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Mine Test of a Cryogenic Refuge Alternative Supply System (CryoRASS)

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Refuge Alternatives Partnership Meeting

This effort is completed as part of CDC Inter-Agency Agreement (IAA/SAA):-
CDC Agreement No: 12FED1213259, NASA SAA No: KCA-4357

Why use liquid air?

- Provide a new technology method for air storage
- Store more air in less space to reduce size & weight
- Store air at lower pressure to improve safety
- Provide heat stress relief to improve comfort & survivability – reduce temperature and humidity

Basic Design considerations

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- Store 96 hours of air supply in liquid form
  - Use 2 x 425 liter + 300 liter dewars for a 23 man chamber
- Preserve quantity and composition of liquid air
  - Use cryocooler to overcome heat leak during long term storage
    - Assume electrical power until emergency
    - Assume no electrical power during emergency
- Simple activation by first miner to enter (1 pull)
- Provide air at 5X oxygen quantity (1.32 ft^3/hr/person)
- Provide cooling for heat stress relief
- Provide dehumidification for heat stress relief
- Provide air circulation within refuge
- Provide partial CO_2 flushing

Basic schematic

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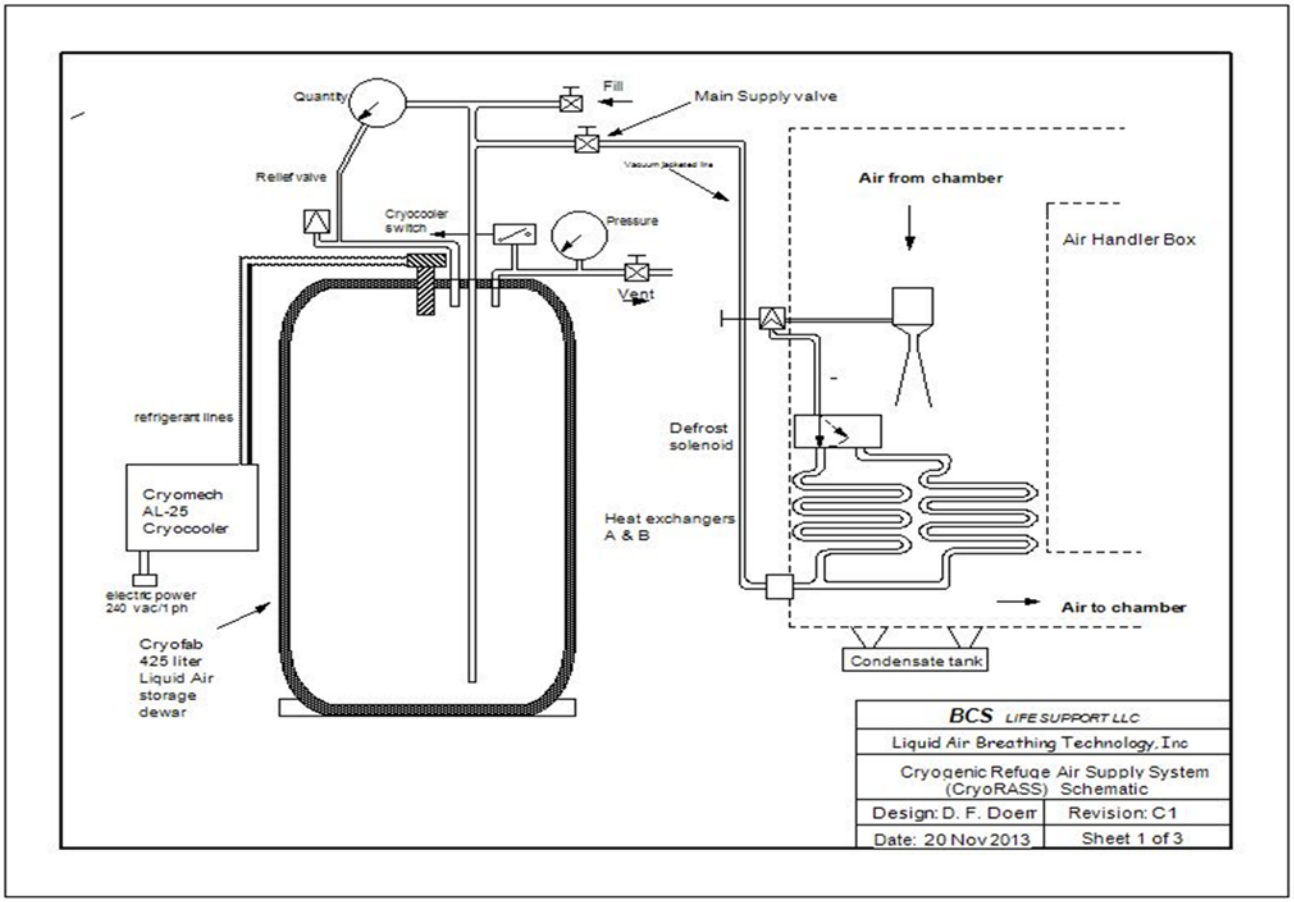

