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UNIVERSITY OF VIRGINIA
CHARLOTTESVILLE, VIRGINIA

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I. SUMMARY

On January 14-16, 1991, National Institute for Occupational Safety and Health (**NIOSH**) investigators conducted an initial survey at the University of Virginia, Charlottesville, Virginia. Specifically, NIOSH was requested to perform Wet Bulb Globe Temperature (**WBGT**) and air velocity measurements in the 5 1/2 miles of steam tunnels at the university, make recommendations regarding medical surveillance protocols for heat stress and the content of a heat stress control program, provide suggestions for methods to control heat stress, and determine the correlation between Botsball and WBGT values for the tunnels. On August 29 and 30, 1991, a NIOSH investigator returned to conduct additional measurements in order to evaluate environmental conditions in the summer months.

On January 15, 1991, WBGT and air velocity measurements were made at various locations in two portions of the steam tunnel system: the section of tunnel between Maupin House and a manhole between Thornton Hall and McCormick Road, and a portion of the tunnel beginning at Tucker Hall. Side by side measurements were made at thirty points using a Botsball thermometer. On August 30, 1991, heat stress measurements were obtained during tasks performed by steamfitters in three locations: repacking a valve at manhole 43, replacing a union by the old hospital loading dock, and installing a blow-off in the portion of the tunnel inside the steel gate.

Metabolic heat produced during the three operations was estimated using the guidelines provided in Occupational Exposure to Hot Environments, Revised Criteria 1986.[1]

The mean of the WBGT measurements made in the tunnel beginning at Maupin Hall was 84.7 °F, with a range from 76.0 to 100.8 °F WBGT. The air velocity measurements ranged from 23 to 379 feet per minute (**fpm**), with a mean air velocity of 219 fpm. The Botsball measurements made side by side with WBGT readings in this portion of the tunnel ranged from 64 to 83 °F with a mean of 74 °F Botsball. The Pearson correlation coefficient between Botsball and Wibget readings was 0.78, indicating a strong correlation. However, when the Botsball readings are converted into equivalent WBGT measurements, the Botsball underestimated measured WBGT readings in all but one instance. Therefore, the Botsball should not be used to predict WBGT measurements in the steam tunnels.

The 1-hour time-weighted average (**TWA**) WBGTs for installing a steam blow-off and replacing a union were 90.8 °F and 84.7 °F, respectively. Neither of these tasks resulted in heat stress measures in excess of the recommended exposure limits for acclimatized workers. However, tasks which expose employees to hot environments for longer periods of time would place the employees at risk of heat stress.

Most of the elements of a heat stress control program were in place at the University. The workers are allowed to schedule their own work and work at their own pace. Maintenance trucks are equipped with Botsballs and coolers of Gatorade™. Additionally, tunnel workers use the buddy system, some training is performed, and a medical surveillance program was initiated recently. Circulating-liquid cooling vests are available for the hottest job categories.

On the basis of the data obtained during this investigation, the NIOSH investigators determined that workers in the steam tunnels are at risk of harmful exposures to excessive environmental heat. Informal preventive measures, such as allowing workers to schedule routine work themselves and work at their own pace, should be supplemented by a written heat stress control program. This program should include a comprehensive survey of conditions in the steam tunnels and a determination of feasible engineering controls based upon this survey.

Keywords: SIC 8221, (Colleges, Universities, and Professional Schools) steam tunnels, heat stress, Botsball, steamfitters.

II. BACKGROUND

On January 14-16, 1991, National Institute for Occupational Safety and Health (**NIOSH**) investigators conducted an initial survey at the University of Virginia, Charlottesville, Virginia. This survey was conducted in response to an employer request for a health hazard evaluation concerning heat stress in the steam tunnels. Specifically, NIOSH was requested to perform Wet Bulb Globe Temperature (**WBGT**) and air velocity measurements in the steam tunnels, make recommendations regarding medical surveillance protocols for heat stress and the contents of a heat stress control program, provide suggestions for methods to control heat stress, and determine the correlation between Botsball and WBGT values for the tunnels. On August 29 and 30, 1991, a NIOSH investigator returned to conduct additional measurements in order to evaluate environmental conditions in the summer months.

