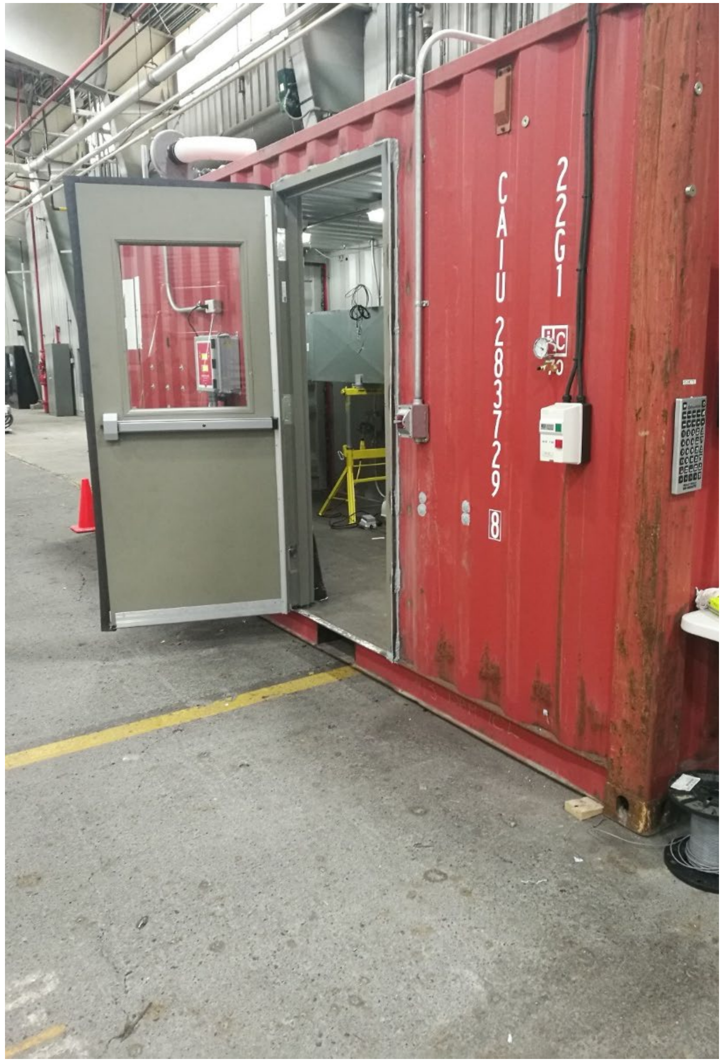
Evaluation of a Cryogenic Air Supply as a Breathable Air Supply for Refuge Alternatives

Lincan Yan, Ph.D.

