PITTSBURGH MINING RESEARCH DIVISION

Metabolic Heat Input and "Critical" Apparent Temperature for RAs

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Refuge Alternative Webinar

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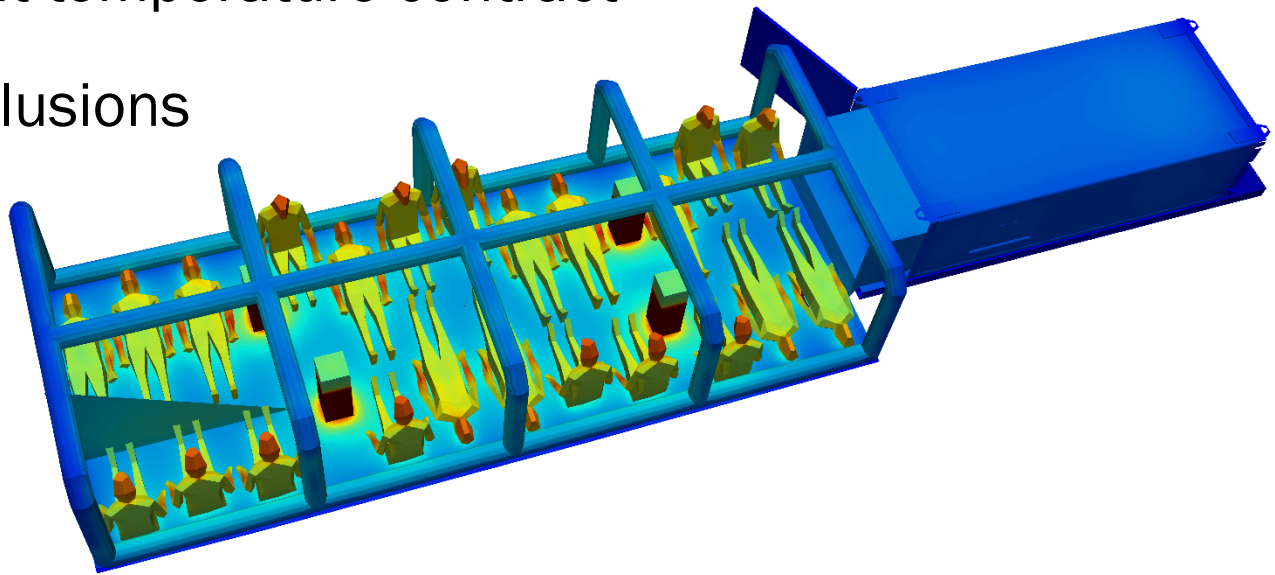
DEPARTMENT OF HEALTH & HUMAN SERVICES · USA

CDC Workplace Safety and Health

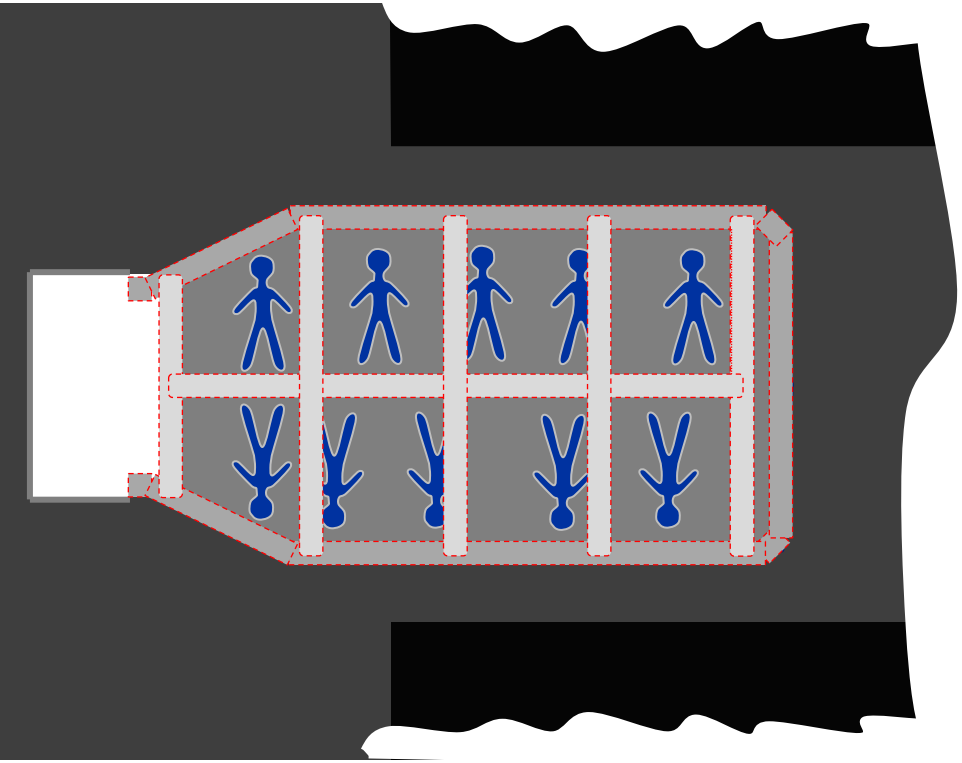
NIOSH

Outline

1. Introduction/background
2. Metabolic heat input contract
3. “Critical” apparent temperature contract
4. Summary & Conclusions



