Development of a Cryogenic Air Supply Evaluation Laboratory and a Human Breathing Simulator

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RA Partnership

November 17-18, 2021

The purpose of an RA is to provide a survivable environment for miners in case of an inescapable mine accident.

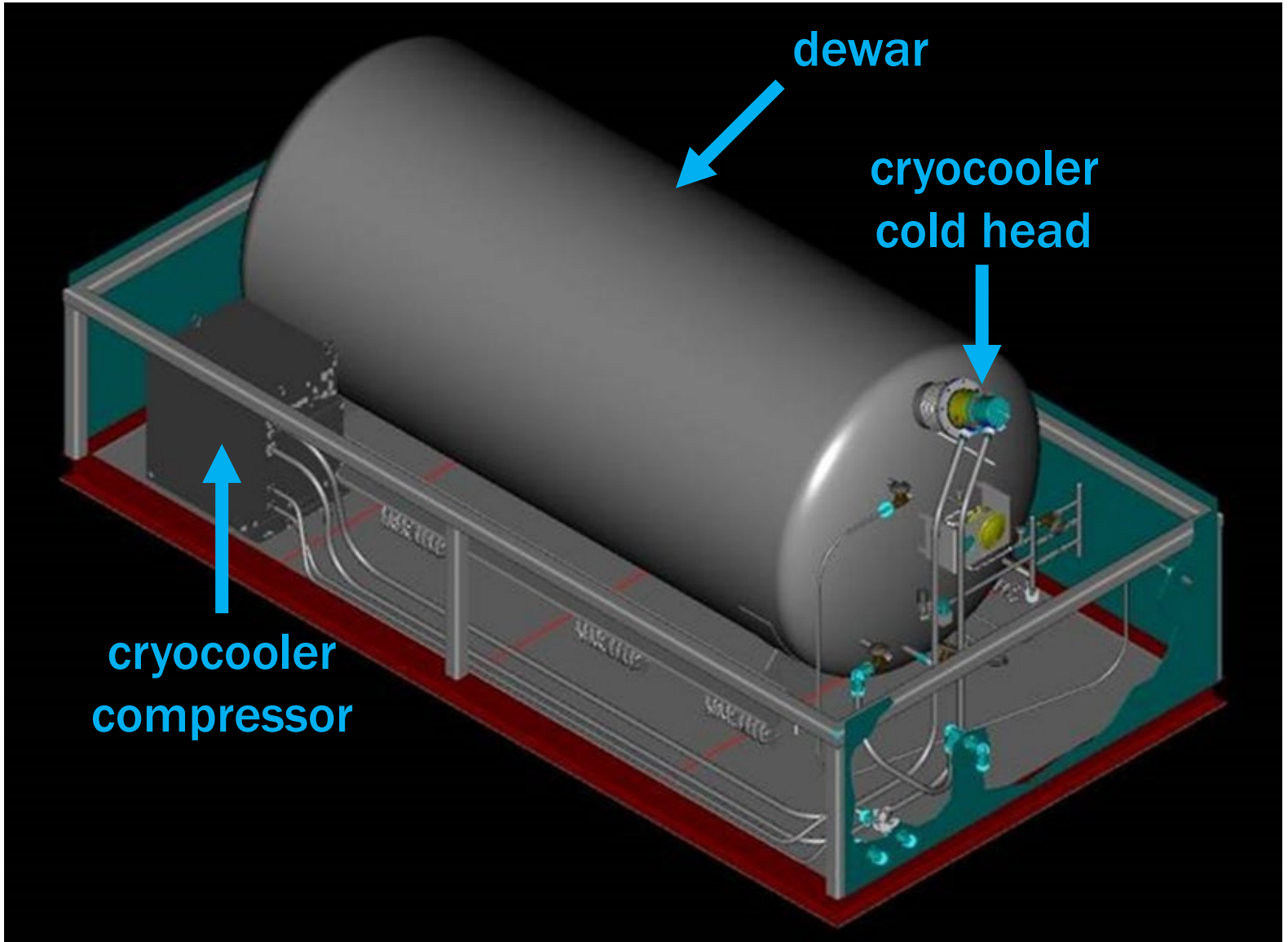
- RAs must provide food & water, shelter, supplies, and a breathable air environment for at least 96 hours
- Oxygen levels in an occupied RA must be 18.5%–23%
- Carbon dioxide levels in an occupied RA must be <1% with excursions to <2.5%

RAs can provide a breathable air environment using either compressed oxygen cylinders or a fresh air source from the surface.

- For RAs that use compressed oxygen cylinders
  - Oxygen must be supplied at 1.32 ft^3/hr per person
  - Carbon dioxide generated by miners must be removed at 1.08 ft^3/hr per person
  - Either soda lime or lithium hydroxide carbon dioxide scrubbers are used

- For RAs that use a fresh air source from the surface
  - Clean air must be provided at 12.5 ft^3/min per person
  - Carbon dioxide scrubbers are not required due to the high volume of fresh air

A cryogenic air supply is a device that maintains air as a liquid until breathable air is needed. *Cryogenic air supplies do not fit into the two categories of systems used to create a breathable air environment in an RA.*



Cryogenic air supplies have several *advantages* that make them well-suited to be used as a refuge chamber breathable air source.

