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July 25, 2008

DEPARTMENT OF LABOR
Mine Safety and Health Administration
RIN 1219-AB58

RE: RIN 1219-AB58

To whom it may concern:

MineARC Systems have been designing, manufacturing, and selling refuge chambers since 1995. MineARC's Hard Rock Mining and Tunneling Refuge Chambers have been rigorously tested and used in real life emergencies with no injuries. It is this experience that has given our company the expertise and knowledge to determine the fundamental requirements for safe entrapment inside an enclosed space such as a refuge chamber.

Integral to the safe operation of a refuge chamber is a cooling system for combating metabolic heat buildup. Uncontrolled, metabolic heat buildup can lead to heat stroke and possible fatalities. MSHA's proposed ruling supports this claim in stating; "*medical evidence reveals that values approaching or exceeding 105°F (apparent temperature) would be life-threatening.*"

The MSHA ruling proposes a maximum internal apparent temperature of 95°F, but omits a maximum external ambient temperature that the chamber must operate under. The proposed ruling does correctly state that, "*ambient temperature in a refuge alternative is affected by the mine temperature.*" More appropriately though, it is the single most important factor in determining the rate of heat transfer to the outside of the chamber. **It is therefore critical for design and testing purposes that the final ruling specifies a maximum ambient mine temperature that the chamber must operate under effectively.** Utilizing generally accepted engineering practices this value would be the maximum expected temperature of the mine in an emergency situation, with an appropriate factor of safety.

The State of West Virginia has already approved refuge chambers without cooling systems. Identical to the MSHA proposed ruling, the West Virginia regulation specifies a maximum internal temperature of 95°F apparent temperature. Approved manufacturers demonstrated compliance by computation and experimentation using an assumed ambient mine temperature of 55°F. From MSHA collated survey data (Campbell, 'Representative Mine Temperatures and Humidities', MSHA), the 55°F value chosen is the minimum temperature of an underground West Virginia coal mine. This value does not consider possible temperature increases in an emergency from loss of ventilation, fire, or an explosion.

To maintain an internal temperature of 95°F apparent, West Virginia approved refuge chambers are entirely dependent on the ambient mine temperature not exceeding 55°F. With many mines in the US having ambient conditions exceeding this temperature, approval centers and manufacturers have a responsibility to coal operators to specify the conditions under which the refuge chamber will successfully operate.

The recent NIOSH simulated testing of West Virginia approved refuge chambers provided partial evidence of the inability of some of these chambers to maintain an internal temperature below the

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specified criteria at a slightly higher temperature of approximately 60°F. This is in spite of the fact that the simulated testing potentially underestimated the heat build up by 20-30% if human occupants had been used (see attached IHST report, 'Assessment of Thermal Environment of Mine Refuge Chamber').

Regardless of this, under Section 7.501 of the MSHA proposed ruling it states that, "*refuge alternatives that States have approved and those that MSHA has accepted in approved ERPs would meet the requirements of this proposed rule*". This statement can only be interpreted as MSHA ignoring operational deficiencies in currently approved chambers as identified in the December 2007 NIOSH report, 'Research Report on Refuge Alternatives for Underground Coal Mines.'

From information provided by NIOSH to MSHA, it is clear that currently approved refuge chambers will not successfully operate under all coal mine conditions encountered in the US.

The proposed rule correctly points out; "*there is currently no permissible air conditioning equipment, which will overcome this problem (heat buildup) in underground coal mines.*" Nevertheless, several refuge chamber manufactures are currently developing intrinsically safe cooling systems. MineARC Systems believes that we have already resolved this issue without the use of a conventional electrically powered air conditioning system. This system is to be tested in a coal mine by the Mines Rescue Board of New South Wales.

To provide MSHA with as much information as possible in regards to heat build up inside a refuge chamber, MineARC Systems commissioned an independent manned test. The purpose of the test was to determine the heat buildup inside a steel refuge chamber at an average external temperature of 80°F. This ambient mine temperature is equivalent to temperatures found in many coal mines in the US, and in most mines in the State of Alabama. The test was conducted with six people in an 8-person MineARC Refuge Chamber. As per the MSHA proposed ruling, each occupant had approximately $60ft^3$ of volume and $15ft^2$ of floor space.

With an average external temperature of 80°F the internal apparent temperature of the refuge chamber reached a staggering 143°F in just 128 minutes. These conditions are considered extreme and life threatening for extended durations.

Attached with this letter is a copy of the independent testing and report completed by Industrial Hygiene and Safety Technology, Inc. MineARC hopes that this report will be useful for MSHA's decision making role in formulating guidelines for the safe operation of refuge chambers in coal mines.

Yours sincerely,

James Rau
General Manager

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Leaders in Quality, Service and Innovation

Assessment of Thermal Environment of Mine Refuge Chamber

Provided for
MineARC Systems America, LLC
4730 Bronze Way
Dallas, TX 75236

Attn: James Rau
General Manager

Report Date: July 11, 2008

Prepared by:
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Vice-President of Operations

Assessment of Thermal Environment of Mine Refuge Chamber

Provided for
MineARC Systems America, LLC
4730 Bronze Way
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Contents

1.0 Purpose and Scope

On June 25, 2008, IHST performed an assessment of the thermal environment of an occupied mine refuge chamber. The assessment took place at the MineARC Systems America, LLC facility, located at 4730 Bronze Way, in Dallas, Texas. It was performed by Derrick Johnson, an industrial hygienist representing Industrial Hygiene and Safety Technology, Inc. (IHST), at the request of James Rau, General Manager for MineARC Systems America, LLC.

The purpose of this study was to determine the occupancy time required to exceed an apparent temperature of 95° F in a refuge chamber not equipped with an air cooling system. The Mine Safety and Health Administration (MSHA) recently issued a proposed rule[1] for mine refuge chambers, specifying 95° F as the maximum apparent temperature permitted inside such chambers. This requirement exactly mirrors pre-existing requirements issued by the state of West Virginia under Title 56, Series 4, Section 8, "Emergency Shelters/Chambers".[2] In addition to tracking of the apparent temperature, this study also compared thermal conditions in the refuge chamber to Threshold Limit Values (TLV) for heat stress recommended by the American Conference of Governmental Industrial Hygienists[3], as well as the Heat Stress Index (HSI) developed by Belding and Hatch[4]. These additional indices were included for comparison, as the apparent heat index is not commonly used in the United States for assessing or controlling occupational heat stress. Comparison of the apparent temperature to the more commonly accepted heat stress indices was therefore of interest.

A key initiator for the study was the decision by the state of West Virginia and MSHA to still permit the use of refuge chambers which fail to maintain an internal apparent temperature of 95 °F or less. This decision was apparently based on the twin difficulties of equipping refuge chambers with intrinsically safe cooling systems and maintaining an acceptable thermal environment in the absence of cooling systems. Intrinsic safety is clearly a highly significant safety consideration, particularly in coal mines and cannot be ignored. However, as refuge chambers are designed for extended occupancy (at least 48 hours), MineARC reasoned the lack of cooling capacity in a fully occupied chamber could result in temperature and humidity extremes potentially dangerous to occupants. A recent NIOSH study on refuge chambers provided partial evidence of such increased risk of heat stress[5]. However, the NIOSH study was not performed with live occupants, due to time and liability constraints involved in such a study. In its study report, NIOSH recommended additional study to further characterize the thermal hazards of un-cooled, occupied refuge chambers.

The scope of the assessment included recording of dry bulb temperature, relative humidity, carbon dioxide concentration, oxygen concentration, and carbon monoxide concentration at 1-minute intervals inside a refuge chamber occupied by six adults dressed in miner's coveralls. Measurements of dry bulb temperature, relative humidity, carbon dioxide, and carbon monoxide were simultaneously recorded outside the refuge chamber.

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[1] 30 CFR, Parts 7 and 75, *Refuge Alternatives for Underground Coal Mines*, June 16 2008, FR Vol 73, No. 116, 7.504(b)(1).

[2] West Virginia Standard 56-4-8, 2007, *Emergency Shelters/Chambers*.

[3] American Conference of Governmental Industrial Hygienists, 2006, "Heat Stress
", *2006 TLVs and BEIs, Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents*, 2006, pp182-200

[4] H.S. Belding, T.F. Hatch, "Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains", *Heat. Piping Air Cond.* 27:129, (1955)

[5] National Institute for Occupational Safety and Health, *Research Report on Refuge Alternatives for Underground Coal Mines*, December 2007

2.0 Literature Review

2.1 Physiological Responses to Heat

Various levels of research have been undertaken to quantify the heat loads generated from the human body within a confined space such as a refuge chamber. The majority of the work has involved theoretical calculations, computer modeling, experimental simulations, and analytical investigations. In doing this work it is has been common to misjudge the severity of heat buildup when a number of persons are placed inside a confined space. Only limited resources have been allocated to performing actual field tests with human subjects. The control of temperature and humidity within a confined space is critical because of the relatively narrow range in which the unprotected human body can operate without developing heat stress.

Heat stress is the combined effect of all the internal and external heat factors which cause the body to become fatigued and stressed. The body needs to maintain a constant internal temperature regardless of varying environmental temperatures. Nielsen suggested that a high core temperature is the ultimate cause of fatigue due to heat stress by virtue of the fact that high temperatures affect motor centers in the body and in turn muscular activity[6].

The human body maintains a normal core temperature in between 96.8 – 100.4°F[7]. If the body's core temperature varies significantly from its normal range, various physiological processes begin to become impaired. In hot environments, the body must be able to cool itself, in order to maintain a viable core temperature. Heating of the body results from metabolic activity and heat contributed from the surrounding environment. The heat produced by metabolic activity increases as the level of activity increases. Heat transfer to and from the body occurs from convective transfer (air movement), radiant transfer, and respiration (heat in exhaled/inhaled air).

The effectiveness of heat transfer away from the body by convection and radiation is determined by air velocity, ambient temperature, solar load and other radiant heat sources. Depending on the level of metabolic activity, the body may be able to lose sufficient heat through these mechanisms alone. As the core temperature begins to rise, the peripheral blood vessels dilate, allowing more blood flow to the skin. The skin temperature varies, but is generally maintained in between 90 - 95°F, slightly lower than the core temperature. This differential allows heat to move from the body's core to the skin, where it can be lost through convection, radiation, and sweating. Sweating occurs when convection, radiation, and respiration become insufficient to dissipate the accumulation of heat from metabolic and environmental sources. Sweating allows the body to lose heat rapidly. Evaporation of sweat absorbs significant amounts of heat from the skin, far more than convection, radiation, and respiration combined. As ambient temperature approach or exceed skin temperature, sweating becomes the body's primary mechanism of heat loss. Sweating depletes the body's water, and in extreme cases, can also deplete certain minerals.

As temperatures rise above 80°F, the relative humidity of the atmosphere plays an increasingly significant role in the human body's ability to cool itself. Convective, radiant, and expired air heat loss mechanisms provide limited cooling capacity, particularly in fully clothed individuals. When the heat dissipation capacity of convective, radiant, and expiration cooling mechanisms are no longer sufficient, the body's core temperature begins to rise and sweating mechanisms are activated. However, the rate of sweat evaporation is limited by the relative humidity of the surrounding air. As the relative humidity increases, the rate of sweat evaporation slows, reducing the body's ability to cool itself. At high relative humidity, evaporation of sweat becomes very slight. Therefore, increasing

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[6] Neilsen, Bodil ,1994, *Heat stress and acclimation*, Ergonomics, vol. 37, no. 1, pp.49-58

[7] Macpherson, Malcom J. "Subsurface Ventilation and Environmental Engineering", *Chapter 17 Physiological Reactions to Climatic Conditions*, 1993, pp 1- 42

humidity at elevated temperatures increasingly reduces the effectiveness of the body's most effective heat-loss mechanism.

If the body's cooling mechanisms cannot dissipate heat sufficiently, a number of heat-related illnesses can occur. Individual susceptibility to these conditions varies greatly, depending on age, physical condition, hydration, and acclimatization to hot conditions. These conditions are briefly summarized in the following bullets, in order of probable occurrence and severity. It is very important to realize that an individual may not experience all the listed conditions in the order specified, or at all. Depending on individual susceptibility, a person may experience a very rapid progression of symptoms, or exhibit few of the less significant symptoms before falling victim to more serious forms of heat-related illness.

