OCCUPATIONAL EXPOSURES DURING ROUTINE ACTIVITIES IN COAL-FUELED POWER PLANTS

by

MONA JILL BIRD

(Under the direction of Dr. Phillip L. Williams)

ABSTRACT

Literature on occupational exposures in coal-fueled power plants is limited. The study evaluated respirable dust, inorganic arsenic, noise, asbestos, and heat stress. Each facility surveyed was divided into five similar exposure groups (SEGs). At each facility, 50 respirable dust, 32 arsenic, and 70 noise samples were collected, for a total of 392 air and 302 noise samples. Twenty personal heat-stress samples were taken. One air sample exceeded the occupational exposure values (OEVs). Of the 302 noise samples, 49 (16%) were equal to or greater than the OSHA 8-hour 85 dBA action level, and 9 (3%) were equal to or greater than the OSHA 8-hour 90 dBA PEL. Heat-stress monitoring indicates 26% of the 1-hour TWAs exceeded recommended heat-stress limits. Some worksites were above the ceiling values recommended by NIOSH. Four employees exceeded recommended limits for heart rate or body core temperature. Controls to better protect the employees have been recommended.

INDEX WORDS: Coal Dust, Inorganic Arsenic, Noise, Heat Stress, Asbestos, and Risk Assessment.

OCCUPATIONAL EXPOSURES DURING ROUTINE ACTIVITIES IN COAL-FUELED POWER PLANTS

by

MONA JILL BIRD

B.S.E.H., The University of Georgia, 1999

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2002

OCCUPATIONAL EXPOSURES DURING ROUTINE ACTIVITIES IN COAL-FUELED POWER PLANTS

by

MONA JILL BIRD

Approved:

Major Professor: Phillip L. Williams

Committee: Cham Dallas
David L. MacIntosh

Electronic Version Approved:

Gordhan L. Patel
Dean of the Graduate School
The University of Georgia
August 2002

To Mom and Dad:

Thank you!

ACKNOWLEDGMENTS

I would like to thank the Georgia Power Company for funding my research at their facilities. Thank you, Grover Higgins, of the Georgia Power Company, for your support during this project. I would also like to extend many thanks to the employees of the Georgia Power Plants for participating cooperatively in this study. I would like to thank my committee members who provided direction during the writing of this thesis. Thank you, Dr. Phillip Williams, Dr. David MacIntosh, and Dr. Cham Dallas; your help has been much appreciated. I would also like to thank the staff of the Environmental Health Science Department for your encouragement during my program; thank you Sandra McPeake and Regina Davis. Apryl Blair, thank you for your hard work this summer during the collection of this data. I could not have asked for a more cooperative co-worker during the project. Thanks McGinnis clan, for all your help. Last of all, I would like to thank my family. You are simply wonderful, and I appreciate all that you have done. Mom, thank you for everything.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Coal-fueled power plants have the responsibility of providing homes, businesses, and schools across the United States and world with electricity. In return, industrial hygienists have the responsibility of anticipating, recognizing, evaluating and controlling the potential health hazards to those employed by the power industry. The fundamentals of industrial hygiene were used to evaluate the potential hazards in coal-fueled power plants during routine work activities. Limited published information is available on the occupational exposures of workers in the coal-fueled power industry. Thus, a risk assessment was performed at five coal-fueled power plants of a large Southeastern power-generating company. Four coal-fueled power plants were evaluated for chemical and noise hazards, and one of the original plants and one additional plant were evaluated for heat stress.

The principle chemical hazards were inorganic arsenic, asbestos, and respirable coal dust. Inorganic arsenic and asbestos have been classified as human carcinogens by the Department of Health and Human Services (DHHS),[1, 2] Environmental Protection Agency (EPA),[3,4] American Conference of Governmental Industrial Hygienists (ACGIH),[5] and the International Agency for Research on Cancer (IARC)[6,7]. The Occupational Health and Safety Administration (OSHA) regulates occupational exposures to inorganic arsenic and asbestos because of their classification as a carcinogen.[8,9] Coal dust is regulated by OSHA in the workplace, with the exception of the mining industry, because of the potential lung disease associated with chronic overexposures to coal dust.[10] Noise, because of its potential to cause noise induced hearing loss, is also regulated by OSHA.[11] The federal government does not regulate heat stress, but several agencies have adopted heat-stress indices and recommendations because of the potentially severe health effects associated with overexposure to heat stress.

The chemical and physical hazards were evaluated because of the potential harm associated with each. The chemical agents and physical hazards were chosen based on the chemical properties, quantity, health-effects data, and past monitoring data as suggested by the "Strategy for Occupational Exposure Assessment."[12] Little published literature was found which establishes past chemical and physical exposures in coal-fueled power plants. Thus, Chapter 2 reviews the health effects associated with the hazards, and it also assesses the indices most commonly used in the industry to evaluate heat stress.

The purpose of this research was to determine the occupational exposures in coal-fueled power plants during routine activities, evaluate the results based on occupational exposure values (OEVs), and to determine if the chemical exposures were significantly different from plant to plant. Chapter 3 summarizes the results of the risk assessment for the chemical and physical hazards conducted at a total of five plants during the summer of 2001.

Previous exposure data and risk assessment data from the power-generating company were used to determine which hazards to evaluate and to determine the sample sizes required for statistical power. Once the data were collected from the coal-fueled power plants, the results were analyzed to determine the occupational exposures at each of the facilities. The data was analyzed to determine the differences between plants and to determine if exposures were in compliance with required OEVs. From the analysis, conclusions and recommendations are made in Chapter 4.

REFERENCES

1. **Agency for Toxic Substances and Disease Registry:** *Toxicological Profile for Arsenic (DHHS).* Atlanta, GA: U.S Department of Health and Human Services, Public Health Services, 2000.

2. **Agency for Toxic Substances and Disease Registry:** *Draft Toxicological Profile for Asbestos (DHHS).* Atlanta, GA: U.S Department of Health and Human Services, Public Health Services, 1999.

3. **Environmental Protection Agency: "**Integrated Risk Information System (IRIS)." [Online] *Arsenic*. http://www.epa.gov/iris/subst/index.html. (Accessed March 11, 2002).

4. **Environmental Protection Agency: "**Integrated Risk Information System (IRIS)." [Online] Asbestos. http://www.epa.gov/iris/subst/index.html. (Accessed March 11, 2002).

5. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH: ACGIH, 2001.

6. **World Health Organization:** " IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals To Humans." [Online] *Arsenic and Inorganic Compounds Vol. 2*. Available at www.193.51.164.11/htdocs/Monographs/Vol02/Arsenic.html. (Accessed April 14, 2001).

7. **World Health Organization:** "IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals To Humans." [Online] Asbestos Supplement 7. Available at www.193.51.164.11/htdocs/Monographs/Suppl7/Asbestos.html. (Accessed April 14, 2001).

8. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Inorganic Arsenic Standard (29 CFR 1910.1018)." [Online]. Available at http://www.osha.gov (Accessed April 23, 2002).

9. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** “Asbestos Standard (29 CFR 1910.1001).” [Online]. Available at http://www.osha.gov (Accessed April 23, 2002).

10. **Hogan, T.J.:** Particulates. In *Fundamental of Industrial Hygiene*, Vol. 4. Plog, B.A., Niland, J. and Quinlan, P.J. Itasca, Illinois: National Safety Council, 1996. pp. 175-196.

11. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** “Occupational Noise Exposure Standard (29 CFR 1910.95).” [Online]. Available at http://www.osha.gov (Accessed January 16, 2002).

12. **Hawkins, N.C., Norwood, S.K., and Rock, J.C. (eds.):** “A Strategy for Occupational Exposure Assessment”. Akron, Ohio: American Industrial Hygiene Association, 1991

CHAPTER 2

REVIEW OF LITERATURE

Typical hazards in coal-fueled power plants include both chemical and physical hazards. The chemical hazards of concern are inorganic arsenic, asbestos, and coal dust. The physical hazards associated most commonly with power plants are noise and heat stress. These are not all the potential hazards, but they are the hazards of the most concern. Published literature currently provides limited data on the occupational exposures in coal-fueled power plants. This literature will review each hazard, its health effects, and the occupational exposure limits set for the hazards. The heat-stress data will review the health effects and the current indices used by industrial hygienists in the field.

Inorganic Arsenic

Arsenic is an element that occurs naturally in the earth's crust and can combine with oxygen, chlorine, and sulfur to form inorganic arsenic.[1] Inorganic arsenic has been classified as a human carcinogen by the Environmental Protection Agency (EPA) based on sufficient human data. The human data showed an increase in lung-cancer death, through mainly inhalation, over several human populations.[2] The ninth report on carcinogens by the Department of Health and Human Services reports that those occupations exposed to inorganic arsenic have consistently been associated with an increased risk of cancer, especially for those employed in the mining and copper smelting industry.[3] Inorganic arsenic is a concern in power plants because of fly ash that can contain trace metals such as arsenic. Fly ash is a byproduct of coal and can be released into coal-fueled power plants through boiler leaks.

Two types of boilers are used in coal-fueled power plants: negative- pressure and positive-pressure boilers. Positive-pressure boilers have a greater pressure inside the boiler than the pressure is outside of the boiler, and they are usually found in older plants. With this greater pressure inside, boiler leaks may occur due to contracting and expanding of boilers during temperature changes. Consequently, it is often difficult to keep positive-pressure boilers from leaking. Boiler leaks may result in potential exposures in the power plants, such as fly ash which can contain inorganic arsenic.[4] Exposures to inorganic arsenic in coal-fueled power plants are more likely to occur during boiler inspections during outage-related work in which employees of the facilities must go inside boilers to work. However, there is little published literature evaluating inorganic arsenic during routine activities.

Arsenic Regulations and Occupational Exposure Limits

OSHA sets regulations for inorganic arsenic exposures in the workplace under the 29 Code of Federal Regulation standard 1910.1018.[5] OSHA has established a permissible exposure level (PEL) of 10 $\mu g/m^3$ and an action level of 5 $\mu g/m^3$ averaged over an eight-hour day.[5] The American Conference of Governmental Industrial Hygienists (ACGIH) has adopted and recommends a Threshold Limit Value (TLV) of 10 $\mu g/m^3$ for an eight-hour, time-weighted-averaged (TWA) day.[6] The National Institute of Occupational Safety and Health (NIOSH) has established a Recommended Exposure Limit (REL) of 2.0 $\mu g/m^3$ 15-minute ceiling limit for inorganic arsenic.[7]

Asbestos

Asbestos is the name given to a group of fibrous minerals, which includes amosite, chrysotile, crocidolite, tremolite, actinolite, and anthophyllite. These are naturally occurring in the environment, and because of their long, strong fibers, and heat-resistant characteristics, they have been used in manufacturing to produce many goods, especially building materials.[8]

Asbestos is used as a thermal insulating material to insulate steam lines and is often used in gaskets and gasket packing in power plants because of its great heat-resistant characteristics. It has been suggested that exposures may exceed recommended NIOSH limits during installation or removal of asbestos-containing insulation, but these exposures could be avoided if other materials were used whenever feasible.[4] No published literature was found which evaluates the exposures to asbestos in the electric power industry.

Asbestos has been classified as a human carcinogen based on the increased mortality incidence of lung cancer, mesotheliomas and gastrointestinal cancers.[8,9] These cancers in the occupationally exposed have been consistent across investigations and study populations, according to the Environmental Protection Agency's IRIS database.[9]

Asbestos is generally associated with three lung diseases in humans. These diseases are asbestosis, lung cancer, and mesothelioma.[10] Asbestosis, a chronic disease, develops when asbestos fibers are inhaled and causes non-malignant scarring of the lungs.[11] Asbestosis is found in the lungs of workers who were exposed to asbestos, but not in the lungs of the general public. Asbestosis generally will cause the person to cough, become short of breath, and can eventually lead to disability or death.[8] Lung cancer is much more likely to develop when an individual is exposed to asbestos and also smokes cigarettes.[12] Mesothelioma causes malignant tumors to cover the surface of the pleura and visceral. Tumors of this type do not occur in the general population but are closely associated with asbestos exposure.[10]

Asbestos Regulations and Occupational Exposure Levels

OSHA is responsible for setting regulations for asbestos exposures in the work place. OSHA has established a PEL of 0.1 f/cc averaged over an eight-hour workday. Employees exposed to asbestos are expected to remain below this level. If exposure is above the PEL, the employer must follow the protocol in the asbestos standard.[13] There are other groups which have established recommended asbestos exposure levels for employees in the workforce. The ACGIH has also established an 8-hour TWA of 0.1f/cc for asbestos.[6] NIOSH has established an eight-hour TWA REL of 0.1 f/cc for asbestos.[7]

Coal Dust/Silica Exposures

Respirable coal dust is another potentially harmful occupational exposure in coal-fueled power plants. Several lung-related diseases have been linked to overexposures to respirable coal dust during coal-mining operations. One such disease is coal workers' pneumoconiosis caused by the inhalation and retention of respirable coalmine dust. It is often linked to emphysema and chronic bronchitis which together can result in pulmonary impairment. Some of the lung impairment may be linked to cigarette smoking, aging, and other factors.[4] Little published literature was found that evaluates the exposure of employees to coal dust or silica at coal-fueled power plants.

Coal Dust/Silica Regulations and Occupational Exposure Levels

OSHA regulates occupational exposures to respirable coal dust outside of the mining industry. OSHA has established an eight-hour-averaged workday OSHA PEL of 2.4 mg/m^3 for all respirable dusts containing less than five percent silica (quartz). However, for dust containing greater than five percent silica, the equation 10 mg/m^3/ ($\%SiO_2$+2) is used to determine the OSHA PEL for the allowable eight-hour TWA for respirable dust during occupational exposures other than those activities in coalmines.[14] ACGIH has adopted TLVs for the respirable fractions of coal dust based on the type of coal the individual was exposed to during work activities. The TLV for anthracite coal dust is 0.4 mg/m^3 and 0.9 mg/m^3 for bituminous coal.[6]

Noise

Noise has been noted as a problem in coal-fueled power plants and because engineering controls are often not feasible, control methods in existing power plants continue to be a problem.[4] Depending upon the level and frequency of the noise, exposure duration, and susceptibility of the individual, noise-induced hearing loss may be temporary or permanent. Temporary loss of hearing may be restored if other exposures do not occur before recovery is complete. Permanent losses are irreversible and cannot be corrected surgically. Individuals with permanent noise-induced hearing loss are often capable of hearing low frequency noise but often have difficulty with higher frequencies and thus have difficulty in hearing speech.[15] Temporary hearing loss can return after the individual is removed from the noise source, and full-hearing capabilities will usually return after 14 hours away from the noise source. Permanent hearing loss will occur after chronic, long-term cumulative exposures to loud noises. This will cause damage to the cochlea and will cause an irreversible threshold shift in the hearing.[11]

Noise Regulations

Noise-induced hearing loss can be controlled by several methods, but often engineering and administrative controls are not feasible. Thus industrial operations must resort to using personal hearing protection. OSHA, under the standard 29 CFR 1910.95, regulates work place noise exposures. OSHA has established an 8-hour TWA PEL of 90 dBA (range 90-130 dBA).[16] In 1983, the hearing-conservation amendment to the 1910.95 OSHA noise standard requires that employers administer an effective hearing-conservation program for employees exceeding an 8-hour TWA of 85 dBA (range 80-130 dBA).[17] This program was implemented to help prevent noise-induced hearing loss and requires employers to implement a monitoring program, start an audiometric testing program, provide hearing protection, start a training program, and maintain records of monitoring, training, and audiometric testing.[16]

Heat Stress and Strain

Heat strain can be best defined as the body's physiological response to heat stress.[18-20] Heat strain can cause a rise in body temperature, fainting or fatigue, or increased thirst.[21] The human body must maintain a deep body core temperature of $37^{o}C \pm 1^{o}C$ in order to maintain normal bodily functions. The body is able to maintain itself within this narrow range by physiological adjustments that allow heat exchange between the body and the ambient environment.[22,20] The following equation is used in literature to describe this phenomenon that allows the heat balance between the body and the environment to remain within this very narrow range.[11,20-25]

$$S = M + C + R + E$$

S represents the heat-storage rate in the body. M represents the metabolic rate, C is the convective heat exchange rate, R is the rate of radiant heat exchange, and E is always negative and is the rate of evaporative heat loss.[11] Convection is the heat dissipated at a rate equal to the heat exchange between the skin of an individual and the air temperature surrounding the skin. The movement of the air velocity over the skin will also play an important role in this relationship. When the ambient temperature is greater than the skin temperature, the body will gain heat from the surrounding areas by convection, but when the temperature is less than the skin temperature, the body can lose heat.[25,26] Radiation will have an effect on the body whenever the surroundings (ex., walls, furnaces, etc.) are above the skin temperature.[25] This heat balance equation is used by several indices to establish the effect that ambient conditions of the environment, work demand, and clothing place on the employee working in heat-stress environments.[11] The body must make these physiological adjustments, which will generally decrease the effects associated with the hot environment.

