This Health Hazard Evaluation (HHE) report and any recommendations made herein are for the specific facility evaluated and may not be universally applicable. Any recommendations made are not to be considered as final statements of NIOSH policy or of any agency or individual involved. Additional HHE reports are available at http://www.cdc.gov/niosh/hhe/reports

HETA 90-0395-2121
JUNE 1991
INTERNATIONAL ASSOCIATION
OF FIRE FIGHTERS (IAFF)
KANSAS

NIOSH INVESTIGATORS:
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I. SUMMARY

On September 20, 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation from the International Association of Fire Fighters (IAFF) to assess the health and safety practices during a brush fire on September 6, 1990, in Sedgwick County, Kansas. A 25-year-old firefighter died of heat stroke at the scene.

During November 13-15, 1990, NIOSH conducted a site visit to Sedgwick County Fire Department in Wichita, Kansas. The visit included a tour of the fire scene, personal interviews with 25 firefighters and support personnel, and review of incident reports, incident command procedures, and other documents.

Upon arriving at the fire scene on September 6, 1990, the firefighter and the captain advanced separate booster lines and fought the brush fire for approximately one hour. Then, the firefighter rested at the engine alone while the captain of the two-man engine company reported to command. Upon arriving at the command station, the captain reported that the firefighter was in need of rehabilitation; then the captain entered rehabilitation. Over the next few hours several individuals mistakenly identified other firefighters as the downed firefighter and assured his captain that he had rested and was then reassigned. The firefighter's body was discovered during cleanup operations.

On the basis of the information obtained during this investigation, the NIOSH investigators concluded that a preventable series of events preceded the firefighter's death. Recommendations for incident command and safety procedures, as well as medical monitoring, rehabilitation of firefighters at fire scenes, and rehydration schedules are present in Section VI of this report.

KEYWORDS: SIC 9224 (Fire Protection), Fire Fighters, Firefighters, Heat Stress, Heat Stroke, Mortality.

II. INTRODUCTION

On September 20, 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request from the International Association of Fire Fighters (IAFF) to assess the health and safety practices during a brush fire on September 6, 1990, in Sedgwick County, Kansas. A 25-year-old firefighter died of heat stroke at the scene.

Prior to the site visit NIOSH representatives from the Hazards Evaluation and Technical Assistance Branch and the Protective Equipment Section reviewed relevant documents including after-incident reports, emergency medical service reports, the decedent's autopsy report, and department policies addressing physical exam schedules, and physical conditioning requirements.

During November 13-15, 1990, NIOSH made a site visit to the Sedgwick County Fire Department (SCFD) in Wichita, Kansas. Accompanied by union and fire department representatives, NIOSH toured the fire scene. Private interviews were conducted with SCFD firefighters, administrators, and support personnel, volunteer firefighters, and Emergency Medical Service (EMS) personnel.

Additional information requested and reviewed included aerial and land photographs taken the day following the fire, a transcription of the incident dispatch tape, "Standard Operation Principles and Procedures" policy, plot maps of the housing addition in which the fire occurred, an itemized list with weights of the deceased firefighter's personal protective clothing and personal possessions, weather data, and additional narrative reports from firefighters who were at the scene.

This report summarizes work practices as they affected the health and safety of the firefighters, including incident command system, safety management, and medical services; discusses heat stress; and proposes recommendations.

III. BACKGROUND

The Sedgwick County Fire Department (SCFD) Fire Suppression Division employs approximately 80 firefighters, 15 lieutenants, 21 captains, and 3 division chiefs. The department primarily responds to fires within Sedgwick County that are outside the Wichita city limits.

The deceased firefighter was 24 years old when he began working for the SCFD in December 1989. He was reported to have been in good health and physical condition. His pre-employment physical examination recommended employment without restrictions.