Pittsburgh Mining Research Division
RA Partnership

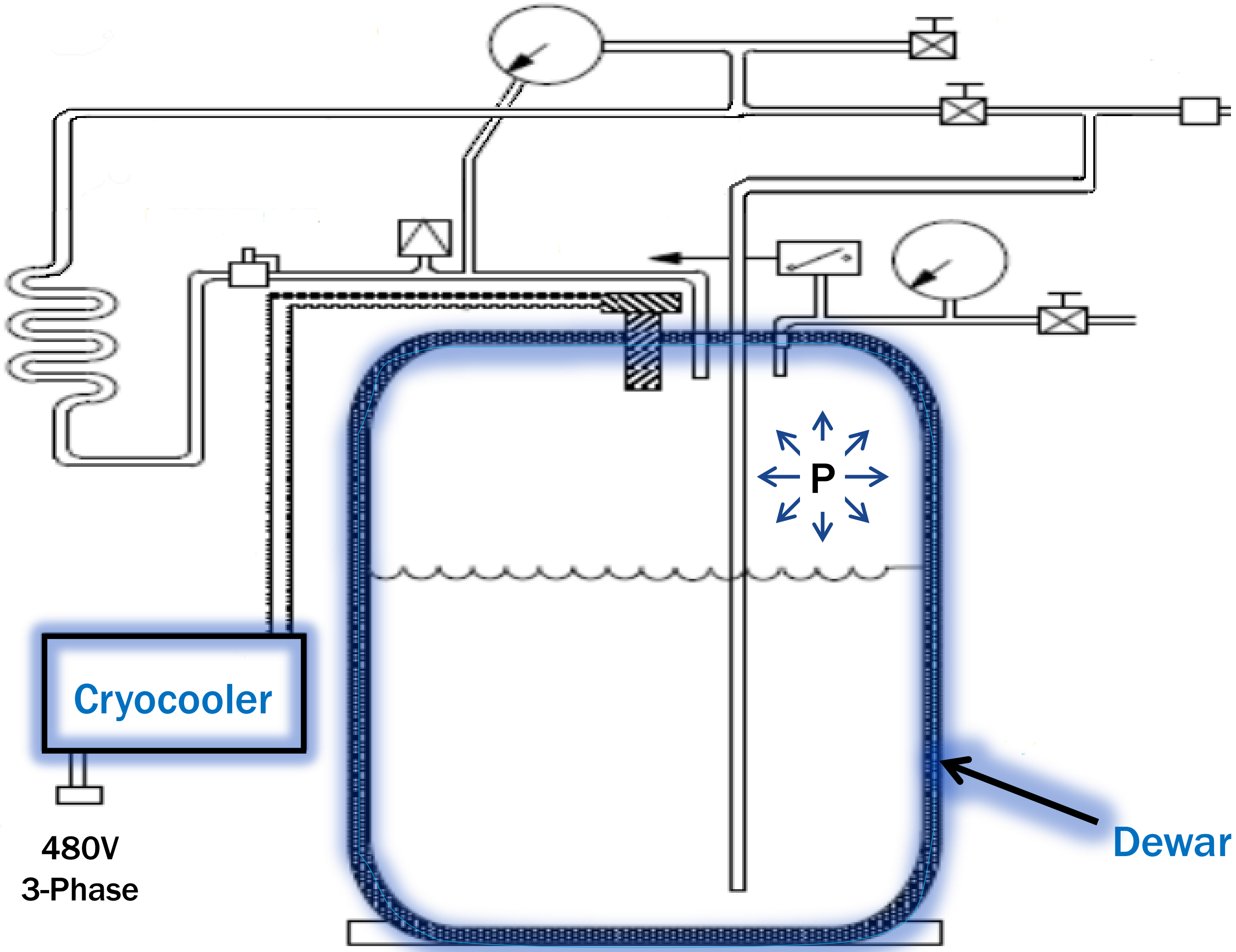
November 17-18, 2021

Objective

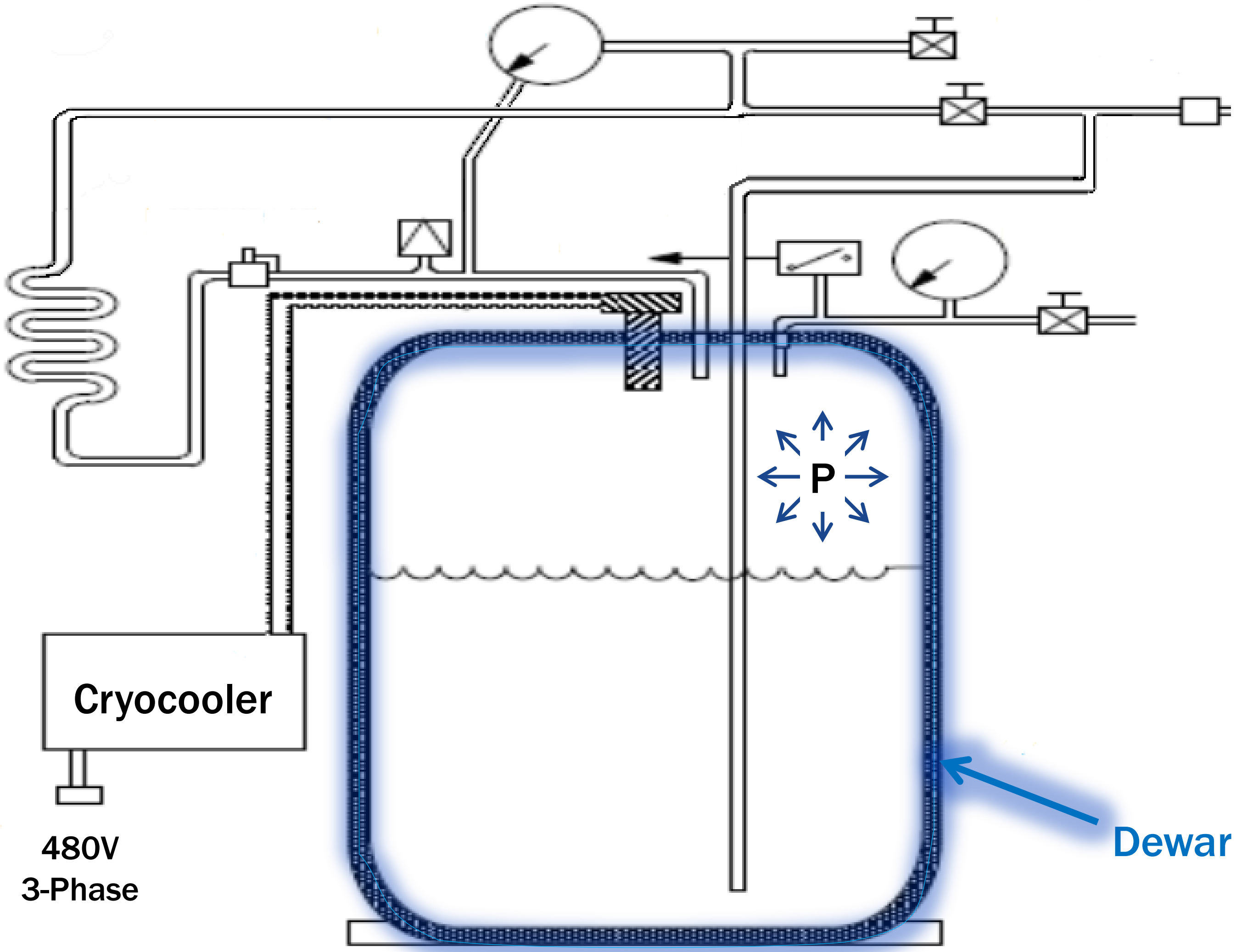


- To simulate human breathing in refuge alternatives
- To characterize the cryogenic air supply as a breathable air source

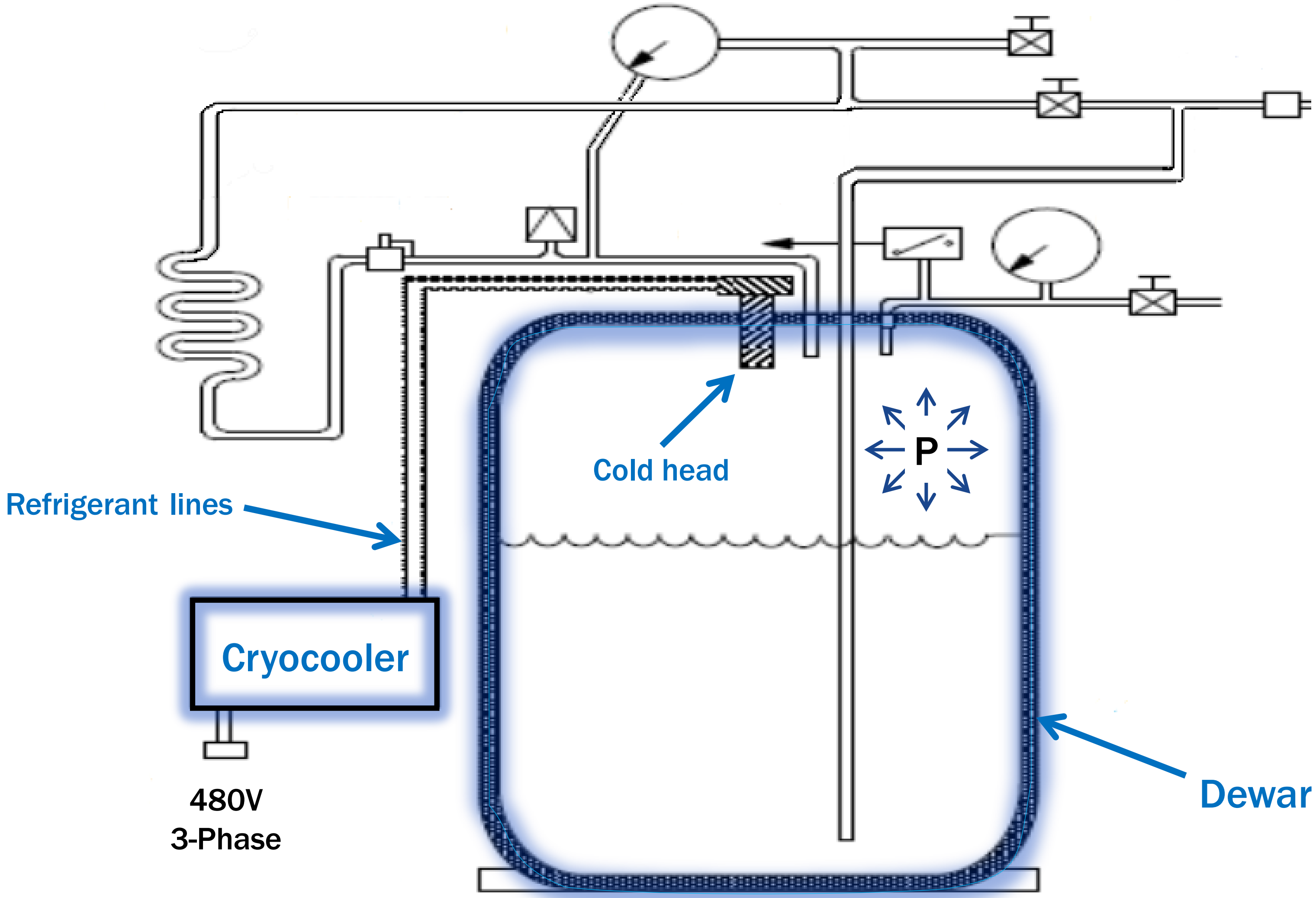
The main components of a cryogenic air supply are the *dewar* and the *cryocooler.*



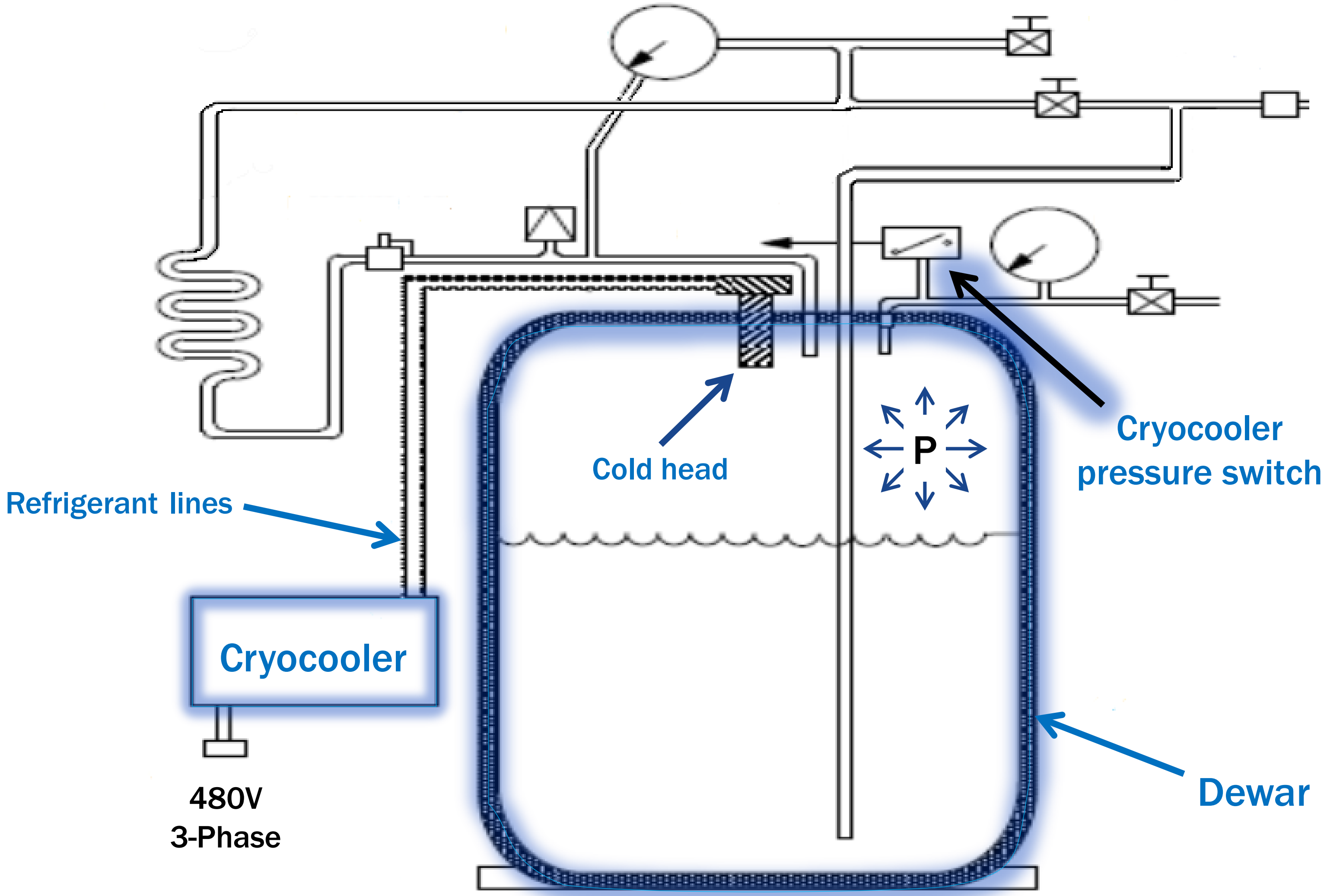
A *dewar* is a double-walled, vacuum-insulated container used to store liquefied gases at cryogenic temperatures (< -90°C, <-130°F).



