ENCLOSURE C

AB 79-COMM-10-3

OMSHR

Office of Mine Safety and Health Research

Built-in-Place Refuge Alternatives

Ed Thimons

CDC NIOSH

ABM9-COMM-10-3

In its 2007 report to congress NIOSH Office of Mine Safety and Health Research stated:

"In-place shelters can offer a superior environment for refuge and in many cases could be connected to the surface via a borehole to provide vital services. Unfortunately, it is impracticable to move in-place shelters frequently, and as such it would be impossible to keep them within 1000–2000 feet of the face. However, their strengths compared to portable chambers are so significant that consideration should be given to allow extended distances if in-place shelters are used to provide refuge for face workers."

There are currently a little over 1,400 refuge alternatives (RAs) employed in U. S. underground coal mines

- Almost all of these are mobile-type RAs with the majority being tent-type designs
- There are 30 built-in-place (BIP) RA designs
  - All of the BIP RAs are located outby the face area
  - They are generally large enough to hold many more miners than just outby personnel
  - All provide more than the OMSHR recommended 85 ft^3 per occupant
  - All have boreholes to surface

BIP RA Stopping /Door Designs

- Two stopping/door designs currently have MSHA approval
  - A MICON-designed and MSHA Technical Support approved stopping /door system
  - A mine-designed and MSHA District Manager approved stopping/door design

Current BIP RA Air Supply Systems

- Fresh breathable air is supplied to the current BIP RAs through a borehole from either:
  - A permanent compressed air supply or blower
  - A portable compressed air supply or blower

Mobile RA Questions

- Purging....Is adequate purging available?
- Heat/Humidity...How to evaluate chambers?
- Time to enter through purging rooms?
- Psychological stress....How will miners react for long periods of time in tightly confined hot/humid conditions?
- Physiological stress....Will confinement in tight quarters with minimal motion cause physical pain and discomfort?
- Effect of water build-up on the floor?
- Will some miners decide to leave after some period of time?
- 96-hour "Ticking clock"

Potential Advantages of BIP RAs

- 750 ft^3/hr of air per occupant vs 1.32 ft^3/hr of compressed O_2 per occupant
- Eliminate the need for CO purging and for CO_2 scrubbing
- Should eliminate heat/humidity rise problems in the RA
- High probability of communication system surviving
- More space per occupant resulting in improved ergonomic and psychological conditions
- More space for additional food, water, medical and other supplies
- Greater probability of surviving secondary explosion
- Significantly fewer operating requirements
- No 96-hour "ticking clock"....better for trapped miners and rescuers
- Number and order in which miners arrive at RA is less important
- Rescue borehole from surface can go directly into the RA

Potential Disadvantages of BIP RAs

- The cost of BIP RAs, if required to be kept within 1,000 ft of the active mining face, would be prohibitive
- Depending on mine circumstances, providing a constant supply of air either via a borehole to surface or via a protected compressed air line could require additional planning and cost
- There may be a need for additional roof and rib support
- Constant low ventilation would be necessary to prevent a buildup of methane and to keep the BIP RA under constant positive pressure fresh air
- The presence of a BIP RA in itself may cause miners to refuge rather than first exhaust all attempts to escape

Major Barriers to Use of BIP RAs

- Need to allow BIP RAs to be located further from the face
- Need to improve system for approving designs for BIP RA stoppings
- Need to deliver a reliable supply of clean, breathable air to a BIP RA

Justification for Allowing BIP RAs to be Located Further from the Face

OMSHR researchers developed three different approaches to determine how far from the face area miners could travel given the 120 minutes of breathing time afforded them by currently available SCSRs

- Approach 1 was based on SCSR-mandated storage cache locations, and examined the MSHA-established criteria for distances between SCSR storage caches as a method of determining acceptable distances from the face area for RA locations

- Approach 2 was based on worst-case SCSR usage times, with OMSHR performing a timeline study of an assumed worst-case scenario for miners involved in a disaster, beginning with the time they first don their initial SCSR and including the times it would take to travel to the face area, assemble as a group, make decisions, and perform switchover to a new SCSR if needed

- Approach 3 was based on established travel times and escape probabilities determined from NIOSH and Bureau of Mines research, including research from 2011 involving actual miners traveling in airways filled with dense smoke in high coal without lifelines, and research from 1990 that considered the probability of making a successful mine escape in high coal with a single SCSR

Results of OMSHR Analysis of Locating BIP RAs Further from the Face and *Draft* Recommendation

Entry height	Approach 1: Based on SCSR-mandated storage cache locations	Approach 2: Based on worst-case SCSR usage times	Approach 3: Based on NIOSH and BOM established travel times and escape probabilities	OMSHR-recommended maximum RA distance from the face
<40 inches	2,200 feet	2,640 feet	NA	2,000 feet
>40–<50 inches	3,300 feet	3,960 feet	NA	3,000 feet
>50–<65 inches	4,400 feet	5,280 feet	6,000 feet	4,000 feet
>65 inches	5,700 feet	6,480 feet	6,500–7,000 feet	5,000 feet

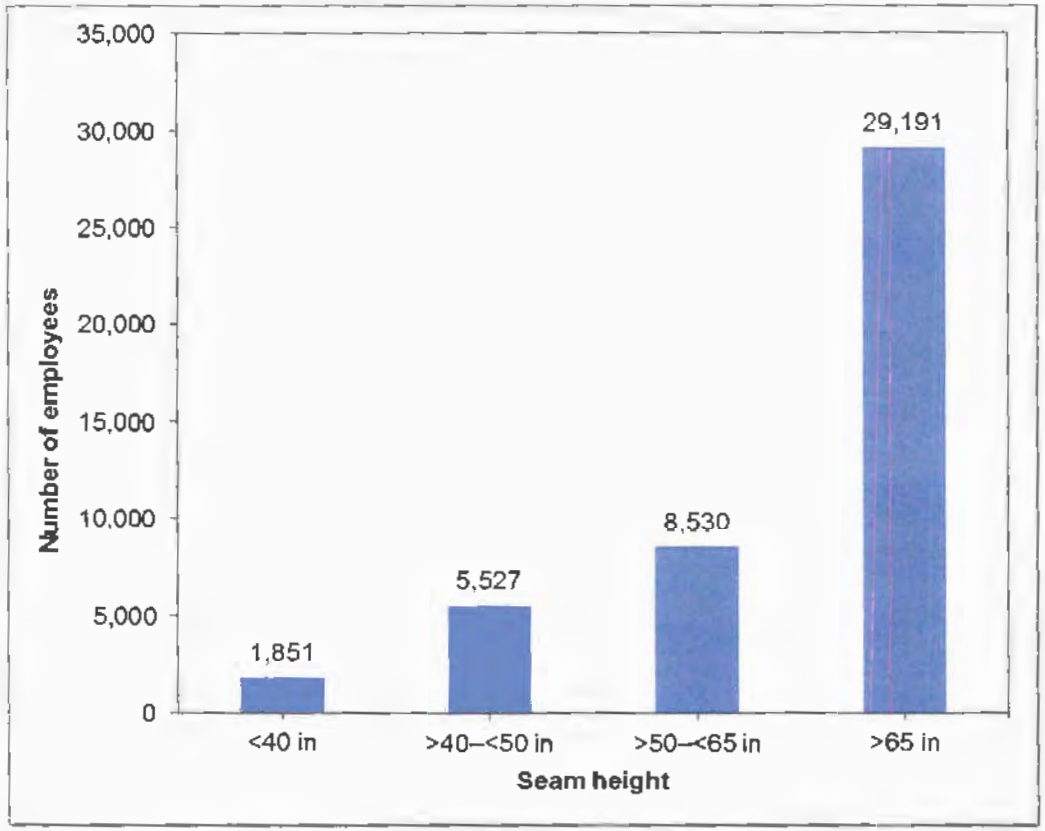
OMSHR-recommended maximum distances of refuge alternatives from the face (rounded down from most conservative findings of the three approaches)

BIP RAs Should be Located Further from the Face Only If They:

- Provide a constant supply of air to the RA either via a protected compressed air line into the RA or a borehole from the surface into the RA
- Provide additional RA space per occupant. The original minimal space requirement of 85 ft^3 per occupant as noted in the NIOSH 2007 report to Congress on refuge alternatives is recommended
- Maintain the RA interior atmosphere under positive pressure when not in use to ensure that the RA contains breathable air immediately upon entry and to keep contaminated air from entering the RA with miner entry

Number of Miners Impacted by Longer Travel Distances

- Almost 65% of coal miners work in seams greater than 65 inches
- Almost 84% work in seam heights greater than 50 inches

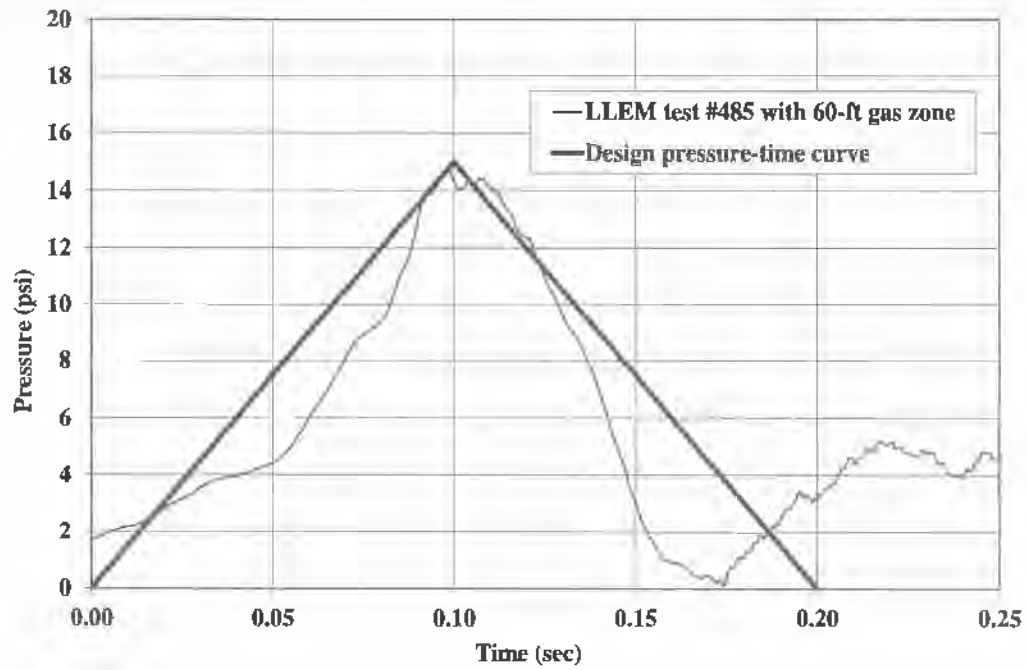


Number of coal mine employees working at underground locations by seam height, 2012, excluding office employees. (data source: MSHA 2013)

Designing RA Stopping/Door Systems for MSHA Approval

Mining companies, stopping/door designers and providers, and universities have reported that they find the current MSHA process for approving stopping/door designs for BIP RAs to be complex and confusing. To facilitate this process, OMSHR has:

- Reaffirmed its recommended design pressure-time curve of 15 psi over 0.2 seconds
- Provided extensive guidelines for use by individuals submitting structural designs of stopping/door systems to MSHA for approval*
- Provided three detailed examples, along with all of the associated structural design calculations, of stopping/door systems which meet the required 15 psi criteria



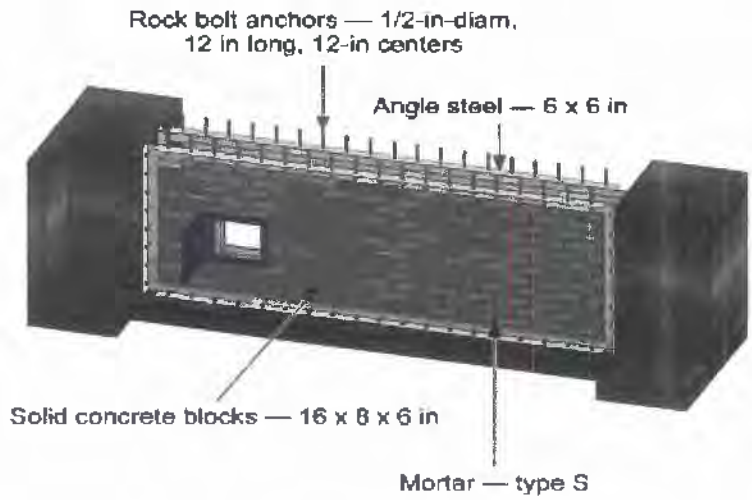
*These designs were adapted from MSHA guidelines for coal mine seal design applications

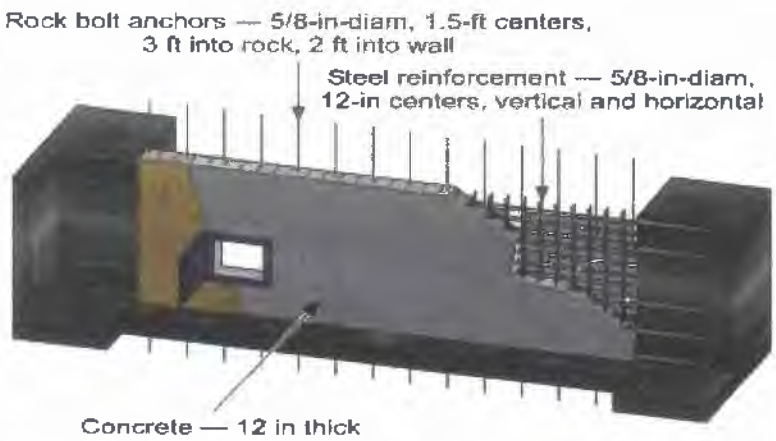
Design Criteria for RA Stoppings

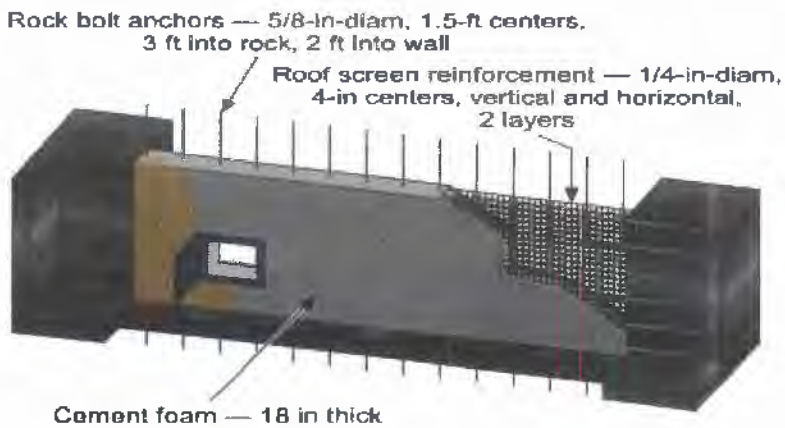
- Structural design criteria
- Foundation design
- Leakage considerations
- Quality control

OMSHR BIP RA Stopping/Door Design Examples

- Unreinforced solid concrete block wall
- Conventional rebar-reinforced concrete wall
- Rebar-reinforced pumpable cement foam wall