There are approximately five and one half miles of steam tunnels at the University. These tunnels provide steam for a variety of uses, including steam tables in food service facilities, steam sterilizers in the hospital, and steam heat in buildings. Thirteen employees may be assigned to work in the steam tunnels, where they perform the maintenance and repair tasks necessary to provide steam service to University facilities.

III. INDUSTRIAL HYGIENE EVALUATION

Methods

On January 15, 1991, thirty-one WBGT measurements were made at various locations in two portions of the steam tunnel system: the section of tunnel between Maupin House and a manhole between Thornton Hall and McCormick Road, and a portion of the tunnel beginning at Tucker hall. Measurements were taken using a Reuter Stokes RSS 211D Wibget heat stress meter (Reuter Stokes, Canada). Side by side measurements were made at thirty points using a Botsball heat stress measuring device belonging to the University. Air velocity was measured using a Compuflow model 8565 thermoanemometer (Alnor Instrument Co, Skokie, IL).

Measurements were taken at each manhole and at the midway point between manholes. Distances were determined using a measuring wheel provided by the university. Air velocities were measured downstream of the point where heat stress measurements were taken, at a distance judged to be adequate to minimize the effect of flow interference caused by the personnel and instrumentation in the tunnel.

On August 30, 1991, heat stress measurements were obtained during tasks performed by steamfitters in three locations: repacking a valve at manhole no. 43, replacing a union by the old hospital loading dock, and installing a blow-off in the portion of the tunnel inside the steel gate. The valve repacking operation was cut short when it was noted that the valve was passing, making repacking unsafe. Heat stress measurements were obtained using a Reuter Stokes RSS 214 Wibget heat stress monitor (Imaging and Sensing Technology Canada, Inc, Cambridge, Ontario, Canada). Air velocity was measured using a Kurz Series 490 Mini Anemometer (Kurz Instruments Inc, Carmel Valley, CA). In addition, a Questemp°II personal heat stress monitor (Quest Electronics, Oconomowoc, WI) was used to measure aural temperature of an exposed employee via a sensor placed in the employee's ear canal. In the Questemp°II monitor the aural temperature is used as an index of core body temperature.

Metabolic heat produced during the three operations was estimated using the guidelines provided in Occupational Exposure to Hot Environments, Revised Criteria 1986.[1] When reviewing the metabolic heat production data presented in this report, it is important to note that errors in estimating metabolic rate from energy expenditure tables are reported to be as high as 30%.[1]

IV. EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to ten hours a day, forty hours a week for a working lifetime without experiencing adverse health effects. However, it is important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled to the limit set by the evaluation criterion. These combined effects are not often considered by the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are the following: 1) NIOSH Criteria Documents and Recommended Exposure Limits (**RELs**), 2) the American Conference of Governmental Industrial Hygienists' (**ACGIH**) Threshold Limit Values (**TLVs**), and 3) the U.S. Department of Labor (**OSHA**) Permissible Exposure Limits (**PELs**).[2,3,4] The OSHA PELs may be required to take into account the feasibility of controlling exposures in the various industries where the agents are found; in contrast the NIOSH RELs are based primarily on concerns relating to the prevention of occupational disease.

A time-weighted average (**TWA**) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended exposure limits or ceiling values which are intended to supplement the TWA where there are recognized health effects from high, short-term exposures.

Heat Stress

Heat stress is defined as the total net heat load on the body with contributions from environmental sources and from metabolic heat production.[5]

Both NIOSH and the ACGIH recommend the use of the WBGT in assessing hot environments. There are no OSHA exposure limits for heat stress. Three different temperature measurements are required to calculate the WBGT:

1. Natural Wet Bulb (**WB**) temperature where the thermometer bulb is kept wet, allowing evaporative cooling.
2. Dry Bulb (**DB**) temperature which is simply a thermometer reading.

3. Globe Temperature (**GT**) in which the thermometer bulb is located inside a hollow black sphere. This arrangement permits the measurement of radiant heat absorbed by the black globe.

