Understanding the Issues Affecting the Accuracy of Measuring Oxygen Consumption Utilizing Metabolic Carts

Thank you for joining us.
The webinar will begin shortly.

AEI TECHNOLOGIES
Metabolic Measurement Systems

Tweet #LifeScienceWebinar #ISCxAEITech

insidescientific

Understanding the Issues Affecting the Accuracy of Measuring Oxygen Consumption Utilizing Metabolic Carts

Phil Loeb
President
AEI Technologies

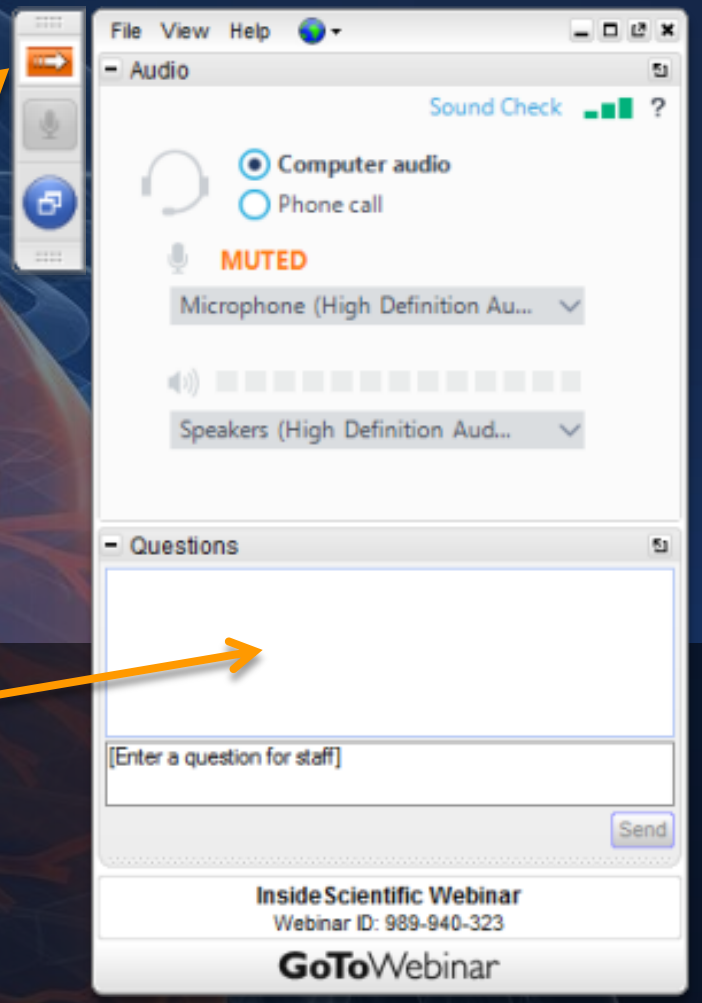
Danny Rutar
Managing Director
Redback Biotek

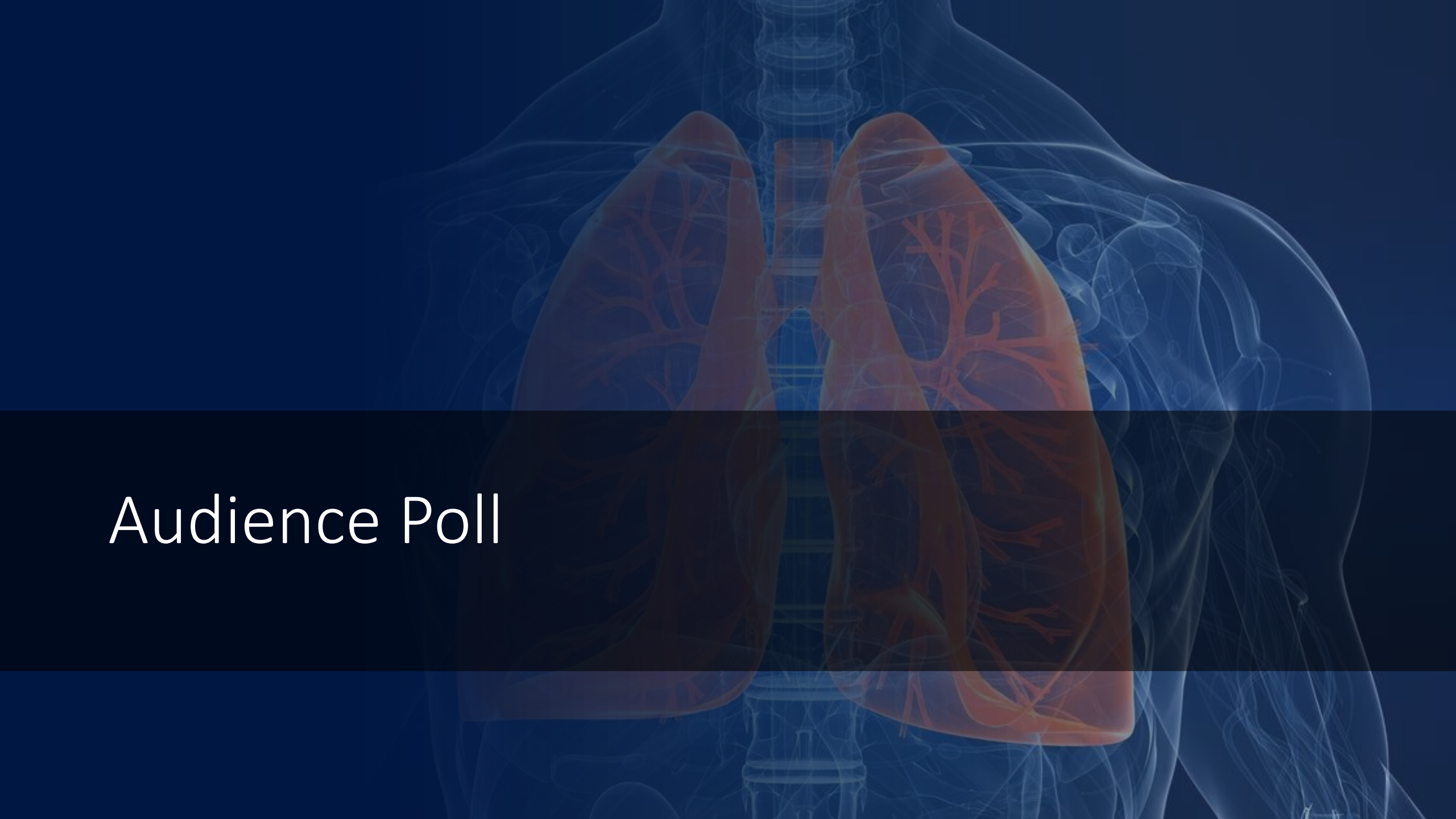
AEI TECHNOLOGIES
Metabolic Measurement Systems

insidescientific

Housekeeping…

- **This webinar is being recorded!** Resources will be made available following the event
- Access or Hide the Webinar control panel by clicking the orange arrow in the side bar
- **We want to hear from you!** Please send questions, thoughts, or comments through the Questions Panel. There will be a brief Q&A session at the end of the webinar.





Audience Poll

Understanding the Issues Affecting the Accuracy of Measuring Oxygen Consumption Utilizing Metabolic Carts