- Supply air instead of oxygen
- Operate at lower pressure (<75 psi) than oxygen cylinders (>4,500 psi)
- Require no power to supply air
- Do not require a borehole or compressed air lines to the surface
- Cool and dehumidify the space supplied with air
- Provide a potential source of drinking water via melting of ice buildup

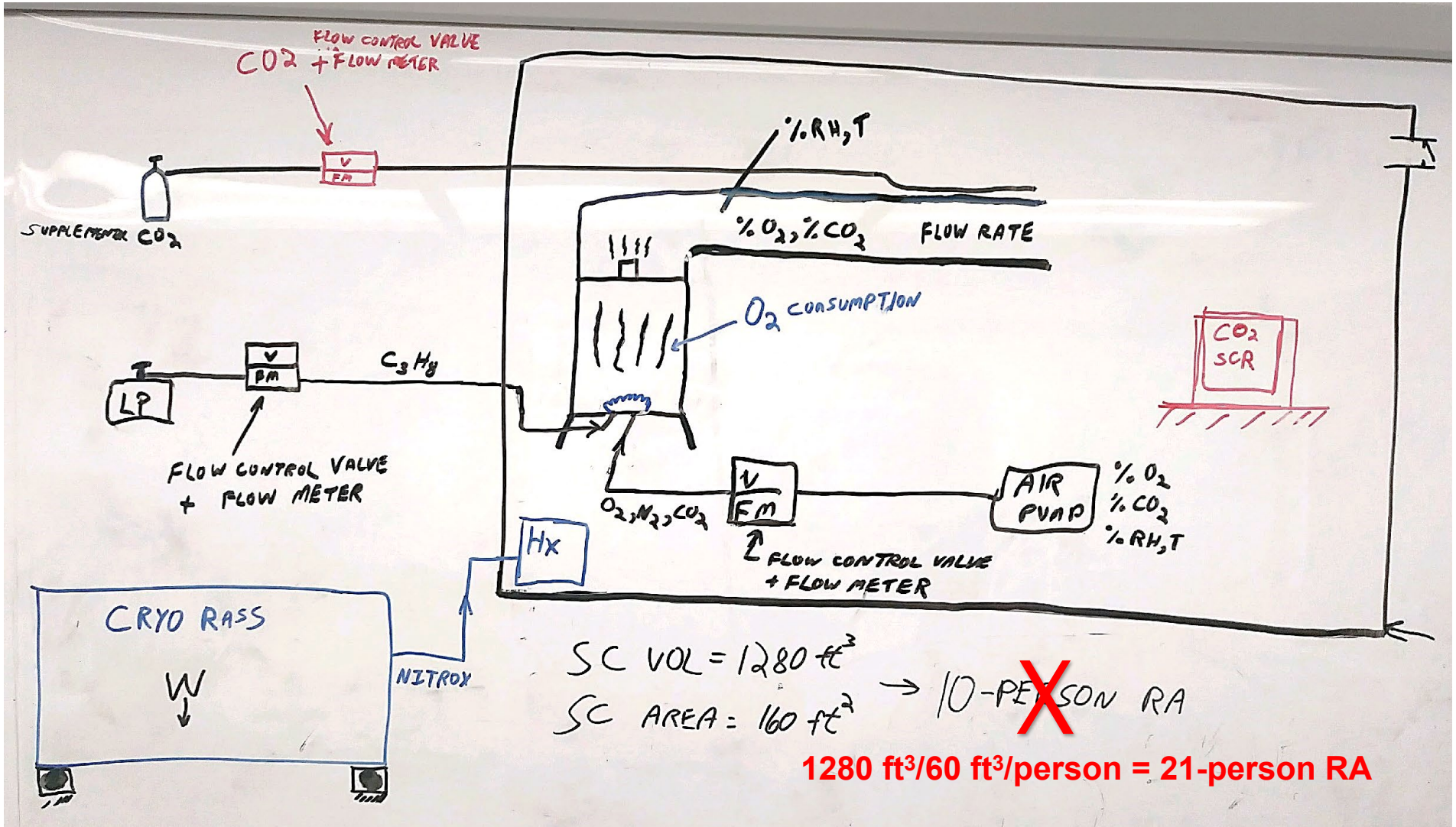
Cryogenic air supplies also have several *challenges* to overcome prior to being ready to use with refuge chambers.

- New technology with respect to mining
- Need to find a source of, or mix your own, liquid air
- Must be designed to protect against rough handling during transport
- Must be designed to withstand a survivable explosion, or be protected by a structure
- Potential risk of exposure to cryogenic liquid during handling

A prototype cryogenic air supply for refuge chambers was developed for NIOSH under a Broad Agency Announcement (BAA) Contract.

NIOSH needed to develop a test method that would allow us to examine the ability of the cryogenic air supply prototype to maintain oxygen levels in an RA-like environment in the range of 18.5% to 23%.

Propane-based "Human Breathing Simulator"



1280 ft³/60 ft³/person = 21-person RA

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Modified Shipping Container

"Cryogenic Air Supply Evaluation (CASE) Laboratory"

Human Breathing Simulator (HBS)

Carbon Dioxide Scrubber Curtains

NIOSH modified an off-the-shelf propane smoker to create a “human breathing simulator” to consume oxygen at the rate of 1.32 ft^3/hr/person as specified in RA regulations.

The human breathing simulator concept is based on burning propane to consume oxygen via delivering air to a sealed combustion chamber.

$$C_3H_8 + 5O_2 \Rightarrow 3CO_2 + 4H_2O$$

Gas	Weight, grams	Normalized
C_3H_8	44.1	1
O_2	160	3.63
Air	686.69	15.57
CO_2	132.1	2.99
H_2O	72.1	1.63

A mass flow controller was used to deliver propane at the rate needed to consume the oxygen of 21 people*.

*Based on the shipping container volume and the RA requirement of 60 ft^3/person

Propane Delivery Lines

Propane Mass Flow Controller

A second mass flow controller was used to deliver excess combustion air (greater than stoichiometric air) to ensure complete propane combustion.