- *Transient heat fatigue* – loss of alertness and interest in assigned tasks; sensations of general malaise and fatigue; generally not life-threatening.
- *Heat syncope, or heat fainting* – temporary loss of consciousness, resulting from insufficient blood supply to the brain; caused by dilation of peripheral blood vessels in response to heat; normally occurs after prolonged periods where the extremities remain immobile; recovery is usually rapid and complete.
- *Heat cramps* – painful muscle contractions in the arms, legs, and abdomen, resulting from excessive fluid loss; rest and administration of fluids is normally an effective treatment.
- *Heat exhaustion* – general term for a number of heat-related symptoms, which may include all or some symptoms including tiredness, thirst, dizziness, numbness, and tingling in the fingers and toes, breathlessness, palpitations, low blood pressure, blurred vision, headache, nausea, and fainting; the victim generally exhibits clammy skin, that may be pale or flushed, and is still sweating; rest in a cooler area and administration of fluids is normally an effective treatment; if the victim is unconscious, heat stress should be assumed, and medial attention sought immediately.
- *Heat stroke* – the most serious form of heat-related illness, immediately life-threatening; in heat stroke, perspiration ceases, and the skin is hot, with blotchy red or bluish coloration; body temperature begins to rise rapidly and uncontrollably; victim may be delirious, disoriented, aggressive or unconscious; shivering and uncontrollable muscular contractions may occur, along with loss of bodily functions; immediate medical attention is required.

Many different indexes have been proposed for predicting the likelihood of heat-related illnesses. These indexes include the apparent temperature, effective temperature, wet-bulb globe temperature, botsball, heat stress index, predicted 4-hour sweat rate, wet Kata thermometer, and many others. Detailed comparisons and discussion of the merits and specific application of all these methods are beyond the scope of this study. However, all of the methods incorporate temperature, relative humidity and workload to estimate the likelihood of development of heat-illnesses. The data generated in this study are used to determine the *apparent temperature*, *indoor wet bulb globe temperature,* and the *heat stress index*. These indices and their application are discussed in more detail in sections 3-5 of this report.

2.2 Significance of Heat Stress to Mine Refuge Chamber Safety

The potential for serious injury due to heat stress is well recognized within the mining industry. Major mining countries such as the United States, Canada, South Africa, and Australia have a plethora of guidelines, research reports, and educational resources to try and combat the effect of heat stress in the workplace. In countries such as South Africa and Australia where mines are deep and ambient conditions are hot, it is common knowledge that entrapment inside a refuge chamber without any form of cooling can have potentially fatal results. The state of Western Australia had the first comprehensive guideline for the design of refuge chambers. The guideline indicated that during simulated emergencies, in which a full complement of people has occupied a refuge chamber for a significant period, humidity and temperature had increased rapidly to potentially heat stroke inducing levels. Brake offers the opinion that a steel refuge chamber without cooling will become a coffin for miners trapped for any significant length of time in most Australian mines[8].

Venter noted in his research into design standards for portable refuge chambers in South Africa that environmental control was not included in currently used and commercially available refuge chambers significantly restricting their occupation time[9]. The restriction was derived from environmental constraints such as the uncontrolled rise in temperature and relative humidity due to normal metabolic activity of the occupants. Venter validated these assumptions by performing a one hour test with 12 occupants inside a 2.4 meter (7.9ft) long cylindrical refuge chamber with no cooling system. During the test, the dry bulb temperature increased from 24.5°C (76.1°F) to 29.4°C (84.9°F), with a corresponding rise in relative humidity from 33.9% to 91.7%. As described explicitly by Venter, the testing conclusively demonstrated the "tomb" effect when environmental control is not employed.

Recent testing of four West Virginia approved coal refuge chambers further validated the heat concerns inside of a refuge chamber with the absence of environmental control. Despite a closed forum for development of the parameters used to simulate human entrapment, the two steel fabricated refuge chambers tested still managed to exceed the *Office of Miners' Health & Safety Training* specified temperature limit of 95°F (35°C) apparent temperature. From NIOSH, the two chambers that failed the criteria had apparent temperatures of 110°F and 124°F (in the published NIOSH report the apparent temperatures are listed incorrectly for the temperature and relative humidity provided)[5]. The simulated testing criteria developed by NIOSH used heaters to replicate metabolic rates at 400 Btu/hour/person. This is considerably lower than the 546 Btu/hour/occupant specified by Brake for an entrapped person consuming 0.5 liters of oxygen per minute and150-250 Watts (511-853Btu) specified by Clarke[10].

To replicate humidity from expired air from the occupants inside the chamber, NIOSH introduced water to the chamber at a rate of 1.5 liters/day/occupant. Research performed by Brake, differs from this rate and is considerable less at approximately 30mL/hr moisture vapor or 0.72 liters/day/occupant. Brake, however recognizes that humidity inside a refuge chamber is more importantly impacted by the sweat rates inside the chamber and are credible at between 0.5 and 2 liters per hour for systems without environmental control. The NIOSH testing made no allowance for sweat rates from the exchange of drinking water (8 quarts or 7.57L for 96 hours) necessary to keep the occupants hydrated. Brake suggests that for 'fit', healthy adults, dehydration is responsible for all of the harmful effects of being in a hot environment.

In a high humidity environment such as a refuge chamber sweating will be profuse. According to NIOSH literature, "In the course of a day's work in the heat, a worker may produce as much as 2 to 3 gallons of sweat."[11] It is well recognized that the gut absorption rate is limited to about 1.4 liters per hour, progressive dehydration will occur irrespective of the amount of water drank. Using Brake's value for expired water vapor and minimum value for sweat rate would give a simulated rate of 12.72 liters/day/occupant. This simulated rate is in excess of eight times the value used by NIOSH during their simulated testing. Also of concern is the fact that NIOSH did not add the moisture to the system at the correct temperature of expired air from a miner at rest, 35°C (95°F). Raytheon, performed Matlab® modeling of the NIOSH simulated test and makes it clear that with the moisture added at the ambient mine temperature of 16°C (60.8°F) the temperatures inside the refuge chambers would be 20-30% lower than correctly modeled human conditions[12].

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[8] Brake D J, and Bates G P, 1999. *Criteria for the design of emergency refuge stations for an underground metal mine,* Proc AusIMM, 304(2):1-8.

[9] Venter J, van Vuren, 1998. *Portable refuge chambers: aid or tomb in underground escape strategies,* Proceedings Mine Rescue: Into the New Millennium, pp 55-78, (Mine Ventilation Society of South Africa).

[10] Clarke M, 2003. Breathing in a sealed environment, Unpublished, (Molecular Products).

[11] NIOSH, April 1986, *Publication No. 86-112, Working in Hot Environments.*

[12] Ratheyon UTD, 2007. *Report on Mine Resguge Chamber Thermal Analysis,* Unpublished (NIOSH)

Inside of a confined space such as a refuge chamber, the most important factor which determines the magnitude of heat loss is the starting conditions inside the chamber. This includes the air temperature, relative humidity, air movement, and radiant temperature. Other impacting components which are dependent on the individual miner are; metabolic heat, clothing, fitness, and age. The internal starting conditions of the chamber can be calculated by performing a heat balance on the chamber with the known mine airway temperature and relative humidity.

Computer modeling completed by Raytheon, describes how the interior conditions of the chamber were calculated using thermodynamic analysis in conjunction with the humidity and dry bulb temperature of the mine airway. This however is not fundamentally necessary, as Brake and Gillies Wu both conclude that the starting temperature and relative humidity inside of a refuge chamber will typically be close to the underground ambient temperatures[13]. This was proven in a manned refuge chamber test performed by Venter, where a mean temperature difference of only 1.6°C (2.88°F) existed between the mean surface temperature of the refuge chamber and the surrounding atmosphere[14]. When the underground ambient temperatures are high and the temperature difference with the surrounding atmosphere is minimal, the heat loss through radiation is minimal.

It is generally accepted that humidity levels are high in the mine environment. This is especially the case for eastern coal mines of the United States where data from mine ventilation surveys collated by MSHA showed the maximum humidity to be as high as 90% in some mines[15]. If West Virginia approved refuge chambers were subject to use in coal mines with above average humidity and temperature, the 95°F apparent temperature would be exceeded quickly. The NIOSH report makes no mention of the time it took for the two failed refuge chambers to meet the apparent temperature criteria. With both chambers exceeding the 'danger' category for the apparent temperature scale; the magnitude of the internal temperatures should have caused reason for significant alarm. The testing protocol grossly underestimated the true environmental conditions of a refuge chamber with human occupancy and yet still proved that heat buildup is a significant issue. The NIOSH testing conclusively verifies that additional testing of West Virginia approved chambers is necessary. To date, controlled human testing has not been completed by NIOSH.

It is evident from all available research and literature that heat buildup inside of a refuge chamber without environmental control still requires significant work. A large proportion of the lack of available test data comes from the common mistake of misjudging the severity of heat build up inside an enclosed environment. With major mining fires and explosions having decreased significantly over the last century, refuge chambers are rarely used. There have been less than a dozen publicized uses of refuge chambers in the last ten years. The low probability of use has resulted in some mining operations choosing to design and build their own refuge chambers in an effort to save costs. These chambers are generally simple in design and constructed without cooling systems and in some instances without a carbon dioxide removal system. It is still common to see refuge chambers which simply have oxygen cylinders, with miners assuming that this is all that is necessary to facilitate survival. This is a fundamental mistake as carbon dioxide is expired at more than twice the rate that oxygen is used, resulting in carbon dioxide poisoning well before oxygen asphyxiation.

Another primary reason, such as in the case of the NIOSH testing, was the concern over liability should one of the test subjects be injured during the heat test. This is a real possibility for chambers that do not have a cooling system and are specified as having 96 hour entrapment duration. It is however inconsistent that the state of West Virginia would give approval to refuge chambers when NIOSH is not prepared to utilize human subjects due to the risk. Similar for refuge chamber

[13] Gillies Wu Mining Technology Pty Ltd, 2007. *Brief Technical Review of possible temperature conditions in a West Virginia refuge chamber of specified design,* Unpublished, (MineARC Systems America, LLC).

[14] Venter J, van Vuren, 1998. *Portable refuge chambers: aid or tomb in underground escape strategies,* Proceedings Mine Rescue: Into the New Millennium, pp 55-78, (Mine Ventilation Society of South Africa).

[15] Campbell C, 2007. *Representative Mine Temperatures and Humidities,* Unpublished (MSHA).

manufactures, it is difficult to find willing participants to subject themselves to the kind of hot and uncomfortable conditions that will eventuate during a manned test. The other major issue is that results of human testing for refuge chambers without cooling are only useful for the conditions under which it is being tested or better. For comparative testing of refuge chambers it is necessary to control as many of the variables as possible. This includes the volume of space per miner, virgin rock temperature, and thermal conductivity of surrounding rock, convective flow over the chamber, and occupants' physical fitness' and age. The key issue presented with review of all the available research is the fact that the NIOSH simulated testing varies significantly from all other available literature on heat buildup in refuge chambers. Even more striking is the fact that with NIOSH concluding that "some commercially available refuge chambers have operational deficiencies that will delay their deployment in mines," such refuge chambers are currently being installed in mines around the United States.

3.0 Materials and Methods

3.1 Refuge Chamber Description

The refuge chamber used for this study was a MineARC HRM-08 steel refuge chamber, serial number MAA-054, manufactured in 2008. This refuge chamber is designed for an occupancy period of 48 hours by up to six (6) adults. Appendix A provides schematic drawings of the chamber. The free interior volume of the chamber is 351 ft^3, providing 58.5ft^3 interior volume per occupant at the design load of six persons. The chamber configuration also provides 15ft^2 of usable floor space. These parameters meet the refuge chamber volume and floor space requirements specified by MSHA's proposed rule. [16]

The chamber was equipped with an active soda lime carbon-dioxide scrubbing system, auxiliary oxygen supply, oxygen candle, and air cooling system. The auxiliary oxygen supply, oxygen candle, and air cooling system remained inactive and unused throughout the study. Only the carbon dioxide scrubbing system was activated during the study.