Heat buildup within an occupied RA is a serious concern



- RAs must be designed to provide a livable environment for up to 96 hours
- RAs have a limited ability to dissipate heat
- Heat input to RA due to miner metabolic heat and CO_2 scrubber heat
- MSHA regulations mandate a maximum apparent temperature of 95°F

Numerous metrics could be used to assess the RA internal conditions for heat stress

- Wet-bulb Temperature - Haldane (1905)
- Effective Temperature - Houghton and Yaglou (1923)
- Equivalent temperature - Dufton (1929)
- Heat Stress Index - Belding and Hatch (1955)
- Wet-bulb Globe Temperature (WBGT) - Yaglou and Minard (1957)
- Discomfort Index - Thom (1959)
- Temperature Humidity Index - Ingram (1965)
- New Effective Temperature - Gagge (1972)
- Humidex - Masterson and Richardson (1979)
- Sultriness Index - Steadman (1979)
- Apparent Temperature - Steadman (1984)
- Heat Index - Rothfusz (1990)
- ISO 7243 WBGT - Parsons (2006)

See:
Implementation and comparison of a suite of heat stress metrics within the Community Land Model version 4.5
By J. R. Buzan, K. Oleson, and M. Huber

http://www.geosci-model-dev.net/8/151/2015/

Regardless of the metric that is used to assess RA heat stress, the *body core temperature* of the occupants is what really matters

- Heat stroke is the most serious heat-related health problem
  - Body core temperature greater than 104°F
  - Occurs when the body's temperature regulation system fails
  - Medical emergency that may result in death
  - Signs & symptoms: confusion, loss of consciousness, seizures, *cessation of sweating*
- Heat exhaustion is the 2nd most serious heat-related health problem
  - Body core temperature greater than 100.4°F
  - Signs & symptoms: headache, nausea, dizziness, weakness, irritability, confusion, thirst, *heavy sweating*

https://www.osha.gov/OshDoc/data_Hurricane_Facts/heat_stress.pdf

Body core temperature is a function of activity level and thermal environment; heat stress is often assessed as a function of both

Work/rest Regimen	Work Load		
	Light	Moderate	Heavy
Continuous work	30.0°C (86°F)	26.7°C (80°F)	25.0°C (77°F)
75% Work, 25% rest, each hour	30.6°C (87°F)	28.0°C (82°F)	25.9°C (78°F)
50% Work, 50% rest, each hour	31.4°C (89°F)	29.4°C (85°F)	27.9°C (82°F)
25% Work, 75% rest, each hour	32.2°C (90°F)	31.1°C (88°F)	30.0°C (86°F)
*Values are in °C and °F, WBGT.			

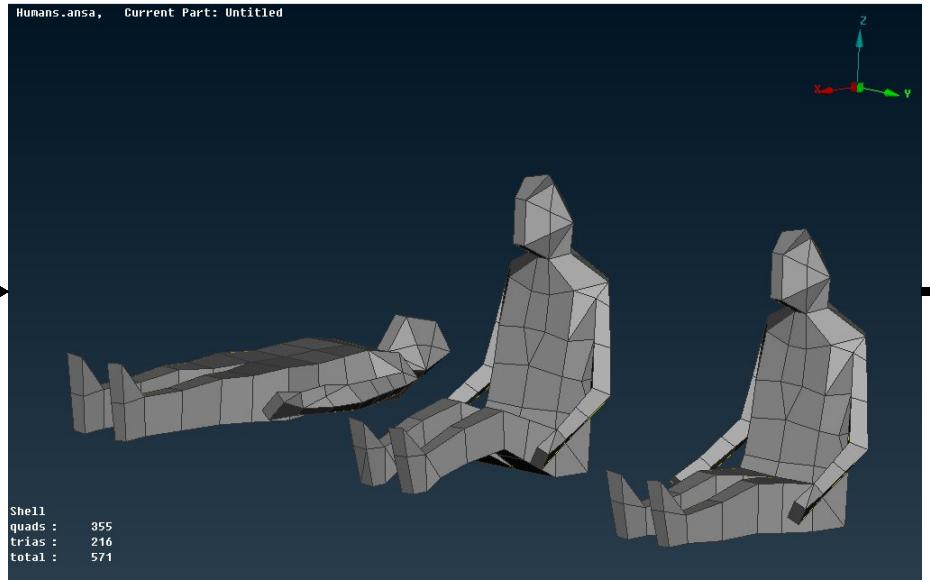
American Conference of Governmental Industrial Hygienists (ACGIH) *Threshold Limit Values for chemical substances and physical agents. Biological Exposure Indices*. American Conference of Governmental Industrial Hygienists, Cincinnati, OH (1996).

Parsons, K. Heat stress standard ISO 7243 and its global application. *Industrial Health*, **44**, 368-379 (2006).

