NIOSH Contract 200-2016-911194, Refuge Alternative Heat Mitigation System (RAHM) Utilizing Advanced Liquid Air Technologies

Development & Testing of a Cryogenic Refuge Alternative Supply System for Mines

Background:

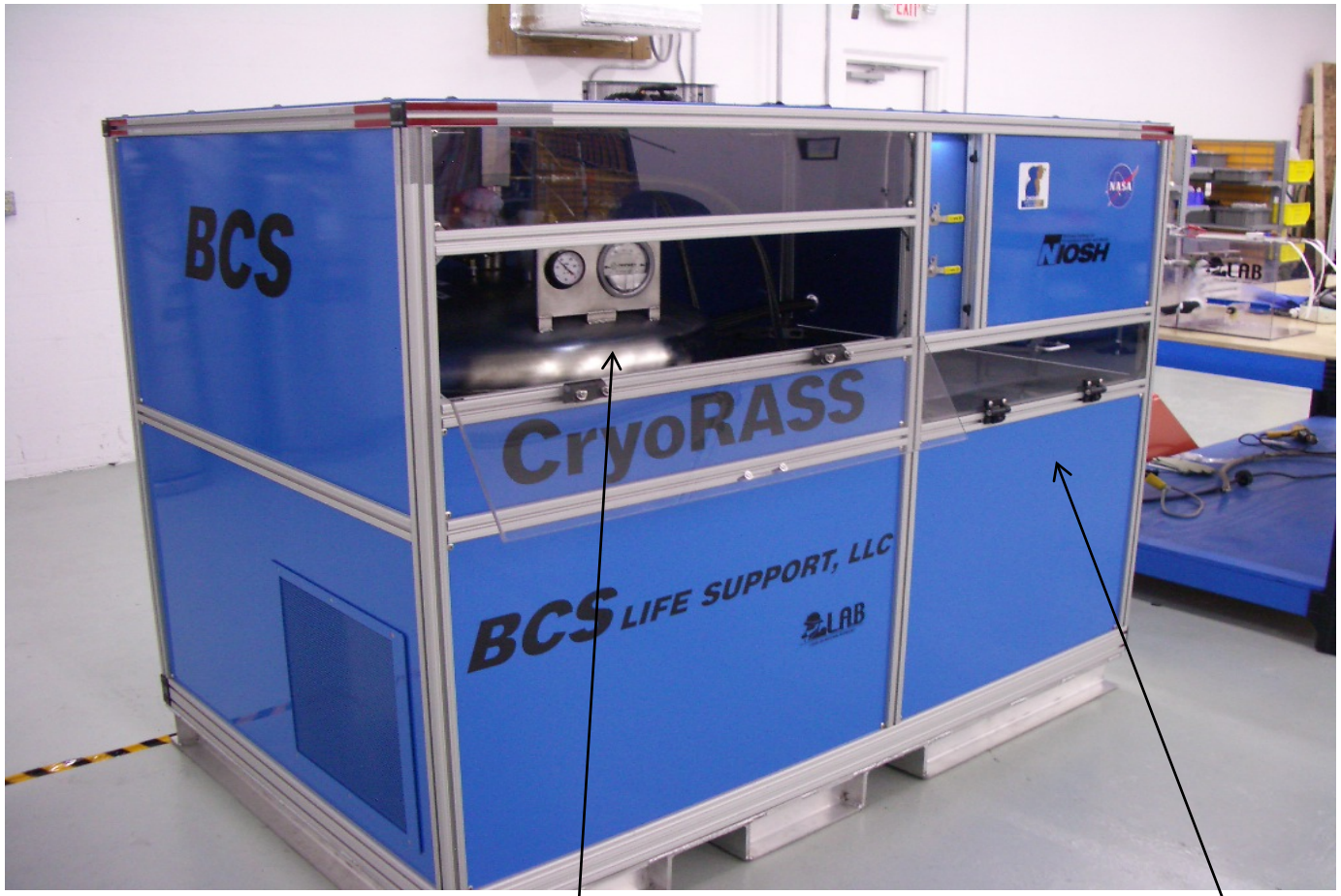
In 2012 NIOSH/OMSHR in collaboration with NASA/KSC's Biomedical Engineering Research Lab, contracted with BCS Life Support, LLC to develop Cryogenic Liquid Air Technology to help improve mine safety.

BCS and NASA were already working on some innovative "Liquid Air Life Support" technology which appeared to be a possible remedy for some mining RA issues.

