Update on NIOSH Refuge Alternative Heat & Humidity Research

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Outline

1. Introduction/background
2. BIP RA Heat/Humidity Tests (Revisited)
3. Field Heat/Humidity Test of Portable RA
4. Planned Heat/Humidity Tests for 2017
5. BP V2.0 Development

Heat and humidity buildup in RAs is a serious concern

- *Heat exhaustion* occurs at body core temperatures between 98.6°F to 104°F
  - Anxiety, confusion
  - Vomiting, low blood pressure, decreased urination
  - Flushing, profuse sweating, rapid heartbeat (increased heat dissipation)
- *Heat stroke* occurs at body core temperatures above 104°F
  - Medical emergency (10% mortality rate)
  - Confusion, irritability, loss of control of body movement, seizures, coma
  - Cessation of sweating, hyperventilation, fluid accumulation in the lungs
  - Rapid breakdown of skeletal muscle tissue, blood clots
  - Heart arrhythmia, liver failure, kidney failure, shock

Management of Heatstroke and Heat Exhaustion. James L. Glazer, M.D., Maine Medical Center, Portland, Maine
Am Fam Physician. 2005 Jun 1;71(11):2133-2140. http://www.aafp.org/afp/2005/0601/p2133.html

Several aspects of RA regulations are related to the thermal conditions inside an RA

- 96-hour duration
- 95°F apparent temperature limit
- Space requirement per miner - 15 ft^2
- Volume requirement per miner based on mine height

Mining Height (inches)	Unrestricted Volume per Person (ft^3)
36 or less	30
36 to 42	37.5
42 to 48	45
48 to 54	52.5
54 or more	60

RA heat transfer is complicated

- Heat sources include metabolic heat from miners and carbon dioxide scrubber heat (when scrubbers are required)
- RAs have a limited ability to dissipate heat
  - Conduction to mine floor strata, convection to mine air, radiation to mine strata
  - Mine strata has low thermal conductivity, acts as a heat insulator
  - “Warm” strata conditions increase temperatures within an RA
- Human heat loss involves sensible and latent heat transfer
  - Sensible: Conduction, convection, radiation
  - Latent: Evaporation of sweat
    - High humidity inside an occupied RA will reduce effectiveness of evaporative cooling
    - RAs have a limited water supply to replenish water lost by sweat

NIOSH conducted tests to examine the need for cooling of BIP RAs

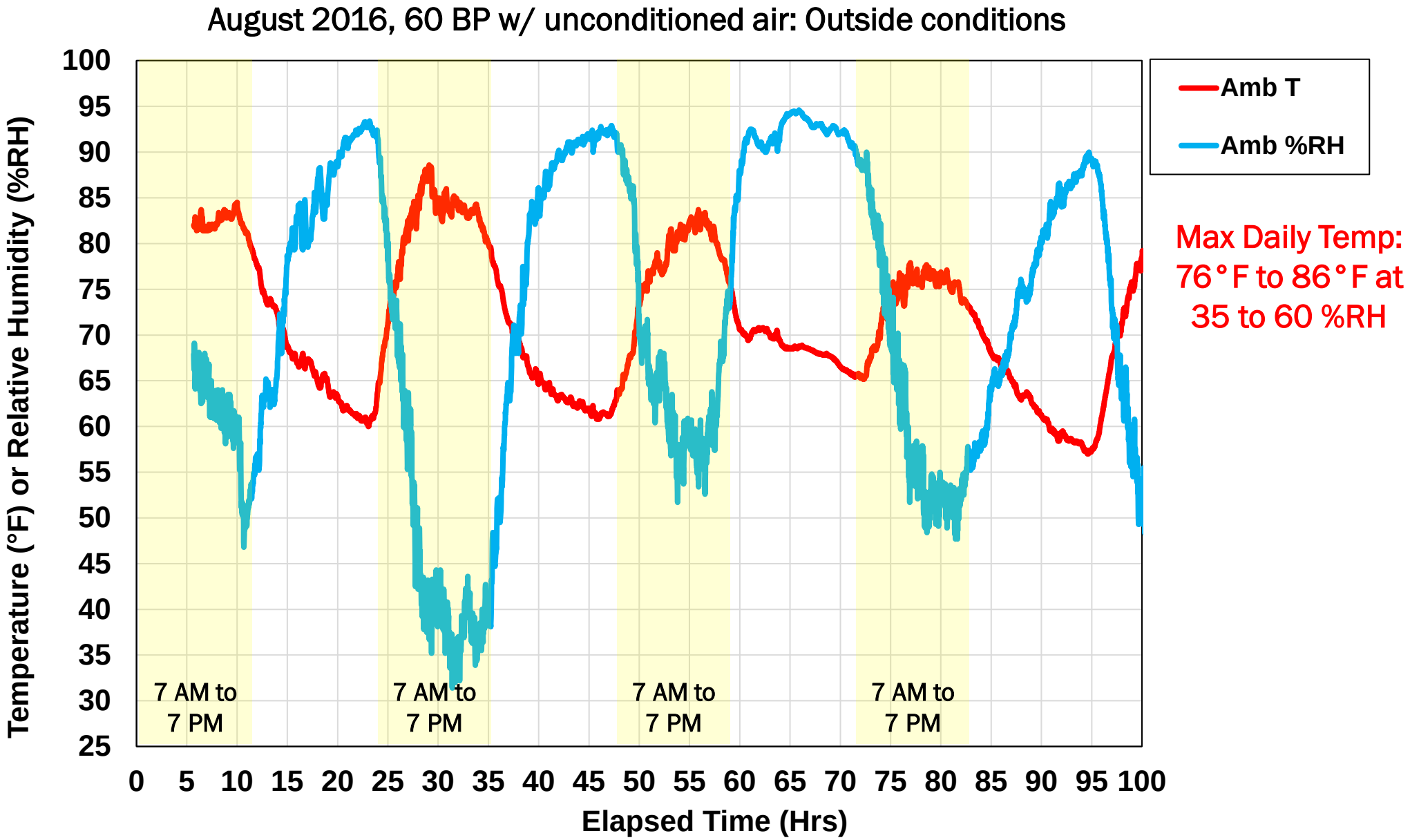
- August 2016: Test w/ 60 SMs w/ borehole air supply delivering unconditioned air
- December 2015 : Test w/ 30 SMs (BIP RA partitioned) w/ no borehole air supply
  - Represents the case of a BIP RA w/ oxygen or compressed air cylinders
- Automatic VARIACs to control power at desired heat input
- Simulated miners (SM) to represent miners' metabolic heat and moisture input
- Heated water tanks to represent CO_2 scrubbing system heat

Automatic VARIAC

Simulated Miners (aka Barrel People)

Borehole Air Supply

For warm conditions above ground w/ 60 SMs and unconditioned borehole air supply, AT was close to the 95°F AT limit, even with "mild" T/RH



