ThermoAnalytics®

Total Thermal Solutions

Miner Thermal Response and RA Maximum Occupancy

RA Partnership Meeting

Mark Klein

mdk@thermoanalytics.com

Agenda

Miner Core Temperature and Moisture Loss Predictions

- TAITherm software overview
- Human thermal model description and validation
- Human core temperature and moisture loss predictions

RA Derating Analysis

- Derating predictions for 23 person inflatable RA and 6 person steel RA in NIOSH Experimental Mine
- Derating predictions for 23 person inflatable RA and 6 person steel RA in five real mines

ThermoAnalytics®

Total Thermal Solutions

Miner Thermal Response

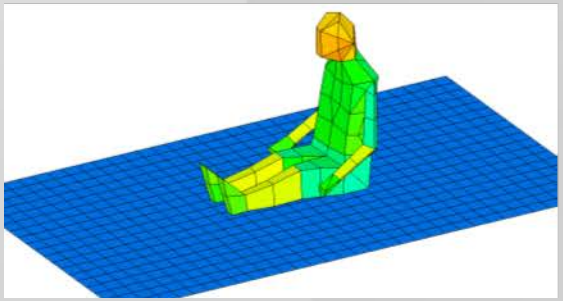
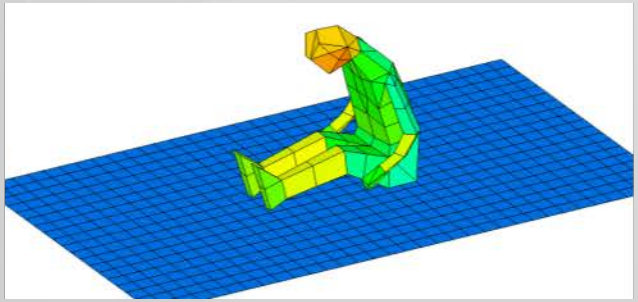
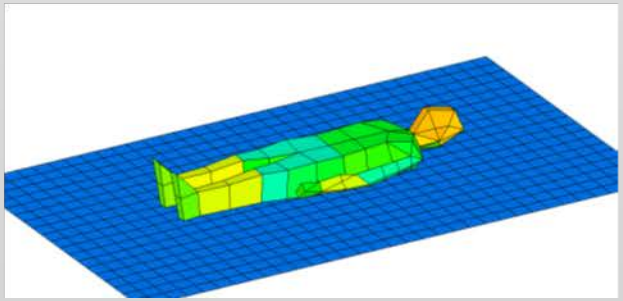
RA Partnership Meeting

Mark Klein

mdk@thermoanalytics.com

Miner Thermal Response

- Objective: Predict miner core temperature and moisture loss in RA-like environments to assess whether current apparent temperature and water ration requirements are appropriate
  - Humans were simulated in a range of steady temperature /humidity environments
  - Human core body temperature and moisture loss were calculated

TAITherm Overview

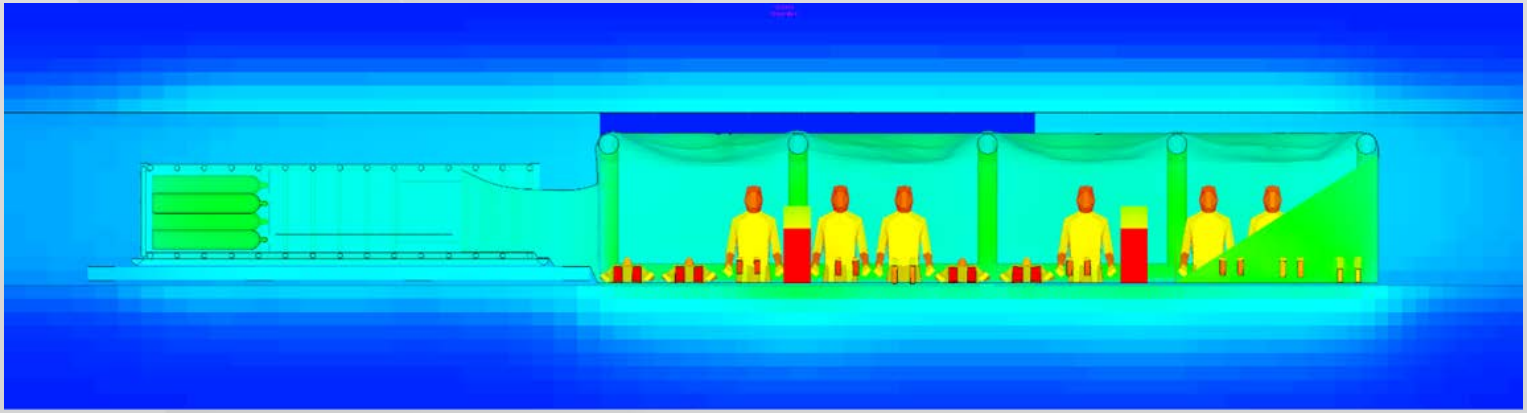
TAITherm is a commercial, 3D, transient, thermal simulation software package

Sensible Heat Transfer:

- Conduction (Inputs: Material thermal properties – density, conductivity, specific heat)
- Convection (Inputs: Surface convection coefficient or surface air velocity)
- Radiation (Inputs: Surface thermal emissivity)

Latent Heat Transfer:

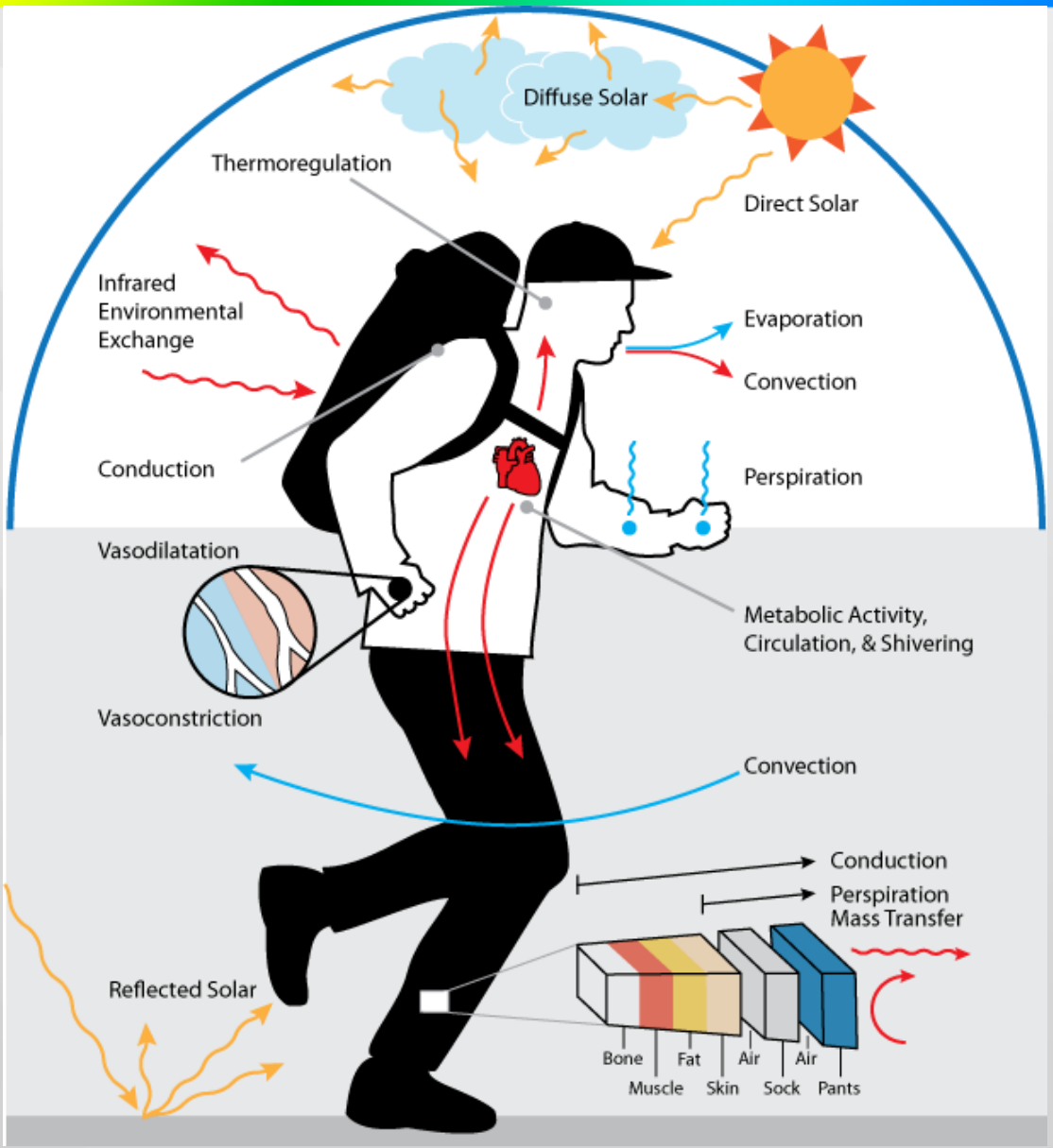
- Evaporation (from human skin)
- Condensation (on shelter surfaces)



Human Thermal Model

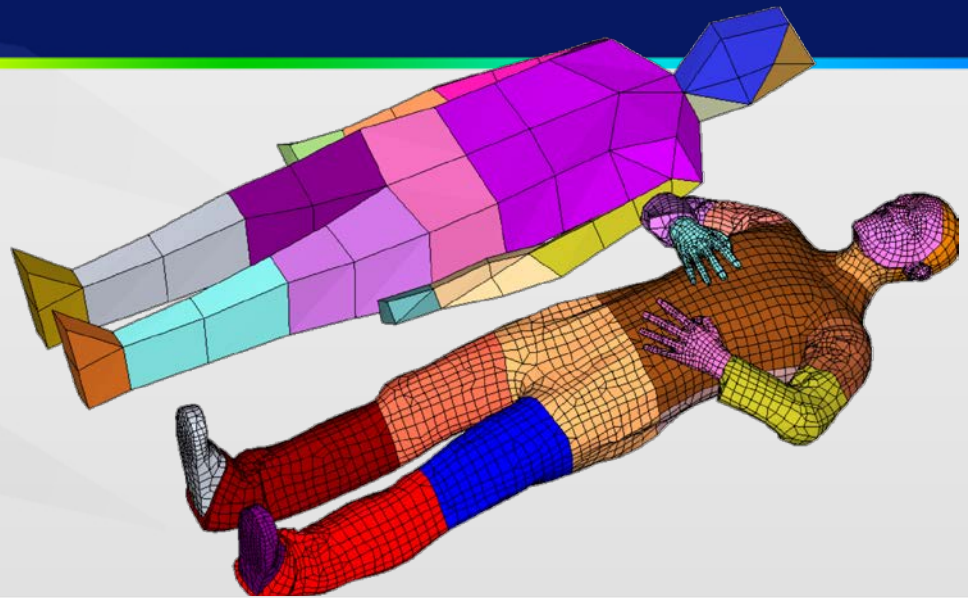
Human Physiology Model

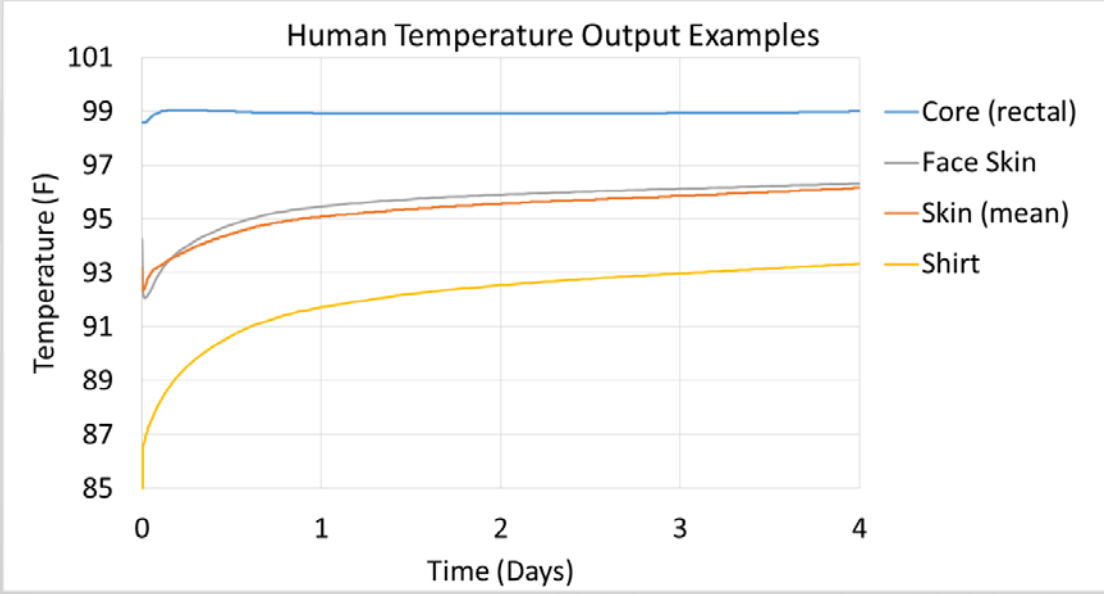
- Active thermal model
  - Metabolic Heating
  - Shivering
  - Respiration
  - Sweating
  - Peripheral Vasomotion (skin blood flow)
- Model predicts
  - Skin Temp
  - Interior Tissue Temps
  - Blood Pool Temp
  - Core Temp
- 20 body segments, each with multiple tissue layers