The WBGT is calculated using the following formulae:

$$WBGT_{INDOORS} = 0.7\ (WB) + 0.3\ (GT)$$
$$WBGT_{OUTDOORS} = 0.7\ (WB) + 0.2\ (GT) + 0.1\ (DB)$$

The Botsball thermometer, formerly called the wet globe thermometer, is an instrument which combines air temperature, humidity, air velocity, and radiant heat into a single reading that can be related to human responses.
The Botsball thermometer is a hollow copper sphere that is painted black and covered with a double layer of black cloth. The cloth covering is kept wet by water seeping from an aluminum reservoir tube attached to the globe. The stem of a dial thermometer passes through a plastic tube along the centerline of the reservoir tube and into the globe.

Four factors influence the exchange of heat between the human body and the environment: (1) air temperature, (2) air velocity, (3) moisture content of the air, and (4) radiant temperature. Industrial heat problems involve a combination of these factors, which produce a working environment that may be uncomfortable or even hazardous because of an imbalance of metabolic heat production and heat loss.

The fundamental thermodynamic processes involved in heat exchange between the body and its environment may be described by the basic equation of heat balance:

$$S=M-E\pm R\pm C$$

where S = the change in body heat content (heat gain or loss);
M = metabolic heat gain associated with bodily functions and physical work; E = heat lost through evaporation of perspiration; R = heat loss or gain by radiation (infrared radiation emanating from warmer surfaces to cooler surfaces); and C=heat loss or gain through convection, the passage of a fluid (air) over a surface with the resulting gain or loss of heat. Under conditions of thermal equilibrium (essentially no heat stress), heat generated within the body by metabolism is completely dissipated to the environment and deep body or core temperature remains constant at about 98.6 °F (37 °C).

When heat loss fails to keep pace with heat gain, the body's core temperature begins to rise. Certain physiologic mechanisms begin to function in an attempt to increase heat loss from the body. First, the body attempts to radiate more heat away by dilating the blood vessels of the skin and subcutaneous tissues and diverting a large portion of the blood supply to the body's surface and extremities. An increase in circulating blood volume also occurs through the withdrawal of fluids from body tissues. The circulatory adjustments enhance heat transport from the body core to the surface. Simultaneously, the sweat glands become active, spreading fluid over the skin which removes heat from the skin surface through evaporation.

Prolonged exposure to excessive heat may cause increased irritability, lassitude, decrease in morale, increased anxiety, and inability to concentrate.

The acute physical disabilities caused by excessive heat exposure are, in order of increasing severity, the following: heat rash, heat cramps, heat exhaustion, and heat stroke.

Heat rash (prickly heat) may be caused by unrelieved exposure to hot and humid air. The openings of the sweat ducts become plugged due to the swelling of the moist keratin layer of the skin which leads to inflammation of the glands. There are tiny red vesicles (fluid filled bumps) visible in the affected area and, if the affected area is extensive, sweating can be substantially impaired. This may result not only in discomfort, but in a decreased capacity to tolerate heat.

Heat cramps may occur after prolonged exposure to heat with profuse perspiration and inadequate replacement of salt. The signs and symptoms consist of spasm and pain in the muscles of the abdomen and extremities. Albuminuria (protein in the urine) may be a transient finding.

Heat exhaustion may result from physical exertion in a hot environment when vasomotor control (regulation of muscle tone in the blood vessel walls) and cardiac output are inadequate to meet the increased demand placed upon them by peripheral vasodilation or the reduction in plasma volume due to dehydration. Signs and symptoms of heat exhaustion may include pallor, lassitude, dizziness, syncope, profuse sweating, and cool moist skin. There may or may not be mild hyperthermia.

Heat stroke is a medical emergency. An important predisposing factor is excessive physical exertion. Signs and symptoms may include dizziness, nausea, severe headache, hot dry skin due to cessation of sweating, very high body temperature (usually 106 °F [41 °C] or higher), confusion, delirium, collapse, and coma. Often circulation is compromised to the point of shock. If steps are not taken to begin cooling the body immediately, irreversible damage to the internal organs and death may ensue.[5]