PERMISSIBLE HEAT EXPOSURE THRESHOLD LIMIT VALUE from OSHA Technical Manual, Section III: Chapter 4

With respect to RAs, the heat input that results from occupant activity affects the resulting environment

- Activity Level
- Size & Age
- Posture
- Clothing
- Air Temperature
- Relative Humidity
- Floor Temperature
- Surroundings Temperature



- Core Temperature
- Skin Temperature
- Heat Loss Via Evaporation (sweat rate)
- Heat Loss Via Convection
- Heat Loss Via Conduction
- Heat Loss Via Radiation

Heat input, core temperature, and RA environmental conditions are linked!

There are a few key issues with assessment of RA heat stress

- The metabolic heat input used to represent miners is based on a "standard" 168-LB male with an 80% rest/20% moderate activity level
  - Must determine the height and weight of miners
  - Need to estimate activity level based on required tasks for in-use RAs
- Most heat stress standards apply to working in hot conditions for relatively short durations (~8 hours) at a light, moderate, or heavy workload
  - RA occupants could be in a hot environment for days at a very light workload
  - Need to determine the temperature/%RH that cause the body core temperature to increase to an unsafe level for these conditions

NIOSH awarded two contracts to examine metabolic heat input and body core temperature of RA occupants

- Metabolic Heat Estimation for Refuge Alternative Testing
  - NIOSH Contract 200-2015-M-87466
  - University of South Florida (USF)
- Determination of the Critical Temperature and Relative Humidity for Miners Entrapped in a Refuge Alternative used in Underground Coal Mines
  - NIOSH Contract 200-2015-M-63212
  - ThermoAnalytics, Inc. (TAI)

The USF contract consists of three main tasks

1. Characterize the anthropometric characteristics of miners
   - Recall that a “standard” 168-LB male has been used for RAs
2. Characterize the maintenance demands of RAs
   - An 80% rest/20% moderate activity level has been used as recommended by Foster-Miller
3. Describe the metabolic rate profile of RA occupants
   - 117 W of metabolic heat has been used for RAs, this is based on items 1 and 2 above

Five data sets were examined to characterize the size of miners

- Texas Tech study of low coal - 1980
- Texas Tech study of medium and high coal - 1980
- ISO TR 7250-2:2010 Basic human body measurements for technological design -- Part 2: Statistical summaries of body measurements from individual ISO populations - 2010
- National Health and Nutrition Examination Survey (NHANES) - data for white non-Hispanic males - 2011
- UMWA convenience sample of 150 male miners - 2016

As expected, it was found that the "average" male coal miner was almost 220 LB, *not* 168 LB

Study	Mean			Standard Deviation			95th Percentile	
	HT (in)	WT (lb)	AGE (yrs)	HT (in)	WT (lb)	AGE (yrs)	HT (in)	WT (lb)
Texas Tech low coal - 1980	68.7	180.6	34.5	2.6	37.0	11.4	72.8	242.5
Texas Tech medium/high coal - 1980	68.6	177.3	31.6	2.7	26.9	9.3	73.2	222.7
ISO USA Males - 2010	69.7	183.4	39.3	3.2	38.4	11.9	74.8	246.9
NHANES non-Hispanic males - 2011	69.8	199.3	-	3.9	48.5	-	76.4	280.0
UMWA sample - 2016	70.7	219.1	44.8	3.2	45.0	11.1	76.0	293.2

Note: 95th percentile = mean + 1.64 SD HT & WT

Activity levels were found to be far less demanding than the currently assumed 80% rest/20% moderate activity level

- Activity level was estimated based on conversations with RA manufacturers about maintenance demands for in-use RAs
- Operations and maintenance of the RA during actual usage is low demand
  - Changing of CO_2 scrubber material
  - Monitoring O_2 and adjusting flow rate
  - Can be ignored in calculations
- Only resting metabolic rate (RMR) needs to be used to estimate metabolic heat input for RAs

Resting metabolic rate (RMR) was calculated for the average coal miner using five methods

- Harris-Benedict (1919)
- Owen (1987)
- WHO (1985) based on weight alone
- WHO (1985) based on height and weight
- Mifflin-St. Jeor (1990)

The calculated RMR for the average coal miner ranged from approximately 84 Watts to 91 Watts

Metric	Mean RMR (W)	Std Dev of RMR (W)
Harris-Benedict	88.6	11.8
Owen	83.7	8.6
WHO w/o Height	89.3	9.8
WHO w/ Height	90.5	9.5
Mifflin-St Jeor	84.7	9.2

The average and standard deviation for the RMR were used to define heat input as a function of the number occupants

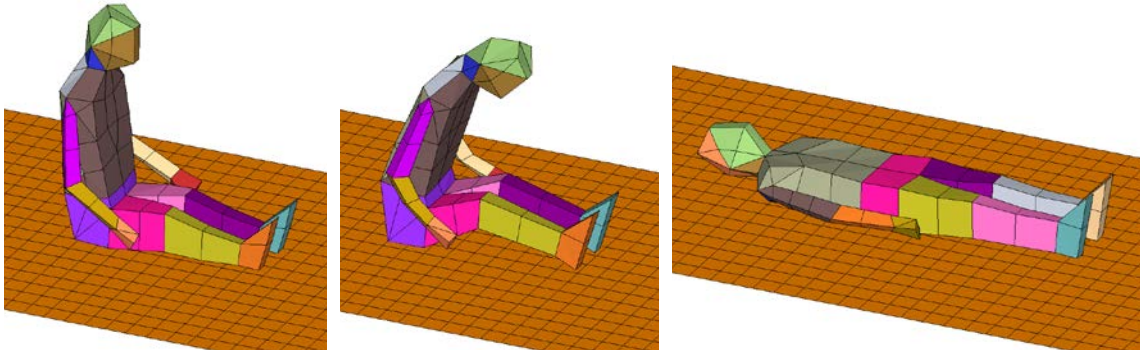
# of Occupants	1.1*Highest RMR† (W)	Heat Input for RA Test/Analysis (W)
95th %ile	134.2	134
2	126.6	126
3	123.2	123
4	121.2	121
5	119.9	120
10	116.5	116
15	115.0	115
20	114.0	114
25	113.5	113
30	113.1	113
35	112.8	113