Combustion Air Pump

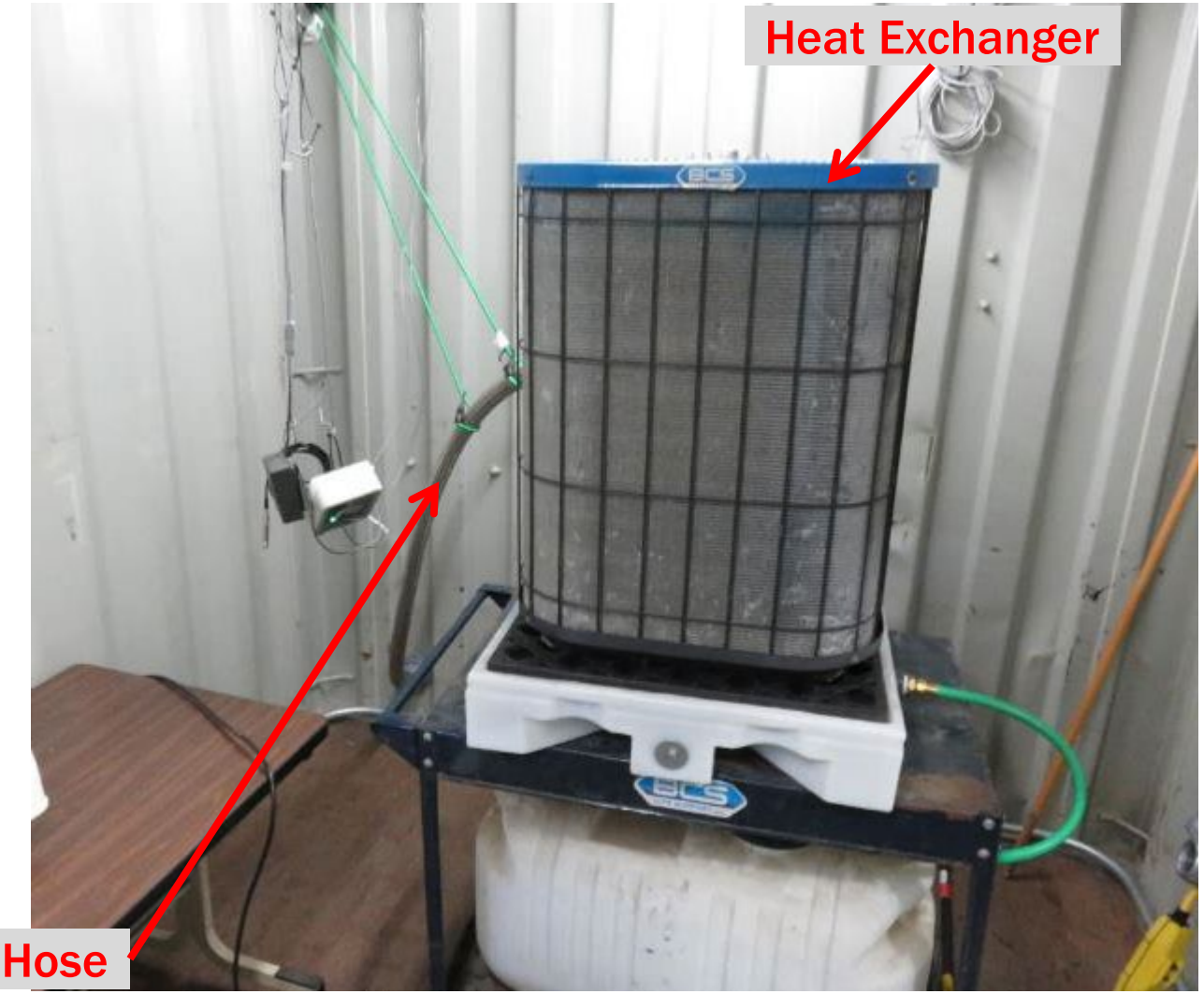
Air Mass Flow Controller

Air Line Bulkhead Fittings

Combustion Air Inlet

We used soda lime scrubber curtains to prevent carbon dioxide buildup inside the shipping container.

After igniting the flame, liquid air was delivered from the cryogenic air supply to a heat exchanger in the shipping container via a vacuum-jacketed hose.



Multiple oxygen sensors and carbon dioxide sensors were used during testing.

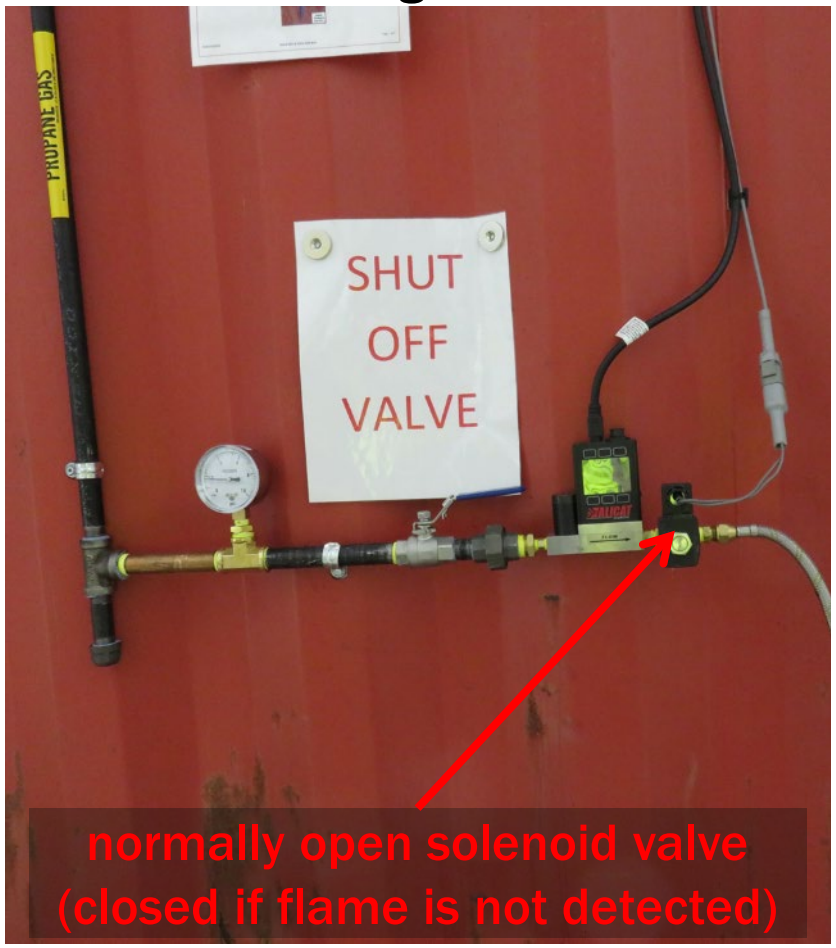
We added several systems to ensure we could perform this research safely.