Phil Loeb

President
AEI Technologies

AEI TECHNOLOGIES
Metabolic Measurement Systems

insidescientific

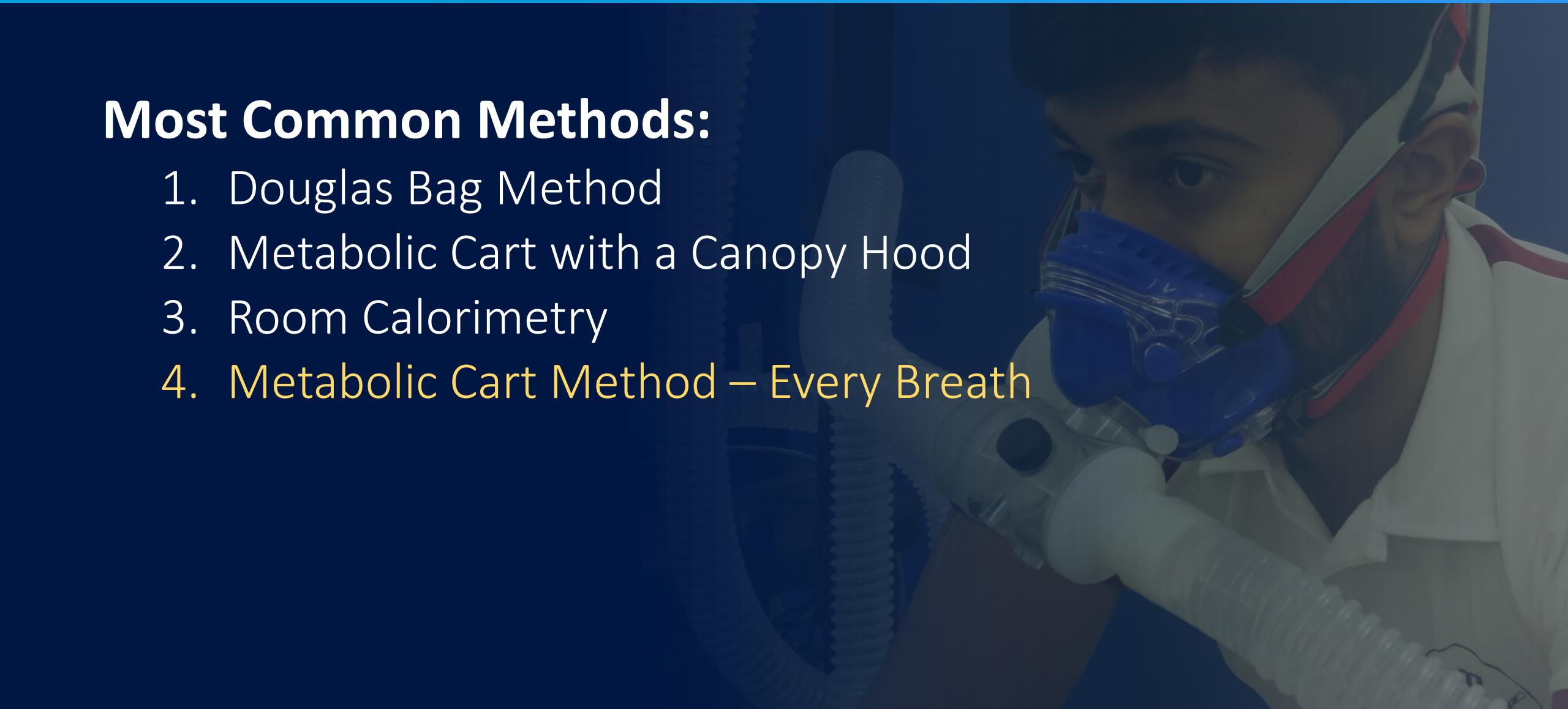
Key Topics:

- Measurements and other factors in VO2
- Error and other issues
- Minimizing errors in VO2
- Summary of Metabolic Cart validation methods
- How the MOXUS Metabolic Cart minimizes errors

VO2 by Indirect Calorimetry

Most Common Methods:

1. Douglas Bag Method
2. Metabolic Cart with a Canopy Hood
3. Room Calorimetry
4. Metabolic Cart Method – Every Breath



What is a Metabolic Cart?

A Metabolic Cart measures:

- Pulmonary Ventilation of every breath
- Oxygen concentration
- Carbon Dioxide concentration
- Temperature, Pressure, Humidity

To *calculate* O_2 Consumption and CO_2 Production

What is a Metabolic Cart?

Oxygen Consumption = Amount of Inspired O2 – Amount of Expired O2

$VO_2 = (V_i * fiO_2) - (V_e * f_eO_2)$ at STPD by convention

CO2 Production = Amount of Expired CO2 - Amount of Inspired CO2

$VCO_2 = (V_e * f_eCO_2) - (V_i * f_iCO_2)$ at STPD by convention

Where

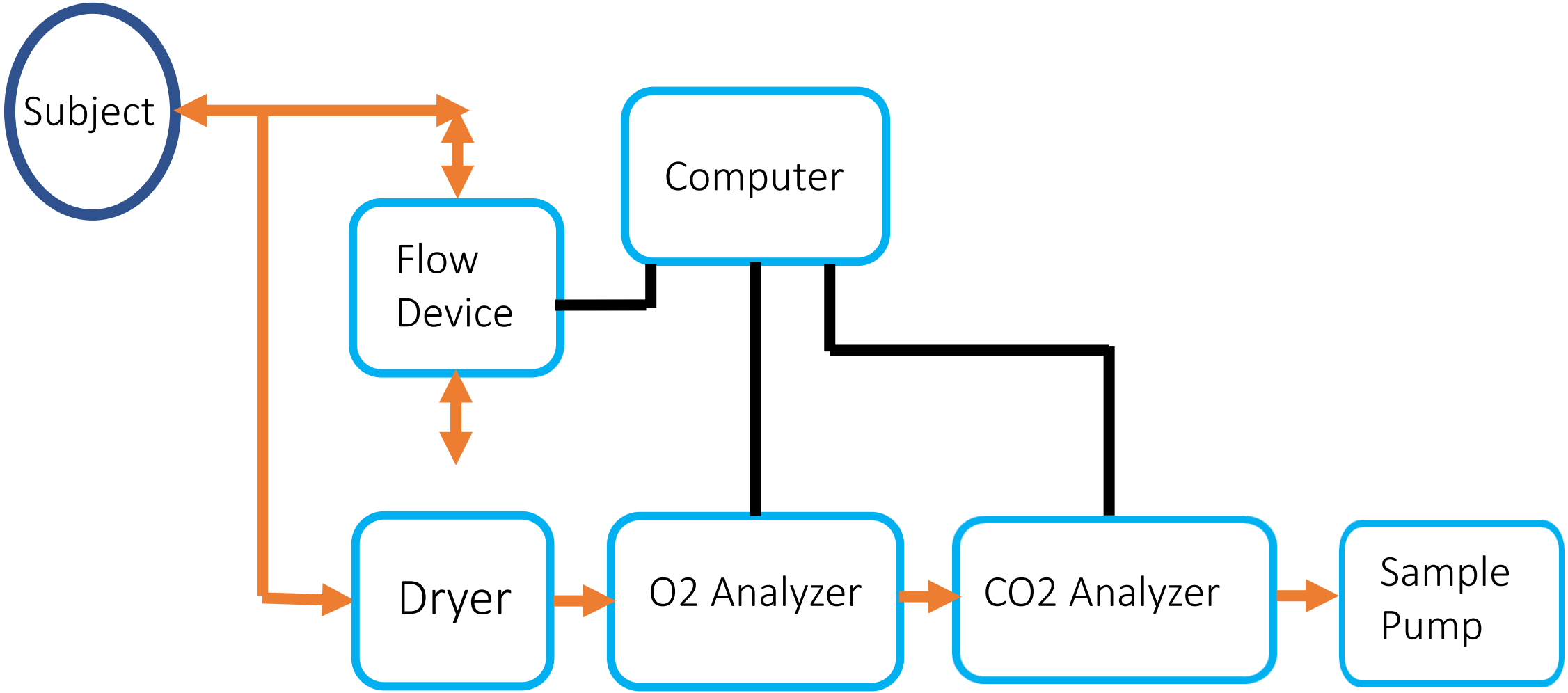
*Expiratory Ventilation = Inspiratory Ventilation * Inspiratory N2 / Expiratory N2*

