TEST PROTOCOL

“FORT” Refuge Fresh Air Flow and Atmospheric Monitoring

Live Subject Testing

A. Test Overview

It is the aim of this test exercise to evaluate the theory and functional aspects of the habitable internal volume and breathable air delivery system of the “Fort” (Fire-resistant Onsite Refuge Technology) refuge at full occupancy. The Fort is constructed of precast concrete walls with intermediate and external layers of insulation, a steel floor, insulated entry door assemblies – all of which form the protective envelope of the occupied refuge space inside. The construction and dimension of the internal volume is that of the standard production model: 104 1/2” deep, 80 1/2” wide, 84” height with total internal volume of 409 CF.

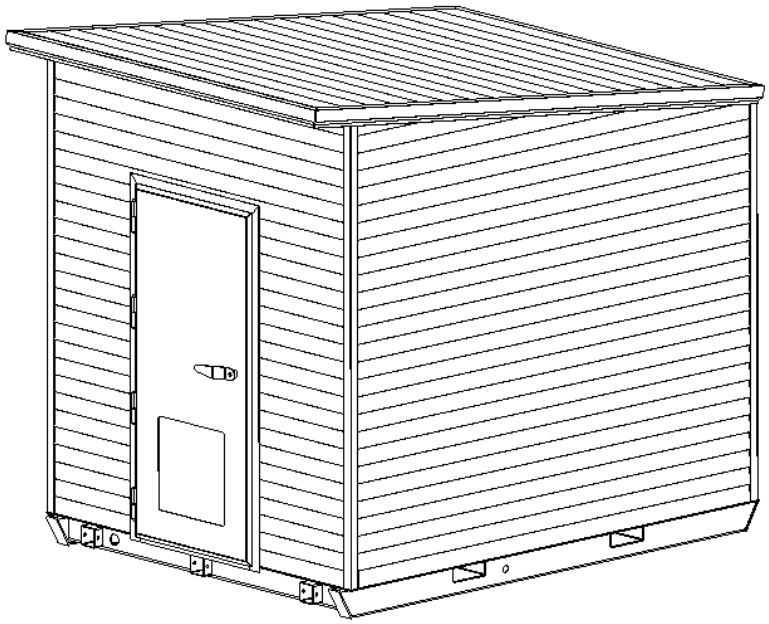

Figure 1

The principal metrics being monitored are:

(1) **Oxygen level in the occupied volume**. The refuge is designed to maintain oxygen levels via delivery of breathable fresh air to maintain 18.5% – 23% oxygen concentration as delivered from the onboard compressed air source. This oxygen range has been adopted in accordance with Mining Safety and Health Administration (MSHA) rules for underground refuges.

Reference: Federal CFR Title 30/Chapter I/Subchapter B/Part 7/Subpart L/7.506(b)

(2) CO_2 removal and CO_2 bulk concentration inside the occupied volume. The refuge is designed to remove human produced CO_2 to maintain levels below the MSHA underground refuge maximum exposure average of 1% (10,000 ppm) or less and excursions that do not exceed 2.5% (25,000 ppm).

Reference: Federal CFR Title 30/Chapter I/Subchapter B/Part 7/Subpart L/7.506(b)(3)

(3) **Anthropogenically produced heat removal and maximum apparent temperature.** The refuge is designed to flush heat from the internal space to maintain a habitable bulk air temperature. Guidance from NIOSH reporting for refuge alternatives conclude short term exposure to apparent temperatures below 120 degrees Fahrenheit do not result in body core temperatures above the 100.4F threshold for heat exhaustion with 80% rest/20% moderate activity levels for average sized, 168 lb., male participants. NIOSH technical references and conclusions can be found below. Mining Safety and Health Administration (MSHA) rules state 95 degrees F apparent temperature maximum as guidance for heat exposure extending to days in duration, but not necessarily durations of only hours in length as the case is here.