Development & Testing of a Cryogenic Refuge Alternative Supply System for Mines

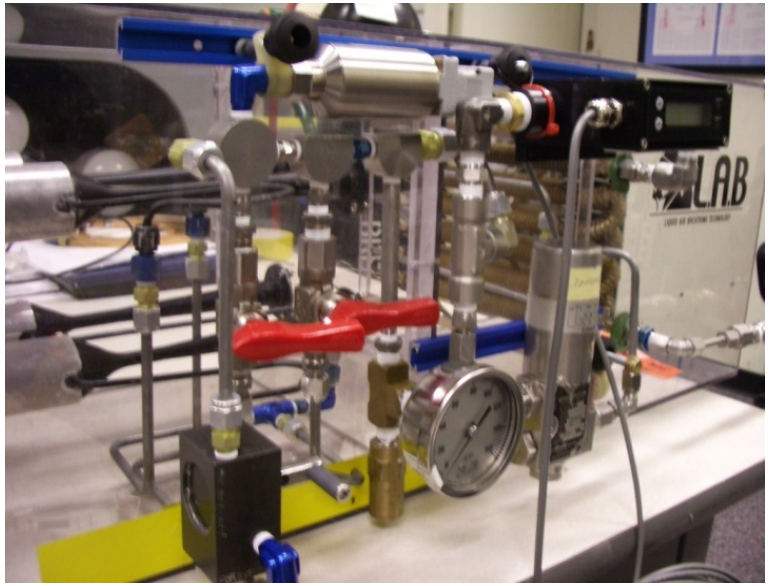
- Why?
  - Provide a new technology method for air storage
  - Store more breathing supply (air) in less space
  - Store air at lower pressure
  - Provide heat stress relief
- Benefits?
  - Cryogenic vessels are lighter in weight
  - Improved safety by lower pressure (75 psi vs. 4500 psi) storage
  - Improved safety by replacing O_2 with less hazardous <u>Air</u>.

CryoRASS Prototype 1



Liquid Air 425 liter Dewar

Cryocooler behind panel



Air Handler box

1st CryoRASS Test, Titusville, FL, Summer, 2013 Using a Trinity 10 Person Steel RA

Test plan for CryoRASS

- **Instrument Refuge chamber for temps, gas, pressure, humidity**
- **Use metabolic simulator to generate heat, consume oxygen, generate CO_2 and water vapor by burning propane**
- **Conduct 96 (continuous) hour test**
- **Isolate chamber from convective effects of lab (plastic sheeting)**
- **Support NASA, NIOSH, MSHA witnesses for test**

National Institute for Occupational Safety and Health NIOSH

CLSS Cryo Life Support Systems, LLC

“96 hr. Test 1” Basic Design Considerations

- Store 96 hours of air supply for 10 occupants
- Preserve quantity and composition of liquid air
- Simple activation by first miner to enter
- Provide cooling for heat stress relief
- Provide dehumidification