Delivering a Reliable Supply of Clean, Breathable Air to a BIP RA

Most of the advantages of a BIP RA disappear if the RA is not guaranteed a constant and highly reliable supply of clean, breathable air. There are two possible approaches:

- Borehole to surface
- Protected compressed air line

Delivering a Reliable Supply of Clean, Breathable Air to a BIP RA

- While a borehole from the surface to the BIP RA would be a highly desirable approach, it is not practical for many mining operations due to drilling costs, difficult terrain, surface rights issues, and maintaining a reliable system for providing air down the borehole

- An alternative approach may be to provide air to the BIP RA via a protected compressed air line carrying clean, breathable air

- Hubble Breathable Air Supply System already has MSHA approval

Delivering a Reliable Supply of Clean, Breathable Air to a BIP RA

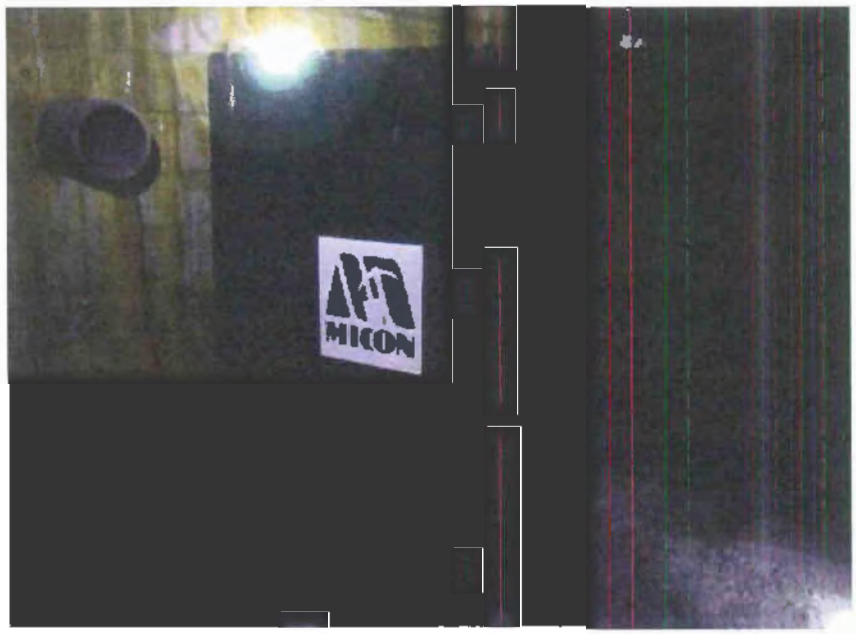
In order to guarantee a supply of clean, breathable air to BIP RAs in an emergency situation, a number of issues need to be considered with respect to the reliability and availability of both the surface compressor station and the protected compressed air line. OMSHR has outlined these considerations in its report.

Economic Drivers to Advance the Use of BIP RAs

- BIP RA designs are needed which employ stopping and door systems that are inexpensive enough to build and leave in place or designed to be quickly and easily disassembled, moved, and reassembled

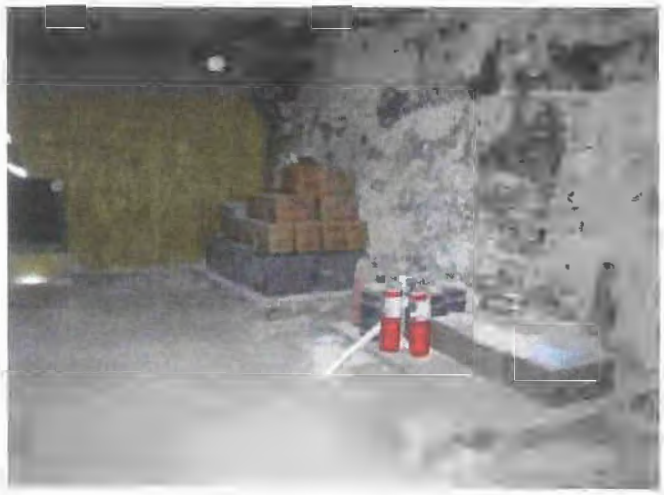
- Novel BIP RA concepts are needed that provide more space and breathable air per occupant and can be easily moved with the face

- Designs for a protected compressed air line that supplies breathable air to the RA occupants and can be advanced with the face are needed.



NIOSH OMSHR Recommendations

- *OMSHR recommends that mines be permitted to locate BIP RAs 2,000 feet or more from the working face depending upon mine entry height*
- *OMSHR recommends that the guidelines set forth in this report be used by industry when submitting stopping design applications for approval by MSHA*
- *OMSHR recommends that a constant supply of clean breathable air be provided to the BIP RAs either from a borehole to surface or through a protected compressed air line system such as the Hubble Breathable Air Units or other comparable designs, and that related technology continues to be developed by industry*



Ed Thimons

EThimons@cdc.gov

www.cdc.gov/niosh/mining

OMSHR

Office of Mine Safety and Health Research

Human Factors Considerations for Refuge Alternatives

Susan M. Moore, PhD

Director, Division of Mining Science and Technology

AB79-COMM-10-3

Human Factors Considerations

- Integrate human limitations and capabilities within specific environment into technology design
  - Physical—e.g., hand strength
  - Cognitive—e.g., ability to process information under duress
  - Physiological—e.g., visual ability in smoke

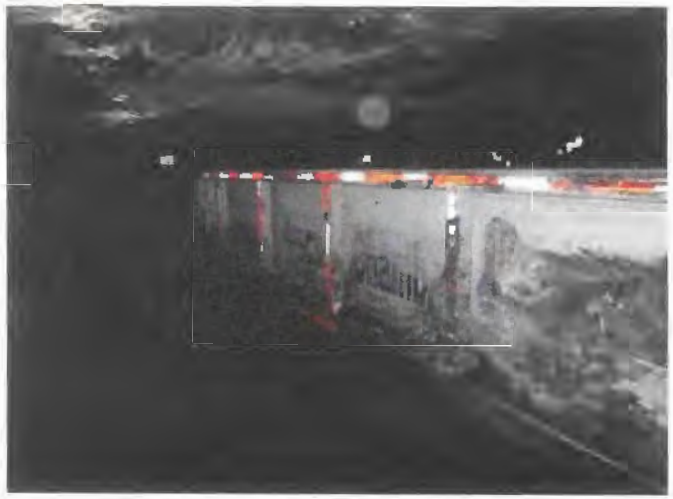
Refuge Alternative Objective

To provide mining stakeholders with recommendations for improved design of existing refuge alternatives related to:

- User Interface Design
- Use of Stretchers
- Space and Volume Requirements
- Food/Water Supply

User Interface Design

- Critical to miners successfully locating, deploying, and using refuge alternatives
  - Signage leading to RA
  - Instructions for deployment and activation
  - Activation of controls



User Interface Design Approach

- Literature/Standards Review
  - Human Centered Design Principles
  - Human Factors Research
  - International and Domestic Standards Organizations
  - Military and Government Standards
- Manufacturer Visits
  - 5 chamber manufacturers (Hard, Inflatable, Built-in-Place)
  - Collected Written Material (Signage & Instructions)
  - Measured Dimensions and Locations of Controls
  - Evaluated Deployment Procedure and Operation

User Interface Design Recommendations

Signage	Operation Labels	Font, Size, Color, Contrast, Readability, Location, Amount, Format, and Content
	Control Labels	
	Other Labels	
Controls	Gauges	Choice, Force, Size, Spacing, Clearance, Location, and Orientation
	Handles	
	Levers	
	Selectors	
	Thumbwheels	
	Knobs	
	Buttons	
	Entries (Doors)	Force, Size, and Location
Instructions		Font, Size, Color, Contrast, Readability, Location, Amount, Format, and Content
Deployment		Progression, Personnel Requirements, Types of Actions, Number of Steps, Organization

Use of Stretchers

- Critical to assist injured or unconscious miners into the refuge alternative without compromising function of airlock

Approach to Use of Stretchers

- Literature Review
  - GSA Ambulance specifications
  - International Building Code
- Two commercial RAs (hard, inflatable)
  - 3types of stretchers
  - Time for 2 people to enter RA with 35 lb. manikin on stretcher and close main chamber door
  - 16 participants, 1 trial with each stretcher and RA combination

Stretcher Types

Recommendations for Use of Stretchers

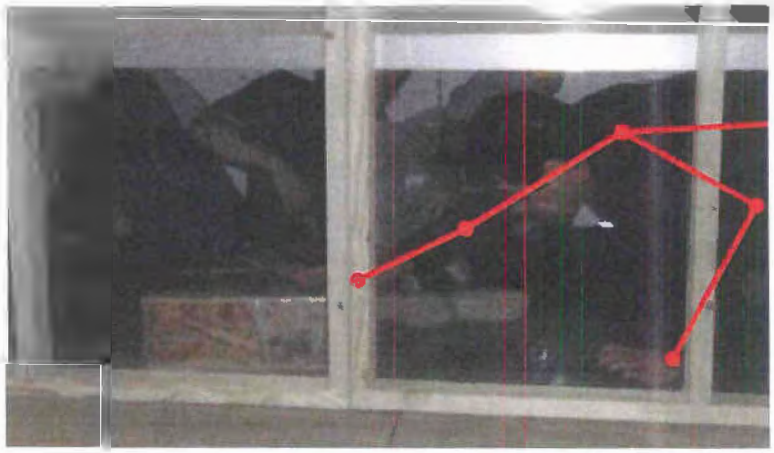
- Consider impact on airlock PPM with stretcher use
  - May need alternative purging practices
- Difficulty with 35 lb. manikin suggests failure potential with more realistic loads
  - Improved door designs with consideration for impact on purging

Space and Volume Needs

- Space and volume provided to each miner must be sufficient to complete life sustaining tasks
- Requirement of 15 ft^2 of floor space per person was evaluated
  - Requirement likely to be increased to address heat and humidity issues
  - Influence of floor space and height on ability to complete tasks still relevant to specific language chosen in revised requirement language

Approach to Space and Volume Needs

- RAs Used
  - 3 mockups, 1 commercial RA (hard)
- Tasks performed
  - Change scrubber cartridge
  - Move across RA
  - Drink
  - Set up and use toilet



- Examples of Data collected
  - Time to complete task (task failures noted)
  - Posture

Space and Volume Recommendations

- Configuration of floor space is not a significant consideration in the design of RAs→ 15 ft^2 of floor space per person adequate
- Minimum allowable height identified as a consideration
  - Tasks that were achievable at 4' were no longer achievable at 2'

Food/Water Supply

- Unclear if existing supply requirements in 30 CFR 75.1507 are sufficient to sustain life throughout duration of occupancy

Approach

- **Standards Review**
  - NATO –conditions for submarines
  - US Coast guard – lifeboat provisions
  - ISO 18813 – survival equipment for rescue boats
  - IMO – International Life Saving Appliance Code
- **Literature Review**
  - Refuge environment studies
  - Emergency ration criteria
  - Army/Navy publications for heat stress control
  - Institute of Medicine's DRI and AI

Food/Water Supply Findings Examples

- Confusing instructions requiring unnecessary cognitive function while under duress
- Water ration insufficient to maintain proper hydration→ electrolyte imbalances can affect cognitive and bodily functions

DIRECTION FOR USE:

- First 24 hours do not drink any water, only if injured or sick. Thereafter use 2 bags per person per day.
- Avoid conditions which cause sweating or increased thirst.
- Discard bag if air or water escapes when squeezed, or mfg. date exceeds 5 years.
- Use *SOS FOOD RATION* to obtain lowest body water requirement.

Food/Water Supply Recommendations

- Write instructions specifically for refuge use
- Include supplies with electrolytes to maintain balance without substantially increasing stored water

EMERGENCY CONSUMPTION:

Drink no water first 24 hours unless sick or injured, or in desert conditions. Thereafter, approximately 8 oz. (2 ea. 4 oz. Bags) per day minimum.

This posi-sealed bag may be checked by squeezing. Replace bag if air or water escapes. Recommended life five years or as established by local Administration.

Conclusion

- Using a human factors approach, numerous opportunities for RA design improvement were identified related to
  - User Interface Design
  - Use of Stretchers
  - Space and Volume Requirements
  - Food/Water Supply
- Majority of the improvements could be implemented directly by the manufacturers with minimal impact on existing RA design

Questions

OMSHR

Office of Mine Safety and Health Research

Mobile RA Purging and Purge Room Contamination

Ed Thimons

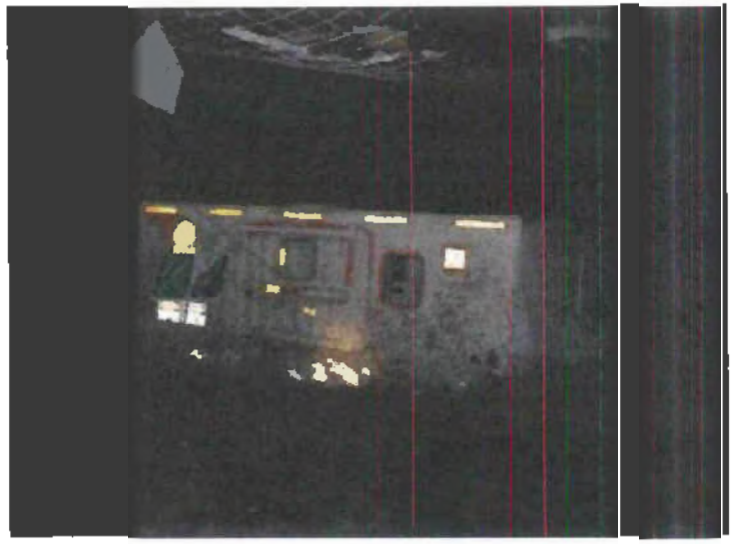
CDC NIOSH

AB79-COMM-10-3

OMSHR Conducted Testing to Answer Two Questions on Purge Rooms in RAs

- Does the current generation of mobile refuge alternatives meet the requirements of 30 CFR § 7.508 (c) (2) which requires RAs to be capable of purging the internal atmosphere from 400 ppm of carbon monoxide (CO) to 25 ppm?

- What is the relationship between the concentration of noxious gases in the mine atmosphere external to the refuge alternative and the concentration that will be present inside the refuge alternative purge room following entry of miners but prior to purging?



Purging Tests Conducted on Two Mobile RAs

- Tests conducted on 57 ft^3 tent-type RA purge room and on 153 ft^3 rigid-steel RA purge room
- Ran purging tests using both CO and SF_6 tracer gas
- CO testing was done with simulated miners occupying the purge rooms and SF_6 testing was done with actual persons in the purge rooms

Results of OMSHR RA Purging Efficiency Tests

- In all tests conducted at purging air flow rates typical of current mobile RAs, CO and SF6 tracer gas concentrations in the purge rooms were reduced by a factor of 16 or more in 4 or less volumetric air flow changes

- Therefore, current purging systems are capable of purging the internal atmosphere from 400 ppm CO to 25 ppm CO as required by 30 CFR § 7.508 (c) (2)

Purging Room Contamination with Miner Entry

- To answer the question concerning the relationship between the concentration of noxious gases in the mine atmosphere external to the refuge alternative and the concentration that will be present inside the refuge alternative purge room following entry of miners but prior to purging, SF_6 tracer gas testing was conducted in the OMSHR reverberation room which has a volume of more than 40,000 ft^3.