Sustainability of Liquid Air

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- Liquid air composition and quantity can be maintained with use of cryocooler
  - Instrumented studies for 6 months show no change
  - Cryocooler for 425 liter dewar requires 7.2 amp/240VAC
- For this test, all three dewars filled on 6 November
- Dewars shipped on 10/11 November – 300 liter cryocooler damaged
- Dewars in mine 12 November – 2 cryocoolers operating (425's)
- Test started 17 November with 300 liter
  - 11 days after fill
  - 7 days after cryocooler failed
- Dewar is self pressurizing with buildup loop, regulator controls pressure at 75 psi

First 96 hour test of CryoRASS

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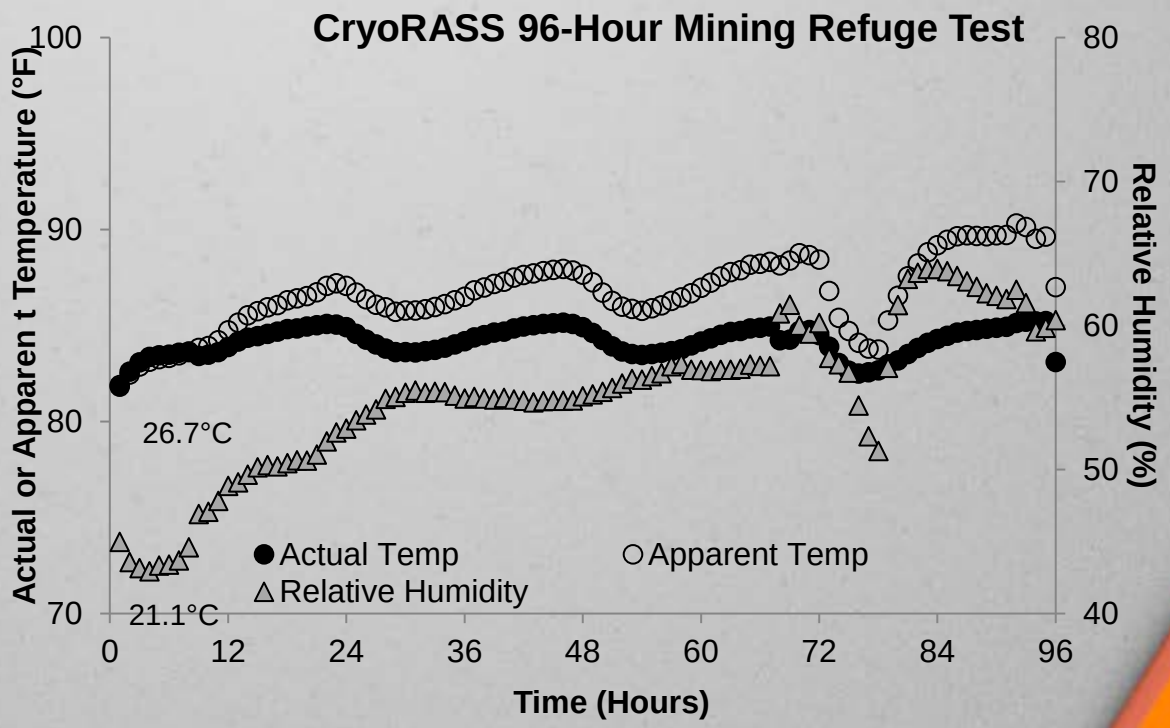

Trinity Refuge Alternative - 10 person

How much liquid air for 23 person inflatable refuge?