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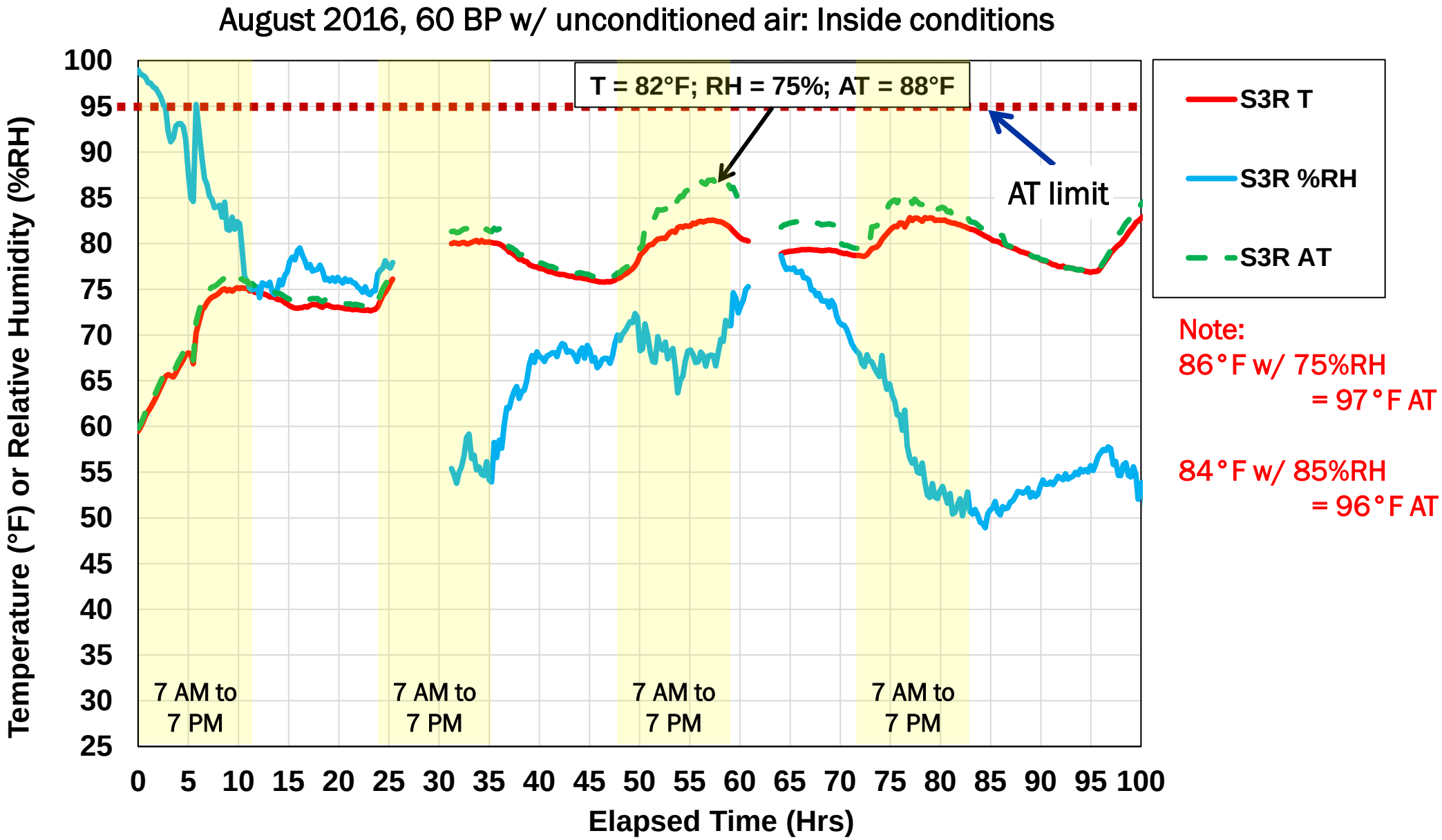
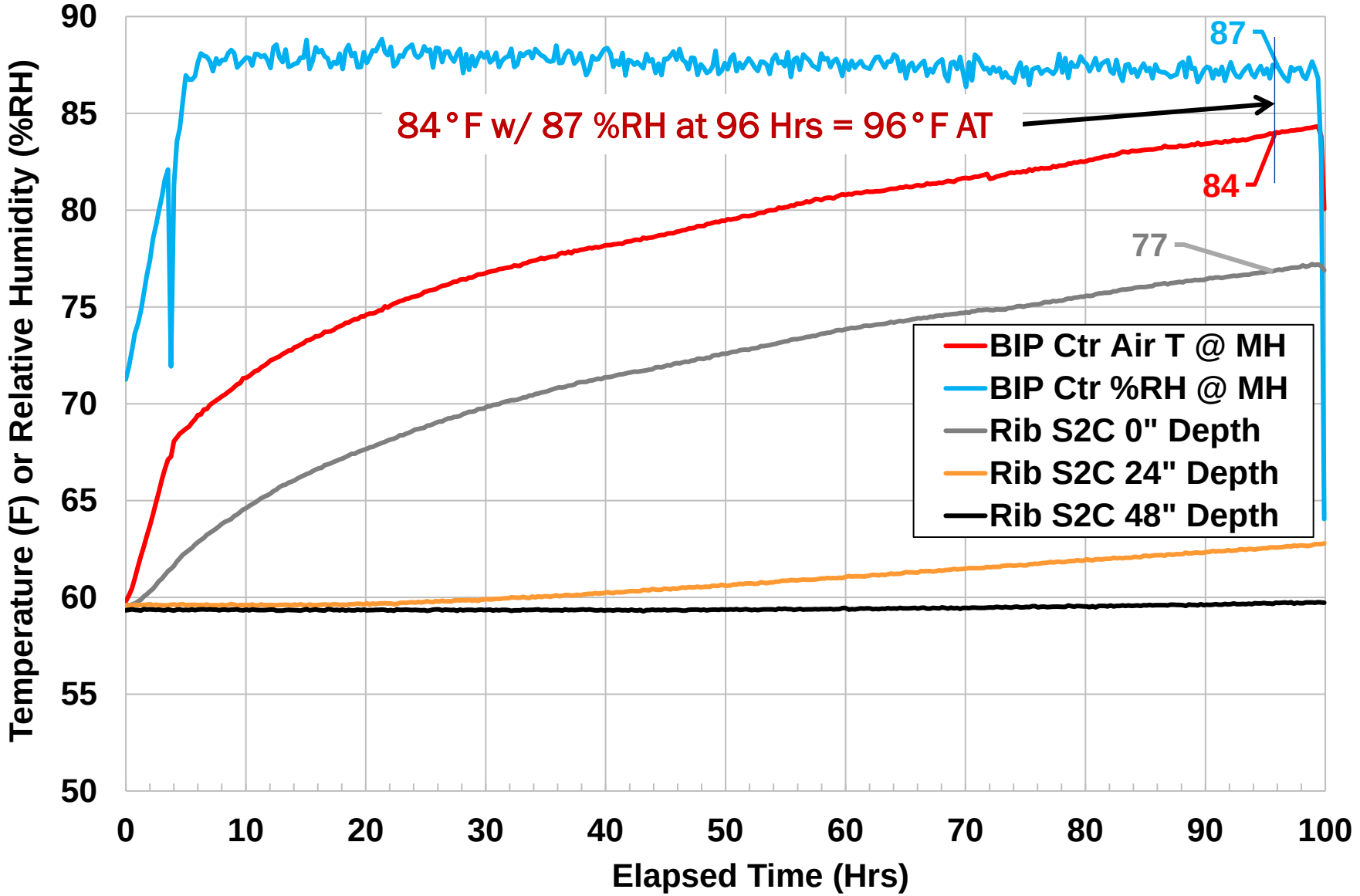


For no borehole airflow w/ 30 SMs (cylinders for air/oxygen), final AT exceeded the 95°F AT limit, even with a ~60°F initial mine temperature