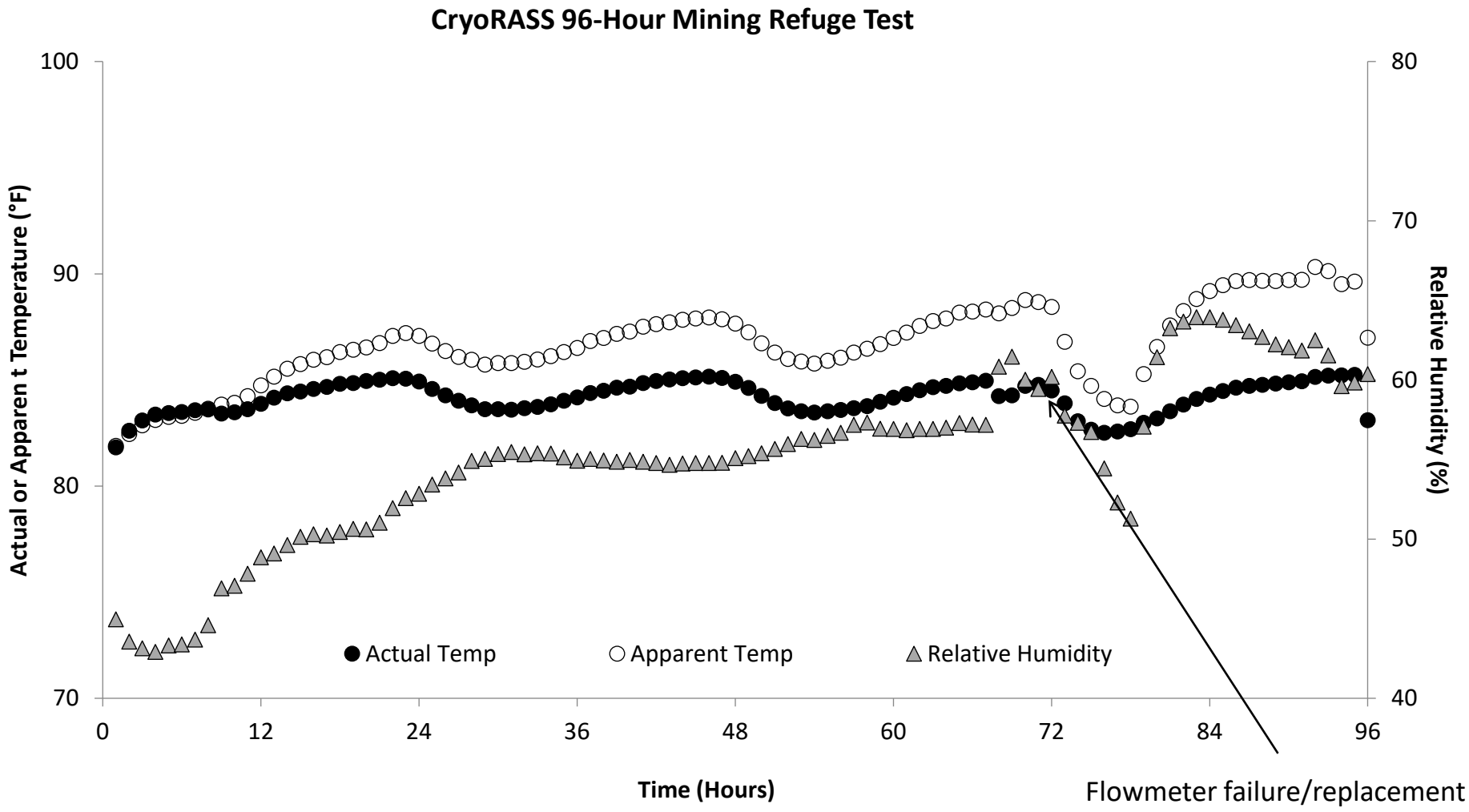
Testing of CryoRASS 1

- **RASS connected to 10 man Trinity chamber**

Test Instrumentation & Video monitoring

Liquid air line to chamber

Test 1 Results: Temperature Data



Test 1 Results Summary

- System operated for 96 hours - continuous
- Temperatures remained in acceptable range throughout
- Considerable humidity removed in heat exchanger
- No effort was made to control CO_2
- Conclusion
  - This test proved feasibility and prototype design
  - Respirable atmosphere maintained
  - Humidity reduced
  - Heat stress relief provided
  - Safety enhanced (low pressure and reduced O2 hazard)