Chronic heat illnesses may occur as after-effects of acute heat illnesses, or they may be brought on by working excessively hot jobs for some time without the occurrence of acute effects. Chronic after-effects associated with acute heat illnesses can include reduced heat tolerance, dysfunction of the sweat glands, reduced sweating capacity, muscle soreness, stiffness, reduced mobility, chronic heat exhaustion, and cellular damage in different organs, particularly in the central nervous system, heart, kidneys, and liver.[5]

Chronic heat illnesses not associated with acute effects of heat may fall into one of two categories, depending upon the duration of exposure. After several months of exposure to a hot working environment, chronic heat exhaustion may be experienced. Symptoms which may develop include headache, gastric pain, sleep disturbance, irritability, tachycardia, vertigo, and nausea. After many years in a hot job, cumulative effects of long-term exposure that may develop are hypertension, reduced libido, impotence, myocardial damage, nonmalignant diseases of the digestive tract, and hypochromia (decreased hemoglobin in the red blood cells).[5]

NIOSH originally defined hot environmental conditions as any combination of air temperature, humidity, radiation, and air velocity that produce a wet bulb globe temperature (WBGT) of 79°F (26°C).[6] In its revised criteria for occupational exposure to hot environments, however, NIOSH provides figures showing WBGT exposures versus duration of exposure and activity level which are not to be exceeded for work in hot environments.[1]

The revised NIOSH criteria and the ACGIH TLV present a permissible heat exposure for different work/rest regimens and work loads at different WBGT levels.[1,3] NIOSH has developed two sets of recommended exposure limits: one for unacclimatized workers, and one for acclimatized workers. The criteria for heat-acclimated workers assume that the workers are fully clothed in summer-weight clothing, are physically fit, have good nutrition, and have adequate salt and water intake. Additionally, they should not have any preexisting medical conditions that may impair the body's thermoregulatory mechanisms. For example, alcohol use and certain therapeutic and social drugs may interfere with the body's ability to tolerate heat.[1,6]

Modifications of the NIOSH and ACGIH evaluation criteria should be made if the worker or conditions do not meet the previously defined requirements. The following modifications have been suggested:[7]

1. Unacclimatized or physically unconditioned - subtract 4°F (2°C) from the permissible WBGT value for acclimatized workers.

2. Increased air velocity (above 1.5 meters per second or 300 feet per minute) add 4°F (2°C). This adjustment cannot be used for air temperatures in excess of 90 - 95°F (32-35°C). This correction does not apply if impervious clothing is worn.

3. Impervious clothing which interferes with evaporation:

   a. Body armor, impermeable jackets - subtract 4°F (2°C)
   b. Raincoats, turnout coats, full-length coats - subtract 7°F (4°C).
   c. Fully encapsulated suits - subtract 9°F (5°C).

4. Obese or elderly - subtract 2 - 4°F (1-2°C).

5. Female - subtract 1.8°F (1°C). This adjustment, which is based on a supposedly lower sweat rate for females, is questionable since the thermoregulatory differences between the sexes in groups that normally work in hot environments are complex.[8] Seasonal and work rate considerations enter into determining which sex is better adapted to work in hot environments.[9]

V. RESULTS

Twenty-seven WBGT measurements were made in the tunnel beginning at Maupin Hall. The mean for these measurements was 84.7 °F, with a range from 76.0 to 100.8 °F WBGT. Twenty-six air velocity measurements, ranging from 23 to 379 feet per minute, were made in this tunnel. The mean air velocity in this portion of the tunnel was 219 feet per minute. Twenty-five Botsball measurements were made side by side with WBGT readings in this portion of the tunnel. These measurements ranged from 64 to 83 °F Botsball, with a mean of 74 °F Botsball. Table 1 presents the environmental data for the length of tunnel entered at Maupin Hall. Table 2 presents the environmental data for a portion of the tunnel beginning at Tucker Hall. The Pearson correlation coefficient between Botsball and Wibget readings was 0.78, indicating a strong correlation. However, when the Botsball readings are converted into equivalent WBGT measurements (Table 3), the Botsball underestimated measured WBGT readings in all but one instance. Therefore, the Botsball should not be used to predict WBGT measurements in the steam tunnels.