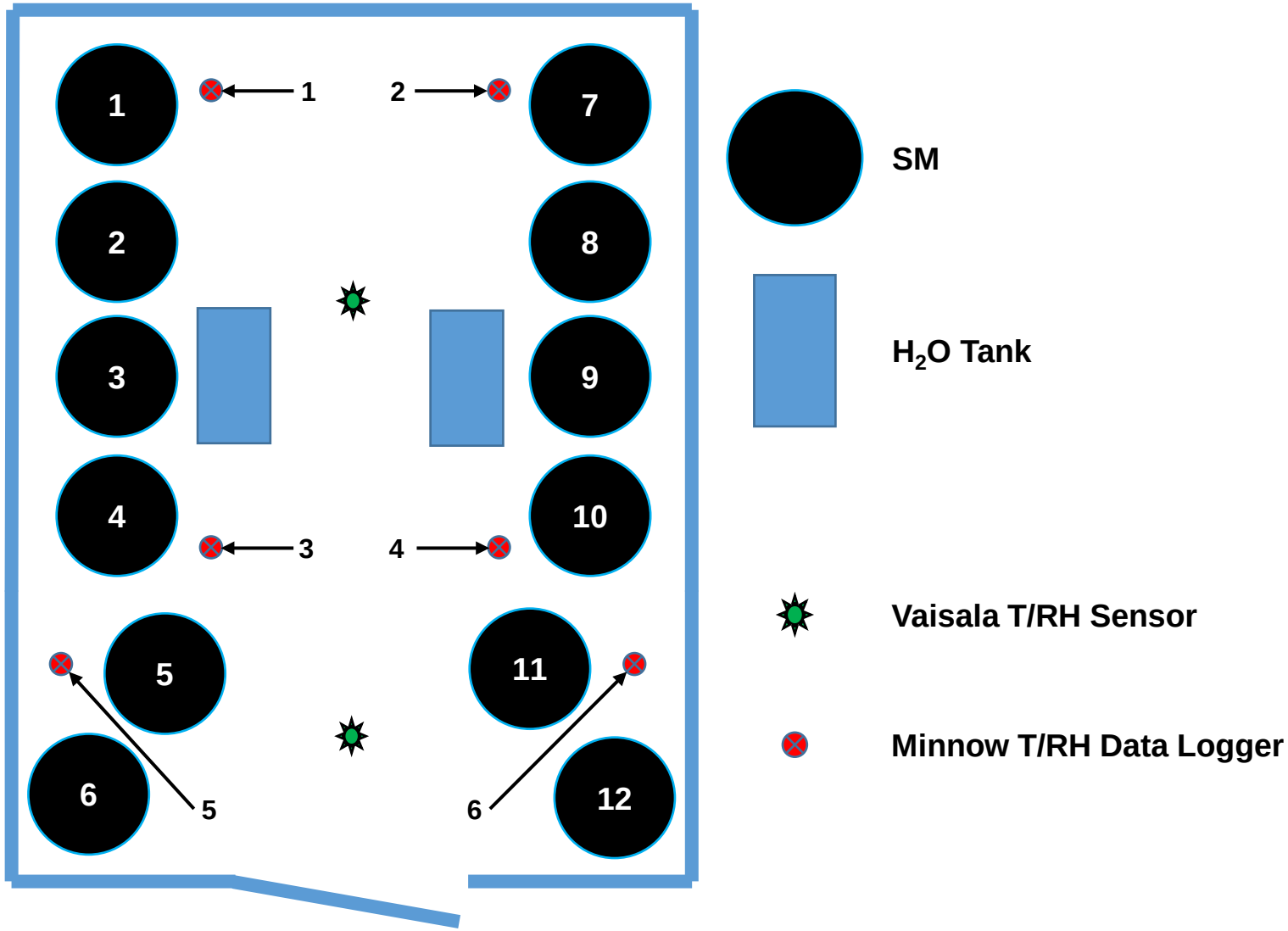


Heat mitigation may be necessary for BIP RAs depending on the BIP RA design and mine specific conditions

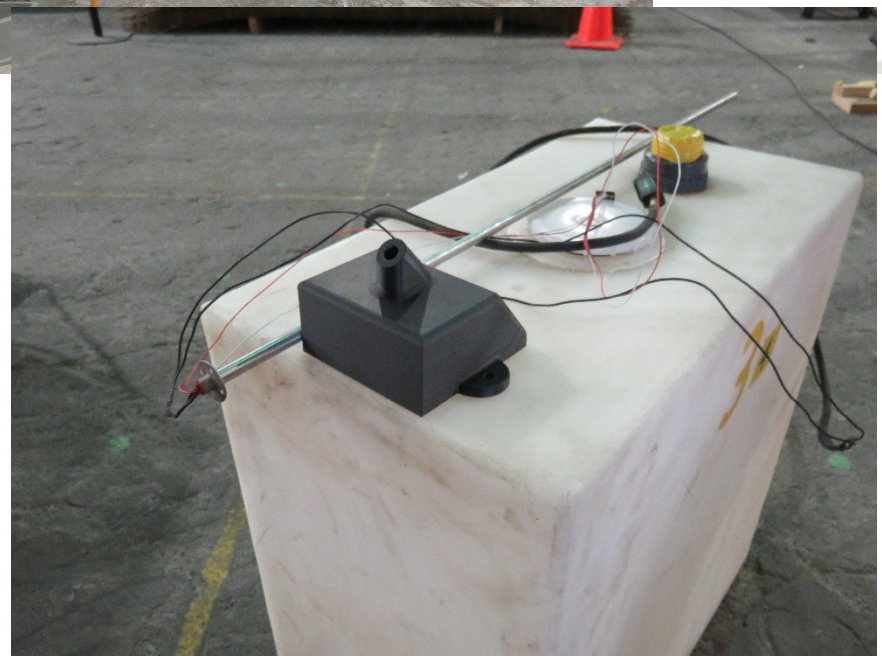
- Air/oxygen supply method
- Mine depth
- Mine air/strata temperature
- Mine strata composition
- Outside atmospheric conditions

NIOSH PMRD conducted field heat/humidity tests on a portable RA

- **Warm mine**
  - Strata temp ~75°F
  - Initial air temp ~75°F
- **As-sold capacity of 12 people**
- **2018 capacity of 6 people (15 ft²/person)**
- **Tested w/ 12 simulated miners**