As reported in the SCFD Fire Investigation Summary, at approximately 10:30 a.m., a Sedgwick County resident ignited a trash pile, containing

household trash, cans, glass, and aerosol cans, that was located about 30 feet southwest of his prefabricated modular home. The temperature was 95°F and winds were blowing out of the southwest at 17-28 miles per hour. The fire spread to the surrounding area. The first SCFD engine was dispatched at 11:42 a.m. and arrived at the scene at 11:57 a.m. Additional engines, tankers, and personnel were immediately dispatched. In total, eighteen SCFD units, including four engines, responded to the alarm. Additionally, nineteen volunteer firefighters from nearby towns assisted.

Winds gusted throughout the afternoon at up to 35 miles per hour, and temperatures remained in the mid-nineties. Fire consumed most of the area behind the residence on Lot 11, and the majority of Lot 10, igniting many of the junked cars, and spread to several adjacent properties (Figure 1). None of the homes in the area, nor the vacant mobile home on Lot 10, sustained fire damage. Firefighters battled the blaze for three hours before bringing it under control. Cleanup was completed, and the last unit left the scene at 9:13 P.M.

IV. DISCUSSION AND FINDINGS

Management of the Fire Incident

Management of Fire Department day-to-day activities is usually vested in a Fire Chief or other titled person who serves as the commander of the fire suppression forces and their activities, including the safety of operating firefighters.[1]

To assist in the management (especially in the operation, coordination, and effectiveness) of wide-scale fire suppression activities, a system was developed for controlling personnel, facilities, equipment, and communications. This system is known as the Incident Command System (ICS).[2] A further refinement of the ICS was later developed by fire service organizations to address all types of emergency incidents and included performance criteria for the components of a system that addressed specific safety and health objectives. This has been developed into a nationally recognized standard known as the Incident Management System (IMS).[3] The National Fire Protection Association has recognized and documented the consequences of operating without such an Incident Management System, resulting in numerous deaths and injuries of firefighters.[3,4]

Safety Management and IMS

In establishing and utilizing IMS, the first priority must be life safety.[2,5] The responsibility for this priority issue is that of the officer in command of the emergency incident.[4,5] The incident commander is responsible for the overall safety of all members and all activities occurring at the scene. The Fire Chief, however, bears the ultimate responsibility for the safety and health of all members of the Department.

The IMS encourages the delegation of authority (but not responsibility) for the safety function at an incident to a firefighter or other competent person, who is specially trained and knowledgeable in safe emergency operations.[2,6] The failure to delegate causes conflict between the positions of command and safety. IMS guidelines generally recommend that the command officer, who is responsible for managing the incident on the strategic level, establish and operate from a stationary command post as soon as

possible after arriving on the scene.[5] In contrast, the delegated safety officer must routinely observe operations at the scene of an incident. This means he must have full authority to move around the incident scene (fire ground) to observe and control safety concerns.[5] Based on the investigation of the September 6 fire, NIOSH found that there was no one in authority who was free to assist the firefighters in recognizing, evaluating, or controlling fire ground hazards.[4]

Medical Services

Medical services should be provided and staffed by the most highly trained emergency medical personnel on the scene. At a minimum, these should be Emergency Medical Technician-A (Basic Life Support) personnel.[5] Their responsibility is to evaluate vital signs and examine firefighters, provide a tentative diagnosis, treat them, and dispose (return to duty, rehabilitation, transport to medical facility). Rehabilitation treatment should consist of additional monitoring of vital signs, removing personal protective equipment, providing rest, and giving forced rehydration.[5] Additionally, these evaluations must be recorded on standard forms along with the patient's identity and complaints and must be signed, timed, and dated.[7]

Medical personnel on the scene of a fire incident should be competent to identify when there may be danger of heat stress, to evaluate, and to manage emergencies.[7,8] Rehabilitation of stressed firefighters was attempted at the September 6 fire, but documentation of proper medical evaluation and disposition was not completed.

A prime feature of IMS is the coordination of interagency response.[6] There was purportedly no agreement for the response of emergency medical services to fire ground emergencies in Sedgwick County. Hence, there was some difficulty in coordinating the activities of the County Fire Department and those of the EMS.