3.2 Test Subjects

Six male adults volunteered to participate in the study, including four MineARC employees, one steel mill worker, and Mr. Johnson of IHST. Participants were dressed in one-piece miner's cotton coveralls and shoes or work boots. Participant ages ranged from 27 to 44 years of age, with weights ranging from 176 to 229 pounds. All participants were reasonably rested prior to refuge chamber entry. All were free of sweat, and exhibited no signs of elevated heart rate, exhaustion, or other adverse physical symptoms prior to chamber entry. Two were smokers, and four were non-smokers. Table 1 provides summary data for the study participants.

Table 1. Test Participant Statistics

Participant Initials	Sex	Age	Weight (lbs)	Smoker?	Occupation
JR	M	27	220	No	Manager
SS	M	33	213	No	Production Manager
DJ	M	45	198	Yes	Industrial Hygienist
KD	M	29	215	No	Workshop Technician
KH	M	39	229	Yes	Workshop Technician
TS	M	38	176	No	Steel Mill Worker

[16] 30 CFR, Parts 7 and 75, *Refuge Alternatives for Underground Coal Mines*, FR Vol 73, No. 116, June 16, 2008, 7.505(a)(1)

3.3 Monitoring Equipment

Interior refuge chamber measurements for carbon dioxide concentration (up to 6000 ppm), dry bulb temperature and relative humidity were collected using a TSI Q-Trak, Model 8554, serial number 8554-09011012. Interior refuge chamber measurements for oxygen and carbon monoxide were collected using BW Micro-5 Gas Alert Monitor, model M5PID-XWQY-A-P-D-B-N, serial number SK108-004724. When carbon dioxide levels exceeded 6000 ppm, a Neotronics Impact Pro monitor, serial ZEL0803005 was used to record carbon dioxide concentrations.

Exterior measurements (outside the refuge chamber) for carbon dioxide, dry bulb temperature, relative humidity, and carbon monoxide were collected using a TSI Q-Trak, Model 8551, serial number 30185.

All instrumentation used for the study was in good working condition, and had received recommended factory servicing and calibration within the past 12 months. TSI Q-Trak units and the BW Micro-5 Gas Alert were calibrated in-house by IHST on 6/24/2008. The Neotronics Impact Pro monitor was calibrated in-house by MineARC on 6/23/08. IHST synchronized date and time for TSI Q-Trak units and the BW Micro-5 Gas Alert with the hygienist's wrist watch, and configured each device to log readings at 1-minute intervals throughout the test period. Readings from the Neotronics Impact Pro monitor were manually recorded by Mr. Johnson during periods when carbon dioxide concentrations exceeded 6000 ppm.

Service, calibration records, and specifications for all equipment are included in Appendix B of this report.

3.4 Methods and Conditions for Study

The study was conducted at the MineArc Systems America, LLC facility, located 4730 Bronze Way, in Dallas, Texas, on June 25, 2008, between the hours of 7:14 a.m. and 10:20 a.m. The refuge chamber was located in an open warehouse area with overhead doors at either end (see photos, Appendix C). Instrumentation for interior monitoring was placed on a stand in the center of the refuge chamber, approximately thirty-four inches (34") above floor level, and approximately twelve inches (12") below eye level of the seated occupants. Exterior monitoring instrumentation was placed on a cart approximately forty inches (40") high, and approximately two feet (2') from the outside wall of the refuge chamber.

All instrumentation was turned on at 7:14 a.m., and allowed to equilibrate and record initial readings for approximately 36 minutes prior to entry into the chamber. The overhead doors in the warehouse were initially closed, but were opened at 7:34 a.m., and remained open for the duration of the study. During the study, outdoor weather conditions were clear and sunny, with variable winds, 7 – 20 mph. Dallas area weather stations[17] reported outdoor dry bulb temperatures ranging from 80.5 to 86.5°F, relative humidity ranging from 73% - 54%, and barometric pressure remaining steady throughout, at approximately 1002 millibars.

All six participants entered the refuge chamber at 7:50 a.m., and the chamber door was sealed at 7:51 a.m. The chamber door remained closed until 9:56 a.m. During the test period, no additional air or oxygen was used to supplement the air in the chamber at the beginning at the test. The refuge chamber's air cooling system was not activated at any time during the study. The chamber remained essentially a sealed, dead air space. The chamber's CO_2 scrubbing system was activated at 9:09 a.m., using approximately one-sixth (1/6) of the recommended chemical charge for the scrubbing system. The reduced charge was used to minimize the thermal impact of the CO_2 scrubbing system on the chamber environment. From the soda lime manufacturer Molecular Products, each liter of CO_2

[17] Weather Underground, http://www.wunderground.com/weatherstation/WXDailyHistory.asp?ID=KTXDALLA68&month=6&day=25&year=2008

absorbed in soda lime produces about 0.907 kJ of energy to the surroundings. Based on a CO_2 expired value of 24L/hour/person this is a total of 144L/hour CO_2 expired. This equates to 36 watts of additional heat generated into the system.

Participants reported physiological reactions and sensations throughout the study period. Physical activity of participants was minimal during the study, limited to note-taking, conversation, and occasional standing. A journal of the occupant's physiological responses to the entrapment can be found in Appendix C.

Participants opened the chamber door for exit at 9:56 a.m. Interior and exterior monitoring instruments were allowed to continue logging until 10:20 a.m.

3.5 Derived Values and Calculations

Dry bulb temperature, relative humidity and oxygen, carbon dioxide, and carbon monoxide readings were measured directly, using the instrumentation specified in Section 3.3 of this report. In addition to these readings, values for wet bulb temperature, apparent temperature (i.e. heat index), indoor wet bulb globe temperature (WBGT), and heat stress index were calculated and charted for each one-minute interval, using a Microsoft Excel spreadsheet. These derived values and calculations are described in the following paragraphs of this section.

- ***Wet bulb temperature:*** The wet bulb temperature is representative of the evaporative cooling capacity of water for a given temperature, relative humidity and atmospheric pressure. It is also used as a component of the wet bulb globe temperature. The wet bulb temperature can be measured directly, using a wet-bulb thermometer, or it can be calculated from the dry bulb temperature, relative humidity and barometric pressure. The wet bulb value was calculated for this study, using the following formula[18]:

$$T_w = \frac{(\phi T + \Delta Td)}{\phi + \Delta}$$

Where:

T_w = Wet bulb temperature (°C)
T_d = Dewpoint temperature (°C)
T = Dry bulb temperature (°C)
rh = relative humidity (%)
e = Ambient vapor pressure (kPa)
ϕ = 0.00066 x Barometric pressure (kPa)

$$e = \frac{rh}{100} \times 0.611^{\frac{17.27 \times T}{(T+237.3)}}$$

$$T_d = \frac{116.9 + 237.3\ln(e)}{16.78 - \ln(e)}$$

$$\Delta = \frac{4098 \times e}{(T_d + 237.3)^2}$$

- ***Wet bulb globe temperature (WBGT):*** The wet bulb globe temperature is a composite temperature measurement recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) as an environmental indicator of heat stress. WBGT is measured using a combination of dry bulb, wet bulb, and globe thermometers. The globe thermometer is essentially a dry bulb thermometer, enclosed in a black metal shell. It is used to measure radiant heat load. In the absence of a significant radiant heat source, the globe temperature will closely

[18] Adapted from Kuemel, B., http://www.faqs.org/faqs/meteorology/temp-dewpoint/, June 12, 1997, retrieved July 30, 2008

approximate the dry bulb temperature.

In this study, the globe temperature was assumed to be the same as the dry bulb temperature, due to the absence of significant radiant heat sources. This assumption helps prevent the WBGT from being over-estimated in the absence of a direct globe temperature measurement. Different formulas are used to calculate the WBGT for indoor and outdoor environments. The indoor formula was used for this study, due to the absence of a significant solar load. The indoor WBGT was calculated using the following formulas[19]:

$$WBGT_{Indoor} = 0.7T_{WB} + 0.3T_G$$

Where:

$WBGT_{Indoor}$ = Indoor wet bulb globe temperature

T_{WB} = Wet bulb temperature

T_G = Globe temperature (assumed equal to dry bulb in this study)

- ***Apparent Temperature (Heat Index):*** The hot weather apparent temperature is a measure of relative discomfort due to combined heat and high humidity. It is based on physiological studies of evaporative skin cooling for various combinations of ambient temperature and humidity. The apparent temperature is easily calculated from the ambient dry bulb temperature and the relative humidity. The hot weather apparent temperature, or heat index, is valid only for temperatures of 80° F and above, and relative humidity of 40% or greater. The hot weather apparent temperature was calculated using the following formulas[20]:

$$HI = c_1 + c_2T + c_3R + c_4TR + c_5T^2 + c_6R^2 + c_7T^2R + c_8TR^2 + c_9T^2R^2$$

Where:

HI = Heat Index (°F)

T = Dry bulb temperature (°F)

R = Relative humidity (%)

$c_1 = -42.379$

$c_2 = 2.04901523$

$c_3 = 10.14333127$

$c_4 = -0.22475541$

$c_5 = -6.83783\times10^{-3}$

$c_6 = -5.481717\times10^{-2}$

$c_7 = 1.22874\times10^{-3}$

$c_8 = 8.5282\times10^{-4}$

$c_9 = -1.99\times10^{-6}$

- ***Heat Stress Index (HSI):*** The Heat Stress Index, or HSI, is an indicator of the degree of heat stress placed on individuals, based on the interaction of metabolic heat generated by work activities and the capacity of the work environment to provide adequate cooling. Air temperature, radiant heat, relative humidity, air velocity and workload are all considered in calculation of the HSI. The HSI is derived by calculating an individual's required heat loss (based on workload and convective and radiant heat exchange) and comparing it to maximum evaporative cooling capacity of a one-liter per hour sweat rate (2400 BTU/hr). The formulas used to calculate the HSI are as follows[21]:

$$HSI = \frac{E_{req}}{E_{\max}} \times 100$$

[19] American Conference of Governmental Industrial Hygienists, "Heat Stress", *2006 TLVs and BEIs, Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents*, 2006, pp182-200

[20] R. G. Steadman, "The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science", *Journal of Applied Meteorology*, July 1979, Vol 18 No7, pp861-873

[21] H.S. Belding, T.F. Hatch, "Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains", *Heat. Piping Air Cond.* 27:129 (1955)

$$M \pm R \pm C = E_{req} \leq E_{\max}$$

Where:

E_{req} = Required evaporative cooling capacity, BTU/hr
E_{max} = Maximum evaporative cooling capacity at 1 liter per hour sweat rate, BTU/hr
M = Metabolic heat production (BTU/hr)
R = Radiant heat exchange, BTU/hr
C = Convective heat exchange, BTU/hr

For workers clothed in shirt and trousers, the following formulas are used to calculate E_{req} and E_{max}:

M = 450 BTU/hr (sitting at ease)

$$R = 15(t_w - 95)$$

$$C = 0.65V^{0.6}(t_a - 95)$$

$$E_{\max} = 2.4V^{0.6}(42 - P_a)$$

Where:

t_w = Wall temperature (°F)
t_a = Air temperature (°F)
t_g = Globe temperature (°F)
V = Air velocity (fpm)
42 = water vapor pressure of wet skin at skin temp of 95 °F (mm Hg)
P_a = Water vapor pressure of air (mm Hg)

4.0 Assessment Results

Figure 1. Comparison of Refuge Chamber Interior and Exterior Temperature and Relative Humidity