The major adaptive mechanisms of the body are peripheral blood circulation and sweating.[25,26] The body is able to increase the flow of the blood to the surface of the skin as the temperature of the body increases. This increase of blood is brought from the center of the body to the surface in order to dissipate heat to the environment by convection and radiation.[19,20] This increase in blood flow to the skin's surface is at the expense of the circulatory system and other internal organs and increases the possibility of heat-strain disorders if excessive.[25] Sweating is also an adaptive mechanism that is initiated when evaporative cooling is required. The sweat will evaporate from the skin as long as the conditions are not excessively humid. This adaptive mechanism will only work if evaporation occurs. Sweating also places strain on the body because it causes dehydration of the body if water is not replaced. Decreased blood volume will occur when there is not enough water to support blood flow, and thus the cardiovascular system must work harder to bring blood to the surface for cooling the body.(27) Metabolic heat is also a major contributor to the heat balance equation and will affect the physiological mechanisms of the body if metabolic rate is excessive under elevated temperature.

Human Health Effects

When the body is unable to maintain itself within the narrow range that is required, the effects on the body will range from minor consequences to potential death. The following section will address the effects associated with exposure to elevated temperatures in which the body cannot properly adjust to the changes. These health effects are well documented in literature and will only briefly be evaluated.

Heat Stroke

A heat stroke is a medically urgent situation that results when the heat-balance mechanism malfunctions. This results in a cessation of sweating in most cases, and the body's core temperature begins to climb.(28,19) The body's rectal temperature will usually be in excess of 40.5°C.(28,19,29,30) Once the body core temperature becomes high enough to damage the hypothalamic temperature-control centers, the body's temperature will continue to increase at a higher rate due to the shutdown of the heat-loss mechanism.(31) The symptoms of over exposure to heat may include the absence of sweating, but this is not always the case.(30) Treatment that halts the rise in body temperature is not always successful in preventing death. The mortality rate can still be high, and if death does not occur, survivors will often be disabled in some capacity due to the high, irreversible internal heat damage.[31]

Heat Exhaustion

Heat exhaustion is the result of the overtaxing of the heat-loss mechanism.[31] It results when body fluids and electrolytes are depleted. If symptoms are recognized and treated promptly, the more severe disorder of heat stroke can be prevented.[31,20] The symptoms of heat exhaustion include profuse sweating, headache, tingling sensations in the extremities, paling skin, vertigo, and thirst.[19,20] Fainting may occur, and body core temperature may be slightly elevated.[20,31] Water loss of greater than 1 percent body weight will reduce the blood volume. This loss of plasma will cause a decrease in the cardiovascular system's ability to respond to work demand and thermoregulation. As dehydration increases, the effect will become greater and symptoms will become apparent. Rehydration and rest of the individual will usually result in immediate recovery in mild cases. In more severe cases, intravenous fluid replacement may be necessary.[18]

Heat Cramps

Heat cramps are common when job activities require laborious work, but the symptoms are less severe and life threatening than those associated with heat stroke and heat exhaustion. Cramps usually occur in the muscle primarily used during the work activity, but they occur most frequently in the extremities, back and abdomen. They are usually very painful and are the result of salt loss through sweating.[18,22] Cramps are usually alleviated with rest, intake of water, and by replacing the lost electrolytes.[22]

Heat Syncope

Heat syncope may cause decreased consciousness or fainting during heat stress. More often than not, it occurs in those who are unacclimatized to the heat and is usually the result of low blood pressure that is caused by a sudden change in posture or by peripheral vasodilatation which allows blood to pool in the extremities.[18,30] To prevent syncope, work activities should involve occasional movement of the extremities. Individuals who experience syncope must be moved to a cooler area and should remain in a lying position until stable.[30]

Heat-Stress Indices

To determine the effects that environmental conditions have on man, heat stress indices have been developed. The indices typically require five readings to make such evaluations. They include: air temperature, wet-bulb temperature, natural wet-bulb temperature, air velocity and the globe temperature.[24] For work in hot environments, there are six minimum requirements for an index to have industrial applications. The six requirements are as follow: (1) Feasibility and accuracy must be proven (2) All important factors must be considered (environmental conditions, workload, clothing, etc.) (3) Measurements and calculations should be simple (4) Measurements should reflect the workers' true exposures but should not interfere with their work performance (5) Limits must be supported by increased risk to health (6) Index should be applicable under a wide range of environmental and metabolic conditions.[22,32] The literature presented will review the most common indices and heat-stress recommendations used in the industrial hygiene field today.

Effective Temperature and Corrected Effective Temperature

The effective temperature (ET) was the first heat-stress index to be developed. [33] The index was based on thermal sensation and was developed in 1923 by Houghten and Yagloglou.[34] This measurement used the wet bulb temperature, dry bulb temperature, and air velocity to determine the estimated ET at different environmental conditions. Test subjects were exposed to several chambers. Each chamber had varying environmental conditions, and the subject would be asked to judge when the sense of warmth in the two chambers were equal. Thus, the ET was based on sense reaction and not air temperatures.[34] The index, when originally developed, did not incorporate the effects of radiant heat. As research developed, a correction was made to the ET to allow for radiant heat effects. This became known as the corrected effective temperature (CET). The limitations of both the ET and CET are that the indices do not account for clothing or workload adjustments.[33] For the purpose of this research, the ET and CET will not be used because of the limitations that are placed on the indices due to the lack of clothing and workload adjustments.

Wet Bulb Globe Temperature (WBGT)

Yaglou and Minard developed the wet bulb globe temperature (WBGT) from a new set of data to control heat casualties at military training centers. The purpose of their research was to control and prevent heat injuries at military centers and to develop safe limits for their work conditions.[33,35] The WBGT combines the effect of four environmental components which are air temperature, humidity, air velocity, and radiation. These components are measured using the dry bulb (T_{db}), natural wet bulb (T_{nwb}), and globe (T_g) temperatures. Several equations have been developed to determine the WBGT for an area, but two equations are predominantly used. The following equations are the most commonly used:

$$WBGT_{indoors} = 0.7\ T_{nwb} + 0.3\ T_g \text{ (no solar load)}$$

$$WBGT_{outdoors} = 0.7\ T_{nwb} + 0.2\ T_g + 0.1\ T_{db} \text{ (solar load present).}$$

The development of the WBGT was based on an algebraic approximation of the ET.[18,36] The WBGT, developed to prevent heat injuries, was used to establish limits in a military camp in 1956, and as a result, the camp's mean heat incident rate dropped considerably in the next four years. The new WBGT method was easier to use to implement the limits at the camps than previously-used methods which required the measurement of air velocity.[37,38]

WBGT analysis, using recommendations by ACGIH and NIOSH, was used to evaluate heat exposure in an aluminum smelter. Work areas were found to be above recommended values. The recommendations for WBGTs were used to implement controls that allowed a decrease in reportable heat injuries at the smelter.[39]

Development of WBGT recommendations

In 1967, the World Health Organization (WHO) met to discuss the issue of heat stress, and they determined that the indices currently in use had inadequacies that made the set upper limits for the indices questionable. The WHO suggested that further research was needed and that a better index should be used to indicate the physiological strain of heat stress on individuals.[40] Dukes-Dobos and Henschel evaluated the heat-stress indices based on the criteria required for a heat-stress index to be applicable in industry. The WBGT was determined to meet all the requirements and was the easiest of all indices to use, and calculations were simple.[32]

The development of the WBGT recommendations stemmed from research of Lind. Lind's research set thermal environmental limits for everyday work based on the physiological assessment of test subjects. Rectal temperatures were evaluated to determine the environmental conditions and workloads an individual could endure before the rectal temperature began to increase. From the research, Lind made recommendations for the upper limits at three different work rates.(41) In 1967, WHO adopted 38^{o}C as the recommended rectal temperature that should not be exceeded during prolonged daily exposures for individuals performing heavy work.(40) Lind defined the prescriptive zones as the temperature range that allowed a test subject's rectal temperature to remain stable, and the upper prescriptive limit zone (UPLZ) is the upper temperature at which the rectal temperature will begin to increase at a set workload. Lind later tested additional workers to determine if individual variations affected the established upper limits for the workers. His research concluded that individual variations did not affect the prescriptive zone of two environmental conditions, but slight corrections were required for the UPLZ in order to protect the majority of the population.(42) Lind's research was extended to determine if there are differences between continuous work at light workloads and intermittent work at heavier workloads with longer rest breaks. It was demonstrated that the physiological responses were similar.(43)

From this research, Dukes-Dobos and Henschel conclude that 8-hour TWAs are not appropriate because exposures greater than one hour could cause the body to accumulate enough heat to cause a heat disorder. Therefore, for continuous work, a 1-hour TWA should be calculated, and for work where rest pauses are taken every 15 minutes, a 2-hour TWA was recommended.[32] Due to the continued research and the heat-stress index requirements for use in the industry as required by NIOSH, the WBGT has been recognized as the recommended standard index for heat stress by NIOSH.[22] NIOSH,[22] ACGIH,[44] OSHA,[28] and the ISO,[45] have recommended the WBGT as the standard index and have established recommended threshold limits for the WBGTs at various workloads.[33]

<u>WBGT Recommendations</u>

NIOSH/TLVs

NIOSH recognizes that not all workers are acclimated to hot environments, and as a result, they have established curves that combine the WBGTs and metabolic workloads for both acclimated and non-acclimated individuals. The non-acclimated curves are called the NIOSH Recommended Alert Limits (RALs) and are established to prevent the increased risk of acute adverse health effects. The heat-acclimated curves are called the NIOSH Recommended Exposure Limits (RELs) that individuals can be expected to encounter without adverse health effects. The RALs and RELs are based on a 1-hour TWA for the WBGTs and the worker’s metabolic rate. These levels have been established so that equilibrium in the human body can be maintained. NIOSH has also established ceiling values for activities that require excursion into hot environments. The ceiling values are related to the WBGT of the environment and the metabolic rate of the worker. NIOSH has established that the ceiling values should not be exceeded unless adequate heat-protective clothing and equipment are used. The ceiling values were established by using the general heat-balance equation presented in the literature.[22]

The current ACGIH TLVs are the revised NIOSH 1986 RELs and RALs. Like the RELs and RALs, the TLVs are presented for both the acclimated and non-acclimated worker.[18] Both the NIOSH and ACGIH values recognize that workers do not generally work continuously in a given hour, and as a result, work/rest regimens were developed for 25, 50, 75, and 100 percent workloads. The recommendations assume that rest and work occur within the same area, but time-weighted averages are allowed for both WBGTs and workloads when workload or when work/rest areas change within the hour.[18]

ISO-WBGT Recommendations

The International Standardizations Organization (ISO) standard 7243 uses the WBGT to estimate the heat stress on workers. The WBGT was chosen because its simplicity would be beneficial in industry. As with the other recommendations, the standard is based on a 1-hour-time-weighted WBGT for a normally-clothed, physically-fit, standard-sized man in good health.[33,45] The standard provides a reference table for continuous work and guidance curves for work/rest regimens. The main difference between this recommendation and others is that at heavy and very heavy workloads the reference value is higher if adequate air movement is present. Also, this method requires that foot, abdomen, and head WBGT measurements be taken if the environmental conditions are not uniform. A weighted WBGT should be made giving equal weighting to the feet and head, and the abdomen should be weighted twice.[45] The main difference between this recommendation and the other WBGT recommendations is that the metabolic rate ranges vary slightly.

OSHA

OSHA makes recommendation for heat stress in the OSHA technical manual Chapter 4.[28] This is only a recommendation. No standard has been established to evaluate heat exposures in industry. The recommendations are based on the 1992 TLVs recommended by ACGIH.[44] The OSHA values apply to physically-fit men who are acclimated, fully clothed, and hydrated. The limits are established so that body core temperature does not exceed 38°C. The recommendations include work/rest regimens and establish three workloads. The main difference between this recommendation and others is the difference of the workloads. The workloads as mentioned above are the same as those for the TLVs established in 1992, but the workloads for the current 2001 TLVs and NIOSH values have been modified slightly. The WBGTs for the work categories have also changed slightly; in most cases less than 0.5°C.[6,28]

Heat Stress Index (HSI)

Belding and Hatch developed the Heat Stress Index (HSI) as a means to evaluate heat stress in terms of physiological strain, and the formula is as follows:

$$E_{req} = M + R + C$$

E_{req} equals the required evaporative heat loss in BTU/hr. The amount of heat exchange that can take place by evaporative cooling depends on the velocity of the air blowing over skin wetted with sweat and of the pressure of water vapor in the air.[21,24] M is the bodily heat production from metabolism, R is the radiation gain by the body, and C is convective heat gain. M is at all times positive, and thus to maintain thermal equilibrium in the body, R + C must be negative by equivalent amounts.