Most of the work performed in the tunnel includes inspecting and cleaning the tunnel, lubricating expansion joints, and repacking valves. To determine whether workers exceed the NIOSH RELs, the metabolic heat generated by these tasks must be measured or estimated. The NIOSH investigators did not observe workers performing any of these tasks (the valve repacking job scheduled for August 30 was cut short due to technical difficulties). However, the data presented in Tables 1 and 2 can be used in conjunction with the procedures for measuring or estimating metabolic heat expenditure presented in Chapter 5 of the revised NIOSH heat stress criteria document to determine whether performance of these tasks places an employee above the NIOSH REL. A copy of the revised criteria document was provided to the requestor by the NIOSH investigators at the time of the initial survey, and additional copies were mailed to the requestor.

Time-weighted average WBGT measurements for two jobs observed on August 30, 1991, are presented in Table 4. Tables 5 and 6 present metabolic heat estimates for these two jobs. Because the valve repacking job was curtailed, estimates of metabolic heat were not performed. Due to the uncertainty inherent in the estimation of metabolic heat produced during the performance of various tasks, a range of estimates is reported, using the high and low values from the revised criteria document. The 1-hour TWA WBGT for installing a steam blow-off was 90.8 °F. The estimated 1-hour TWA metabolic heat produced during this activity ranged from 120 to 138 kilocalories per hour (**kcal/hr**). The 1-hour TWA WBGT for replacing a union was 84.7 °F. The 1-hour TWA estimates of metabolic heat produced during this activity ranged from 144 to 162 kcal/hr. Figure 1 is the NIOSH recommended heat-stress exposure limits for heat acclimatized workers.[1] This figure indicates that neither of these tasks resulted in heat stress measures in excess of the NIOSH RELs. Aural temperatures measured during these two tasks confirm this. The mean aural temperature measured during the installation of the steam blow-off was 98.7 °F, while the mean aural temperature measured during the replacement of a union was 98.5 °F. However, tasks which expose employees to hot environments for longer periods of time would place the employees at risk of heat stress. For example, the valve repacking job, which was estimated to take an hour and a half to complete, would have placed employees in an environment where the WBGT was measured at 109.5 °F, and where the dry bulb temperature was measured at 142.6 °F. Employees were assumed to be acclimatized because they are steamfitters assigned to tunnel work, and because the return visit occurred at the end of the summer.

VI. CONCLUSIONS

Based upon the results described earlier, employees working in the steam tunnel are at risk of heat stress, depending upon the location in the steam tunnels where work is performed, and the nature and duration of the work. From the conversations that the NIOSH investigators had with workers and management, it appeared that most of the elements of a heat stress control program were in place at the University. The workers are allowed to schedule their own work and work at their own pace. Maintenance trucks are equipped with Botsballs and coolers of Gatorade™. Additionally, tunnel workers use the buddy system, some training is performed, and a medical surveillance program has been initiated recently. Circulating-liquid cooling vests are available for the hottest job categories. However, there is little environmental exposure data to indicate which areas of the tunnels are the hottest and limited data on the metabolic heat produced during work in the tunnels. These data would assist in selecting control measures for the various tasks performed in the tunnels.

VII. RECOMMENDATIONS

1. The metabolic heat generated by each of the tasks performed in the steam tunnels should be determined.

2. A comprehensive survey of the steam tunnel system to determine environmental heat exposures should be performed. This task could be performed by a student with training in the use of the measuring device and the purpose of collecting the measurements. By mapping the location of the measurements in the tunnels, the areas which are in excess of the NIOSH RELs can be further investigated to determine feasible control measures.

3. Damaged asbestos-containing insulation must be repaired.

4. The informal heat stress control measures now in place should become the basis for a written heat stress control policy and program that designates the individual responsible for each portion of the program. The heat stress control program should address the topics listed in the NIOSH document <u>Criteria for a recommended standard....Occupational Exposure to Hot Environments</u>, including the heat alert described in the document. This document also provides medical surveillance guidelines.[1] Several copies of this document were provided to the requestor during the course of this investigation.

5. The WBGT is the accepted heat stress index. The University should purchase one or more instruments which measure WBGT. Reliable WBGT heat stress meters are currently available from several manufacturers.