- Three purging rooms were used in this testing:
  - A 57 ft^3 tent-type RA purge room, designed for a maximum of 7 people
    Door is 4.25 ft^2
  - A 102 ft^3 mock-up RA purge room, designed for a maximum of 8 people
    Door is 6.7 ft^2
  - A 153 ft^3 rigid-steel RA purge room, designed for a maximum of 8 people
    Door is 9.5 ft^2

Purge Room Contamination Test Procedure

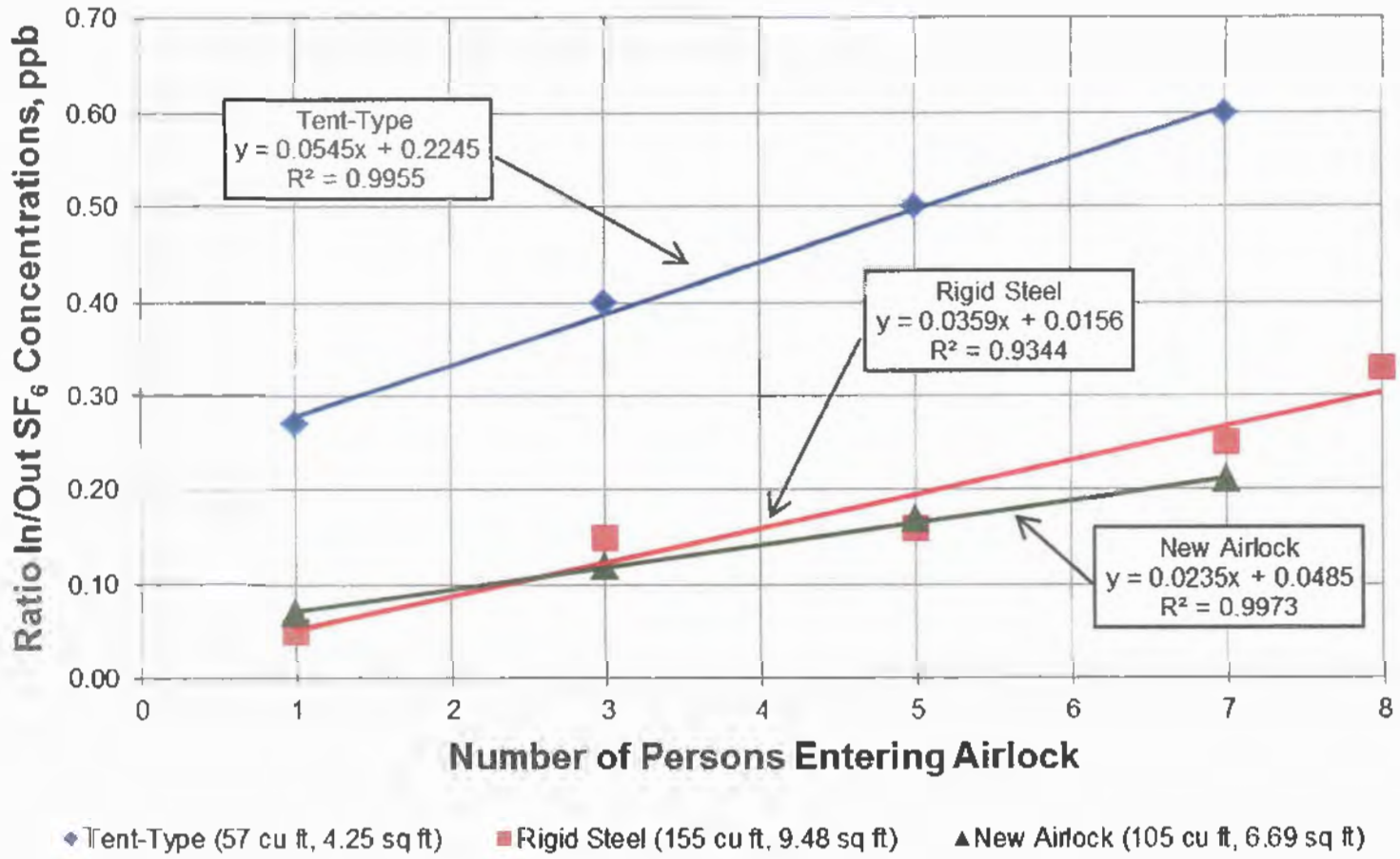
- Release SF_6 into Reverberation Room and mix to obtain uniform concentration
- Individuals (varying numbers) enter purging room and sample SF_6 in purge room
- Ratio of SF_6 in purge room to SF_6 reverberation room provides the contamination factor

Purge Room Contamination Test Findings

- Contamination factor is impacted by number of individuals entering, size of door, time door is open, and purge room size
- Had to account for SF_6 carried into purge room in test subject lungs

Chamber	Number of Subjects Entering Airlock	Time to Enter, sec	Door Size, sq ft	Airlock Volume (Empty), cu ft	Airlock Volume (Occupied), cu ft	SF_6 Contaminant Ratio (Inside Airlock vs. Outside)[1,2]
Tent-type	1	20	4.25	57	54.2	0.20
Tent-type	1	20	4.25	57	54.2	0.20
Tent-type	1	20	4.25	57	54.2	0.26
Tent-type	1	20	4.25	57	54.2	0.28
Tent-type	1	20	4.25	57	54.2	0.29
Tent-type	3	36	4.25	57	48.5	0.39
Tent-type	5	38	4.25	57	42.9	0.48
Tent-type	7	70	4.25	57	37.2	0.58
Rigid steel	1	15	9.50	153.5	150.7	0.05
Rigid steel	3	28	9.50	153.5	145.0	0.15
Rigid steel	5	15	9.50	153.5	139.4	0.18
Rigid steel	7	31	9.50	153.5	133.7	0.25
Rigid steel	8	42	9.50	153.5	130.9	0.32
Mock-up airlock	1	12	6.70	102	99.2	0.07
Mock-up airlock	3	17	6.70	102	93.5	0.12
Mock-up airlock	5	21	6.70	102	87.9	0.16
Mock-up airlock	7	25	6.70	102	82.2	0.19

Graph of Purge Room Contamination Factors per Number of Occupants



Purge Room Contamination Conclusions

- The contaminated air concentration inside an RA purge room after refuging miners enter could be as high as 58% of the exterior concentration
- The percentage of outside contaminant entering a small purge room of a tent-type mobile refuge alternative ranged from 20% to 58%, while for a larger purge room in a rigid steel RA it ranged from 5% to 32%
- The number of miners entering, the time the door is open, purge room volume, and door size are all factors with respect to the contaminant concentration which results in the purge room

Recommendations Resulting from OMSHR Purge Room Research

- A mine ambient CO level should be established based on a disaster scenario
- The expected contamination factor for a specific RA should be determined experimentally
- Since it may be nearly impossible to reduce the CO concentration in a purge room to 25 ppm or less given possible levels of contamination, limitations on purging capacity, and time constraints, additional measures may need to be taken to protect miners who take refuge

Additional Purge Room Contamination Testing

- MSHA has used this contamination factor data to evaluate all current mobile RAs in terms of how much contaminant could result in the main RA chamber
- To further supplement these test results, OMSHR has been requested by MSHA and two manufacturers to conduct additional tests on specific mobile RA designs
- We have just completed testing of one tent-type RA purge room and are currently testing a second design

Addition Purge Room Contamination Test Results to Date

- A. L. Lee purge room had a high contamination factor due to the large opening of the zippered door. The contamination factor was similar that that found in the earlier A. L. Lee design tested

- Preliminary contamination factor results for the Strata purge room are somewhat lower than for the other tent-style RA that was tested, but additional testing is continuing and needs to be completed.

Ed Thimons

Ethimons@cdc.gov

www.cdc.gov/niosh/mining

CDC Workplace Safety and Health NIOSH

OMSHR

Office of Mine Safety and Health Research

Demonstration of an Occupancy Derating Strategy for Mobile Refuge Alternatives used in Underground Coal Mines

David S. Yantek

CDC NIOSH

AB79-COMM-10-3

Demonstration of an Occupancy Derating Strategy for Mobile Refuge Alternatives used in Underground Coal Mines

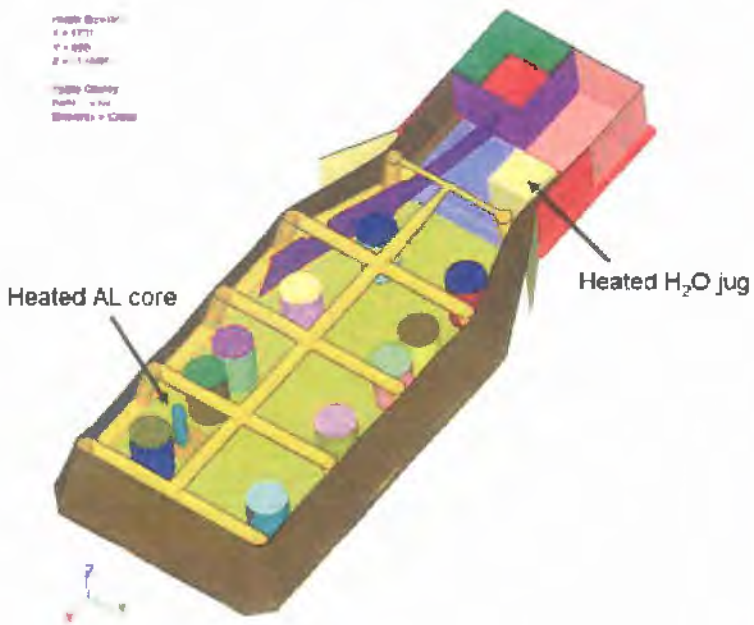
- Objective: Demonstrate how to use test data in conjunction with a validated thermal simulation model to develop derating tables for a production tent-type RA
- Approach: Develop and demonstrate a method that all RA manufacturers can use to develop derating tables
- Approximately 15-month effort

Demonstration of this derating strategy requires several intermediate steps

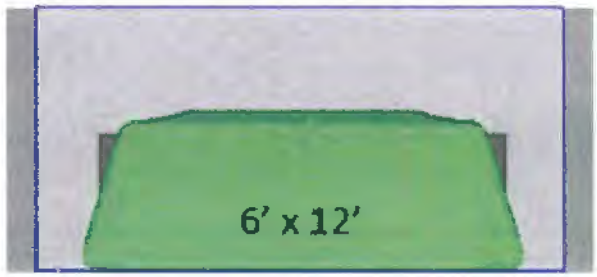
- Benchmark results with simulated miners versus “real” miners
- Determine if method of varying heat input to represent RA at less-than-full capacity affects results
- Investigate effect of initial mine air and ambient temperatures
- Perform in-mine testing for several capacities, ambient temperatures, etc.
- Develop and validate thermal simulation model and use validated model to develop a derating table

Previously validated model of the training RA as-tested in the SRCM was modified and used to ...

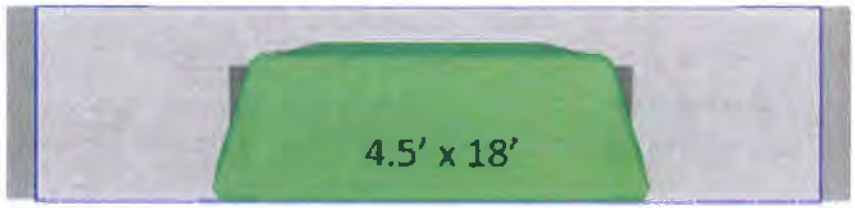
- Benchmark simulated miners against "real" miners
- Examine method of varying heat input
- Investigate effect of initial mine temperatures



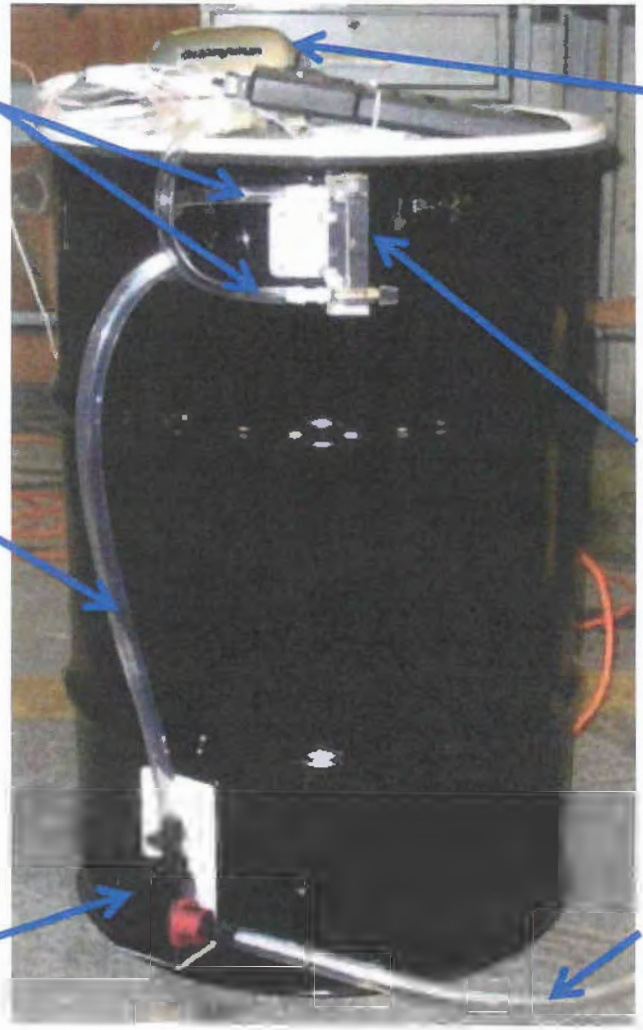
Original Mine Dimensions



Modified Mine Dimensions

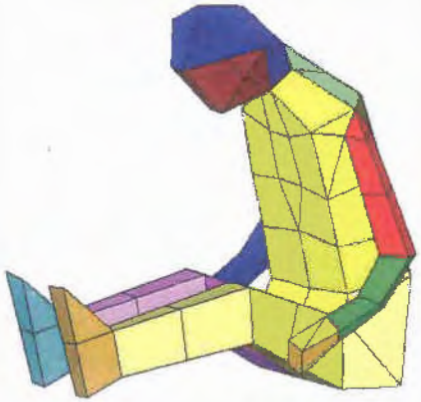


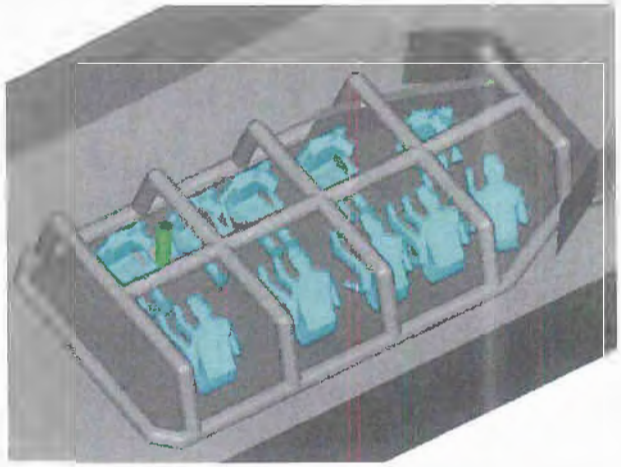
Heat input from OMSHR-developed simulated miners modeled as dry only, or dry plus moisture