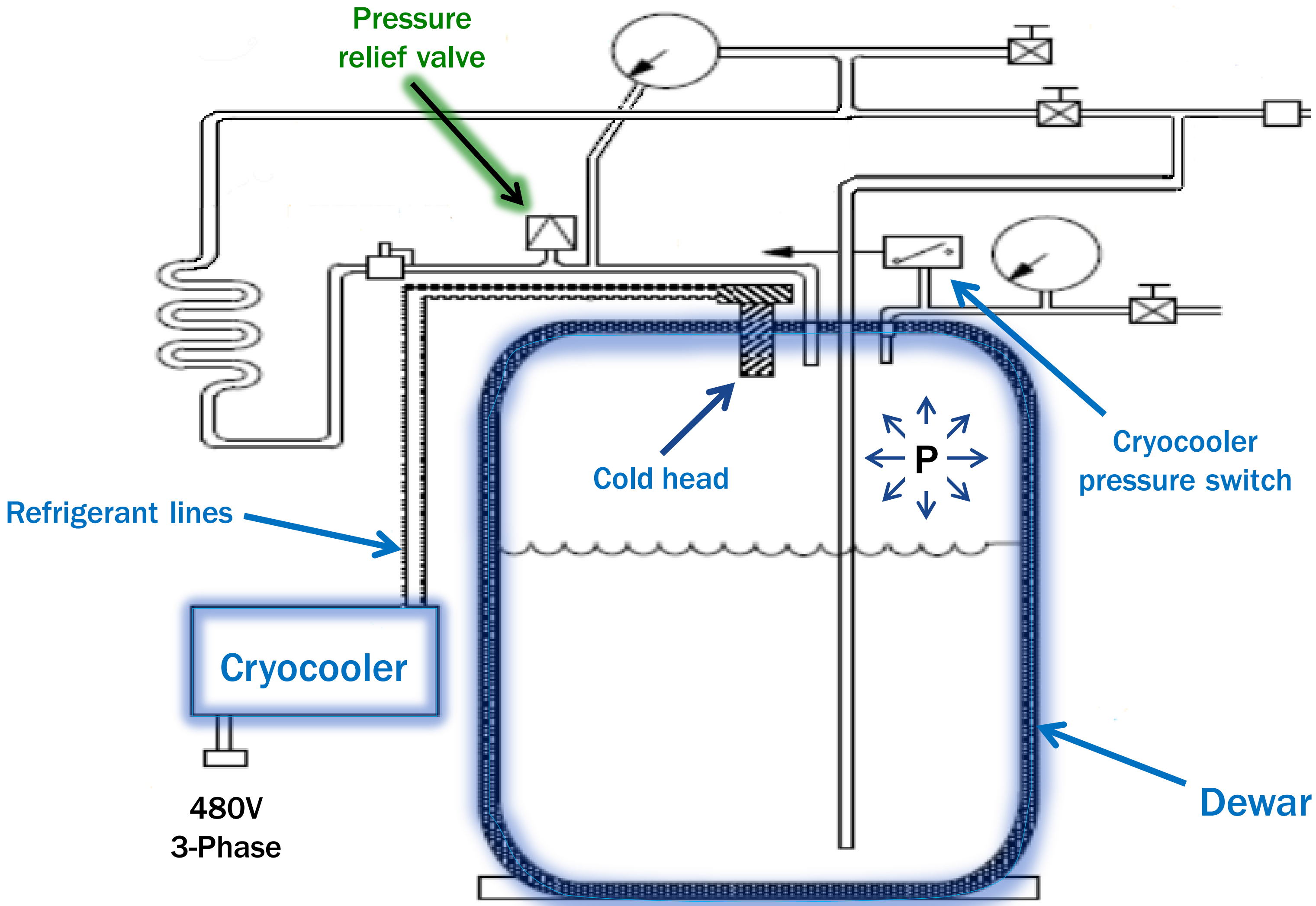
A *cryocooler* is an electrically powered refrigeration system designed to maintain liquids at cryogenic temperatures.



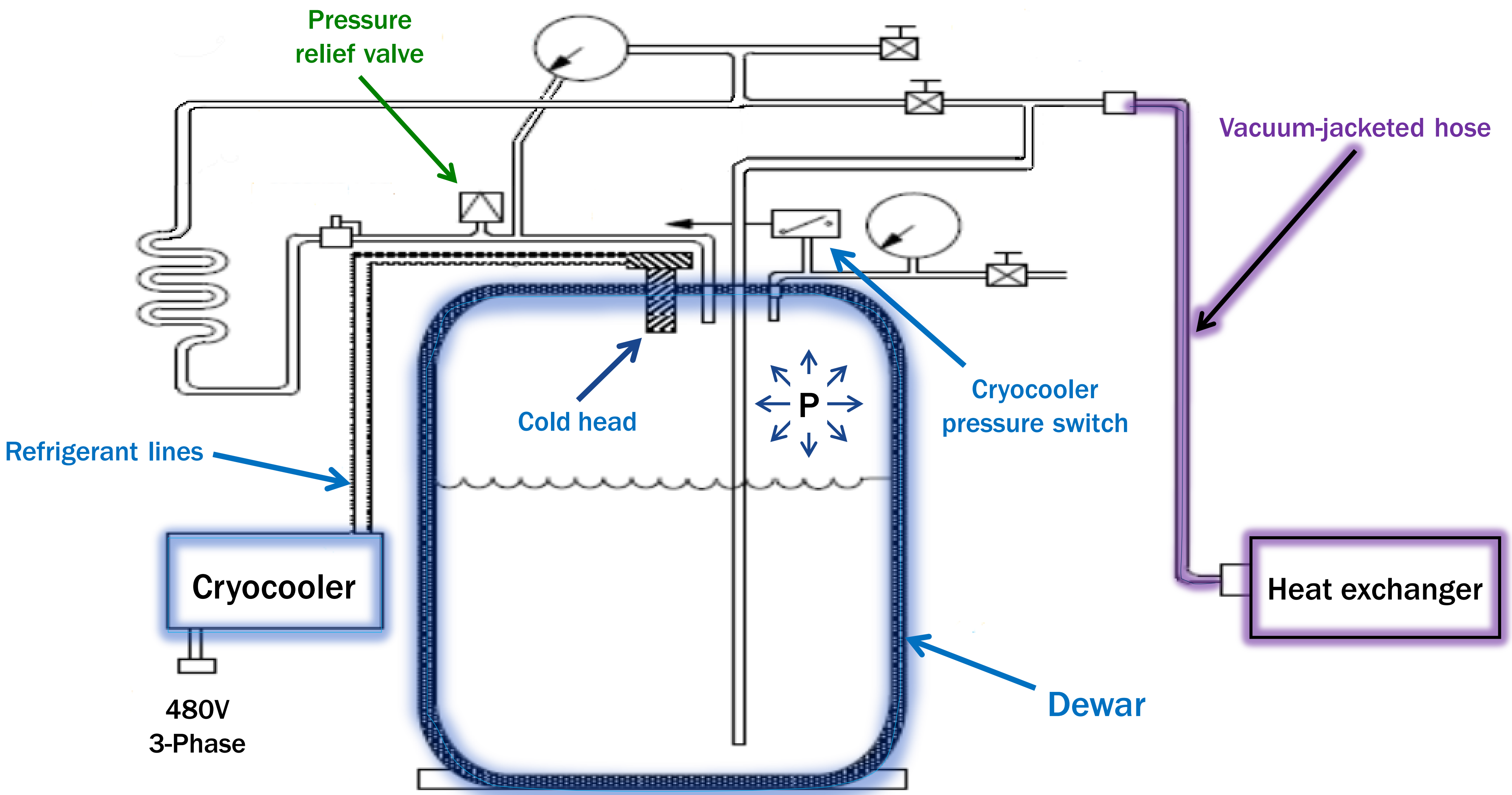
The cryocooler is controlled by a *pressure switch* with adjustable low pressure (off) and high pressure (on) setpoints.