The development of the heat stress index is based on the effect of heat stress on the body to produce strain. The first primary strain on the body is marked by an increase of blood circulating to the skin surface to be cooled. As a result, a second strain can be seen by an increased heart rate. However, the basis for the HSI as proposed by Belding and Hatch is the second primary strain of sweat production and its evaporation. The body's ability to be cooled by the evaporative effect of the sweat from the body plays an important role in evaluating physiological response. The Belding and Hatch method has several fixed components in the equations. It assumes the surface area of the individual is 20 square feet, and it assumes the skin temperature is 35^{o}C, which is more closely associated with moderate stress.(21)

In developing the HSI, several assumptions were made. They include the following: (1) sweat rate is an appropriate index for overall heat strain (2) sweating is proportional to imposed heat stress and (3) heat strain can be represented in terms of heat stress. The HSI is designed as a standard for a young man of average physique and fitness and who is acclimatized to heat. This index is based on the average sweating capacities of an average-sized man. Belding and Hatch used the assumptions above to calculate an index of strain for the work situation by using E_{req}/E_{max} x 100. An index of 10-30 is considered moderate heat stress at which almost all of the working population could work. An index of 40-60 is considered severe heat stress but which a majority of the population could endure. Indexes of 70-100 are considered very severe heat stress that may impair physical ability during the work but will not generally cause heat strain effects to linger after exposure. Indexes above 100 indicate that heat balance cannot be maintained, and prolonged exposure may not be acceptable.(21) From the information, the maximum allowable exposure time for a single exposure can be calculated. The information will also allow the minimum allowable time for recovery in a cooler environment to be calculated.(21) Belding reported adjustments to the equations used to derive radiation, convection and E_{max}. The adjustments included equations for estimating effects on nude and clothed individuals.(36)

Limitations

Several limitations have been placed on the HSI index. These limitations make it less useful for predicting physiological strain in an individual. Research in gold mines indicates the index underestimates the cooling power of the mines by approximately 40% when compared to other indices. The HSI was also found to underestimate the convection exchange and evaporative exchange.(46) Humphreys addresses the application of heat stress indices in industries, specifically the HSI. Humphreys notes that the index often permitted very short allowable exposure times which hinders productivity. He suggests that several components of the index may decrease the exposure time unnecessarily, and interpretation should not always be taken literally.(47)

One problem with such indices is the assumption that a worker is an averaged-sized man, which is not always the case. Error is usually present in estimation of the metabolic rate; overestimation of the metabolic rate usually decreases the allowed exposure time. Metabolic rate accuracy is hard to achieve unless work is performed in a laboratory. Error can also be associated with this index because the index assumes that all evaporative heat exchange is effective in cooling the body which is not the case if clothing is present. Also, such indices assume uniform heat transfer during the entire exposure period, but convective and radiant heat exchange will usually not be uniform if the individual is moving from a cooler work or break area. This could result in lag time before the body begins warming, and so allowable exposure time may be increased.[47] The HSI does not correctly differentiate between hot-dry and hot-humid conditions and is not applicable at very high heat-stress conditions.[22] Research also indicates that the index may overestimate the cooling effects of wind, and overestimates the warming effect of humidity.[48] Due to limitations placed on this index, it may not be a good indicator of physiological strain. However, the index is useful in evaluating the corrective measures that could be used to control the heat-stress environment.[20]

ISO 7933 – Required Sweat Rate

The ISO standard 7933, referred to as the required sweat rate (SR_{req}), was developed as a detailed analysis of hot working conditions and is intended for use when reference values in the ISO 7243 are exceeded.[23] ACGIH recommends this analysis when the TLVs are exceeded or when workdays are extended beyond eight hours.[6,18] The standard is intended for use in conditions that may cause an elevated core temperature or excessive water loss.[23] The analysis is used to calculate the heat balance of the human body and the sweat rate required (SR_{req}) to maintain it in equilibrium.[49] The ISO 7933 is an improved development of the HSI.[21,50] The SR_{req} is an improvement to the HSI, as noted in the TLV documentation, in several ways which include: (1) recognition that sweat evaporation efficiency is lost at higher sweat rates (2) limits exposures based on the maximum rate of cooling achievable after adjusting for sweating efficiency (3) limits exposures based on risk of dehydration (4) accounts for clothing beyond a regular work uniform.[18] The standard was developed to evaluate situations that could potentially elevate core temperatures or cause an excessive loss of water, to determine the controls that could be implemented to reduce the effects of the heat, and to determine the maximum allowable exposure time in order to limit heat strain.(23)

The analysis requires the general measurements and components of other indices, but the calculations are much more complex. Thus, for all practical purposes, the analysis should not be performed by hand but by a computer program developed by the ISO. The complexity of the analysis makes it less practical for use in industry, and the program is not readily available. Other limitations have been placed on this analysis. Research suggests that this analysis has flaws that should be improved upon for future use. Malchaire et al. have reviewed the ISO 7933 standard and found considerable improvements could be made. The researchers' evaluations concluded that 14 revisions should be made to improve the quality and accuracy of the standard. Thus, the required sweat rate index was renamed as the predicted heat strain. The new predicted heat strain model was compared to laboratory and field studies, and the model was found to be more reliable than the ISO 7933 standard.(51,52)

Other research concludes that the ISO 7933 standard should not be used when radiant heat temperatures are greater than the air temperature due to the overestimation of the required sweat rates.(53) Parson et al. have proposed corrections to the ISO 7933 method to account for wind and human movement and thermal clothing properties. These adjustments would allow for increased exposure times.(54) Parson also states that the ISO 7933 analysis is not appropriate without modification if exposure time is short (less than 30 minutes) or if special clothing is required. Physiological monitoring is then suggested.(50) This evaluation shows that heat-stress indices are changing continually, and improvements are always being sought. The literature strongly implies that changes should be made to increase the accuracy and usefulness of this index.

Electric Power Research Institute (EPRI)

Often industrial jobs, such as work around boilers or emergency work, may require employees to work in very hot conditions for a period of time. In such cases, it may not be feasible to assign a work/rest schedule, but it may be more appropriate to evaluate the work area based on ceiling values. In 1991, EPRI developed a heat-stress management program for power plants that helped establish recommended stay times for the electric power industry.(27,33) The program recommends a stay time for an individual based on clothing and workload. The workloads have stay-time ranges with the lower end recommended as the more conservative stay time, and the higher end of the range recommended for more-fit individuals.(33) The available stay times are presented based on the WBGT temperatures between 20 and 50^{o}C, three metabolic work levels, and four types of clothing. The EPRI stay time limits assume that the worker is heat acclimatized, physically fit, free of illness, adequately hydrated, and a member of the general working population.(55)

A study by Ramsey evaluated the threshold recommended values, such as the NIOSH REL, against the ceiling values of other recommended values, such as EPRI, and found that threshold limits allowed much shorter exposure times than those for ceiling value recommendations. This variation is mainly due to the differences between ceiling limits and threshold values. The threshold values such as the recommended NIOSH REL, according to Ramsey, are based on the idea that heat storage starts increasing at the environmental and metabolic heat levels recommended and that work practice and controls should be initiated beyond this point. However, the ceiling values such as the EPRI values are more appropriate to use when protective practices and controls are in place.[55] However, the EPRI programs not only have a table of recommended stay times, but they have developed a program called heat exchange analysis (HEXAN) which allows the dry bulb, psychrometric wet bulb, natural wet bulb, globe temperature, air velocity, clothing, metabolic rate and acclimation of the worker and work area parameters to be entered into a database. The program will recommend stay time (or action times) for that work area based on the provided information. This method accounts for the heat exchange between the body and the environment by metabolism, radiation, convection, and evaporation. The program will use the heat balance equation to determine the amount of required heat loss by sweat evaporation (E_{req}) to maintain the body in equilibrium. The computer program will then determine the maximum evaporation (E_{max}) possible based on the clothing and the ability of the ambient air to absorb water vapor. If E_{req} is greater than E_{max}, then the body will begin storing heat. If heat storage occurs, the system will use the heat storage rate and the maximum permissible storage that the employee can tolerate before the body core temperature becomes too high to determine the action time or the amount of time the worker can work before his body temperature rises. This system is useful because changes can be made to the system that would allow those responsible for controlling heat in the environment to determine what would happen if the metabolic rate, air velocity, clothing, etc. were changed.[27] Thus, the system could be used to determine the type of controls that would work best to decrease heat stress in the work area.

The EPRI heat-exchange analysis was based on the International Standardizations Organization (ISO) standard 7933. However, two major changes were made to the ISO 7933 method. They include the extension of clothing to include those typically used in nuclear power plants and other industries, and a less conservative criterion was used in calculating the action time. The ISO 7933 standard allows for an increase of 0.8^{o}C in the core temperature, but the EPRI approach in determining the action time allows an increase of 1.2^{o}C. This approach is deemed appropriate due to the program's requirements for proper training of individuals about heat stress and implementing the practice of self-determination. Employees should be allowed to break if they detect heat strain in themselves or other co-workers. The non-conservative approach to heat stress is not appropriate if such measures are not in place.[27] After approaching the action time limit, employees should be allowed to recover in a cooler area. If an employee must work in the area longer than the recommended action time for that area, then countermeasures are required for the work area for that particular work activity.[27]

The initial steps of this program are to identify heat-stress jobs, the locations, approximate time required for the job, and the status of the worker's acclimation. Next, employee clothing and metabolic rates should be evaluated, and environmental conditions of the work area should be determined. From the information gathered, the action time can be determined by simply entering the data into the HEXAN program developed by EPRI. The program will give a recommended action time and recommendations at the level of heat stress indicated. For example, personal protection may be required if going beyond the recommended action time, and the program will make recommendation as to how to reduce the heat stress and increase the action time.

Exceeded action times should be addressed by implementing job-specific countermeasures, which can include engineering, administrative, and personal protections. These measures will either decrease the heat stress of the environment, or they will allow the employee to work for longer durations without increasing his potential for heat strain. Examples of the engineering controls can be metabolic rate, air temperature and humidity, air velocity and radiant heat. Administrative controls may include personal monitoring, check times, recovery allowance and work/rest cycles, better scheduling of hot work, change in clothing requirements, and the implementation of buddy systems. Personal protection may include circulating air systems, ice-cooling garments, circulating-liquid systems, and reflective clothing.(27) EPRI recommended actions times are suitable only for those industries requiring work in hot areas and where work/rest regimens are not always feasible if productivity is required. This system allows employees to work in hot environments, but only if self-determination and training are implemented along with the less conservative action times.

Physiological Analysis

The recommendations of the heat-stress indices are useful in evaluating heat stress of work environments. The recommendations are designed with the intent of protecting the most heat-intolerant individuals. However, most workers are capable of working beyond the recommended stay times due to individual variations. The protectiveness of the recommendations curtails productivity in the workplace, and the only remedy to the dilemma is to increase the allowable exposure times.(56) OSHA recommends that personal monitoring be performed when work environments impose an increased risk of heat stress. Personal monitoring suggestions include heart rate recovery checks, oral temperature measurements, or measurement of body water loss. It recommends that an oral temperature of 37.6°C or greater should result in decreasing the next work cycle by one-third. It also recommends that the total bodyweight loss for the day should not exceed 1.5%, and fluids should be increased if exceeded.[28]

The ACGIH also makes recommendations for physiological evaluation. The recommendations are for a sustained heart rate in excess of 180 bpm (beats per minute) minus the worker's age; a body core temperature of 38.5°C or greater for acclimated individuals or 38°C for non-acclimated individuals; a 110 bpm recovery heart rate at one minute after peak work effort; and work should be discontinued if symptoms of nausea, fatigue, dizziness, or lightheadedness occur. Sustained peak heart rate can be used as an index of physiological strain for high-level exposures to heat stress.[6] Core temperature values have been used as an indicator of heat stress, and the WHO, in 1969, advised that deep body temperature should not exceed 38°C for extended daily exposures for heavy work. They also stated that high rectal temperatures, where deep body temperature is continually monitored, in itself did not provide sufficient reason for eliminating exposures unless the deep body temperature reaches 39°C.[40]

Research has been conducted in aluminum smelters to evaluate the impact of working in areas above the TLVs. Oral temperature and averages heart rates indicated little to no heat strain, but recovery heart rates indicated physiological strain. Thus, conducting physiological measurements, especially for WBGTs above the recommended values, is useful in determining the level of strain.[57]

Individual Variations

Although heat stress limits have been established to protect the majority of the population, there are personal factors that cause individual variations in response to heat. All the variations are well documented in literature and will only be mentioned as an issue that should be considered when determining the heat tolerance of individuals. The personal variation factors include age, obesity, hydration, and prescription drug usage, gender, and heat acclimation. Clothing may play an important role in evaluation, especially if special clothing is required.(18)

CONCLUSION/SUMMARY

Due to the potential health hazards associated with the chemical and physical hazards presented, the quantity of the potential hazards, the number of employees potentially exposed, and the limited data available in published literature or through the power-generating company, the study presented in Chapter 3 was conducted. The study presents the results and makes recommendations for improvements for workers at power-generating facilities.

REFERENCES

1. **Agency for Toxic Substances and Disease Registry (ATSDR):** "ToxFAQs™ ." [Online] *Arsenic*. Available at http://www.atsdr.cdc.gov/ (Accessed March 11, 2002).

2. **Environmental Protection Agency: "**Integrated Risk Information System (IRIS)." [Online] *Arsenic*. Available at http://www.epa.gov/iris/subst/ (Accessed March 11, 2002).

3. **U.S Department of Health and Human Services**: 9th Report on Carcinogens for Revision 2001 [Online]. *Inorganic Arsenic Compounds*. Available at http://ehp.niehs.nih.gov/roc/toc9.htm#search (Accessed March 11, 2002).

4. **Bridbord, K., J. Costello, J. Gamble, D. Groce, M. Hutchison, W. Jones, J. Merchant, C. Ortmeyer, R. Reger, W. Wagner:** Occupational Safety and Health Implications of Increased Coal Utilization. *Environ Health Perspect*. 33:285-302 (1979)

5. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Inorganic Arsenic Standard (29 CFR 1910.1018)." [Online] Available at http://www.osha.gov (Accessed August 7, 2001).

6. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. Cincinnati, OH: ACGIH, 2001.

7. **National Institute for Occupational Safety and Health (NIOSH):** Recommendations for Occupational Safety and Health (DHHS (NIOSH) 92-100). Washington, D.C: Government Printing Office, 1992.

8. **Agency for Toxic Substances and Disease Registry (ATSDR):** "ToxFAQs™." [Online] *Asbestos*. Available at http://www.atsdr.cdc.gov/ (Accessed March 11, 2002).

9. **Environmental Protection Agency: "**Integrated Risk Information System (IRIS)." [Online] *Asbestos*. Available at www.epa.gov/iris/subst/ (Accessed March 11, 2002).

10. **Witschi, H. R., J.A. Last:** Toxic Response of Respiratory System. In *Casarett and Coull's Toxicology: The Basis Science of Poisons.* 5th ed. C.D. Klaassen. New York: McGraw-Hill, 1996. pp 443-462.

11. **Hogan, T.J.:** Particulates. In *Fundamentals of Industrial Hygiene.* 4th ed. B.A. Plog, J. Niland, P.J. Quinlan. Itasca, Illinois: National Safety Council, 1996 pp. 175-196.

12. **Selikoff, I.J., E.C. Hammond, and J. Churg:** Asbestos Exposure, Smoking and Neoplasia. *J. Am. Med. Assoc.* 204:106-112 (1968) Cited in *Basic Toxicology: Fundamentals, Target Organs, and Risk Assessment.* Washington, D.C.: Taylor and Francis, 1996.

13. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Asbestos Standard (29 CFR 1910.1001)." [Online]. Available at http://www.osha.gov (Accessed April 23, 2002).

14. **Occupational Safety and Heath Administration (OSHA), U.S. Department of Labor:** *"1910.1000 (Tables Z-1, Z-2, and Z-3), Table Z-3 Mineral Dusts."* [Online] Available at http://www.osha.gov (Accessed April 24, 2002).

15. **Michael, P.L.:** Industrial Noise and Conservation of Hearing. In *Patty's Industrial Hygiene and Toxicology Vol. 1 Part A.* 4th ed. G.D. Clayton, F.E. Clayton. New York: John Wiley and Sons, Inc., 1991. pp. 937-1039.

16. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Occupational Noise Exposure Standard (29 CFR 1910.95)." [Online]. Available at http://www.osha.gov (Accessed January 16, 2002).

17. **Occupational Health and Safety Administration**: "OSHA Technical Manual." [Online] *Chapter 5: Noise Measurements*. Available at http://www.osha-slc.gov/dts/osta/otm/otm_toc.html (Accessed April 6, 2002).

18. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Documentation of the Threshold Limit Values For Physical Agents*, 7th Ed. Cincinnati, Ohio: ACGIH, 2001.

19. **Triservice Publication:** *Occupational and Environmental Health: Prevention, Treatment and Control of Heat Injury* (TB MED 507/NAVMED P-5052-5/AFP 160-1). Washington, D.C: Departments of the Army, the Navy, and the Air Force, 1980.

20. **Ramsey, J.D., T.E. Bernard:** Heat Stress. In *Patty's Industrial Hygiene*, 5th Ed, Vol. 2. R.L. Harris. New York: John Wiley and Sons, Inc., 2000. pp.925-984.