PASS (Personal Alert Safety System)

The PASS is a small (cigarette pack size) electrical device which sounds a distinctive audible alarm when either activated manually or automatically if no movement of the firefighter can be detected in any 30-second period.[9] Most recommendations are that the PASS devices be worn at all times.[4,9]

The Sedgwick County Fire Department had provided PASS devices to the firefighters; however, department policy is that it be worn on the Self Contained Breathing Apparatus (SCBA) harness. PASS devices were therefore not available for use, as the firefighters were not wearing the SCBA (reports received by NIOSH indicate that conditions did not warrant the use of SCBA on this brush fire).[10]

Personal Identifiers and Assignment

Standard recommendations for fire ground operations require a system to account for the identity and assignment of fire personnel on the scene.[3,4,5] This may consist of roll calls during the incident, special markings on the individual's coat and/or helmet, etc. Additionally, some fire departments distinctly equip firefighters not yet fully qualified for a particular level of training or experience with a piece of personal protective equipment (e.g., helmet or protective coat) of a distinctive color so that they and their

operations can receive additional supervision on the fire ground.

Staffing

A two-firefighter engine company is, at a minimum, 50% understaffed and increases the work effort of the two firefighters by a factor of three.[4,11,12] In a brush fire where one firefighter operates the pump, the second person is left to pull 200' of booster through rough terrain covered with low-lying undergrowth. At the September 6 fire, the pump was left unattended and each of the two firefighters advanced a separate booster line up to 200' in opposite directions from the engine.

Heat Stress

The relevant environmental data were obtained from the National Weather Service, Wichita Station, for September 6, 1990, and are summarized in Table 1. Firefighters face a high risk of heat injury under these conditions due to the heavy work they must perform and the protective clothing they must wear. While insulating firefighters from the high radiant heat loads at the fire scene, protective clothing also limits the ability to lose heat through sweat evaporation. However, full firefighter protective clothing was appropriate for this particular fire incident, due to the potential hazard from exploding vehicle gas tanks. The protective coat and trousers were constructed as follows: The outer shell was of Nomex® 7-1/2 oz. Aramid 3®, treated with Zepel® as a water repellent. A moisture barrier of Gore Tex® with a Nomex® face cloth, and a thermal liner of 7-1/2 oz. Nomex® face cloth quilted to 100% Nomex® batt face cloth.

The two most serious heat-related illnesses are heat exhaustion and heat stroke. According to the NIOSH document, Occupational Exposure to Hot Environments, Revised Criteria, 1986[13], symptoms of heat exhaustion include fatigue, nausea, headache, dizziness, pallor, weakness, and thirst. Factors which may predispose a person to heat exhaustion include sustained exertion in the heat, failure to replace the water lost in sweat, and lack of acclimatization. Heat exhaustion responds readily to such prompt treatments as moving to a cooler environment, resting in a recumbent position, and administering fluids by mouth.

Heat stroke is the more serious of the heat-related illnesses and is considered a medical emergency. Symptoms of heat stroke include hot, red, dry skin, a rectal temperature of 104°F (40°C) or above, confusion, possible convulsions, and/or loss of consciousness. Factors which may predispose a person to heat stroke include sustained exertion in the heat by unacclimatized workers, lack of physical fitness, obesity, recent alcohol intake, dehydration, individual susceptibility, and chronic cardiovascular disease.[11] Immediate treatment of suspected heat stroke is required. Treatments to reduce body temperature rapidly include immersing in chilled water, rinsing with alcohol, wrapping in a wet sheet, and/or fanning with cool, dry air. A physician's care is required to treat possible secondary disorders such as shock or kidney failure. While heat exhaustion cases greatly outnumber heat stroke cases, every case of heat exhaustion should be treated as having the potential to develop into heat stroke.

Acclimatization is a physiological adaptation to heat stress that occurs over a short period of time. After acclimatization has occurred, the body sweats more while losing less salt and can maintain a lower core temperature and lower cardiovascular demands.

A person becomes acclimatized to a certain work intensity and temperature with repeated exposures to that work load and temperature. Formal acclimatization procedures may not be necessary for all firefighters; however, training drills should be held outdoors regularly so that seasonal acclimatization can occur. For additional protection against heat stress, firefighters may want to perform their regular aerobic training activities outdoors, especially in the spring and summer.