oxygen, carbon monoxide, carbon dioxide, & %LEL sensors

flame sensor

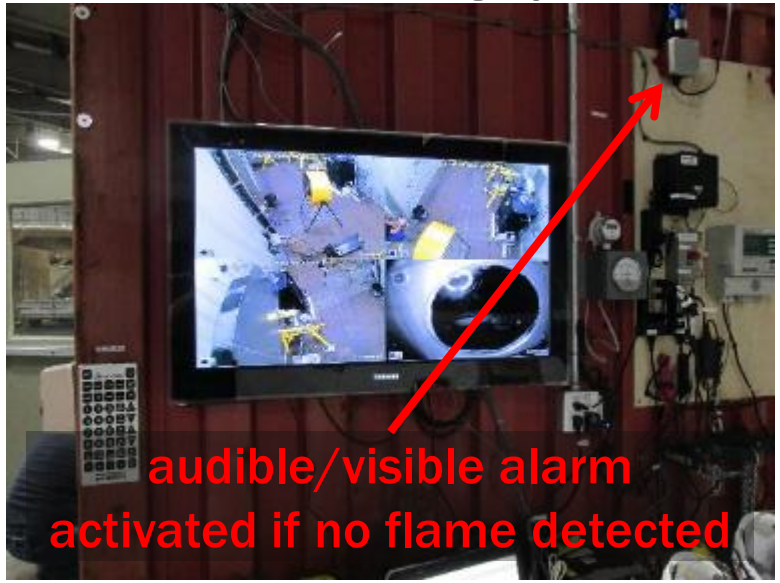
video camera

automatic gas shutoff



gas monitor w/ audible alarm

video monitoring system



