Helium Sensitivity of JLab Oxygen Monitors

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Outline

- JLab Spill Tests
- Investigation
- Theory
- Modifications
- Future Plans

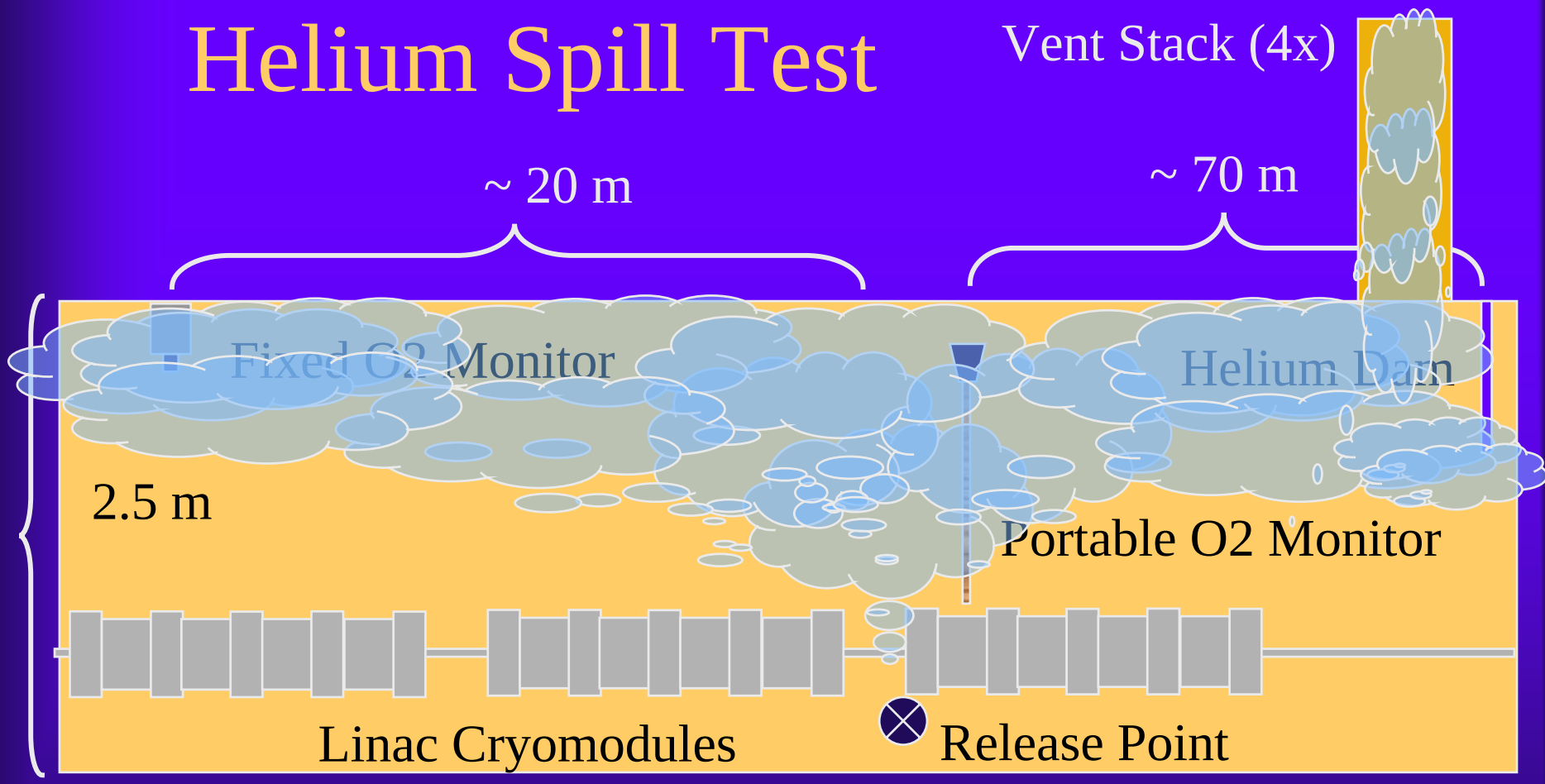
The Problem

- JLab maintains a helium inventory of > 150,000 liquid liters (*ll*)of helium.
- Worst case spill could release as much as 3200 *ll* which expands to 2.5 million gaseous liters, enough to make the tunnel air oxygen deficient.
- The Lab conducts spill tests on new tunnel configurations to verify mitigation measures.
- Last test uncovered a nonlinearity in the oxygen monitoring systems that could lead to monitors not alarming when they should.