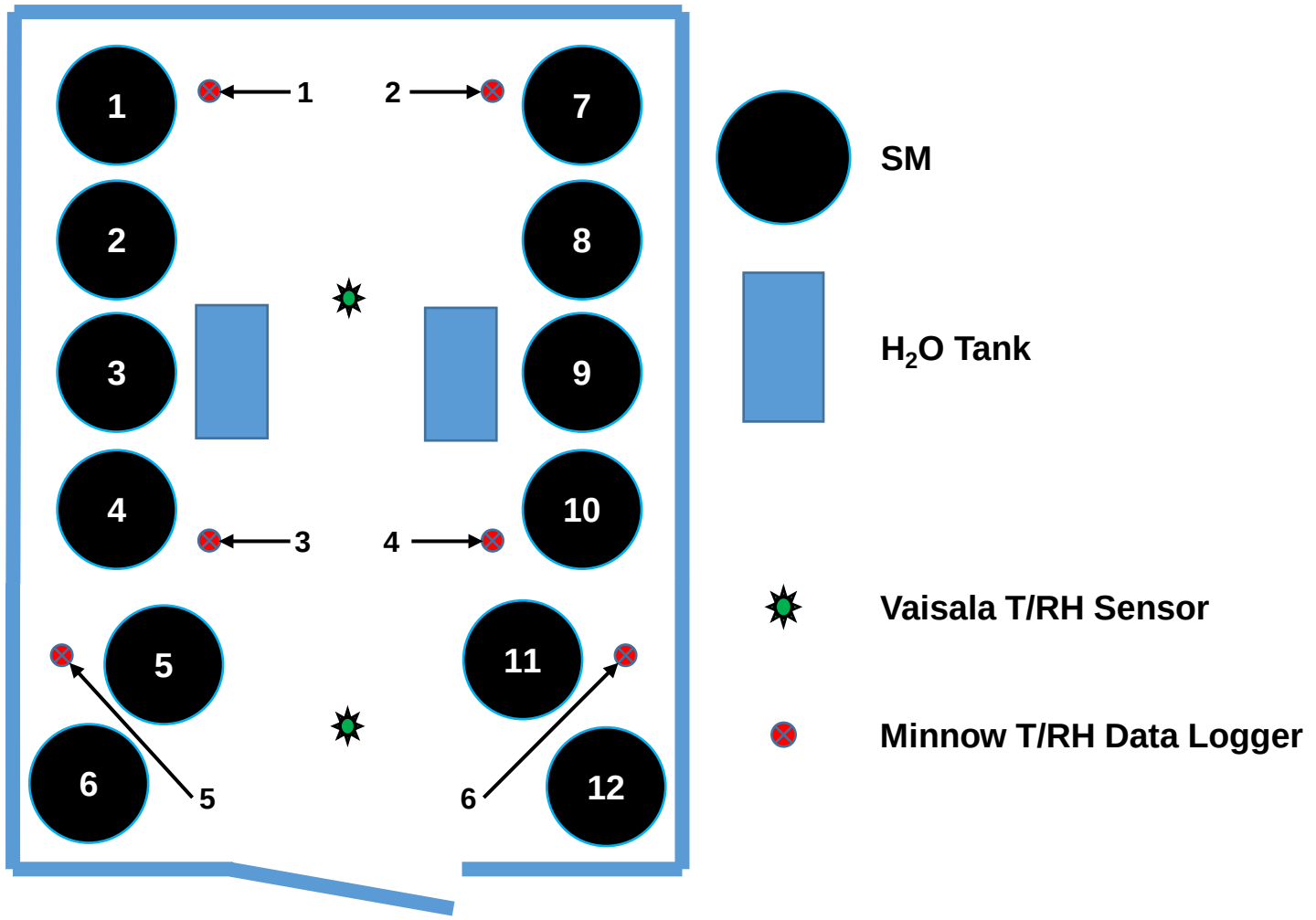


Prior to field tests, equipment was gathered and a mock test was set up

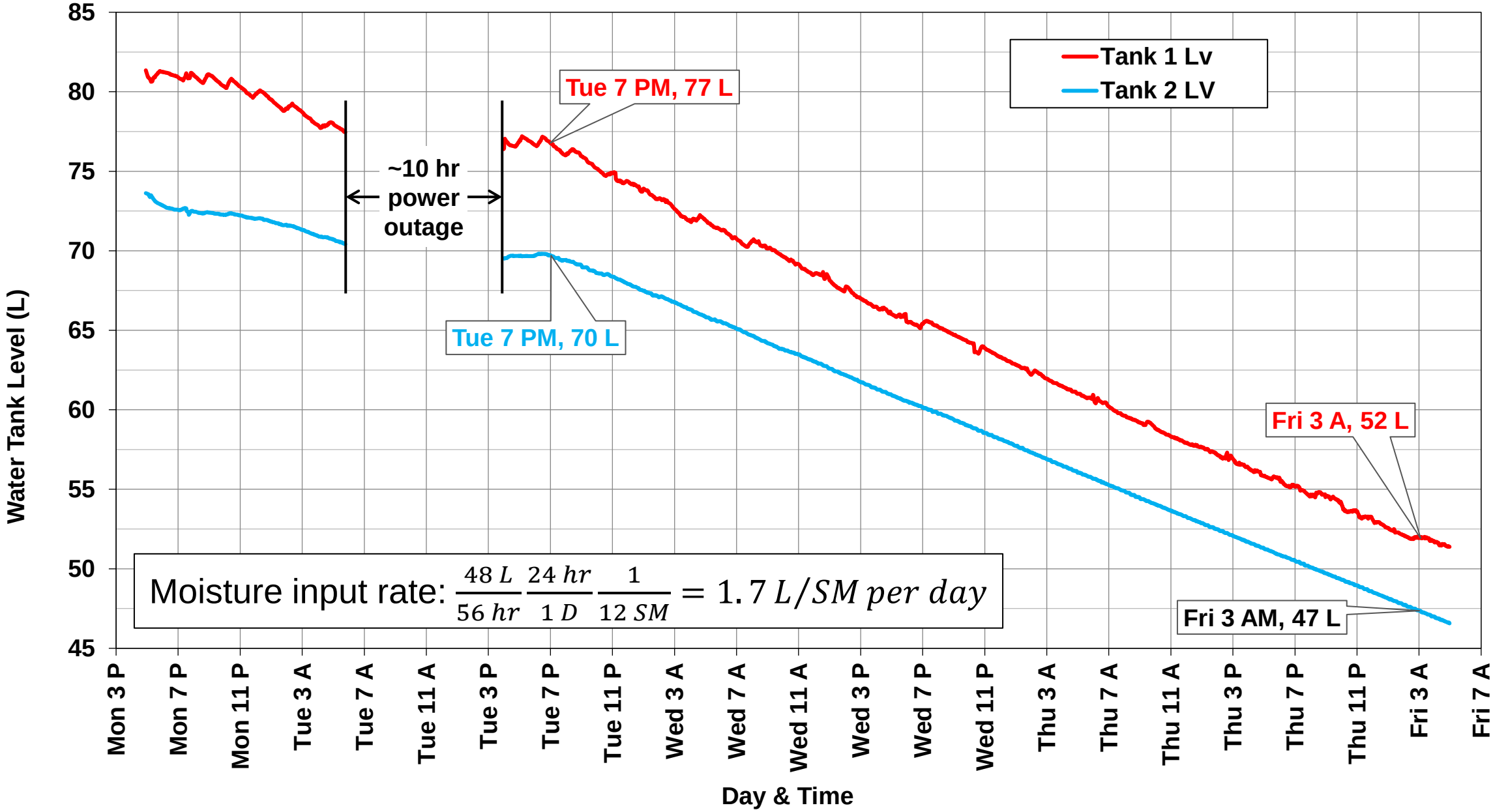


All “standard” NIOSH test procedures were followed during field H/H testing

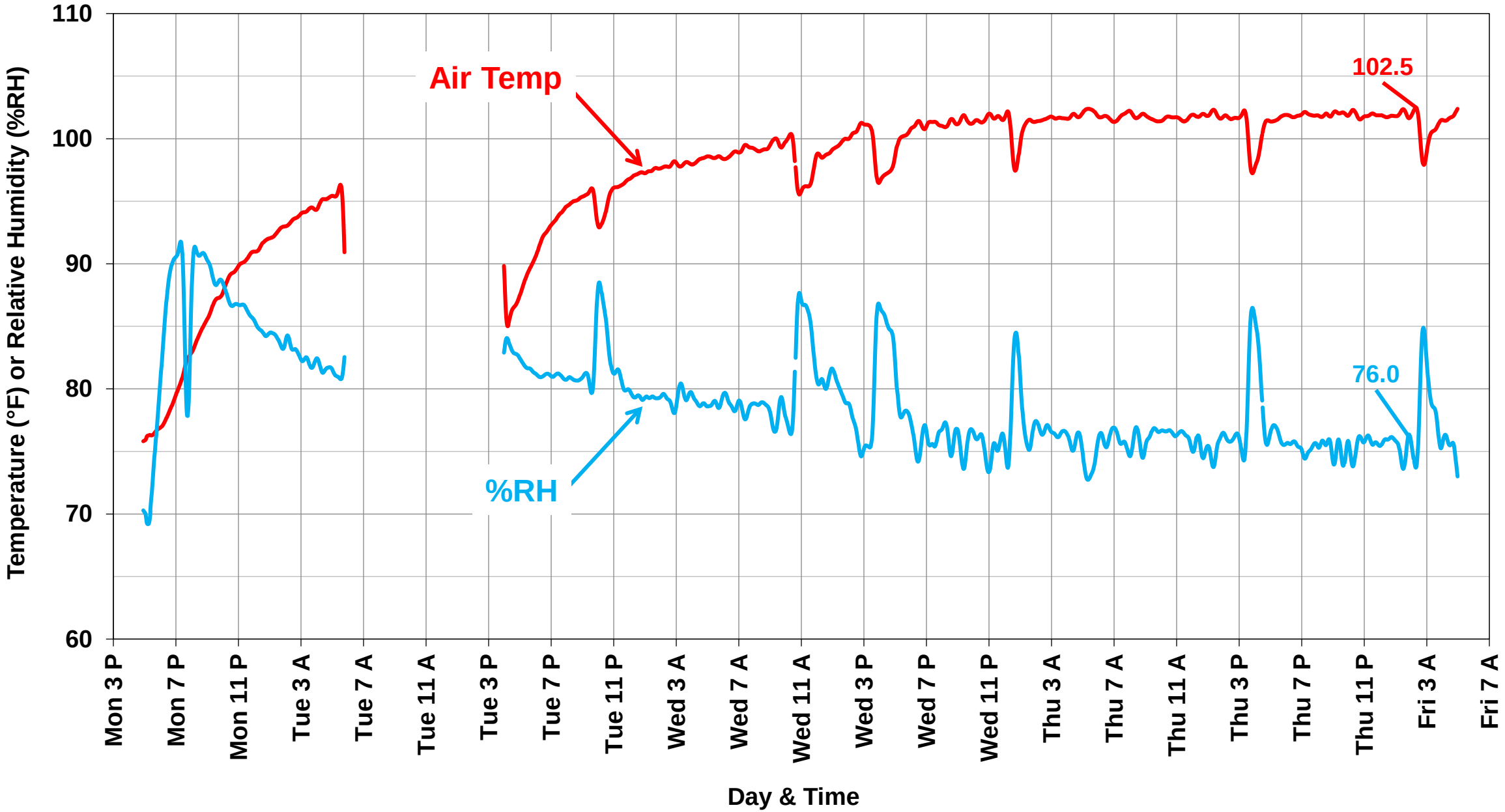
- 117 W of “metabolic heat” per SM