The metabolic demands of firefighting range from 60 to 100% of maximum aerobic capacity. Tasks such as stair climbing, roof venting, and rescue operations, when performed in full gear, have an energy cost of 85 to 100% of maximum capacity and lead to near maximum heart rates. It is clear from these estimates that a high level of cardiovascular fitness is an advantage in performing firefighting tasks. The higher level of fitness would allow a longer work period and provide a greater reserve in case of an unexpected increase in work demands or in extreme environmental conditions.

There are fire incidents during which even the fittest, most acclimatized firefighter will be exposed to significant heat stress. For this reason, many fire departments have adopted formal procedures for on-scene rehabilitation and have incorporated them into their standard operating procedures manuals. The general goals of rehabilitation are the following: 1) to provide physical and mental rest, allowing the firefighter to recuperate from demands of emergency operations and adverse environmental conditions, 2) to revitalize firefighters by providing fluid replacement and food as needed, and 3) to provide medical monitoring , including treatment of injuries, to determine if and when firefighters may return to action.

V. CONCLUSION

According to the Sedgwick County Coroner, the primary cause of the death of the firefighter was heat stroke. The factors contributing to this particular death due to heat stroke include exposure to a hot ambient temperature ($\geq$95°F), a high radiant heat load, and performance of moderate to heavy work while wearing protective clothing.

Events that preceded the firefighter's death included singly advancing a booster line and fighting the brush fire for approximately one hour, then resting at the engine alone while the captain of the two-man engine company reported to command. Upon arriving at the command station, the captain reported that the firefighter was in need of rehabilitation; then the captain entered rehabilitation. Over the next few hours several individuals mistakenly identified other firefighters as the downed firefighter and assured his captain that he had rested and was then reassigned. The firefighter's body was discovered during cleanup operations.

On the basis of the information obtained during this investigation, the NIOSH investigators concluded that a preventable series of events preceded the firefighter's death.

VI. RECOMMENDATIONS

1. The positions of command and safety must be separated at complex fire scenes where there are multiple fire companies and equipment, mutual aid responses, multiple exposures from a fire ground covering a large area, and so forth. Such

separation will allow the Safety Officer to function in a manner consistent with the duties recognized as appropriate and as established by department standard operating procedures.

2. The Department should make the wearing of PASS devices mandatory for all firefighters any time they are involved in rescue, firefighting, or other hazardous duties. Rescue operations should begin immediately upon such an alarm or whenever there is difficulty in locating operating crews.

3. Firefighters operating at emergency incidents must always operate in teams of two or more (buddy system). A buddy system allows two firefighters to observe each other for signs of medical emergencies such as heat stress and to provide help to each other if needed. Another obvious advantage of a buddy system is to permit firefighters to share work, thereby reducing the metabolic heat they produce and in turn reducing the heat stress. All firefighter team members operating in hazardous areas must be in communication with each other and with incident command through visual, audible, physical, electronic, or other means in order to provide assistance in case of emergency.

4. To aid in the overall management of the fire scene and to assist the fire ground commander and firefighter teams in recognition and control, personal markings to insure positive identification of individuals, such as fluorescent and retroreflective name tags/letters should be affixed to protective coats, helmets, or equipment.

5. Inexperienced firefighters must be provided with additional supervision. Experience must not be solely dependent on the period of employment, but also on the type of fires fought (brush, residential, commercial, etc.) If there are only one or two of a particular type of fire a year, it may take more than 1 year (usual probationary period) to gain the necessary experience in fighting that type of fire.

6. Search and rescue operations should be initiated immediately upon reports of personnel in trouble or upon failure to locate operating crews.

7. The replacement of fluids (water) lost in sweat is the most practical work practice a firefighter can adopt to protect himself against heat-related illness. Since thirst is an insufficient indicator that lost fluids have been replaced, firefighters should be encouraged to drink beyond the point of thirst while on a call or after an aerobic workout. Ideally, 5 to 7 ounces of water should be consumed every 15 to 20 minutes during firefighting activities. Salt tablets should not be used.