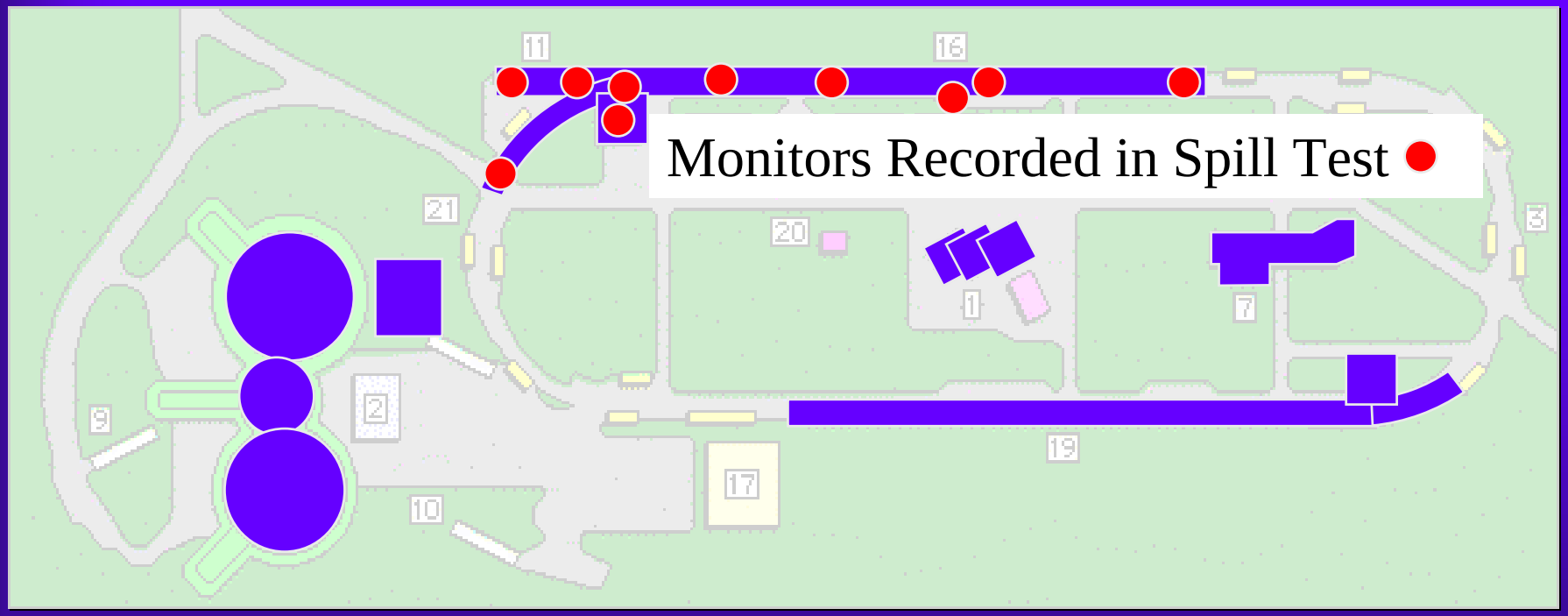
Oxygen Monitoring Systems

- Detect Oxygen levels in cryogenic areas
- 80 sensors spread around facility
- Set to alarm at ≤ 18% oxygen
- Alarms include evacuation lights and horns