† Highest value across all RMR estimates +10% to allow for an upper limit on the predication error

$$RMR_{95thmean} = RMR_{mean} + 1.64\ RMR_{sd} / \sqrt{n}$$

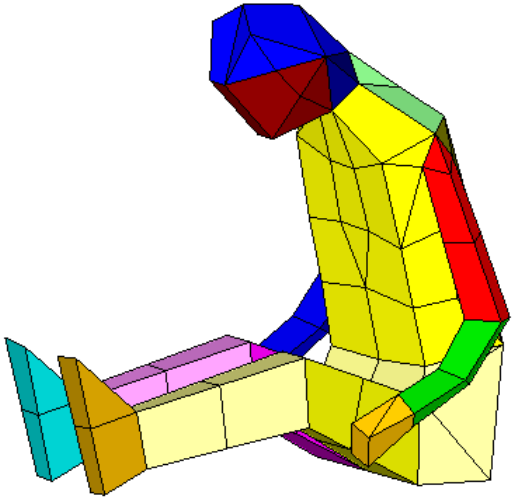
The TAI contract examined an RA occupant's core temperature and sweat rate as a function of apparent temperature

- Dry-bulb temperatures from 81°F to 90°F
- %Relative humidity from 90%RH to 99%RH
- Apparent temperatures between 88.5°F and 130.6°F
- Investigate the effects of
  - Posture (sitting or lying)
  - Activity level
  - Miner size



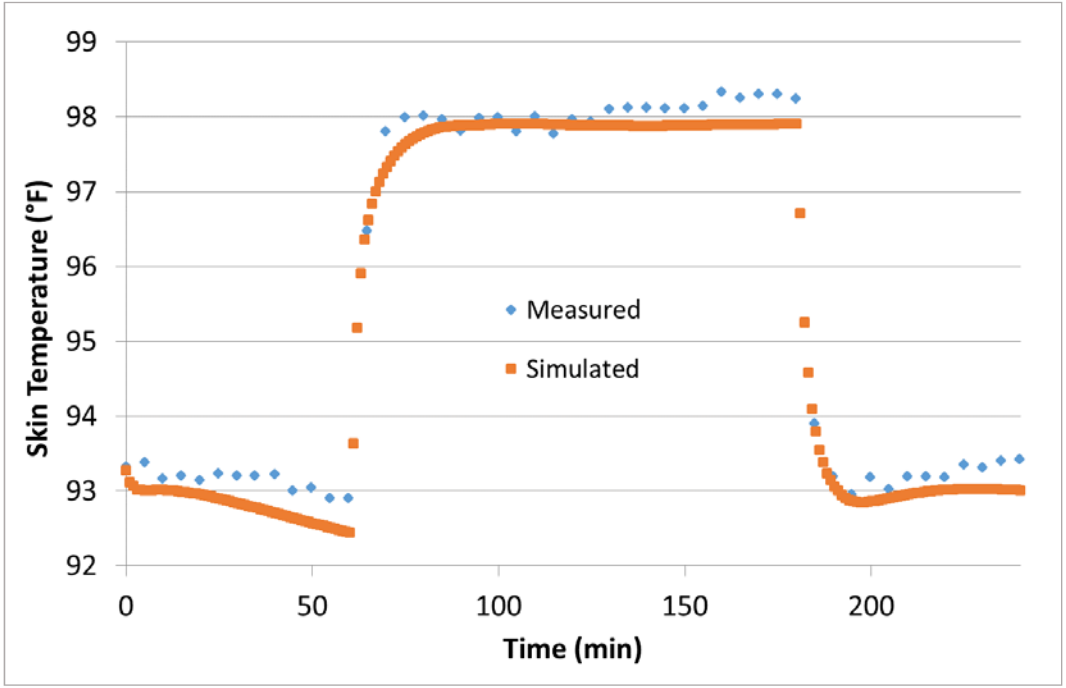
TAI used their human thermal model and TAITherm software to perform the analysis

- The thermoregulation model
  - Simulates body processes used to maintain core temperature
  - Includes shivering, sweating, and changes in skin blood flow
  - Predicts body core temperature for transient, asymmetric environments
  - Calculates surface and deep tissue temperatures within the human body