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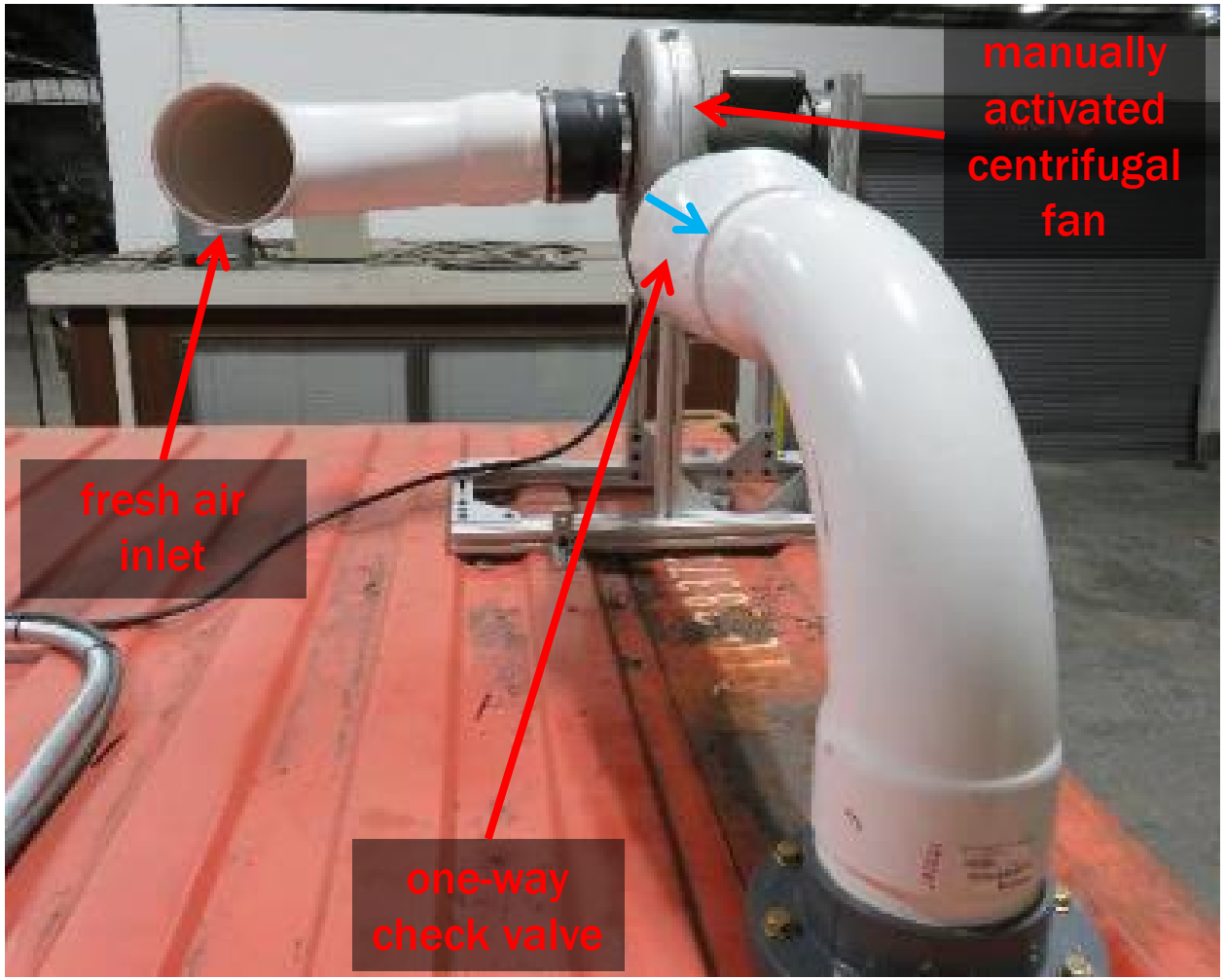
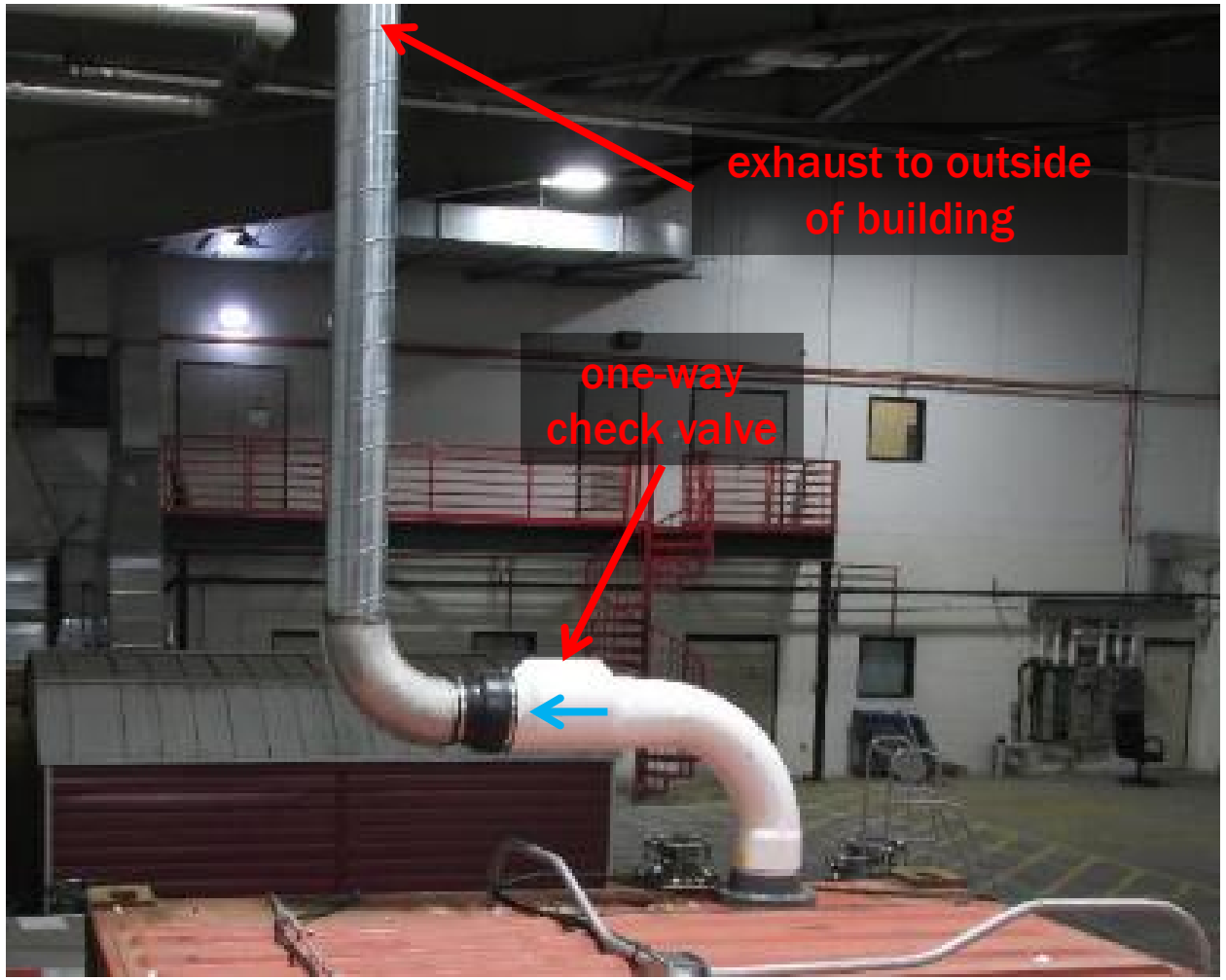
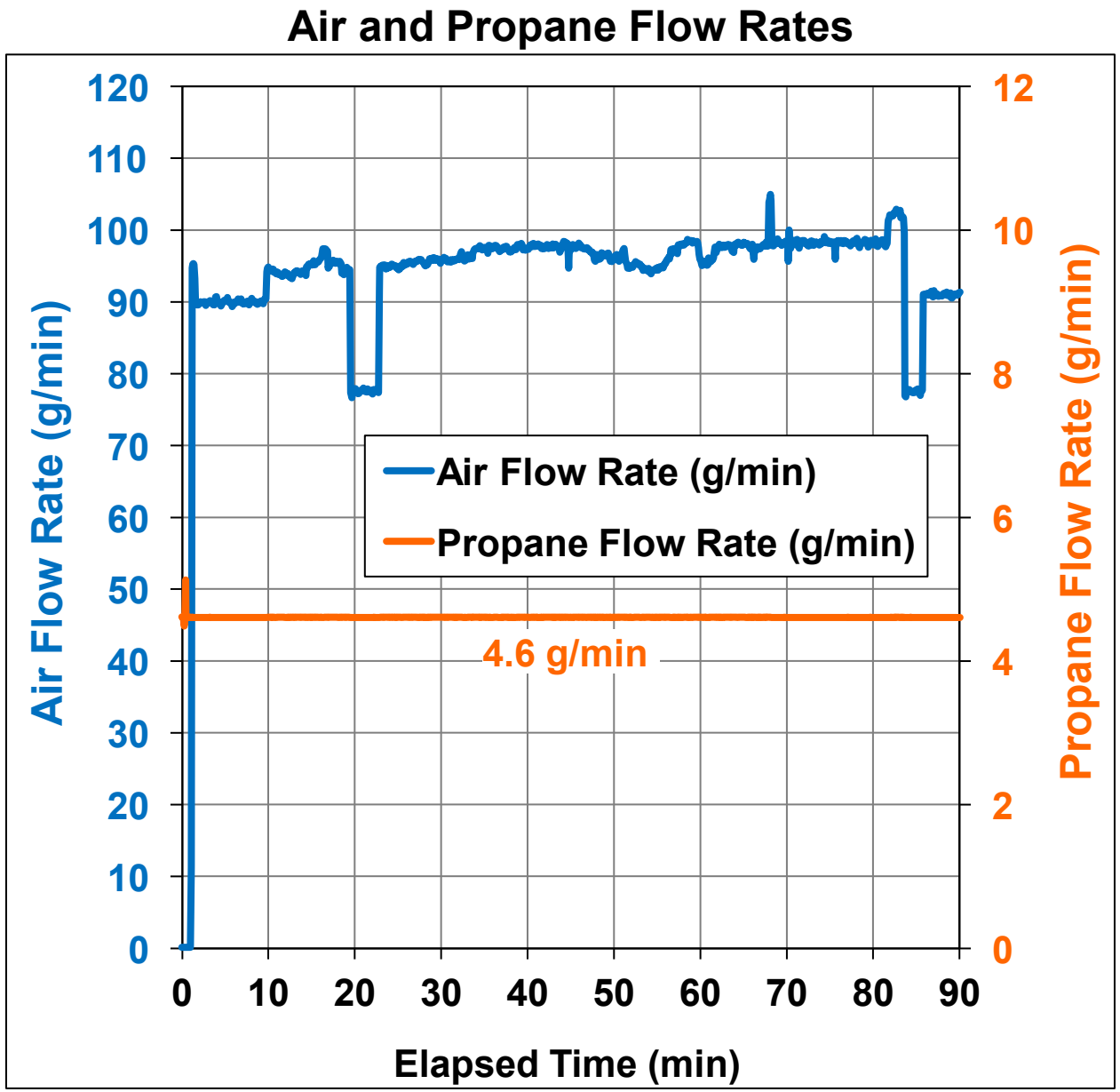
fresh air delivery system





