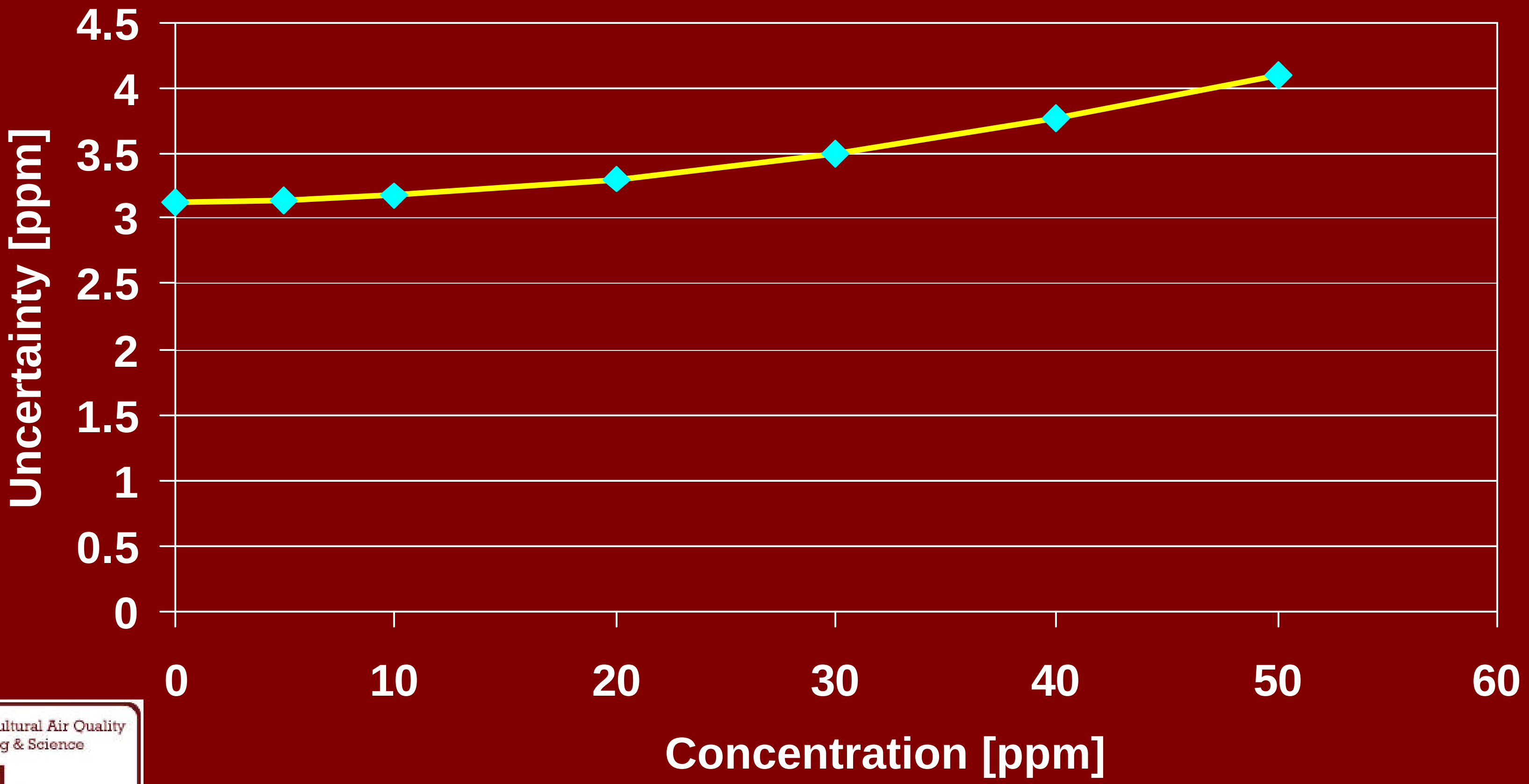
Center for Agricultural Air Quality Engineering & Science
CAAQES

Uncertainty Budget (cont.)