Helium Spill Test

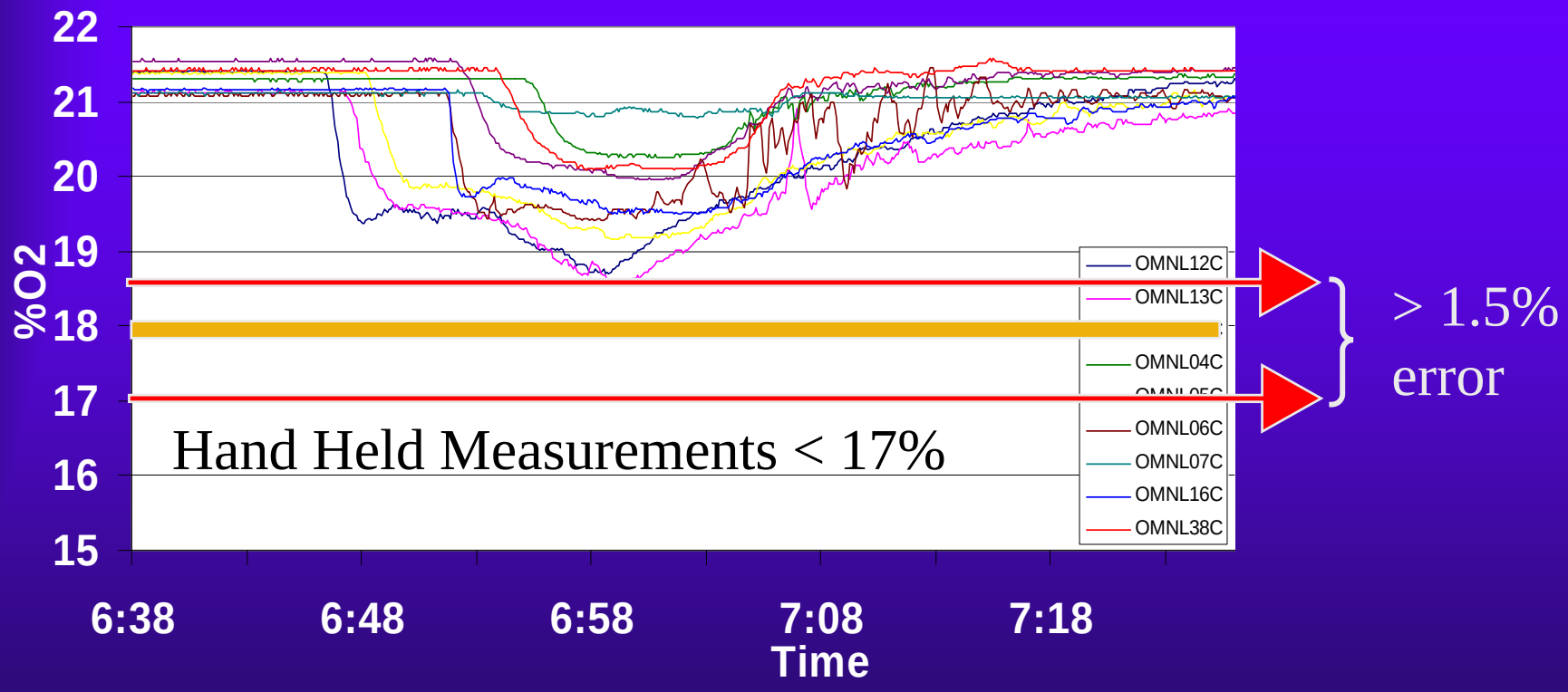


JLab Helium Use/ODH Areas



He Spill Test Data

Data for 9 monitors located in linac tunnel



Recording Personal Monitor

Helium Spill

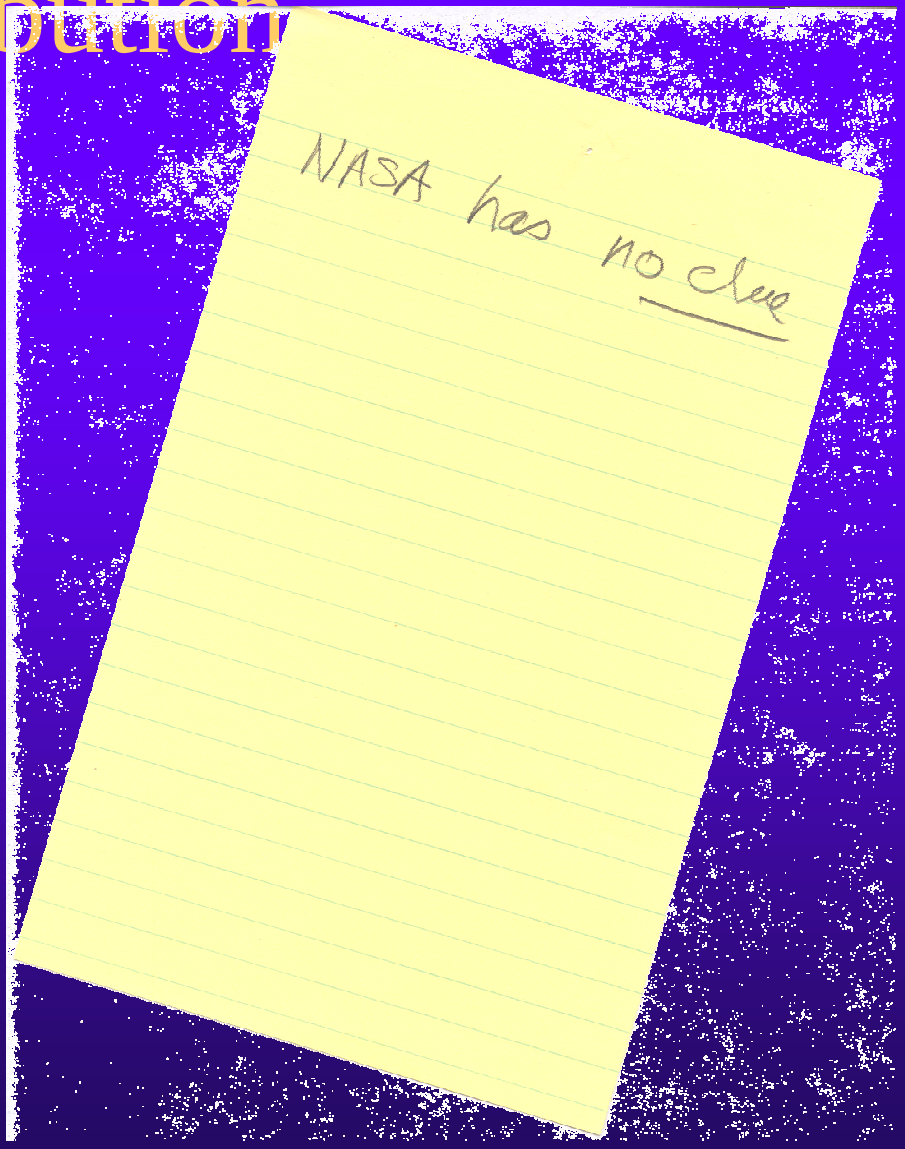
Aftermath

- Measurements/models made to isolate the source of the problem.
- Found that the electrochemical oxygen monitor had a non-linear response when air is mixed with helium.
- Suspended all access to tunnel areas until a safe means could be found, e.g. SCBA
- Posted notice and request for information to safety and sensor related mail groups.

Response

- Labs that have responded have the same problem in one or more types of sensors.
- All major manufacturers of oxygen cells have made measurements to qualify their products.
- Some manufacturers have uncovered problems in other types of oxygen measurement equipment
  - Laser based sensors < 5% O2
  - Zirconium based cells (thermal based measurement)
- Went to local NASA lab to see if they could help…