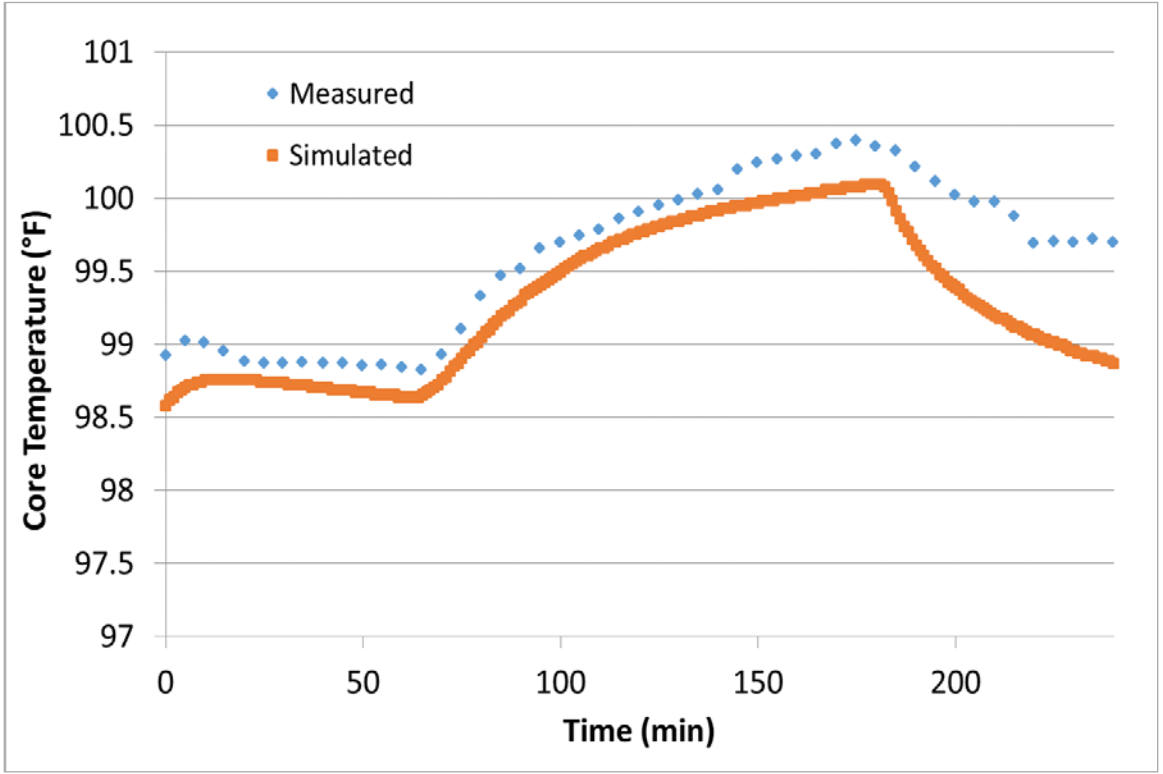
The TAITherm human thermal model (HTM) has been validated with published human subject test data

- Skin temperature comparison: *human subjects sitting quietly in a hot environment*
- Ambient temperature started at 82.4°F, then was raised to 118.4°F for 120 minutes, and then returned to 82.4°F



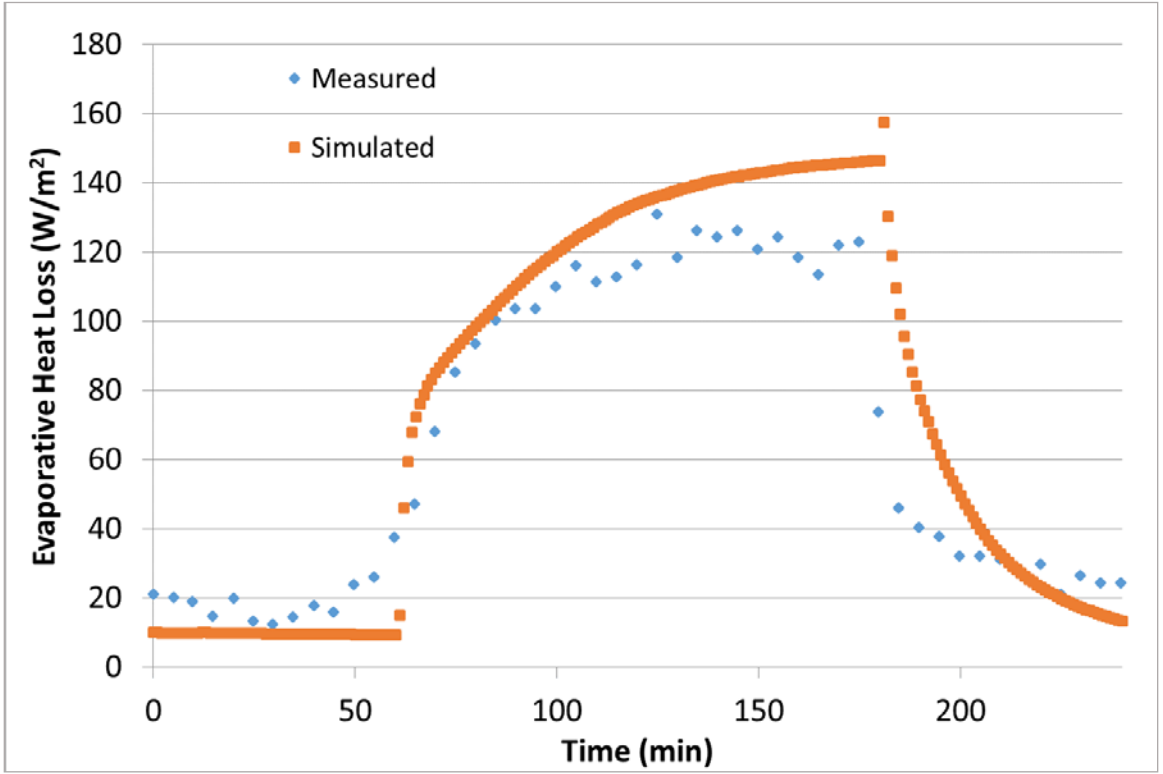
The TAITherm human thermal model (HTM) has been validated with published human subject test data