Human Thermal Model

- Model Inputs
  - Shell element surface mesh
  - Clothing
  - Activity Level
  - Physical contact
- Model Outputs
  - Clothing & Skin temperatures
  - Local & whole body heat fluxes
  - Core body temperature
  - Thermal Sensation & Comfort (local and whole body)

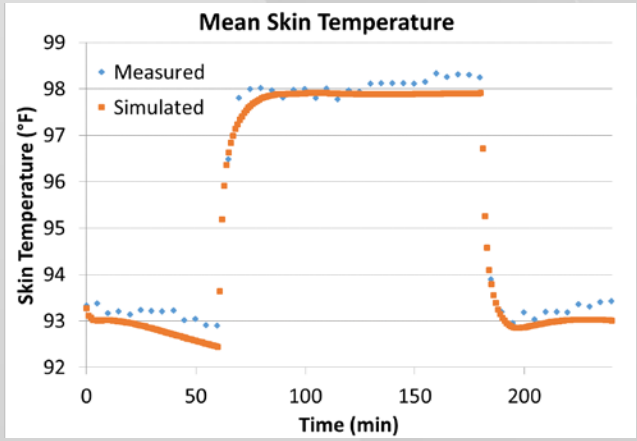


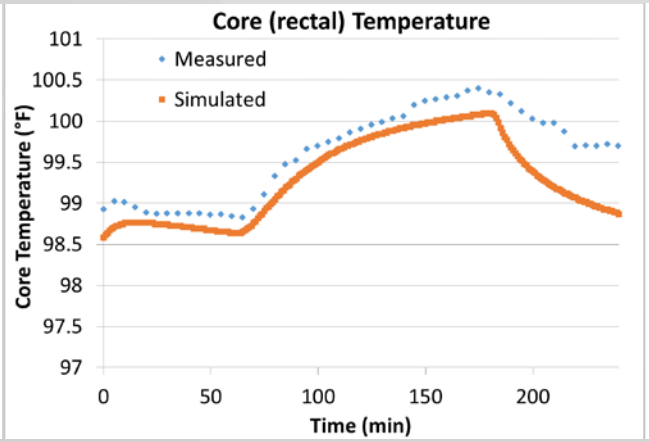


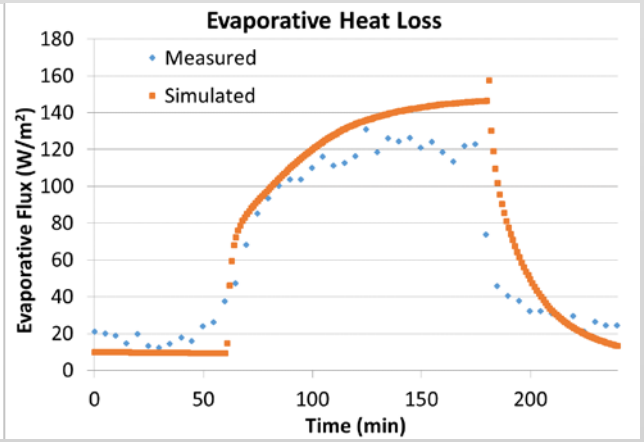
ThermoAnalytics

Human Model Validation

- Human subject tests performed by Stolwijk and Hardy
  - Core and skin temperatures were measured on humans sitting quietly in:
    - 82.4°F (28°C) for 60 minutes
    - 118.4°F (48°C) for 120 minutes
    - 82.4°F (28°C) for 60 minutes
- TAITherm simulation used the same environmental temperatures, activity level, and clothing as human subject tests







ThermoAnalytics

Core Temperature Metric

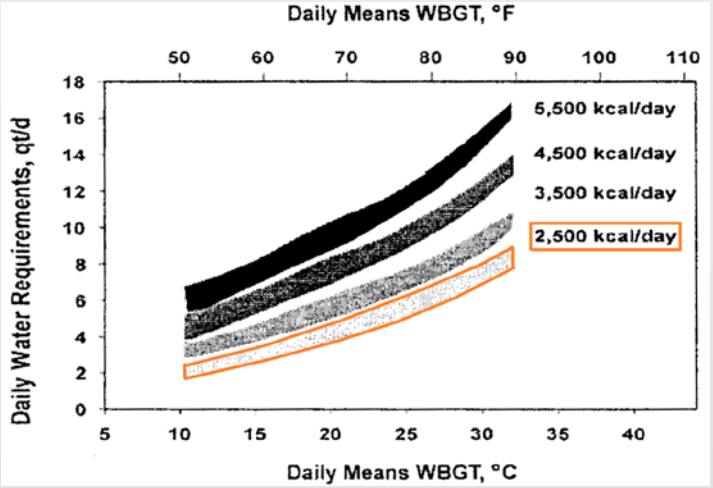
"The body's core temperature provides the 'best' single physiological measure to estimate physical work capabilities during hot conditions"

→ "Heat Stress Control and Heat Casualty Management" Technical Bulletin, US Army Research Institute of Environmental Medicine

- Uncompensated Heat Stress Limit - 100.4°F (38°C)
  - Uncompensated heat stress occurs when the individual's evaporative cooling requirements exceed the environment's evaporative cooling capacity
  - Recommended for uncontrolled environments

Moisture Loss

- Current regulations require RAs to have 2.13 L/day (2.25 qt/day) per person
- US Army guidelines recommend 1.9 to 7.5 L of water per day for an inactive person in a hot environment



* "Heat Stress Control and Heat Casualty Management" Technical Bulletin, US Army Research Institute of Environmental Medicine

- The TAITherm Human Model predicts moisture loss due to sweating and respiration
- Unaccounted losses are about 0.8 to 2.75 L additional per day

Source	Loss (L/day)
Respiratory loss	-.25 to -.35
Urinary loss	-.50 to -1.0
Fecal loss	-.10 to -.20
Insensible loss	-.45 to -1.9
Metabolic production	+.25 to +.35
Net loss (sedentary)	-1.05 to -3.10
Net loss (sedentary) – Respiratory loss	-.80 to -2.75
Sweat losses in various sports	-.455 to -3.63
Net loss (athlete)	-1.55 to -6.73