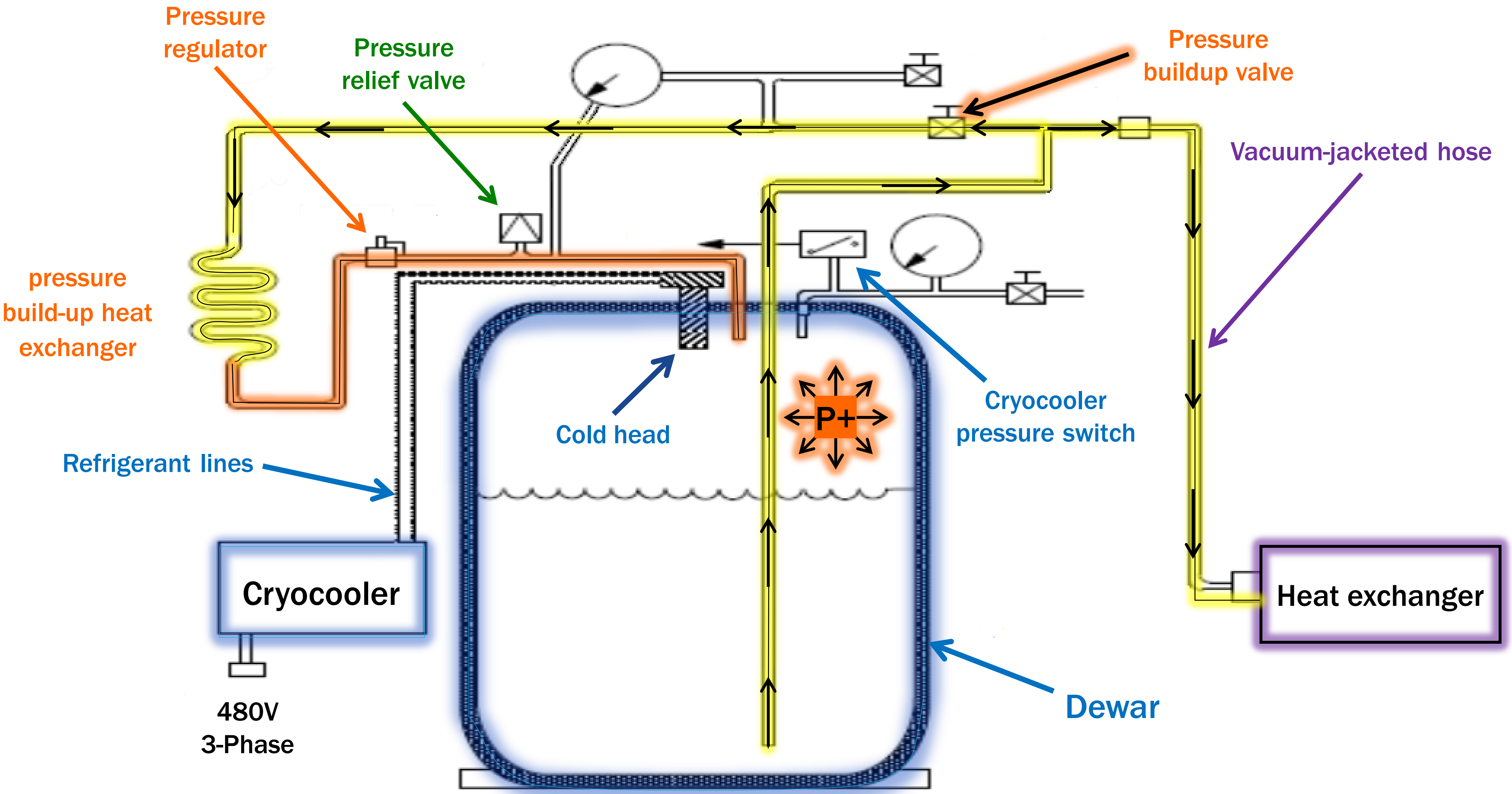
In case the cryocooler loses power or malfunctions, a *pressure relief valve* limits the pressure inside the dewar.



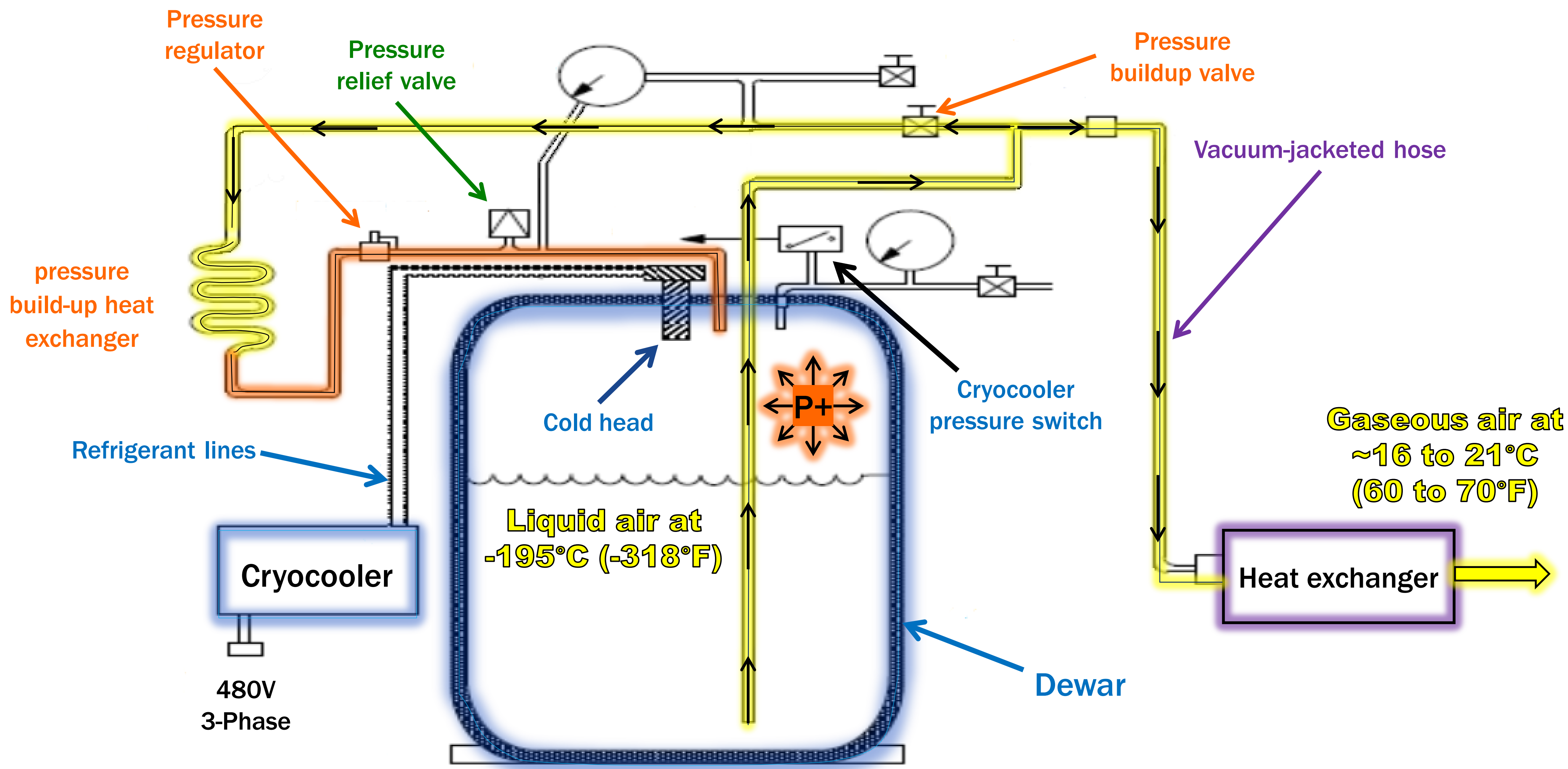
To deliver air from the cryogenic air supply, the cryocooler is turned off and a *vacuum-jacketed hose* is connected to a *heat exchanger* in the space where air is needed.