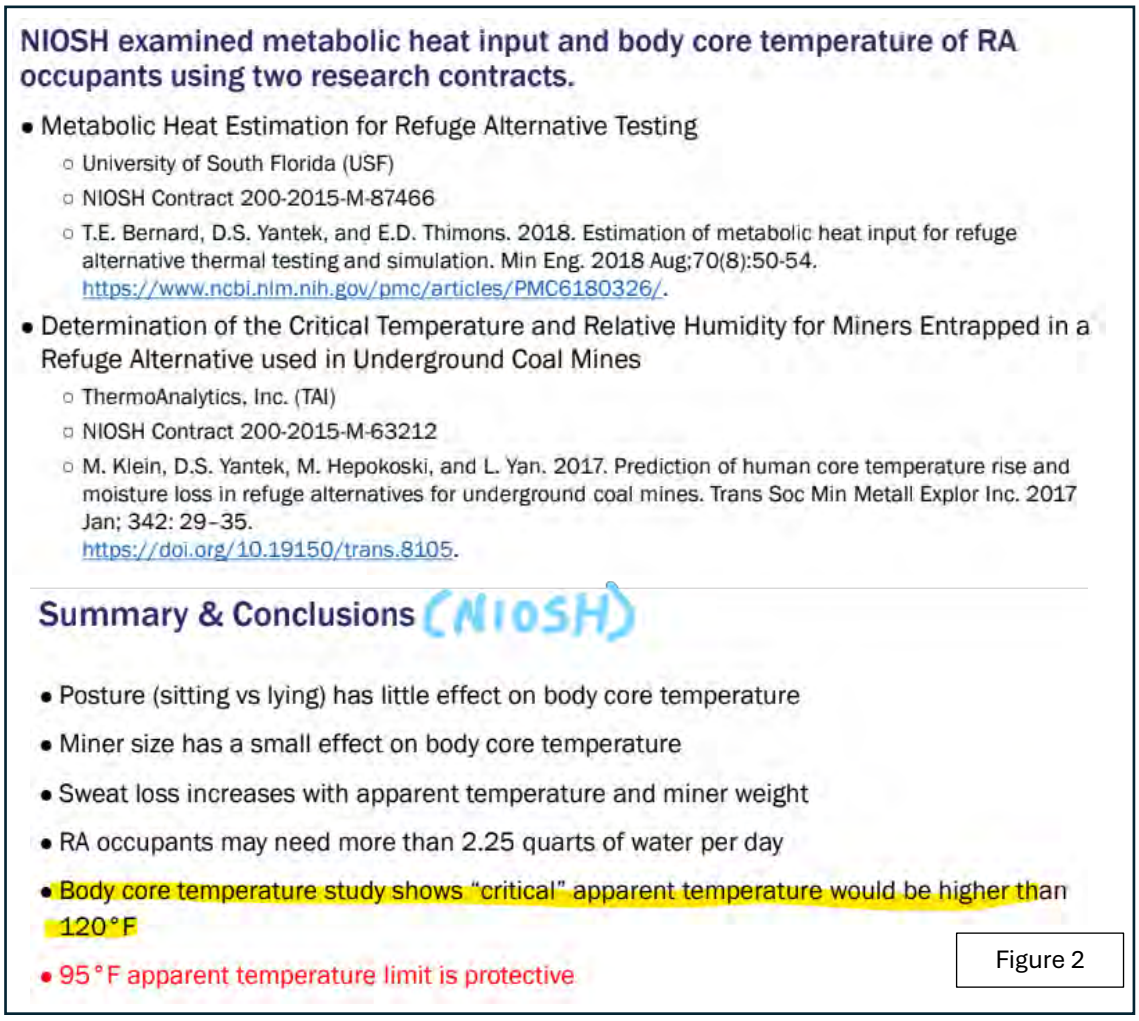

Figure 2

B. Test Parameters

The following parameters shall be monitored, recorded, and verified as per the methods listed.