* Sawka, M., S. Cheuvront and R. Kenefick, "Hypohydration and Human Performance: Impact of Environment and Physiological Mechanisms", Sports Medicine

Core Temp/Moisture Loss Analysis

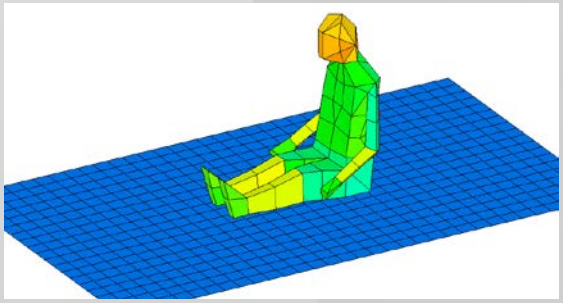
Temperature and Humidity Variations:

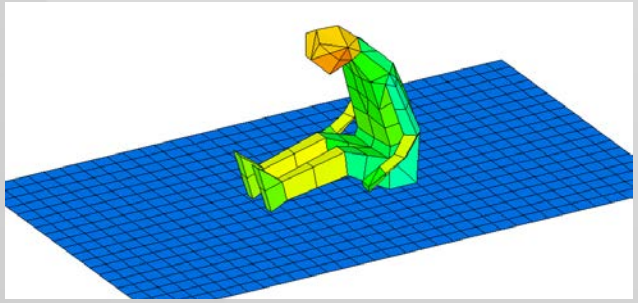
- 81°F to 91°F in 1°F increments
- 95% RH

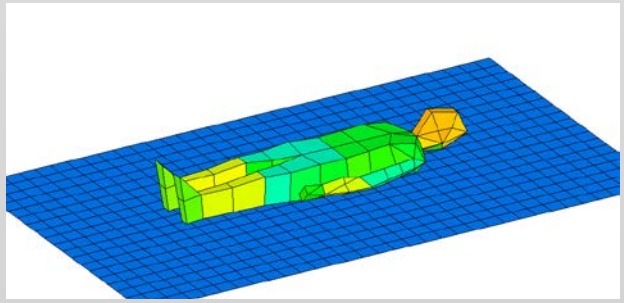
→ 88.5°F to 131.7°F Steadman Apparent Temperature

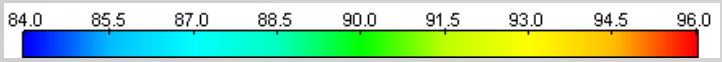
Assumptions:

- Air and floor modeled at same constant (steady) temperature for 24 hours
- Human wearing t-shirt and boxer shorts





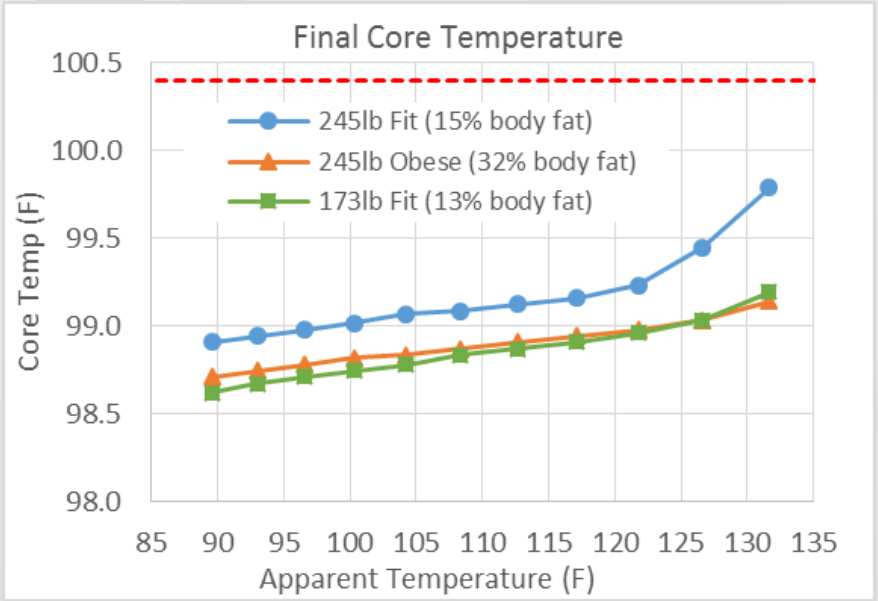


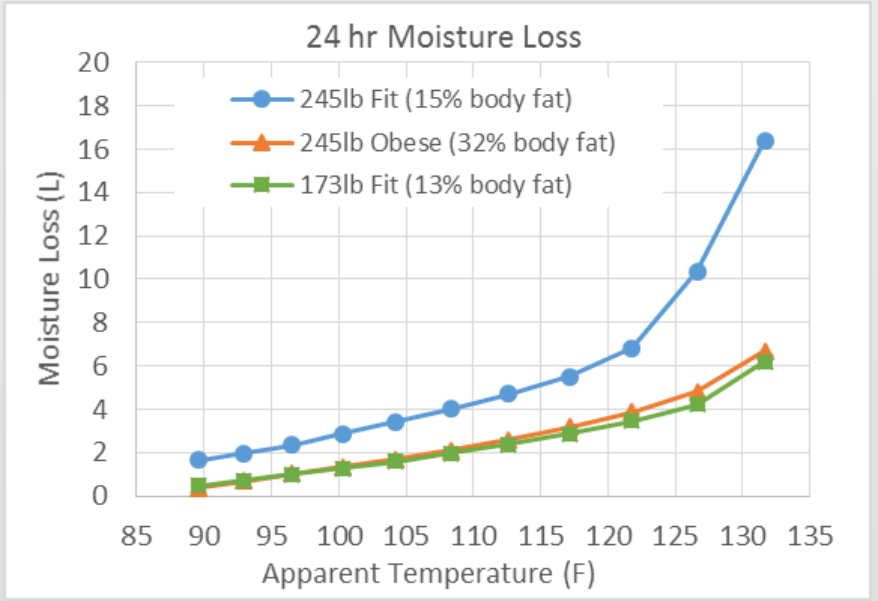


Human Size Variations

- University of South Florida recommendation:
  - 50th percentile miner: 5’ 9”, 183 lbs
  - 95th percentile miner: 6’ 4”, 275 lbs
- TAITherm Model Variations:
  - 50th percentile: 5’ 9”, 173 lbs, 13% body fat
  - 95th percentile (fit): 6’ 5”, 245 lbs, 15% body fat
  - 95th percentile (obese): 6’ 5”, 245 lbs, 32% body fat