$V_e = V_i * (100-f_iO_2-f_iCO_2) / (100-f_eO_2-f_eCO_2)$; Haldane transform

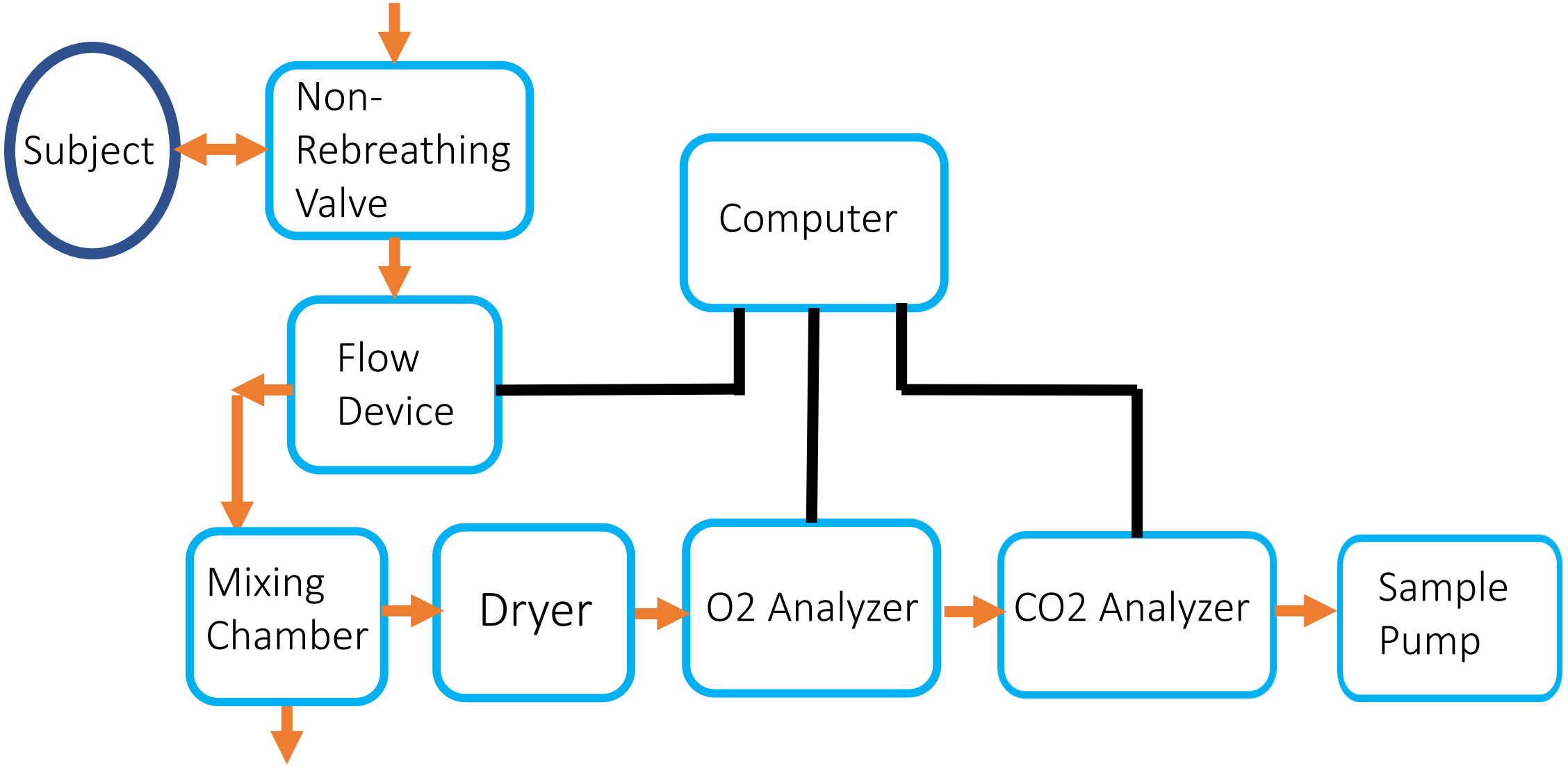
And

O2 and CO2 concentrations are dry gases.

Metabolic Cart – Generic BxB



Metabolic Cart – Generic Mixing Chamber

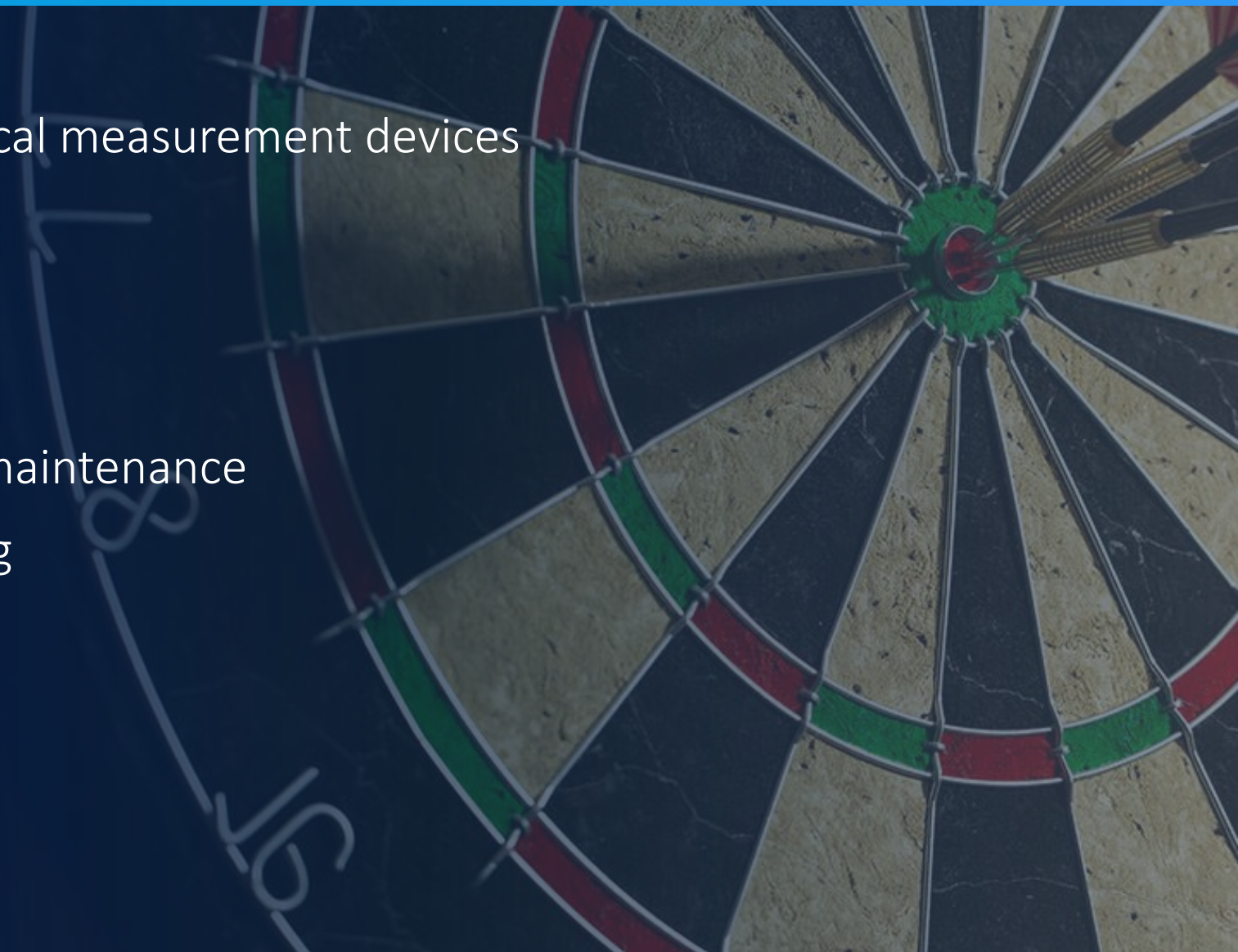


Physical Measurements

1. O2 – for both inspiratory & expiratory air
2. CO2 – for both inspiratory & expiratory air
3. Flow
4. Temperature – for STPD correction
5. Pressure – for STPD correction
6. Humidity – for STPD correction
7. Time

Factors Affecting Accuracy

1. Calibration of system physical measurement devices
2. Calibration Gas
3. Testing Environment
4. Subject Preparation
5. Metabolic Cart setup and maintenance
6. Time delays of gas sampling
7. Humidity of Gas Sample
8. Operator Initiated errors



Calibration of System Devices

- ✓ Generally, calibrate at 2 points. These calibration points should be close to the expected data points.
- ✓ Use a calibration standard as accurate as possible.

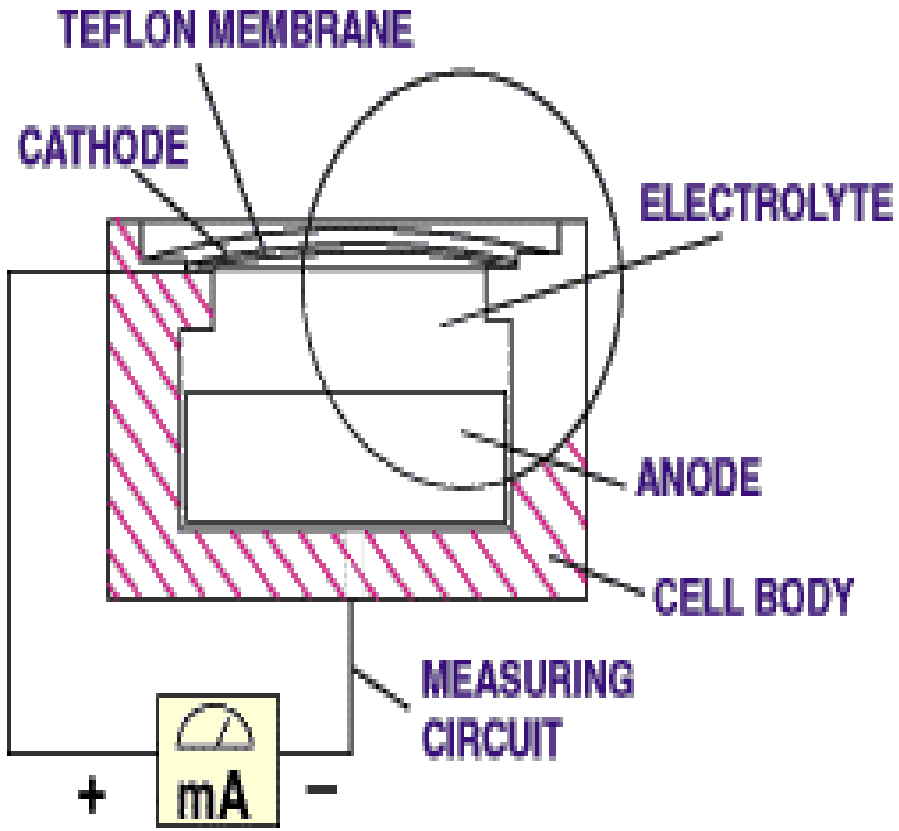
IMPORTANT: Calibration does NOT mean 0 errors; Calibration does NOT improve manufacturer's specified accuracy. Calibration does NOT provide validation.