- Core temperature comparison: *active human subjects in a warm environment*



The TAITherm human thermal model (HTM) has been validated with published human subject test data

- Evaporative heat loss comparison: *active subjects in a warm environment*



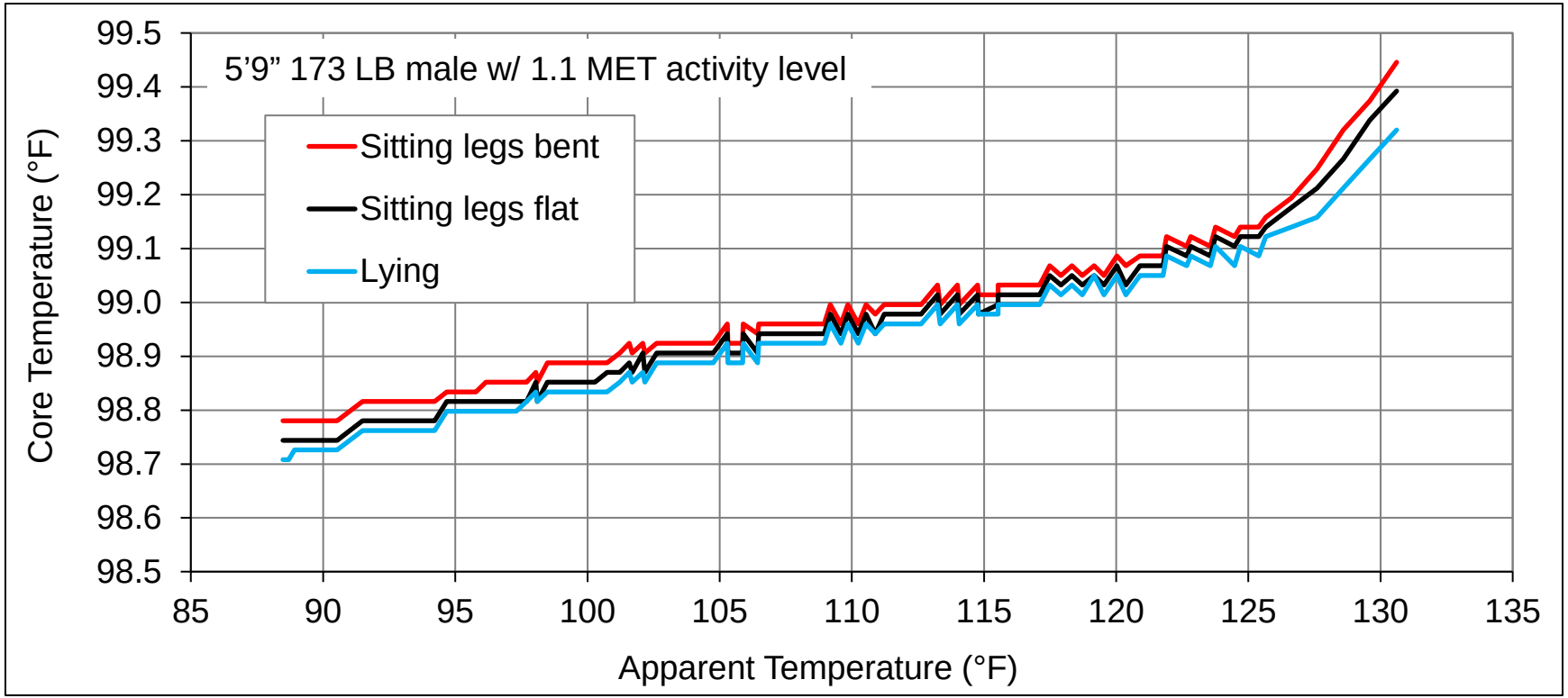
The goal of this contract was to find the “critical” apparent temperature that would cause the body core temperature to exceed 100.4°F

From Heat Stress Control and Heat Casualty Management, TB MED 507, US Army and Air Force:

- *The body's core temperature provides the “best” single physiological measure to estimate physical work capabilities during hot conditions*
- Uncompensated heat stress
  - Evaporative cooling requirements exceed the evaporative cooling capacity
  - Threshold is defined as 38°C (100.4°F)