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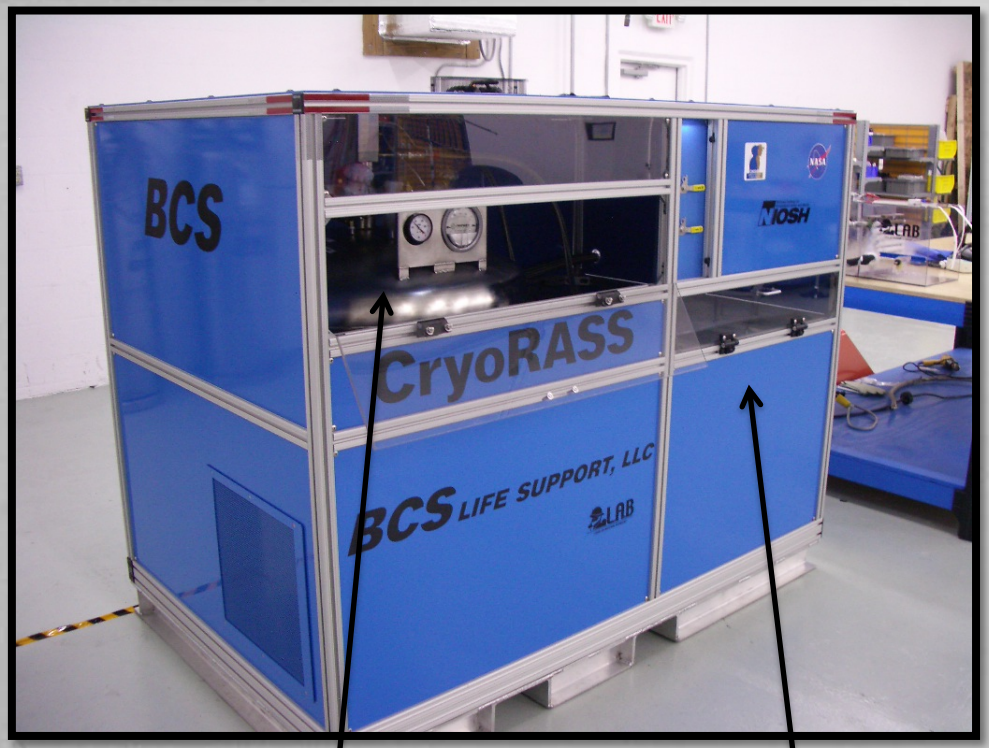
- MSHA requirement = 1.32 ft^3 oxygen/ hour/person
  - X5 = 6.6 ft^3/hr since O_2 is ~20% component of air
  - for 23 miners = 152 ft^3/hr
  - for 96 hours = 14,575 ft^3 (total)
  - gaseous flow rate = 4300 liters/hr = 72 liters/minute (minimum)(2.5 SCFM)

- Volumetric expansion ration for liquid to gaseous air = 728 : 1
  - total liquid required = 20 ft^3 or 566 liters
  - → minimum flow to air handler = 72 liters/minute (gaseous)(2.5 SCFM)
    - to provide maximum duration (165 hr)

- CryoRASS storage for this test = 425 CryoRASS + 425 CryoASFS + 300 ZL
  - For 96 hours, can flow (1150 x 728) = 837,200 liters gaseous (29,600 ft^3)
  - → maximum flow rate (for 96 hr) = 145 liters/minute (5.1 SCFM)
    - to provide maximum cooling and dehumidification

CryoRASS Prototype 1



Liquid Air 425 liter dewar

Cryocooler behind panel

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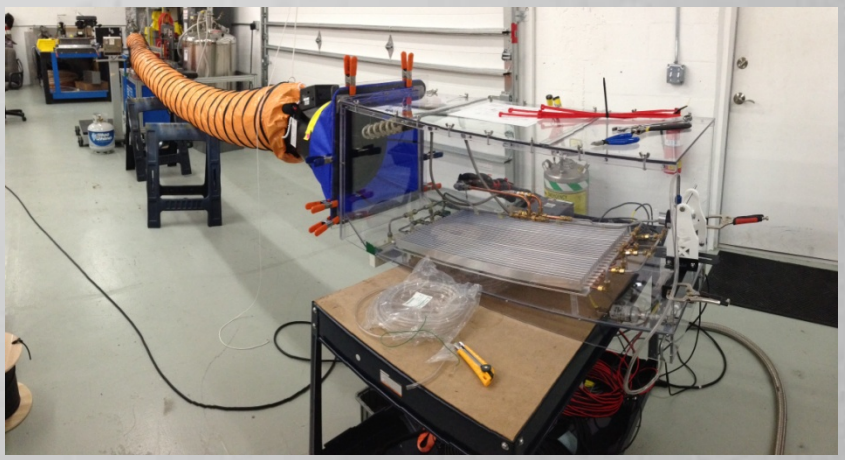

Air Handler box
with duct work

How was CryoRASS tested?

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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