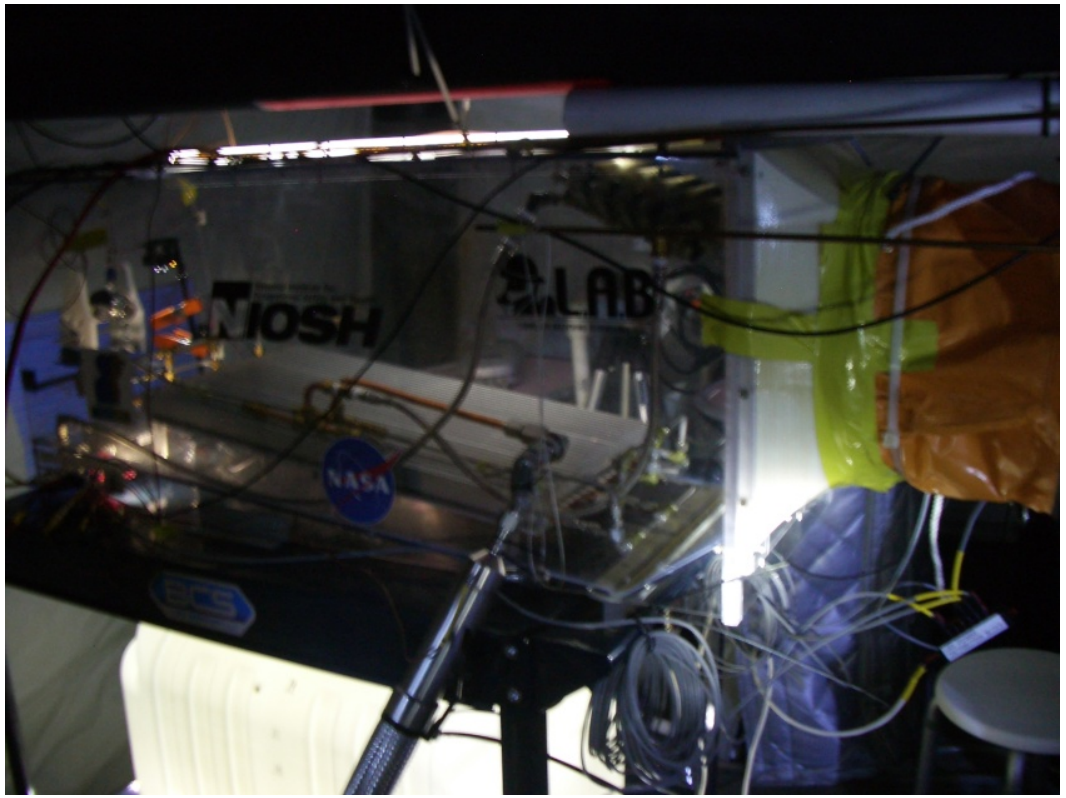
Test 2

2nd CryoRASS Test, Bruceton, November, 2014
23 Person Inflatable

Test plan for CryoRASS in Experimental Mine

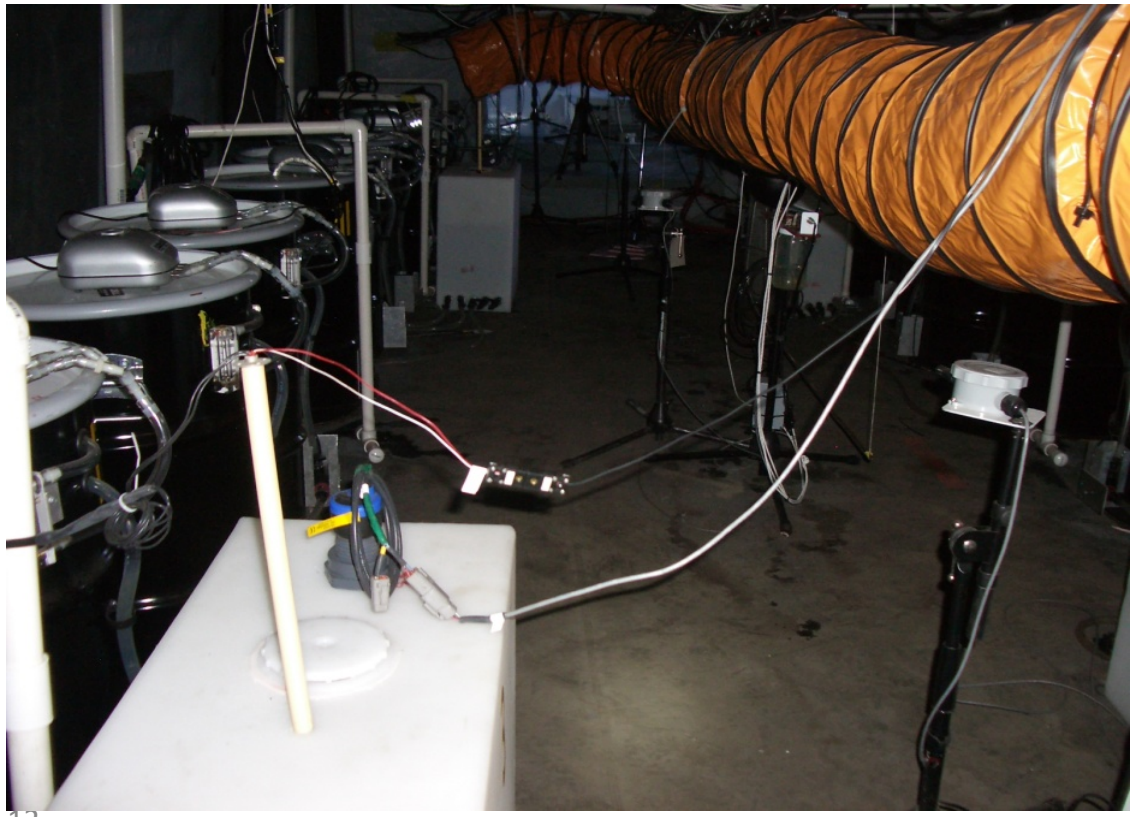
- Commercially available, inflatable Refuge chamber
- Instrument for temperatures, pressure, humidity
- Use “barrel person” simulator to generate heat and water vapor
  - Add 494 BTU/person
  - Add 1.3 liter water /person/day
- Conduct 96 (continuous) hour test
- Isolate chamber in cross-cut with insulated walls
- Digitally record all data
- Test conducted by Pittsburgh OMSHR personnel
- BCS/LABtech support on site for operation of CryoRASS 1