Then, the *pressure buildup valve* is opened. The *vapor pressure* in the dewar and the *pressure build-up circuit* force liquid air to flow from the dewar to the heat exchanger.



As the *liquid air* flows through the heat exchanger, it absorbs heat from the surroundings converting the liquid to *gaseous air*.



Air and propane delivery, mass flow controllers for the HBS

Propane gas controller

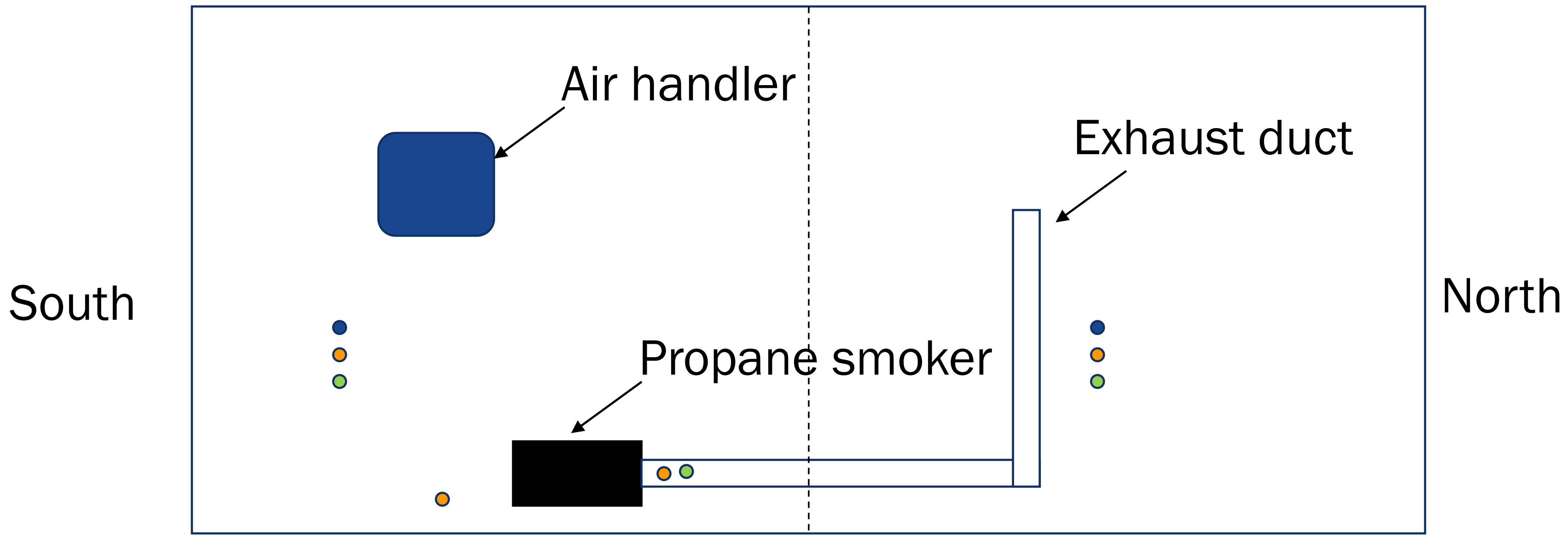
Safety solenoid valve

Propane gas line

Air delivery pump

Air mass controller

Sensor locations



T/RH sensor
O_2 sensor
CO_2 sensor

Concept of Human Breathing Simulator (HBS)

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

Gas	weight, gram	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

Test #1 (96 hours)—O_2 consumption rate from federal regulations

- Based on oxygen consumption rate from federal regulations

  1.32 cu ft or 37.4 liters of pure oxygen per hour/person
- Cryo air supply
- CO_2 scrubbing curtains

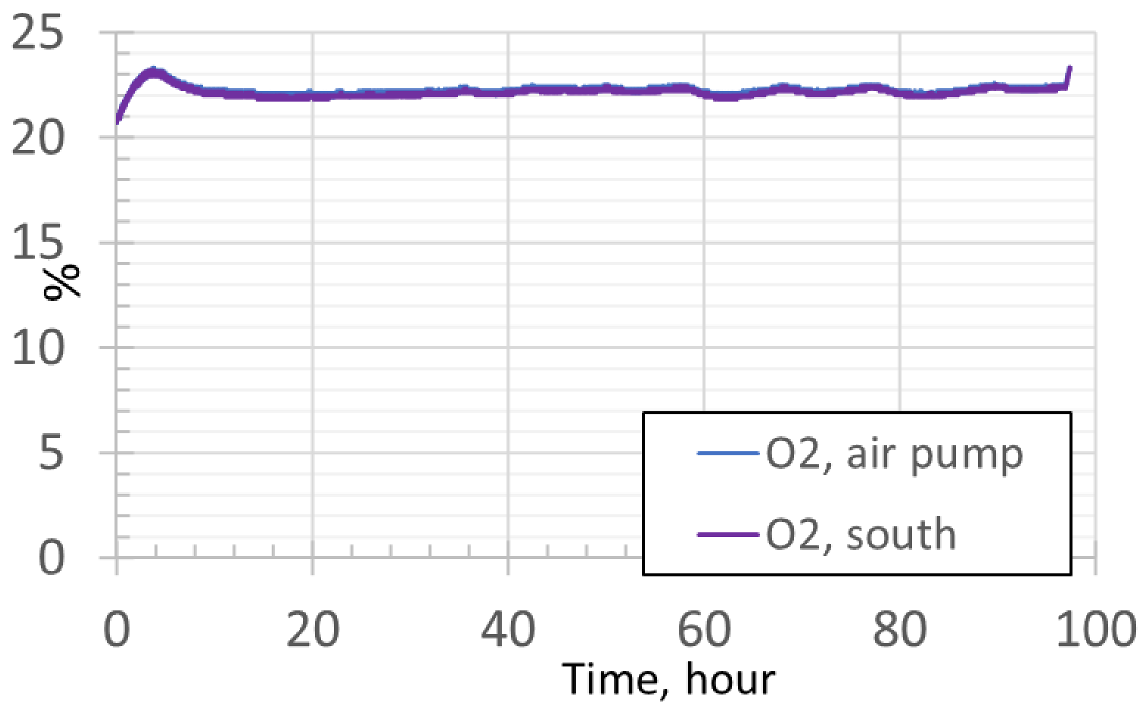
Test #2 (96 hours)—University of South Florida consumption rate