In lieu of human subjects testing, ThermoAnalytics' Human Thermoregulation Model was used to benchmark performance of simulated miners

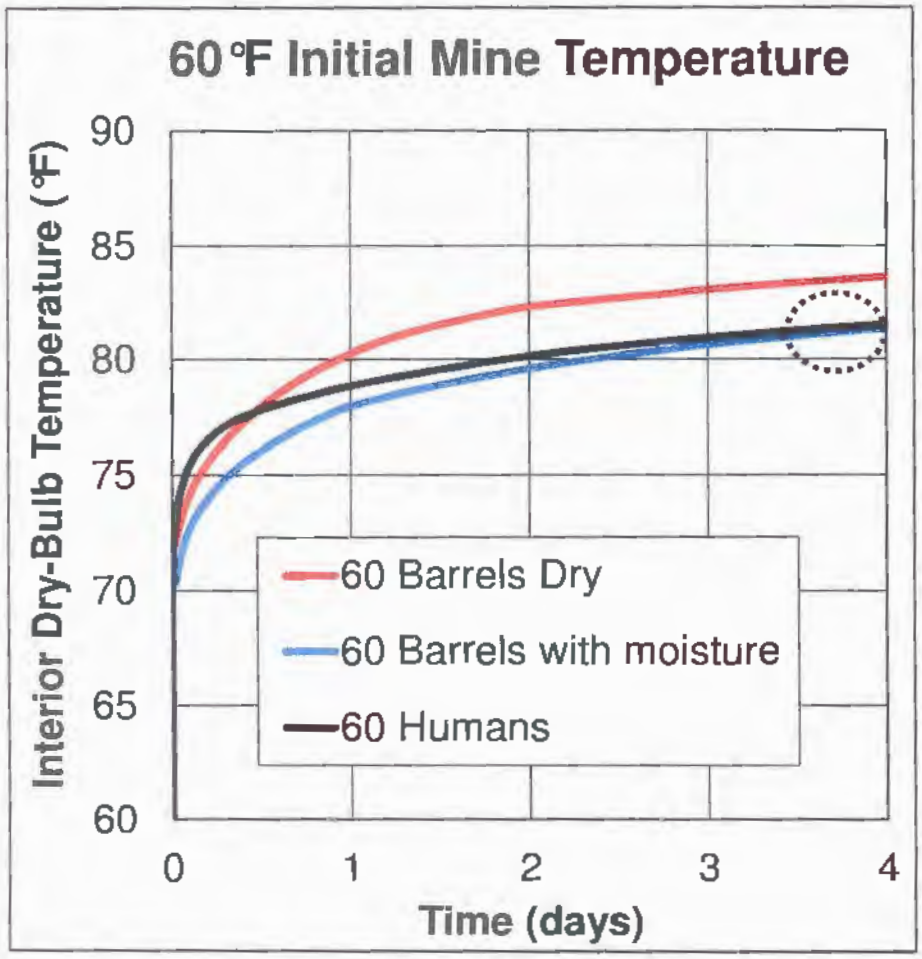
- HTM includes:
  - metabolic heating
  - shivering
  - vasomotion
  - sweating
  - respiration

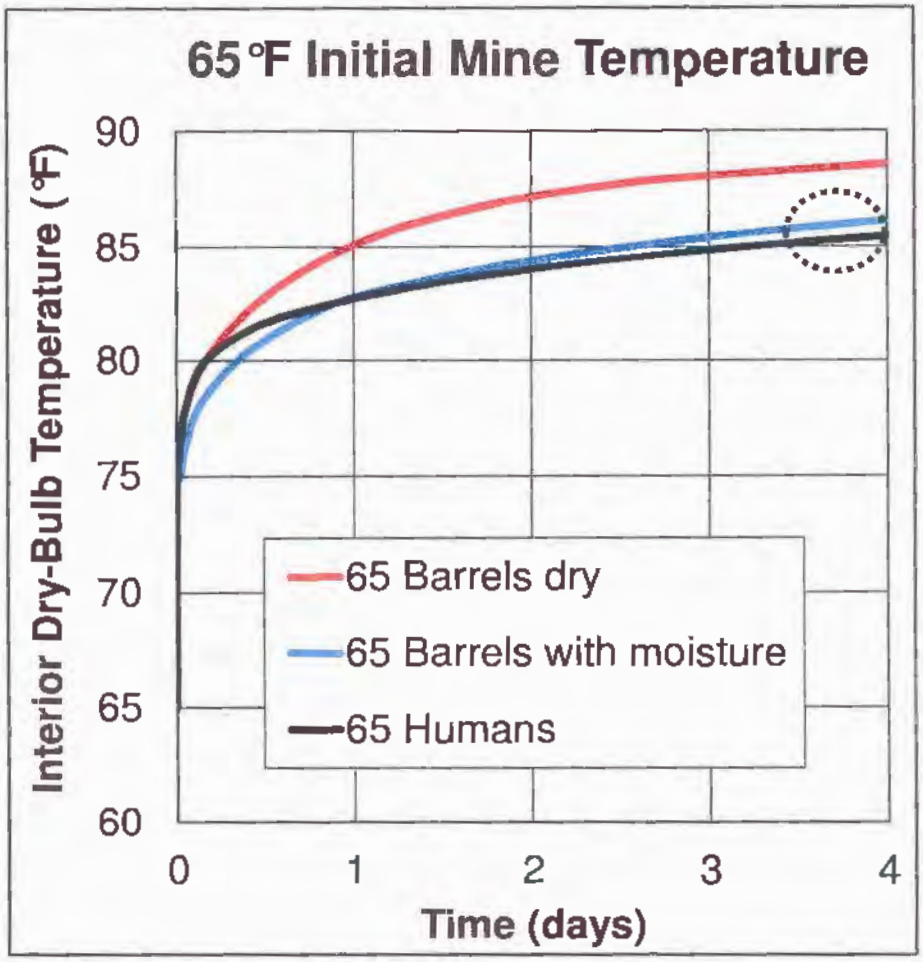




- HTM miners modeled sitting and wearing boxer shorts
- Compare results with HTM vs results with simulated miners
  - Simulated miners with sensible heat only
  - Simulated miners with sensible plus latent heat
- Examine heat loss mechanisms from "real" people (conduction, convection, radiation, sweating)

Dry-bulb temperature for simulated miners with moisture generation closely agrees with the dry-bulb temperature for "real" miners





For conditions that result in apparent temperatures near 95°F, the simulated miners yield similar apparent temperatures to the "real" miners

Heat Input	Initial Mine Air and Strata Temperatures Set to 60°F			Initial Mine Air and Strata Temperatures Set to 65°F		
	Interior Air Temp	Relative Humidity	Apparent Temp	Interior Air Temp	Relative Humidity	Apparent Temp
"Real" miners	81.5°F	87.8%	89.4°F	85.5°F	92.3%	104.7°F
Simulated miners, dry	83.6°F	NA	-	88.6°F	NA	-
Simulated miners w/ moisture	81.4°F	80.2%	87.4°F	86.1°F	80.0%	100.1°F

Note: Simulated miners w/moisture input provided 1 L of H_2O per miner per day

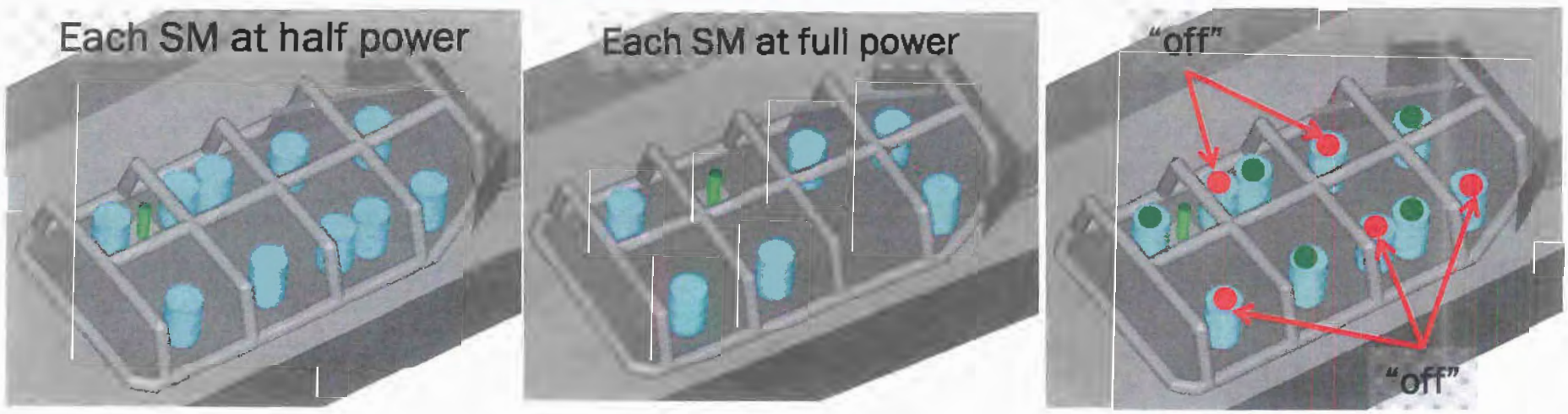
The effect of the heat input variation method was examined using the existing validated model

Method 1
- RA at full capacity
- Reduce power to each simulated miner
- Easiest to vary heat input (use variAC)

Method 2
- RA at desired capacity
- Each simulated miner provided full power
- Most time-consuming

Method 3
- RA at full capacity
- Desired number of simulated miners "on"
- Remaining simulated miners "off"

Example: 10-person RA at half capacity (5 miners)



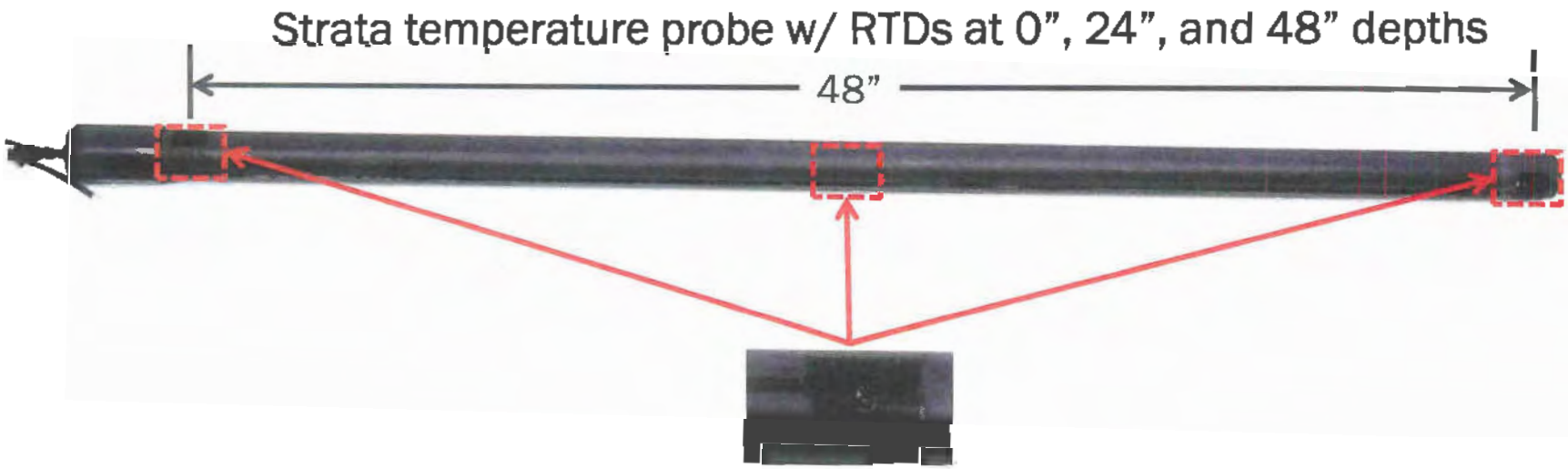
The method of varying the heat input had minimal effect on the final dry-bulb temperature

Heat Variation Method	Final Interior Dry-bulb Temperature for Number of Simulated Miners at Initial Mine Air and Strata Temperature		
	7 Miners, 65°F	5 Miners, 70°F	3 Miners, 75°F
Method 1: Volume Knob	82.0	82.2	81.9
Method 2: Remove Non-powered Simulated Miners	82.1	82.6	82.8
Method 3: Leave Non-powered Simulated Miners	82.0	82.1	82.4

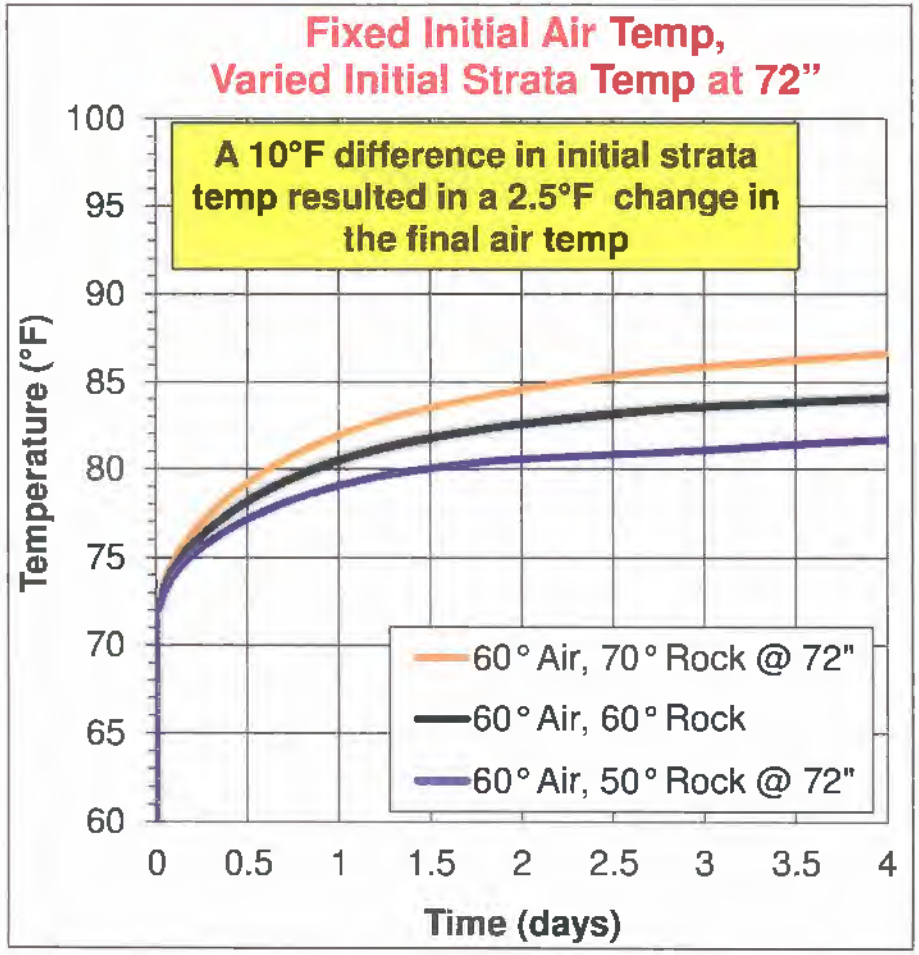
Note: Results from simulated miners with dry heat input