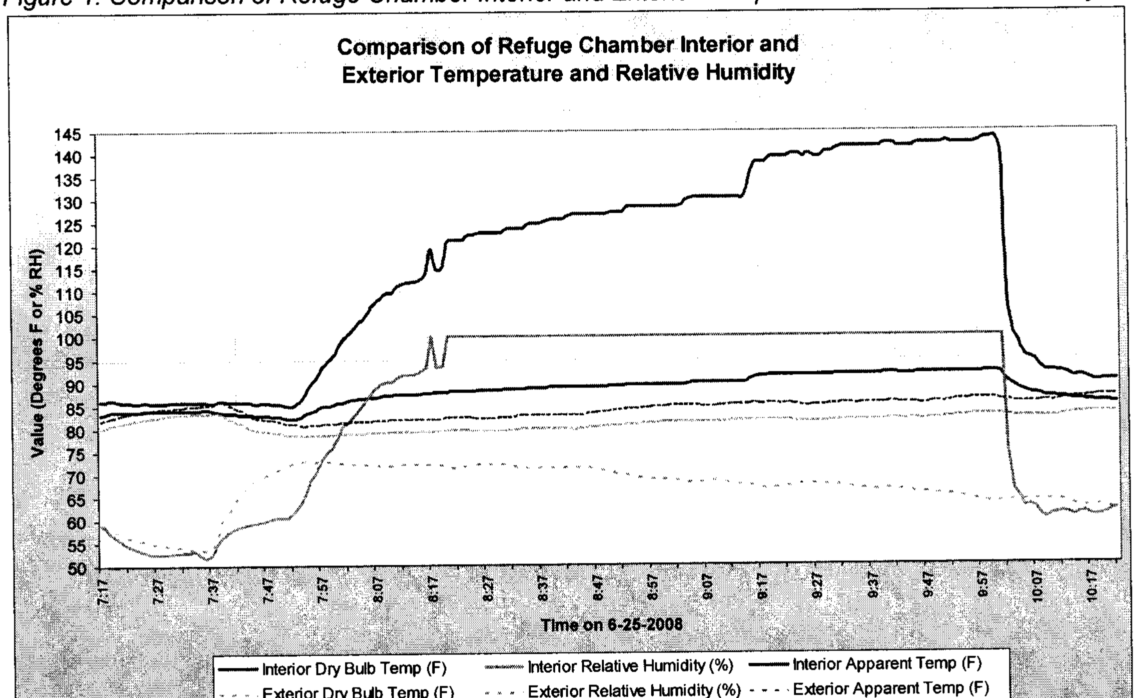


Figure 2. Detail of Refuge Chamber Interior and Exterior Apparent Temperature

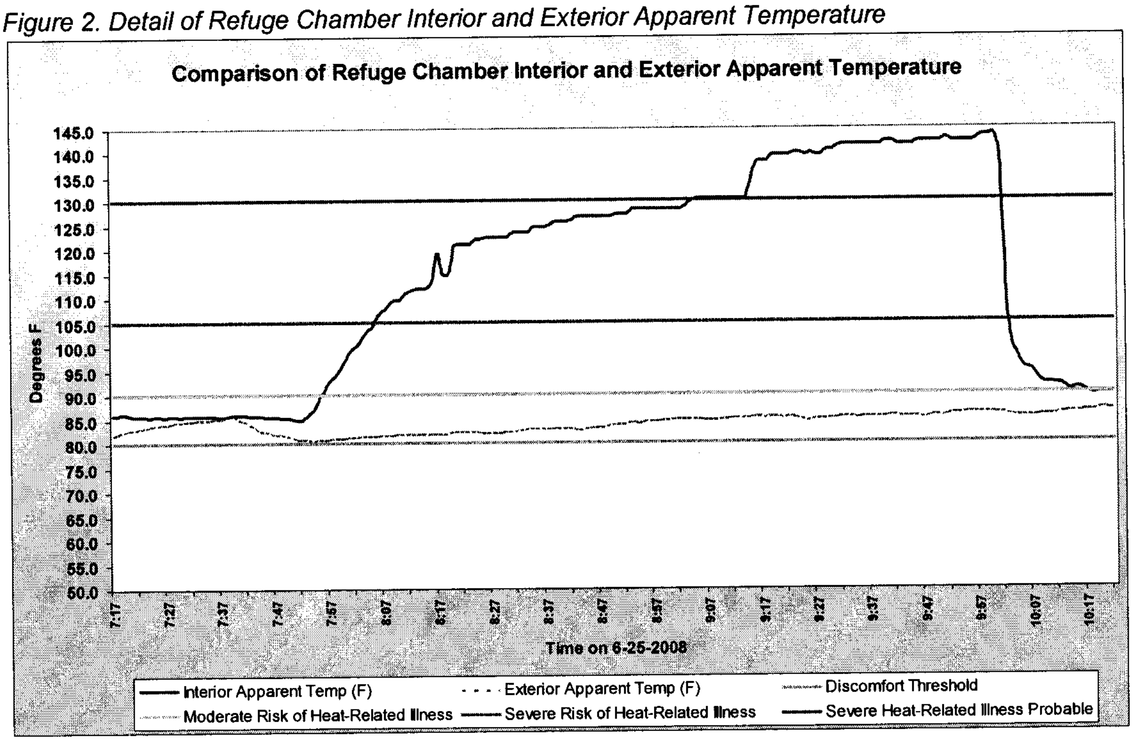


Figure 3. Indoor Wet-Bulb Globe Temperature (WBGT) for Refuge Chamber Interior

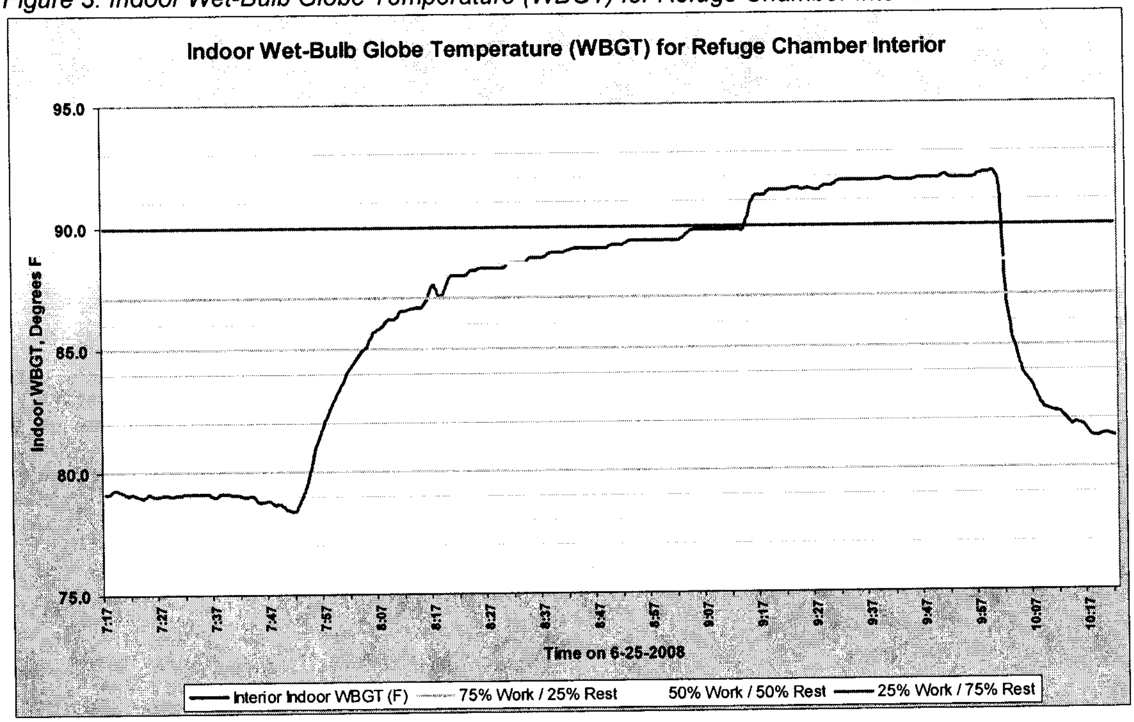


Figure 4. Heat Stress Index (HSI) for Refuge Chamber Interior

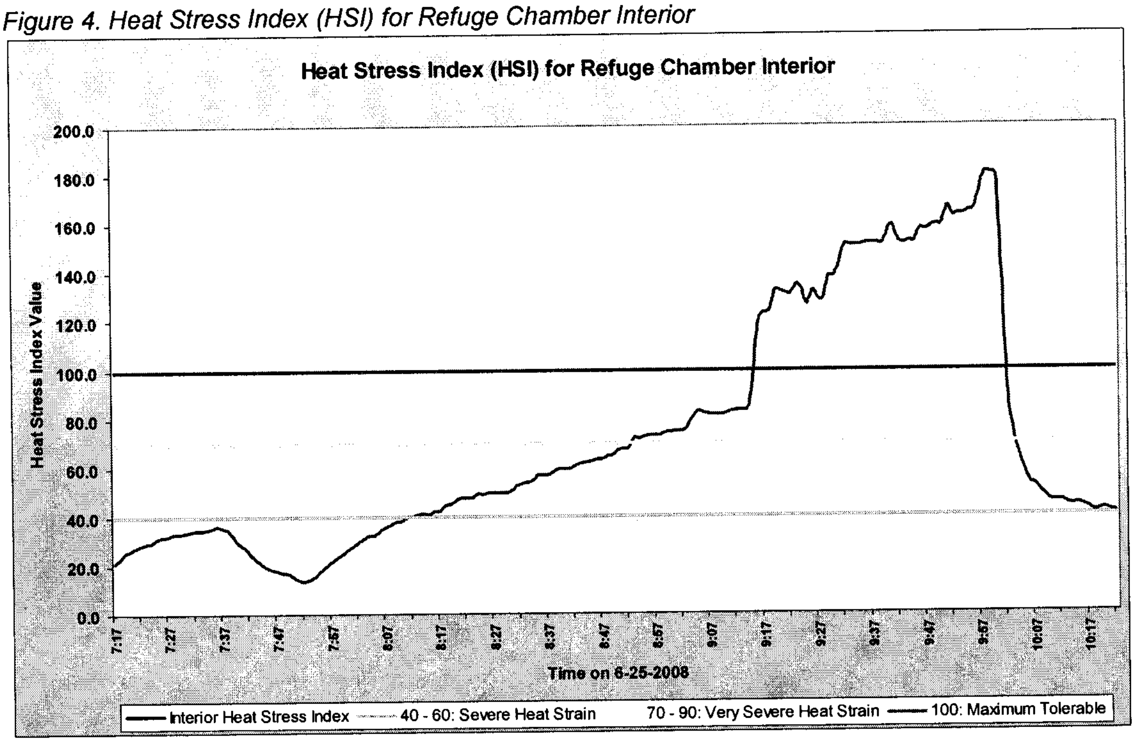


Figure 5. Additional Parameters Measured

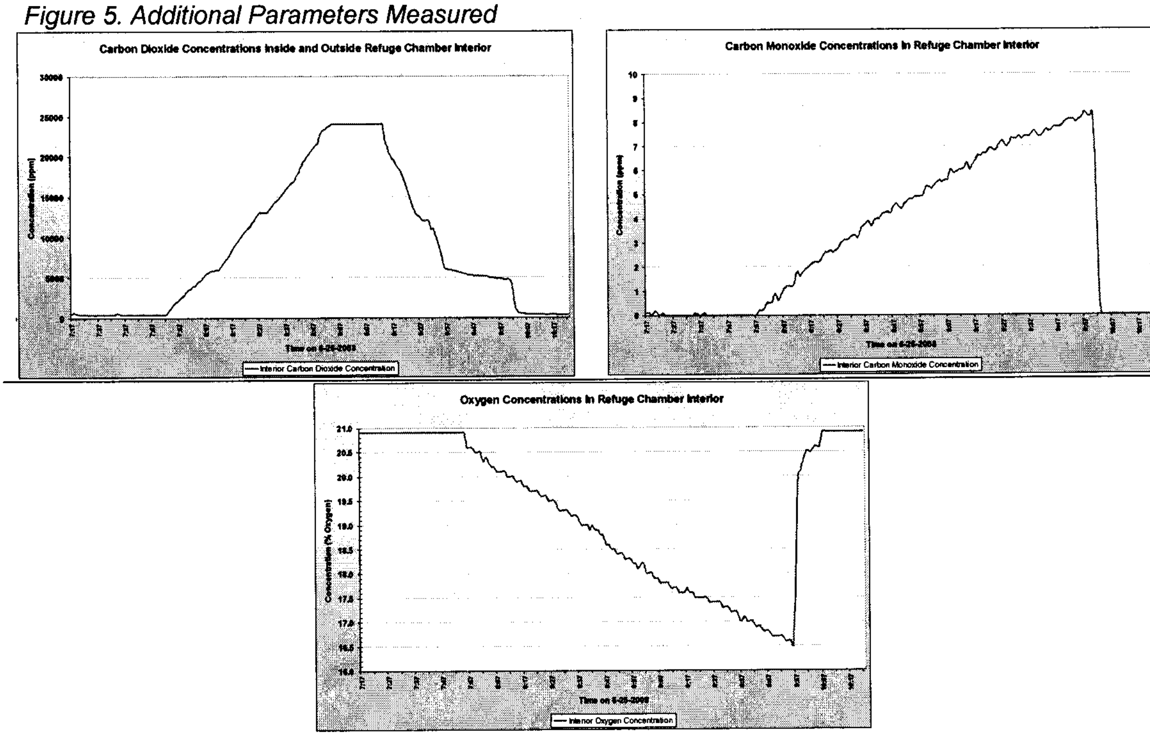


Figure 6. Chronology of Key Events During Study

Time	Event Description
07:14	Monitoring instruments activated and logging begun
07:34	Shop doors opened to allow entry and circulation of cooler outside air around refuge chamber
07:50	Six volunteers entered refuge chamber
07:51	***Door to refuge chamber sealed***
07:55	Noted formation of water condensate film on interior ceiling of refuge chamber
08:01	All occupants exhibiting some degree of sweating
08:18	Interior Q-Trak reached >= 95% RH, >= 6000 ppm carbon dioxide
08:54	Interior carbon dioxide levels reached 24000 ppm (2.4%), upper limit of instrumentation
09:09	Activated carbon dioxide scrubbing system, with ~1/6 normal chemical charge
09:56	Opened refuge chamber door, and occupants exited
10:20	Stopped all monitoring instruments