21. **Belding H.S., T.F. Hatch:** Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains. *Heat/Piping/Air Cond*. 27: 129-136 (1955).

22. **National Institute for Occupational Safety and Health (NIOSH):** *Criteria for a Recommended Standard. Occupational Exposure to Hot Environment* (DHHS [NIOSH] 86-113). Washington, D.C: U.S. Government Printing Office, 1986.

23. **International Organization for Standardization (ISO):** *Hot Environments-Analytical Determination and Interpretation of Thermal Stress Using Calculation of Required Sweat Rate* (ISO 7933). Geneva: ISO, 1989

24. **American Industrial Hygiene Association (AIHA):** *Heating and Cooling for Man in Industry.* Akron, Ohio: AIHA, 1975.

25. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Industrial Ventilation.* Cincinnati, OH: ACGIH, 1992

26. **Brouha, L.:** *Physiology in Industry: Evaluation of Industrial Stresses By the Physiological Reactions of the Worker.* 4th ed. Great Britain: Pergamon Press Ltd., 1960.

27. **Bernard, T.E., W.L. Kenney, J.F. O'Brien, and L.F. Hanes:** "Heat Stress Management Program for Power Plants," (NP4453L). Palo Alto, CA: Electric Power Research Institute, 1991.

28. **"OSHA Technical Manual. Chapter 4: Heat Stress."**[Online] Available at http://www.osha-slc.gov/dts/osta/otm (Accessed October 31, 2001).

29. **Lind, A.R.:** Tolerable Limits for Prolonged and Intermittent Exposures to Heat. In *Temperature Its Measurement and Control in Science and Industry*. Part 3 Biology and Medicine. J.D. Hardy (ed.). New York: Reinhold Publishing Corporation, 1963.

30. **Barrett, M.B.:** Heat Stress Disorders Old Problems, New Implications. *AAOHN J.* 39(8): 369-380 (1991).

31. **Sherwood, L.:** *Human Physiology From Cells To Systems*. 3rd ed. New York: Wadsworth Publishing Co., 1997.

32. **Dukes-Dobos F. and A. Henschel:** Development of Permissible Heat Exposure Limits For Occupational Work. *ASHRAE J.* 15:57-62 (1973).

33. **Ramsey J.D. and M.Y. Beshir:** Thermal Standards and Measurement Techniques. In *Occupational Environmental-Its Evaluation and Control.* City, State: AIHA press, 1997

34. **Houghten, F.C. and C.P. Yagloglou:** Determining Equal Comfort Lines. *J Am Soc Heat Vent Eng*. 29:165-176 (1923).

35. **Yaglou, C.P. and D. Minard:** Control of Heat Casualties at Military Training Centers. *Arch Ind Health*. 16:302-316 (1957).

36. **Hertig B.A.:** Thermal Standards and Measurement Techniques. In *The Industrial Environment-Its Evaluation and Control* (NIOSH). Washington, D.C: U.S Governmental Printing Office, 1973.

37. **Minard D.:** Studies and Recent Advances in Military Problems of Heat Acclimatization. *Mil Med*. 132(4): 306-315 (1967).

38. **Minard D.:** Prevention of Heat Casualties in Marine Corps Recruits. *Mil Med*. 126: 261-272 (1961).

39. **Bernard, T.E. and R.R. Cross:** Case Study Heat Stress Management: Case Study in an Aluminum Smelter. *Int J Ind Erg*. 23: 609-620 (1999).

40. **World Health Organization (WHO):** "Health Factors Involved in Working Under Conditions of Heat Stress." (WHO tech. rep. ser. 412) Geneva: WHO, 1969.

41. **Lind, A.R.:** A Physiological Criterion for Setting Thermal Environmental Limits for Everyday Work. *J Appl Physiol*. 18(1):51-56 (1963).

42. **Lind, A.R.:** Effect of Individual Variation on Upper Limit of Prescriptive Zone of Climates. *J Appl Physiol*. 28(1):57-62 (1970).

43. **Lind, A.R.:** Physiological Effects of Continuous or Intermittent Work in the Heat. *J Appl Physiol*. 18(1):57-60 (1963).

44. **American Conference of Governmental Industrial Hygienist (ACGIH):** *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* Cincinnati, OH: ACGIH (1992).

45. **International Organization for Standardization (ISO):** "Hot Environments-Estimation of the Heat Stress on Working Man, Based on the WBGT Index (Wet Bulb Globe Temperature)" (ISO 7243). Geneva: ISO, 1989.

46. **Wyndham, D.:** Research in the Human Sciences in the Gold Mining Industry. *Am Ind Hyg Assoc*. 35: 113-136 (1974).

47. **Humphreys, C.M.:** The Application of Heat Stress Indices. *J Occup Med.* 13(8): 377-379 (1971)

48. **Givoni, B.:** *Estimation of the Effect of Climate on Man: Development of a New Thermal Index* (Research Report to UNESCO). Haifa, Israel: Building Research Station, Technion, 1963. Cited in Man, Climate and Architecture by B. Givoni. London: Applied Science Publishers LTD, 1976.

49. **Parson, K.C.:** International Heat Stress Standards: A Review. *Ergonomics*. 38(1): 6-22 (1995)

50. **Parson, K.C.:** International Standards for the Assessment of the Risk of Thermal Strain on Clothed workers in Hot Environments. *Ann Occup Hyg*. 43(5): 297-308 (1999)

51. **Malchaire, J., A. Piette, B. Kampmann, P. Mehnert, H. Gebhardt, G. Havenith, E. Den Hartog, I. Holmer, K. Parsons, G. Alfano and B. Griefahn:** Development and Validation of the Predicted Heat Strain Model. *Ann Occup Hyg.* 45: 123-135 (2001).

52. **Malchaire, J., B. Kampmann, G. Havenith, P. Mehnert, and H.J. Gebhardt:** Criteria for Estimating Acceptable Exposure Times in Hot Environments: A Review. *Int Arch Occup Environ Health.* 73:215-220 (2000).

53. **Forsthoff, A., P. Mehnert, and H. Neffgen:** Comparison of Laboratory Studies with Predictions of the Required Sweat Rate Index (ISO 7933) for Climates with Moderate to High Thermal Radiation. *Applied Ergonomics.* 32:299-303 (2001).

54. **Parson, K.C., G. Havenith, I. Holmer, H. Nilsson, and J. Malchaire:** The Effects of Wind and Human Movement on the Heat and Vapour Transfer Properties of Clothing. *Ann Occup Hyg.* 43(5): 347-352 (1999).

55. **Ramsey, J.D.:** Heat and Clothing Effects on Stay Times. *Int J Ind Erg.* 13: 157-163 (1994).

56. **Bernard, T.E. and W.L Kenney:** Rationale for a Personal Monitor for Heat Strain. *Am Ind Hyg Assoc J.* 55(6):505-514 (1994).

57. **Logan, P.W. and T.E. Bernard:** Heat Stress and Strain in an Aluminum Smelter. *Am Ind Hyg Assoc J.* 60:659-665 (1999).

CHAPTER 3

OCCUPATIONAL EXPOSURES DURING ROUTINE ACTIVITIES IN COAL-FUELED POWER PLANTS[1]

[1]Bird, Mona J., MacIntosh, David L., Higgins, Grover H., and Williams, Phillip L. To be submitted to the *American Industrial Hygiene Association Journal.*

ABSTRACT

Limited information is available on occupational exposures during routine, non-outage work activities in coal-fueled power plants. This study evaluated occupational exposures to the principal potential contaminants in the facilities, including respirable dust (coal dust), arsenic, noise, asbestos, and heat stress. The data was collected over a three-month period during the summer of 2001 in five facilities, which were chosen to be representative of the coal-fueled power plants of a large southeastern power-generating company. Each of the facilities was divided into five similar exposure groups (SEGs) based upon previous exposure assessments and job tasks performed. From 4 of the 5 facilities, approximately 50 respirable coal dust, 32 arsenic, 15 asbestos and 70 noise samples were collected for a total of 392 air samples and 302 noise samples. One of the previous facilities surveyed was also evaluated for heat stress and one additional coal-fueled power plant was surveyed for a total of 20 personal heat-stress samples. Personal monitors and area WBGT monitors were used. Of the nearly 400 air samples collected, only one exceeded an allowable occupational exposure value. Of the approximately 300 noise samples 49 (or 16%) were equal to or greater than the OSHA 8-hour Action Level of 85 dBA, and 9 (or 3%) were equal to or greater than the OSHA 8-hour PEL of 90 dBA. Heat-stress monitoring at the facilities indicates 26% of the 1-Hour TWAs were exceeded for one or all of the recommended heat-stress limits. The data also concluded that some work sites were above the heat stress ceiling values recommended by NIOSH. Four of the 20 employees which were personally monitored exceeded the recommended limits for heart rate or body core temperature. This indicates that there is a potential for heat strain if signs and symptoms are ignored. Recommendations are made to better control the heat stress exposure.

Key Words: Coal Dust, Arsenic, Noise, Heat Stress, Asbestos, and Risk Assessment.

Assessments of worker exposure to chemical hazards during outages at coal-fueled power plants indicate that arsenic, silica, and respirable dust can potentially be above occupational exposure values (OEVs).[1,2] While some data are available on occupational exposures at these plants during outages,[2-4] little information other than to electromagnetic fields[5-7] is published on employee exposures during routine activities in the coal-fueled power industry. Coal-fueled power plants operate under routine conditions approximately 60-70% of the time and employ thousands of workers. Area sampling of respirable dust at three coal-fueled power plants in the Southeastern United States have indicated that some work areas have the potential to be above the OEVs during normal operation.[8] A NIOSH report evaluating occupational safety and health implications of the increased use of coal in the United States concluded that asbestos, fly ash (arsenic), coal dust, noise, heat, and SO_2 are the potential occupational problems in coal-fueled power plants.[9] Hence, information is needed on routine occupational exposures in coal-fueled power plants to fully assess the potential hazards posed to workers.

To obtain such information, we assessed exposure of workers to coal dust, silica, arsenic, asbestos, noise, and heat stress during routine work activities under normal operations in several coal-fueled power plants. We analyzed variability of exposures among facilities and among job classifications within facilities to identify determinants of exposure and employees that may be at greatest risk. The information was used to recommend controls that could better protect the employees from the potential hazards.

MATERIALS AND METHODS

Sampling Sites and Experimental Design

Five coal-fueled power plants of a large Southeastern power-generating company were surveyed (Table 1). All five facilities were similar in operations and varied only in size and how coal was fed to the boiler. Air and noise sampling took place over a two-month period during the summer of 2001, and heat-stress monitoring took place in August during the same summer.

Prior to sampling, the employees of the generating facilities were divided into five similar exposure groups (SEGs) based upon previous employee exposure assessments, similarity between work activities and potentially similar exposures.[10] Table 2 depicts the five SEGs and their job categories.

Sample sizes for chemical hazards and noise for each SEG were determined based upon past historical data collected over an eleven-year period by the company. The sample size for respirable coal dust, arsenic and asbestos was selected to detect a 100% difference of mean concentrations among SEGs of the plants as significant (α=0.05) with statistical power of 0.8. The 100% change was chosen based on the low exposure levels in the historical data for these substances as compared to the OEVs. The sample size for noise was selected to detect a 10% difference of mean concentrations among SEGs of the plants as significant (α=0.05) with statistical power of 0.8. As determined statistically by the sample-size formula,[11] at least 8 arsenic, 14 asbestos, 10 coal-dust, and 14 noise samples per SEG at each plant were collected. At each facility, the samples were collected over 8 to 13 days. Employees worked typical eight-hour shifts with the exception of a small portion of employees who worked 10-hour shifts. Employees within each SEG were randomly chosen to wear the sampling apparatus in their personal breathing or hearing zone throughout their work shift.

Team leaders and/or employees of each SEG at each plant and compliance personnel at each plant were interviewed at the five coal-fueled power plants to determine the SEG potentially at the highest risk for heat strain. Based on the interviews, the Mechanic's SEG was determined to have the highest risk. Heat-stress monitoring was conducted in August of 2001. Due to the limited time and equipment available, only two of the five coal-fueled power plants were chosen for area and personal heat-stress monitoring.

Mechanics who were performing job activities that required work in hot areas of the plant were evaluated during the course of their work shift. Before work activities began, randomly selected employees were suited with personal heat-stress monitors that were worn for the duration of the shift. Employees were evaluated at each work site to appropriately place area monitors and to evaluate the work activities, work/rest regimens, and rehydration habits. Each day the data were downloaded from both the personal and area monitors. Height, weight, age and clothing data were collected from each employee who was personally monitored during the survey.

Instrumentation and Analytical Procedures

Air Sampling

Air samples were collected using MSA Escort and MSA Escort Elf air-sampling pumps (Mine Safety Appliances Co., Pittsburgh, PA). The sampling method, media, and laboratory for each air contaminant can be found in Table 3. Pumps were calibrated each morning prior to use and checked to ensure calibration each afternoon following the sampling using a BIOS International DC-1 Dry Cal (Pompton Plains, NJ). All pumps were maintained within ±5.0% of the recommended flow rate.

One of the concerns of aerosols in coal-fueled power plants is the exposure to particulates containing silica. To assess worker exposure to silica, a sample of bulk coal was obtained from each plant on the days that respirable particulate sampling was conducted. Silica was assayed in bulk coal samples as opposed to air samples since past facility results indicated a large portion of the personal samples would be below the detection limit for silica. A bulk sample of the coal used in the facility during the shift was collected from the tripper floor where coal is deposited into bunkers. The silica content (% of coal) was used to determine the permissible exposure limit (PEL) established by OSHA.[15,16] By using this approach, the silica content of the coal used each day could be determined even if respirable particulate samples were below the detection limit.

Area Asbestos

Area asbestos sampling was conducted at four of the five facilities. Sampling pumps were placed in areas near asbestos-containing materials (e.g., removed turbine shells, piping containing asbestos, or in areas with asbestos warning signs) that employees would potentially encounter during a work shift. At each site a sample was placed on a tripod or on equipment near the breathing zone of an average-sized person.

Noise

Area noise samples at four of the five plants were taken throughout the boiler house and in the fossil-fuel service (FFS) areas. The Quest 2400 sound level meter (Quest Technologies, Oconomowoc, WI) was used for the area surveys. Personal samples were taken at four of the five facilities using one of the four following Quest Technologies dosimeters: the Q-200, Q-300, M-27, or Micro-15 dosimeter (Quest Technologies, Oconmowoc, WI). All dosimeters were capable of simultaneously determining both the 80 and 90-threshold limit (TL) settings. Each dosimeter and sound level meter was calibrated before and after each sampling period by using the DC-20 calibrator (Quest Technologies, Oconomowoc, WI). All results were recorded at the end of a shift for each employee monitored.

Statistical analysis using the SAS® software release 8.2 was used to evaluate the noise samples.(20) The data were analyzed using an ordinary linear regression model to evaluate significant differences among the plants or designated SEGs from plant to plant for both the 80 and 90-TL noise measurements. A significance level of 0.05 was used for all statistical tests. The 80 and 90-TL noise data were designated as the dependent variables, and the plants and SEGs were designated as the independent variables. To determine which SEGs were significantly different among the plants, analysis which tested the main effects of the means was used. This evaluation determined if a designated SEGs at one plant varied significantly from a designated SEG at another plant.

To determine if there was correlation between repeated measurements, a traditional mixed linear model and the Pearson correlation coefficient (R) was used. The correlation coefficient was also used to determine if there was a relationship between the repeated samples and the number of days apart the samples were collected.