Instrumentation diagram

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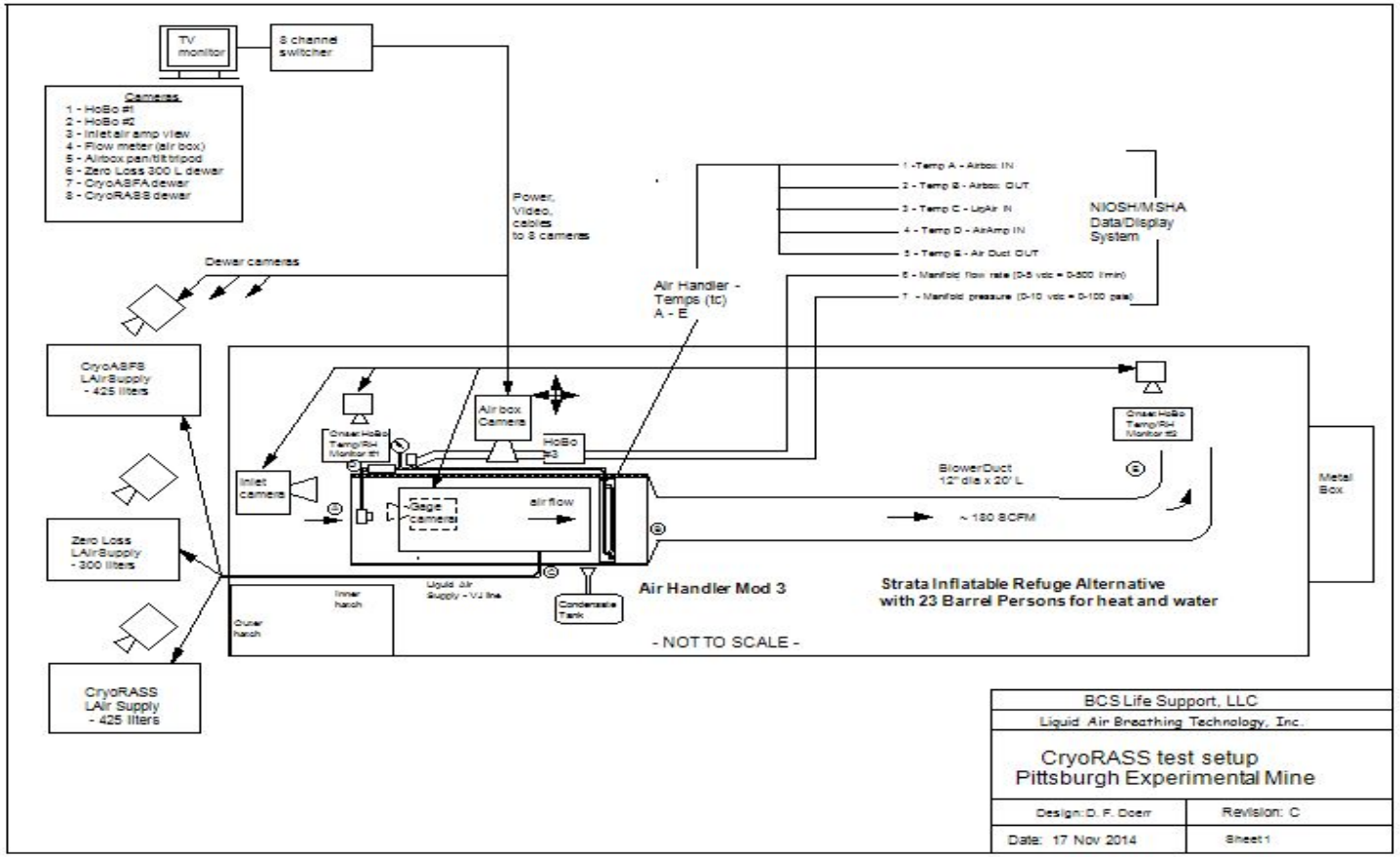

Refuge chamber interior

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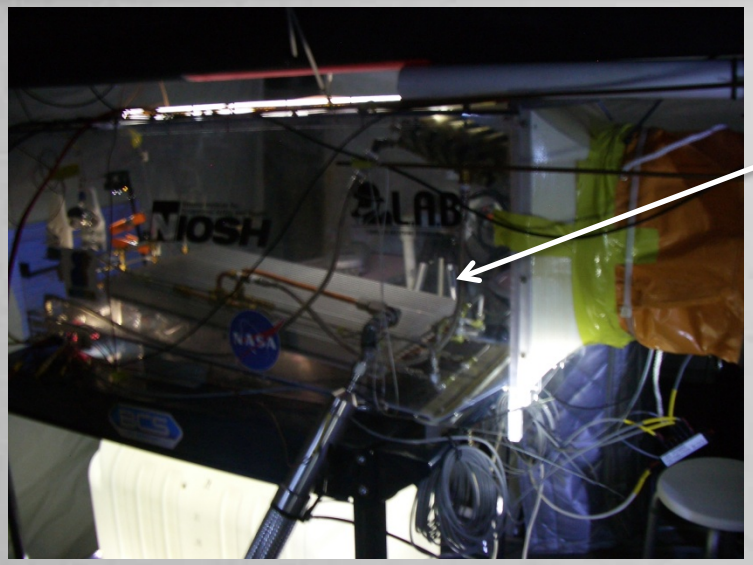
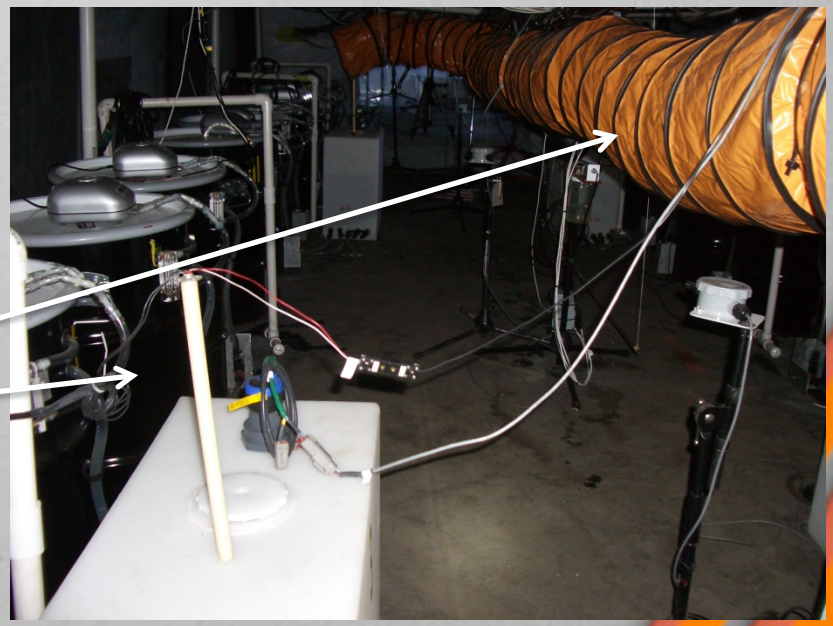