5.0 Discussion

5.1 Temperature, Humidity in the Occupied Chamber

Data generated during the study demonstrated rapid increases in relative humidity and dry bulb temperature after the chamber was occupied and shut. Within eight (8) minutes after occupancy, the increases in temperature and relative humidity resulted in an apparent temperature of 95.5°F, above the maximum internal temperature permitted by the proposed MSHA standard. Within fifteen (15) minutes of occupancy, apparent temperature reached 106.4°F, above the 105°F threshold for severe risk of heat-related illnesses[22]. Within sixty-four (64) minutes, apparent temperature reached 130°F, the threshold of extreme risk of serious heat-related illness. Apparent temperature continued to climb throughout the remainder of the test period, reaching a maximum of 143.4°F after one hundred twenty-eight (128) minutes of occupancy. Apparent temperatures did not decrease until the refuge chamber door was opened, allowing entry of outside air.

The steady increase in apparent temperature was the result of continuing elevation of ambient temperature and relative humidity inside the occupied chamber. Over the approximate two-hour (128 minute) test period, measured dry bulb temperature inside the chamber increased by 9.8°F, while the exterior temperature increased by 7.6°F. Interior relative humidity reached saturation (100% RH) within nineteen (19) minutes. Exterior relative humidity fell from 72% to 64.1%. As the refuge was sealed, exterior relative humidity had no impact on the interior relative humidity.

Inside a closed refuge chamber, the body's attempts at cooling, coupled with the essentially recycled air supply, appears to create a feedback loop. The heat lost through radiation, convection, and expiration cause warming of the interior air. Expired air also increases the relative humidity. As the occupants begin to sweat, the evaporation of that sweat further saturated the interior air. This increasing saturation, in turn, limits the effectiveness of the sweating itself, resulting in increasing sweat production, in the body's attempt to maintain effective cooling. The feedback cycle continues until the atmosphere is saturated, and sweating is minimally effective. Convection, radiation, and expiration continue to add heat to the surrounding air, and become increasing ineffective at body cooling as ambient temperatures rise.

5.2 Apparent Temperature within the Refuge Chamber

Figure 2 provides a comparison of the interior and exterior apparent temperatures measured during the study. The threshold of severe risk of heat related illness (105°F) as indicated by the apparent temperature was reached very quickly (within about fifteen minutes). Activation of carbon dioxide scrubbing systems, which are exothermic (heat-generating) was delayed for over an hour, to avoid adding the additional heat load to the interior air. In spite of the delayed activation, apparent temperature reached 130°F in slightly over one hour after occupancy. Immediately following activation of the carbon dioxide scrubbing system, apparent temperature rapidly increased again, rising quickly to nearly 140°F. The apparent temperatures reached during the study are clearly indicative of severe risk of life-threatening manifestations of heat-related illnesses.

5.3 Other Heat Stress Indices

The apparent temperature, or similar variants, are widely reported by weather service bureaus in the United States and other countries as the *heat index*, and considered appropriate for persons performing walking or similar light activity. However, the apparent temperature has not enjoyed wide acceptance as an index of occupational heat stress in the United States. This study also used the recorded data to calculate the *indoor wet-bulb globe temperature (WBGT)* and the *heat stress index (HSI)*. Certain assumptions were used in calculation of the WBGT and HSI in this study. All of the assumptions tend to minimize the various index values, preventing overestimation.

- Personnel are normally dressed and performing light work (sitting, standing, etc.);
- The globe temperature in the chamber interior is equivalent to the dry bulb temperature, due to minimal radiant heat load;
- The wall temperature of the refuge is equivalent to that of the exterior atmosphere; and,
- An air flow of 100 fpm is present in the chamber (this is likely a very generous estimate, particularly prior to activation of carbon dioxide scrubbers).

[22] R. G. Steadman, "The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science", *Journal of Applied Meteorology*, July 1979, Vol 18 No7, pp861-873

Figures 3 and 4 show the indoor WBGT and HSI index values inside the refuge chamber. Both indices clearly indicate the interior refuge chamber conditions are capable of producing heat-related illnesses upon continued exposure. As observed with the apparent temperature index, key thresholds are crossed in less than an hour, and heat stress indices continue to rise until the chamber is opened. The data strongly suggests severe risk of heat-related illnesses, regardless of the particular index used. The close agreement between the various indices suggests that apparent temperature is an effective index of heat stress for use in evaluation of refuge chambers.

5.4 Carbon Dioxide, Oxygen, and Carbon Monoxide Results

Figure 5 presents the results of carbon dioxide, oxygen, and carbon monoxide measurements. The data for these gases affirms carbon dioxide scrubbers, carbon monoxide scrubbers, and supplementary oxygen are necessary components of a refuge chamber. The rapid elevation of carbon dioxide concentration suggests that early activation of scrubbers would be required under normal use scenarios. Scrubbers are exothermic, and will therefore begin adding to the overall heat load very soon after chamber occupancy. Likewise, chemical oxygen generating devices are also exothermic, and, if used, will also contribute to the overload thermal load. It is of interest that two of the chamber occupants were smokers, and that carbon monoxide concentrations increased steadily throughout the study period to a maximum of 8.4 ppm.

5.5 Physiological Effects Reported by Refuge Chamber Occupants

All six chamber occupants were reasonably fit males of less than 45 years of age. All were residents of the state of Texas, and had achieved some degree of acclimatization to elevated temperatures and humidity common to north Texas summers. Sweating began almost immediately for all but one occupant, who reported frequent use of a steam sauna. This individual did not begin to visibly sweat until about thirty minutes into the occupancy period. The rate of sweating varied from moderate to heavy, depending on the individual. The clothing of all occupants was significantly saturated within the first thirty minutes of the test period. All occupants reported they felt uncomfortably hot after ten to twenty minutes.

As carbon dioxide levels climbed, occupants reported sensations of air hunger, as well as increased breathing and heart rate. Activation of the carbon dioxide scrubber appeared to alleviate these sensations.

In the latter half of the test period, flushing of the face, particularly the ears became noticeable on all occupants. Around 9:15, a number of occupants noted marked reduction or cessation of sweating, particularly around the hands and wrists. One occupant began to notice slight tingling in the hands and around the lips around this time. One occupant began to experience a perception of slight difficulty in thinking quickly and clearly in the latter half of the test period.

No occupants reported dizziness, sleepiness, weakness or nausea during or after the test period. Occupants consumed approximately 8-16 ounces of fluid each throughout the test period, and increased their fluid intake throughout the remainder of the day. While occupants made no effort to conserve water, it is notable that this rate of fluid intake is approximately 3-6 times the rate of available water specified in the MSHA proposed ruling for 96 hour refuge chambers.

All occupants experienced significant fatigue after the test period, which persisted for the remainder of the day.

5.6 Comparison to NIOSH Study Results

NIOSH performed a study of four (4) refuge chambers from various manufacturers[23]. Two of the chambers were inflatable models and two were steel. Occupant capacity of the chambers ranged from 12 – 36 persons. None were equipped with air cooling systems. NIOSH did not use live personnel for the testing, but instead used a series of mechanical means to simulate heat and moisture production in the tested chambers. Of particular interest in comparison to this study are the results for the two steel chambers (one 12-person chamber and one 26-person chamber). Although conducted in a mine environment with an ambient exterior temperature of approximately 60°F, both chambers failed to maintain internal apparent temperatures below 95°F. Apparent temperatures, dry bulb and wet bulb temperatures were comparable to those found in this study. The NIOSH report appears to contain an error in reporting the apparent temperature for the 26-person chamber. The NIOSH report provides a maximum apparent temperature of 110°F, with a dry bulb temperature or 90.5°F, and a relative humidity of 92.6%. The apparent temperature calculation provides a higher value, and in a separate data summary for the same project, NIOSH presents the apparent temperature as 124°F[24]. These maximum values correspond relatively closely with those developed during this study, although IHST was unable to locate any data that indicated the length of time required to reach these maximums.

The NIOSH results for the inflatable chambers indicate overall lower temperature and relative humidity for those chambers. The details of the inflatable chambers' construction are not provided in the NIOSH report, making it difficult to interpret this discrepancy, particularly with regards to the overall low relative humidity reported. If the inflatable chambers do not exhaust interior air nor introduce outside air, and the chambers remained properly closed throughout the test, the much lower relative humidity when compared to the steel chambers is difficult to explain. Manufacturers appear to have been allowed to correct various mechanical problems (including chamber deflation) which occurred during the NIOSH tests[25], further compounding problems in interpretation of the data.

In short, the apparent temperature results for steel chambers tend to support those developed during this study, even with the considerably lower external temperatures. Raytheon UTD described issues with the NIOSH test methods which tended to result in underestimation of internal temperatures[26].

In the text of its report, NIOSH states that testing with live personnel was desirable, but considered impractical, given the time constraints of its study mandate. IHST agrees with NIOSH that further development of testing protocols is appropriate, and tests with live personnel is critical in validation of testing models used for approval and certification processes.

5.8 Topics for Further Study

The external temperature of the atmosphere surrounding the refuge chamber exterior will influence the internal temperature. Colder exterior temperatures will allow greater loss of radiant heat from the shelter interior. Material of construction (i.e., steel, plastic, etc.) will also have an impact on radiant heat exchange, although a study by Raytheon UTD indicated the impact on actual interior refuge temperature is small[27]. During this study the external temperature of the atmosphere outside the refuge chamber (79.1 – 82.6°F) was higher than the average temperature reported for most coal mines during the winter months[28]. The temperature was comparable to ranges for coal mines in

[23] National Institute for Occupational Safety and Health, *Research Report on Refuge Alternatives for Underground Coal Mines*, December 2007

[24] National Institute for Occupational Safety and Health, *Survivability Evaluation of Mine Refuge Chambers*, December 19, 2007

[25] National Institute for Occupational Safety and Health, *Survivability Evaluation of Mine Refuge Chambers*, December 19, 2007

[26] Raytheon UTD, *Report on Miner Refuge Chamber Thermal Analysis*, December 6, 2007

[27] Raytheon UTD, *Report on Miner Refuge Chamber Thermal Analysis*, December 6, 2007

[28] Campbell C, 2007. *Representative Mine Temperatures and Humidities,* Unpublished (MSHA).

Alabama during the summer months, as well as non-metal mines in the spring and summer months. IHST was unable to obtain coal mine temperature data for the summer months. Additional data on coal mine temperatures during summer months would be very desirable. IHST believes further testing and certification/approval evaluations would be ideally based on the warmest average temperatures under which the refuge chambers would be used.

NIOSH studies reported somewhat lower relative humidity in steel chambers than IHST found in this study of a steel chamber. The inflatable chambers studied by NIOSH appeared to have remarkably low relative humidity. Without further information on the specific test methods or design of the various chambers, the difference in measured relative humidity is puzzling. Considering the rapidity with which the atmosphere became saturated during this study with live occupants, IHST believes further investigation and testing may be appropriate to resolve this apparent discrepancy.