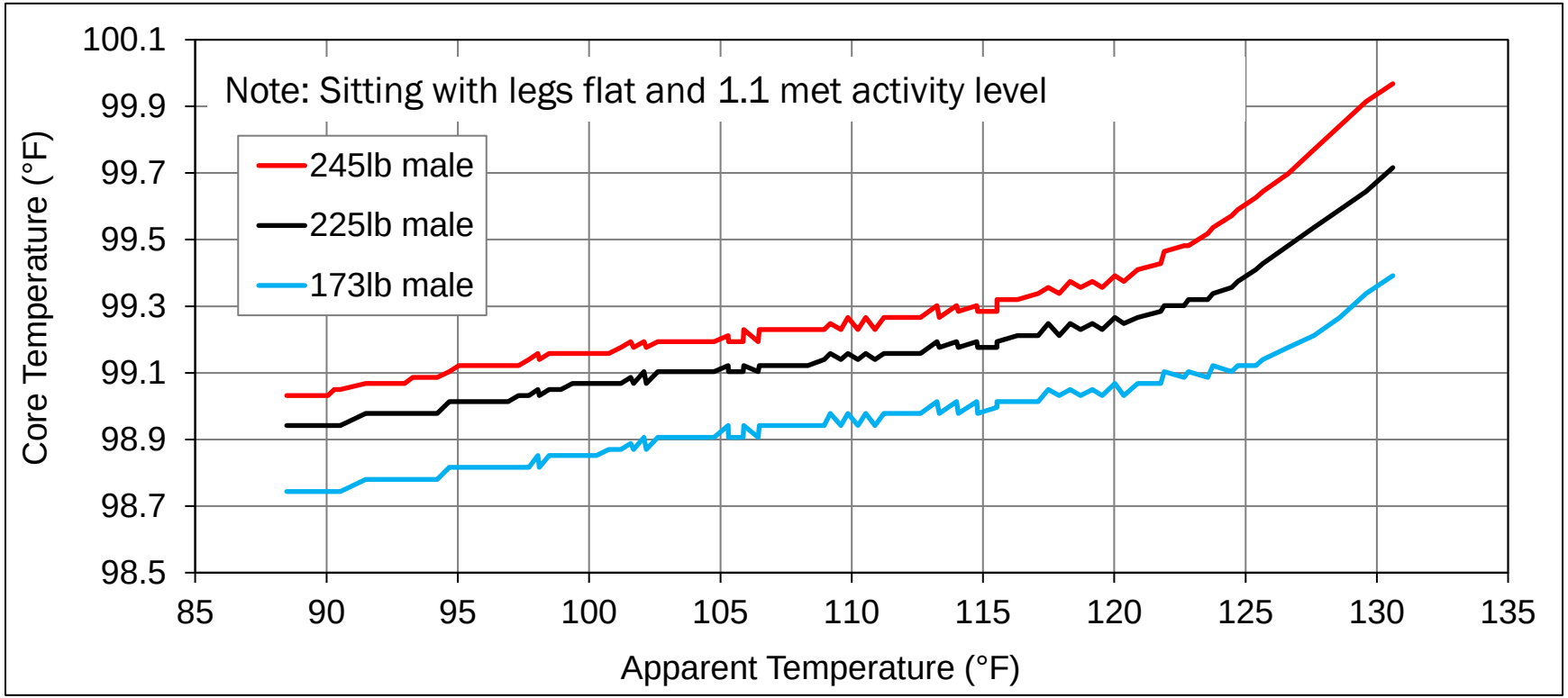
Posture (sitting or lying) was found to have a negligible effect on core temperature