Heat-Stress Monitoring

Both area and personal heat-stress sampling was performed. Heat stress was evaluated by comparing the WBGT values along with the metabolic work rates to recommended values in published literature.[17,18] The QuestTemp°34 and Quest Temp°36 with an attached Quest Air Probe (Quest Technologies, Oconomowoc, WI) were used to determine the area dry bulb, wet bulb and globe temperatures. The wet-bulb-globe temperature (WBGTs) and air velocity were also determined at each work and break site by using the area monitors. The area monitors were placed on tripods as close to the work area as possible without interfering with employee work activities. The employee's metabolic work rate was determined based on surveys of the worker's activities and published literature.[19] The calculated time-weighted averages (TWAs) and area values were compared to recommended TWAs and ceiling values.

Each employee who was personally monitored was suited each morning before work began with either the Metrosonic hs-3800 (Metrosonics, Oconomowoc, WI) or the Questemp II monitors (Quest Technologies, Oconomowoc, WI). Data were downloaded from both monitors at the end of each shift.

RESULTS

Table 1 provides a summary of the number of samples collected at each of the facilities for all chemical and physical hazards.

Silica/Respirable Coal Dust

Quartz silica ranged from ≤0.6% to 4.4% of coal for all plants sampled. Four of 203 respirable coal-dust samples collected were greater than the limit of detection (0.13 – 0.37 mg/m^3). Two samples above the detection limit were from Plant 1 with levels of

0.15 (Operations SEG) and 0.19 mg/m^3 (Mechanics SEG). Plant 2 also had one sample (0.84 mg/m^3) from the Mechanic's SEG above the limit of detection. Plant 4 had the only overexposure from the SEG Instrument and Control (I&C) with an exposure of 5.3 mg/m^3. The sample was above OSHA's PEL of 2.4 mg/m^3 for dust containing less than 5% silica and was also above the respirable dust OSHA PEL of 5 mg/m^3 for dust containing no silica.(16)

Inorganic Arsenic

A total of 128 inorganic arsenic samples (8 samples per SEG per plant) was taken at four of the five facilities across all SEGs except the Fossil-Fuel Services (FFS) group. FFS was not sampled for arsenic because plant interviews concluded that the FFS employees have very little or no contact with fly ash during normal operations. All samples were below the limit of detection (0.37 – 0.72µg/m^3) and below the OSHA PEL of 10µg/m^3.(21)

Area Asbestos

A total of 61 area asbestos samples was taken among the four plants. A total of 12 samples was greater than the limit of detection (0.003 f/cc). Two of these samples were collected at Plant 1, three at Plant 2, one at Plant 3, and six at Plant 4. The values which ranged from 0.003-0.007 f/cc are well below the OSHA PEL of 0.1 f/cc.(22)

Noise

A total of 302 noise samples was taken among four plants and five SEGs, and an overview of the data are provided in Table 4. A total of 55 samples (18%) was greater than or equal to the OSHA action level of 85 dBA.(23) A total of 12 samples (4%) was greater than or equal to the 90- dBA OSHA PEL.[23] The individual descriptive statistics including the 75, 90, and 95 percentiles for both the 80 and 90-TL per plant can be reviewed in Table 5.

Of the 302 noise samples, repeated measurements were taken from 49 of the employees across all four plants. Repeated measurements were taken within an average of 4.1 days. The range between the repeated samples was 1-13 days apart. The number of sampling days between sampling dates was analyzed to determine if there is a relationship between the repeated samples and the number of days apart the samples were taken. No relationship was established with a small correlation coefficient of R= 0.21.

Of the 49 employees of whom the repeated measurements were taken, 42 had two repeated measurements and 7 had three repeated measurements. The Pearson correlation coefficient (R) and SAS®, using the procedure Proc Mixed, was used to determine the correlation between the repeated measurements. The correlation coefficient measures the strength between two variables.[24] The R=0.60 for the 80-Threshold Limit (TL) and R=0.62 for the 90-TL. Due to the relatively strong correlation coefficient, the repeated measurements were averaged. The correlation coefficients were considered to be relatively strong due to the differences associated with the data before and after the repeated measurements were averaged. Thus, analysis was performed using 246 samples at both the 80 and 90-TL. Of these samples, 46 (19%) were greater than the OSHA action level of 85 dBA, and 7 (3%) were greater than the OSHA PEL of 90 dBA.

Confidence intervals were constructed with the purpose of determining if the second day of measurements for noise for an employee could be estimated with 95% confidence. The mean difference between day 1 and day 2 of measurements for the 80 and 90-TL was 1.2 and 1.4 dBA respectively with standard deviations of 6.7 and 8.6 dBA. Using the data, confidence intervals were constructed and tested.

Statistical analysis was performed using the 246 samples, termed actual, in which the repeated samples were averaged. The original 302 noise samples, termed original, were not analyzed statistically, but comparisons of noise levels above the recommended values were made between the two sets of results. Descriptive statistics for the 246 actual noise samples collected at the four facilities for both the 80 and 90-TL are presented in Table 6 and 7 respectively.

The data included noise samples from the five formed SEGs from each plant. There was a significant difference among the SEGs at each of the plants (p=<0.0001-0.0062) for both the 80 and 90-TL. This means that SEGs in a plant cannot be compared to other SEGs within the same plant.

Analysis, using the Tukey's test, to test differences between means of SEGs among each plant was performed. No significant difference (p=0.05) was found among the same SEGs from plant-to-plant for both the 80 and 90-TL except for the SEG FFS and I&C. For FFS at both the 80 and 90-TL, there is a significant difference (p=0.0005 and p=<0.0001 respectively) between the means of the SEG for at least one of the plants. Tukey's analysis, at a significance level of p=0.05, establishes that Plant 3 for FFS is significantly different from the three other plants for both the 80 and 90-TL. No other plants vary significantly for FFS.

Tukey's analysis for the SEG I&C established that the means of Plants 1 and 2 are significantly different (p=0.05) at the 80-TL. The graphical presentation in Figures 1 and 2 shows this relationship visually.

Evaluations of the OSHA overexposures per SEG are presented in Table 4. The Mechanic and Operations SEGs have the highest percentage of overexposures at 32.7 and 31.3 % respectively for the 80-TL. The descriptive statistics per SEG by plant, along with plant totals, have been broken down and are also shown in Table 5.

Heat Stress

The WBGT index is the most commonly used heat-stress index, and the ACGIH TLVs[18,28] and NIOSH RELs[17] have established recommended guidelines for using the index in the workplace. The guidelines are based on 1-hour TWAs for the WBGT and metabolic rate for continuous work and 2-hour TWAs for intermittent work [28]. The guidelines were developed from previous research by Lind[26] and Dukes-Dobos et al.[27]. OSHA's technical manual [28] contains recommendations which are the 1992-1993 TLVs,[29] and recommendations have been made by the International Standardization Organization in the ISO 7243[30] method. The major difference between the recommendations is the metabolic rate categories. Although 1-hour and 2-hour TWAs were calculated, 1-hour TWAs are more appropriate for the continuous work patterns at these particular plants.

The heat-stress evaluation took place at Plant 3 and 5 during August of 2001. The evaluation was performed with the assumption (based on observations) that the long-time employees of the company were acclimated to heat, wore summer clothing, and were in good health. No adjustments were made for clothing or body weight. Values were compared to recommendations for acclimated individuals because evaluation was conducted at the end of the summer when the long-time employees were well acclimated to the heat. Ranges were determined for the work areas at the plants evaluated during the survey. The WBGT values of Plant 5 ranged from 26.2° to 35.7°C, and the air temperature as determined by the dry bulb temperature range was 30.7° to 47°C. The ranges of Plant 3 were 26.9° to 44.3°C for the WBGT and 32.4° to 64.7°C for the air temperature.

1-Hour and 2-Hour TWAs

Table 8 represents the overexposures encountered at each of the two facilities evaluated for both the 1 and 2-hour TWAs. The data conclude there are job activities that have the potential to be above the recommended levels. At Plants 3 and 5, 34% and 20% of the 1-hour TWAs and 23% and 8% of the 2-hour TWAs were respectively above recommended ACGIH TLVs. A common job activity that requires work in elevated temperatures is soot blower repairs which were monitored during the survey, but any job requiring work close to the boiler could be considered a high-heat work activity.

Ceiling Values

NIOSH ceiling values were evaluated at each of the work sites during the shift. The NIOSH ceiling results, as presented in Table 8, indicate ceiling values are exceeded in some work areas for employees during a work shift. At Plants 3 and 5, 12% and 4% of the work sites exceeded the recommended NIOSH ceiling values. Ceiling values were exceeded during soot blower repairs a majority of the time.

EPRI Recommendation Values

EPRI's heat-stress management plan was used to determine if the plants were within recommended stay times. The HEXAN program was used as outlined in the report.[19] Data collected at the plants were entered into the program, and action times were established for the work area based on the information entered. All exposure times were less than the allowable exposure times as seen in Table 8. The analysis also allows for multiple-site exposure analysis when employees work in different environments before going to a cooler area to recover. Only one employee at Plant 3 worked beyond the allowable limit for multiple-site analysis.

Heat- Stress Index (Belding and Hatch)

Belding and Hatch[31] heat-stress indexes indicate there are calculated heat stress indexes (HSI) of greater than 100. A HSI of 100 is considered the limit that an average person can work for 8 hours without danger of heat strain[31]. At Plant 5, 12 (24%) of the work activities went beyond the recommended allowable exposure time. At Plant 3, 11 (22.4%) work activities extended beyond the allowable exposure time.

Personal Monitoring Data

A total of 20 personal samples was taken between the two plants. Heart rates and predicted rectal temperatures, using a skin sensor disk, were evaluated. The average heart rates ranged from 80 to 121 beats per minute (bpm). The maximum skin temperature ranges were 35.9 to 38.3^{o}C. A total of 4 employees (20%) exceeded recommended heart rates or body temperatures (see Table 9). One of the four employees exceeded recommended body temperatures twice during the same shift.

DISCUSSION

Chemical Hazards

Based on our data, chemical exposures at coal-fueled power plants are expected to be low and of minimal concern for routine day-to-day activities unless activities or processes change. There may be unique maintenance activities that may have potential inorganic arsenic exposures not represented by this survey. These activities are not performed routinely and should be evaluated on an individual basis. One respirable coal-dust sample exceeded the allowed limit and involved maintenance on equipment with an accumulation of dust. Equipment with ash or coal dust build-up should be cleaned prior to work in the area in order to lower the exposure. The activities associated with the overexposure should be monitored in the future, and employees should be trained in proper work practices to minimize exposures. Asbestos maintenance plans should be maintained to insure that the low exposures represented in this study continue.

Noise Exposures

Area noise measurements in the coal-fueled power plants and fossil-fuel service areas at the plants indicate that individual noise exposures have the potential to be high. The noise ranges inside the boiler house were 74 to104 dBA across the four plants evaluated. The noise ranges in the fossil-fuel areas were 70 to 108 dBA across the plants. A large portion of the noise samples fell below the OSHA action limit and PEL (refer to Tables 6 and 7). This indicates that employees are spending significant portions of their shift in areas well below 80-and 90-dBA threshold levels.

From the noise data, it can be concluded that the Mechanics and Operations SEGs have the highest potential for being overexposed across the plants. Mechanics and Operations were also the highest-exposure groups at each individual plant with the exception of Plant 3 in which FFS had the highest exposure (Table 6). These higher exposures were expected since the Mechanics and Operations spend a large portion of their work shift inside the boiler house. The company can use the data to evaluate changes that need to be made to minimize the exposures associated with the two highest SEGs.

The noise data indicates that employees should continue to wear hearing protection while working inside the plant and in FFS areas. The data also indicate that there are differences among plants for the FFS and I&C SEGs. The overall conclusion is that varying plant sizes (amount of coal which is run to the facility), and the coal-dust cleaning process on the tripper floor are the major differences, with Plant 3 being significantly different from the other plants. Work patterns associated with Plants 1 and 2 contributed to the significant difference between the I&C SEG of the plants. Plant 1 employees spent considerably more time in the shop than did Plant 2 workers. By determining the differences among SEGs from plant to plant, the company can evaluate the SEGs to determine the controls or work practices that should be implemented to minimize overexposures for the SEG at a particular facility.

Repeated Measurements

As indicated in the results section, repeated samples from 49 employees were averaged due to a considerably high correlation coefficient. The high correlation indicates that the noise sampling is repeatable with no significant difference between the sampling days. This data will help the company predict future exposures for routine activities. The repeated samples were further analyzed to determine if a relationship could be established between repeated samples and the number of days between the sampling dates. Analysis indicates that there is no relationship; therefore, samples may be taken and repeated several days later. This enhances the relationship between the reproducibility of repeated measurements over longer durations. In addition, confidence intervals were established for the repeated noise samples collected, and it was found that the second-day measurements could be predicted with 95% confidence.

The company currently has a hearing-conservation program in place for all its facilities. Based on the mean values, all SEGs were within the OSHA limits, but some individuals in all SEGs had some employees that exceeded the allowable OSHA values (See Table 5). Consequently, the hearing-conservation program should be continued.

Heat Stress

Heat stress is a concern in the coal-fueled plants because of the high radiant heat generated from the boilers. Employees must often work inside the boiler house to make repairs. The most common activities that require work near boilers are soot blower repairs which require employees to work within an approximate range of one to thirty feet from the boiler. Of the 20 Mechanics personally monitored in the survey, all but 4 employees worked on the soot blower at some point during the day. Thus, activities were very similar for all employees during the survey.

The 1-hour and 2-hour TWA analysis indicates there are job activities that have the potential to be above the recommended levels. As indicated in Tables 8 and 10, the percent of rest time during the elevated levels is low. To minimize elevated levels, rest should be increased. Employees should not work continuously for an hour in elevated temperatures. The percent rest as depicted in Table 10 indicates that many of the overexposed employees are experiencing less than 25% rest within a hour. By increasing the rest time, metabolic rate will decrease, and their exposure should fall below the recommended values. However, in some instances, increased rest would not prevent the overexposure because WBGT values are too high. The 2-hour TWAs show the same trends.

Due to the fact that cooled break areas were not located in the vicinity of the work area, the employees tended to work for longer durations before breaking. By designating cool areas closer to work places, employees would be more likely to take mini-breaks. This would allow the body to begin recovering and would decrease the likelihood of heat strain. In most instances, employees could simply break in the stairways located off of each floor. The stairways are not air-conditioned, but they are much cooler than the boiler house itself. It is recommended by NIOSH that 5 to 7 ounces of cool water be drunk every 15 to 20 minutes.(17) Employees should be encouraged to frequently drink water, and to take small water coolers to the work areas so that mini waterbreaks can be taken during the work activity.

NIOSH Ceiling Values

NIOSH, in the 1986 documentation for occupational exposure to heat, states that ceiling values have been established based on combined environmental and metabolic rates. The documentation states that no worker should be exposed to any of the proposed combinations without being provided with and properly using heat-protective clothing.(17) This evaluation also addressed the WBGTs at each worksite during the course of a shift because metabolic rates and environmental temperatures varied during the shift. Because work areas can exceed recommended ceiling values, it is important that the need for personal protective equipment be evaluated. This evaluation will help determine the type of equipment that best suits the needs of the employee.