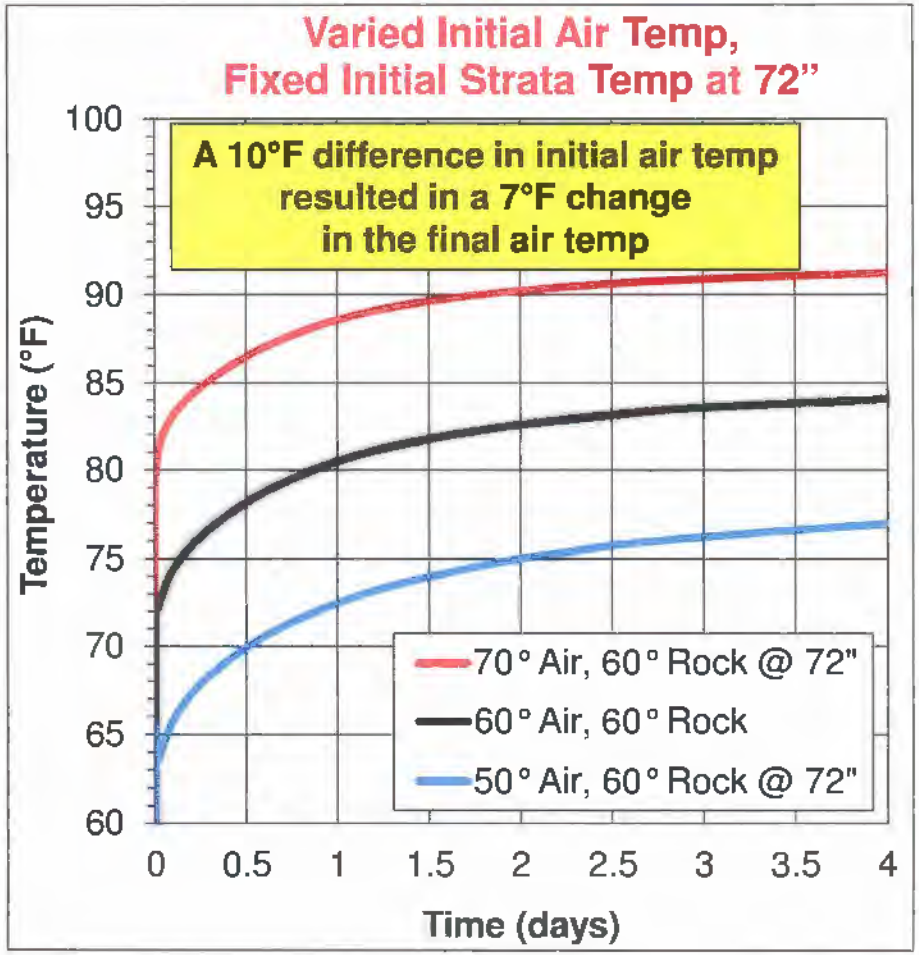
Need to define mine ambient temperature for de-rating purposes, data collection in progress

- Examine temperature variations due to location, mine depth, and/or mine geology
- Develop an "ambient" temperature that considers the strata temperature
- Use measured temperatures with mine stratigraphy to examine variation of RA capacities



Simulations show the final air temperature is affected by both the initial mine air and strata temperatures





A series of in-mine tests will be conducted on a production model tent-type RA in OMSHR's Experimental Mine

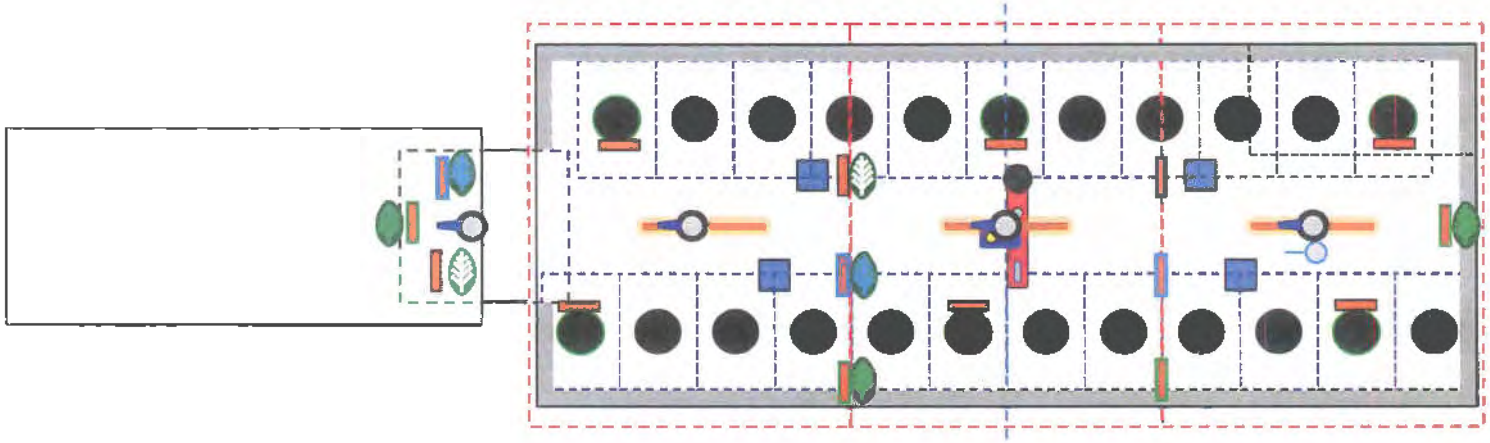
In-mine tests will be used to collect data with the purpose of developing derating tables

- Heat input using simulated miners controlled by automatic variAC to hold input power constant
- Tests conducted at several RA capacities, for example 100%, 75%, 50%
- Heat input will be varied by leaving non-powered simulated miners in tent
- Elevated temperature test conducted with mine air preheated by minimum of 10 °F

RA and mine will be thoroughly instrumented to provide data to validate a thermal simulation model and to develop derating tables

- Air temperature and relative humidity measurements within RA and in mine air
- Condensation sensors within RA
- Surface temperatures measured on outside of RA
- Mine strata surfaces and temperatures with depth
- Airflow in RA and within mine due to natural convection

Interior sensors



- Simulated miner
- 48" long averaging RTD
- Temp/RH Sensor
- Condensation sensor (roof)
- Condensation sensor (wall)
- Condensation sensor (floor)
- Water tank & CO_2 scrubber heat
- WBGT Array (DBT, WBT, BGT, AF)
- Omnidirectional airflow sensor
- RTD ribbon sensor (roof)
- RTD ribbon sensor (wall)
- RTD ribbon sensor (floor)

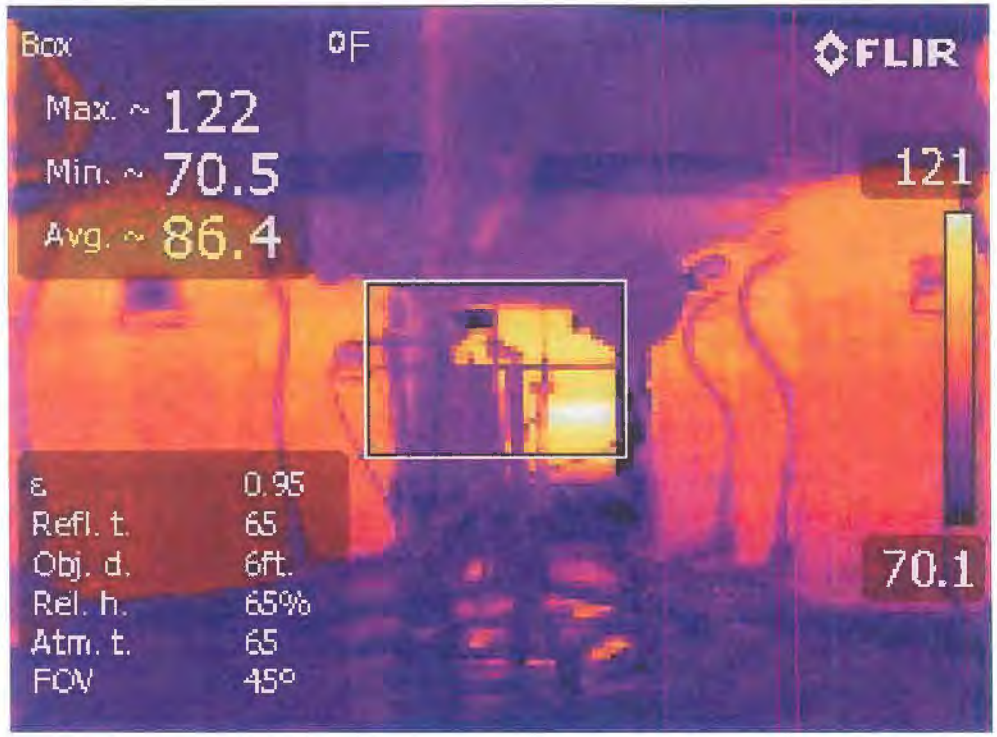
A thermal simulation model of the production RA in the EM will be developed and validated

- Develop model using proven techniques
  - Mine strata modeled in 3-inch-thick layers
  - Strata temperature at 6-foot depth assumed constant
- Validate model using OMSHR-collected test data
- Use both simulated miners and "real" miners for heat input
- Develop derating table from 55 °F to 75 °F (finding max number of miners so that RA interior is below 95 °F AT)
- Use temperatures and stratigraphy from cooperating mines to examine RA capacity for real mines

Demonstration of an Occupancy Derating Strategy for Mobile Refuge Alternatives for Underground Coal Mines

David S. Yantek

dyantek@cdc.gov



www.cdc.gov/niosh/mining

OMSHR

Office of Mine Safety and Health Research

Temperature Rise in Mobile Refuge Alternatives

David S. Yantek

AB79-COMM-10

Outline

1. RA regulations related to heat and humidity
2. Heat and humidity concerns with RAs
3. OMSHR research on RA heat buildup

Several regulations are related to heat buildup within RAs

- RA must provide breathable air for at least 96 hours
- Must provide at least 15 FT^2 of floor space per miner
- Must provide 30 to 60 FT^3 of volume per miner depending on mine height
- RA interior can not exceed 95 °F apparent temperature

Dry-bulb Temperature and Relative Humidity that Yield an Apparent Temperature of 95 °F	
Dry-bulb Temperature (°F)	Relative Humidity
83.7 °F	85%
83.1 °F	90%
82.6 °F	95%

Heat input is due to the metabolic heat of miners and the exothermic RXN of the CO2 scrubber

- Miners assumed to generate 117[1] watts per miner
- CO2 scrubber system assumed to generate
  - 50 watts per miner for lithium hydroxide
  - 27.5 watts per miner for soda lime
- Heat input is a combination of sensible and latent heat
  - Sensible (dry) heat raises the dry-bulb temperature
  - Latent (wet) heat increases the relative humidity
  - Both sensible and latent heat increase the apparent temperature

[1] Based on a "standard" 165-LB male with an assumed 80% rest and 20% moderate activity level

Original approvals were based on engineering calculations

- In 2007, OMSHR tested four mobile RAs at Lake Lynn and two failed the 95 °F apparent temperature limit
- MSHA requested OMSHR to provide guidance on determining apparent temperature for approval purposes

Major concerns to be addressed through research

- Validity of the *infinite-heat-sink* assumption
  - Used in the engineering calculations for initial approvals
  - Subsequently used in some manufacturers' test facilities
- Lack of a standard test procedure to determine the apparent temperature
  - Test facility design, test facility thermal behavior
  - Heat input method, dry heat only, dry heat plus moisture
  - Test start-up procedure
  - Strategy for developing "derating tables"
- Development of an occupancy derating strategy for warmer mines (>55 °F)

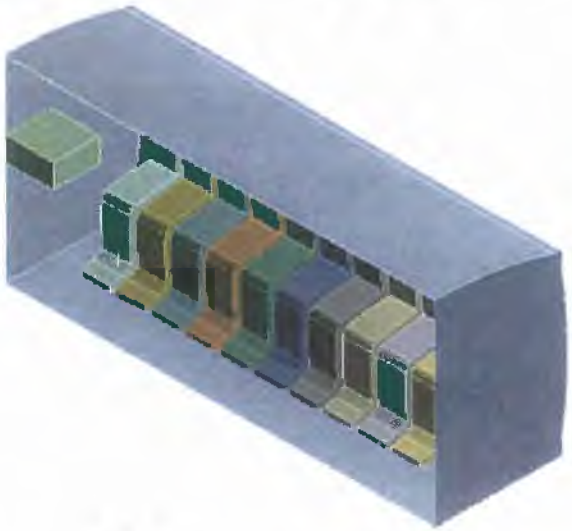
From 2008 to 2013, OMSHR conducted research on multiple aspects of RAs with emphasis on purging and temperature rise

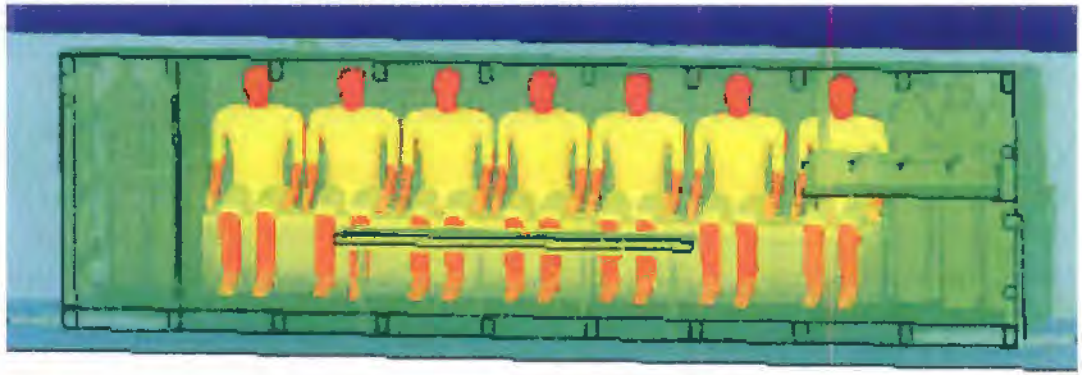
- Goal: Establish a scientific basis to determine the apparent temperature in chambers under different conditions

- Methodology: Create accurate models and execute a robust experimental program to investigate specific research questions to develop a standardized test

Note: HSRB approval could not be obtained for human subject testing

Several iterations of models were developed and used to examine factors that affect apparent temperatures





Models used to examine effect of:

- Infinite-heat-sink assumption
- Mine geometry, geology, and ambient temperature
- Chamber material and thickness
- Air stratification and air flow