- 27.5 W of CO_2 scrubber heat per SM
- SMs preheated for ~2-3 hrs at beginning of test
  - SMs wrapped in quilted fiberglass blankets
  - Double power input for preheat period
- Automatic VARIAC to control heat input



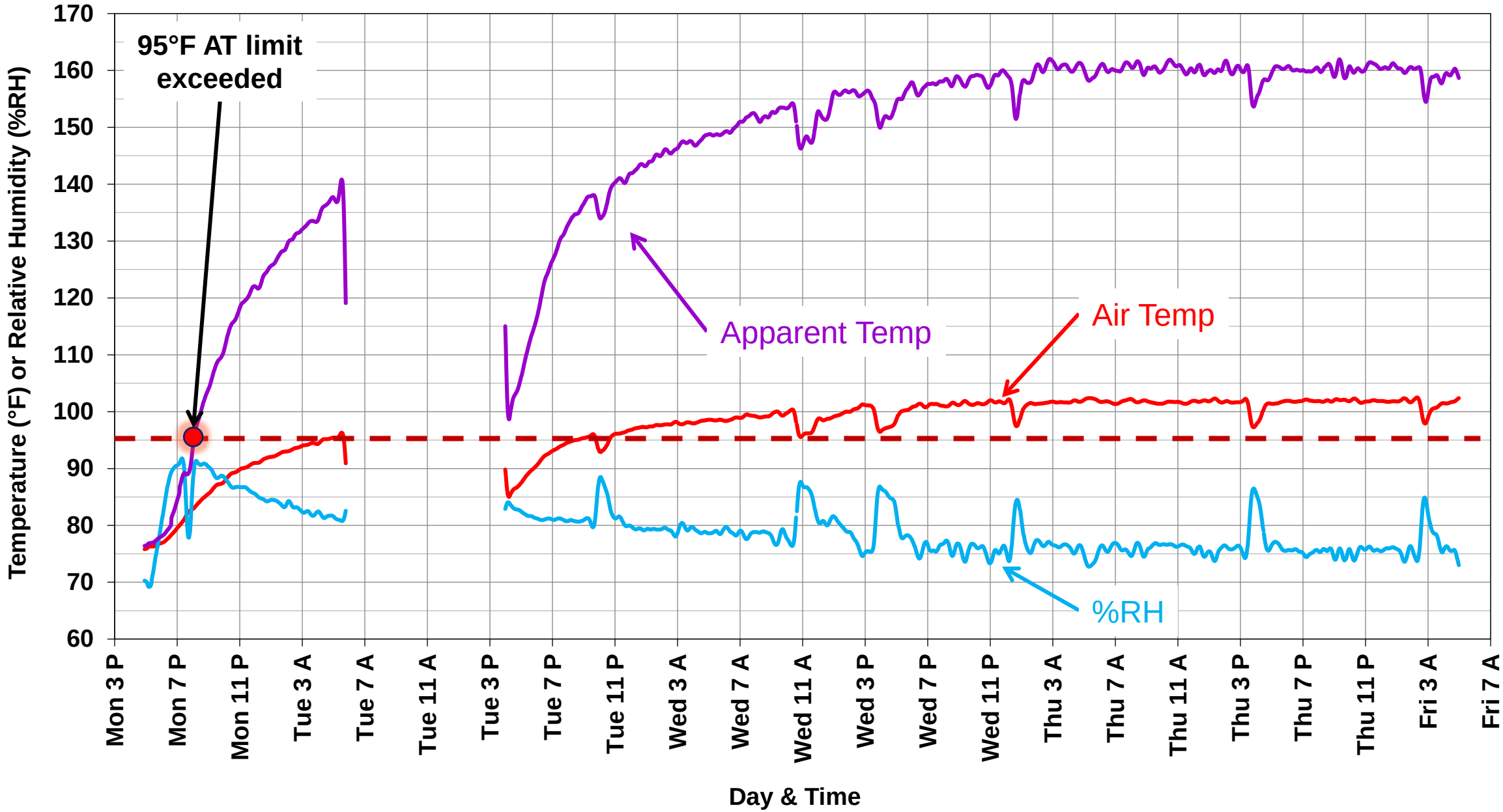
The average moisture input rate per simulated miner was 1.7 L/SM per day