6. The steam tunnels meet the NIOSH definition of a confined space.[10] According to this definition, a confined space is a space which has <u>any</u> <u>one</u> of the following characteristics:
   - limited openings for entry and exit
   - unfavorable natural ventilation
   - not designed for continuous worker occupancy

   Therefore, the university should include the tunnel system in its confined space entry program.

7. A copy of a military heat stress control document, which includes the Navy's Permissible Health Exposure Limits (PHEL) curves was provided to the requestor. These curves may be well suited to the type of work performed in the steam tunnels and could be used to determine work rest regimens as part of the University's heat stress control program.[11]

8. The revised NIOSH criteria document on heat stress presents a simple procedure for evaluating work and heat strain in which the body temperature and pulse rate are measured during recovery following a workcycle or at specified times during the workday.[1] This procedure, or other physiologic measures, such as aural temperature, may be a useful adjunct to environmental measures of heat stress to determine which tasks or locations in the steam tunnels present a potential heat stress hazard to personnel.

9. The effect of the tightly-woven polyester work uniforms worn by physical plant personnel on heat stress should be explored.

10. During the summer months, employees recover outdoors in areas that seem cool in contrast to the steam tunnels, but are in fact exceedingly hot (the high temperature on August 30 was 94 °F, dry bulb). Employees should be encouraged to seek shaded areas or air conditioned locations to facilitate recovery after exiting the steam tunnels.

VIII. REFERENCES

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IX. AUTHORSHIP AND ACKNOWLEDGEMENTS

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1. Industrial Hygienist, University of Virginia
2. Employee Representative, UVA Utilities
3. OSHA, Region III
4. Department of Labor and Industry, Commonwealth of Virginia
5. NIOSH

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1
Environmental Measurements, Tunnel Beginning at Maupin Hall
The University of Virginia, Charlottesville, Virginia
January 15, 1991
HETA 91-007

Location[1]	Time	WBGT (°F)[2]	Botsball (°F)	Air Velocity (feet/minute)
+165◎	0750	87.7	--	50
+49	0845	86.0	75	171
+50◎	0855	89.1	74	223
same, center of manhole	0900	89.3	77	35
+62	0905	79.4	71	284
+106◎	0915	83.0	73	282
+78	0925	77.5	69	379
+87◎	0935	78.8	69	371
+95	0945	89.4	70	383
+107◎	0955	83.2	75	364
+95	1005	83.2	73	327
+112◎	1015	93.9	73	230
same, near radiant pipe	----	92.4	74	---
+84◎	1045	90.7	79	185
+140	1055	93.0	81	102
+12◎	1100	100.8	83	190
+43	1110	84.8	79	223
+45◎	1120	85.8	78	105
+41	1125	81.3	75	230
+48◎	1130	83.8	76	293
+69	1140	77.1	70	279
+189	1150	82.4	75	279
+91◎	1200	82.0	74	228
+62	1205	79.0	71	279
+89◎	1210	76.4	64	38
+128	1215	76.0	70	152
+140	1230	80.5	74	23

[1]Measured in feet beginning at convertor room for Maupin Hall
[2]Readings in WBGT indoors ($WBGT_{in}$=0.7 NWB + 0.3 GT, where: WBGT = Wet Bulb Globe Temperature, NWB = Natural Wet-Bulb Temperature, and GT = Globe Temperature).
◎ = manhole.

Table 2
Environmental Measurements, Tunnel Beginning at Tucker Hall
The University of Virginia, Charlottesville, Virginia
January 15, 1991
HETA 91-007

Location[1]	Time	WBGT (°F)[2]	Botsball (°F)	Air Velocity (feet/minute)
+75	1514	82.8	75	43
+101	1525	89.7	77	52
95	1530	88.1	79	49
repeat at +101	----	90.3	84	--

[1]Measured in feet beginning at the entrance in Tucker Hall
[2]Readings in WBGT indoors ($WBGT_{in}$=0.7 NWB + 0.3 GT, where: WBGT = Wet Bulb Globe Temperature, NWB = Natural Wet-Bulb Temperature, and GT = Globe Temperature).