Human Size Results





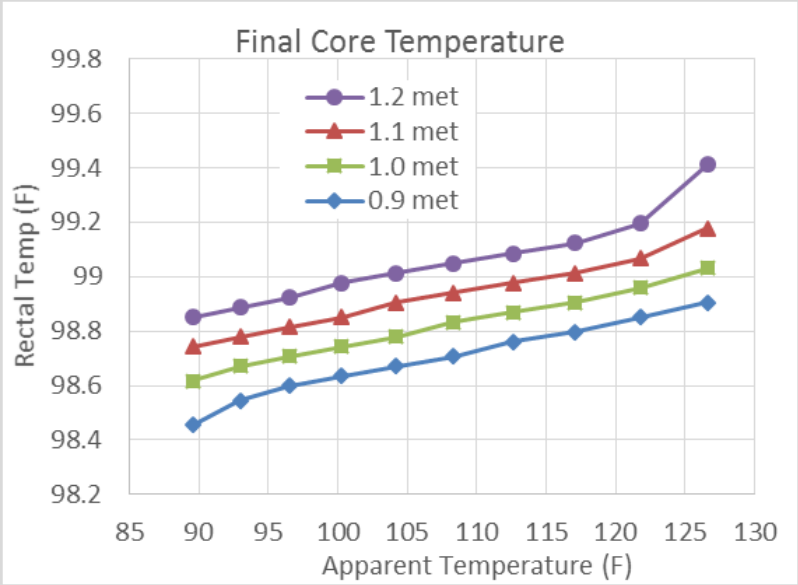
- Core temperature and moisture loss both increase significantly above 120°F apparent temp
- Large, fit person is worst case since metabolic heating occurs mostly in muscle tissue → a muscular person will have more metabolic heating than an overweight person of the same total weight (sedentary condition)

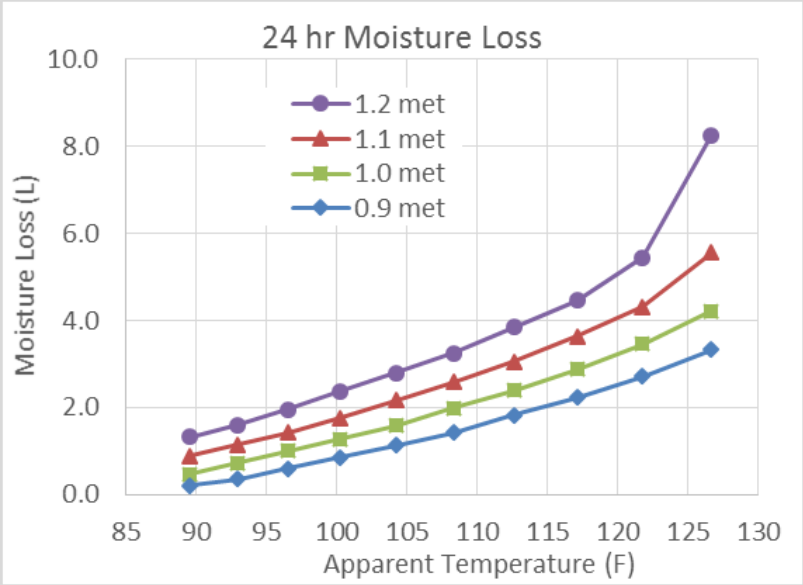
Activity Level Variations

- USF Recommendation:
  - 120 W metabolic rate for 95th percentile miner
- TAITherm allows user to specify activity level in terms of “metabolic equivalent of task” (MET)
- TAITherm model variations
  - 0.9, 1.0, 1.1, 1.2 met (120 W to 162 W for 95% miner)

	W/m^2	met
Resting		
Sleeping	40	0.7
Reclining	45	0.8
Seated, quiet	60	1.0
Standing, relaxed	70	1.2
Walking (on level surface)		
3.2 km/h (0.9 m/s)	115	2.0
4.3 km/h (1.2 m/s)	150	2.6
6.4 km/h (1.8 m/s)	220	3.8
Office Activities		
Reading, seated	55	1.0
Writing	60	1.0
Typing	65	1.1
Filing, seated	70	1.2
Filing, standing	80	1.4
Walking about	100	1.7
Lifting/packing	120	2.1
Driving/Flying		
Car	60 to 115	1.0 to 2.0
Aircraft, routine	70	1.2
Aircraft, instrumented landing	105	1.8
Aircraft, combat	140	2.4
Heavy Vehicle	185	3.2
Miscellaneous Occupational Activities		
Cooking	95 to 115	1.6 to 2.0
Housecleaning	115 to 200	2.0 to 3.4
Seated, heavy limb movement	130	2.2
Sawing (table saw)	105	1.8
Handling 50 kg bags	235	4
Pick and shovel work	235 to 280	4.0 to 4.8
Miscellaneous Leisure Activities		
Dancing, social	140 to 255	2.4 to 4.4
Calisthenics/exercise	175 to 235	3.0 to 4.0
Tennis, singles	210 to 270	3.6 to 4.0
Basketball	290 to 440	5.0 to 7.6
Wrestling, competitive	410 to 505	7.0 to 8.7
* Compiled by ASHRAE from various sources.		
For additional information, see Buskirk (1960),		
Passmore and Durnin (1967), and Webb (1964).		

Activity Level Results

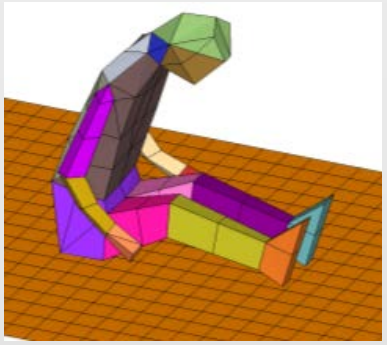


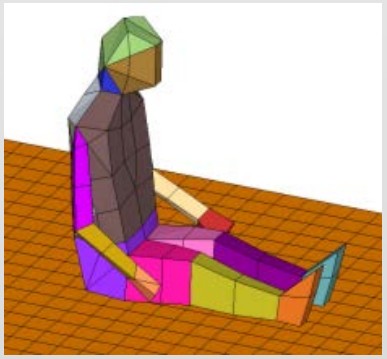


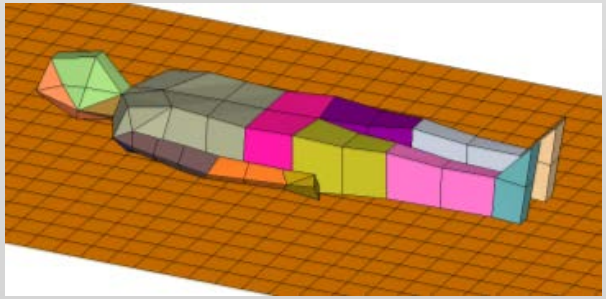
- Results shown for 50th percentile miner
- Activity level has a noticeable effect on both core temperature and moisture loss, but average activity level in an RA is expected to be low (0.9 – 1.0), according to research by USF