8. Regardless of the size of the fire department, procedures concerning rehabilitation should be included in the department's standard operation procedures. These procedures should include guidelines for initiating and enforcing rehabilitation efforts and managing the resources and personnel within the rehabilitation sector. The responsibility for initiating the appropriate rehabilitation efforts should belong to the incident commander. When the incident size is large or the level of physical exertion and/or environmental conditions are extreme, the implementation of rehabilitation procedures should be considered by the incident commander. The rehabilitation sector should be located in an area outside the operational activity

area, where protective equipment and clothing can be safely removed. Resources should consist of a mobile canteen, a shady or air conditioned area for resting, and an advanced life support unit.

9. The Department should conduct periodic reviews of heat stress-related topics for fire department members. Such topics as recognizing the signs and symptoms of heat-related illnesses, rehydration after firefighting and exercise activities, and acclimatization should be included in the training. The Sedgwick County Fire Department's Health/Fitness Manual could be used as a resource for this training.

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Copies of this report have been sent to:

1. Sedgwick County Fire Department, Wichita, Kansas
2. International Association of Firefighters, Local 2612
3. International Association of Firefighters, Washington, D.C.
4. Occupational Safety and Health Administration

Copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

TABLE 1

Environmental Conditions
September 6, 1990, Wichita, Kansas

International Association of Firefighters (IAFF)
Sedgwick County, Kansas

HETA 90-395

Time	Temp (°F)	Dew Point (°F)	Wind Speed	Visibility
11:52 AM	95	55	24	Scattered to broken
12:51 PM	95	57	23	cloud cover, 12 miles
1:51 PM	95	57	22	visibility
2:51 PM	98	52	18	
3:50 PM	96	53	26	

TABLE 2

Recommended Exposure Limits Based on Dry Bulb Temperature for Firefighters in Turnout Gear (°F)*

International Association of Firefighters (IAFF)
Sedgwick County, Kansas

HETA 90-395

Work/Rest Regimen	Work Load Moderate	Heavy
Continuous work	80°F	77°F
75% Work/ 25% Rest, each hour	82°F	78°F
50% Work/ 50% Rest, each hour	85°F	82°F
25% Work/ 75% Rest, each hour	88°F	86°F

* Temperatures represent dry bulb values substituted for Wet Bulb Globe Temperature (WBGT) values in Table 1, p.88, of the Threshold Limit Values.[2]

APPENDIX I

Chronology of The Fire

The fire under investigation occurred in a rural residential area in the far southeast corner of Sedgwick County, Kansas. Lots in the immediate vicinity range in size from 7/10 to 1/2 acres. Most of the residences are prefabricated construction. The gently rolling terrain is covered by a heavy weed undergrowth and small trees. The soil is sandy.

Lot 11, on which the fire began, is nearly rectangular and covers about 1/2 acres (Figure 1). One prefabricated house sets approximately 110 feet west of the road near the south border of the lot and faces east south-east. Lot 10 is north of Lot 11 and is of similar size and shape, but has fewer trees. A salvage yard, with over 50 junked automobiles, covers most of Lot 10. An uninhabited mobile home is near the north edge of the property line.

EMS Activities

SCFD did not have a formal agreement as to the role of Sedgwick County EMS in the rehabilitation of fire fighters at fire scenes. However, it is common practice for EMS to be called to stand by in the event that a fire fighter requires emergency treatment and transport. However, according to transcripts and charting of the incident, an EMS medic was assigned to be in charge of medical operations at the scene. SCFD Medical Quality Control Officer, an emergency medical intensive care technician (EMICT), was assigned to be an aid for the incident commander. However, she assisted with rehabilitation of several firefighters.

A Sedgwick County EMS ambulance arrived at around 12:35 p.m. and parked next to the command post. The two EMICTs provided fluids to firefighters as they approached the command post. When the EMICTs thought firefighters appeared exhausted or overly hot, they requested the firefighters to "rehab" inside the air-conditioned ambulance. Blood pressure and pulse were checked on at least some of the firefighters who entered rehabilitation, but firefighters were not asked to identify themselves and no recordings of names or vital signs were made.