“Proof testing” showed the CASE Lab and HBS worked as intended.



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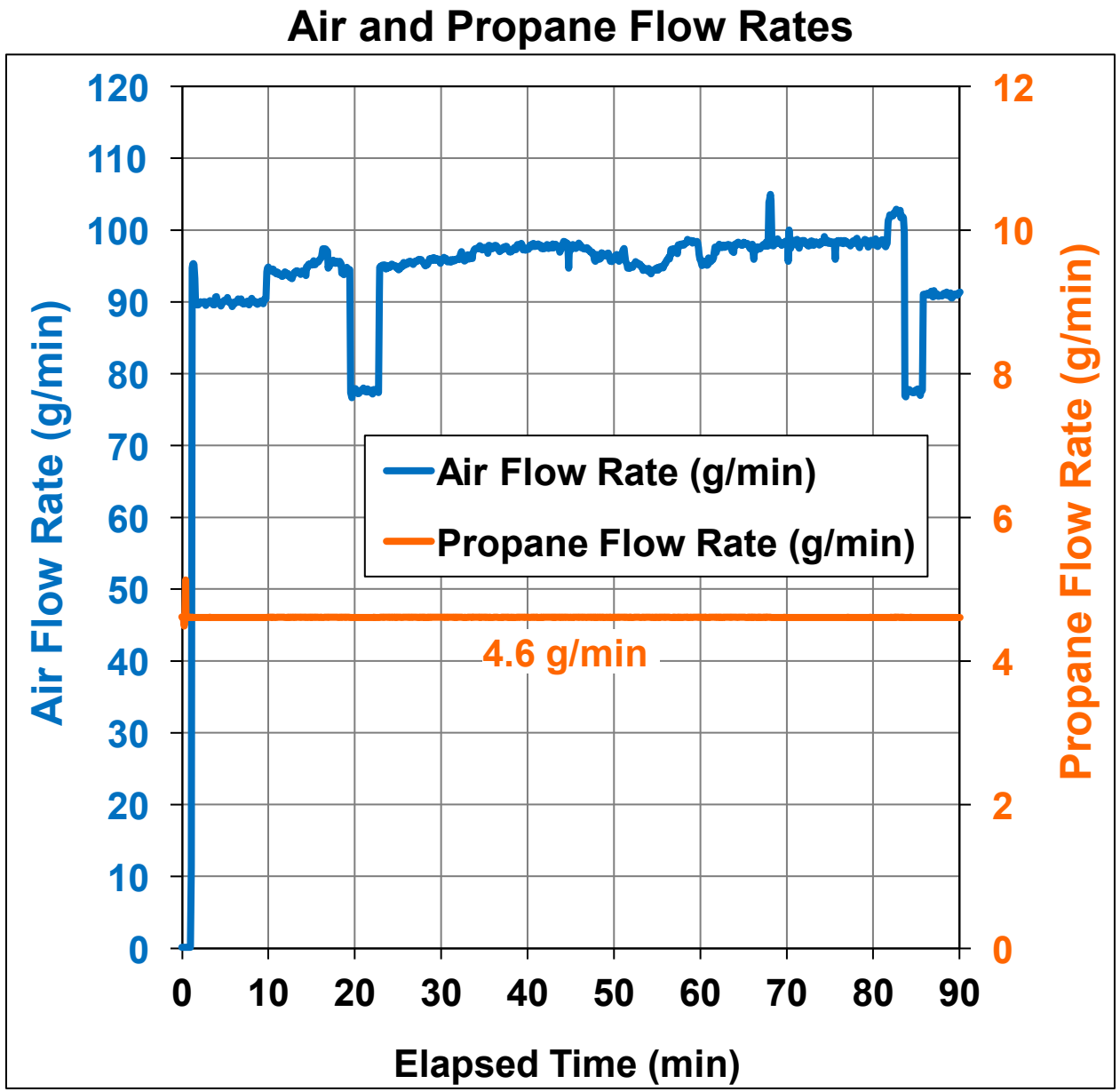