6.0 Conclusions and Recommendations

Under the test conditions of this study, thermal-environmental conditions inside the steel refuge chamber produced unacceptable risk of heat-related illnesses after less than an hour of occupancy. Significance of the risk of heat-related illness was supported by comparison to three (3) separate indices of heat stress, the apparent temperature, the indoor wet bulb globe temperature, and the heat stress index.

Elevation of ambient temperature and significant, rapid elevation of relative humidity, which limit the body's natural cooling mechanisms, are the primary causes of increased heat stress. Convective, radiant, and expired heat from occupants, as well as heat from exothermal chemical devices (scrubbers, etc.), appear to be the primary contributors to increases in ambient temperature. Water vapor from expired air and evaporation of sweat appear to the primary contributors to elevated relative humidity.

IHST believes air cooling systems should be required in refuge chambers intended for more than a few hours occupancy. Air cooling systems can lower the ambient temperature, as well as reduce overall humidity through condensation of water vapor on the cooling elements. Both actions play key roles in reducing the primary environmental factors contributing to heat stress. IHST recognizes the importance of intrinsic safety for such air cooling systems. If intrinsically safe air cooling systems are not currently available, IHST believes they are technically feasible, and every effort should be made to support development and use of such systems in refuge chambers.

Limitations

The items observed and documented in this report are intended to be representative of the conditions of the subject property on the inspection date. Air samples collected from the facility provide information on the presence of specific airborne chemicals in the facility on the survey date.

This document is the rendering of a professional service, the essence of which is the advice, judgment, opinion, or professional skill. In the event that additional information becomes available that could affect the conclusions reached in this investigation, IHST reserves the right to review and change if required, some or all of the opinions presented herein.

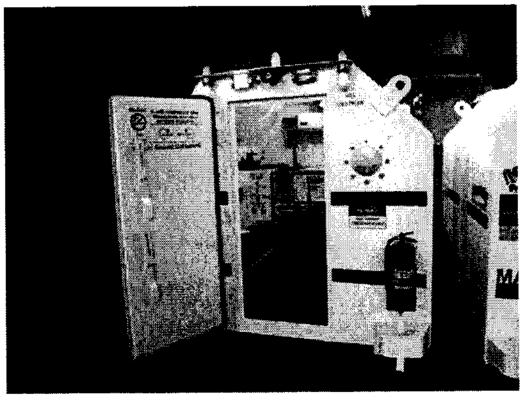
This report has been prepared for exclusive use of the client and their representatives. No unauthorized reuse of reproduction of this report, in part or whole, shall be permitted without prior written consent. If you have any questions concerning this report, please do not hesitate to contact our office.

Derrick K. Johnson
Industrial Hygienist
Vice-President of Operations, IHST, Inc.

Tracy K. Bramlett

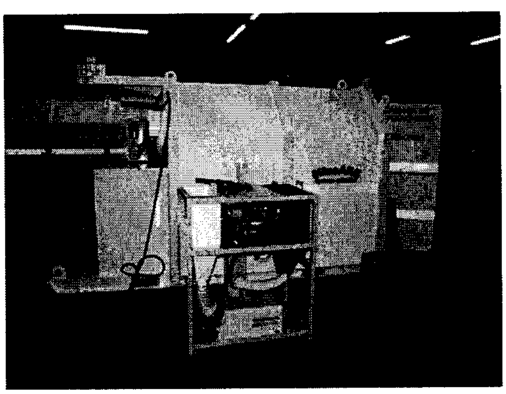
Tracy K. Bramlett, CIH, CSP
President, IHST, Inc.

Photographs

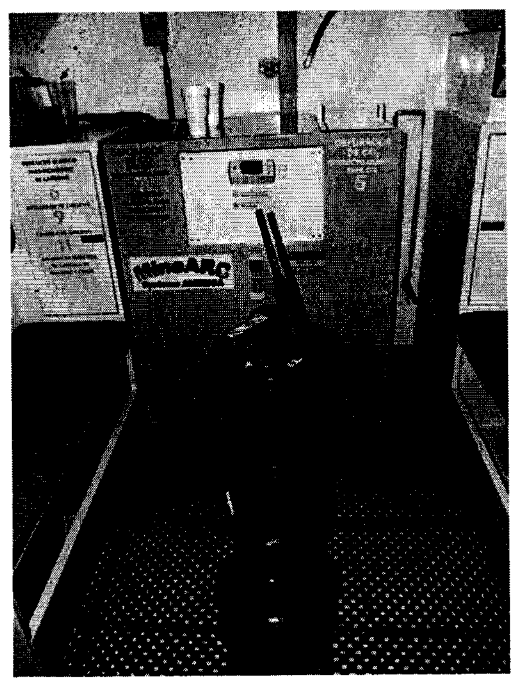


MineARC HRM-08 Steel Refuge Chamber used in study; unit has 8-person design capacity

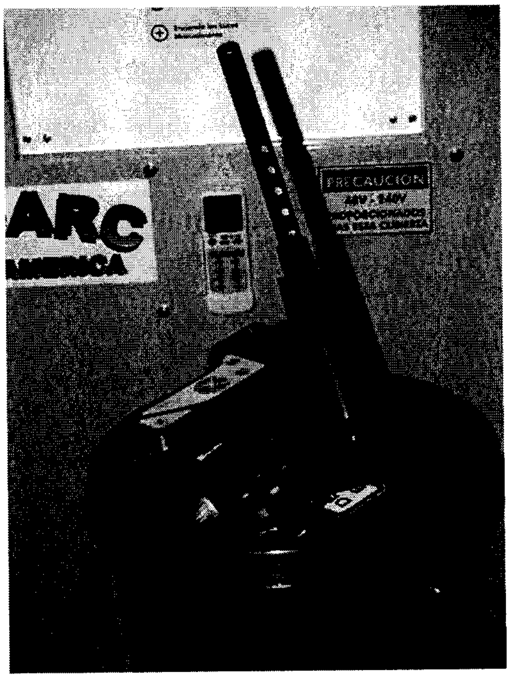
MineArc facility warehouse showing open warehouse doors and general area layout



Cart with monitoring equipment for exterior of refuge chamber

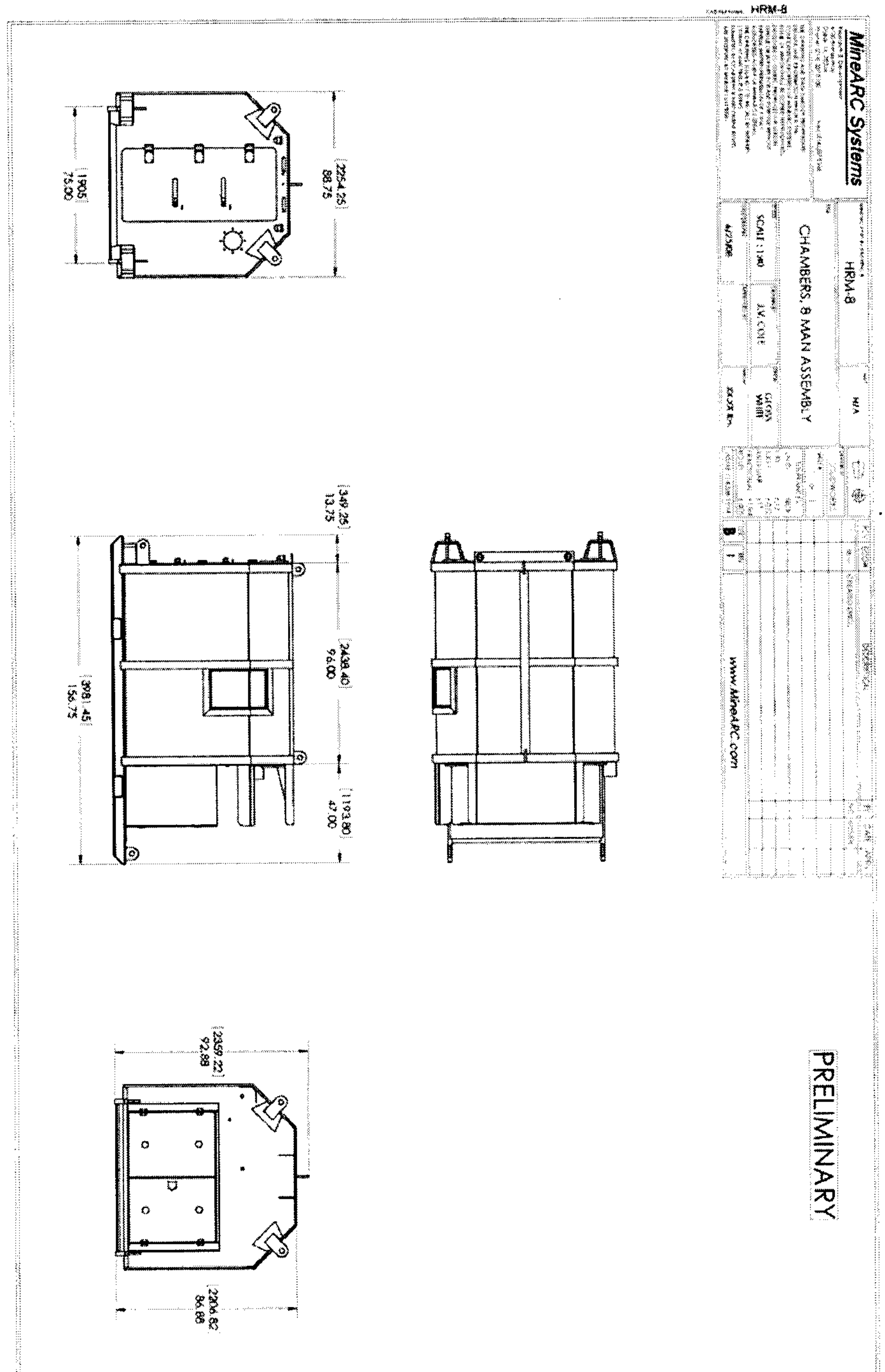


Monitoring equipment placement within refuge chamber



Detail of monitoring equipment for chamber interior

Appendix A. Schematic Drawing of HRM-08 Refuge Chamber



Appendix B. Instrument Calibration and Specification Data

TSI - Customer Service Report

RMA Number 800066136

Ship-to party 17149	Sold-to party 17149
IND HYGIENE & SAFETY TECH 2235 KELLER WAY CARROLLTON TX 75006-2515	IND HYGIENE & SAFETY TECH 2235 KELLER WAY CARROLLTON TX 75006-2515

Service Information:
Purchase Order 10302007AHG
Purchase Order date 11/01/2007

Description Calibration of Q-Trak 8551

Equipment 855130185
Serial Number 30185
Material 8551

Service Description:

Findings:
meter came in for annual calibration.

Action:
cleaned, calibrated, final function check.