Common Types of Metabolic Cart Errors

- × O2 Measurement
- × CO2 Measurement
- × Flow Measurement
- × Gas Calibration
- × Gas Sample Humidity
- × Temperature Measurement
- × Pressure Measurement
- × Relative Humidity Measurement
- × Metabolic Cart Setup/Maintenance
- × Gas Sampling Time Delay
- × Time Measurement

Most Important Sources of Error

- × O2 Measurement
- × CO2 Measurement
- × Flow Measurement
- × Gas Calibration
- × Gas Sample Humidity
- × Temperature Measurement
- × Pressure Measurement
- × Relative Humidity Measurement
- × Metabolic Cart Setup/Maintenance
- × Gas Sampling Time Delay
- × Time Measurement



O2 Measurement Errors

Oxygen Analyzer accuracy errors

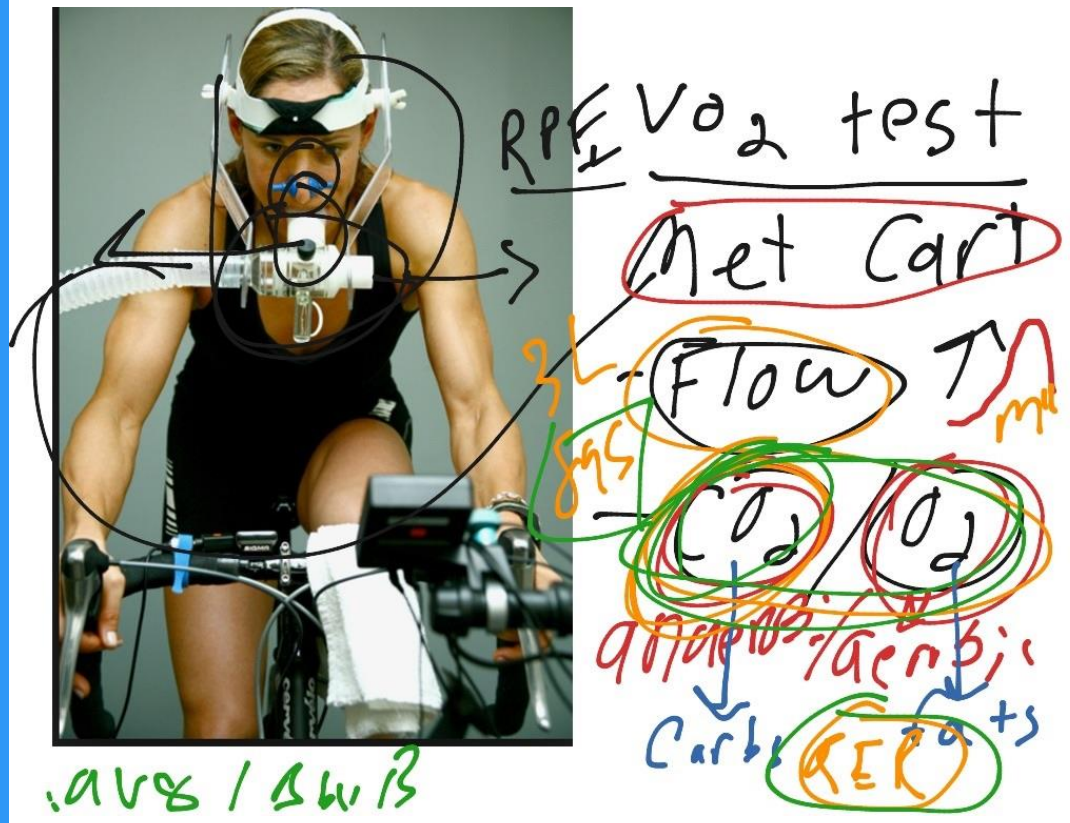
The greatest source of error in Metabolic Cart Systems!

Interferant gas errors

CO_2 Measurement Errors

Carbon Dioxide Analyzer accuracy errors.

Interferant gas errors



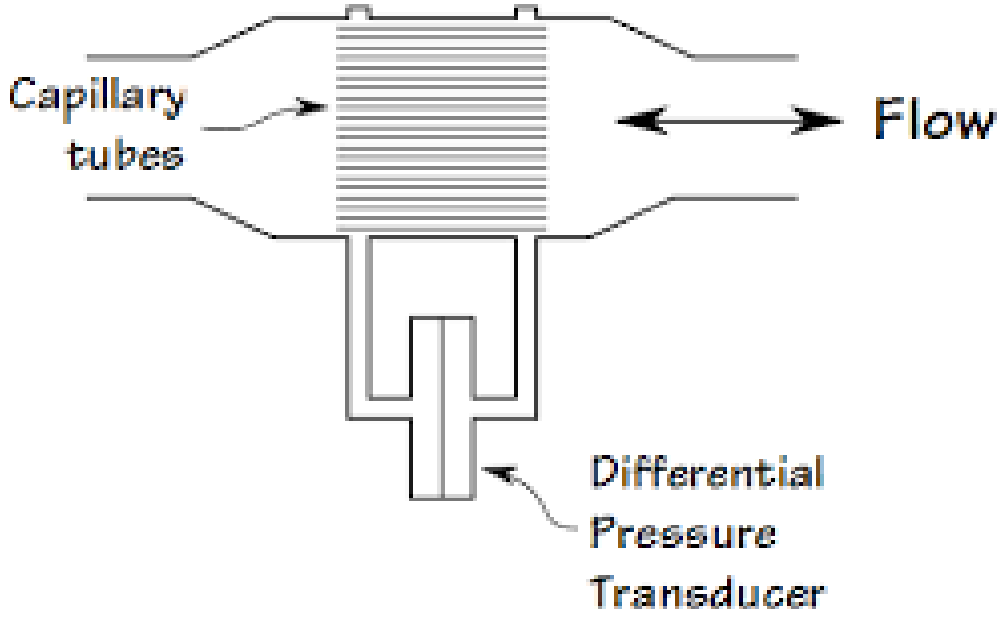
Flow Measurement Errors

Turbine flow measurement errors:

- Moment of Inertia compensation
- Impeller contamination

Pneumotach flow measurement errors:

- Linearization compensation
- Contamination



Gas Calibration Errors

Calibration Gas cylinder accuracy

Gas flow rate and pressure effects

Stabilization times

Gas Sample Humidity Errors

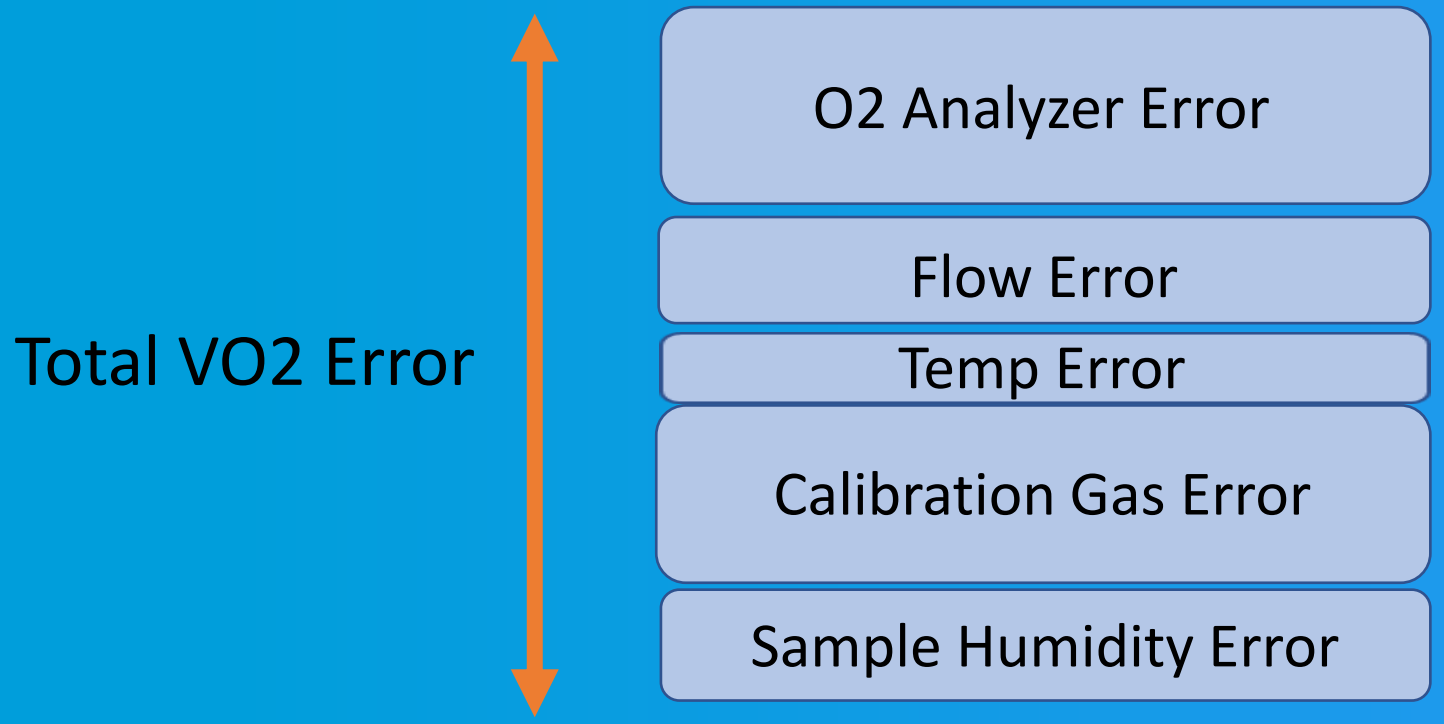
Nafion tubing, if used, not working properly