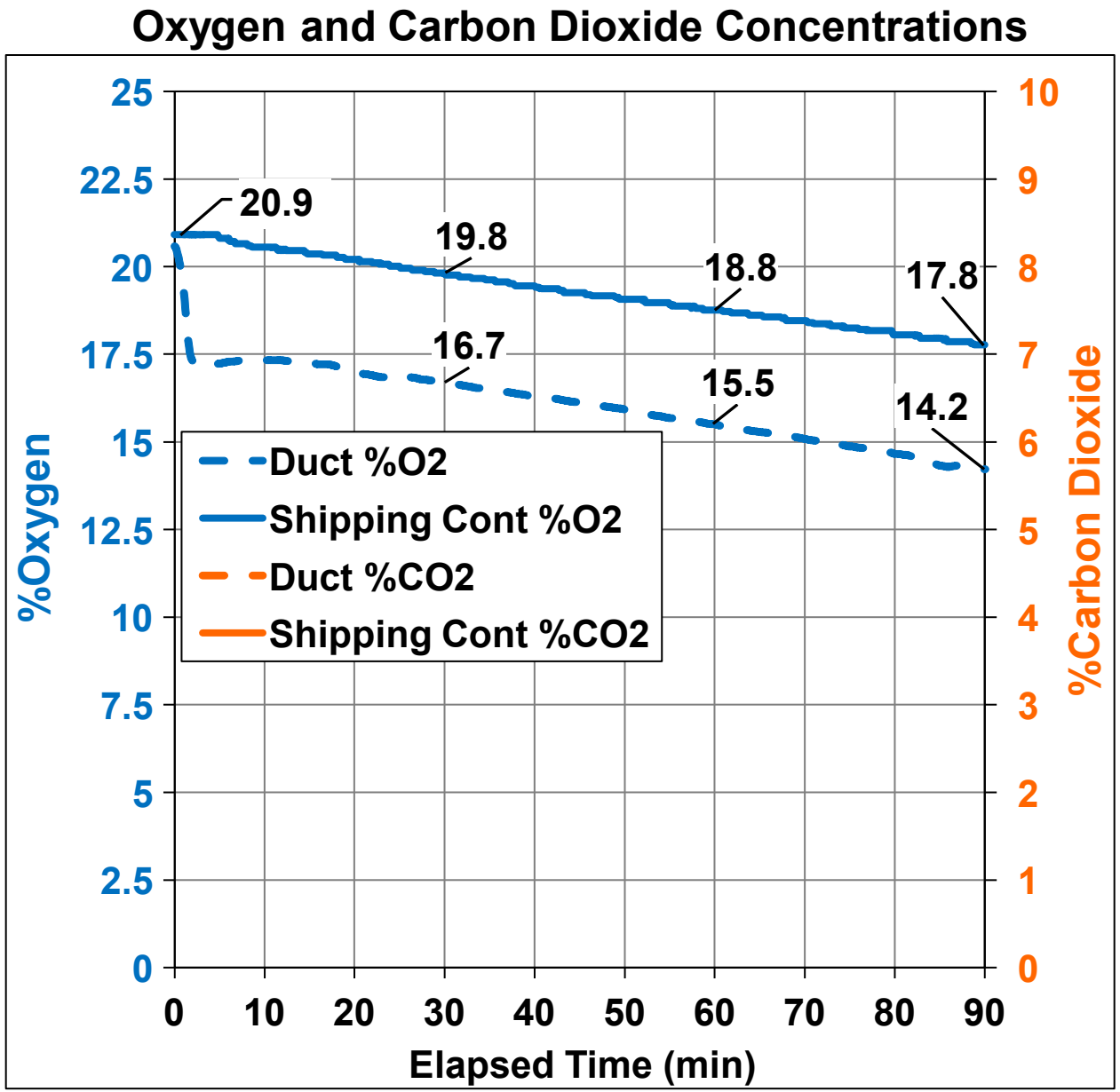

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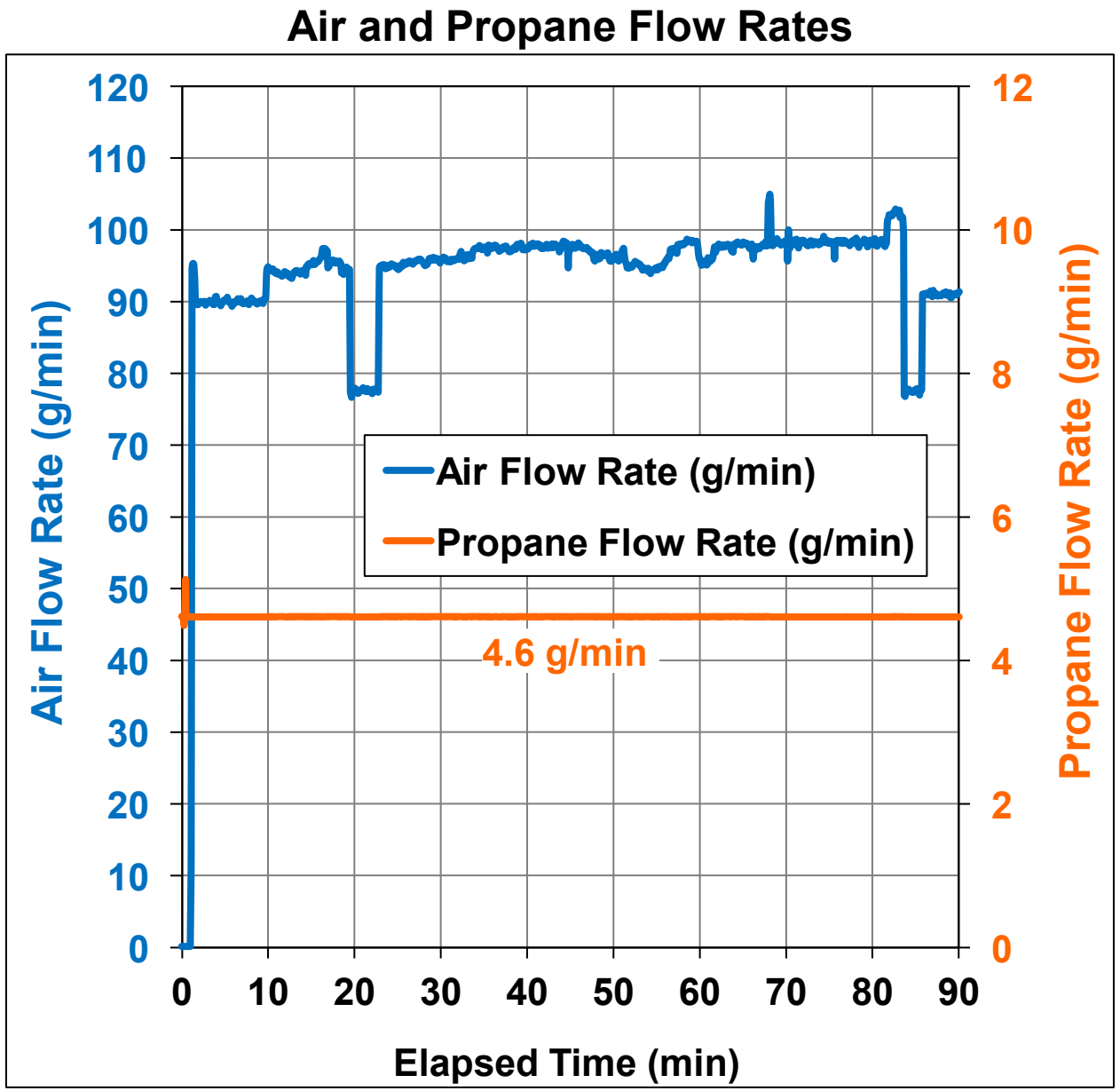