Air Handler Box
- liquid air input from bottom

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



Testing of CryoRASS

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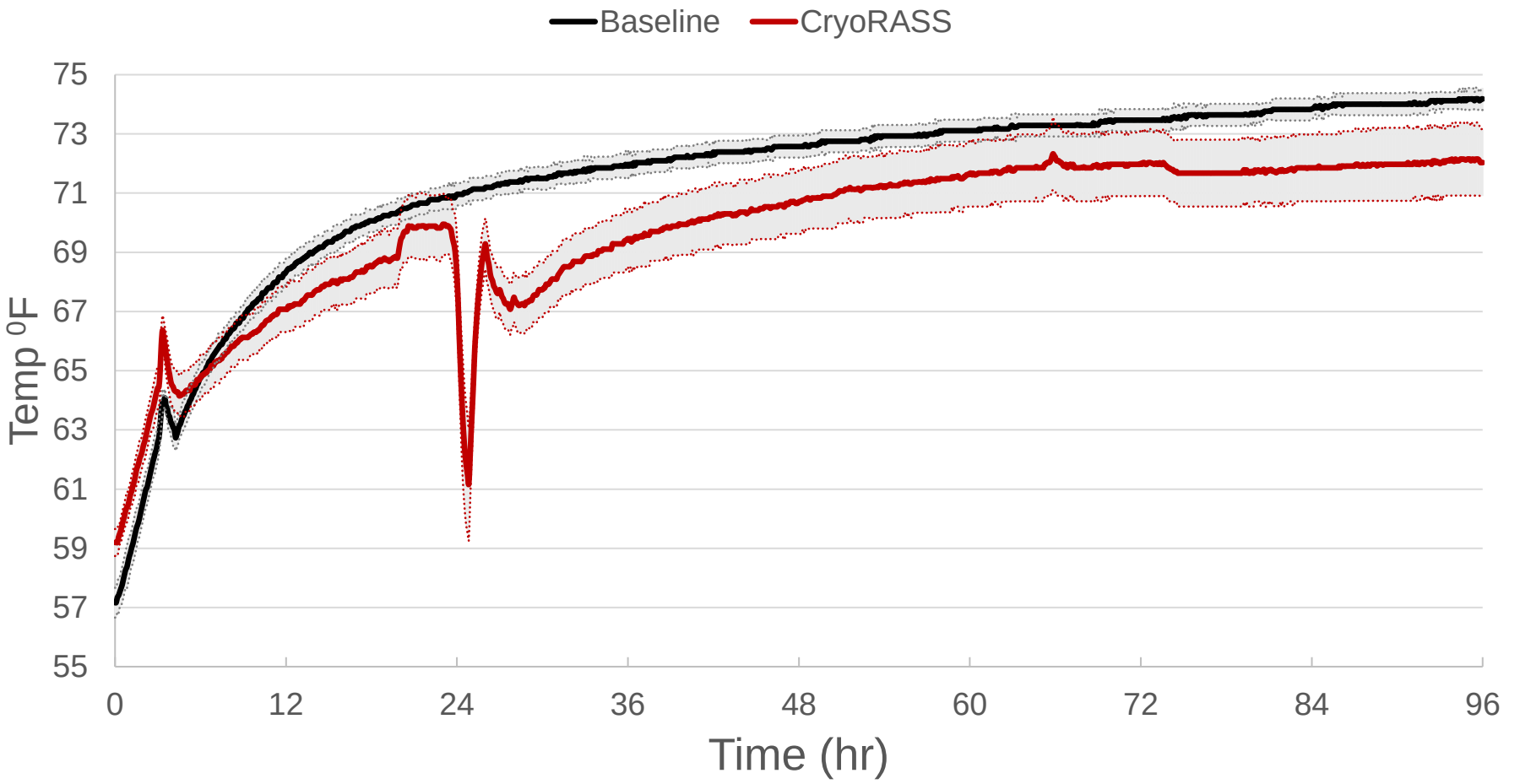
RASS connected to 23 man Inflatable chamber