EPRI Values

Based on the action times allowed, EPRI(19) designates the work areas as either a high, moderate, or low heat-stress environment. It is recommended that jobs falling in the hot and moderate categories require general countermeasures, but analysis of the environment can be terminated if an area is designated as having low heat stress. However, this program is advisable only if training and the use of self-determination are allowed. For Plant 3, only one worksite fell into the hot-job category, and 19 fell into the moderate-heat category. For Plant 5, no worksites fell into the hot-work category, and 6 sites were termed moderate-heat environments. However, of these allowed stay times, none were exceeded for either of the facilities because the work activities required less work time or because the employee used self-determination to break before heat strain developed. The management program, under high and moderate heat-stress conditions, indicates that employees should be trained in the management of heat stress. Using this more-detailed analysis of heat stress, indications are that employees have the potential for heat strain; however, since work times were less than the allowable time and minimum recovery times were observed, the plants appear to be adequately controlling heat stress. However, the analysis based on the ISO 7933[(32)] is different in that it allows for a less-conservative approach in calculating the action times, and the literature indicates the ISO 7933 method needs improvements to be considered a good basis for determining heat strain.[(33-36)] Thus, because of the less-conservative approach used and questions concerning the method on which the program is based, the analysis should be approached with caution and used only when combined with training and self-determination at the facilities. Both of these are currently in practice at each of the facilities surveyed. Of all the heat stress indices evaluated in this survey, the EPRI analysis was the only analysis in which no values were exceeded.

Heat Stress Index (HSI)

According to Belding and Hatch, an index of greater than 100 indicates that thermal balance can no longer be maintained.[31] Employees at both plants work in indexes greater than 100. However, Humphrey's paper on the application of heat-stress indices indicates that the allowable exposures times permitted by such indices as the HSI should be used only as an indicator of how stressful the situation is.[37] Limitations have been placed on this method, and as a result, the ISO 7933 approach has evolved from the HSI.[25] The limitations placed on the HSI do not make it a good indicator of heat strain, but literature suggests the HSI is still useful in evaluating the environment to determine the type of controls that could be implemented to decrease the potential for heat strain. Thus, it can be concluded from the analysis that an index above 100 should be more closely monitored, and only acclimated individuals should perform the work and only then when under the supervision of another individual.[37]

Personal Heat-Stress Monitoring

Although heat-stress indices can be used to predict the anticipated physiological results of an individual, it is often more appropriate to assess the physiological responses themselves, especially if recommended limits for the other indices are exceeded. Two monitors were used to evaluate the physiological responses of the employees. The hs-3800 (Metrosonics, Inc.) developed from research by Bernard and Kenney[38] and the Quest Temp II (Quest Technologies) monitors were used. Although literature suggests the monitors do have shortcomings,[39-41] they were used to evaluate the physiological responses to heat stress. The TLV documentation sets guidelines for evaluating excessive heat strain by recommending that work be discontinued when a peak heart rate

(180 minus age) per individual is sustained for several minutes, when the body-core temperature is greater than 38°C, or if symptoms of heat strain develop.[18,25]

It can be concluded from the data that the employees have the potential to exceed recommended physiological guidelines as recommended by ACGIH. The individual results for the personal monitoring exceeds can be reviewed in Table 9. From the 5 exceeded times, all but two were encountered when ceiling values were above recommended levels. No relationship could be associated between overexposures of the personal data and the overexposures of the 1-hour and 2-hour TWAs. All personal monitoring exceeds occurred during soot blower repairs. Employees used self-determination to keep their bodies from experiencing strain, and all employees were in the process of leaving just prior to the alarming of their personal monitors. No controls were used for any exceeds with the exception of one employee who wore a hooded respirator for a short duration during the exceeded work activity.

Cooling fans and portable air conditioners are available for use, but employees are not inclined to use them because of the difficulty of moving them to areas in which they will only work for short durations.

CONCLUSION

Chemical evaluation at the plant indicates that asbestos, inorganic arsenic, and coal-dust exposures, under normal routine activities, are expected to be low. However, there may be unique maintenance activities not performed on a day-to-day routine basis that should be evaluated on an individual basis. The highest potential for chemical exposure can occur when equipment with ash and/or coal-dust buildup is worked on without removing the excess dust. Thus, employees should be encouraged to remove the buildup, especially when the work activity may cause dust to be distributed into the air. As with any industrial hygiene survey, job procedures or processes that change should be reevaluated.

Noise exposure indicates that there are instances when employees may be exposed to levels above the OSHA 8-hour action level of 85 and 90-dBA PEL TWAs. Employees should continue wearing hearing protection inside the boiler house, and the current hearing-conservation program should remain in place.

Heat stress is the main issue at the facilities. Personal monitoring indicates employees have the potential to be overexposed with the potential for heat strain. However, the employees were very aware of how they felt and were observed throughout the survey to take breaks as they were needed. Heat potential inside the plant varies, depending upon the location, and no recommendation can be made that will address every area in the plant. However, the company could make improvements that will better protect the employee from the potential for heat strain. Cooled break areas should be designated where employee could take short breaks to cool themselves without having to leave the general work area. Water consumption should be improved, and employees could take small coolers of water to the worksite. More standardized work/rest regimens may help alleviate the instances where an employee works for extended periods and breaks for extended periods. Because ceiling values can be exceeded, personal protective controls such as cooling vests, air-circulating suits, etc. should be evaluated and employed to prevent excessive strain. The most effective way to determine if employees are experiencing heat strain is to monitor them individually. This method would decrease the possibility of overestimating the work rate and would provide information on each individual employee. However, in most instances, each employee was aware of his body's response and was given freedom to take as many breaks as necessary. The plants evaluated for heat stress indicate that there have been complaints of heat strain in the past five years, but all were treated on site with the exception of one individual who require medical attention. Thus, it can be concluded that heat strain could potentially be a problem and should be better controlled in the future at these facilities.

The short-term effects associated with noise and heat stress are well documented in published literature. Noise-induced hearing loss is associated with noise exposure at high levels, and heat-associated illnesses such as heat exhaustion, heat syncope, heat stroke, etc. are readily apparent effects associated with elevated heat exposure. However, further investigation on the potential chronic effects associated with these exposures would be beneficial. The results of a meta-analysis study found an association between occupational noise exposure and hypertension to be statistically significant. However, the study also concludes that the relationship between noise exposure and cardiovascular disease is still inconclusive [42]. Heat stress places a cardiovascular strain on the body, and a study on the long-term, chronic effects on the cardiovascular system posed by the day-to-day heat exposures would be beneficial.

REFERENCES

1. **Yager, J.W., J.B. Hicks, and E. Fabianova:** Airborne Arsenic and Urinary Excretion of Arsenic Metabolites During Boiler Cleaning Operations in a Slovak Coal-Fired Power Plant. *Environ Health Perspect.* 105: 836-842 (1997).

2. **Mattorano, D.A.:** Clinch River Power Plant Cleveland, Virginia. *Health Hazard Evaluation Report* (HETA 95-0393-2633). Cincinnati, OH: NIOSH Publication Office, 1997.

3. **Levy, B.S, L. Hoffman, and S. Gottsegen:** Boilermaker's bronchitis. Respiratory Tract Irritation Associations with Vanadium Pentoxide Exposure During Oil-to-Coal Conversion of a Power Plant. *J Occup Med.* 26(8): 567-570 (1984).

4. **Drozdenko, L.A., A.V. Povarov, N.S. Shpinikova, G.A. Plisiugina, and I.M. Merkur'eu:** Hygienic Evaluation of the Atmosphere and the State of Health of Workers Performing Repair Operations Within the Boilers of the Estonian State Regional Electric Power Station. *Gig Tr Prof Zabol.* August 8, 1976 pp.29-31.

5. **Sahl J.D., M.A. Kelsh, R.W. Smith, and D.A. Aseltine:** Exposure to 60 Hz Magnetic Fields in the Electric Utility Work Environment. *Bioelectromagnetics.* 15(1): 21-32 (1994).

6. **Guenel P., J. Nicolau, E. Imbernon, G. Warret, and M. Goldberg:** Design of A Job Exposure Matrix on Electric and Magnetic Fields: Selection of An Efficient Job Classification for Workers in Thermoelectric Power Plant Production Plants. *Int J Epidemiolo.* 22(2):16-21(1993).

7. **Kromhout H., D.P. Loomis, G.J. Mihlan, L.A. Peipins, R.C. Kleckner, R. Iriye, and D.A. Savitz:** Assessment and Grouping of Occupational Magnetic Field Exposure in Five Electric Utility Companies. *Scand J Work Environ Health*. 21(1):43-50 (1995).

8. **Lehocky, A.H. and P.L. Williams:** Comparison of Respirable Samplers to Direct-Reading Real-Time Aerosol Monitors for Measuring Coal Dust. *Am Ind Hyg Assoc J* 57:1013-1018 (1996).

9. **Bridbord, K., J. Costello, J. Gamble, D. Groce, M. Hutchison, W. Jones, J. Merchant, C. Ortmeyer, R. Reger, W. Wagner:** Occupational Safety and Health Implications of Increased Coal Utilization. *Environ Health Perspect* 33:285-302 (1979).

10. **Hawkins, N.C., S.K. Norwood, J. C. Rock (eds.):** *A Strategy for Occupational Exposure Assessment.* Akron, OH: AIHA, 1991.

11. **Kleinbaum, D.G., L.L. Kupper, and K.E. Muller (eds.):** *Applied Regression Analysis and Other Multivariable Methods*. 2nd ed. Boston: PWS-KENT Publishing Co., 1988.

12. **National Institute for Occupational Safety and Health (NIOSH):** Particulates Not Otherwise Regulated, Respirable: Method 0600, issue 2. In *NIOSH Manual of Analytical Methods (NMAM).* 4th ed. (DHHS [NIOSH] pub. no. 94-113). Washington, D.C.: Government Printing Office, 1994.

13. **National Institute for Occupational Safety and Health (NIOSH):** Elements by ICP: Method 7300. In *NIOSH Manual of Analytical Methods (NMAM).* 4th ed. (DHHS [NIOSH] pub. no. 94-113). Washington, D.C.: Government Printing Office, 1994.

14. **National Institute for Occupational Safety and Health (NIOSH):** Asbestos Fibers by PCM: Method 7400. In *NIOSH Manual of Analytical Methods (NMAM).* 4th ed. (DHHS [NIOSH] pub. no. 94-113). Washington, D.C.: Government Printing Office, 1994.

15. **Occupational Safety and Health Administration, U.S. Department of Labor:** Quartz and Cristobalite in Workplace Atmospheres. [Online] *OSHA ID-142*. Available at http://www.osha.gov/dts/sltc/methods/inorganic/id142/id142.html (Accessed April 24, 2002).

16. **Occupational Safety and Heath Administration (OSHA), U.S. Department of Labor:** *"1910.1000 (Tables Z-1, Z-2, and Z-3), Table Z-3 Mineral Dusts."* [Online] Available at http://www.osha.gov (Accessed April 24, 2002).

17. **National Institute for Occupational Safety and Health (NIOSH):** *Criteria for a Recommended Standard. Occupational Exposure to Hot Environment* (DHHS [NIOSH] 86-113). Washington, D.C: U.S. Government Printing Office, 1986.

18. **American Conference of Governmental Industrial Hygienists (ACGIH):** Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati, OH: ACGIH, 2001.

19. **Bernard, T.E., W.L. Kenney, J.F. O'Brien, and L.F. Hanes:** "Heat Stress Management Program for Power Plants," (NP4453L). Palo Alto, CA: Electric Power Research Institute, 1991.

20. **SAS® Institute Inc.:** *SAS® Software Release 8.2* [Computer Software] SAS Institute Inc., 1999-2001.

21. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Inorganic Arsenic Standard (29 CFR 1910.1018)." [Online] Available at http://www.osha.gov (Accessed April 23, 2002).

22. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Asbestos Standard (29 CFR 1910.1001)." [Online]. Available at http://www.osha.gov (Accessed April 23, 2002).

23. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Occupational Noise Exposure Standard (29 CFR 1910.95)." [Online]. Available at http://www.osha.gov (Accessed January 16, 2002).

24. **Ott, R.L.:** *An Introduction to Statistical Methods and Data Analysis.* 4th ed. Belmont, CA: Duxbury Press, 1993.

25. **American Conference of Governmental Industrial Hygienists (ACGIH):** Documentation of the Threshold Limit Values For Physical Agents, 7th Ed. Cincinnati, Ohio: ACGIH, 2001.

26. **Lind, A.R.:** Physiological Effects of Continuous or Intermittent Work in the Heat. *J Appl Physiol* 18(1):57-60 (1963).

27. **Dukes-Dobos F. and A. Henschel:** Development of Permissible Heat Exposure Limits For Occupational Work. *ASHRAE J* 15:57-62 (1973).

28. **Occupational Health and Safety Administration**: "OSHA Technical Manual." [Online] *Chapter 4: Heat Stress*. Available at http://www.osha-slc.gov/dts/osta/otm (Accessed October 31, 2001).

29. **American Conference of Governmental Industrial Hygienists (ACGIH):** Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices. Cincinnati, OH: ACGIH, 1992-1993.

30. **International Organization for Standardization (ISO):** "Hot Environments-Estimation of the Heat Stress on Working Man, Based on the WBGT Index (Wet Bulb Globe Temperature)" (ISO 7243). Geneva: ISO, 1989.

31. **Belding H.S., T.F. Hatch:** Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains. *Heat/Piping/Air Cond.* 27: 129-136 (1955).

32. **International Organization for Standardization (ISO):** *Hot Environments-Analytical Determination and Interpretation of Thermal Stress Using Calculation of Required Sweat Rate* (ISO 7933). Geneva: ISO, 1989.

33. **Malchaire, J., A. Piette, B. Kampmann, P. Mehnert, H. Gebhardt, G. Havenith, E. Den Hartog, I. Holmer, K. Parsons, G. Alfano and B. Griefahn:** Development and Validation of the Predicted Heat Strain Model. *Ann Occup Hyg.* 45: 123-135 (2001).

34. **Malchaire, J., B. Kampmann, G. Havenith, P. Mehnert, and H.J. Gebhardt:** Criteria for Estimating Acceptable Exposure Times in Hot Environments: A Review. *Int. Arch Occup Environ Health.* 73:215-220 (2000).

35. **Forsthoff, A., P. Mehnert, and H. Neffgen:** Comparison of Laboratory Studies with Predictions of the Requried Sweat Rate Index (ISO 7933) for Climates with Moderate to High Thermal Radiation. *Applied Ergonomics.* 32:299-303 (2001).

36. **Parson, K.C.:** International Heat Stress Standards: A Review. *Ergonomics*. 38(1): 6-22 (1995).

37. **Humphreys, C.M.:** The Application of Heat Stress Indices. *J Occup Med*. 13(8): 377-379 (1971).

38. **Bernard, T.E. and W.L Kenney:** Rationale for A Personal Monitor for Heat Strain. *Am Ind Hyg Assoc J*. 55(6): 505-514 (1994).

39. **Reneau, P.D. and B.A. Phillip:** Validation of a Personal Heat Stress Monitor. *Am Ind Hyg Assoc J*. 57:650-657 (1996).

40. **Green, J.M., A.J. Clapp, D.L. Gu, and P.A. Bishop:** Prediction of Rectal Temperature by the Questemp II Personal Heat Strain Monitor Under Low and Moderate Heat Stress. *Am Ind Hyg Assoc J*. 60:801-806 (1999).

41. **Muir, H., P.A. Bishop, R.G. Lomax, and J.M. Green:** Prediction of Rectal Temperature From Ear Canal Temperature. *Ergonomics*. 44(11): 962-972 (2001).

42. **van Kempen, E., Kruize, H., Boshuizen, H., Ameling, C., Staatsen, B., and de Hollander, A.:** The Association between Noise Exposure and Blood Pressure and Ischemic Heart Disease: A Meta-analysis. *Environ Health Perspect J*. 110(3):307-317(2002).