TSI®

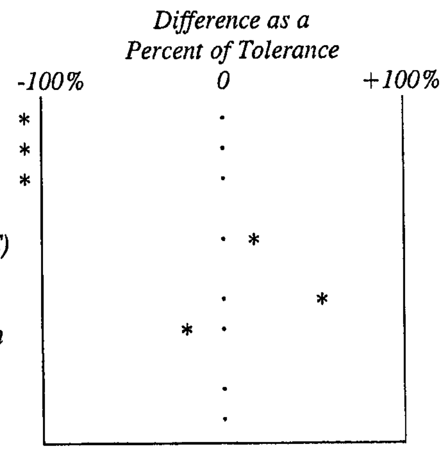
AS FOUND STATUS

TSI Model *8551* TSI Serial No. *30185*

Description *Q-Trak Indoor Air Quality Meter*

CALIBRATION VERIFICATION RESULTS

Calibration Standard	*Instrument Output*	*Difference*
505 ppm	*400 ppm*	*-20.79 %*
1213 ppm	*1101 ppm*	*-9.23 %*
3011 ppm	*2842 ppm*	*-5.61 %*
50.0°F (10.0°C)	*50.2°F (10.1°C)*	*0.2°F (0.1°C)*
74.1 %rh	*75.8 %rh*	*1.7 %rh*
19.8 %rh	*19.2 %rh*	*-0.6 %rh*
102 ppm	*118 ppm*	*16 ppm*
36 ppm	*43 ppm*	*7 ppm*



Tolerance

CO2: ±3% of reading ±50ppm
Temperature: ±1.0°F (±0.6°C)
Humidity: ±3.0% rh
CO: ±3% of reading or ±3ppm, whichever is greater

Calibration Environment

Ambient Temperature: *73.4 °F (23.0 °C)*
Barometric Pressure: *738.4 mmHg*

Applicable Test Report		Date Last Verified
Barometric Pressure		05-04-07
Temperature	(-8-32°C)	01-23-07
	(25-55°C)	01-23-07
Dew Point		09-29-06

Tested by
TSI Incorporated

NOV 5, 2007
Test Date

Mailing Address: P.O. Box 64394 St. Paul, MN 55164 USA
Shipping Address: 500 Cardigan Road St. Paul, MN 55126 USA
Phone: (800) 926-8378 or (651) 490-2760 **Fax:** (651) 490-2704

TSI CERTIFICATE OF CALIBRATION AND TESTING

TSI Model *8551* TSI Serial No. *30185*

Description *Q-Trak Indoor Air Quality Meter*

CALIBRATION VERIFICATION RESULTS

Calibration Standard	*Instrument Output*	*Difference*	*Difference as a Percent of Tolerance* (-100% 0 +100%)
505 ppm	*489 ppm*	*-3.17 %*	* ·
1213 ppm	*1200 ppm*	*-1.07 %*	* ·
3011 ppm	*2973 ppm*	*-1.26 %*	* ·
50.0°F (10.0°C)	*49.8°F (9.9°C)*	*-0.2°F (-0.1°C)*	* ·
104.0°F (40.0°C)	*104.2°F (40.1°C)*	*0.2°F (0.1°C)*	· *
34.3 %rh	*33.2 %rh*	*-1.1 %rh*	* ·
74.0 %rh	*73.3 %rh*	*-0.7 %rh*	* ·
55.6 %rh	*54.6 %rh*	*-1.0 %rh*	* ·
18.8 %rh	*19.0 %rh*	*0.2 %rh*	*
102 ppm	*102 ppm*	*0 ppm*	*
36 ppm	*36 ppm*	*0 ppm*	*

Tolerance

CO2: ±3% of reading ±50ppm
Temperature: ±1.0°F (±0.6°C)
Humidity: ±3.0% rh
CO: ±3% of reading or ±3ppm, whichever is greater

Calibration Environment

Ambient Temperature: 73.4 °F (23.0 °C)
Barometric Pressure: 744.1 mmHg

TSI Incorporated does hereby certify that all materials, components, and workmanship used in the manufacture of this equipment are in strict accordance with the applicable specifications agreed upon by TSI and the customer and with all published specifications. All performance and acceptance tests required under this contract were successfully conducted according to required specifications. Furthermore, all test and calibration data supplied by TSI has been obtained using standards whose accuracies are traceable to the National Institute of Standards and Technology (NIST) or has been verified with respect to instrumentation whose accuracy is traceable to NIST, or is derived from accepted values of physical constants. Calibration procedures for this instrument comply with MIL-STD-45662A with an exception of the humidity calibration standard which has a calibration accuracy ratio of 2:1 with respect to the accuracy specifications of the instrument.

Applicable Test Report	Date Last Verified
Barometric Pressure	05-04-07
Temperature (-8-32°C)	01-23-07
(25-55°C)	01-23-07
Dew Point	09-29-06

Calibrated by
TSI Incorporated

☑ Final Function Check

NOV 6, 2007
Calibration Date

Mailing Address: P.O. Box 64394 St. Paul, MN 55164 USA
Shipping Address: 500 Cardigan Road St. Paul, MN 55126 USA
Phone: (800) 926-8378 or (651) 490-2760 **Fax:** (651) 490-2704

Industrial Hygiene and Safety Technology, Inc.
2235 Keller Way, Carrollton, TX 75006
(972) 478-7415 fax (972) 478-7615

Direct-reading Instrumentation Calibration Record

Type of Instrument Calibrated:

- ☐ CO Monitor
- ☐ CO2 Monitor
- ☒ CO/CO2 Monitor
- ☐ LEL/O2/CO/H2S/PID Combo Monitor
- ☐ Other: ____________

Instrument Name: Q-Trak

Instrument Model No. 8551 (tag # 5432)

Last Factory Service Date: 11/2007

Instrument Serial No. 30185

Type of Test:

- ☐ Response Verification (Bump Test)
- ☒ Full Calibration, w/Response Correction

Calibration Event Summary

Challenge Agent	Container or Lot ID	Exp. Date	Ref Conc.	Instrument Response	% Diff	Corr. Factor	OK?
☒ Carbon Dioxide	LTD 168-mm-cm	Apr 2010	1000 ppm	997 ppm	-0.3%	+3 ppm	☑
☒ Carbon Monoxide	LTD168-mm-cm	Apr 2010	35 ppm	35 ppm	0%	0 ppm	☑
☐ Hydrogen Sulfide							☐
☐ Isobutylene							☐
☐ Methane (LEL)							☐
☐ Oxygen							☐
☐ Other ____________							☐

Comments: Temp, RH set during factory service

Printed Name: Derrick Johnson

Signature: [signature]

Date, Time: 6-24-08; 10:33

Include hard copy original of completed record in project file. Upload copies of completed record to online job file and online equipment record.

TSI Q-Trak, Model 8551

Specifications

CO_2

Sensor type......................................Non-Dispersive Infrared (NDIR)
Range ....0 to 5000 ppm
Accuracy ....±(3% of reading + 50 ppm) at 25°C
(Add uncertainty of ±0.36% of reading
per °C [±0.2% of reading per °F] for
change in temperature.)
Resolution ....1 ppm

Temperature Sensor

Type ....Thermistor
Range ....0 to 50°C (32 to 122°F)
Accuracy ....±0.6°C (1.0°F)
Resolution ....0.1°C (0.1°F)
Response time ....30 seconds (90% of final value, air
velocity at 2 m/s)
Display units ....°C or °F (user selectable)

Humidity

Sensor type......................................Thin-film capacitive
Range ....5 to 95% RH
Accuracy ....±3% RH (includes ±1% hysteresis.)
Resolution ....0.1% RH
Response time ....20 seconds (for 63% of final value)

CO Sensor

Sensor type......................................Electro-chemical
Range ....0 to 500 ppm
Accuracy ....±3% of reading or 3 ppm whichever is
greater [add ±0.5%/°C (0.28%/°F) away
from calibration temperature]
Resolution ....1 ppm
Response time ....<60 seconds to 90% of final value.

Power Requirements

Batteries ....Four AA-size alkaline or rechargeable
or
AC adapter ....6 VDC nominal, 300 mA [Q-TRAK Plus
monitor mates with 5.5 mm OD x
2.1 mm ID plug, center pin positive(+)]
Approximate battery life.................Up through 20 hours (alkaline).

Physical

External dimensions........................107 mm x 183 mm x 38 mm
(4.2 in. x 7.2 in x 1.7 in.)
Probe length ....31.2 mm (12.3 in.)
Probe diameter ....1.8 cm (0.75 in.)
Weight .... 0.59 kg (1.3 pounds) [with batteries]
Display..128 x 64 Graphics display module with
backlight.

Maintenance Schedule

Factory calibration ....Annually
User calibration...............................As needed

Serial Interface

Type RS-232
Baud rate...9600
Data bits 8
Stop bits 1
Handshaking ....None
Data format ....ASCII

TSI - Customer Service report

Thank you for the opportunity to service your instrument.

RMA Number: 800077119

Ship-to party 17149	Sold-to party 17149
IND HYGIENE & SAFETY TECH 2235 KELLER WAY CARROLLTON TX USA	IND HYGIENE & SAFETY TECH 2235 KELLER WAY CARROLLTON TX USA

Service Information:

Purchase Order 040408AHG
Purchase Order Date 04/09/2008

Description Calibration of Q-Trak Plus 8554

Equipment 8554-09011012
Serial Number 8554-09011012
Material 8554

Service Description:

Findings:
Instrument returned for yearly calibration.

Action:
Meter & probe were inspected, recalibrated, & ran functional check.

Thank you for using TSI instruments.

TSI®

Certificate of Calibration and Testing

Q-TRAK PLUS Indoor Air Quality Meter

New Instrument

TSI Model	8554	Test Date	5/5/2008
TSI Serial Number	8554-09011012	Test Time	9:31
Firmware Version	1.60		

CALIBRATION VERIFICATION RESULTS

Calibration Standard	*Instrument Output*	*Actual Difference*	*Tolerance*
1001 ppm CO_2	1002 ppm CO_2	1 ppm	± (3% + 50 ppm)
2500 ppm CO_2	2511 ppm CO_2	11 ppm	± (3% + 50 ppm)
100.0 ppm CO	99.5 ppm CO	-0.5 ppm	± 3% or 3 ppm
40.0 °C	40.0 °C	0.0 °C	± 0.6 °C (1.0 °F)
30.0 % rh	30.3 % rh	0.3 % rh	± 3% rh
60.0 % rh	57.7 % rh	-2.3 % rh	± 3% rh

TSI Incorporated does hereby certify that all materials, components, and workmanship used in the manufacture of this equipment are in strict accordance with the applicable specifications agreed upon by TSI and the customer and with all published specifications. All performance and acceptance tests were successfully conducted according to required specifications. All test and calibration data supplied by TSI has been obtained using standards whose accuracies are traceable to the National Institute of Standards and Technology (NIST) or has been verified with respect to instrumentation whose accuracy is traceable to NIST, or derived from accepted values of physical constants. Calibration procedures for this instrument comply with MIL-STD-45662A, with the exception of the humidity calibration standard, which has an accuracy ratio of 2:1, with respect to the accuracy specifications of the instrument.

Calibration Environment	Applicable Test Reports	Date Last Verified
Ambient Temperature 24.2 °C	Humidity	10/02/2007
Barometric Pressure 737.56 mmHg	Barometric Pressure	05/04/2007

Calibrated By [signature]

TSI Incorporated

Shipping Address 500 Cardigan Road St. Paul, MN 55126 US

Phone (800)874-2811 or (651) 490-2811 **Fax** (651) 490-3824

Certificate of Calibration and Testing

Q-TRAK PLUS Indoor Air Quality Meter

As Found

TSI Model	8554	Test Date	5/1/2008
TSI Serial Number	8554-09011012	Test Time	12:23
Firmware Version	1.60		

CALIBRATION VERIFICATION RESULTS

Calibration Standard	*Instrument Output*	*Actual Difference*	*Tolerance*
1000 ppm CO_2	877 ppm CO_2	-123 ppm	± (3% + 50 ppm)
2501 ppm CO_2	2278 ppm CO_2	-223 ppm	± (3% + 50 ppm)
100.0 ppm CO	90.6 ppm CO	-9.4 ppm	± 3% or 3 ppm
40.0 °C	40.0 °C	0.0 °C	± 0.6 °C (1.0 °F)
30.0 % rh	31.2 % rh	1.2 % rh	± 3% rh
60.0 % rh	60.9 % rh	0.9 % rh	± 3% rh

TSI Incorporated does hereby certify that all materials, components, and workmanship used in the manufacture of this equipment are in strict accordance with the applicable specifications agreed upon by TSI and the customer and with all published specifications. All performance and acceptance tests were successfully conducted according to required specifications. All test and calibration data supplied by TSI has been obtained using standards whose accuracies are traceable to the National Institute of Standards and Technology (NIST) or has been verified with respect to instrumentation whose accuracy is traceable to NIST, or derived from accepted values of physical constants. Calibration procedures for this instrument comply with MIL-STD-45662A, with the exception of the humidity calibration standard, which has an accuracy ratio of 2:1, with respect to the accuracy specifications of the instrument.