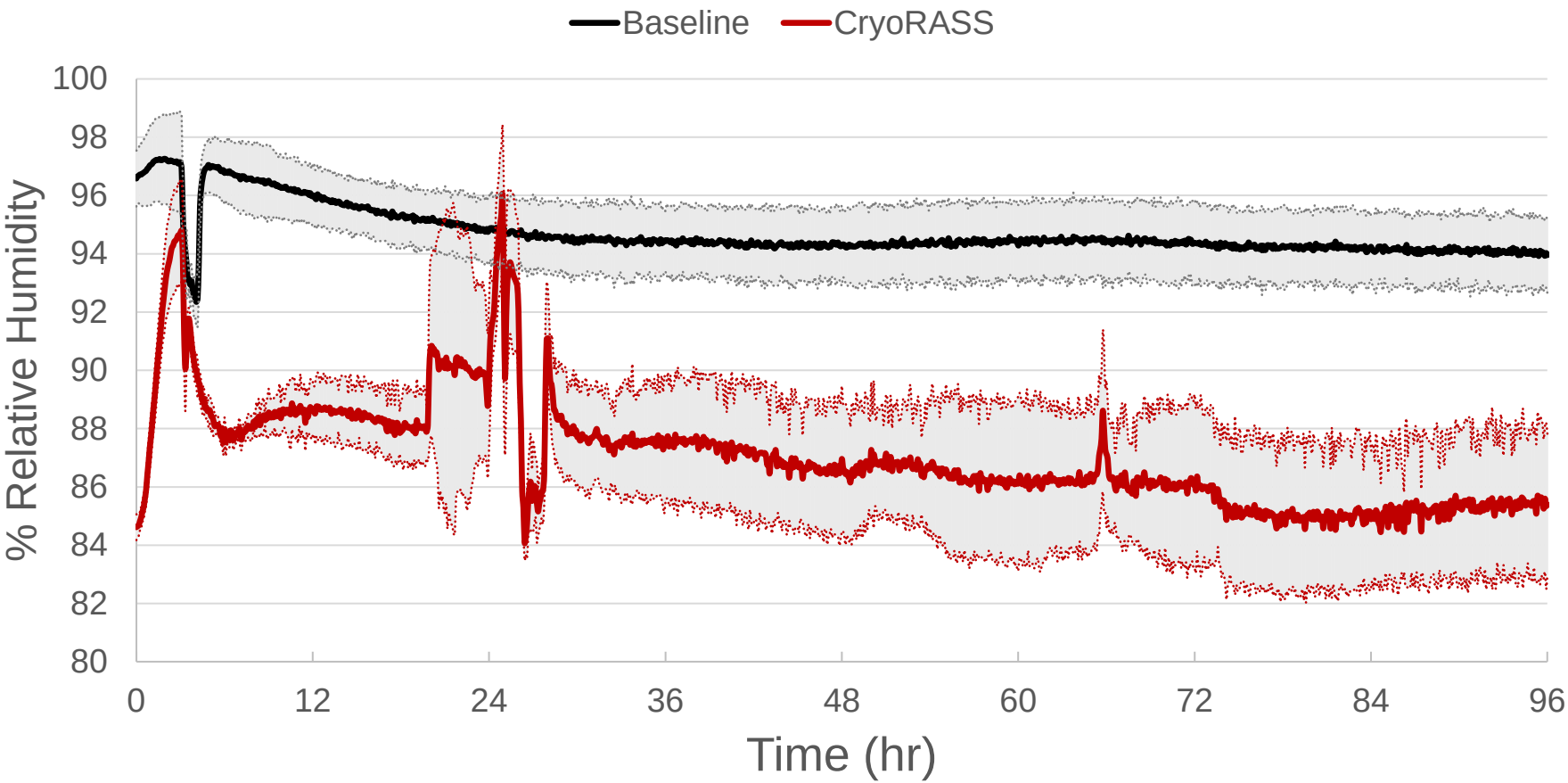
Test Instrumentation & video monitoring

Air Temperature



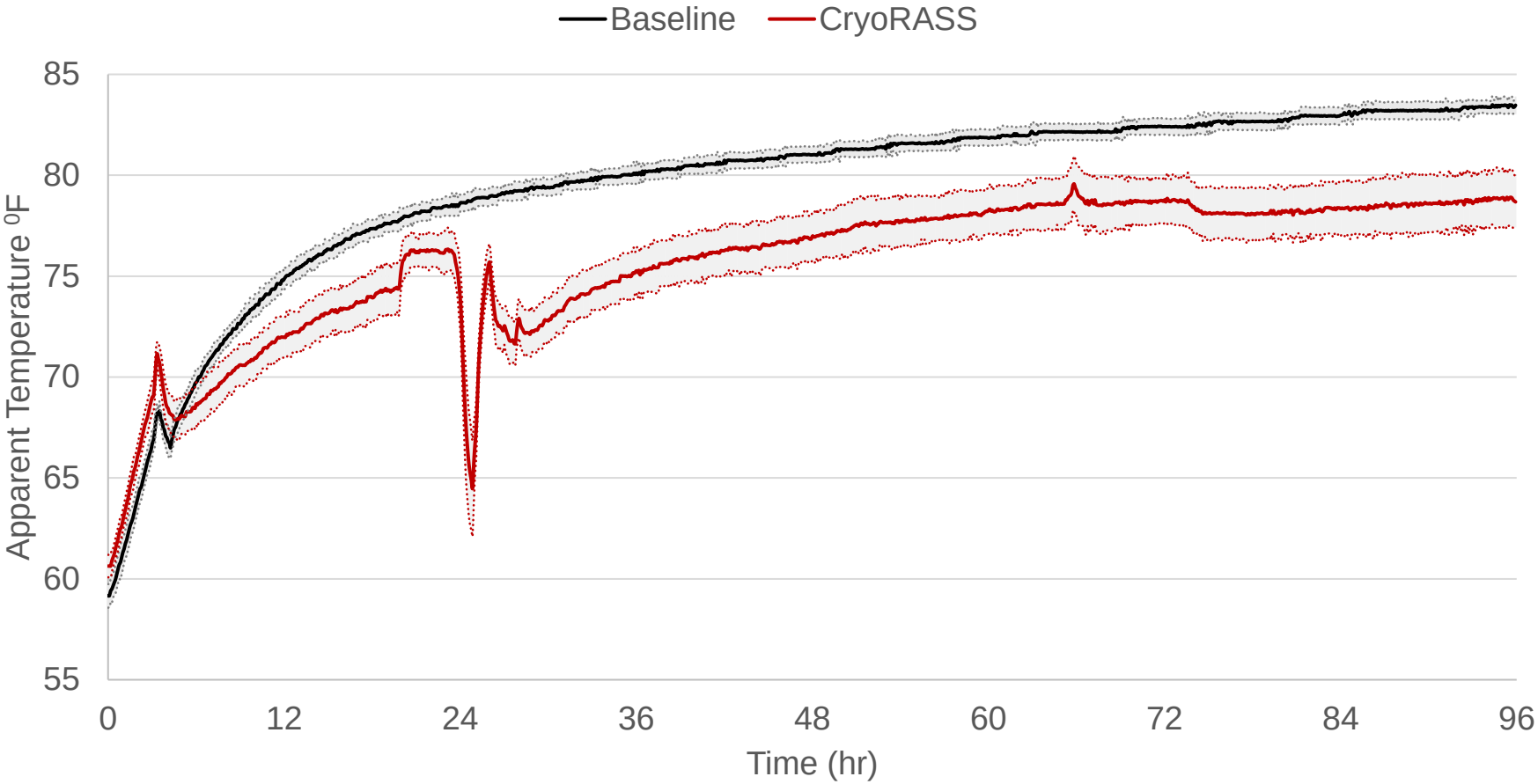
Plotted is the average and standard deviations of three temperature readings inside the refuge chamber (Front, middle, end) for each test. The data was collected at 1sample/20 sec and re-sampled post-test 1 sample/ 5 minutes.

Relative Humidity



Plotted is the average and standard deviations of three Humidity readings inside the refuge chamber (Front, middle, end) for each test.
The data was collected at 1sample/20 sec and re-sampled post-test 1 sample/ 5 minutes.

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

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- 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%
  - RH down to 76% at duct outlet

- 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**

- No effort was made to model or control CO_2

Conclusion

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- This test proved concept feasibility and prototype design
- CryoRASS system creates refuge air circulation (~ 150 SCFM)
- Since 140 liters/min (5.1 SCFM) added, then140 l/m (w/water vapor + CO_2) expelled
- 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.