RA Interior



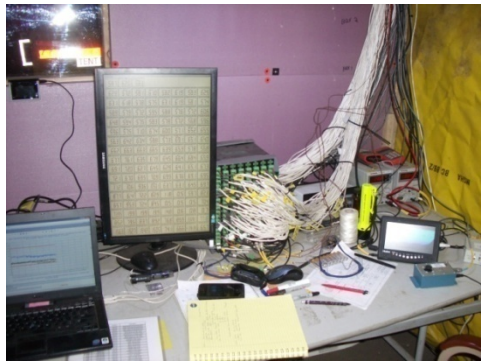
Air Handler Box
- liquid air input from bottom

Air duct from air handler (right)
Note “barrel persons” (left)



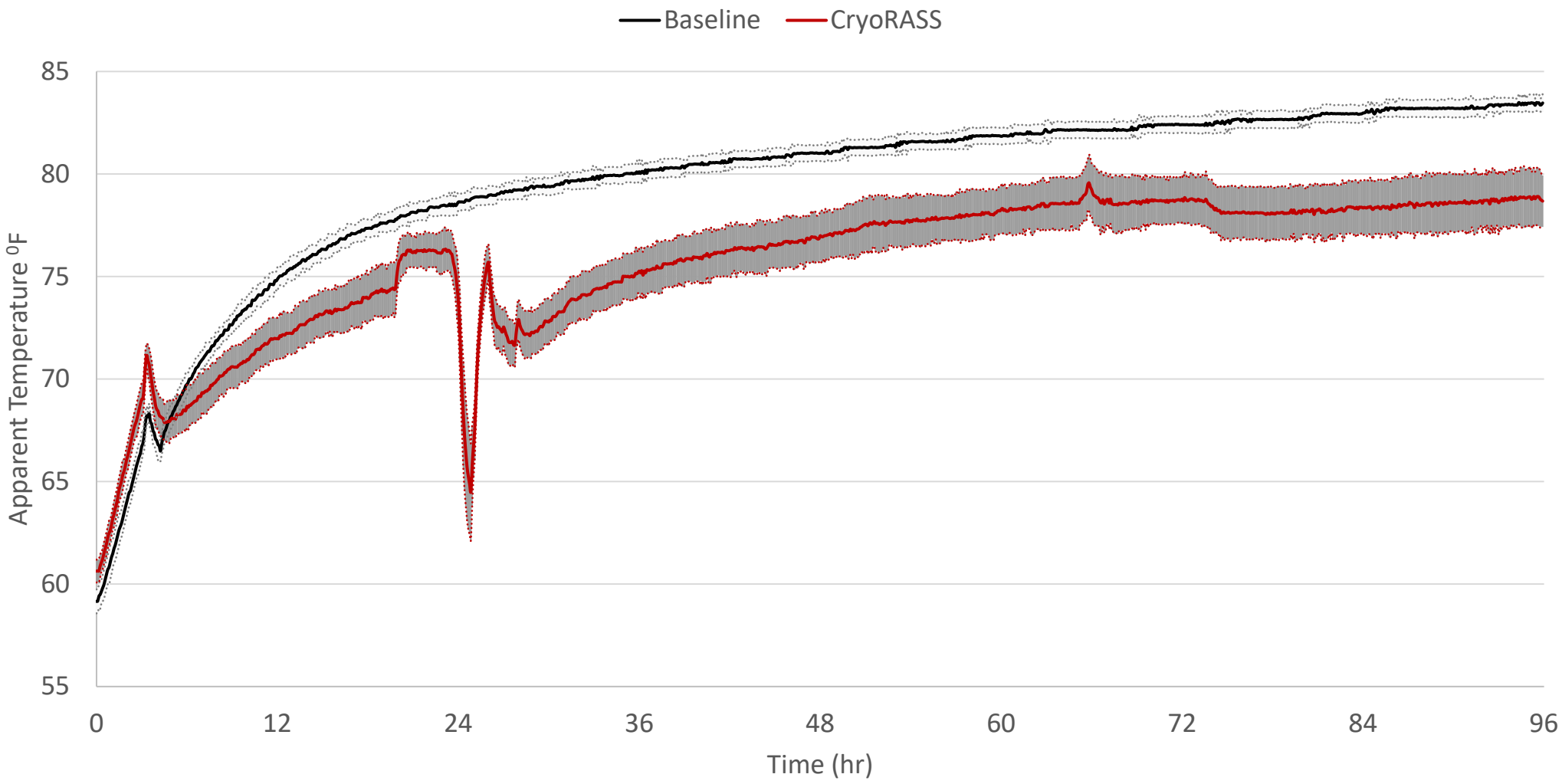
2nd Test of CryoRASS, Heat & Humidity

- **RASS connected to 23 man Inflatable chamber**



Test Instrumentation & video monitoring

Apparent Temperature



Plotted is the apparent temperature calculated by using the Wet Globe Bulb Temp approximation. The average and standard deviations of Three Humidity/Temperature readings inside the refuge chamber (Front, middle, end) was used for the WGBT calculation.