Nasa's Contribution



EC Cell Chemistry

Alkaline Electrolyte

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

OR

$$O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$$

Acid Electrolyte

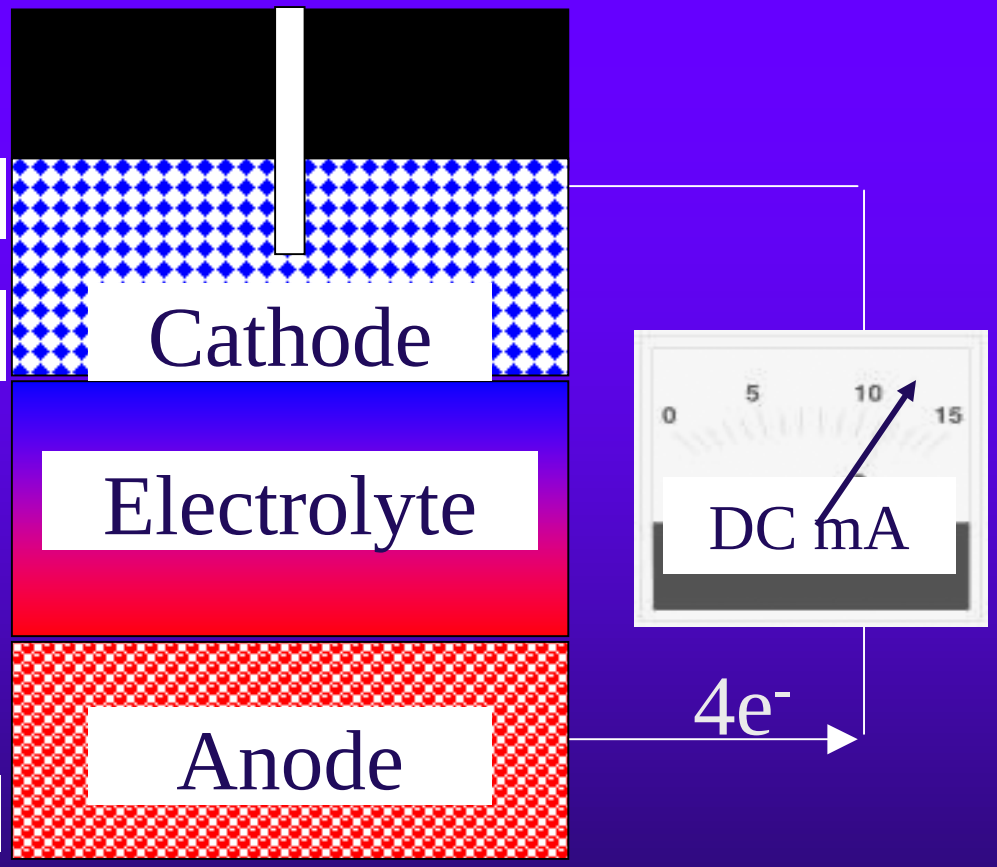
Alkaline Electrolyte

$$2Pb + 4OH^- \longrightarrow 2PbO + 2H_2O + 4e^-$$