- ***Test Time Duration**: The test shall be considered full duration at four (4) hours from the time of outer door close to door open at the end of the evaluation – to represent the standard recommended use case of the refuge.*

  Verification Method(s): clock and data log

- ***Occupants**: A total of eight (8) human participants will occupy the refuge for the test duration. Verification Method(s)*

- *Physical count, participants are to be organized by WSS on the day of test*
- *The combined body weight total of the participants shall equal or exceed the average of a 50% male/50% female weight combination as might be expected during normal use of a refuge. Average U.S. male weight is 199.8 lbs., and the average female weight is 170.8 lbs (CDC 2025). Therefore, the average weight of the participants shall be 185.3 lbs. or greater.*
- *Measurement to be by calibrated scale*

- ***Fresh Air Delivery**: Fresh air delivery to the inside of the refuge is to be provided via release of the stored onboard compressed air supply from the cylinders. The air flow shall be initiated by the occupants after entry and the main door closes.*

  <u>Verification Method(s):</u> The total volume of air released shall be computed from the weight of the air released from the cylinders as measured by a calibrated scale to ascertain net change in total cylinder weight from test start to test conclusion.

- ***Onboard Fresh Air Supply**: The onboard fresh air supply shall consist of compressed air cylinders The stored air source is required to be USP (United States Pharmacopeia) or compliant with similar suitable breathable air standard.*

  <u>Verification Method(s):</u> physical cylinder count, cylinder labeling or documentation review of contents for compliance

- ***Fresh Air Release Time**: The fresh air release is designed to continue over the duration of the test. Tail-off of air flow at the conclusion of the test period is normal and is not abnormal. Temperature change, normally warming, within the refuge is expected to occur as tail-off happens.*

  <u>Verification Method(s):</u>

  - *Measurement/data record of manifold pressure over time via pressure transducer*
  - *Measurement/data record of cylinder pressure over time via pressure transducer*
  - *Verification via participant aural indication*

- *Review of the logged metrics of temperature, bulk CO_2 concentration, bulk oxygen concentration for performance and/or unusual system function*

- ***Oxygen level:*** *Bulk oxygen percentage within the refuge as per section A (1) shall be monitored for compliance.*

Verification Method(s): measurement via qty 2 oxygen sensors placed centrally at mid-level elevation to be consistent with head level of sitting participants

- ***CO_2 Input:*** *CO_2 shall be added to the refuge volume only as produced by the metabolic processes of the participants – no verification to be performed beyond the verification of average participant body weight described above to ensure target body mass and metabolic capacity is present.*
- ***CO_2 level****: CO_2 bulk percentage within the refuge shall be monitored for compliance with section A (2).*

Verification Method(s): measurement via qty 3 total CO_2 sensors placed centrally, 1 unit biased high-level elevation, 1 unit biased mid-level elevation, 1 unit biased low-level elevation

- ***Refuge Internal Temperature****: Bulk temperature within the refuge shall be monitored for compliance with the expectations of section A (3).*

  Verification Method(s): measurement via qty 2 total RTD probes placed centrally, qty 1 biased mid-to-high-level elevation, qty 1 biased low-to-mid-level elevation

- ***Ambient Temperature Outside of Refuge****: Ambient test facility air temperature shall be monitored and recorded.*

  Verification Method(s): measurement via qty 1 total RTD probe

- ***Onboard Air Store - main pressure, downstream regulated air pressure, release hose pressure****: Each respective pressure shall be monitored and recorded to verify consistent system function over the duration.*

Verification Method(s): qty 1 pressure sensor tapped into the compressed air source supply manifold (high pressure), qty 1 pressure sensor tapped into low pressure side, qty 1 pressure sensor tapped into release hose.

- ***Relative Humidity**: The bulk air relative humidity inside the refuge shall be monitored.*

  <u>Verification Method(s)</u>: qty 1 RH sensor centrally located.