- Final core temperature vs apparent temperature for three different poses



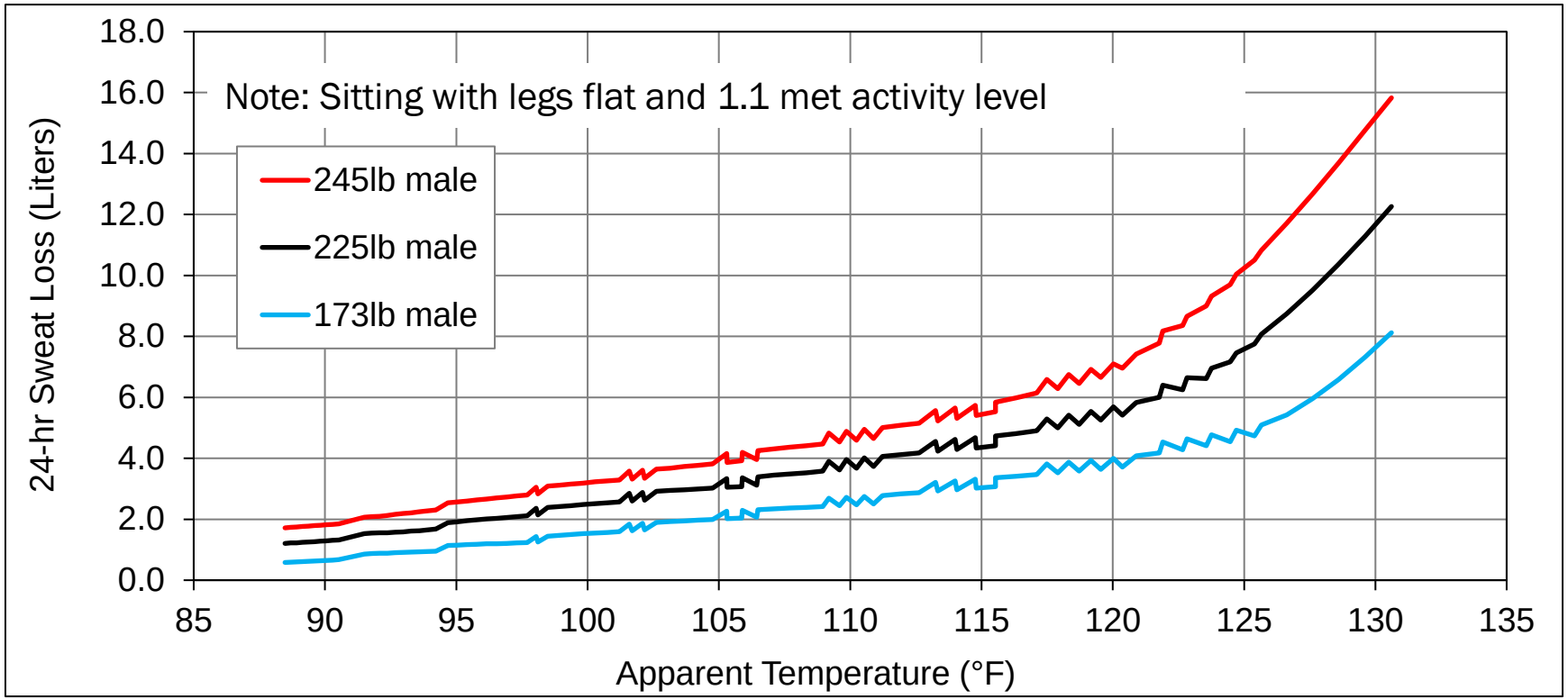
Body core temperature response versus apparent temperature has a consistent shape across all sizes

- Final core temperature vs apparent temperature for three different size humans



Sweat rates increase significantly with apparent temperature and miner size

- 24-hr sweat loss vs apparent temperature for three different size humans



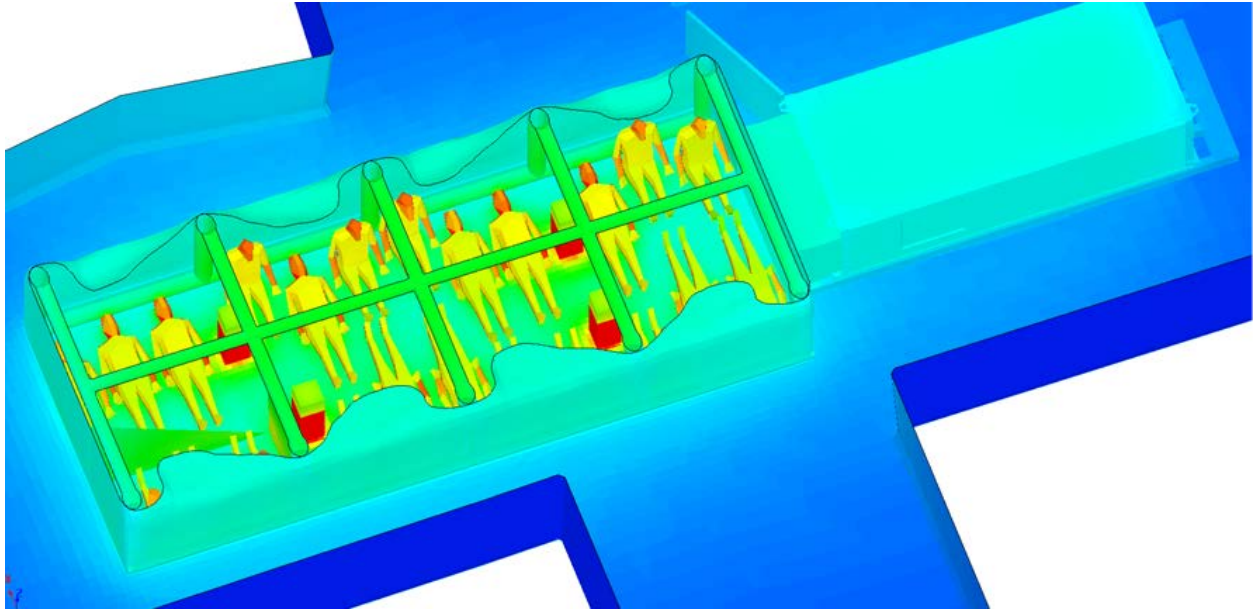
Summary & Conclusions

- Average miner size found to be larger than the “standard” male: 5’9” 225 LB
- Maintenance demands of RAs are not a factor for heat input; resting metabolic rate should be used
- Heat input for test/analysis should be based on number of RA occupants
  - 135 W for a single occupant
  - 113 W for 25 or more occupants

Summary & Conclusions

- Body core temperature study shows “critical” apparent temperature would be higher than 120°F
- 95°F apparent temperature limit is protective
- Posture (sitting vs lying) has little effect on body core temperature
- Miner size has a small effect on body core temperature
- Sweat loss increases with apparent temperature
- RA occupants may need more than 2.25 quarts of water per day

Questions?



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