Desiccant, if used, not working properly

Leaks in the gas sampling path

Cumulative Error

Metabolic Cart errors are all cumulative and contribute to reducing System Accuracy



Metabolic Cart Error Examples

Presenting examples of 2 common Metabolic Cart sources of errors:

Gas Analyzer Error

Calibration Gas Error

Gas Analyzer Error Example

Utilize the textbook equations for Exercise:

$$VO_2 = (Vi * fiO_2) - (Ve_{avg} * feO_2);$$
$$VCO_2 = (Ve * feCO_2) - (Vi_{avg} * fiCO_2);$$
Where $Ve = Vi * (100\text{-}fiO_2\text{-}fiCO_2) / (100\text{-}feO_2\text{-}feCO_2)$ [Haldane transform]

Assume all other errors are zero.

Error Example – Gas Analyzer 1

Expected Values		Worst Case Values	
fiO2	20.93	fiO2	21.03
fiCO2	0.03	fiCO2	0.13
feO2	17.00	feO2	16.90
feCO2	4.00	feCO2	3.90
Haldane	1.00	Haldane	1.00
Vi (L/min)	150.00	Vi (L/min)	150.00
Ve	150.08	Ve	149.32
VO2	5.88	VO2	6.31
VCO2	5.96	VCO2	5.63
RER	1.01	RER	0.89

O2 Accuracy = 0.1% absolute
CO2 Accuracy = 0.1% absolute

Gas analyzer Error Contribution	
VO2 % Error	7.28
VCO2 % Error	-5.53
RER % Error	-11.94

Error Example – Gas Analyzer 2

Expected Values		Worst Case Values	
fiO2	20.93	fiO2	20.94
fiCO2	0.03	fiCO2	0.05
feO2	17.00	feO2	16.99
feCO2	4.00	feCO2	3.98
Haldane	1.00	Haldane	1.00
Vi (L/min)	150.00	Vi (L/min)	150.00
Ve	150.08	Ve	149.96
VO2	5.88	VO2	5.93
VCO2	5.96	VCO2	5.89
RER	1.01	RER	0.99

O2 Accuracy = 0.01% absolute
CO2 Accuracy = 0.02% absolute

Gas analyser Error Contribution	
VO2 % Error	0.84
VCO2 % Error	-1.08
RER % Error	-1.91

Analysis & Conclusions

Metabolic Carts utilizing less accurate gas analyzers may result in data far outside of acceptable limits

A very small error in Oxygen will result in a very large error in VO2

Calibration Gas Error Examples

Utilize the textbook equations for Exercise:

$$VO_2 = (V_i * fiO_2) - (V_e * f_eO_2);$$
$$VCO_2 = (V_e * f_eCO_2) - (V_i * f_iCO_2);$$
Where $V_e = V_i * (100\text{-}f_iO_2\text{-}f_iCO_2) / (100\text{-}f_eO_2\text{-}f_eCO_2)$ [Haldane transform]

Assume all other errors are zero.

Calibration Gas Error Example 1

Gases - Expected Values		Worst Case Values	
O2 (High)	21.00	O2 (High)	22.05
O2 (Low)	16.00	O2 (Low)	15.20
CO2 (High)	4.00	CO2 (High)	4.20
CO2 (Low)	0.03	CO2 (Low)	0.03
fiO2	20.93	fiO2	21.98
fiCO2	0.03	fiCO2	0.03
feO2	17.00	feO2	16.20
feCO2	4.00	feCO2	4.20
Haldane	1.00	Haldane	0.98
Vi (L/min)	150.00	Vi (L/min)	150.00
Ve	150.08	Ve	146.97
VO2	5.88	VO2	9.16
VCO2	5.96	VCO2	6.13
RER	1.01	RER	0.67

2 Cal Gases Utilized:
uncertainty = 5%

Cal Gas Error Contribution	
VO2 % Error	55.75
VCO2 % Error	2.85
RER % Error	-33.97

Calibration Gas Error Example 2

Gases - Expected Values		Worst Case Values	
O2 (High)	21.00	O2 (High)	21.02
O2 (Low)	16.00	O2 (Low)	15.98
CO2 (High)	4.00	CO2 (High)	3.98
CO2 (Low)	0.03	CO2 (Low)	0.03
fiO2	20.93	fiO2	21.03
fiCO2	0.03	fiCO2	0.13
feO2	17.00	feO2	16.90
feCO2	4.00	feCO2	3.90
Haldane	1.00	Haldane	1.00
Vi (L/min)	150.00	Vi (L/min)	150.00
Ve	150.08	Ve	149.32
VO2	5.88	VO2	6.31
VCO2	5.96	VCO2	5.63
RER	1.01	RER	0.89

2 Cal Gases Utilized:
uncertainty = 0.02% absolute

Cal Gas Error Contribution	
VO2 % Error	1.35
VCO2 % Error	-0.58
RER % Error	-1.90

Analysis & Conclusions

Metabolic Carts utilizing less accurate calibration gas may result in data far outside of acceptable limits.

A very small error in Calibration Gas will result in a very large error in VO2

What is Validation?

Validation is proving the Metabolic Cart does what its designed to do.

What is a Metabolic Cart?

A Metabolic Cart measures:

- Pulmonary Ventilation of every breath
- Oxygen concentration
- Carbon Dioxide concentration
- Temperature, Pressure, Humidity

To *calculate* O2 Consumption and CO2 Production

Metabolic Cart Validation

Metabolic Cart Validation should include BOTH:

Verification of Physical Measurement Components

AND

System Verification - determination of VO2 and VCO2

Component Verification

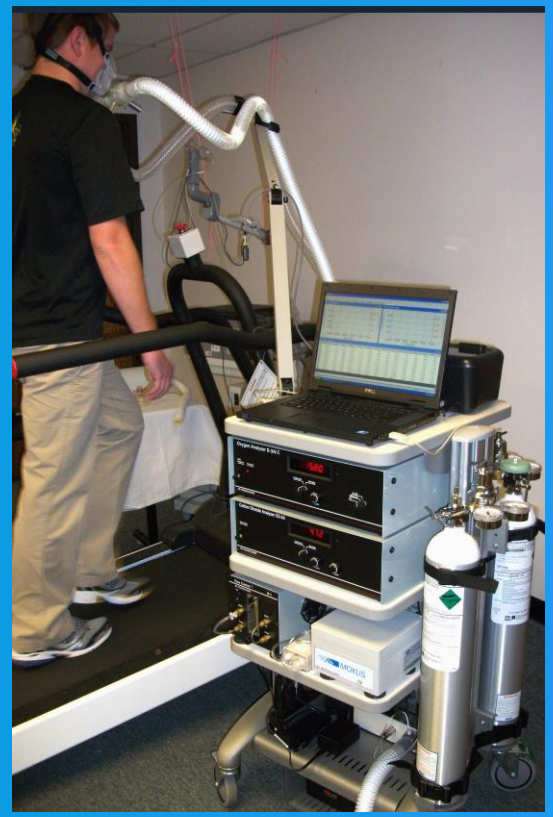
It is best to periodically return the components to the manufacturer for factory testing

On site verification may be performed using Standards at multiple points in the operating range

System Verification Methods:

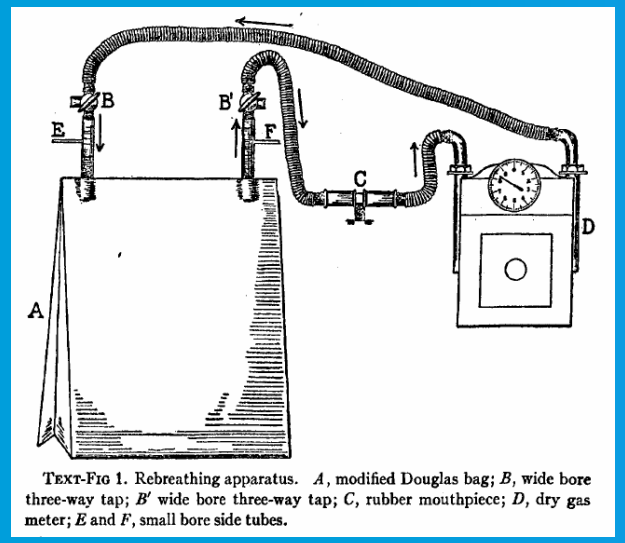
Alcohol Burn

Subject Testing



System Verification Methods:

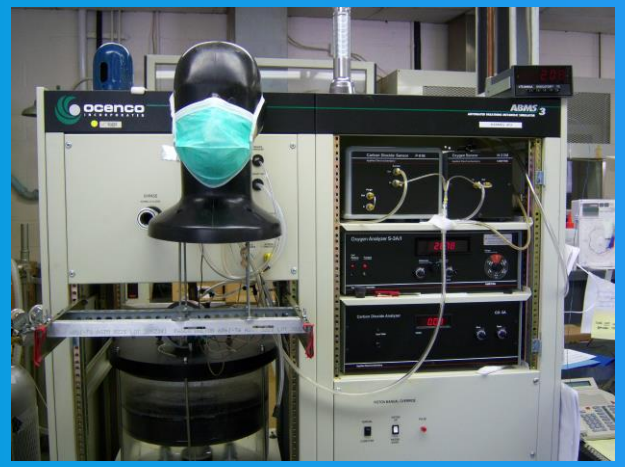
Douglas Bag Method

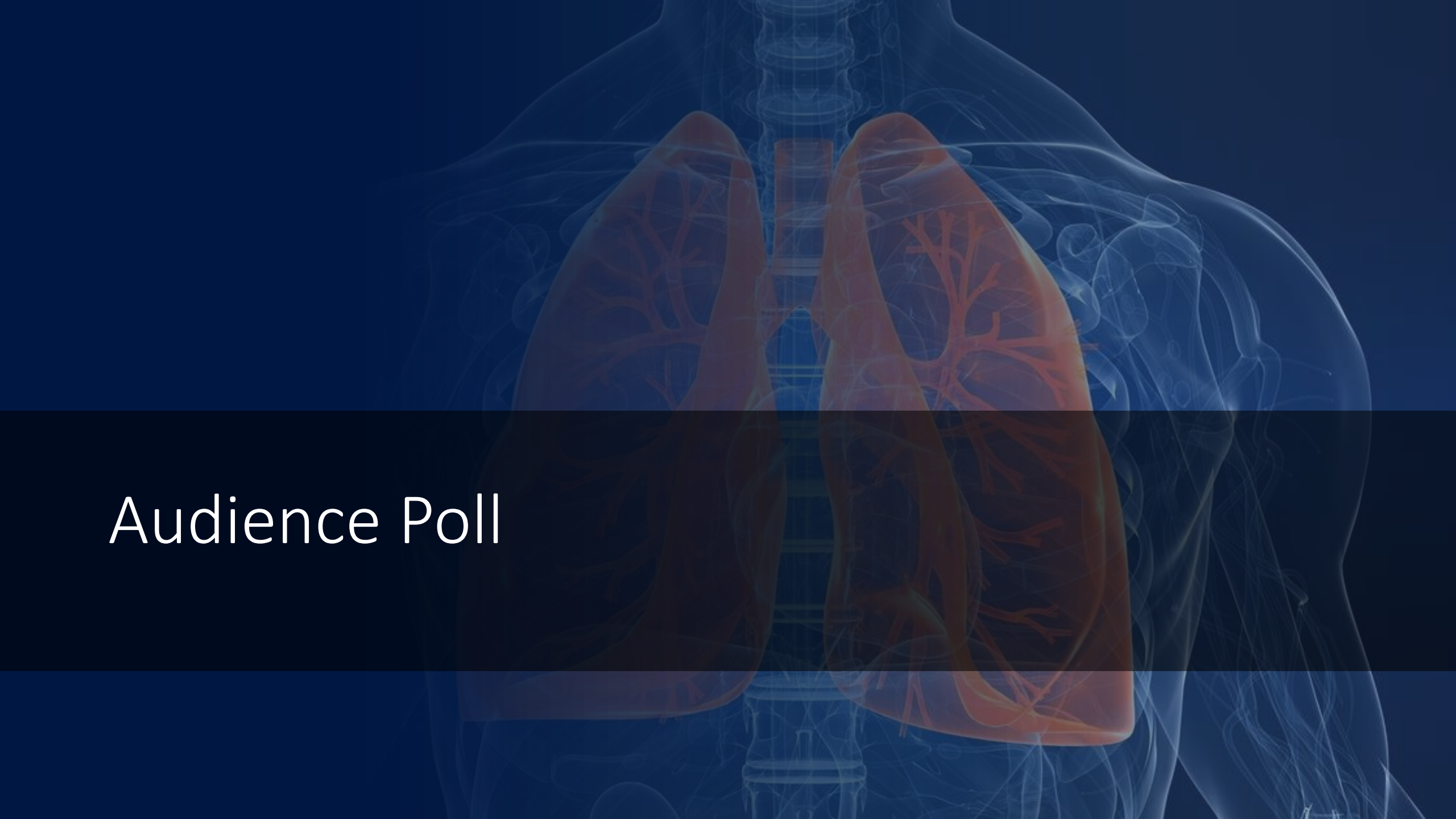


TEXT-FIG 1. Rebreathing apparatus. *A*, modified Douglas bag; *B*, wide bore three-way tap; *B'* wide bore three-way tap; *C*, rubber mouthpiece; *D*, dry gas meter; *E* and *F*, small bore side tubes.

System Calibrator

- Best Method-





Audience Poll

Danny Presentation Title Here

Danny Rutar

Managing Director
Redback Biotek

redback biotek

insidescientific

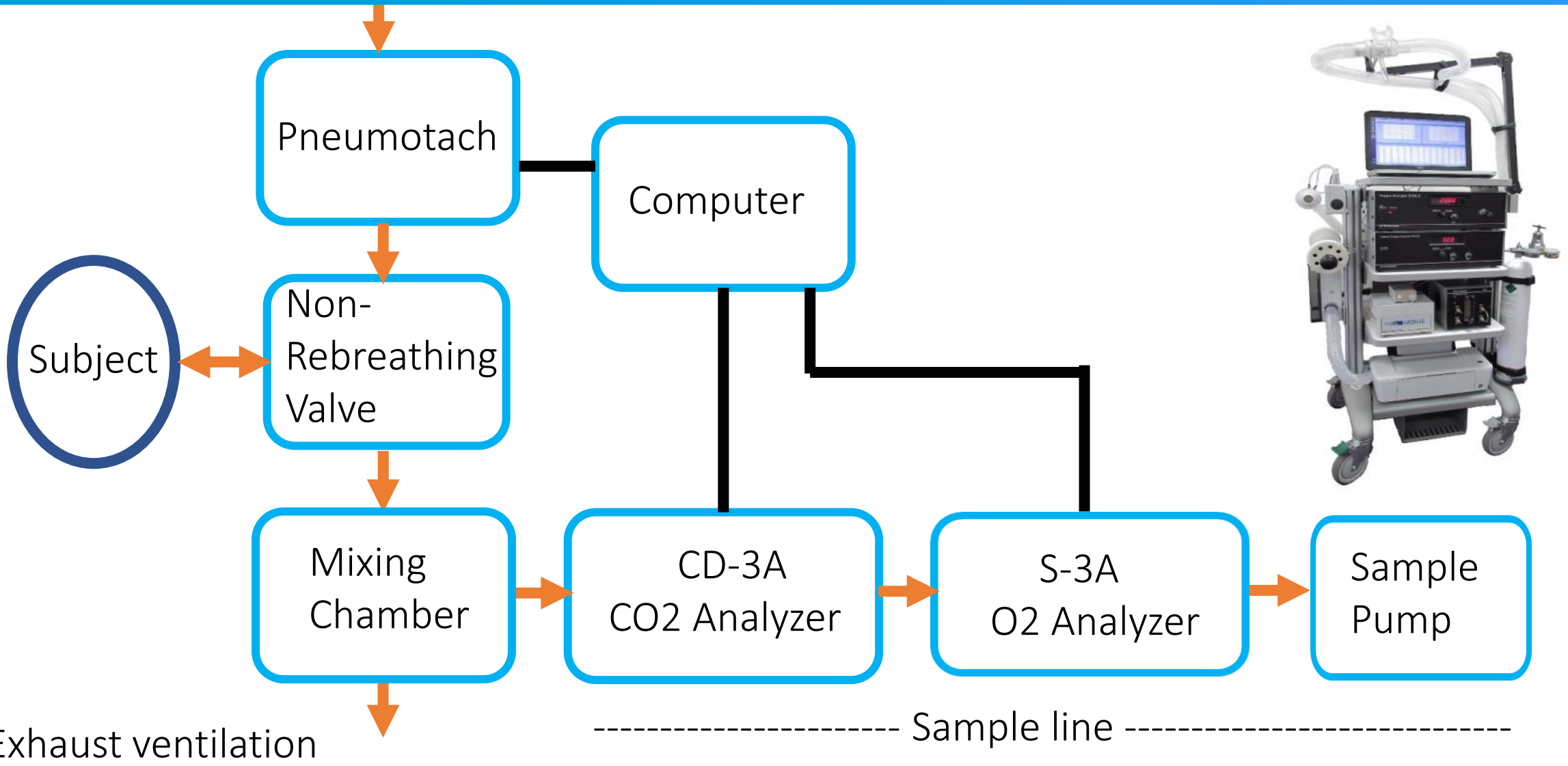
MOXUS Metabolic Cart

- Modular System
- Uses textbook equations for VO2 and VCO2

(very few modern system show algorithms)

- BxB Systems use proprietary algorithms

MOXUS Metabolic Cart



Why is the Oxygen Sensor the Most Important Factor in Metabolic Measurement?