On several occasions EMICTs carried fluids to firefighters who were resting nearer the fire. In one such instance, an EMICT assisted a firefighter who was resting under a small tree located southeast of the house on Lot 11. No personal or station identification is displayed on SCFD personal protective clothing, and the EMICT did not ask the firefighter his name, but was later told by SCFD personnel that the firefighter was Firefighter A. Upon reviewing available accounts of this incident, we are reasonably certain that the individual who EMS assisted was not Firefighter A.

Deceased Firefighter's Activities

Firefighter A reported to work at 7:00 a.m. on September 6, 1990. As part of their usual physical fitness routine, the station crew drove to a nearby city park to exercise where Firefighter A jogged his usual three miles. Upon

returning to the station, he had begun to prepare his lunch when the fire alarm sounded. Leaving his lunch behind, he rode in Engine six (E-6) with the shift captain to the fire scene. They were the first firefighters to arrive; it was 11:55 a.m. Within 15 minutes of arriving at the scene, the captain had requested additional engines and tanks, volunteers from nearby small towns, and for an EMS ambulance to stand by at the scene.

The two man crew maneuvered E-6 behind the house and down a gradual incline to a clearing near the head of the fire. There, they began fighting the fire (Figure 1). As additional units arrived, the captain assigned them to other areas in an attempt to contain the rapidly spreading fire.

At about 12:20 p.m., the captain of E-6 radioed that he and Firefighter A had been fighting the fire with separate booster lines, and that they were "just worn out." Similar requests for relief were radioed at 12:27 and 12:41 p.m.

Another SCFD firefighter stated that he reported to E-6 upon arriving at the fire scene in a tanker truck and saw Firefighter A and the captain. According to the tape transcript, this occurred sometime between 12:27 p.m. and 12:41 p.m. Then, he and a volunteer firefighter pulled lines from the tanker across the fence separating Lot 11 and Lot 10 and began extinguishing the fire that had spread north into the salvage yard. The two continued fighting the fire until the tanker ran out of water. After refilling the tanker, the SCFD firefighter returned to E-6 to find that it had been abandoned.

As reported in conversations with the captain, both he and Firefighter A fought the fire until they were exhausted. Both returned to E-6, lowered their trousers, and rested. At that time, the assistant chief arrived at the address, but he was unable to find E-6's location. After several attempts to explain his location to the chief over the radio, the captain stated that he would "try to make it to the road" to accompany the chief into the fire scene. The captain instructed Firefighter A to remove his personal protective clothing, to get a drink of water, and to rest on the tailgate of E-6 while the captain reported to the chief. The captain stated that he would return with some relief firefighters, and then left, walking northeast along the fence line separating Lot 11 and Lot 10.

The chief had established the command post in a vehicle parked on the road adjacent to Lot 10 (Figure 1). An ambulance was parked next to the command post, with technicians standing by, to treat injured or exhausted firefighters. As the captain approached the command post, he was overcome by exhaustion and ordered by the chief to enter the ambulance for rehabilitation. The captain advised the chief that Firefighter A was tired and needed to be relieved. At about 1:35 p.m. the order to have Firefighter A report to the command post was radioed and receipt of the order was anonymously acknowledged.

While the captain was in the EMS unit, a request to assist a downed firefighter was issued. Believing the firefighter to be Firefighter A, the captain attempted to leave rehabilitation to check on his crew member. He was instructed by the Medical Quality Control Officer to remain in the unit. The downed firefighter was not Firefighter A. Upon leaving rehabilitation, the captain inquired as to Firefighter A's status and was told that he had been assigned to drive a tank truck. Firefighter A's body, dressed in full personal protective clothing, was discovered at approximately 4:00 p.m. by a volunteer firefighter. It was located west and slightly north of the house on Lot 11 in a brush covered, unburned area near the barbed wire fence separating Lots 10 and 11 (Figure 1). The terrain in this area is wooded and has a gradual downward slope away from the house. This may have prevented others from seeing the downed firefighter from a distance. The body was lying supine, on a car wheel, near the barbed wire fence separating Lots 10 and 11. Assessment by EMS personnel revealed rigor mortis. The Sedgwick County

Coroner's Report of death listed the cause of death to be heat stroke. Drug and alcohol screening results were negative.