Pose Variations

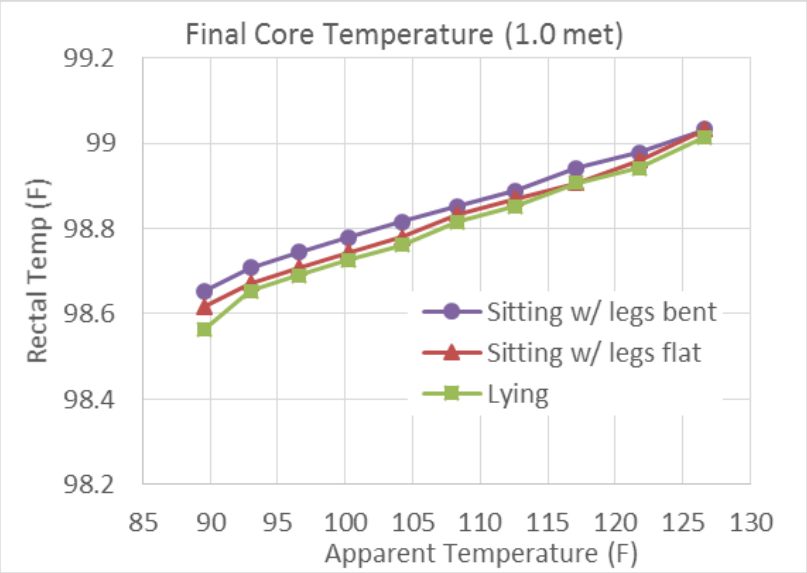
- Three poses were simulated
  - Seated with legs bent
  - Seated with legs flat
  - Lying (supine)

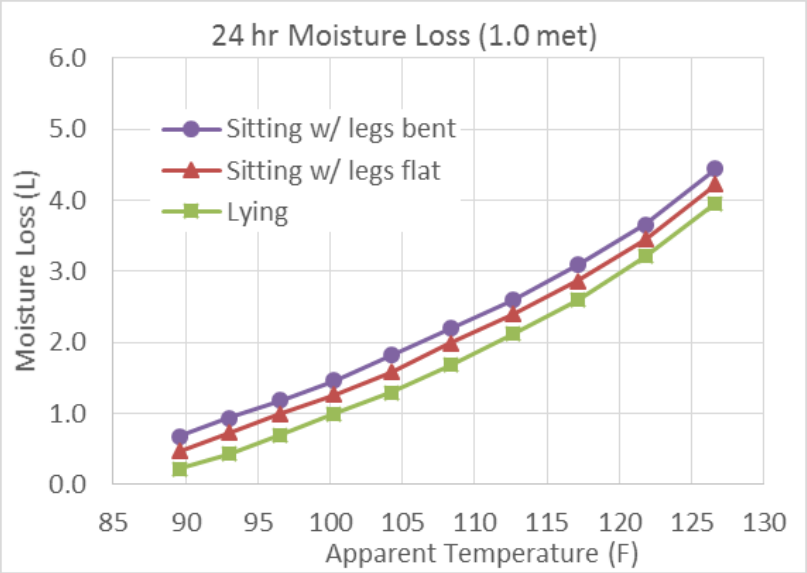






Pose Results





- 50th percentile size, 1.0 met activity level
- Pose had a small effect on predicted core temperature and moisture loss due to differences in contact area with floor

Conclusions

- 95°F apparent temperature limit appears to be protective
  - Core temperature predictions did not exceed the uncompensated heat stress limit until the apparent temperature exceeded 135°F
  - 2.25 qt/day appears to be sufficient up to the 95°F apparent temperature limit for an average size miner

ThermoAnalytics®
Total Thermal Solutions

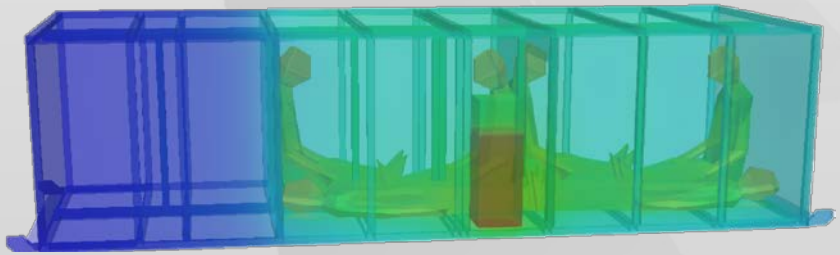
RA Maximum Occupancy (Derating)