- ***Air Quality**: The particulate concentration of the air inside the refuge shall be monitored.*

  <u>Verification Method(s)</u>: qty 1 sensor centrally located.

- ***Sound Level**: The sound level emitted by the function of the fresh air release system will be periodically measured and recorded by hand as information gathering only.*

  <u>Verification Method(s)</u>: qty 1 handheld sensor centrally located.

C. Test Setup

The prototype refuge shall be configured as follows and in accordance with the requirements and figures found in section (E):

<u>Inside the Refuge:</u>

- 8 people
- Flip up seats installed along rear (4) and along the left-hand side as entering adjacent to front wall (4) for a total of 8
- Air cylinders arranged on the right-hand side adjacent to the front and side walls in two rows – all enclosed by a coroplast cover
- Video camera recording for video observation of the occupants
- All sensors listed in section (E)

<u>Outside the Refuge:</u>

- Datalogger
- Temperature measurement of ambient facility
- Laptop for observation
- Attending technical personnel

D. Test Procedure

1. Weigh air cylinders prior to test and after to calculate the total air release.
2. Connect fresh air cylinders to the delivery system.
3. Weigh all occupants, record age, sex, and medical restrictions.
4. Record pulse and blood pressure of all occupants.
5. Record body temperature of all occupants.
6. Advise all occupants of the nature of the test as per the following:
    a. Test is 4 hours long without breaks.
    b. The door will always be unlocked so that occupants can freely exit if necessary. However, there are no scheduled bathroom breaks. If it is urgent and necessary to exit for a break, one person will leave and another will enter to take the person's place taking care to do so quickly to not disturb the bulk air atmosphere inside the refuge.
    c. Normal sedentary activities are permitted while passing the time. It is fine to switch seats if desired.
    d. The air temperature may become colder or warmer as the air release progresses, and it is recommended to dress accordingly to adapt to any change that may occur. Temperatures inside are expected to range from chilly to warm.
    e. There will be two attending observers – one inside and one outside – and they will be in contact with one another throughout the test. The observer on the inside will monitor oxygen and CO_2 levels to make sure they are ok as well as communicate with the other occupants about how they feel and other instructions.
    f. If at any time a person feels nauseous, light head, ill, or faint – let the attending occupant know immediately.
    g. There will be a camera monitoring the occupants on the inside.
    h. Snacks and drinks are permitted.
    i. No smoking, vaping, tobacco use, etc. during the time of the test.
    j. It is suggested to have something to read or do to pass the time.
    k. Use of phones is permitted.
    l. The sound of rushing air into the refuge is not loud but may be bothersome. Headphones are permitted, even encouraged, to help with this. Listening to music or other media may be helpful.

m. Occupants are to remain awake so that health status checks and ongoing assessments can be made.

Test prep and start:

7. Add pressure transducers to fresh air system at the (1) high side, (2) low side, and (3) hose.
8. Place the sensor tree inside the refuge at a central location. Feed wires to the outside and splice onto the umbilical connected to the datalogger.
9. Turn on datalogger and confirm all sensors have been successfully connected and are reading normally.
10. Ensure all test instrumentation is connected to the back-up power supply.
11. Activate camera on laptop and begin recording.
12. Have occupants enter the Fort and make themselves comfortable but leave the doors open until the test starts.
13. Begin datalogging, instrument:
    a. CO_2 levels inside the refuge will be data logged, 30-second interval.
    b. Fresh air delivery pressures will be data logged, 30-second interval.
    c. Time, date, temperature will be data logged, 30-second interval.
    d. Fresh air delivery systems pressures (manifold pressure, regulated pressure, release pressure) data logged, 30-second interval.
    e. Begin datalogging, Temtop instrument for RH, Air Quality, Ins. Temp.
14. When ready to start the test, (1) close the doors and (2) have participants turn on all compressed air tanks at the tank head (as per standard operating procedure) to begin the release of fresh air. Double check that all valves are on, and that air is flowing as expected based on experience. If the sound of air is not heard, re-open the doors to allow fresh air to enter.
15. The following are to be periodically checked by the inside attending observer, verified by outside observer on data logger:
    a. Visual check of oxygen and CO_2 levels by attending observer, every 15 minutes. **If at any time oxygen levels fall below 18.5% or CO_2 rises above 10,000 ppm for more than a 5-minute excursion, the test shall be aborted, doors opened, and egress of all occupants expeditiously completed.**
    b. Occupant pulse checks will be taken every 30 minutes by a verbal roll call. Normally, each person takes their own reading and will report it verbally to