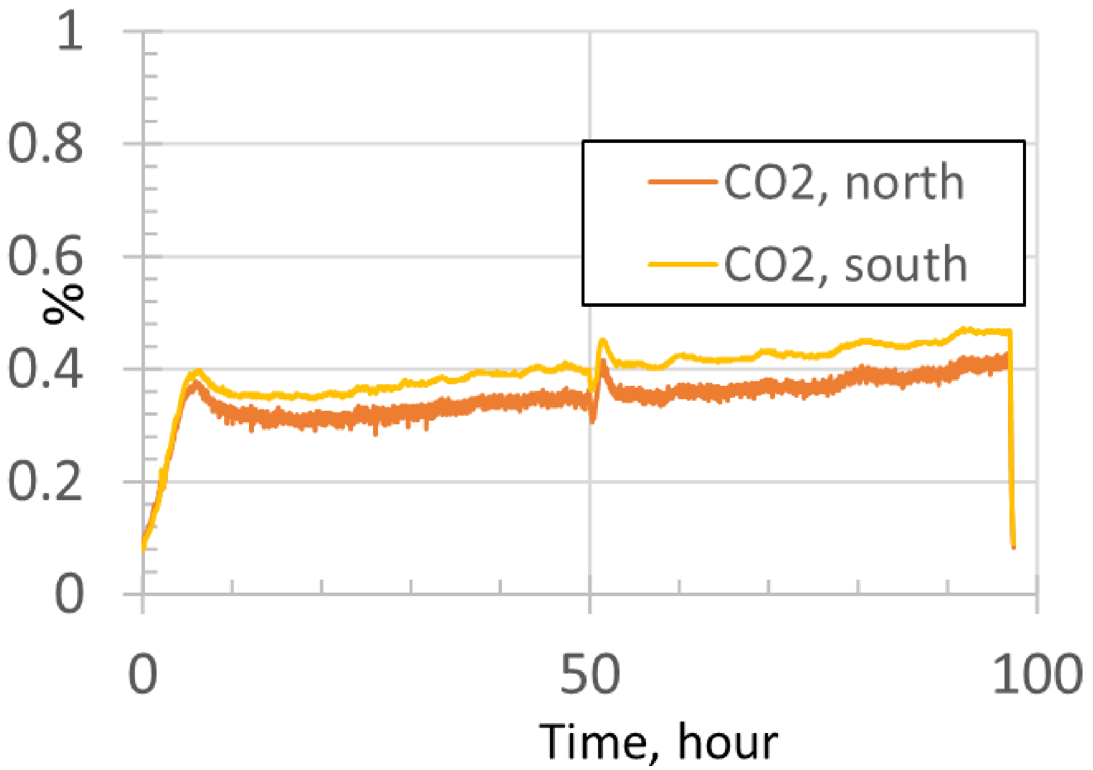
- Based on oxygen consumption rate of University of South Florida ~19 liters pure oxygen per hour/person
- Cryo air supply
- CO_2 scrubbing curtains

	Federal Regulation: O_2 consumption at 1.32 ft3/hr/person CO_2 generation at 1.08 ft3/hr/person			
	21 Miners	Propane Burner		
Fuel burning rate	NA	0.28 kg/hr (0.62 LB/hr)		
O_2 mass consumption rate	1.01 kg/hr (2.23 LB/hr)			
O_2 volume consumption rate	0.78 m3/hr (27.7 ft3/hr)			
CO_2 mass generation rate	1.1 kg/hr (2.4 LB/hr)	0.8 kg/hr (1.76 LB/hr)		
CO_2 volume generation rate	0.64 m3/hr (22.7 ft3/hr)	0.47 m3/hr (16.6 ft3/hr)		

	Federal Regulation: O_2 consumption at 1.32 ft3/hr/person CO_2 generation at 1.08 ft3/hr/person		Bernard Research: O_2 consumption at 0.67 ft3/hr/person CO_2 generation at 0.60 ft3/hr/person	
	21 Miners	Propane Burner	21 Miners	Propane Burner
Fuel burning rate	NA	0.28 kg/hr (0.62 LB/hr)	NA	0.14 kg/hr (0.31 LB/hr)
O_2 mass consumption rate	1.01 kg/hr (2.23 LB/hr)		0.52 kg/hr (1.15 LB/hr)	
O_2 volume consumption rate	0.78 m3/hr (27.7 ft3/hr)		0.4 m3/hr (14.1 ft3/hr)	
CO_2 mass generation rate	1.1 kg/hr (2.4 LB/hr)	0.8 kg/hr (1.76 LB/hr)	0.63 kg/hr (1.39 LB/hr)	0.42 kg/hr (0.93 LB/hr)
CO_2 volume generation rate	0.64 m3/hr (22.7 ft3/hr)	0.47 m3/hr (16.6 ft3/hr)	0.36 m3/hr (12.6 ft3/hr)	0.24 m3/hr (8.47 ft3/hr)

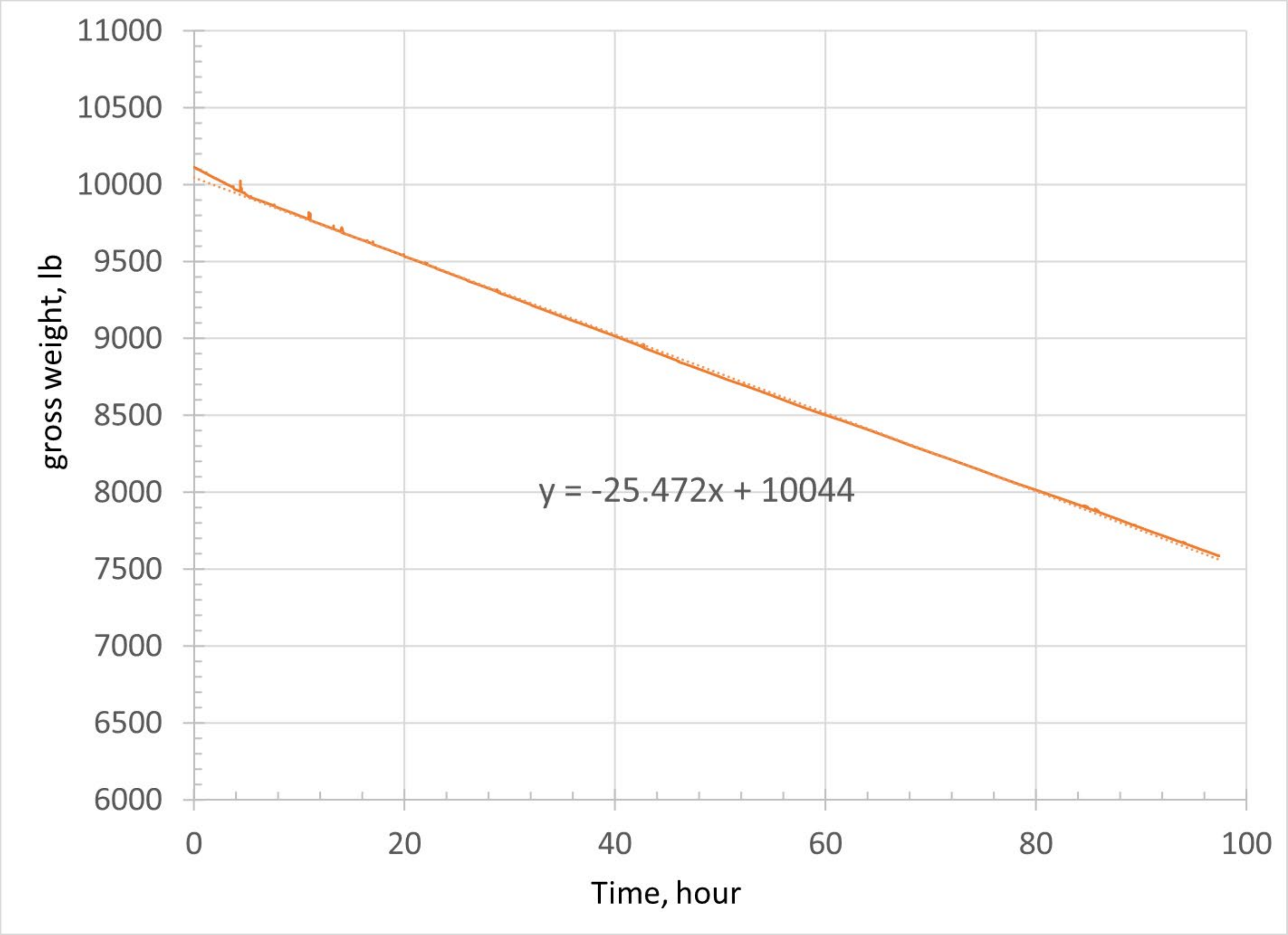
Test #1 results—O_2 level ~22%, CO_2 level <1%