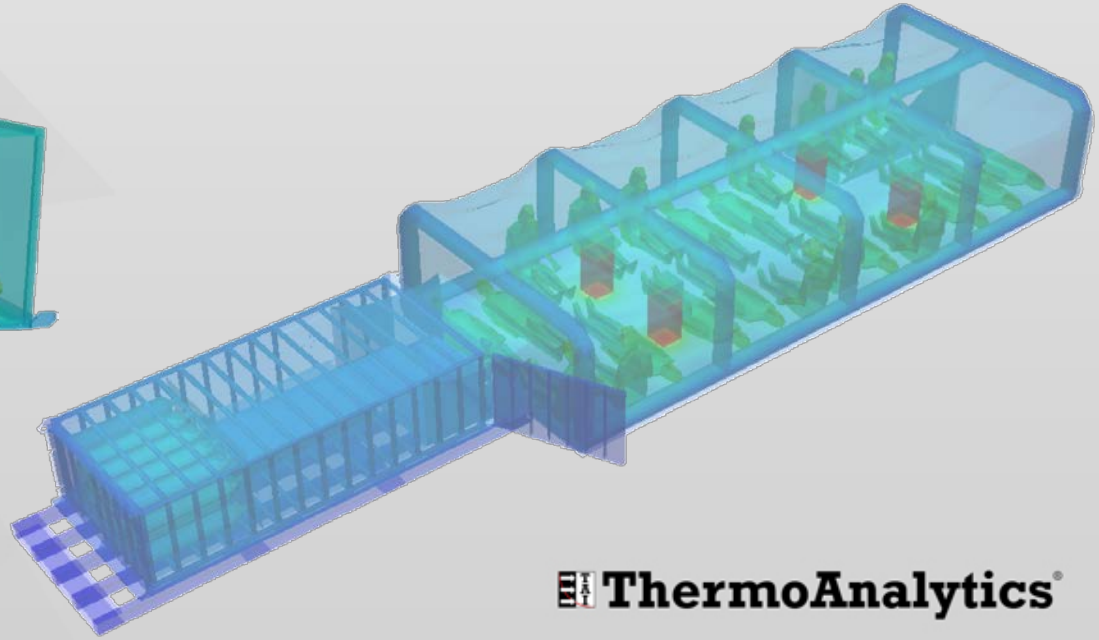
RA Partnership Meeting

Mark Klein
mdk@thermoanalytics.com

Derating Analysis

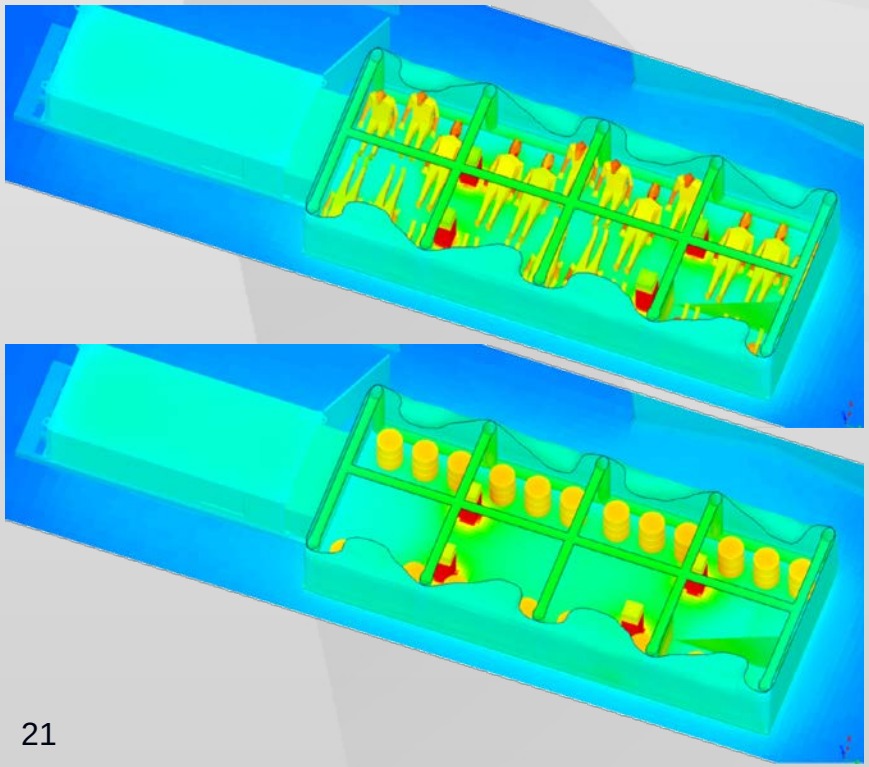
- RAs were simulated in mines with various ambient temperatures
  - If the interior apparent temperature exceeded 95°F, the number of occupants was reduced (derated)
- Validated thermal models of a 23 person inflatable RA and a 6 person steel RA in the NIOSH Experimental Mine were used as the starting point
  - 4 day transient simulations with calculated shelter, human, and mine strata temperatures





RA Derating – 23 person tent

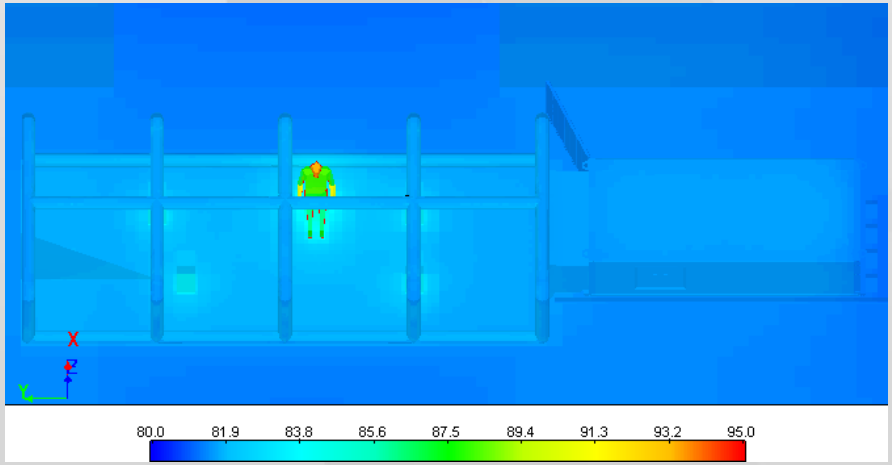
- NIOSH Experimental Mine derating analysis
  - Measured rock thermal properties and mine dimensions
  - Initial mine air and rock temperatures varied from 55 to 75°F (initial strata temperature constant through depth)
  - Humans and Barrels both used for heat input (117 W/person)



Initial Mine Temp (F)	Heat Input	Number of Occupants	Final Air Temp (F)	Final RH (%)	Final App. Temp (F)
55	Humans	23	73.0	85.2	72.0
60	Humans	23	77.1	85.7	78.6
65	Barrels	23	82.7	90.6	93.9
	Humans	23	82.5	90.2	93.1
70	Barrels	23	87.5	90.2	***111.4***
	Barrels	16	82.6	93.2	94.4
	Humans	16	82.1	93.9	93.0
75	Barrels	20	90.3	91.1	***124.2***
	Barrels	9	82.4	95.7	94.6
	Humans	9	82.2	97.0	94.5

RA Derating – 23 person tent

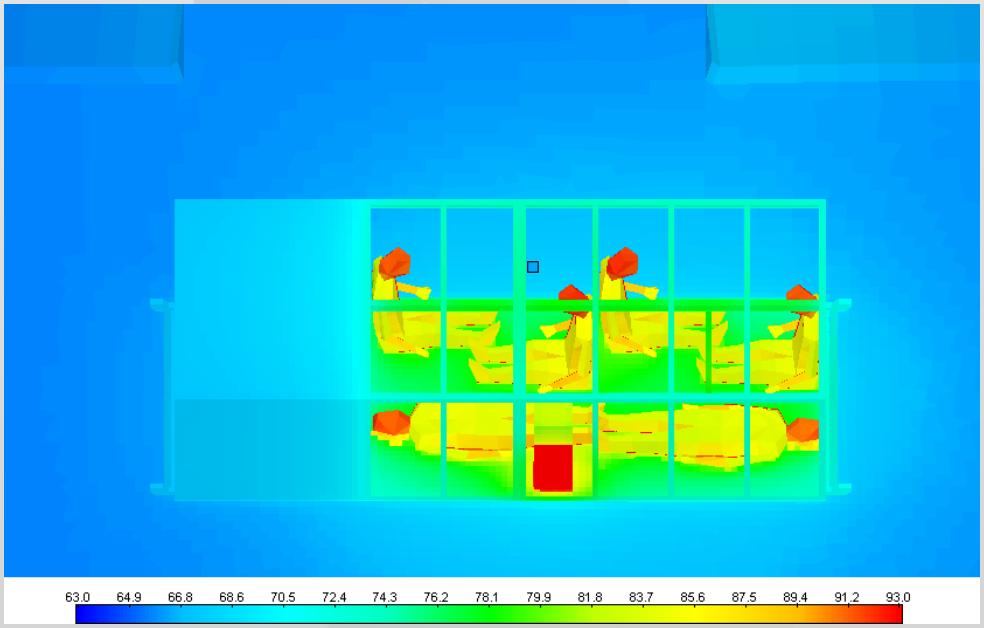
- Real Mines
  - Unique air and strata temperatures, rock types, and mine dimensions for each mine
  - Humans used for heat input (117 W/person)