The following table is converted from Gore et. al
(The Australian Institute of Sport)

RELATIVE ERROR	TYPICAL	ABSOLUTE ERROR	% VO_2 ERROR
+1% FeO_2	**0.5**	**0.17%**	**-6.46**
+1% Vi	2.0	1.36 L/min	+1.00
+1% Pbarr	0.05	7.6 mmHg	+1.01
+1% CO_2	1.0	0.03%	-0.23

The smallest amount of Oxygen error (0.17%) will transpose as a very large error in VO2 (6.46%)

Reference values

VO2 = 4.5495 • VI STPD =136.10 • VE STPD = 136.70 • FIO2 = 0.1751% • O2 = 0.2093% • Haldane assumptions

O2 Analyzer Accuracy

- Zirconia Oxide
- +/- 0.01% O2 Accuracy
- VO2 error contribution = 0.5%
- The lowest error, most stable system in the business.

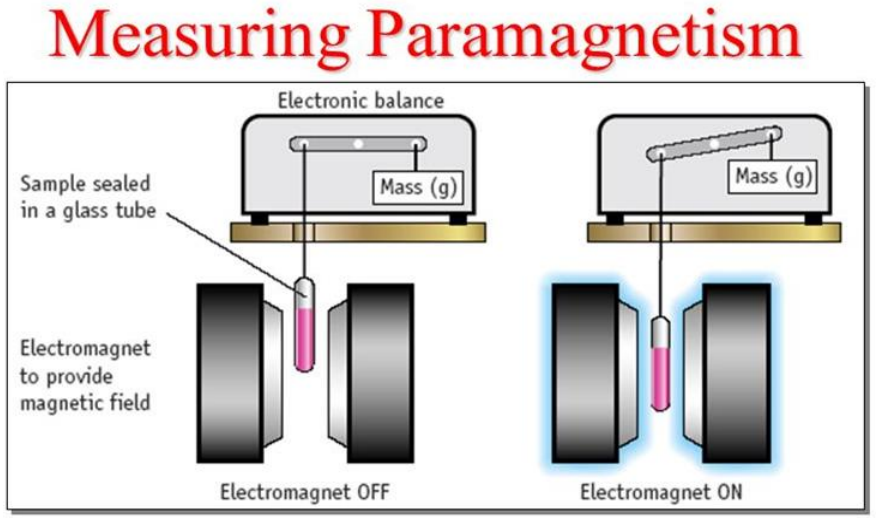
Oxygen Sensor Comparison

P1 side (cathode): O2 + 4e --> 2O2

P2 side (anode): 2O2- --> O2 + 4e

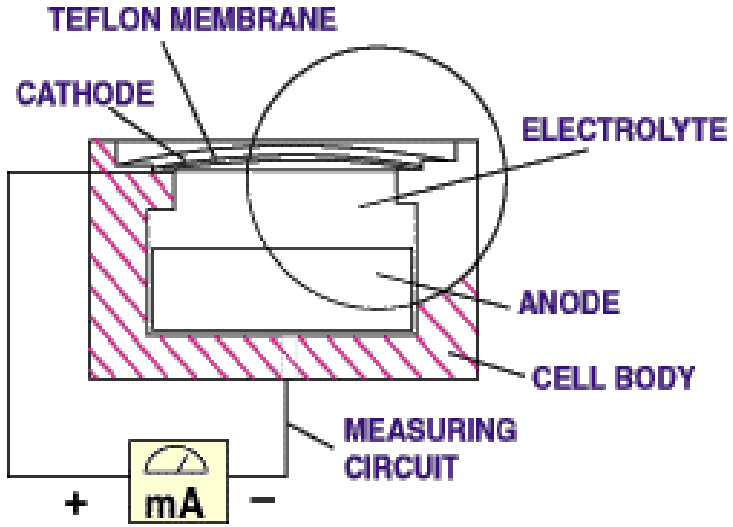
Zirconia

- Average 20 year cell life
- zirconia ceramic is a solid electrolyte
- conductive only to oxygen ions at 700+DegC.
- Most sensitive +/- 0.001% (Photosynthesis experiment)
- Most accurate +/- 0.01%
- Fastest response 0.1sec to 90%
- Low drift 0.03% in 24 hrs



Paramagnetic

- 5-10 year cell life
- Subject to N2/CO2 magnetics
- Good sensitivity +/- 0.05%
- Good accuracy +/- 0.05%
- good response: 0.1 sec to 90%
- Drift: 0.1% in 24 hrs

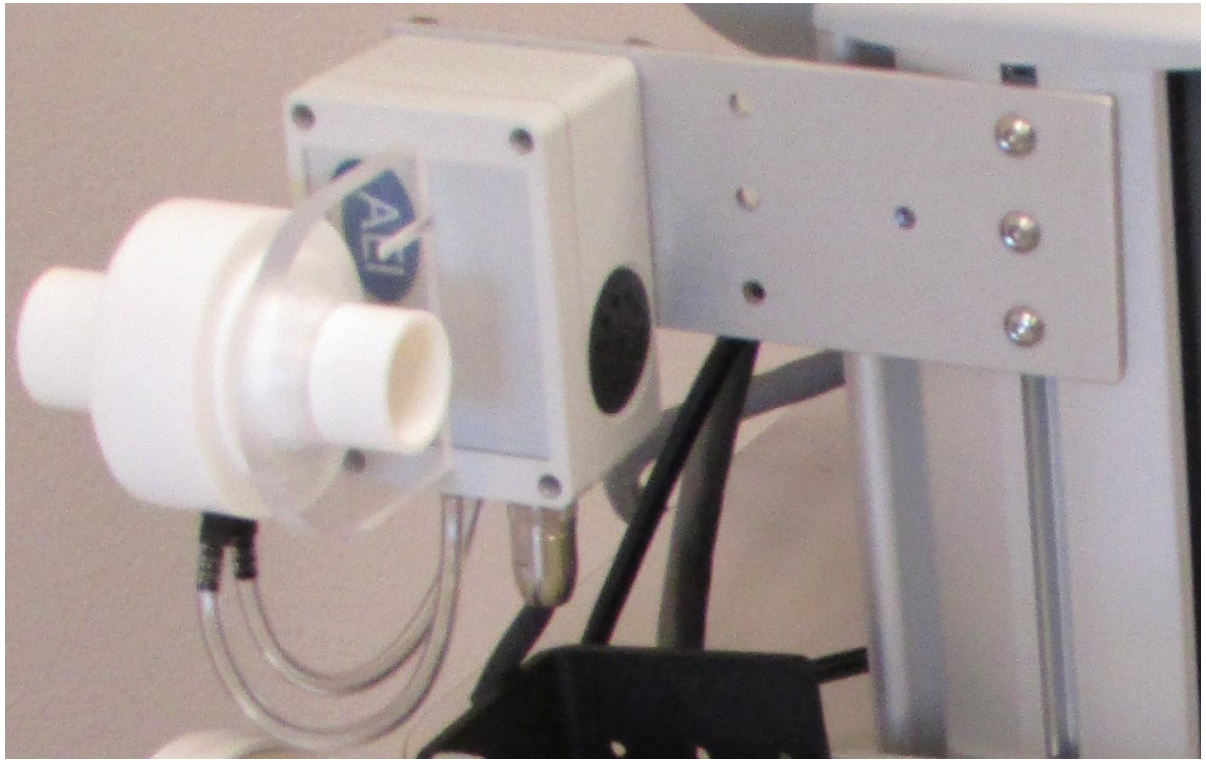


Galvanic Fuel Cell

- 12 month cell life
- Jelly electrolyte b/w anode/cathode
- O2 permeable membrane
- Good sensitivity +/- 0.04%
- Good accuracy +/- 0.04%
- Good response: 0.1 sec
- High drift