Test Results Summary

- Actual (dry bulb) temperatures were marginally lower (- 3° F)

- Considerable humidity removed (~ 11 gal + ~ 1 gal frost + 3.4 gal expelled out through relief valve and/or leaks)
  - RH down to 85%

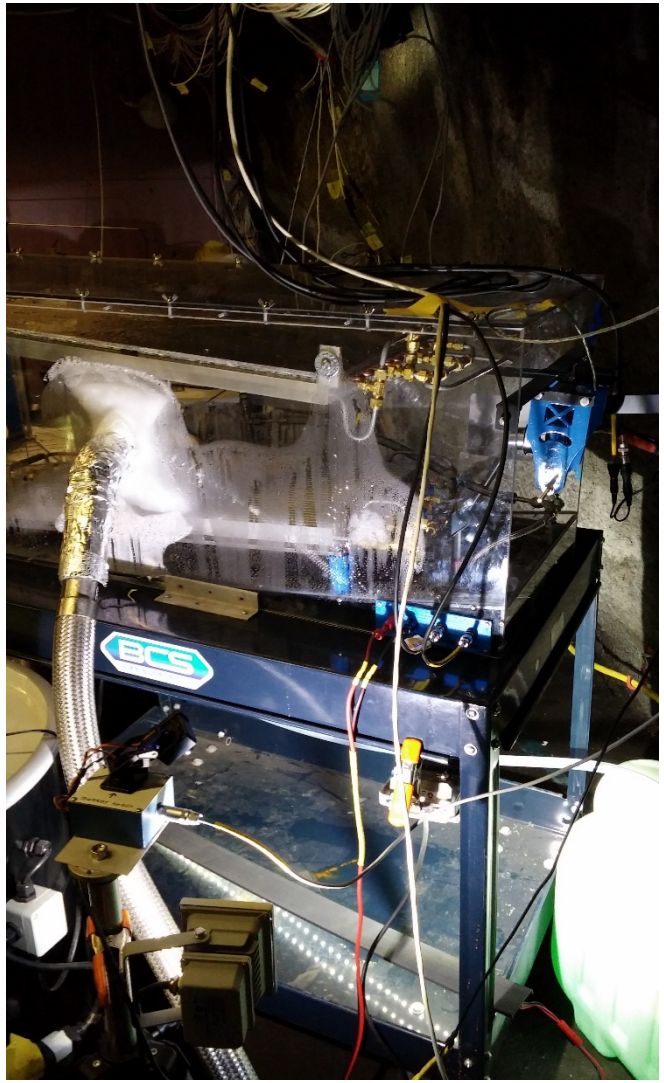
- Apparent temperature reduction:
  - Baseline: 74°F, 94% RH = 83.1°F Apparent
  - CryoRASS: 73°F, 85% RH = 77.2°F Apparent
  - **Overall apparent temperature reduction: 6°F**

Conclusion

- This test proved concept feasibility and prototype design
- CryoRASS system creates refuge air circulation (~ 150 SCFM)
- Temperature and humidity reduced
- Heat stress relief provided (6°F apparent temp reduction)
- Safety enhanced (low pressure air source)
- Air source space & weight requirement decreased
- Although not specifically tested here, increased airflow will purge CO_2, reducing the CO_2 levels in the chamber, thus reducing the need for CO_2 scrubbing. Since CO_2 scrubbing is a significant exothermic reaction, any reduction in the CO_2 concentration will result in additional heat savings.