OR

$$2Pb + 2H_2O \longrightarrow 2PbO + 4H^+ + 4e^-$$

Acid Electrolyte

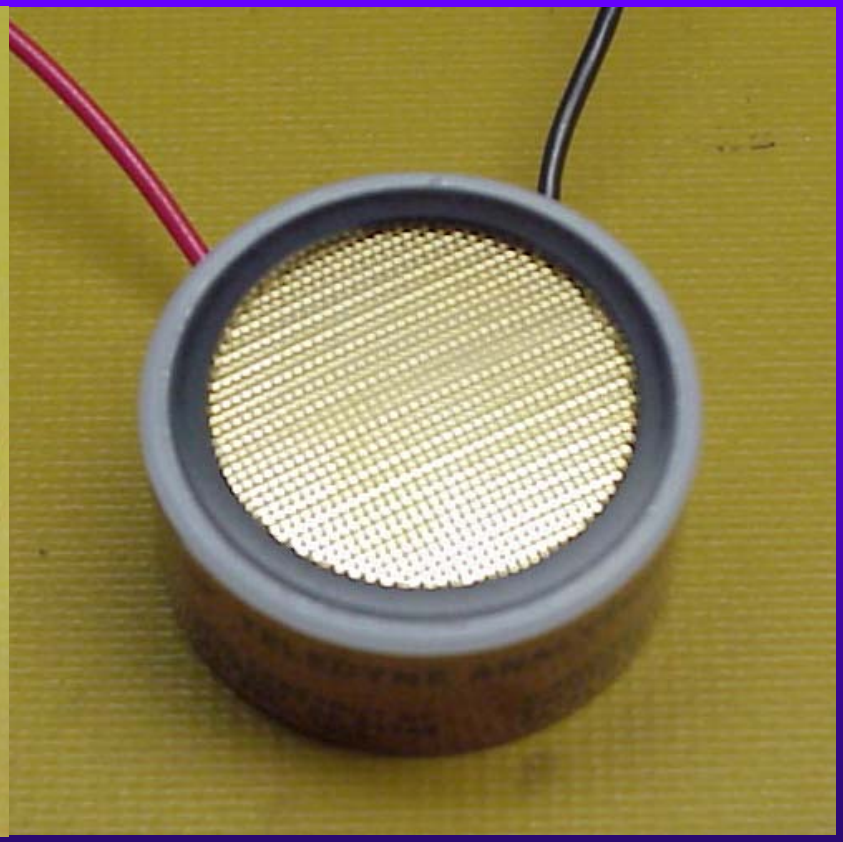


$$O_2 + 2Pb \longrightarrow 2PbO$$

Example Cells

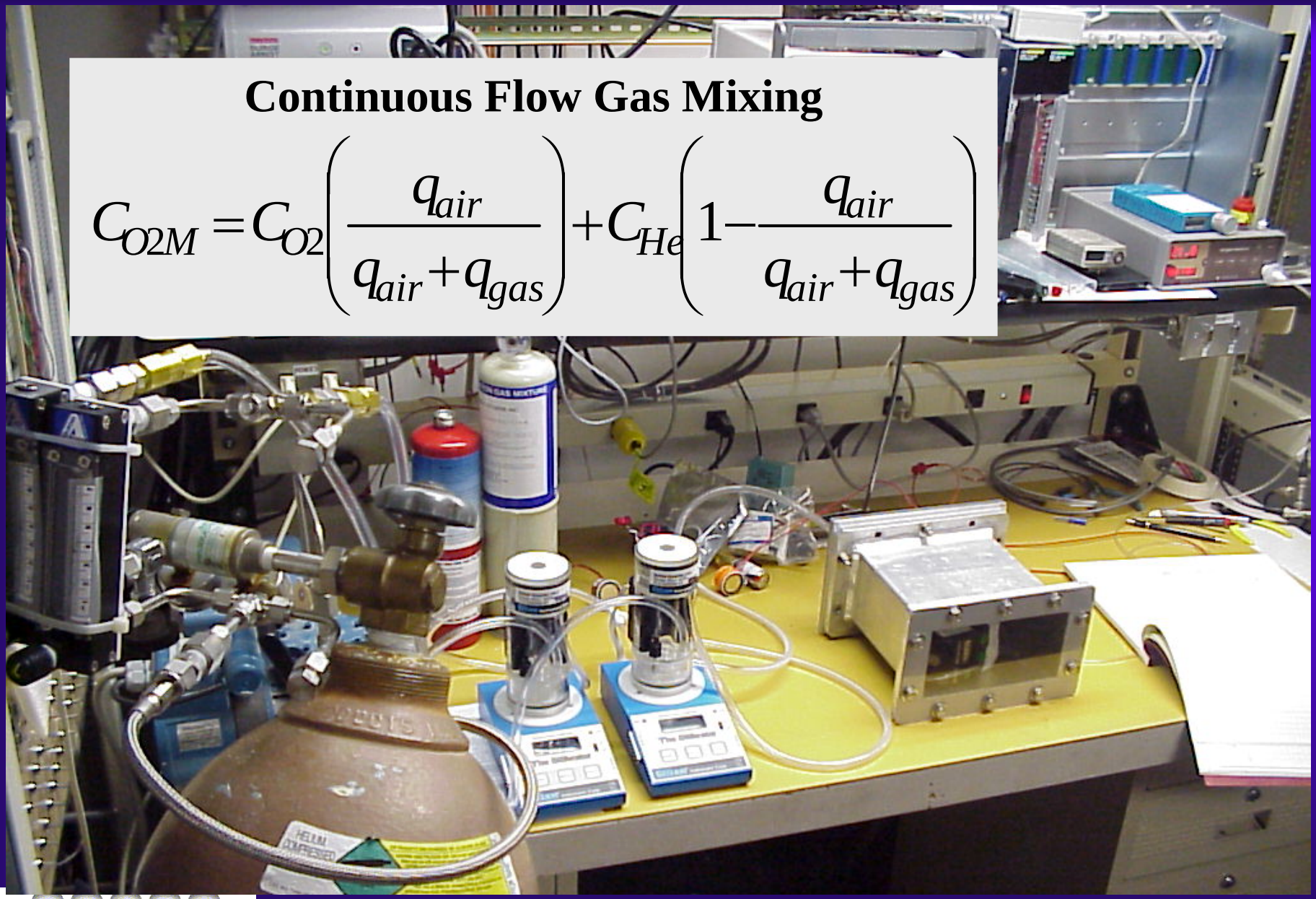
Capillary Diffusion

Membrane Diffusion

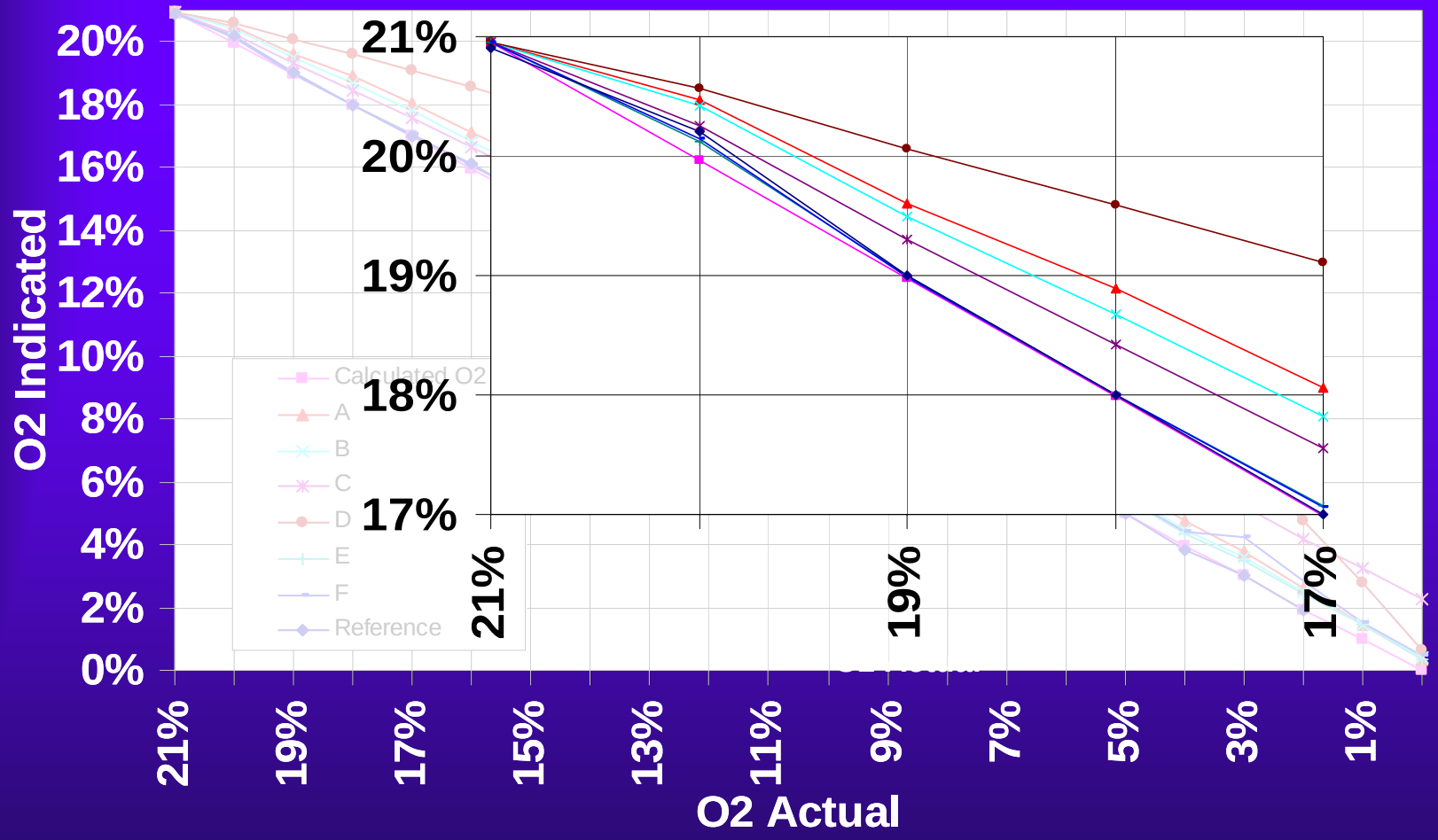