Table 1. Plant and Sample Descriptions

	Plant 1	**Plant 2**	**Plant 3**	**Plant 4**	**Plant 5**	**Total Sample Numbers**
Plant Capacity in Mega Watts	800	3160	3420	1540	1250	N/A
Notable Variations	Coal Deposited to Bunkers From Carts	Coal Deposited From Carts to Coal pile	Coal Deposited From Carts to Coal pile; Cleaning Process on Tripper	Coal Deposited to Bunkers From Carts	Coal Deposited to Bunkers From Carts	N/A
# Area Asbestos Samples	15	15	15	15	0	60
# Personal Arsenic Samples	32	32	32	32	0	128
# Personal Respirable Coal Dust Samples	50	50	50	53	0	203
# Personal Noise Samples	71	78	75	78	0	302
# Personal Heat-Stress Samples	0	0	11	0	9	20
# Area Heat Stress	0	0	49	0	50	99

Table 2. Similar Exposure Groups (SEGs) and Job Categories within the Exposure Group

SEG	Job Categories
Electricians	Electricians Apprentice Electricians
Fossil Fuel Services (FFS)	Coal Equipment Operators (CEO) Switchman/Samplers Mechanic Tractor Operators (MTO)
Instruments and Controls (I&C)	Sr. Instrument Technicians Instrument Technicians
Mechanics	Mechanics Apprentice Mechanics
Operations	Boiler Turbine Operators (BTO) Assistant Boiler Turbine Operators (ABTO) Auxiliary Equipment Operators (AEO)

Table 3. Air Sampling Summary

Contaminate	Sampling Media	Flow Rate[a] (L/Min)	Average Sampling Duration in Minutes and (Ranges)	Analytical Method	Lab Performing Analysis
Respirable Coal Dust	5-µm PVC (polyvinyl chloride) Filter inserted in a 10-mm Dorr-Oliver graphite filled nylon cyclone	1.7	419 (304-536)	NIOSH 0600[12]	Analytical Environmental Services (AES) (Atlanta, Georgia)
Arsenic	37mm 0.8-µm MCE (mixed cellulose ester) Filter	2.0	421 (277-557)	NIOSH 7300[13]	AES
Asbestos	25mm 0.8-µm MCE (mixed cellulose ester) Filter assembled with cowl	2.0	452 (421-499)	NIOSH 7400[14]	AES
Silica	Bulk Sample Taken	N/A	N/A	OSHA ID 142[15]	Wisconsin State Laboratory of Hygiene (Madison, Wisconsin)

a= Pre and Post-Calibration Flow Rate ± 5%

Table 4. Descriptive Statistics for Noise of Four Coal-Fueled Power Plants

Plant	No. Samples	Mean[a]	SD[b]	Samples >85[a]	85-dBA 75%	85-dBA 90%	85-dBA 95%	Max	Mean[c]	SD[d]	90-dBA 75%	90-dBA 90%	90-dBA 95%	Max	Samples >90[c]
1	71	76.8	8.1	9	82.3	87.2	90.1	93	71.7	11.1	79.2	85.9	90	92.8	4
2	78	78.7	6.1	8	82.8	86.5	88.7	97.9	74.4	7.9	79.7	84.5	87.4	97.8	2
3	75	80.2	6.3	21	84.4	88.3	90.6	92.2	75.2	8.6	81.0	86.2	89.3	91.3	3
4	78	79.1	7.6	17	84.2	88.8	91.6	92.2	74.4	10.6	81.5	88.0	91.8	91.6	3
Total	**302**	**78.7**	**6.3**	**55**	**82.9**	**86.8**	**89.1**	**97.9**	**74**	**8.5**	**79.7**	**84.9**	**88.0**	**97.8**	**12**

a= 80 threshold limit (TL) (80-130 dBA)
b= standard deviation of 80-TL
c= 90 threshold limit (TL)
d= standard deviation of 90-TL (90-130 dBA)
e=75, 90, 95 percentiles

Table 5. SEG Descriptive Statistics with Number and Percentage of Samples Greater than 85 and 90 dBA

SEGs	Sample No.	80-TL Mean	80-TL SD	[c]75%	90%	95%	Max	No.>85 dBA	%>85 dBA	90-TL Mean	90-TL SD	75%	90%	95%	Max	No.>90 dBA	%>90dBA
Electricians	53	77.4	5.6	81.2	84.6	86.6	92.2	4	7.6	71.9	8.3	77.5	82.5	85.6	91.6	2	3.8
[a]FFS	47	77.7	5.5	81.4	84.8	86.7	92.9	7	14.9	71.4	7.5	76.5	81.0	83.7	91.3	1	2.1
[b]I&C	44	73.9	6.5	78.3	82.2	84.6	85.7	2	4.5	67.9	8.6	73.7	78.9	82.0	84.9	0	0
Mechanics	54	82.9	4.7	86.1	88.9	90.6	91.4	18	32.7	79.5	6.6	84.0	88.0	90.4	90.4	2	3.6
Operations	48	80.5	7.9	85.8	90.6	93.5	90.7	15	31.3	77.2	10.2	84.1	90.3	94.0	90.2	2	4.2
PlantTotals	246	78.6	6.1	82.7	86.4	88.6	92.9	46	18.7	73.8	8.2	79.3	84.3	87.3	91.6	7	2.9

a=significant difference between plants using Tukey's means test (p=0.05) at the 80 and 90-TL.
b=significant difference between plants using Tukey's means test (p=0.05) at the 80-TL.
c=75, 90 and 95 percentiles

Table6. 80-TL Descriptive Statistics per Plant and SEG

Plant	SEG	No. Samples	Mean (dBA)	SD (dBA)	Min (dBA)	Max (dBA)	No.>85	%>85
1	Electricians	12	78.2	5.3	67.4	87.7	1	8.3
	Mechanics	14	81.2	6.4	64	89.8	3	23.1
	I&C	8	69.2	4.3	61.1	73.3	0	0
	FFS	10	74.1	4.1	68.9	81.3	0	0
	Operations	8	79.5	13.0	51.4	90.4	4	50
	Plant Total	**51**	**76.9**	**7.0**			**8**	**15.7**
2	Electricians	13	77.2	4.6	66.5	83.4	0	0
	Mechanics	14	82.6	4.9	72.4	91.4	4	28.6
	I&C	11	77.5	4.8	67.3	81.7	0	0
	FFS	13	75.1	6.1	67.2	84.2	0	0
	Operations	16	79.2	5.3	67.6	86.3	2	12.5
	Plant Total	**67**	**78.4**	**5.2**			**6**	**9**
3	Electricians	14	77.9	4.2	73.7	90.1	1	7.1
	Mechanics	13	83.3	3.3	78.5	88.6	6	46.2
	I&C	11	74.4	4.2	67.7	80.8	0	0
	FFS	11	84.1	5.8	76.1	92.9	6	54.5
	Operations	12	81.4	7.7	60.6	89	5	41.7
	Plant Total	**61**	**80.2**	**5.2**			**18**	**29.5**
4	Electricians	14	76.2	8.0	65.3	92.2	2	14.3
	Mechanics	14	84.3	3.6	77.9	89.9	5	35.7
	I&C	14	73.3	9.4	56.7	85.7	2	14.3
	FFS	13	77.8	5.6	68.9	85.4	1	7.7
	Operations	12	82.1	6.5	69.2	90.7	4	33.3
	Plant Total	**67**	**78.6**	**6.9**			**14**	**20.9**
	Total Across Plants	**246**	**78.6**	**6.1**			**46**	**18.7**

Table 7. 90-TL SEG's Descriptive Statistics per Plant and SEG

Plant	SEG	No. Samples	Mean (dBA)	SD (Dba)	Min (dBA)	Max (dBA)	No.>90	%>90
1	Electricians	12	73.1	8.6	61.4	86.9	0	0
	Mechanics	14	79.0	8.0	57.5	89.5	1	7.7
	I&C	8	63.9	5.1	55.7	68.7	0	0
	FFS	10	64.4	4.2	59.7	72.0	0	0
	Operations	8	75.2	17.8	38.2	90.2	1	12.5
	Plant Total	**51**	**71.8**	**9.5**			**2**	**3.9**
2	Electricians	13	71.6	6.5	61.3	79.8	0	0
	Mechanics	14	79.2	6.3	65.1	90.4	1	7.1
	I&C	11	74.0	5.7	63.9	81.6	0	0
	FFS	13	68.6	9.0	57.6	82.5	0	0
	Operations	16	75.9	6.0	67.6	85.4	0	0
	Plant Total	**67**	**74.0**	**6.8**			**1**	**1.5**
3	Electricians	14	71.6	6.7	64.9	89.7	1	7.1
	Mechanics	13	79.5	4.2	72.3	86.8	0	0
	I&C	11	66.8	6.6	52.1	75.9	0	0
	FFS	11	80.9	7.4	70.2	91.3	1	9.1
	Operations	12	78.4	8.3	70.3	87.8	0	0
	Plant Total	**61**	**75.4**	**6.7**			**2**	**3.3**
4	Electricians	14	71.4	10.5	58.1	91.6	1	7.1
	Mechanics	14	80.5	7.2	62.9	89.4	0	0
	I&C	14	66.3	12.4	50.2	84.9	0	0
	FFS	13	71.4	7.7	65.1	81.1	0	0
	Operations	12	79.0	9.7	61.3	90.2	1	8.3
	Plant Total	**67**	**73.6**	**9.7**			**2**	**2.3**
	Total Across Plants	**246**	**73.8**	**8.2**			**7**	**2.8**

Table 8. Recommended Heat Stress Guidelines

	Plant 3			Plant 5				
Area Recommended Heat Stress Guidelines	Total # Samples	# Over Exposures	% Over	Total # Samples	# Over Exposures	% Over	Principle Factor Influencing Elevated Levels	Recommended Controls
ACGIH TLV[1]								
1-Hour TWA	41	14	34	40	8	20	▪ Elevated Temperatures ▪ Percent Rest During Elevated Levels Is Low ▪ Metabolic rate ▪ Rest for Exceeds At Plant 3 is Considerably Less	▪ Increase Rest ▪ Decrease Metabolic Rate ▪ Decrease Temperature If Possible
2-Hour TWA	22	5	23	24	2	8		
OSHA[2]								
1-Hour TWA	41	17	42	40	9	23		
2-Hour TWA	22	6	27	24	2	8		
ISO 7243								
1-Hour TWA	41	13	32	40	5	13		
2-Hour TWA	22	5	23	24	2	8		
NIOSH Ceiling	49	6	12	50	2	4	▪ Metabolic Rate Is High ▪ Temperatures Are Elevated	▪ Personal Protective Equipment ▪ Decrease Metabolic Rate
EPRI[3]	49	0	0	50	0	0	▪ No Elevated Levels	This Method is Less Conservative and Should be Only Implemented When Self-Determination and Training used
Heat Stress Index[4]	49	11	22	50	12	24	▪ Metabolic Rate Is High ▪ High Temperatures	▪ Acclimated Individuals ▪ Supervision

1 – ACGIH TLV is Identical to NIOSH 1986 RELs and RALs
2- Identical to 1992-1993 TLV Values
3-Electric Power Research Institute-Heat Stress Management Program for Power Plants
4-Belding and Hatch Heat Stress Index

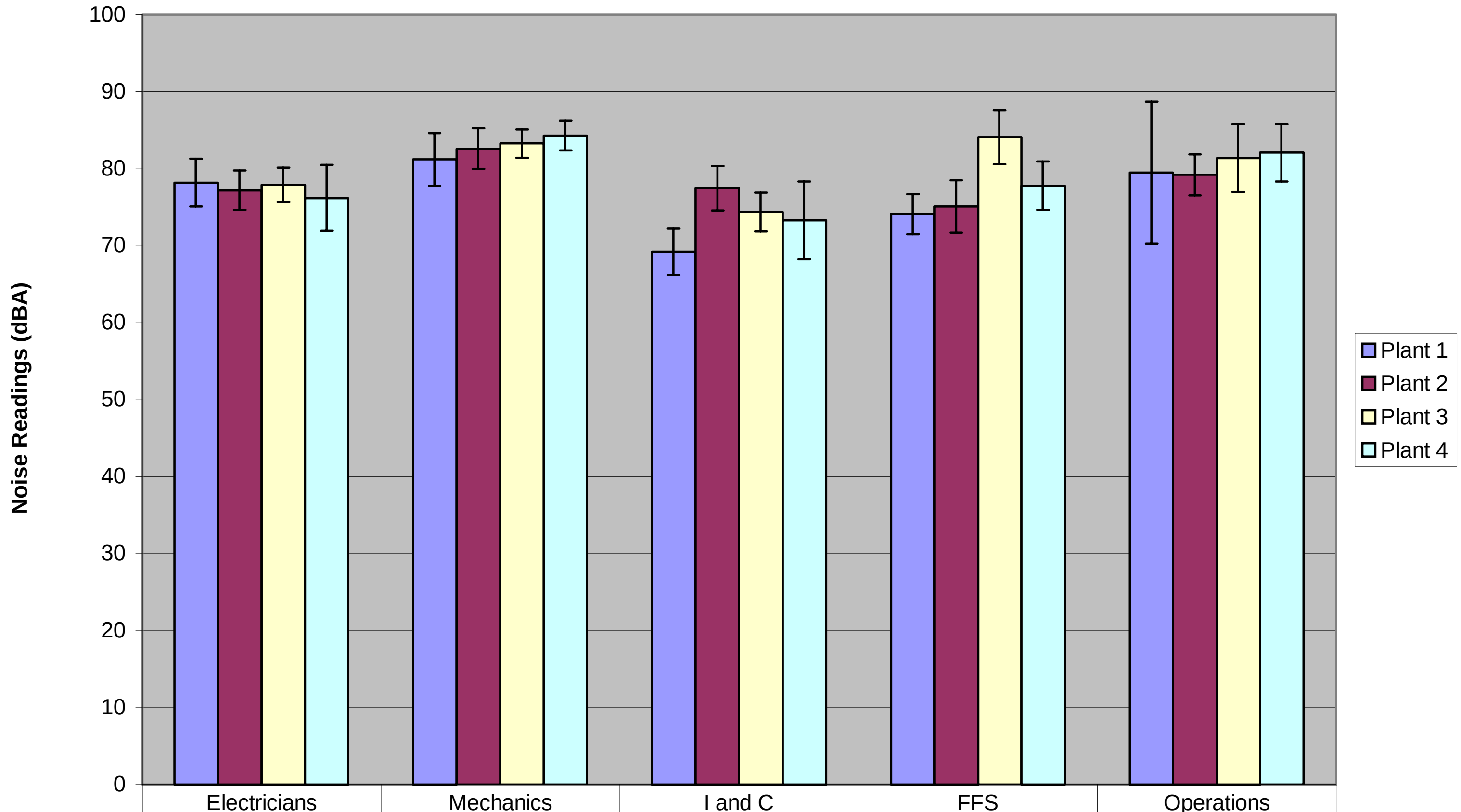
Table 9. Exceeded Individual Physiological Response Results

Employee	**No. of Exceeds During Shift**	**Guideline Exceeded**	**Other Recommendation Exceeded**
5-1	1	-Sustained Peak HR for 17 minutes	-1-Hr TWA -Ceiling Values -HSI Greater than 100
5-2	1	-Predicted Core Temp. of 38^{o}C -Sustained Peak HR for 13 minutes	-1-Hr TWA -Ceiling Values -Allowable Time for HSI Exceeded
3-1	2	- Predicted Core Temp. of 38^{o}C	-Allowable Time for HSI Exceeded for Second Exceed -Ceiling Values Exceeded for Both
3-2	1	- Predicted Core Temp. of 38^{o}C	-2-Hr TWA -HSI Greater Than 100