Entry Observations

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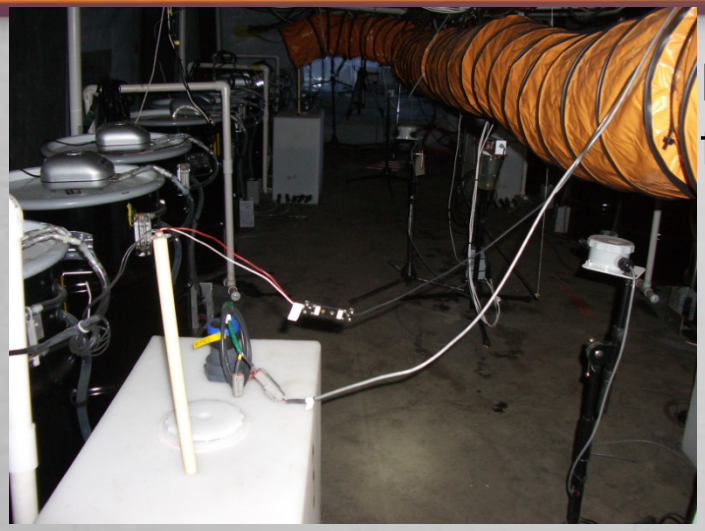
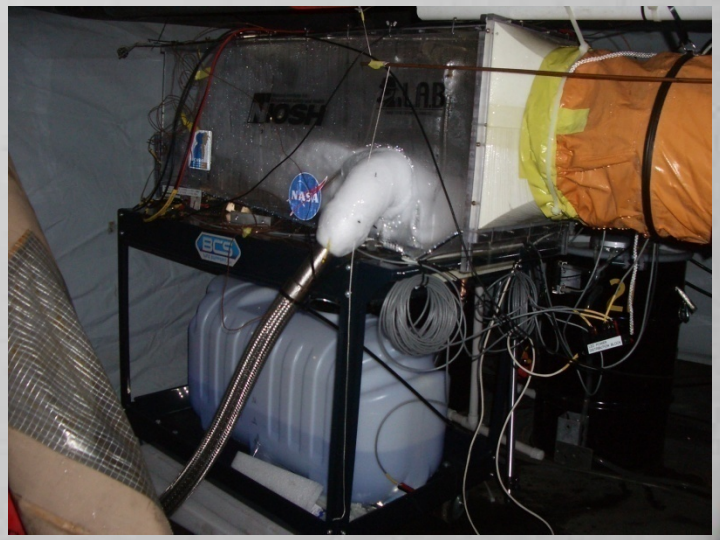


Note dry
floor in tent 2 & 3



Air handler, cold plate
and condensate tank

Partially dry
floor in tent 1

What's next?

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CryoRASS Prototype #2 will:

- Add second cold plate to air handler box
- Change to1000 liter horizontal dewar (low seam mines)
- Ruggedize construction to comply with MSHA
- Larger, ruggedized cryocooler
- Design to fit existing inflatable, hard chambers, and "built in place"
  - Options
    - Stand alone CryoRASS connected to inflatable, hard refuge, or built in place
    - Fit CryoRASS components into inflatable's storage box
    - Fit CryoRASS components into airlock of hard refuge
- Include Air Curtain at entryway vs purge (next page)

Air Curtain in place of Purge

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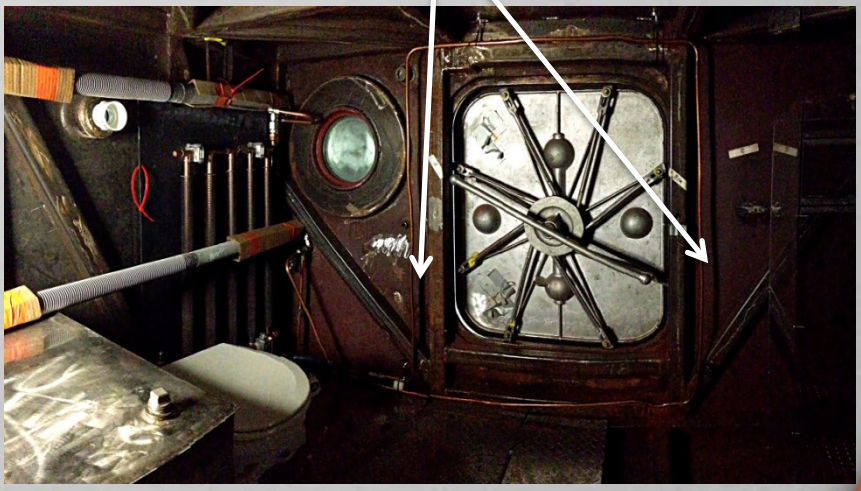
Video clip
of air curtain

Vent tubes



Measuring
air flow
from air
curtain

Questions?

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