	Number of Occupants	Initial Mine Air Temp (F)	Final RA Air Temp (F)	Final RH (%)	Final App. Temp (F)
Mine 1	23	65.6	82.5	92.5	93.7
Mine 2	23	69.4	83.4	93.3	***97.4***
	21	69.4	82.2	91.9	92.8
Mine 3	9	81.3	87.2	99.4	***116.8***
	3	81.3	83.5	98.8	***100.2***
	1	81.3	82.1	99.3	94.5
Mine 4	23	62.7	78.9	84.9	82.3
Mine 5	23	66.4	80.6	88.6	87.1

RA Derating – 6 person rigid

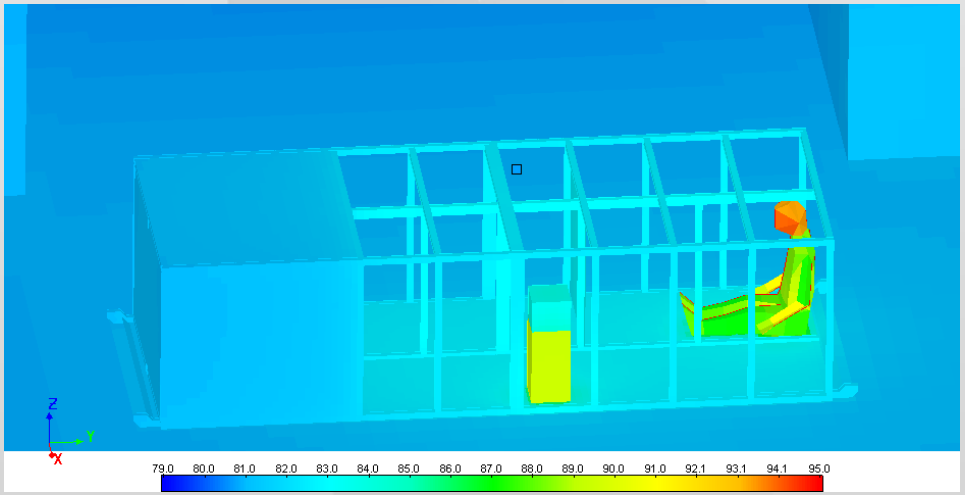
- NIOSH Experimental Mine derating analysis
  - Measured rock thermal properties and mine dimensions
  - Initial mine air and rock temperatures varied from 55 to 75°F (initial strata temperature constant through depth)
  - Humans used for heat input (117 W/person)



Initial Mine Temp (F)	Number of Occupants	Final Air Temp (F)	Final RH (%)	Final App. Temp (F)
55	6	73.2	83.9	72.5
60	6	77.6	84.0	79.7
65	6	81.3	90.0	89.4
70	5	83.3	94.5	***97.4***
	4	81.3	93.3	90.0
75	3	83.6	96.1	***99.3***
	2	81.2	95.6	90.5

RA Derating – 6 person rigid

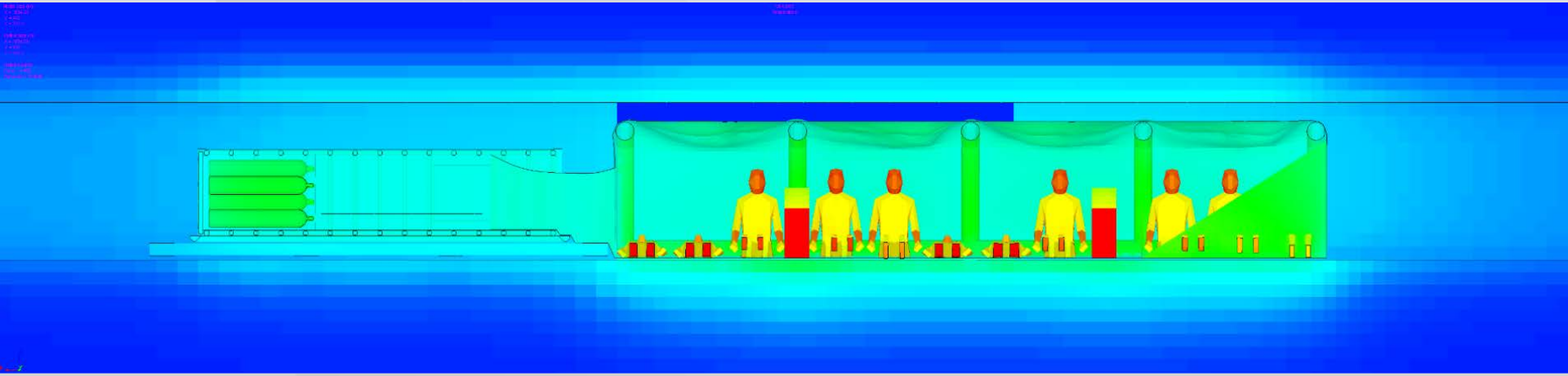
- Real Mines
  - Unique air and strata temperatures, rock types, and mine dimensions for each mine
  - Humans used for heat input (117 W/person)



	Number of Occupants	Initial Air Temp (F)	Final Air Temp (F)	Final RH (%)	Final App. Temp (F)
Mine 1	6	65.6	81.8	90.0	90.8
Mine 2	6	69.4	82.7	91.6	94.2
Mine 3	2	81.3	86.0	98.6	***110.4***
	1	81.3	83.5	98.3	***99.9***
Mine 4	6	62.7	75.8	83.3	76.4
Mine 5	6	66.4	79.8	85.7	84.4

Conclusions

- Both RAs require derating at mine temperatures of 70°F and higher
- Results were consistent between NIOSH Experimental Mine and real mines, but mine strata composition and initial mine strata temperatures at depth do have an effect



Questions?

Mark Klein
mdk@ThermoAnalytics.com
906-482-9560