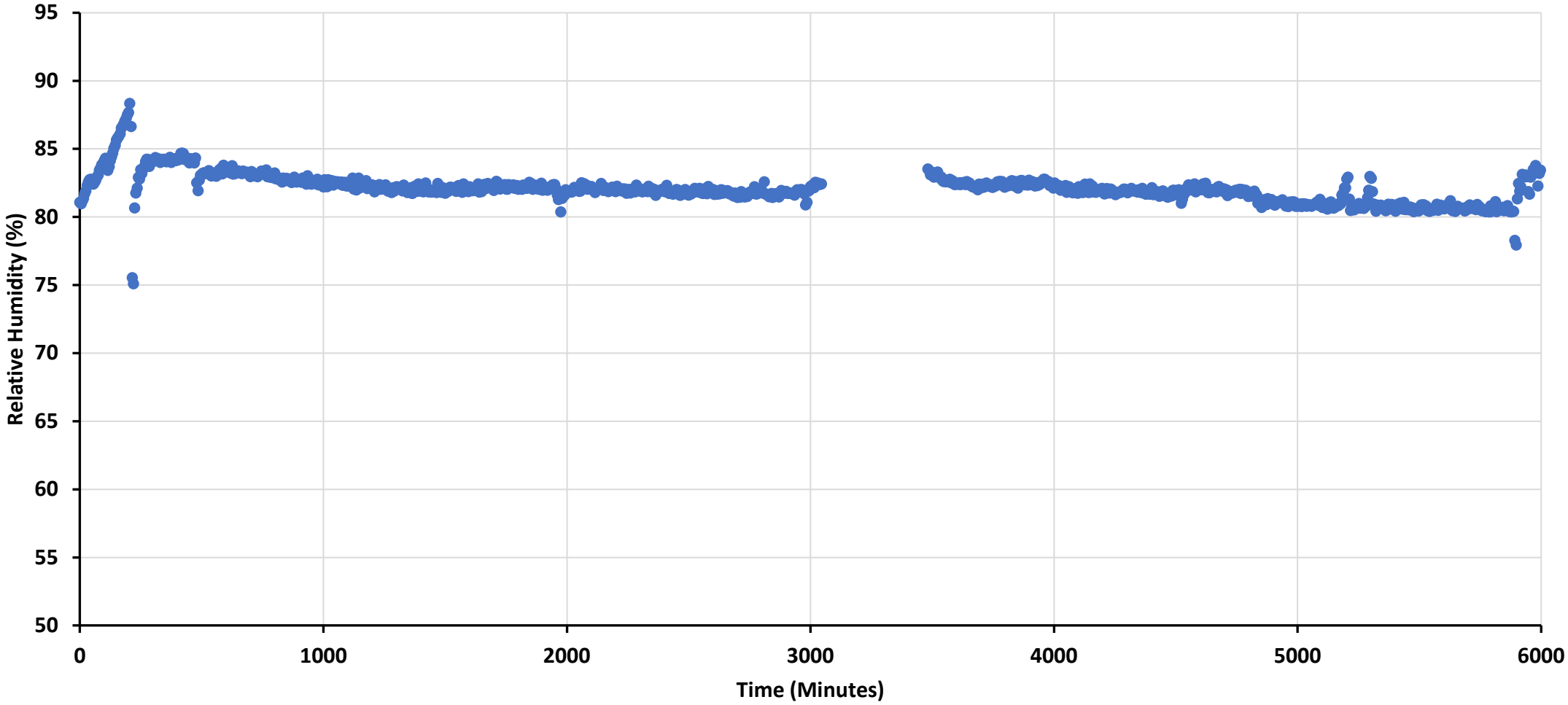
3rd CryoRASS Test, Bruceton, Fall, 2015
30 Person BIP