Continuous Flow Gas Mixing

$$C_{O2M} = C_{O2}\left(\frac{q_{air}}{q_{air}+q_{gas}}\right) + C_{He}\left(1-\frac{q_{air}}{q_{air}+q_{gas}}\right)$$



EC Cell Measurements



Effusion/Diffusion

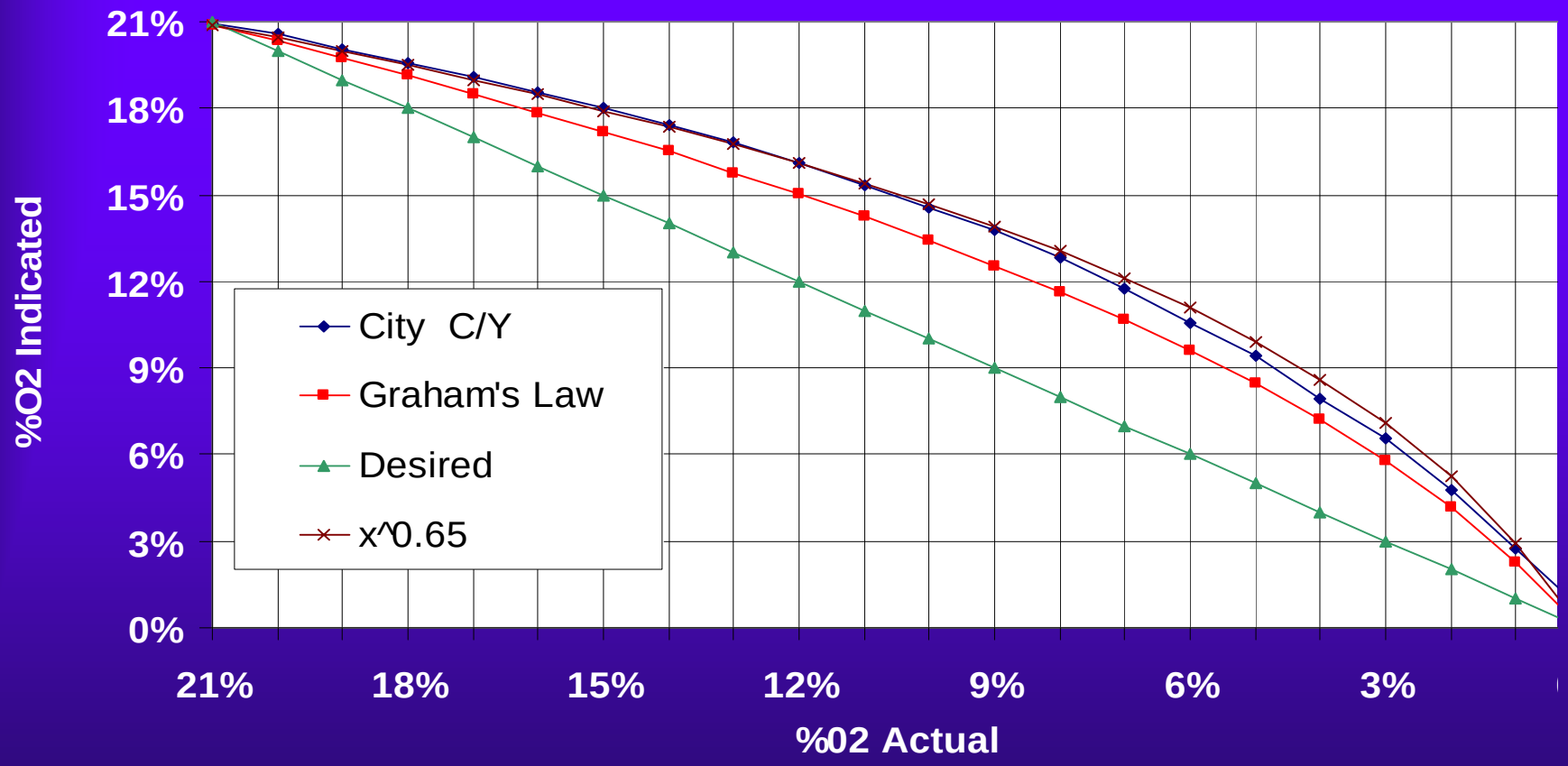
- "Ideal" nonlinearity described by Graham's Law of Effusion