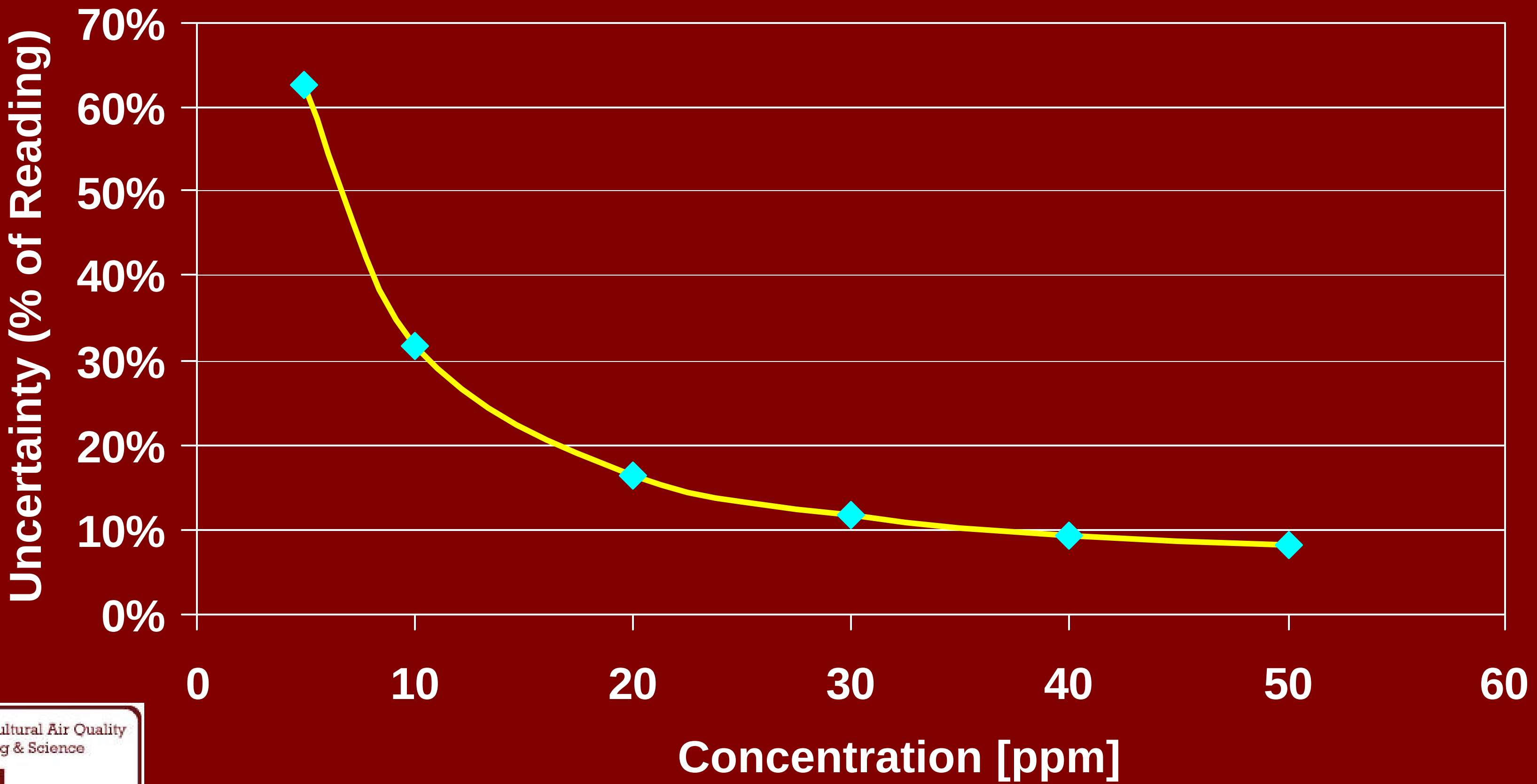


Center for Agricultural Air Quality Engineering & Science
CAAQES

Instrument Uncertainty for 50 ppm Range



Instrument Uncertainty for 50 ppm Range



Center for Agricultural Air Quality Engineering & Science
CAAQES

Reducing the Uncertainty

- Original system
  - – 9.4% uncertainty @ 40 ppm
- Changing to a 0.5% uncertainty flow controller
  - – 8.7% uncertainty @ 40 ppm
- Changing to a 1% uncertainty calibration gas
  - – 9.1% uncertainty @ 40 ppm
- Changing both flow controller and calibration gas
  - – 8.3% uncertainty @ 40 ppm

Center for Agricultural Air Quality Engineering & Science
CAAQES

Discussion

- First-order Taylor Series likely overestimates uncertainty
  - Assumption that errors are independent does not hold true for the analyzer
- Study suggests 9.4% uncertainty @ 40 ppm with 50 ppm span

Center for Agricultural Air Quality Engineering & Science

CAAQES

Conclusions

- Reporting uncertainty is essential
  - Quality data transfer
  - Internal QA/QC
- Proper ranges must be selected to reduce uncertainty

Center for Agricultural Air Quality Engineering & Science

CAAQES

The only thing that makes life possible is permanent, intolerable uncertainty; not knowing what comes next.

Ursula K. LeGuin

Center for Agricultural Air Quality Engineering & Science
CAAQES