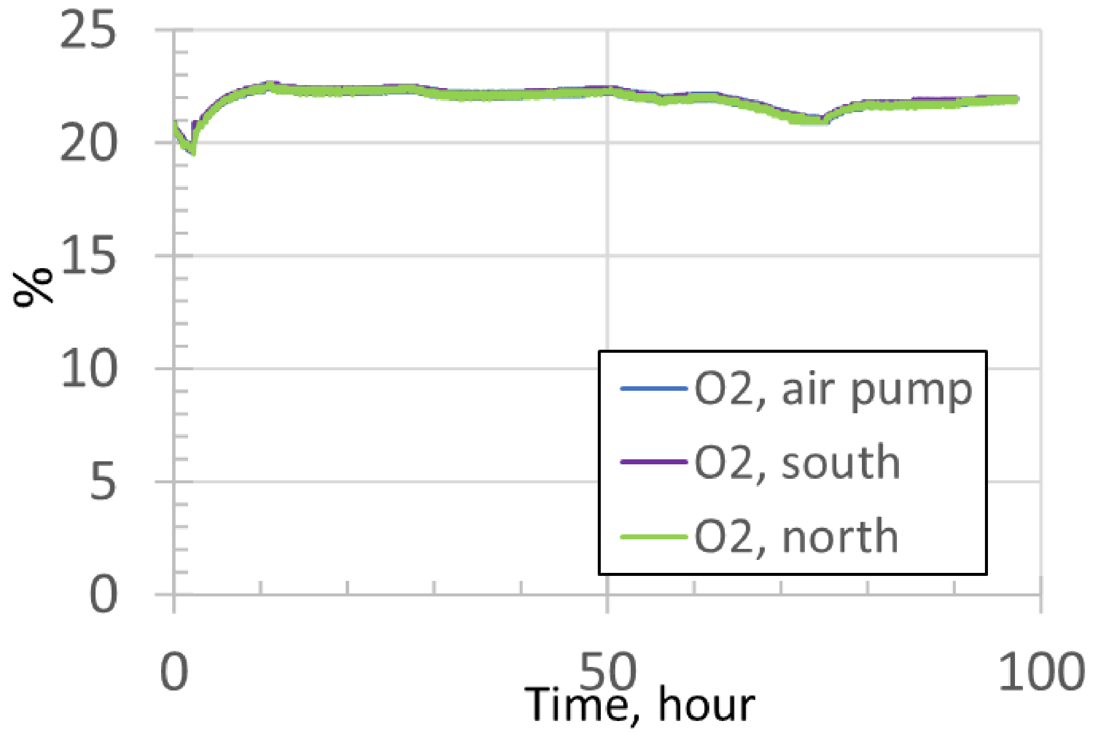
"This information is distributed solely for the purpose of pre dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. It does not represent and should not be construed to represent any agency determination or policy."

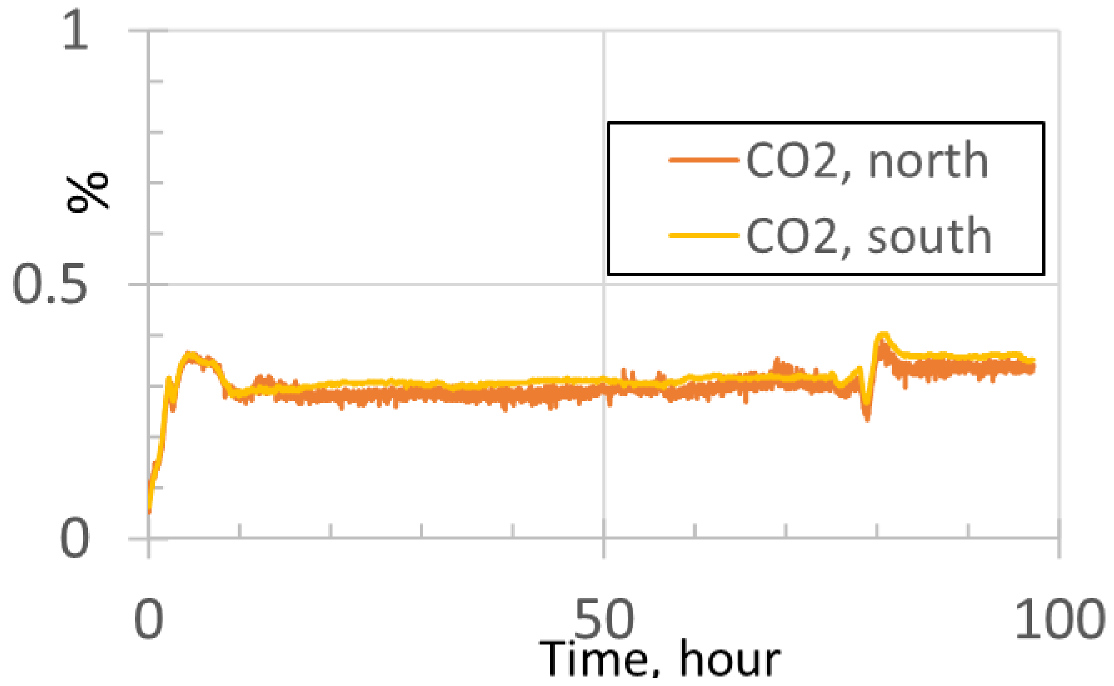
Test #1 results—cryo air weight loss at 25.5 lb/hr



"This information is distributed solely for the purpose of pre dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. It does not represent and should not be construed to represent any agency determination or policy."

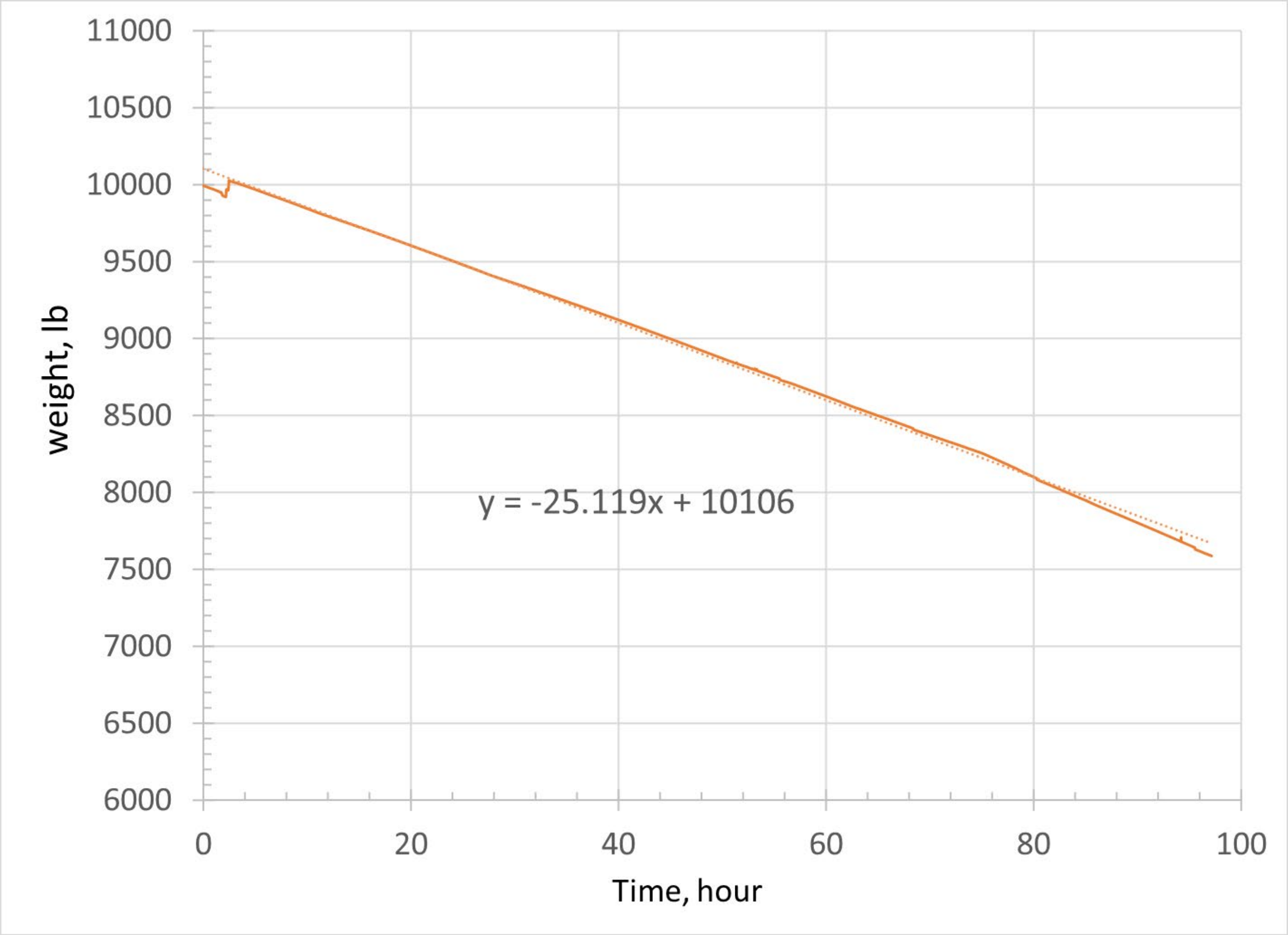
Test #2 results—O_2 level 20%-22%, CO_2 level <1%