the attending observer for recording. At the same time, all occupants should reflect on their physical disposition and alert the attending observer if they feel lightheaded, nauseated, or otherwise sense any physical change that might be concerning.

c. Noise level measurement, every 30-minute interval.

16. At the completion of 4 hours, the occupants should remain until the attending observer says to open the doors and exit the refuge.
17. Occupants should remain around the test area following completion for 15 minutes to ensure they feel normal. Fill out the questionnaire if available.

E. Testing Equipment

	MEASUREMENT	TYPE	MANUF	MODEL	LAST CAL	ID#
1	CYL. PRESS.	TRANSDUCER	OMEGADYNE	PX309-7.5KGI	1/9/26	072908D038
2	REG. PRESS.	TRANSDUCER	OMEGADYNE	PX309-300GV	1/9/26	012810D016
3	RELEASE PRES.	TRANSDUCER	OMEGADYNE	PX309-500GV	1/9/26	051711D934
4	DATA LOG	DIGITAL	GRAPHTEC	GL-800	1/8/26	H70711
5	CO_2 HIGH	IR	TROLEX	TX6350.00.278	7/22/25	JG01420
6	CO_2 MID	IR	TROLEX	TX6350.00.278	7/22/25	JG01421
7	CO_2 LOW	IR	TROLEX	TX6350.00.278	7/22/25	JG01427
8	O_2 MID-HIGH	IR	TROLEX	TX6350.00.257	02/01/26	JE00798
9	O_2 MID-LOW	IR	TROLEX	TX6350.00.257	02/01/26	JE00799
10	INSIDE TEMP. (MID-HIGH)	RTD	DWYEROMEGA	HSRTD-2-100-A-5M	ICE WTR/BOIL 02/02/26	STE-2602
11	INSIDE TEMP. (MID/LOW)	RTD	DWYEROMEGA	HSRTD-2-100-A-5M	ICE WTR/BOIL 02/02/26	STE-2603
12	AMB. OUTSIDE TEMP.	RTD	DWYEROMEGA	HSRTD-2-100-A-5M	ICE WTR/BOIL 02/02/26	STE-2604
13	WEIGHT/MASS	STRAIN GA.	RUBBERMAID	4040	01/29/26	STE-2601
14	TEMP, RH, PM 2.5, PM10, PARTICLES, AQI, TVOC, HCHO	LASER, SELF-LOGGING	TEMTOP	LKC-1000S+2ND	10/23/24	74A22
15	SOUND LEVEL	-	EXTECH	407738	11/18/16	H079392/EN-TI079
16	VIDEO WITH AUDI0 (BY WSS)					

Table 1

Participant Biometric Data Sheet

	Name	Age	Wgt (lbs)	Height	M/F	Temp	Smoker
1							
2							
3							
4							
5							
6							
7							
8							

Average weight of participants: _____

Participant Heart Rate and Blood Pressure Measurements

	Pre-start	:30	1:00	1:30	2:00	2:30	3:00	3:30	4:00
1HR									
1BP									
2HR									
2BP									
3HR									
3BP									
4HR									
4BP									
5HR									
5BP									
6HR									
6BP									
7HR									
7BP									
8HR									
8BP									

Sound level readings (dB):								
Start	:30	1:00	1:30	2:00	2:30	3:00	3:30	4:00

Table 2