The thermal conditions inside the RA reached 102°F at 76 %RH



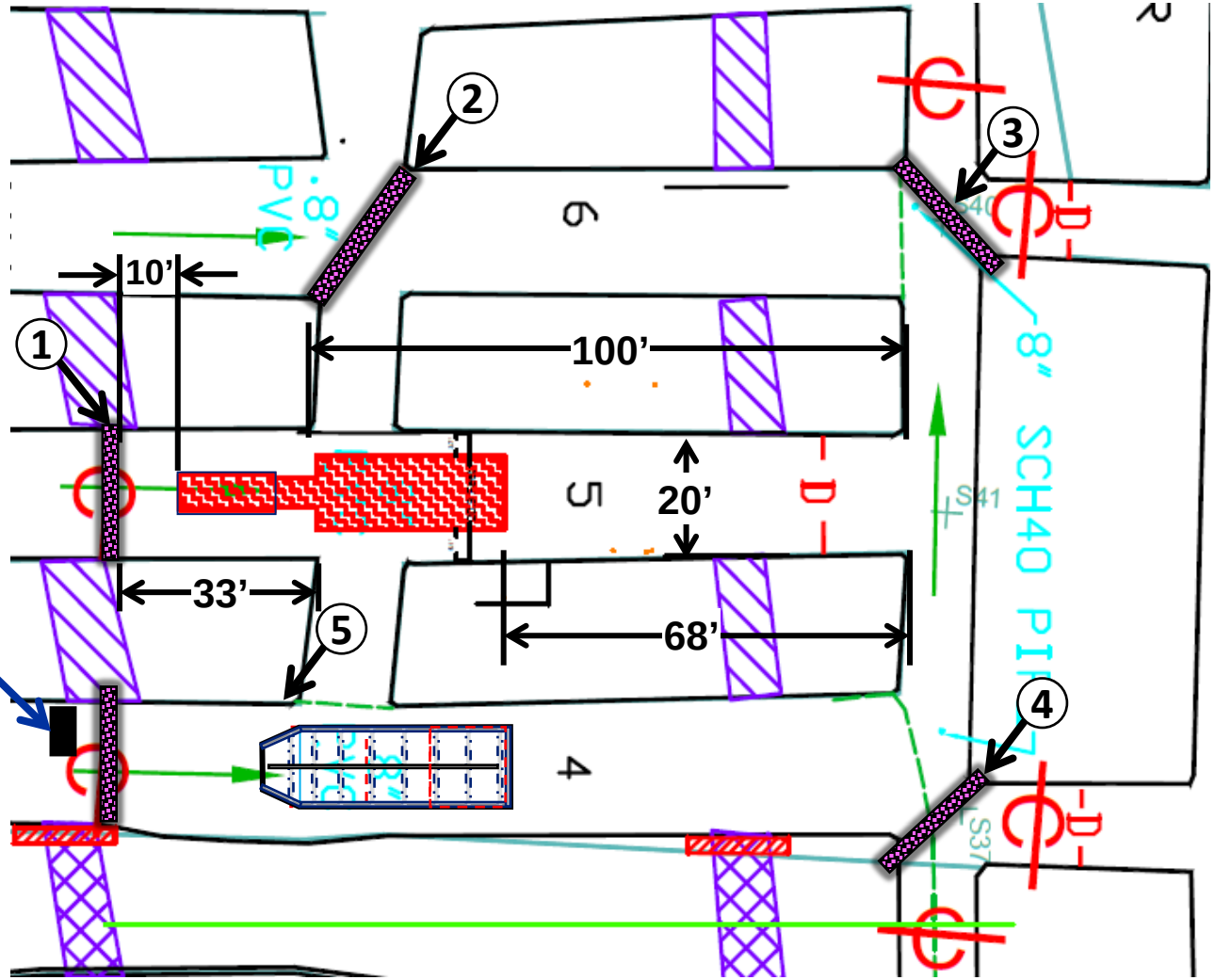
The apparent temperature exceeded the 95°F AT limit in about 4 hours



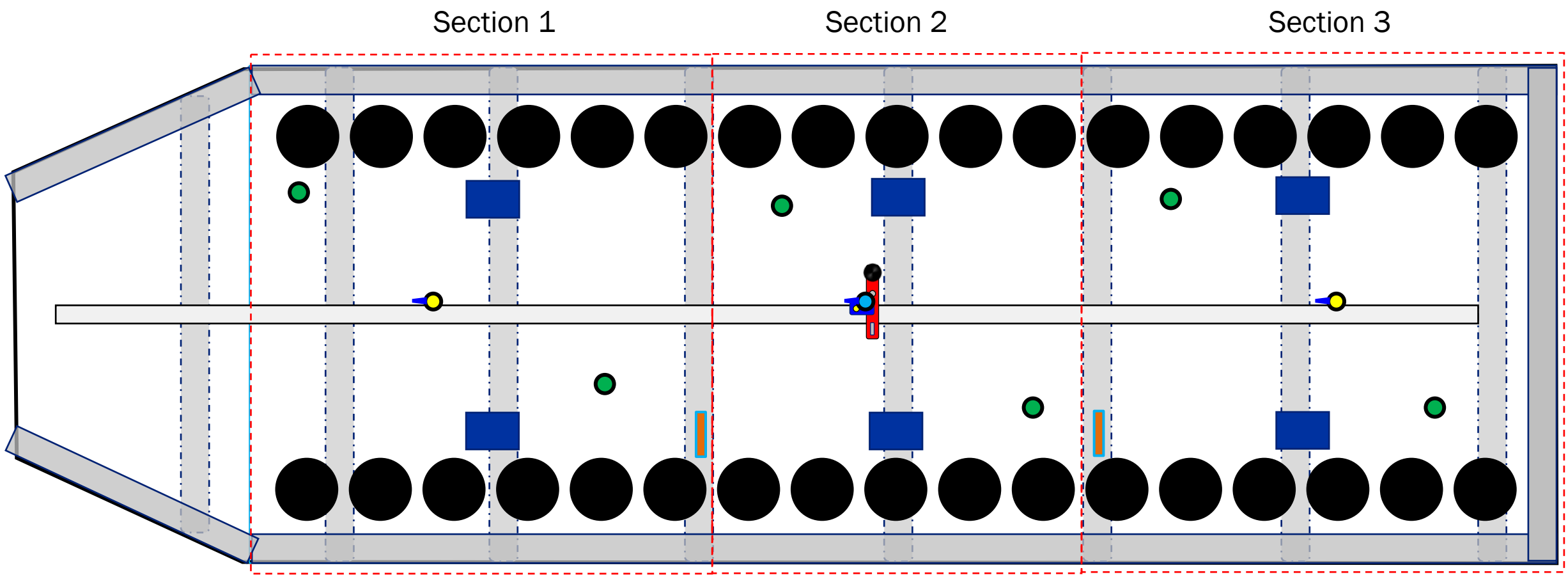
Cooling and/or derating of RAs will be necessary for warm mines