APPENDIX II

Additional Heat Stress Information

The following sections provide additional information and references on heat stress and its prevention. The information is applicable to firefighting as well as other occupational exposures to hot environments.

Heat Stress Indices and Work/Rest Cycles

During the past fifty years, a variety of schemes has been developed for predicting the heat stress workers might experience in hot work environments. These schemes rely on various heat stress indices which include some or all of the important environmental factors (dry bulb, wet bulb, and mean radiant temperatures and air velocity). Since the early 1970's, the Wet Bulb Globe Temperature (WBGT) index has become the most frequently used and recommended heat stress index.[1,2] The WBGT index is based on objective and subjective data obtained from individuals exposed to various combinations of environmental and metabolic heat stress factors. The calculation of the WBGT for indoors is:

$$WBGT = 0.7T_{nwb} + 0.3T_g$$

for outdoors:

$$WBGT = 0.7T_{nwb} + 0.2T_g + 0.1T_{db}$$

T_{nwb} = natural wet bulb temperature

T_g = black globe temperature

T_{db} = dry bulb temperature

NIOSH has published Recommended Exposure Limits (RELs) based on WBGT for metabolic workloads ranging from 116 Watts (very light work) to 580 Watts (very heavy work).[3] These RELs are based on the assumption that nearly all acclimatized workers with adequate water intake should be able to function effectively without exceeding a deep body temperature of 100.4°F (38°C). These limits apply to the "standard worker" of 154 lbs (70 kg) body weight and 19.4 ft^2 (1.8 m^2) body surface area wearing lightweight work clothing. When other than lightweight, single layer clothing ensembles are worn, the WBGT limits must be lowered accordingly (6 to 10°C for impermeable ensembles) (4). When a vapor and air impermeable encapsulating ensemble is worn, the dry bulb or adjusted dry bulb temperature can be substituted for the WBGT.[3] When the above recommendation is applied to firefighters wearing full turnout gear, the resulting Recommended Exposure Limits for four basic work/rest cycles are shown below. It has been estimated that a firefighter's metabolic rate at a fire scene is a time-weighted average of between 300 and 400 watts.[4] This work intensity corresponds to the moderate work load presented in Table 2.[2]

Medical Monitoring

NIOSH has recommended that physiologic monitoring consisting of an oral temperature and/or pulse rate when impermeable clothing is worn at an adjusted dry bulb temperature exceeding 68°F. The suggested frequency of physiologic monitoring for moderate work varies from once every two hours at an adjusted dry bulb temperature of 90°F (32°C).[3] A recovery heart rate, taken during the third minute of seated rest, exceeding 90 beats per minute, and a recovery heart rate taken during the first minute of rest minus the third minute recovery heart rate of 10 beats per minute or fewer indicate excessive heat strain. An oral temperature of 100.4°F (38°C) or

above is also indicative of heat stress. Firefighters should not be allowed to return to work until their heart rate and oral temperature are below these limits.

Personal Cooling Devices

When large fires must be suppressed during periods of hot weather, the air temperature surrounding a firefighter ranges from 140 to 572°F.[5] One possible solution for avoiding heat stress under these extreme conditions is the use of auxiliary cooling devices.

Several personal cooling devices which have been evaluated in various industries include water-cooled garments, air-cooled garments, ice packet vests and wettable cover garments. A non-flame resistant, wetted cover garment would not meet the safety requirements for firefighters' protective clothing, and an air-cooled garment would severely limit mobility. Of the two remaining possibilities, ice packet vests would provide the more practical and economical solution to heat stress problems. Further investigation into the feasibility of using personal cooling devices during fire fighting is needed.[4]

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