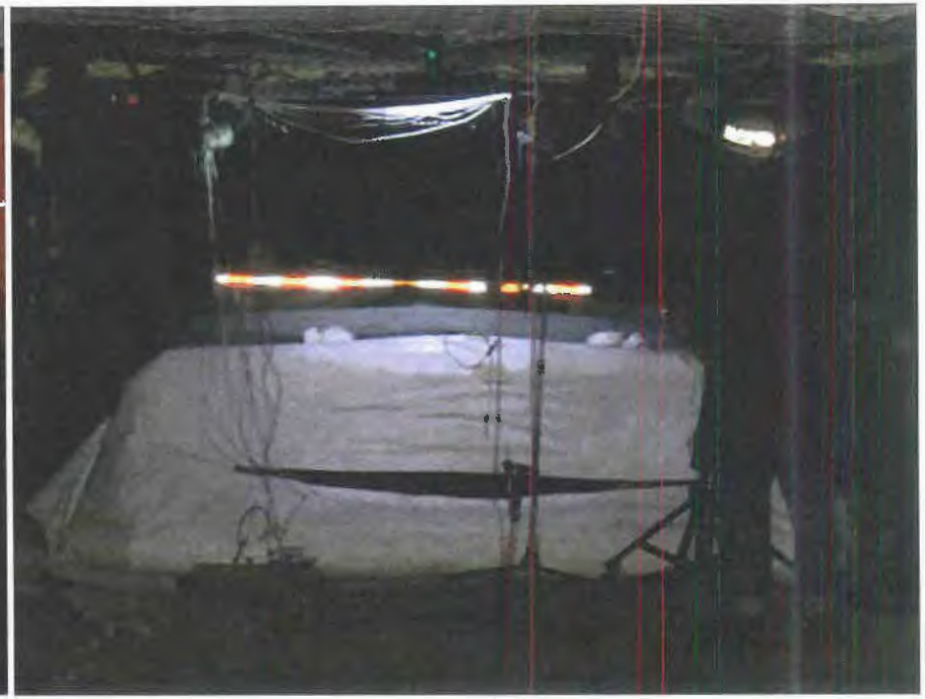
OMSHR conducted experiments to examine several aspects of RA heat testing

- Validity of infinite-heat-sink assumption for mines
- Influence of test facility on temperature rise
- Effect of including moisture on temperature rise
- Ability of tested RA to meet 95 °F AT limit
- Method to determine derated capacity for warmer mines (>55 °F)

OMSHR conducted 96-hour AT tests on a 10-person[2] tent-type training RA

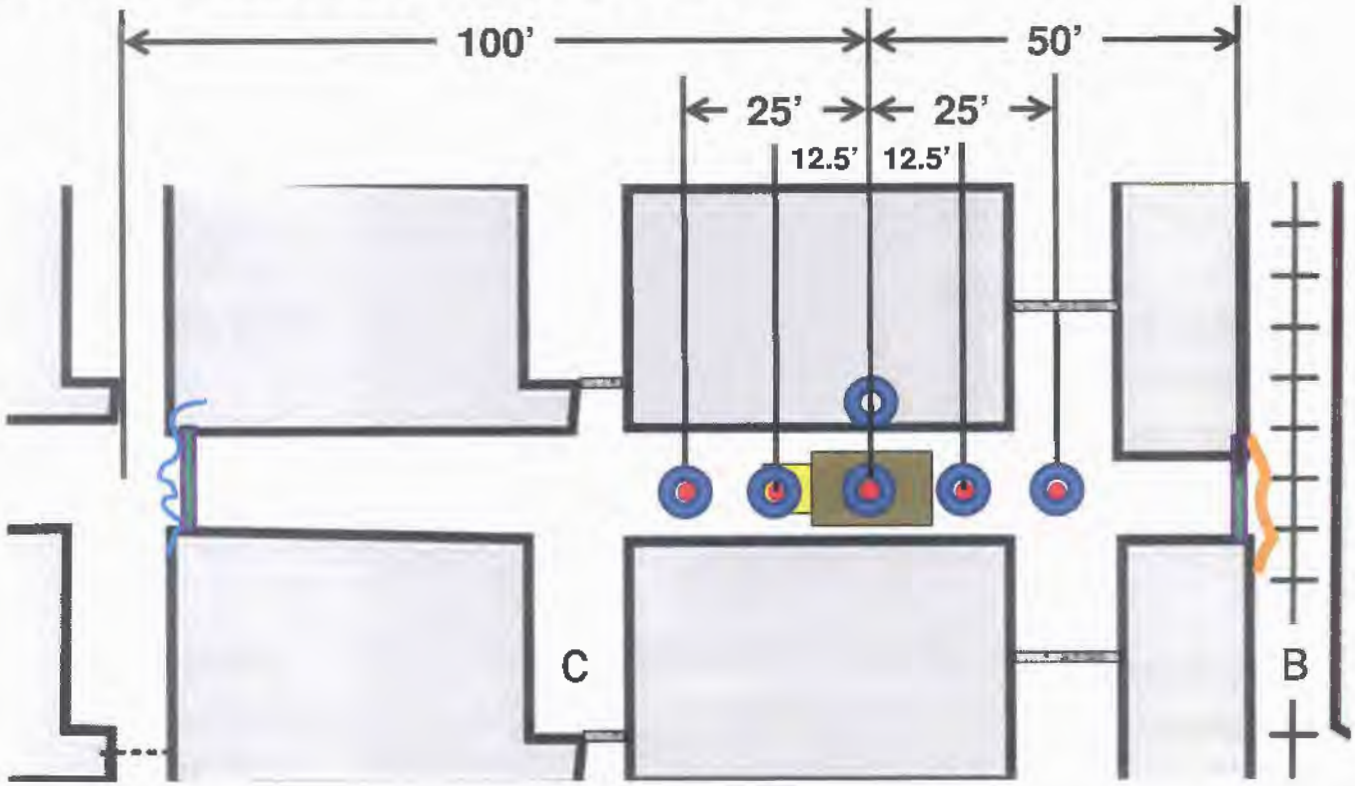
High bay
- Dry heat only

Safety Research Coal Mine
- Dry heat
- Dry heat plus 1 Liter of H_2O/miner/day



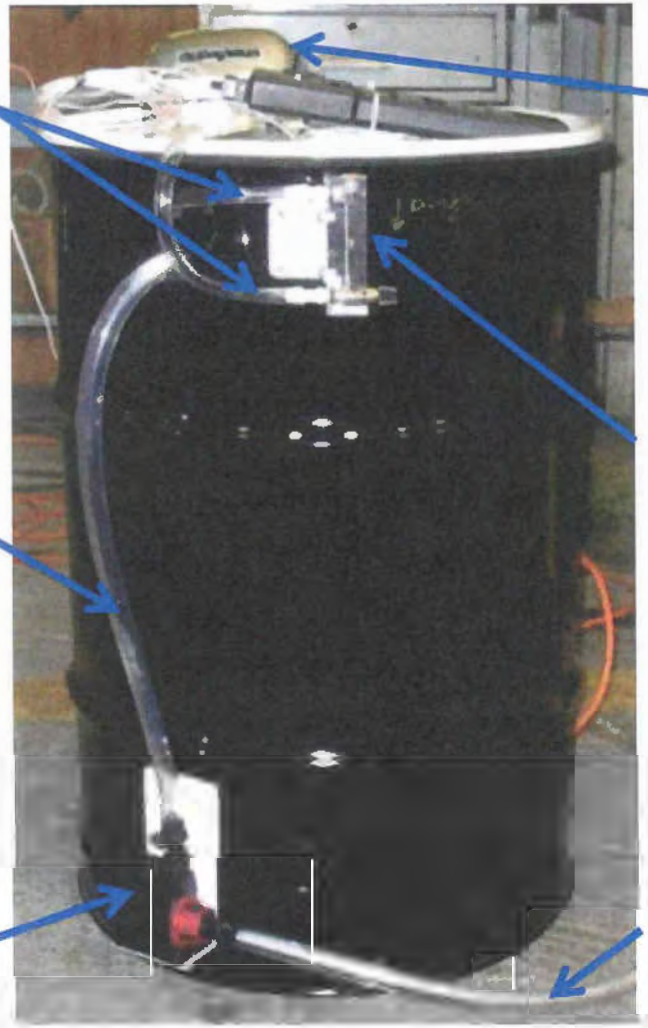
[2] Meets space requirementsof 15 ft^2 per person and volume requirement of 54 ft^3 per person for mine heights up to 54 inches

In-mine testing was conducted in a 150-foot-long test area of OMSHR's SRCM

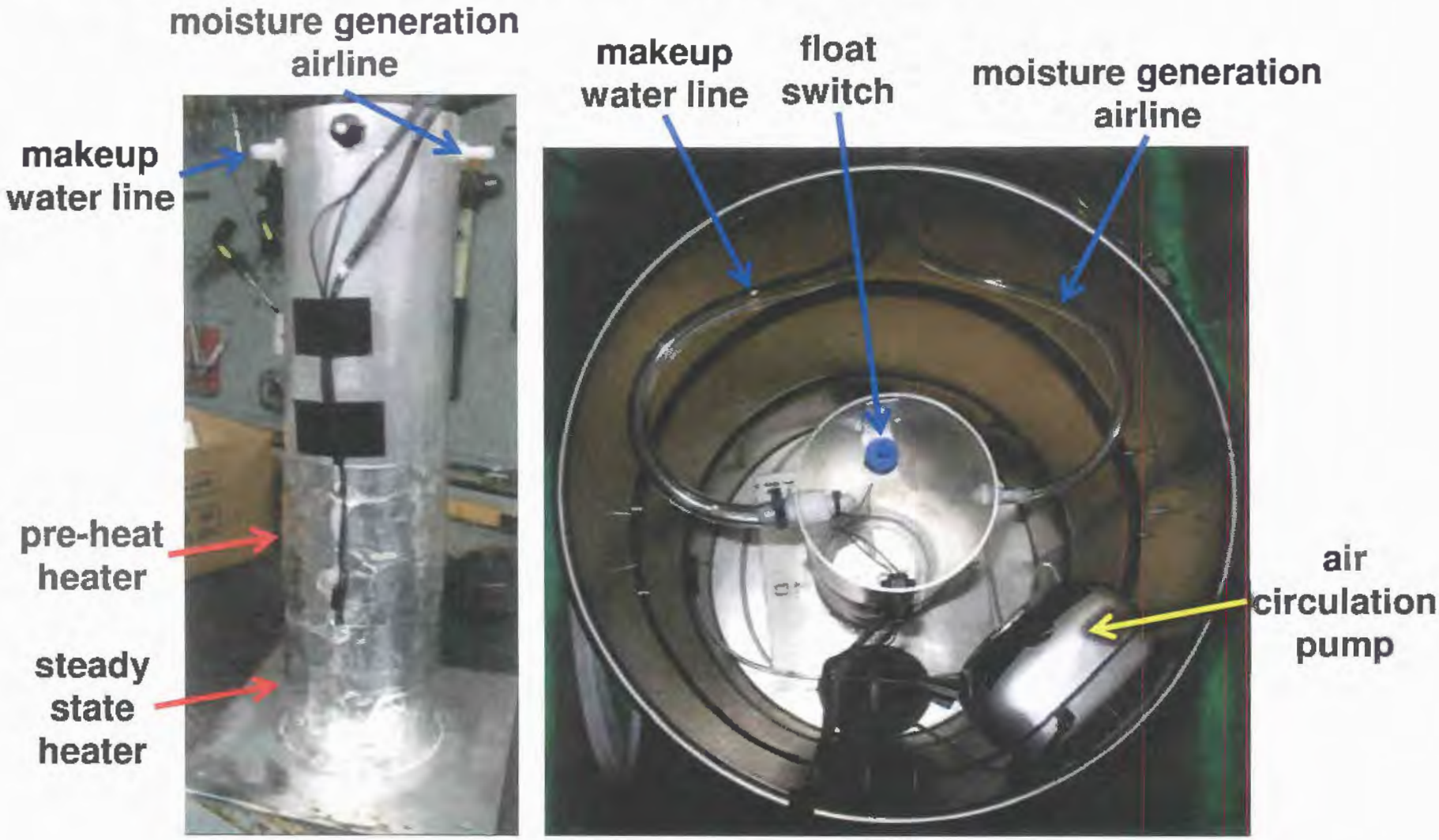


plastic sheeting
12-inch-thick concrete stopping
wood frame w/ expandable foam
refuge chamber
air temp measurement loc
strata temp measurement loc
brattice

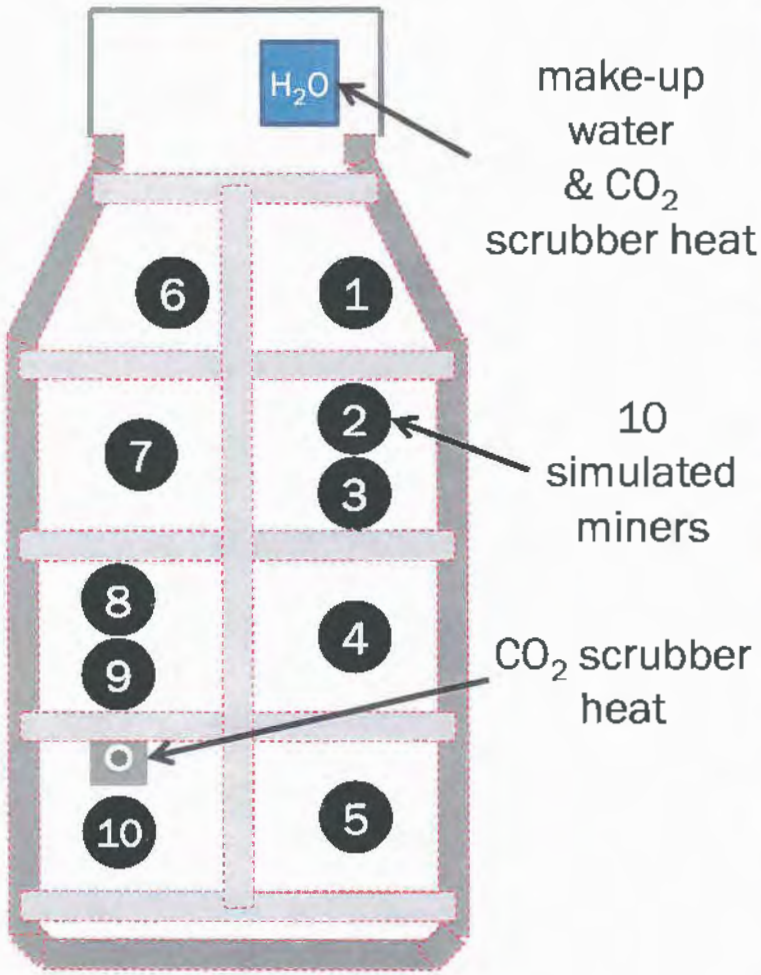
OMSHR developed simulated miners to provide heat that is representative of real miners