1-HR=Heart Rate
2=bpm=beats per minute

Table 10. Descriptive Statistics of Values Above Recommended Levels

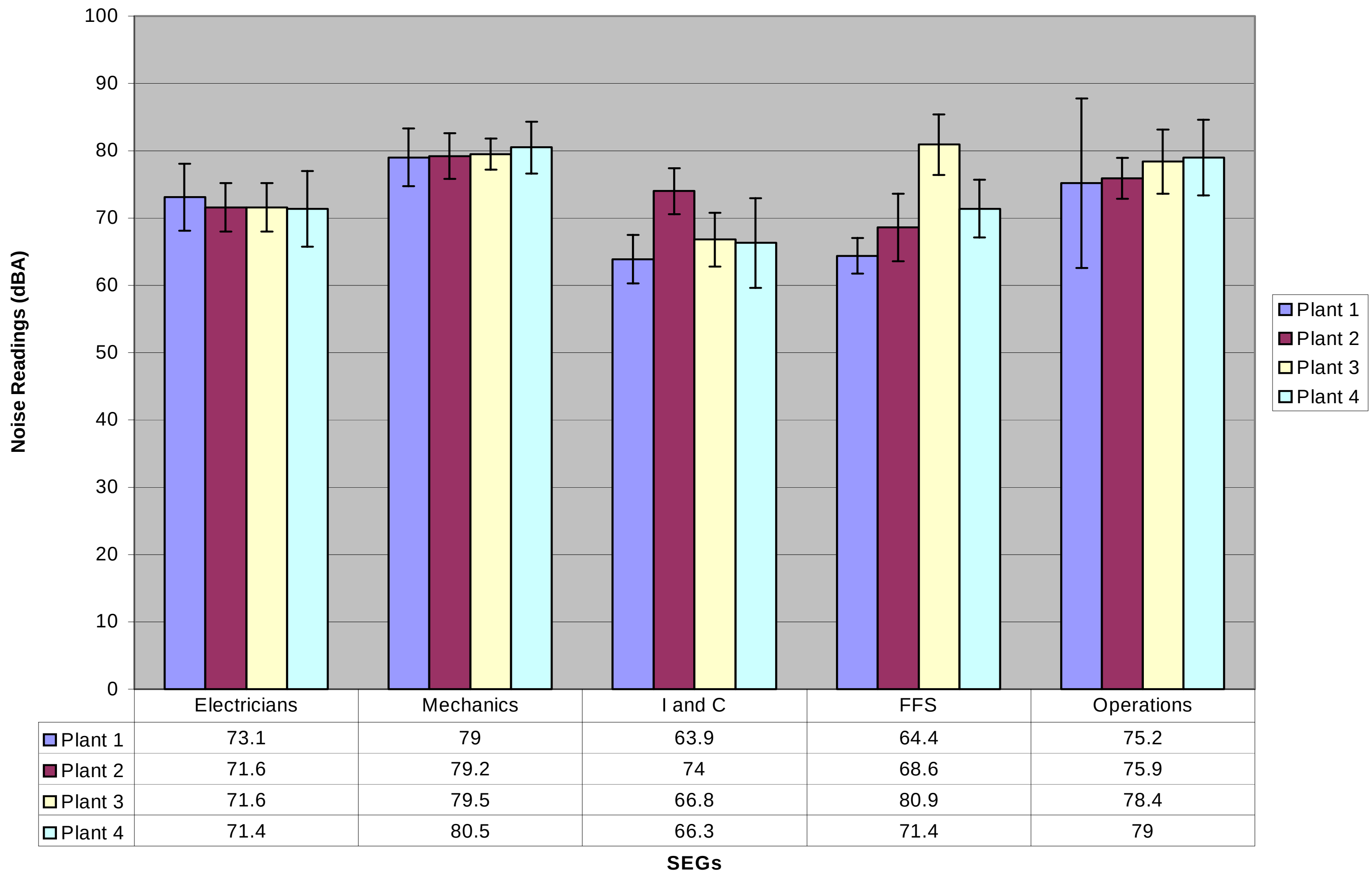
Plant	TWA	# Above Recommended Values	% Above Recommended Values	Mean Watt (SD)	Mean WBGT (SD)	Mean % Rest (SD)	# ≤ 25% Rest	% of aboves ≤ 25% Rest
Including All overexposures								
5	1-Hr	9	22.5	244.21 (41.1)	30.5 (1.44)	23.6 (19.0)	6	66.7
3	1-Hr	17	41.5	282.6 (29.9)	29.9 (2.1)	7.2 (10.2)	16	94
5	2-Hr	2	8.3	228 (9.9)	29.7 (0.92)	24 (18.4)	1	50
3	2-Hr	6	27.3	289.7 (33.7)	29.2 (1.54)	10.5 (9.63)	6	100
Including RELs/TLVs overexposures								
5	1-Hr	8	20	241.2 (42.9)	30.9 (0.90)	25 (19.7)	5	62.5
3	1-Hr	13	31.7	282.0 (33.3)	30.6 (1.9)	9.46 (10.7)	12	92.3
5	2-Hr	2	8.3	228 (9.9)	29.7 (0.92)	24 (18.4)	1	50
3	2-Hr	5	22.7	288.4 (37.5)	29.2 (1.62)	7.8 (7.8)	5	100



	Electricians	Mechanics	I and C	FFS	Operations
Plant 1	78.2	81.2	69.2	74.1	79.5
Plant 2	77.2	82.6	77.5	75.1	79.2
Plant 3	77.9	83.3	74.4	84.1	81.4
Plant 4	76.2	84.3	73.3	77.8	82.1

SEGs

Figure 1: 80-TL by Plant and SEGs (Actual Data Means with ± 2SE)



	Electricians	Mechanics	I and C	FFS	Operations
Plant 1	73.1	79	63.9	64.4	75.2
Plant 2	71.6	79.2	74	68.6	75.9
Plant 3	71.6	79.5	66.8	80.9	78.4
Plant 4	71.4	80.5	66.3	71.4	79

Figure 2: 90-TL by Plant and SEG (Actual Data Means with ± 2SE)

CHAPTER 4

CONCLUSION

The data presented indicate that the chemical hazards asbestos, inorganic arsenic, respirable coal dust, and silica exposures during routine activities of coal-fueled power plants are expected to be below the occupational exposure values (OEVs). The chemicals of concern do not differ among the facilities of the power-generating company or the SEGs formed. However, there is a potential for levels above the OEVs if coal or ash buildup is not cleaned from equipment prior to beginning work. Although coal dust levels were low at Plant 3, the method of cleaning the tripper floors (floor where coal is brought inside the plant) with compressed air is an undesirable cleaning method and should be replaced with a less potentially-dangerous method. Methods from other facilities should be evaluated to determine if their cleaning methods would be more effective. The evaluation included those activities that were performed on a day-to-day routine basis, but there may be unique maintenance activities that should be evaluated on an individual basis, and monitoring should be conducted if high exposures are expected.

Area noise-measurement data of the plants concluded that the coal-fueled power plants have the potential to exceed the acceptable 90-dBA permissible exposure level (PEL) established by the Occupational Safety and Health Administration (OSHA).[1] Personal noise monitoring concludes that all SEGs have the potential to exceed the hearing-conservation program level of 85 dBA (18.7%). All the SEGs, except

I&C, also had employees (2.9%) who exceeded the PEL of 90 dBA. The statistical analysis with a significance of p=0.05 concludes that the means of the SEG FFS are different among Plant 3 and all the other plants (1,2, and 4) for both the 80 and 90-TL levels. The means of the SEG I&C are also significantly different (p=0.05) between Plants 1 and 2 for the 80-TL. The Mechanics and Operations SEGs were the highest-exposure groups at all the plants with the exception of FFS at Plant 3 for the 80-TL. The levels dropped for all SEGs at the 90-TL with all plants having only a total of seven personal noise samples above the 90-TL.

It is recommended that the employees continue wearing hearing protection inside the plant and fossil fuel services area where noise hearing-protection signs are designated. Employees should also wear hearing protection while operating heavy equipment or while operating loud tools while inside the shop areas. The hearing-conservation program already implemented at the facilities should remain intact for all SEGs and plants, but the program could be refined for the SEG I&C at all plants except Plant 4. Plant 4 had personal noise levels above the 85 dBA requirement. The company should evaluate the Mechanics and Operations SEGs to determine if additional measures should be taken to protect the hearing of these individuals. It would also be advisable for the company to determine the reason for the unusually high levels associated with the SEG FFS at Plant 3. The increased amount of coal that is run at the facility is probably the major reason for increased noise readings; however, it may also be associated with the cleaning method used. Additional monitoring is recommended to determine the reason for the increased noise. If the cleaning method is the reason for the increased noise levels, the method should be replaced with a less-noisy method.

The study found that heat stress is the biggest issue that should be addressed in the facilities. ACGIH[2] and NIOSH[3] values were exceeded for both the 1-hour and 2-hour TWAs and for the ceiling limits. The data suggests that some of the limits would not have been exceeded had the metabolic rate decreased and/or the percent rest increased. However, by evaluating the data individually, it also suggests that WBGT levels were too high to be accommodated by using the time-weighted-averages (TWAs) recommendations (ex. TLVs, RELs, ISO[4] etc.). An evaluation using ceiling and/or a heat exchange analysis would have been more appropriate for the situation. More-detailed analysis using the EPRI method concludes that there are areas of potentially high and moderate heat stress, but the employees are generally working well below the required time. This method should be used with caution since it is based on the ISO 7933[5] standard, which has some shortcomings,[6-8] and because this less-conservative method allows for a higher body core temperature increase. Physiological monitoring indicates approximately 20% of the employees monitored were working above at least one of the physiological suggested limits. However, the equipment used for such monitoring data also has shortcomings.[9-11]

Due to the fact that employees went beyond the recommended levels for both the TWAs and ceiling values, measures should be taken to insure the safety of the employees. Physiological monitoring methods should be evaluated, and the most appropriate method for the situation should be implemented. Physiological monitoring conducted by this survey is not suggested for use because of the uncertainties associated with the reliability of the measuring devices and the cost that would be required for their use.

During the survey, several concerns and suggestions were noted that could help prevent potential heat strain in the future. There are six suggestions to help prevent heat strain at the facilities. Consumption of water should be increased. Smaller quantities of water should be drunk more frequently. Employees could take small water coolers to the work area in order to take more frequent mini waterbreaks. Work areas and air-conditioned break areas are often too distant from each other. If possible, break areas should be located closer to the work areas. Employees should know where a cool area is located at all times. The designated cooler area may simply be a stairway that is generally much cooler than the work area. Small, air-conditioned rooms could be constructed near hot working areas. This should encourage shorter, more-frequent breaks. As presented in the EPRI report, for jobs that require longer work durations in the same location, tents with portable air conditioners could be erected for the duration of the work activity. However, the report cautions that the use of air conditioners in such a manner may cause surface contaminants to become airborne; therefore, this method should be used with caution.(12)

Personal protection should be used when WBGT levels, combined with metabolic rates, are exceeding the NIOSH ceiling values. NIOSH states that no person should work in areas above the recommended ceiling values without proper personal protection.(3) Evaluations and field tests should be conducted to determine the protection that would work best and be best received by the employees that must use the devices. It should be noted that equipment required for short work bouts in moderate to hot environments might not be the equipment needed for extended work in extremely hot conditions. For example, if an employee works 15 minutes before taking a break and then works 15 minutes again after a 30 to 45-minute break, the employee would not necessarily need to use the same personal-protection equipment as for a job that will take longer or for jobs where breaks cannot be taken as often. Many times personal protective equipment will require a setup that can be straining in hot conditions. The employer should not only provide the equipment, but the employer should determine the best way to implement the equipment's use. Therefore, one type of personal protective equipment may not suit the needs of the employees in all areas and work activities at the plant.

Employees in all the facilities should continue training, and acclimation should take place as the hot summer months approach. New employees should be given special consideration during the acclimation process to determine if they are physically fit and able to endure the hot environments. Training should include a lifestyle of healthy habits that will improve the employee's adaptation to the heat. The employee should be made aware that drugs have the potential to cause decreased tolerance to heat. As practiced at the facilities, any job in a hot environment should be done in the cooler part of the day or year if possible. The EPRI report also outlines several potential methods that could be used to decrease the heat-stress potential. They are as follow: (a) Engineering Controls: cool room or tents (as mentioned above) and portable cooled-air blowers (b) Administrative Controls: scheduling hot work for cooler times (c) Personal Protection: circulating air systems, ice-cooling garments and liquid-cooling systems. A more detailed explanation can be found in the EPRI report and in the literature concerning the evaluations of personal protective equipment of heat stress.(12)

Overall, heat stress is the main issue of concern at these facilities. Controls and practices could help reduce the risk of heat strain. Although heat stress is the major issue, unique maintenance activities should not be overlooked if there is a potential for elevated arsenic or respirable dust exposures. Maintaining the hearing-conservations program for noise at the facilities should help prevent noise-induced hearing loss of the employees.

REFERENCES

1. **Occupational Safety and Health Administration (OSHA), U.S. Department of Labor:** "Occupational Noise Exposure Standard (29 CFR 1910.95)." [Online]. Available at http://www.osha.gov (Accessed January 16, 2002)

2. **American Conference of Governmental Industrial Hygienists (ACGIH):** 7th Edition Documentation of the Threshold Limit Values For Physical Agents. Cincinnati, OH: ACGIH, 2001.

3. **National Institute for Occupational Health and Safety (NIOSH):** Criteria for a Recommended Standard. Occupational Exposure to Hot Environments (DHHS [NIOSH] 86-113). Washington, DC: U.S. Governmental Printing Office, 1986.

4. **International Organization for Standardization (ISO):** "Hot Environments-Estimation of the Heat Stress on Working Man, Based on the WBGT Index (Wet Bulb Globe Temperature)" (ISO 7243). Geneva: ISO, 1989.

5. **International Organization for Standardization (ISO):** "Hot Environments-Analytical Determination and Interpretation of Thermal Stress Using Calculation of Required Sweat Rate (ISO 7933). Geneva: ISO, 1989.

6. **Kampmann, B. and C. Piekarski:** The Evaluations of Workplaces Subjected to Heat Stress: Can ISO 7933 (1989) Adequately Describe Heat Strain In Industrial Workplaces. *Applied Ergonomics.* 31: 59-71 (2000)

7. **Malchaire, J., A. Piette, B. Kampmann, P. Mehnert, H. Gebhardt, G. Havenith, E. Den Hartog, I. Holmer, K. Parsons, G. Alfano and B. Griefahn:** Development and Validation of the Predicted Heat Strain Model. *Ann Occup Hyg.* 45: 123-135 (2001)

8. **Forsthoff, A.**, **P. Mehnert, and H. Neffgen:** Comparison of Laboratory Studies with Predictions of the Requried Sweat Rate Index (ISO 7933) for Climates with Moderate to High Thermal Radiation. *Applied Ergonomics.* 32:299-303 (2001).

9. **Green, J.M., A.J. Clapp, D.L. Gu, and P.A Bishop:** Prediction of Rectal Temperature by the Questemp II Personal Heat Strain Monitor Under Low and Moderate Heat Stress. *Am Ind Hyg Assoc J.* 60:801-806 (1999).

10. **Muir, I.H., P.A. Bishop, R.G. Lomax, and J.M Green:** Prediction of Rectal Temperature From Ear Canal Temperature. *Ergonomics.* 44: 962-972 (2001).

11. **Reneau, P.D. and P.A. Bishop:** Validation of a Personal Heat Stress Monitor. *Am Ind Hyg Assoc J.* 57:650-657 (1996).

12. **Bernard, T.E., W.L. Kenney, L.F. Hanes, J.F. O'Brien:** "Heat Stress Management Program for Power Plants," (NP4453L). Palo Alto, CA: Electric Power Research Institute, 1991