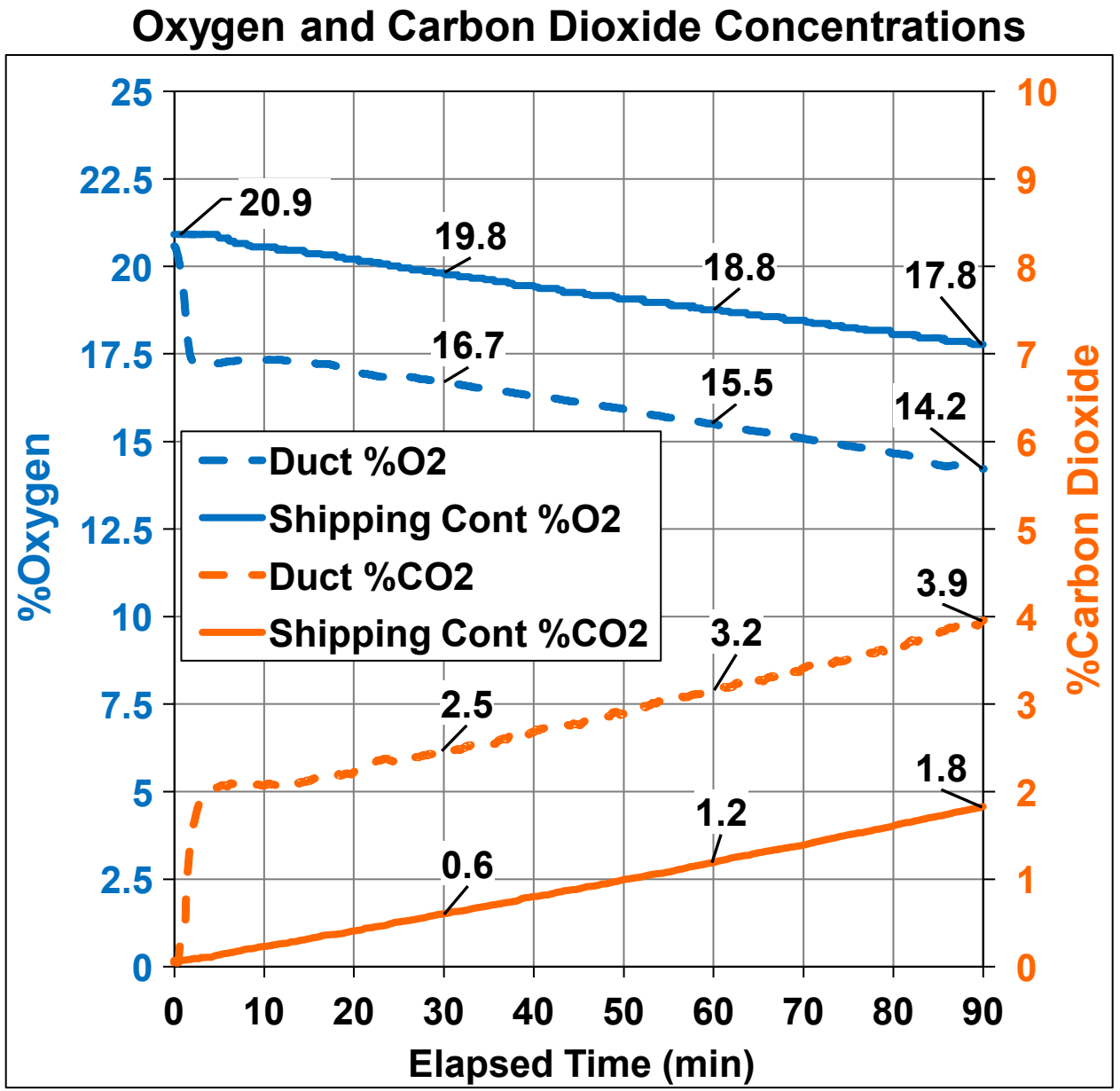

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Questions?

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NIOSH Mining Program
www.cdc.gov/niosh/mining