Barrel Persons & AirBox

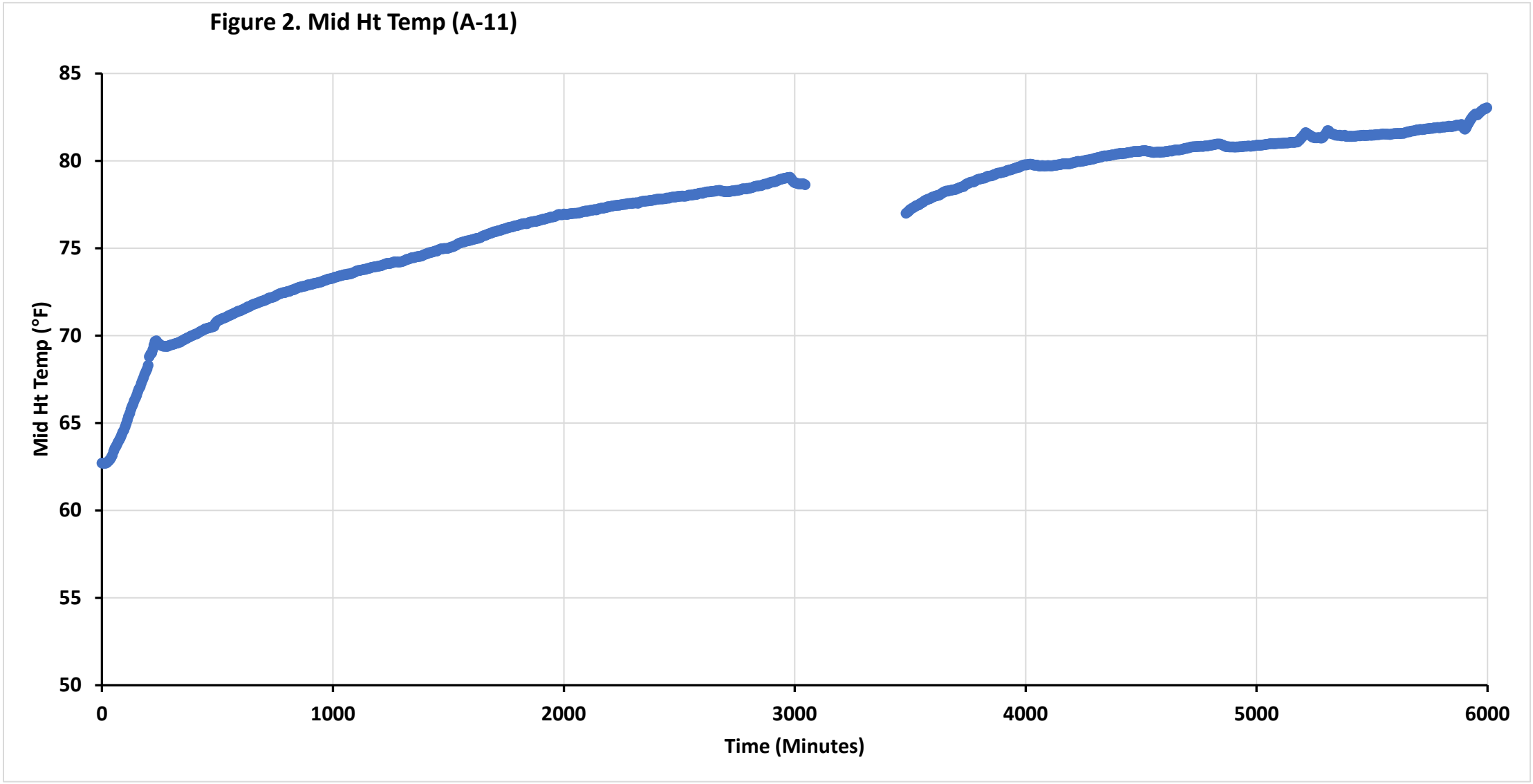


Relative Humidity

Figure 1. Relative Humidity (A-12)



Mid-height Temperature



Conclusion

- The primary conclusion from this 3rd test of the CryoRASS in the BIP RA at the NIOSH Experimental Mine was the third **successful demonstration** of a 4 day supply of respirable gas that also **provided cooling and reduction of humidity.** This was a system reliant upon cryogenic air and no electric power was required during use.
- This refuge supply system concept again demonstrates **RA air circulation** with the intent of sequestering low quality chamber air (CO_2, moisture, low O_2) in an area near the refuge relief valve and introduction of new air into recirculated air while scrubbing moisture via condensation, all of which took place in the air handler unit.
- Humidity reduction was apparent and averaged about 80%. Approximately 26 gallons of water was removed during this test. with about 1 more gallon of frost still in the air handler at test termination.

NIOSH CryoRASS Prototype II

Currently!

NIOSH Contract 200-2016-911194, Refuge Alternative Heat Mitigation System (RAHM) Utilizing Advanced Liquid Air Technologies

1. A commercial/production model of the liquid air system capable of providing breathable air and cooling for a RA or BIP shelter occupied by 30 persons will be designed and assembled. The 30-person size was selected because this size would cover a majority of the RAs and BIP shelters currently in use. The system will be designed such that it can be retrofitted to existing RAs or BIP shelters, or be included as the primary breathable air component in newly constructed RAs or BIP shelters. The production model will include a 1500l (1585qt) Dewar, cooling system, heat exchanger, and all associated electronic, plumbing, and control systems.

Progress

- Airbox- Has been tested to assure required airflow performance.
- Containment Structure- Fabrication in progress.
- Fluid System- Fabrication in progress.

Schedule

- July ’17, Titusville, FL
  - Wet Test of CryoRASS
- September ‘17, Bruceton
  - Delivery of CryoRASS System
- October ‘17, Bruceton
  - Begin Testing
- February ’18, Project Complete