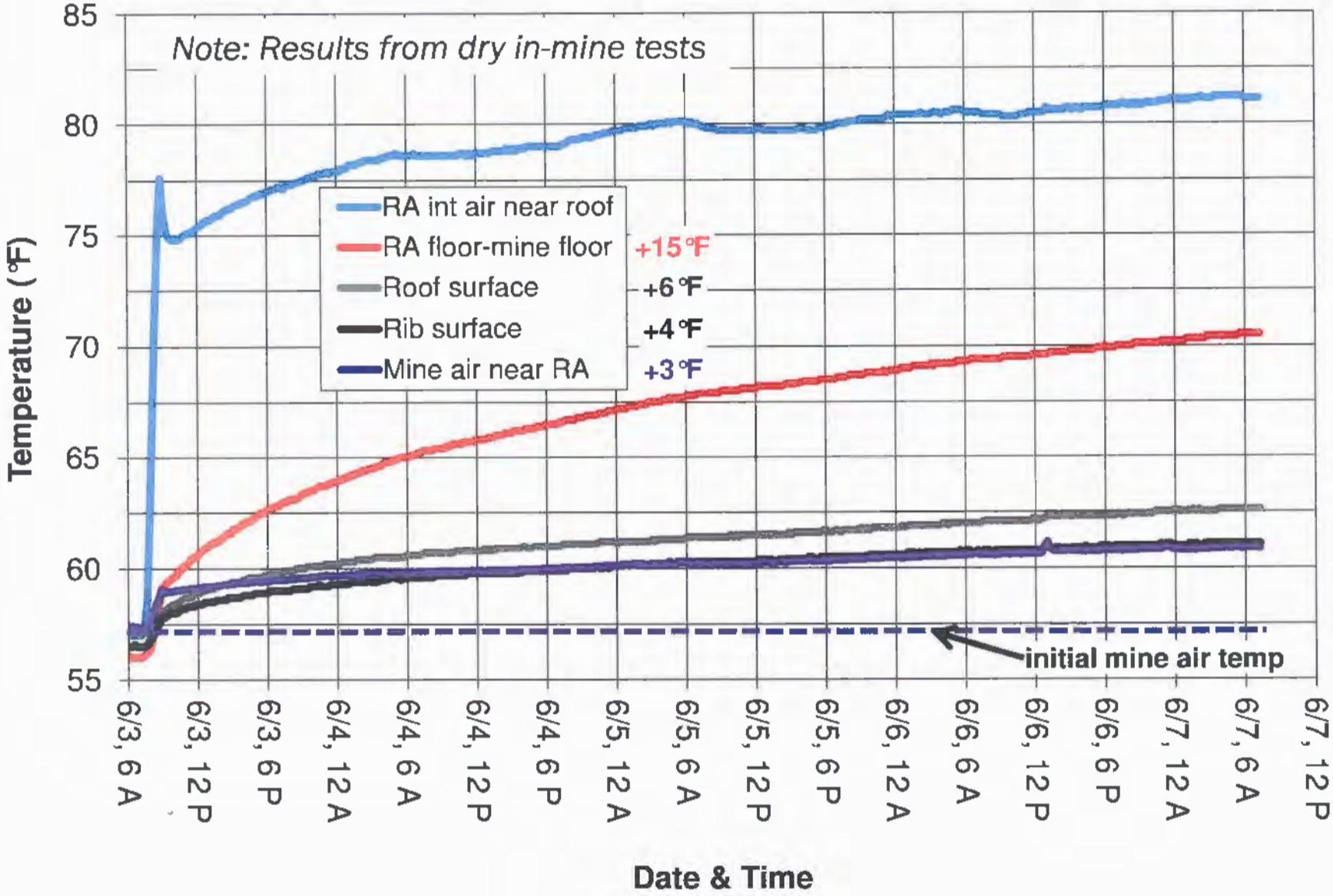
Heated, water-filled core inside simulated miners can be used to generate moisture



Heat input of 1670 watts to represent metabolic heat and CO_2 scrubber heat of 10 miners

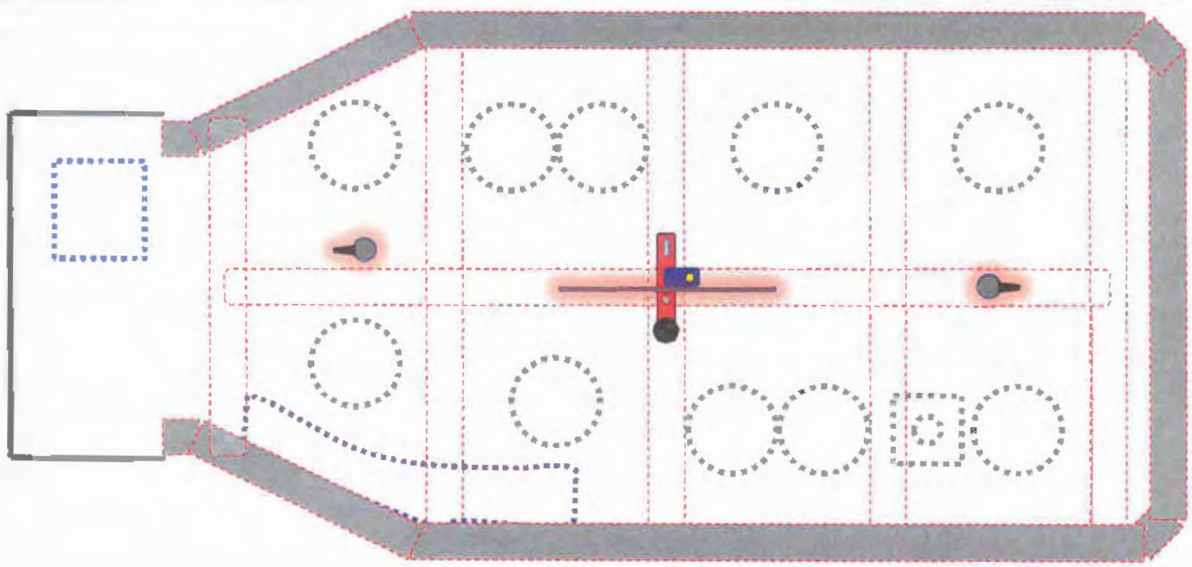


The mine temperatures *did not* remain constant



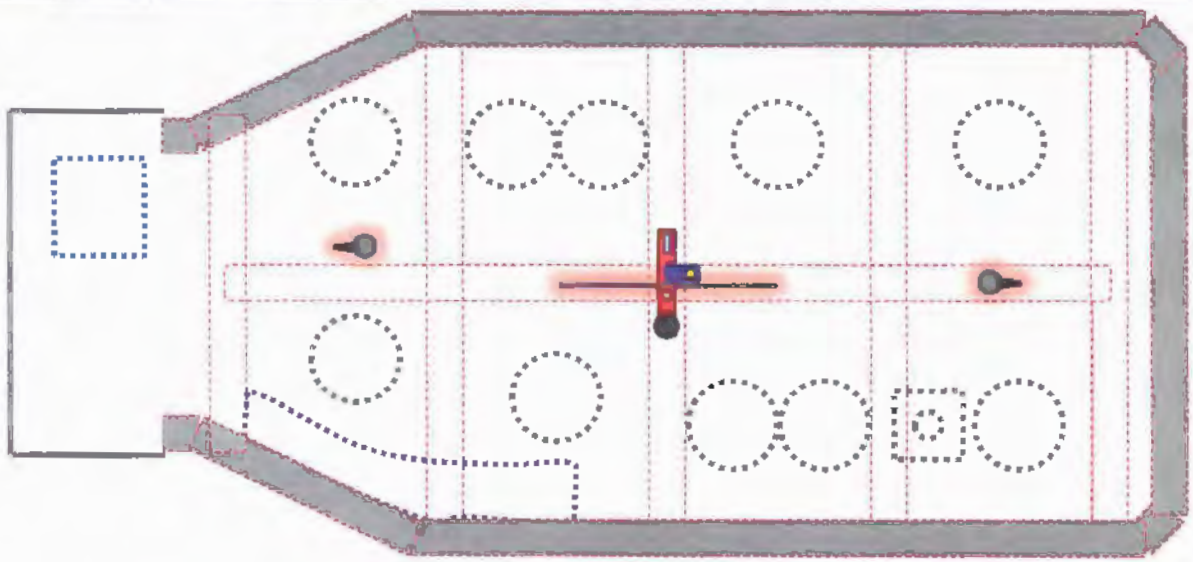
The temperature rise was higher for the in-mine tests than it was for the high bay tests

Dry-bulb Air Temperatures Inside Tent			
Test	Tent Center Near Floor	Tent Center Midheight	Tent Center Near Roof
High Bay, Dry	17.1	20.1	21.0
In-mine, Dry	19.9 (+16%)	23.8 (+18%)	25.2 (+20%)

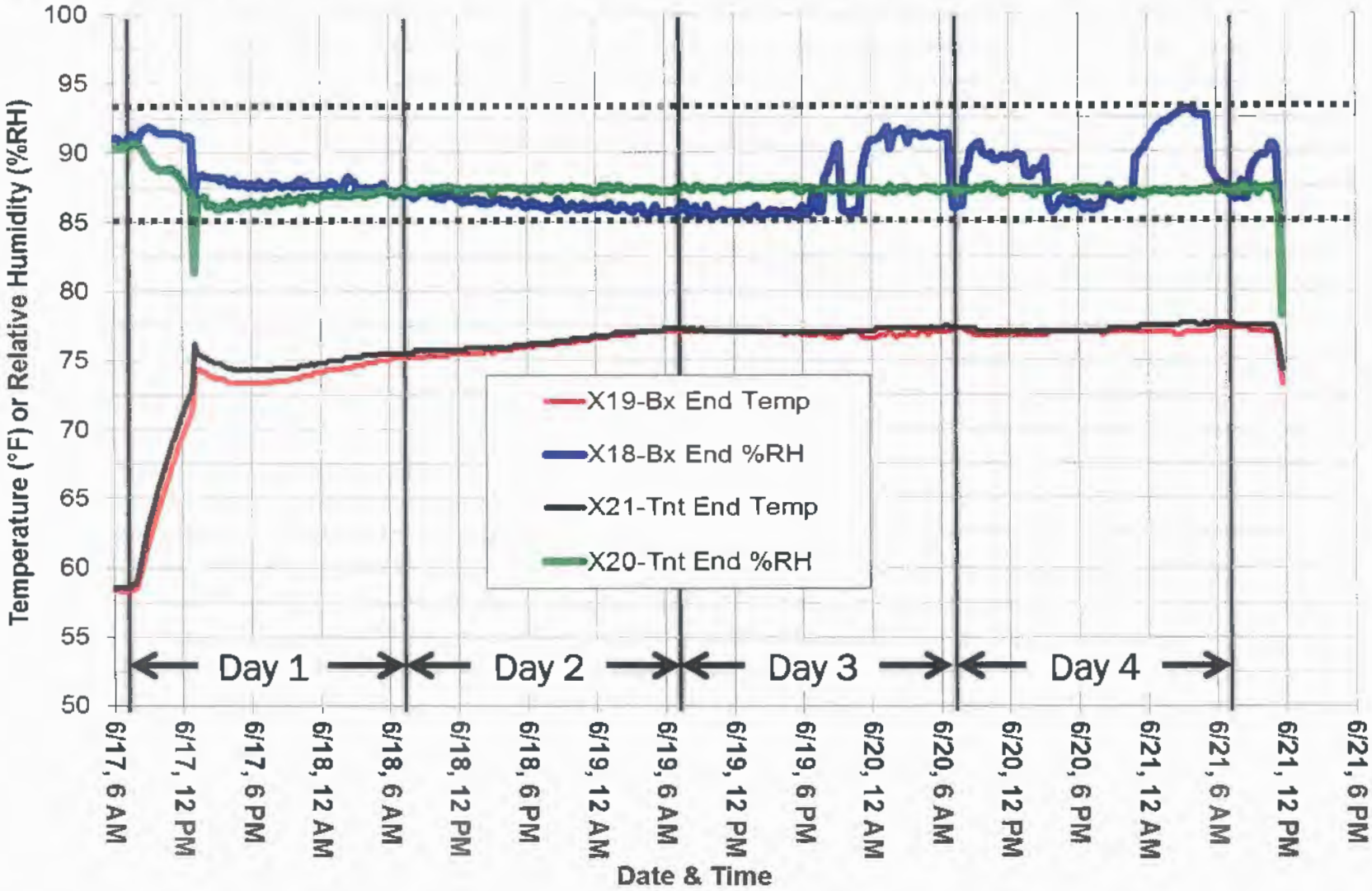


Including moisture *may* reduce dry-bulb temperature rise (mine was slightly preheated from dry tests)

Dry-bulb Air Temperatures Inside Tent			
Test	Tent Center Near Floor	Tent Center Midheight	Tent Center Near Roof
In-mine, Dry	19.9	23.8	25.2
In-mine, Wet	18.0 (-10%)	20.8 (-13%)	22.4 (-12%)



With a moisture input of 1 L/miner/day, the relative humidity ranged from 85 %RH to 93 %RH



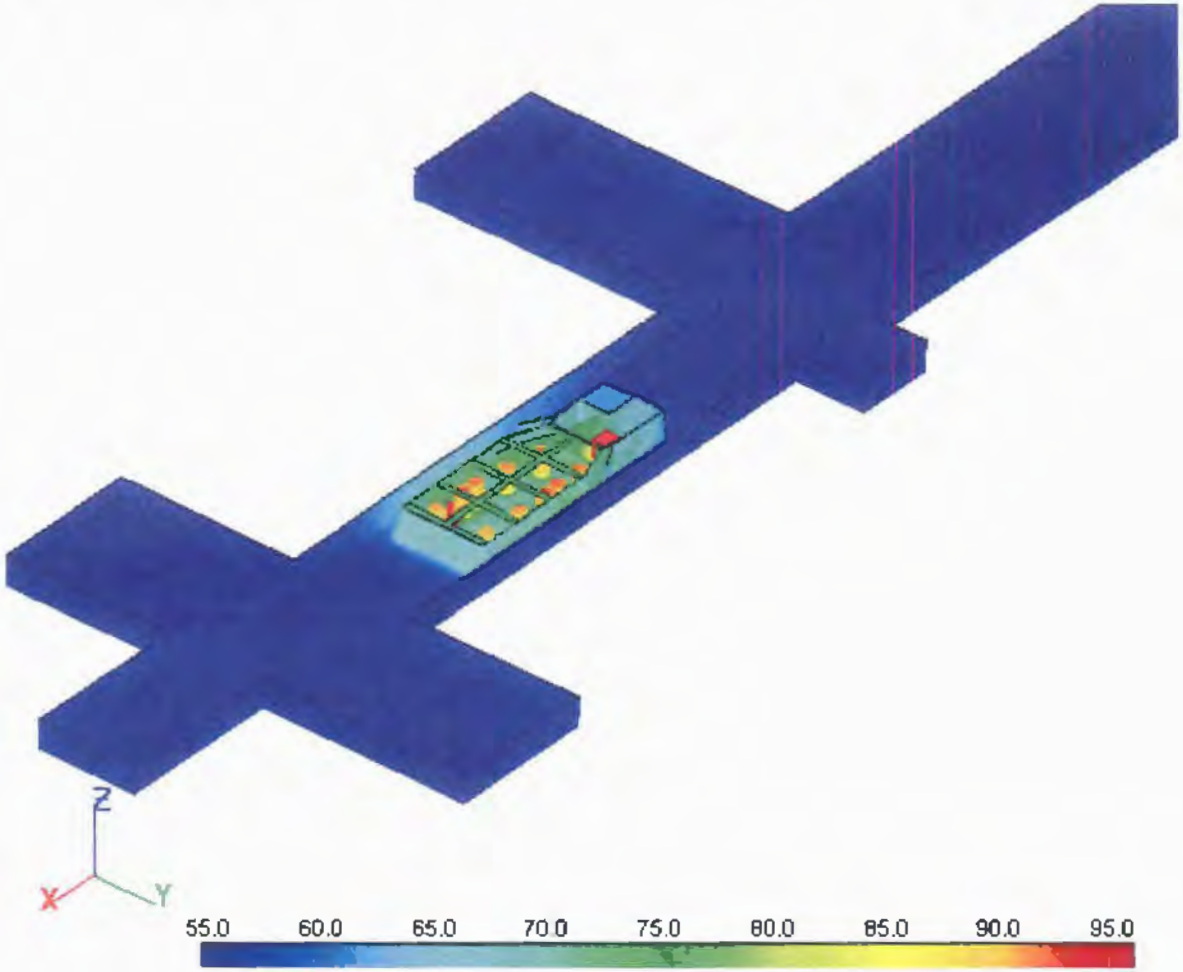
The dry in-mine test data was used to examine the apparent temperature for the RA as-tested in the SRCM (57.5°F initial mine air temperature)