$$\frac{dE_1}{dE_2} = \sqrt{\frac{M_{g2}}{M_{g1}}}$$

- Can be used to model cell behavior in a variety of gases
- Measurements show an exaggerated curve with the exponent (n) ~ 0.65

$$M = \left(\frac{M_{air}}{M_{(air+He)}} \right)^n$$

Model of Cell Behavior



EC Cell Response

- Ideal Cell Response

$$S = K \ln \frac{1}{1-C}$$

- Correction for diffusion

$$M = \left(\frac{M_{air}}{M_{(air+He)}} \right)^n$$

- Corrected (1) for recalibration at 18% O2 and diffusion

$$S = 0.851 M \ln \left(\frac{1}{1-C} \right)$$

Recalibration

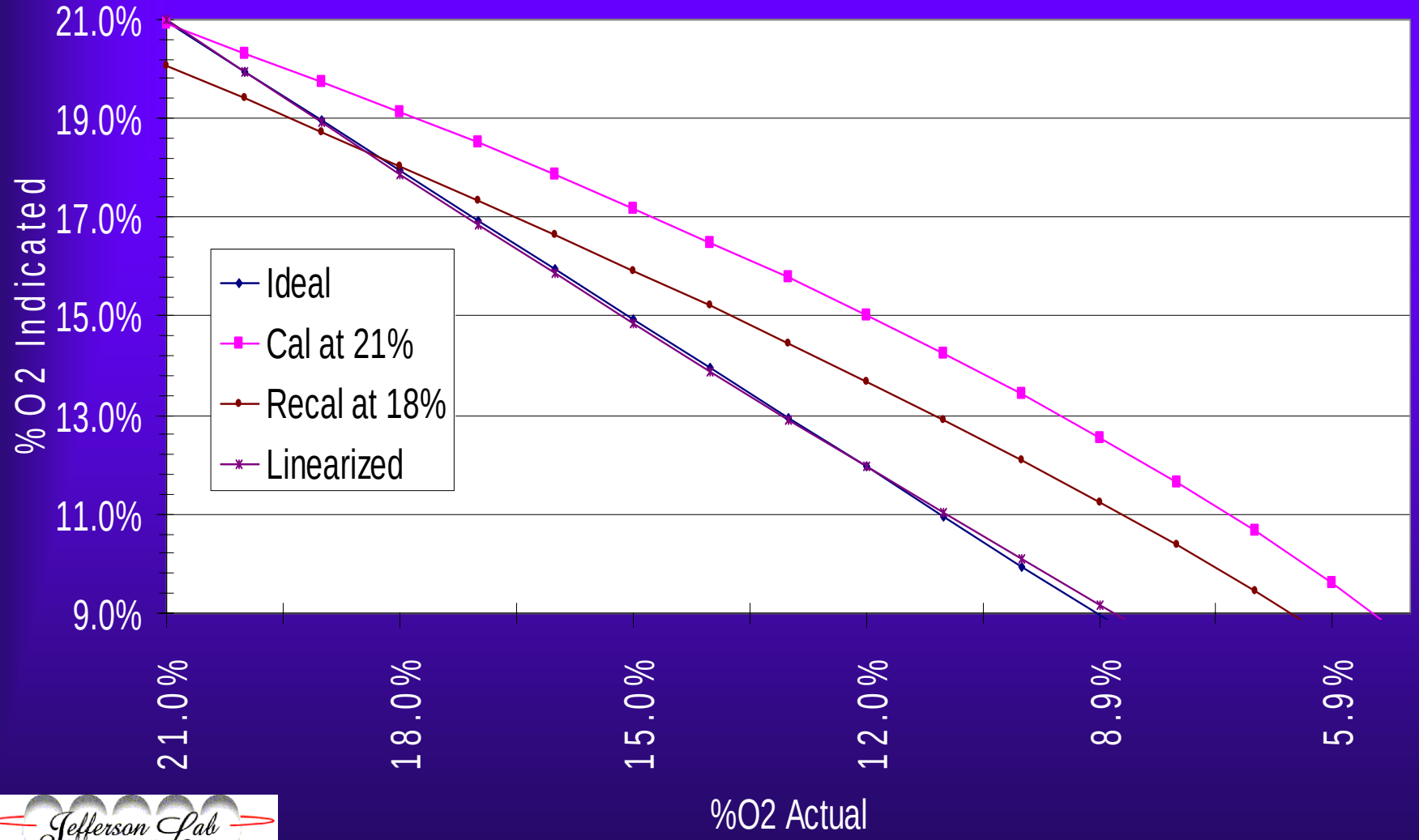
- Can use model to find best set point that will give maximum range and still alarm at 18% O2.
- Decided on procedure to calibrate at 18% and alarm at 18.5%.
- All JLab heads now recalibrated.