Table 3
Comparison of WBGT Predicted by Botsball with Measured WBGT
The University of Virginia, Charlottesville, Virginia
January 15, 1991
HETA 91-007

Botsball (°F)	Calculated WBGT[1] (°F)	Measured WBGT(°F)
75	79.3	86.0
74	78.1	89.1
77	81.7	89.3
71	74.6	79.4
73	76.9	83.0
69	72.4	77.5
69	72.4	78.8
70	73.5	89.4
75	79.3	83.2
73	76.9	83.2
73	76.9	93.9
74	78.1	92.4
79	84.3	90.7
81	87.0	93.0
83	90.8	100.8
79	84.3	84.8
78	83.0	85.8
75	79.3	81.3
76	80.5	83.8
70	73.6	77.1
75	79.3	82.4
74	78.1	82.0
71	74.6	79.0
64	67.4	76.4
70	73.6	76.0
74	78.1	80.5
75	79.3	82.8
77	81.7	89.7
79	84.3	88.1
84	91.9	90.3

1. WBGTs were calculated from Botsball readings using the equation:[12]

$$WBGT = 0.0118B^2 - 0.560B + 54.9$$

Table 4
Time-Weighted Average WBGT Measurements:
Installing a Steam Blow-off and Replacing a Union
The University of Virginia, Charlottesville, Virginia
January 15, 1991
HETA 91-007

Installing a Steam Blow-off:

$$\frac{(5\ \text{min})(93.2\ °\text{F})+(5\ \text{min})(95.0\ °\text{F})+(5\ \text{min})(95.8\ °\text{F})+(5\ \text{min})(95.3\ °\text{F}) +(5\ \text{min})(96.2\ °\text{F})+(5\ \text{min})(96.4\ °\text{F})+(5\ \text{min})(95.5°\text{F})+(25\ \text{min})(84.5\ °\text{F})}{60\ \text{min}}$$

= 90.8 °F WBGT 1 hour TWA

Replacing a Union:

$$\frac{(5\ \text{min})(94.5\ °\text{F})+(5\ \text{min})(94.9\ °\text{F})+(5\ \text{min})(95.4\ °\text{F})+(5\ \text{min})(95.6\ °\text{F})+(40\ \text{min})(79.5\ °\text{F})}{60\ \text{min}}$$

= 84.7 °F WBGT 1 hour TWA

WBGT: Wet Bulb Globe Temperature
min: Minutes

Note: All WBGT values are $WBGT_{INDOORS}$.

Table 5
Estimated Energy Cost of Installing Steam Blow-off
The University of Virginia, Charlottesville, Virginia
January 15, 1991
HETA 91-007

Time	Task Description		Estimated Energy Cost (kcal/min)*	
			Light	Heavy
0945 - 0950	Lifting pipe with assistance, standing	Both Arms	1.5	2.5
		Standing	0.6	0.6
		Basal M.R.†	1.0	1.0
0950 - 0952	Positioning bolts, standing	Both Hands	0.4	0.9
		Standing	0.6	0.6
		Basal M.R.	1.0	1.0
0952 - 0955	Tightening bolts, using both arms, standing	Both Arms	1.5	2.5
		Standing	0.6	0.6
		Basal M.R.	1.0	1.0
0955 - 0957	Positioning and tightening bolts, standing	Both Arms	1.5	2.5
		Standing	0.6	0.6
		Basal M.R.	1.0	1.0
0957 - 0958	Repositioning, holes not aligned, placing gasket, standing	Both Hands	0.4	0.9
		Standing	0.6	0.6
		Basal M.R.	1.0	1.0
0958 - 1005	Positioning and tightening bolts, standing	Both Arms	1.5	2.5
		Standing	0.6	0.6
		Basal M.R.	1.0	1.0
1005 - 1009	Walking out of tunnel	Walking	2.0	3.0
		Basal M.R.	1.0	1.0
1009 - 1045	Recovery, travel back to physical plant	Sitting	0.3	0.3
		Basal M.R.	1.0	1.0