- The tested RA reached the apparent temperature limit
  - 95°F AT assuming 95 %RH; 94°F AT assuming 90 %RH
- A derating table was developed for the *tested* RA assuming a fixed temperature rise of 2.5°F/miner at 95 %RH

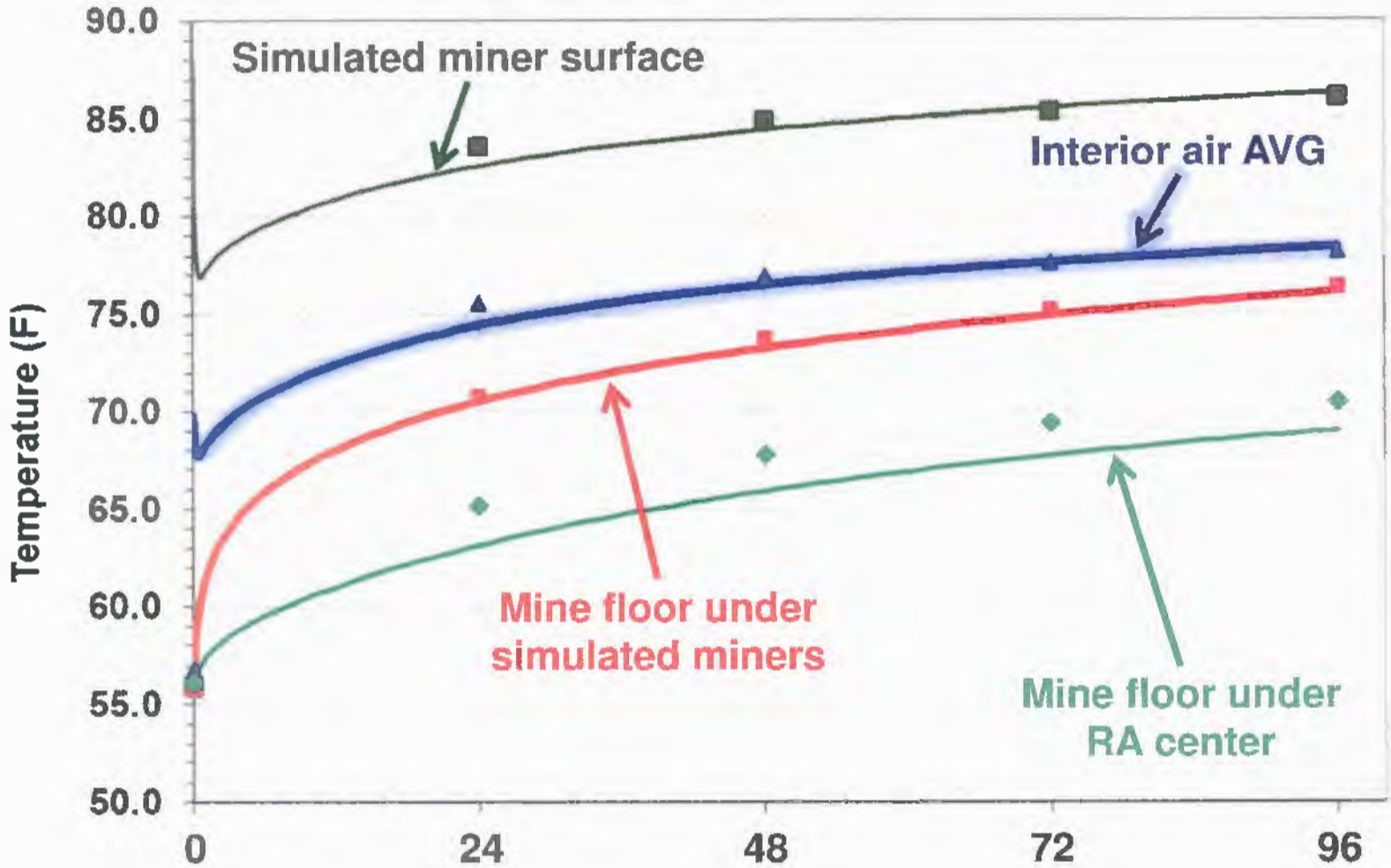
Mine Initial Ambient Temperature	Derated Capacity
60°F	8
65°F	6
70°F	4
75°F	2

Note: The above values are applicable only to the tested RA as-tested in the SRCM

OMSHR contracted ThermoAnalytics, Inc. to develop and validate a thermal simulation model of the RA as-tested in the SRCM



The thermal simulation model showed good agreement with the in-mine test data



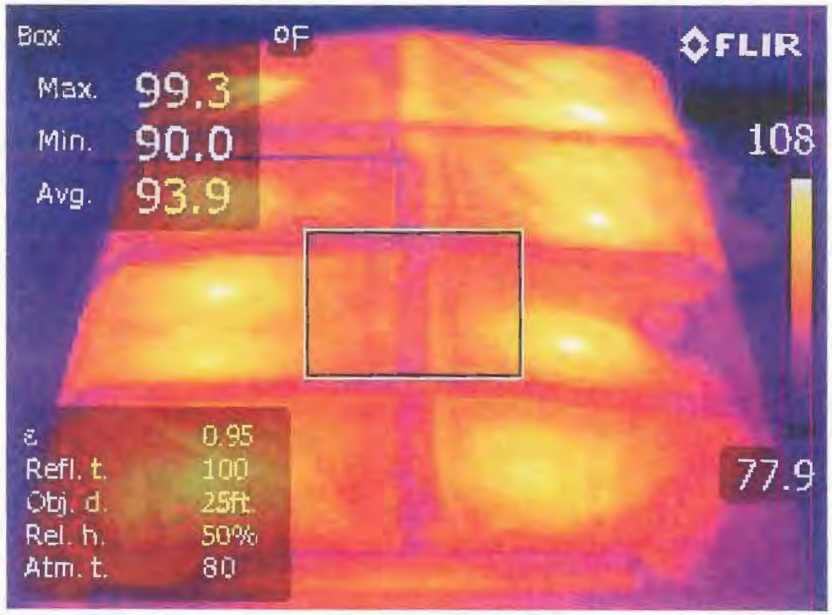
Key Findings from 2013 OMSHR RA Research

- Mine does *not* act as an infinite heat sink
- Test facility affects air temperature rise inside RA
  - ΔT was 16%-20% less in the high bay than it was in the mine
- Including latent heat may reduce temperature rise compared to sensible-heat-only tests
  - ΔT was 10%-13% less for in-mine wet test than it was for the in-mine dry test
- RAs may reach the apparent temperature limit at lower mine ambient temperatures than previously expected
- Derated capacity tables can be developed using a combination of physical testing and thermal simulation

Temperature Rise in Mobile Refuge Alternatives

David S. Yantek

dyantek@cdc.gov



www.cdc.gov/niosh/mining

OMSHR

Office of Mine Safety and Health Research

Overview of Research on Refuge Alternatives

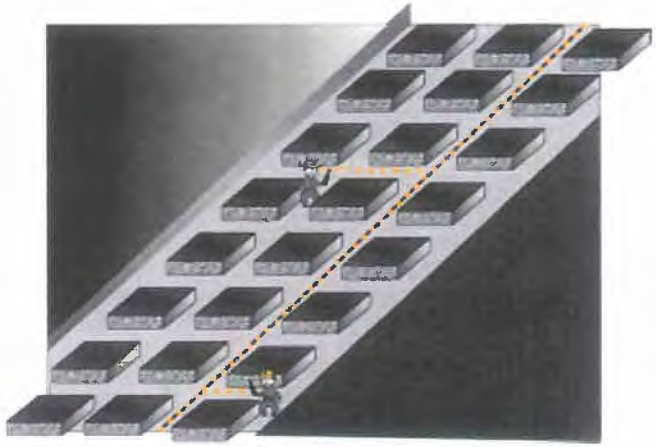
May 22, 2014

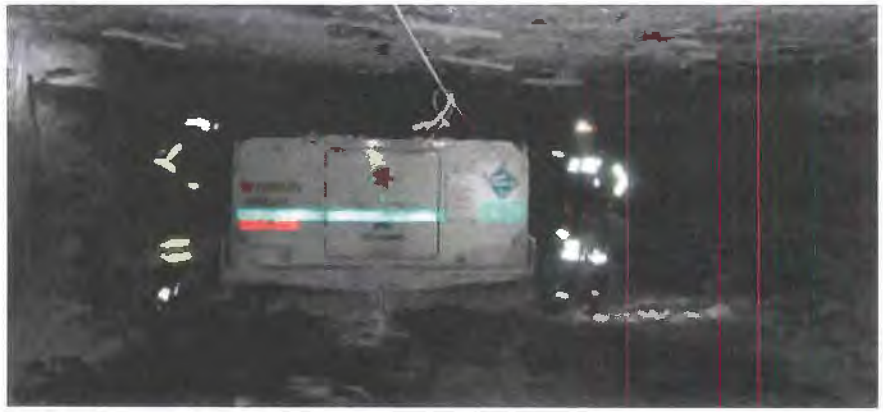
DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

AB79-COMM-10-3

MINER Act Imperatives

communications & tracking, oxygen supply, and refuge alternatives





Perspective -- Barricades vs. Refuge Alternatives

Perspective – Barricades v. Refuge Alternatives

Evaluation of Chambers in Lake Lynn Experimental Mine

In-Mine Evaluation of Chambers

Evaluation of Chambers in Lake Lynn Experimental Mine (2007)

- Protocol Development & Testing in collaboration with WV Task Force and MSHA A&CC
- Findings Reported on 12/19/2007
  - 2 of 4 failed the O_2 flow rate
  - 3 of 4 failed CO_2 level limit
  - 2 of 4 failed the temperature limit
  - Unable to evaluate purging
  - (operating instructions) all problematic
- Significant concerns
  - Purging
  - Temperature Rise
  - Deployment & Operating Procedures
- These formed the basis for the 2008-2013 research project and the results will be summarized at this meeting

CO Purging

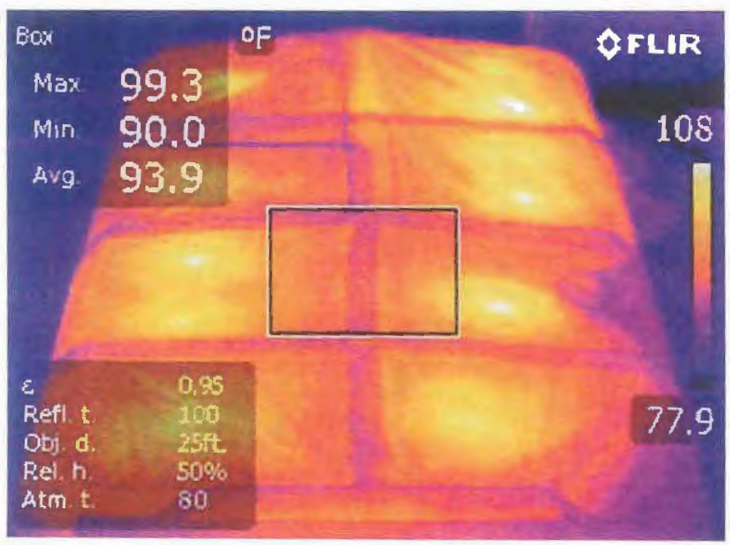
1. Assess capability to purge from 400 ppm to 25 ppm

2. Assess contamination during entry

Temperature Rise

1. Develop an explanation for the difference between the temperature rise predicted by the certification calculations and the observed values in the Lake Lynn experiments

2. Develop and validate analytical and experimental tools that could be used in a certification process



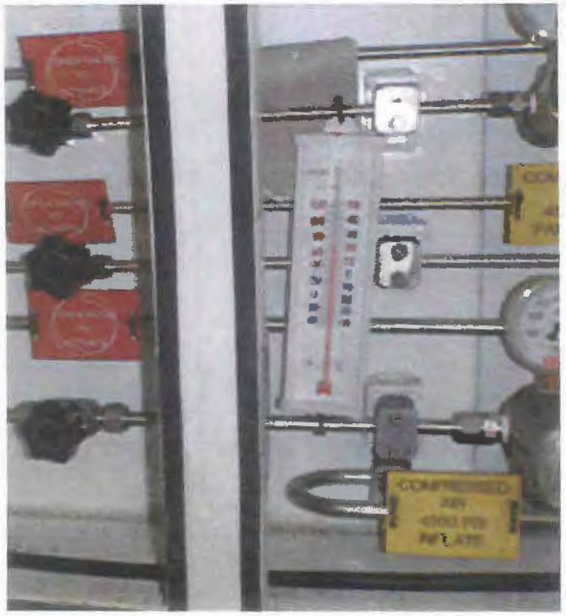
Usability

Deployment and Operating Instructions

Instructions for Unexpected Situations

Area & Volume Requirements

Water & Nutrition



BIP Refuge Alternatives

- Heat/humidity issues more easily managed
- Purging issues easily managed
- Tolerability issues are lessened
- Time constraints are significantly relaxed
- More options for communication with the surface

- *Unintended barrier: to protect miners at the face – must locate within 1000' of face*

Moving Forward – Generation 2.0 RAs

- Accept that: *despite the best efforts* of government and industry under extreme time pressures, the first generation practices and products are not perfect.

- Use lessons learned to implement new policies, practices, and technologies for the benefit of mineworkers

Moving Forward – Generation 2.0 Refuge Alternatives

- Address limitations in mobile RAs, and recognize that some limitations are inherent and serious. Adjust technology, practices, and policies accordingly for Generation 2.0

- Re-visit the NIOSH Report to Congress on RAs, specifically:
  - Value of RAs only in the context of an integrated escape plan (global practices)
  - Superiority of Built-in-Place (BIP) Refuge

OFFICE OF MINE SAFETY & HEALTH RESEARCH

Improving Mineworker Health & Safety Through Research & Prevention…

www.cdc.gov/niosh/mining

JKohler@cdc.gov