Final Calibration

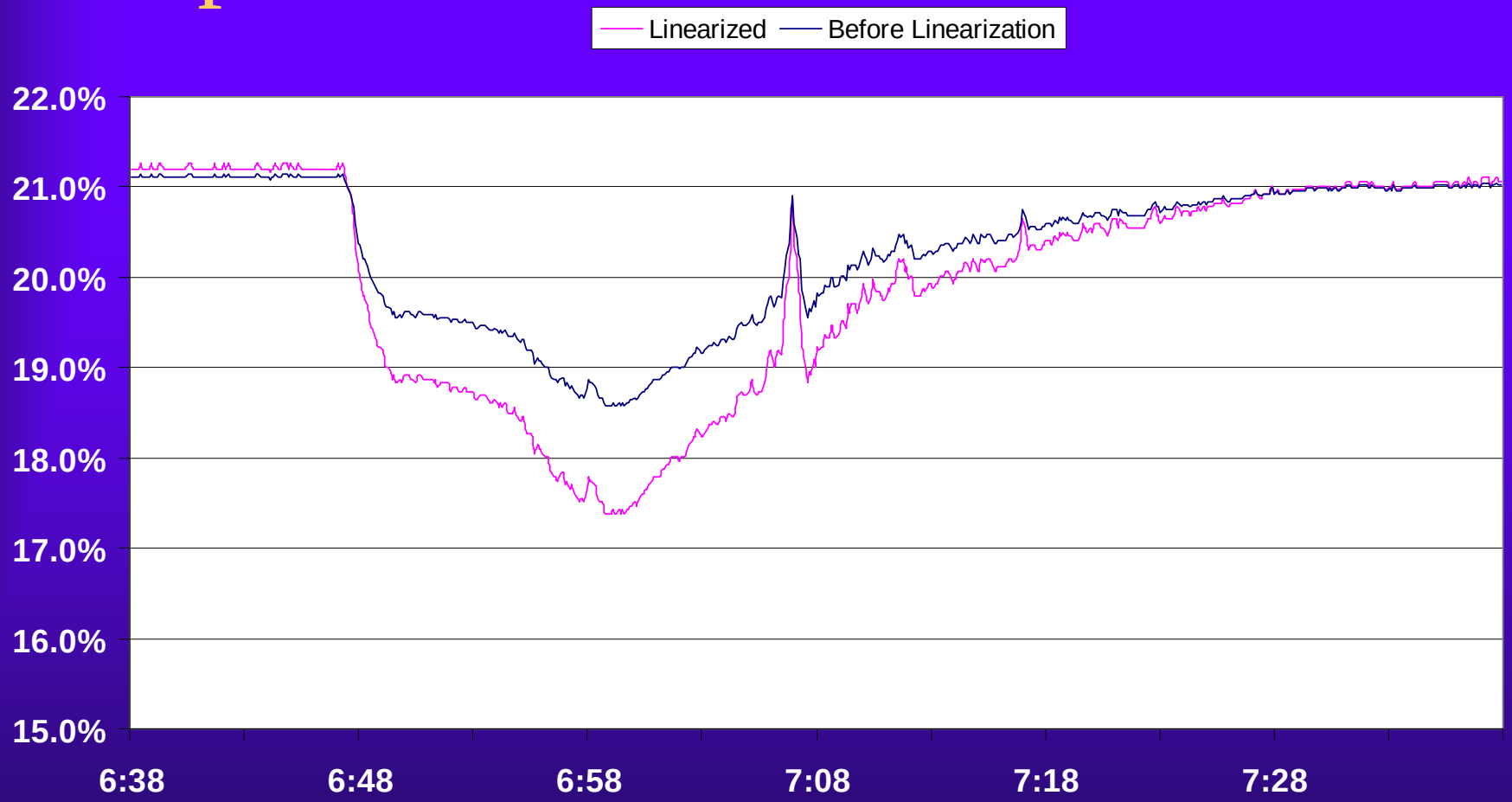
Response equation can be solved to give calibration factors for relinearizing sensors that have been recalibrated at 18 % O_2.

$$S = 1.074Ci * \left(\frac{28.90574}{(118.853Ci + 4.0076} \right)^{-0.65}$$

Relinearization



Spill Data Revisited



Future

- Find a replacement sensor that is truly linear
- Integrate the new sensor into the existing ODH alarm system
- Modify tunnel helium containment/evacuation system
- Redo spill tests

Conclusions

- Properties of the diluting gas can have a significant impact on the ability to measure oxygen.
- Electrochemical cells with a capillary type diffusion barrier have a highly nonlinear response in the presence of helium.
- JLab has developed a model of the cell behavior that can be used to recalibrate existing systems.