Estimated One Hour Time-Weighted Average (**TWA**) Energy Cost:

$$TWA_{light} = \frac{(3.1\ \text{kcal/min}\cdot 5\ \text{min})+(2.0\ \text{kcal/min}\cdot 2\ \text{min})+(3.1\ \text{kcal/min}\cdot 3\ \text{min}) +(3.1\ \text{kcal/min}\cdot 2\ \text{min})+(2.0\ \text{kcal/min}\cdot 1\ \text{min})+(3.1\ \text{kcal/min}\cdot 7\ \text{min}) +(3.0\ \text{kcal/min}\cdot 4\ \text{min})+(1.3\ \text{kcal/min}\cdot 36\ \text{min})}{60\ \text{min}}$$

$$TWA_{heavy} = \frac{(4.1\ \text{kcal/min}\cdot 5\ \text{min})+(2.5\ \text{kcal/min}\cdot 2\ \text{min})+(4.1\ \text{kcal/min}\cdot 3\ \text{min}) +(4.1\ \text{kcal/min}\cdot 2\ \text{min})+(2.5\ \text{kcal/min}\cdot 1\ \text{min})+(4.1\ \text{kcal/min}\cdot 7\ \text{min}) +(4.0\ \text{kcal/min}\cdot 4\ \text{min})+(1.3\ \text{kcal/min}\cdot 36\ \text{min})}{60\ \text{min}}$$

$= 2.0 - 2.3$ kcal/min

* kilocalories per minute
† metabolic rate

Table 6
Estimated Energy Cost of Replacing a Union
The University of Virginia, Charlottesville, Virginia
January 15, 1991
HETA 91-007

Time	Task Description	Estimated Energy Cost (kcal/min)*	Light	Heavy
0845 - 0852	Using two wrenches, kneeling	Both arms	1.5	2.5
		Kneeling	2.5	2.5
		Basal M.R.†	1.0	1.0
0852 - 0853	Applying joint compound with one hand, kneeling	One hand	0.4	0.9
		Kneeling	2.5	2.5
		Basal M.R.	1.0	1.0
0853 - 0854	Using two wrenches, kneeling	Both arms	1.5	2.5
		Kneeling	2.5	2.5
		Basal M.R.	1.0	1.0
0854 - 0858	Waiting for parts, kneeling	Kneeling	2.5	2.5
		Basal M.R.	1.0	1.0
0858 - 0859	Using two wrenches, kneeling	Both arms	1.5	2.5
		Kneeling	2.5	2.5
		Basal M.R.	1.0	1.0
0859 - 0900	Open valve with one hand, check for leaks, kneeling	One hand	0.4	0.9
		Kneeling	2.5	2.5
		Basal M.R.	1.0	1.0
0900 - 0940	Recovery	Standing	0.6	0.6
		Basal M.R.	1.0	1.0
0940 - 0945	Preparing for and walking to next job	Walking	2.0	3.0
		Basal M.R.	1.0	1.0

Estimated One Hour Time-Weighted Average (**TWA**) Energy Cost:

$$TWA_{light} = \frac{(5.0\ \text{kcal/min}\cdot 7\ \text{min})+(3.9\ \text{kcal/min}\cdot 1\ \text{min})+(5.0\ \text{kcal/min}\cdot 1\ \text{min}) +(3.5\ \text{kcal/min}\cdot 4\ \text{min})+(5.0\ \text{kcal/min}\cdot 1\ \text{min})+(3.9\ \text{kcal/min}\cdot 1\ \text{min}) +(1.6\ \text{kcal/min}\cdot 40\ \text{min})+(3.0\ \text{kcal/min}\cdot 5\ \text{min})}{60\ \text{min}}$$

$$TWA_{heavy} = \frac{(6.0\ \text{kcal/min}\cdot 7\ \text{min})+(4.4\ \text{kcal/min}\cdot 1\ \text{min})+(6.0\ \text{kcal/min}\cdot 1\ \text{min}) +(3.5\ \text{kcal/min}\cdot 4\ \text{min})+(6.0\ \text{kcal/min}\cdot 1\ \text{min})+(4.4\ \text{kcal/min}\cdot 1\ \text{min}) +(1.6\ \text{kcal/min}\cdot 40\ \text{min})+(4.0\ \text{kcal/min}\cdot 5\ \text{min})}{60\ \text{min}}$$

$= 2.4 - 2.7$ kcal/min

* kilocalories per minute
† basal metabolic rate