"This information is distributed solely for the purpose of pre dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. It does not represent and should not be construed to represent any agency determination or policy."

Test #2 results—cryo air weight loss at 25.1 lb/hr

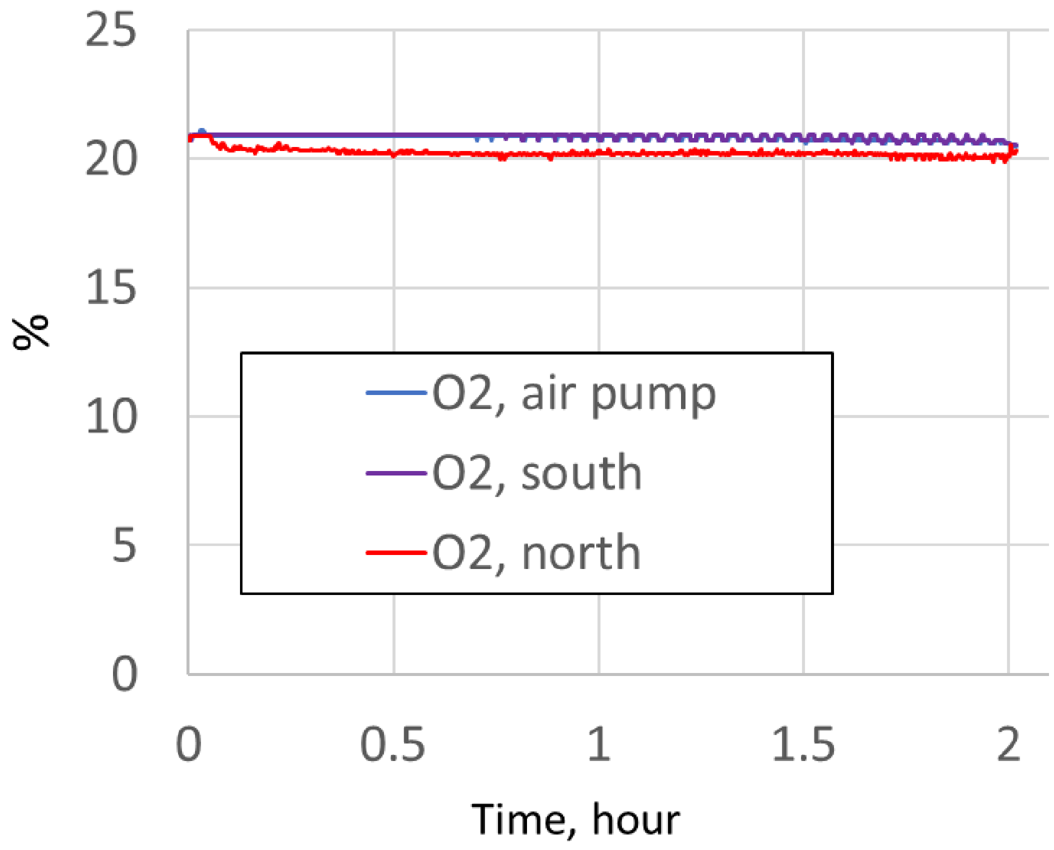


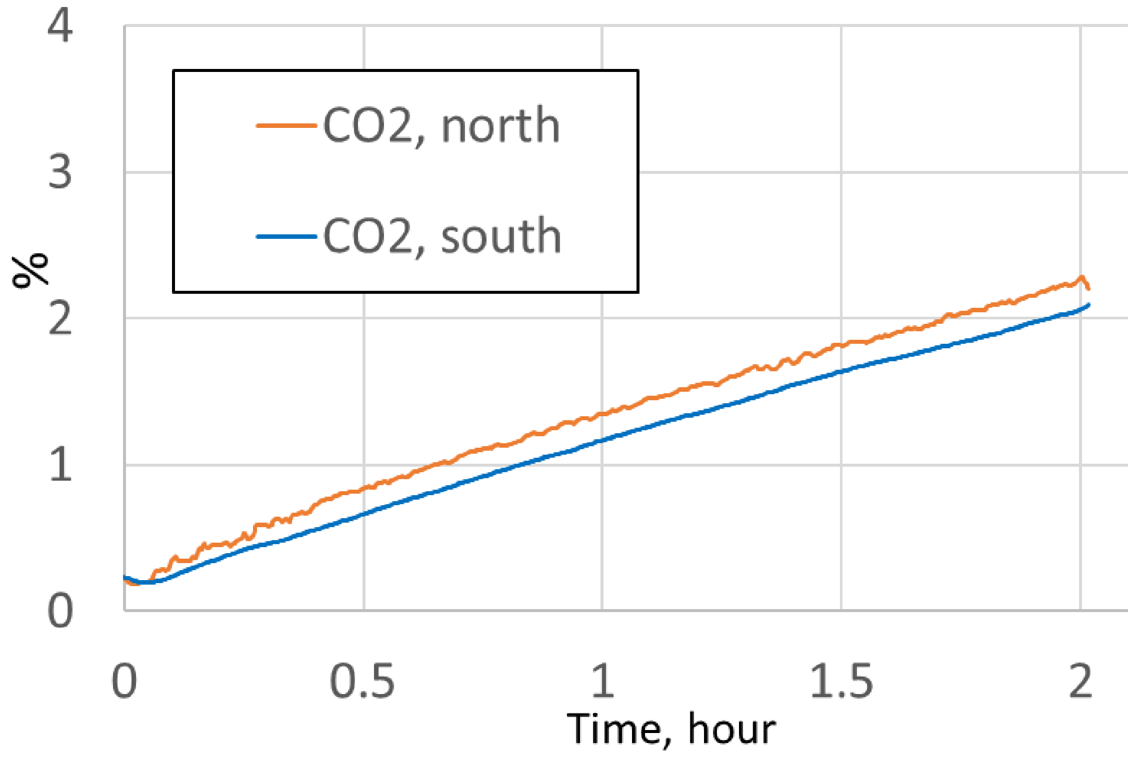
“This information is distributed solely for the purpose of pre dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. It does not represent and should not be construed to represent any agency determination or policy.”

Test #3 (2 hours)—how fast the %CO_2 will increase w/o mitigation

- NO CO_2 scrubbing curtains
- Based on federal regulation oxygen consumption rate
- Cryo air supply

Test #3 result—CO_2 will exceed the 1% limit within 1 hour





"This information is distributed solely for the purpose of pre dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. It does not represent and should not be construed to represent any agency determination or policy."

Conclusion

- Both 96-hour tests show the cryogenic air supply can maintain the O_2 and CO_2 level within the federal regulation limit
- CO_2 level will increase dramatically without CO_2 mitigation
- The 2000-liter CryoRASS has the capacity to provide breathable air for 21 people for at least 96 hours
- Need the capacity of adjusting the cryo air flow rate from inside

Thank you!

Lincan Yan
LYan1@cdc.gov
412-386-6876