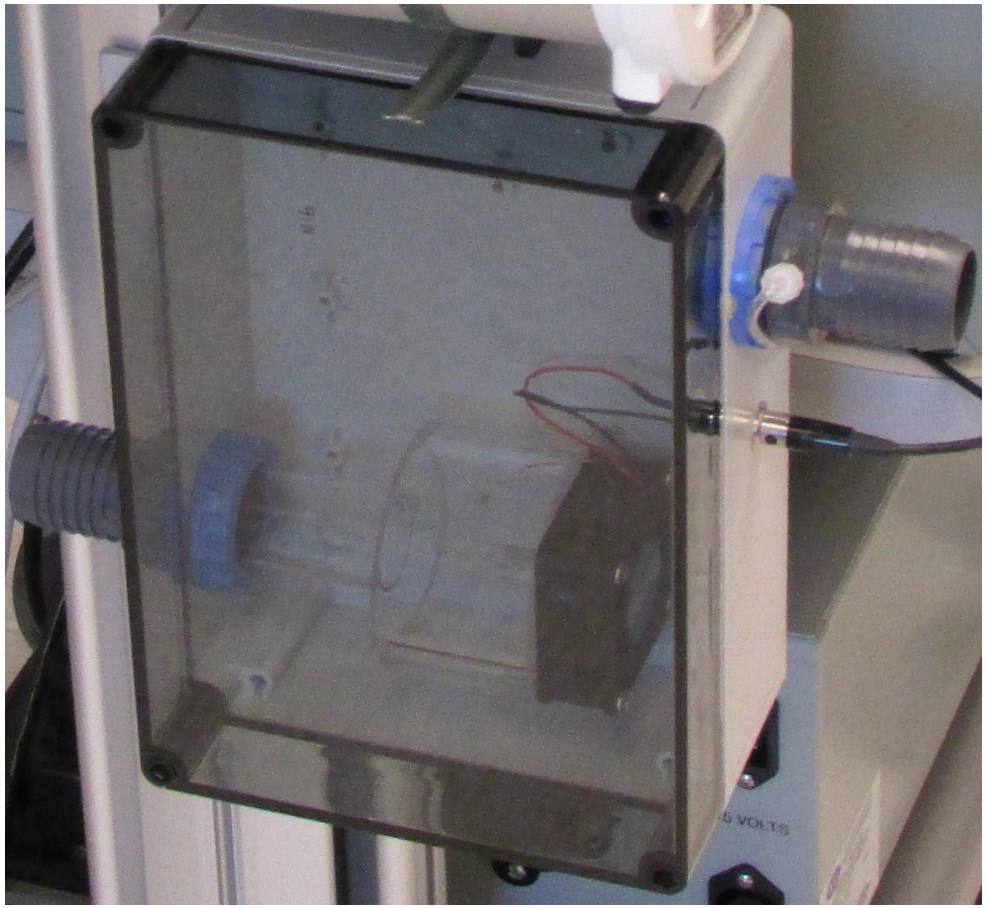
Flow Accuracy

- Flow linearization table created from data certified at a national testing laboratory.
- <1% error - The best in the business.
- VO2 error contribution = 0.7%



Mixing Chamber Advantages

- Every breath recorded
- O2 & CO2 synchronized to each breath
- Very consistent between breaths
- VO2 & VCO2 - simple formulas
- Data validated
  - Douglas Bags & Simulators
- Unique active chamber
  - Improves mixing & response time



Cal Gas Accuracy

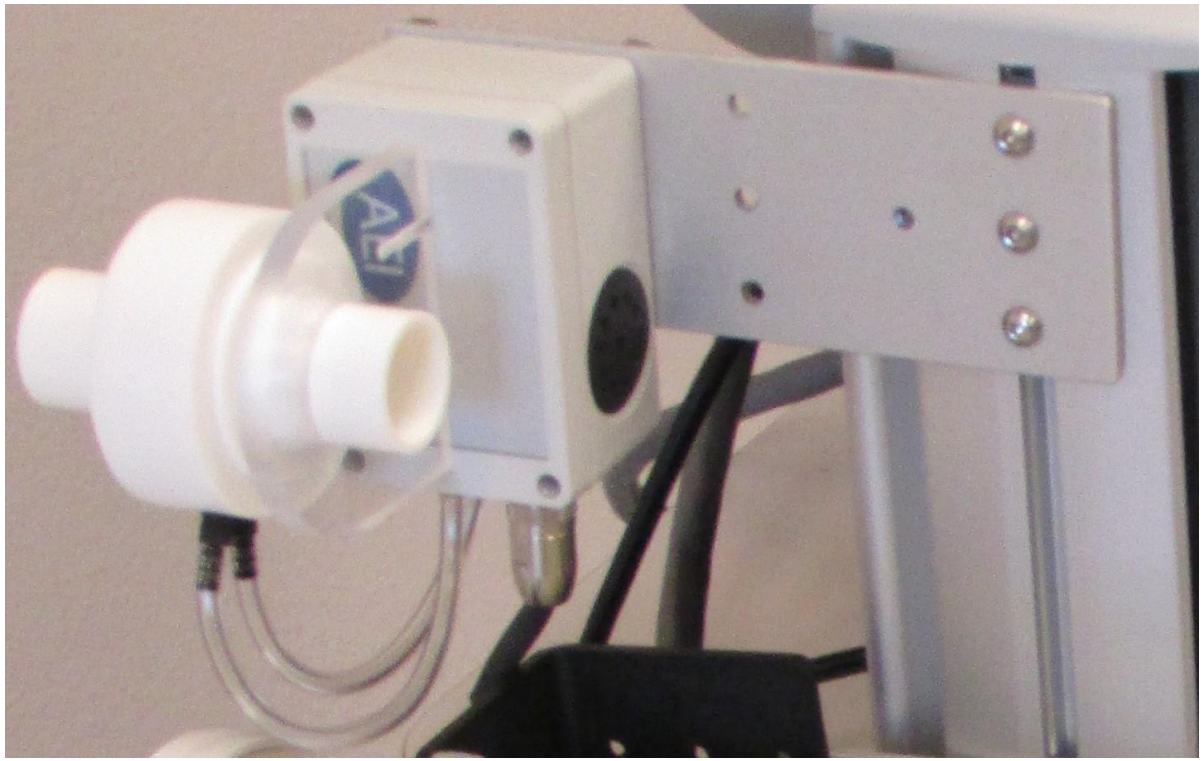
- Primary Laboratory Standard gases, certified gravimetrically
- Accuracy = +/- 0.02% absolute
- This means a VO2 error of 0.7%

CO2 Analyzer Accuracy

- +/- 0.02% CO2 Accuracy
- 25 msec Response Time vs 100 msec or more
- Uses internal Reference Cell and Chopper Motor

Temp/RH/Press Accuracy and Data Collection

- Ambient Temperature, Relative Humidity, and Pressure provide BTPS/STPD corrections for each breath.
- Accuracy for these measurements is typically: Temperature +/- 0.5 deg. C; Pressure +/- 1 mmHg; Humidity +/- 1% rh



Ability to Ignore Aberrant Breaths

- Allows the user to disable (or re-enable) individual breaths that, due to aberrations such as sighs, swallowing, coughing, talking or tubing artifacts, might skew the true average.
  - Not possible with Douglas Bags
  - Difficult with BxB Systems
- Allows elimination of selected data rows that are printed on the report. This function is most useful to eliminate the warm up and cool down periods of a test thereby reporting only on the exercise protocol of the test.

Projected VO2 Error for Various Metabolic Systems

(Based on manufacturer specifications – absolute values)

MANUFACTURER & MODEL	O_2 SENSOR TYPE	O_2 CELL LIFESPAN	O_2 ACCURACY % ABSOLUTE	CO_2 ACCURACY % ABSOLUTE	VENTILATION ACCURACY % ABSOLUTE	VO_2 ERROR
AEI Tech.	**Zirconia**	**20-30 years**	**0.01**	**0.02**	**1**	**1.16**
Other 1	Galvanic fuel cell	12-18 months	0.04	0.04	2	2.96
Other 2	Paramagnetic	5-10 years	0.1	0.02	2	5.73
Other 3	Paramagnetic	5-10 years	0.1	0.1	2	5.85
Other 4	Galvanic fuel cell	12-18 months	0.1	0.1	3	6.25

Note that our systems provide the highest accuracy for both Oxygen and Ventilation on the market, giving rise to much superior metabolic accuracy.

Summary

- We covered the typical measurements and factors in determining VO2
- A Metabolic Cart is a very complex instrument with many sources of error and many potential sources of error.
- We provided some examples and ideas to minimize errors.
- There is no universally accepted standard for validation of Metabolic Carts. Validating the Metabolic Cart data is difficult and expensive.
- The MOXUS Metabolic Cart provides an exceptional value in high accuracy VO2 and VCO2 measurements.

References

- Physiological Tests for Elite Athletes, Second Edition, Australian Institute of Sport, Chapter 7.
- Principles of Exercise Testing and Interpretation, Fourth Edition, Wasserman et.al.
- Design Control Guidance for Medical Manufactures, US Food and Drug Administration.
- American Thoracic Society & American College of Chest Physicians Joint Statement on Cardiopulmonary Exercise Testing, 2003.
- MOXUS Instruction Manual, AEI Technologies.

Q&A Session:

Please submit questions for our presenters through the Questions Window. While all questions cannot be answered during our live session, all will be reviewed and answers provided following our event.

Phil Loeb
President
AEI Technologies

Danny Rutar
Managing Director
Redback Biotek

AEI TECHNOLOGIES
Metabolic Measurement Systems

Tweet #LifeScienceWebinar #ISCxSableSys

insidescientific