Calibration Environment	Applicable Test Reports	Date Last Verified
Ambient Temperature 23.9 °C	Humidity	10/02/2007
Barometric Pressure 726.20 mmHg	Barometric Pressure	05/04/2007

Calibrated By

TSI Incorporated

Shipping Address 500 Cardigan Road St. Paul, MN 55126 US

Phone (800)874-2811 or (651) 490-2811 **Fax** (651) 490-3824

Industrial Hygiene and Safety Technology, Inc.
2235 Keller Way, Carrollton, TX 75006
(972) 478-7415 fax (972) 478-7615

Direct-reading Instrumentation Calibration Record

Type of Instrument Calibrated:

- ☐ CO Monitor
- ☐ CO2 Monitor
- ☒ CO/CO2 Monitor
- ☐ LEL/O2/CO/H2S/PID Combo Monitor
- ☐ Other: ______________________

Instrument Name: Q-Trak Plus

Instrument Model No. 8554 (tag # 5431)

Last Factory Service Date: 5/2008

Instrument Serial No. 8554-09011012

Type of Test:

- ☐ Response Verification (Bump Test)
- ☒ Full Calibration, w/Response Correction

Calibration Event Summary

Challenge Agent	Container or Lot ID	Exp. Date	Ref Conc.	Instrument Response	% Diff	Corr. Factor	OK?
☒ Carbon Dioxide	LTD168-mm-cm	Apr 2010	1000 ppm	997 ppm	-0.3%	+3 ppm	☑
☒ Carbon Monoxide	LTD168-mm-cm	Apr 2010	35 ppm	34.5 ppm	-1.4%	+0.5 ppm	☑
☐ ~~Hydrogen Sulfide~~							☐
☐ ~~Isobutylene~~							☐
☐ ~~Methane (LEL)~~							☐
☐ ~~Oxygen~~							☐
☐ ~~Other~~ ______							☐

Comments: Temp, RH set during factory service.

Printed Name: Derrick Johnson

Signature: [signature]

Date, Time: 6-24-08; 11:48

Include hard copy original of completed record in project file. Upload copies of completed record to online job file and online equipment record.

TSI Q-Trak, Model 8554 Specifications

CO_2
Sensor type......................................Non-Dispersive Infrared (NDIR)
Range ....0 to 5000 ppm
Accuracy ....±(3% of reading + 50 ppm) at 25°C
(Add uncertainty of ±0.36% of reading
per °C [±0.2% of reading per °F] for
change in temperature.)
Resolution ....1 ppm
Temperature Sensor
Type ....Thermistor
Range ....0 to 50°C (32 to 122°F)
Accuracy ....±0.6°C (1.0°F)
Resolution ....0.1°C (0.1°F)
Response time ....30 seconds (90% of final value, air
velocity at 2 m/s)
Display units ....°C or °F (user selectable)
Humidity
Sensor type......................................Thin-film capacitive
Range ....5 to 95% RH
Accuracy ....±3% RH (includes ±1% hysteresis.)
Resolution ....0.1% RH
Response time ....20 seconds (for 63% of final value)
CO Sensor
Sensor type......................................Electro-chemical
Range ....0 to 500 ppm
Accuracy ....±3% of reading or 3 ppm whichever is
greater [add ±0.5%/°C (0.28%/°F) away
from calibration temperature]
Resolution ....1 ppm
Response time ....<60 seconds to 90% of final value.
Power Requirements
Batteries ....Four AA-size alkaline or rechargeable
or
AC adapter ....6 VDC nominal, 300 mA [Q-TRAK Plus
monitor mates with 5.5 mm OD x
2.1 mm ID plug, center pin positive(+)]
Approximate battery life.................Up through 20 hours (alkaline).
Physical
External dimensions........................107 mm x 183 mm x 38 mm
(4.2 in. x 7.2 in x 1.7 in.)
Probe length ....31.2 mm (12.3 in.)
Probe diameter ....1.8 cm (0.75 in.)
Weight .... 0.59 kg (1.3 pounds) [with batteries]
Display..128 x 64 Graphics display module with
backlight.
Maintenance Schedule
Factory calibration ....Annually
User calibration...............................As needed
Serial Interface
Type RS-232
Baud rate...9600
Data bits 8
Stop bits 1
Handshaking ....None
Data format ....ASCII

125038

BW Technologies by Honeywell
Warranty Registration Card

Register to activate your product warranty. Complete and return by mail or fax to +1-403-273-3708.
Please complete the following information to ensure BW can better serve your needs.

The information provided on this card is confidential and for BW Technologies only; it will not be distributed to third parties.

☐ Check this box if you don't want to receive product updates and industry information.

Name: Andrew Glaser Company: IHST, Inc.
Address: 2235 Keller Way
City: Carrollton
State/Prov: TX Zip/Postal: 75006 Country: USA
Phone: (972) 478-7415 Fax: (972) 478-7615 Email: andrew@ihst.com
Industry Type: Consulting, Industrial Hygiene Date Purchased/Activated: 5/7/2008
Item Name: Micro-5 PID Model #: M5PID-XWYQ-A-P-D-B-N Serial #: SK108-004724

Check all applicable boxes for each sensor supplied with your product

☒ H_2S (Hydrogen Sulfide)
☒ CO (Carbon Monoxide)
☒ %LEL (Combustibles)
☒ O_2 (Oxygen)
☒ PID (VOC)
☐ Cl_2 (Chlorine)
☐ ClO_2 (Chlorine Dioxide)
☐ CO_2 (Carbon Dioxide)
☐ ETO (Ethylene Oxide)
☐ HCl (Hydrogen Chloride)
☐ HCN (Hydrogen Cyanide)
☐ NH_3 (Ammonia)
☐ NO (Nitric Oxide)
☐ NO_2 (Nitrogen Dioxide)
☐ O_3 (Ozone)
☐ PH_3 (Phosphine)
☐ SO_2 (Sulfur Dioxide)

Factory Calibration Certificate
Model #:M5PID-XWQY-A-P-D-B-N

Serial #:
S K 1 0 8 - 0 0 4 7 2 4

Calibration Date:
01-May-08

Factory Alarm Settings:	LOW	HIGH	TWA	STEL
H_2S:	10ppm	15ppm	10ppm	15ppm
CO:	35ppm	200ppm	35ppm	50ppm
LEL:	10.0%	20.0%		
O_2:	19.5%	23.5%		
PID:	50	100	50	100

Calibration Gas: Cyl # 2958 Cyl # 2815
Test Gas: Cyl # 2923 Cyl # 2814

Instrument Calibration:	
H_2S:	25ppm
CO:	100ppm
LEL:	50%
O_2:	20.9%
C_4H_8:	100ppm

LEL: ■ Methane ☐ Pentane ☐ Hexane ☐ Propane

338862 349945
Calibrated By Final Inspection
124285

Industrial Hygiene and Safety Technology, Inc.
2235 Keller Way, Carrollton, TX 75006
(972) 478-7415 fax (972) 478-7615

Direct-reading Instrumentation Calibration Record

Type of Instrument Calibrated:

- ☐ CO Monitor
- ☐ CO2 Monitor
- ☐ CO/CO2 Monitor
- ☒ LEL/O2/CO/H2S/PID Combo Monitor
- ☐ Other: ____________

Instrument Name: BW Micro-5 PID

Instrument Model No. M5PID-XWQY-A-P-D-B-N (tag # 5567)

Last Factory Service Date: 5/7/2008

Instrument Serial No. SK108-004724

Type of Test:

- ☐ Response Verification (Bump Test)
- ☒ Full Calibration, w/Response Correction

Calibration Event Summary

Challenge Agent	Container or Lot ID	Exp. Date	Ref Conc.	Instrument Response	% Diff	Corr. Factor	OK?
☐ Carbon Dioxide	~~FAI-421-3~~	~~5/2009~~					☐
☒ Carbon Monoxide	FAI-421-3	5/2009	100 ppm	100 ppm	0%	0ppm	☑
☒ Hydrogen Sulfide	FAI-421-3	5/2009	25ppm	25ppm	0%	0ppm	☑
☐ Isobutylene							☐
☒ Methane (LEL)	FAI-421-3	5/2009	50% LEL	50% LEL	0%	0% LEL	☑
☒ Oxygen	FAI-421-3	5/2009	18%	18.0%	0%	0% O_2	☑
☐ Other ____________							☐

Comments: PID not calibrated during this event.

Printed Name: Derrick K. Johnson

Signature: [signature]

Date, Time: 6-24-2008

Include hard copy original of completed record in project file. Upload copies of completed record to online job file and online equipment record.

Specifications

Instrument dimensions: 14.5 x 7.4 x 3.8 cm (5.7 x 2.9 x 1.5 in.)

Weight: 300 g (10.6 oz.)

Operating and Storage Conditions:
Temperature:
VOC: -10°C to +40°C (-14°F to +104°F)
Other gases: -20°C to +50°C (-4°F to +122°F)
Humidity:
O_2: 0% to 99% relative humidity (non-condensing)
VOC: 0% to 95% relative humidity (non-condensing)
Combustibles: 5% to 95% relative humidity (non-condensing)
Cl_2: 10% to 95% relative humidity (non-condensing)
HCN, ClO_2: 15% to 95% relative humidity (non-condensing)
Other gases: 15% to 90% relative humidity (non-condensing)
Pressure:
95 to 110 kPa

Alarm setpoints: May vary by region and are user-settable.

Detection range:
O_2: 0 – 30.0% vol. (0.1% vol. increments)
CO: 0 – 999 ppm (1 ppm increments)
H_2S: 0 – 100 ppm (1 ppm increments)
Combustibles: 0 – 100% LEL (1% LEL increments) or 0 – 5.0% v/v methane
PH_3: 0 – 5.0 ppm (0.1 ppm increments)
SO_2: 0 – 100 ppm (1 ppm increments)
Cl_2: 0 – 50.0 ppm (0.1 ppm increments)
NH_3: 0 – 100 ppm (1 ppm increments)
NO_2: 0 – 99.9 ppm (0.1 ppm increments)
HCN: 0 – 30.0 ppm (0.1 ppm increments)
ClO_2: 0 – 1.00 ppm (0.01 ppm increments)
O_3: 0 – 1.00 ppm (0.01 ppm increments)
VOC: 0 – 1000 ppm (1.0 ppm increments)

Sensor type:
H_2S/CO: Twin plug-in electrochemical cell
Combustibles: Plug-in catalytic bead
VOC: Photoionization detector (PID)
Other gases: Single plug-in electrochemical cell

O_2 measuring principle: Capillary controlled concentration sensor

Pump flow rate: 250 ml/min. (minimum)

Alarm conditions: TWA alarm, STEL alarm, low alarm, high alarm, multi-gas alarm, sensor alarm, pump alarm, low battery alarm, confidence beep, automatic shutdown alarm

Audible alarm: 95 dB at 1 ft. (0.3 m) variable pulsed dual beepers

Visual alarm: Dual red light-emitting diodes (LED)

Display: Alphanumeric liquid crystal display (LCD)

Backlight: Automatically activates whenever there is insufficient light to view the display (if enabled) and during alarm conditions.

Self-test: Initiated upon activation

Calibration: Automatic zero and automatic span

Appendix C. Occupant's Journal

Time	Observation
7:51	Shut door to start test.
7:55	Condensation on roof of chamber observed.
8:01	All participants with the exception of one sweating. Participant not sweating admits to using steam rooms frequently.
8:21	All participants sweating profusely.
8:29	One participant notices an increase in their heart rate
8:40	Three occupants felt increased heart rate and lightness of head.
8:50	All occupants notice breathing is more strenuous.
9:10	Start CO_2 scrubbing system utilizing 1/6th of normal chemical.
9:15	One occupant removes top of miner's overalls to increase comfort (wearing a shirt underneath).
9:18	All occupants' detect that hands and in particular fingers have swollen significantly.
9:30	All occupants notice slower thinking and fatigue.
9:35	Condensation is observed dripping from the roof of the refuge chamber.
9:40	Two occupants notice that skin is no longer sweating on hands (starting to feel clammy).
9:45	All occupants have ceased to sweat on hands, fingers have blue tinge, and wrinkled as though having been in the water for too long.
9:50	Water puddles noticed pooling on floor of refuge chamber. One occupant is perspiring so excessively it is flowing continuously from the bottom of the legs of his coveralls.
9:55	Headache reported by one occupant. Other occupants notice that his eyes are glowing (probably due to low oxygen concentration).
9:56	A decision is made that the oxygen concentration is getting too low and the heat is at dangerous levels. Test stopped.