- Field test showed a dry-bulb temperature rise about 27.5°F for 12 simulated miners
- If tests were performed with 6 simulated miners
  - Expect a dry-bulb temperature rise of about 13.8°F
  - Resulting dry-bulb temperature would be about 89°F
  - RA interior would exceed 95°F AT limit if %RH reaches or exceeds 54 %RH
- For this mine and RA, cooling or occupancy derating would be required
- NIOSH is working to develop heat mitigation systems via contracts

NIOSH plans to conduct several tests on a portable tent-type RA to support contracts to develop a battery-powered RA AC system and a cryogenic air supply



Temperature and relative humidity will be measured at 9 locations within the RA



Temp/RH Sensor, WiFI Data Logger

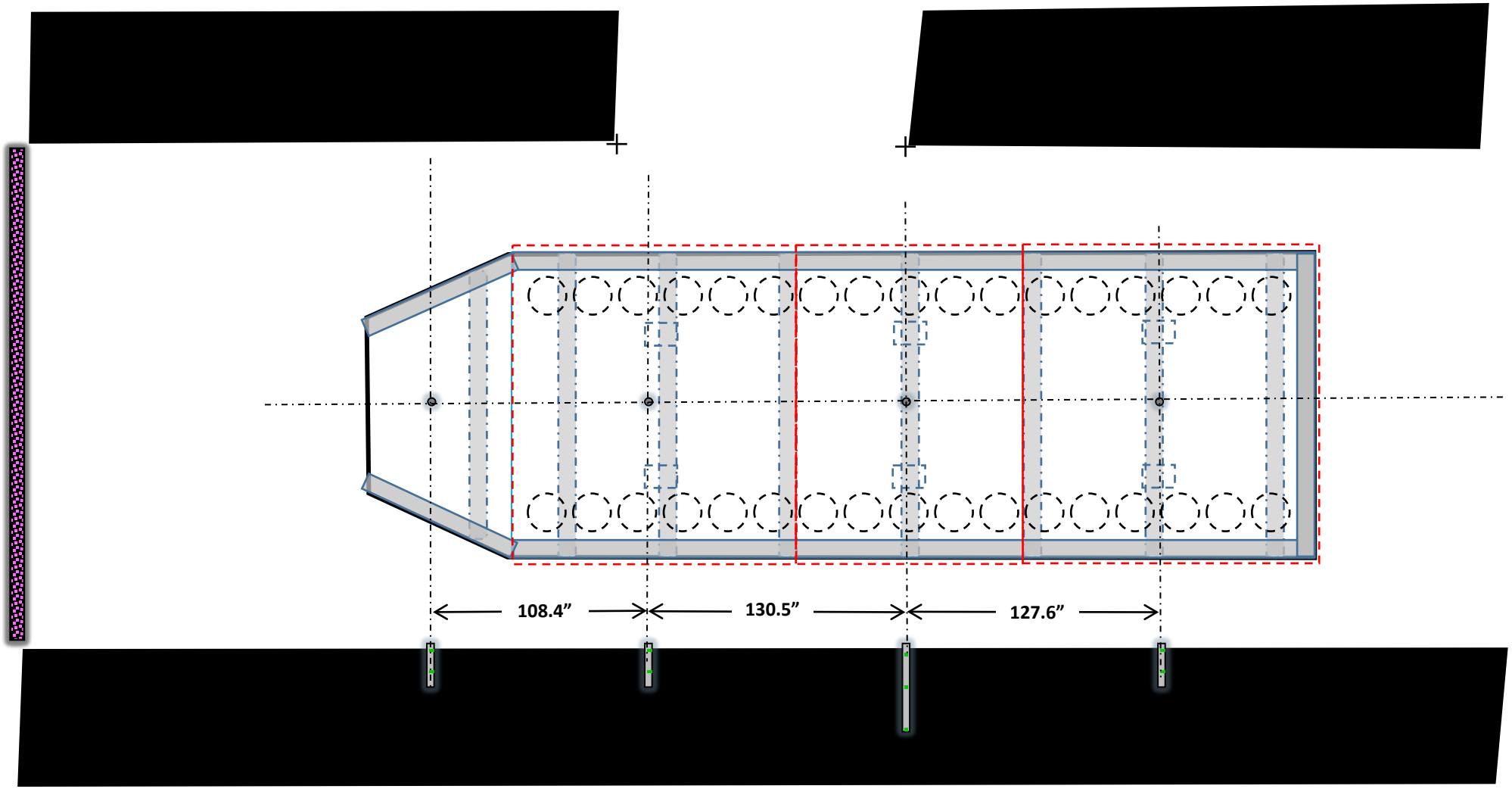
WBGT Array (DBT, WBT, BGT, AF). Qty: 1

Temp/RH Sensor, Vaisala HMP110. Qty: 2

RTD ribbon sensor (floor). Qty: 2

Temp/RH Sensor, Vaisala HMP155A. Qty: 1

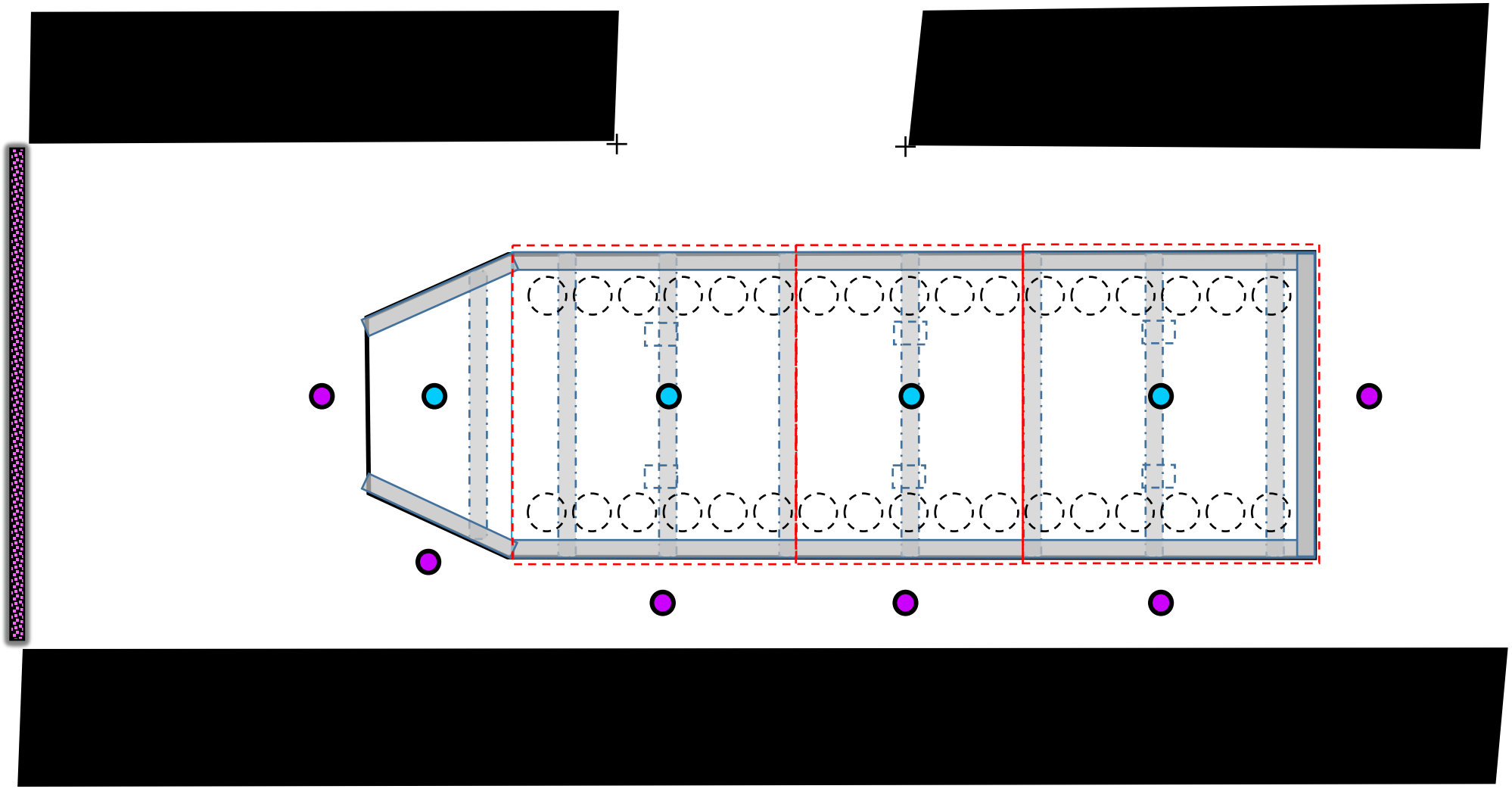
Mine strata temperatures will be measured using probes w/ RTDs



- Strata temperature probe, overhead view. Qty: 4 floor, 4 roof

- Strata temperature probe, side view. Qty: 4 rib

Mine air temperature will be measured at 7 locations around and above the RA



Midheight Temp Sensor, WiFI Data Logger

Overhead Temp Sensor, WiFI Data Logger

To support heat mitigation strategy development, heat/humidity tests will be conducted with baseline conditions and with the mine air preheated

- High bay test
- Baseline In-mine test
- In-mine tests with battery-powered AC system
  - Mine at “natural” temperature
  - Mine air temperature heated to 85°F
- In-mine tests with cryogenic air supply
  - Mine at “natural” temperature
  - Mine air temperature heated to 85°F

NIOSH developed a revised simulated miner for use in the upcoming RA heat/humidity tests

Goals for BPV2.0 design:

- Reduce number of parts and cost
- Simplify assembly
- Improve safety
- Maintain uniform surface temperature
- Eliminate need to wrap while preheating
- Reduce preheat time
- Improve representation of miners in an RA
  - Direct specific amount of heat to ground
  - Provide control of “sweat rate”

A simulated sweat system w/ adjustable sweat rate was developed using stepper-motor-driven dosing pumps and soaker hose

The resulting sweat delivery system appears to meet its design intent

Approximately 1 hour elapsed

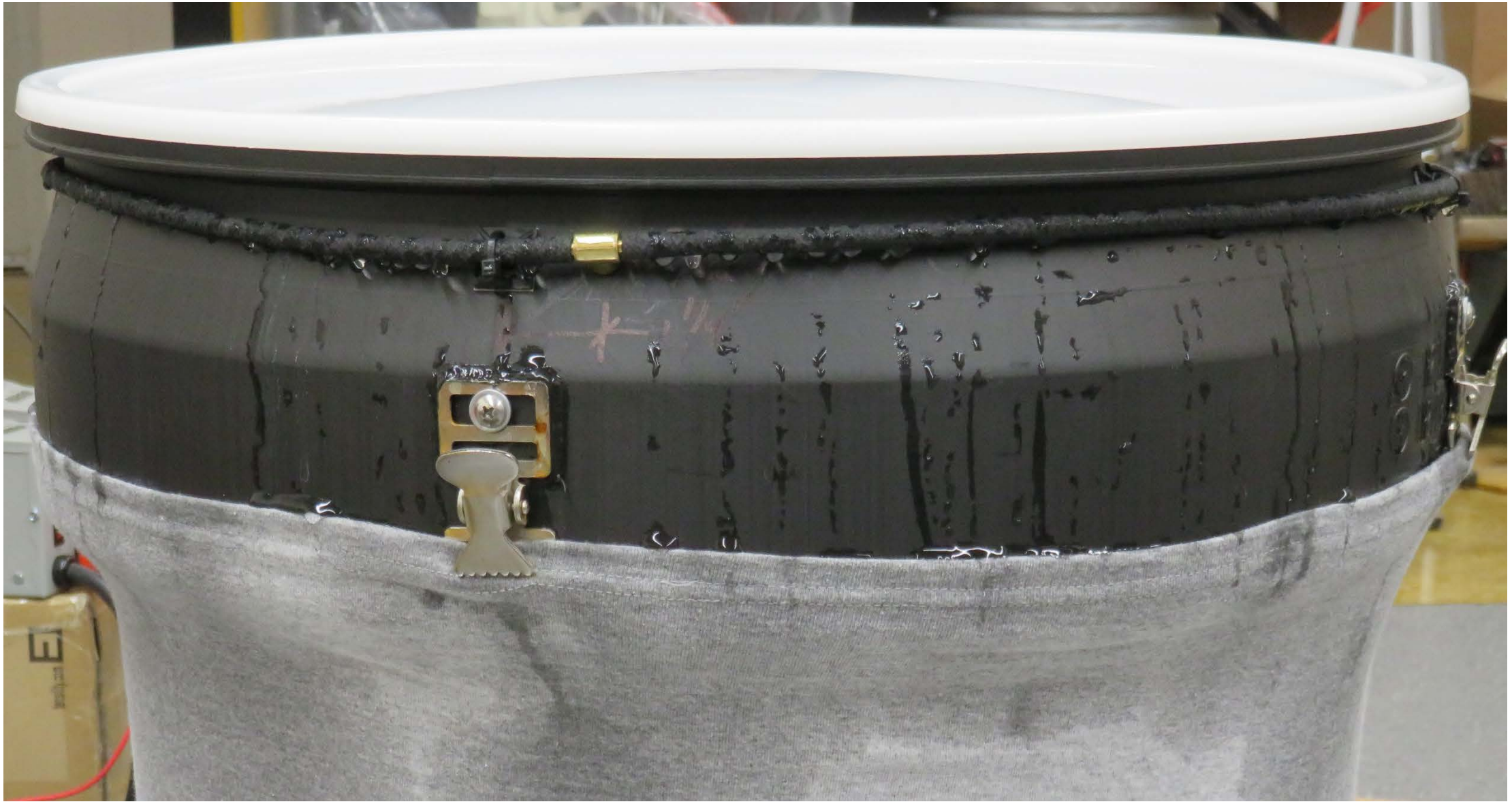
The resulting sweat delivery system appears to meet its design intent

Approximately 1 hour 15 minutes elapsed

The resulting sweat delivery system appears to meet its design intent

Approximately 2 hours 20 minutes elapsed

The resulting sweat delivery system appears to meet its design intent



Heat mitigation system development is necessary for RAs

- Simulations and testing have shown that adverse thermal conditions can occur inside occupied RAs, especially in “warm” mines
- Current contracts for developing two RA cooling systems: a cryogenic air supply and a battery-powered AC system
    - Testing required to ensure the developed cooling systems can provide the necessary cooling w/ elevated mine temperatures ~85°F
    - RA cooling systems must be made “mine worthy”
        - Durable
        - Permissible

Thank you for your attention!

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