VI. CONTROL OF HEAT STRESS

From a review of the heat balance equation $[H=(M-W)\pm C\pm R-E]$, described in Chapter III, Section A, total heat stress can be reduced only by modifying one or more of the following factors: metabolic heat production, heat exchange by convection, heat exchange by radiation, or heat exchange by evaporation. Environmental heat load (C, R, and E) can be modified by engineering controls (e.g., ventilation, air conditioning, screening, insulation, and modification of process or operation) and protective clothing and equipment; whereas metabolic heat production can be modified by work practices and application of labor-reducing devices. Each of these alternative control strategies will be discussed separately. Actions that can be taken to control heat stress and strain are listed in Table VI-1 [113].

TABLE VI-1.--Checklist for controlling heat stress and strain

Item	Actions for consideration
I. Controls	
M, body heat production of task	reduce physical demands of the work; powered assistance for heavy tasks
R, radiative load	interpose line-of-sight barrier; furnace wall insulation, metallic reflecting screen, heat reflective clothing, cover exposed parts of body
C, convective load	if air temperature is above 35°C (95°F); reduce air temperature, reduce air speed across skin, wear clothing if air temperature is below 35°C (95°F); increase air speed across skin and reduce clothing
E_{max}, maximum evaporative cooling by sweating	increase by: decreasing humidity, increasing air speed
	decrease clothing
II. Work practices	shorten duration of each exposure; more frequent short exposures better than fewer long exposures schedule very hot jobs in cooler part of day when possible
exposure limit	self-limiting, based on formal indoctrination of workers and supervisors on signs and symptoms of overstrain
recovery	air-conditioned space nearby

(continued)

TABLE VI-1.--Checklist for controlling heat stress and strain

III. Personal protection R, C, and E_{max}	cooled air, cooled fluid, or ice cooled conditioned clothing reflective clothing or aprons
IV. Other considerations	determine by medical evaluation, primarily of cardiovascular status careful break-in of unacclimatized workers water intake at frequent intervals to prevent hypohydration fatigue or mild illness not related to the job may temporarily contraindicate exposure (e.g., low grade infection, diarrhea, sleepless night, alcohol ingestion)
V. Heat wave	introduce heat alert program

Adapted from Reference 113.

A. Engineering Controls

The environmental factors that can be modified by engineering procedures are those involved in convective, radiative, and evaporative heat exchange.

1. Convective Heat Control

As discussed earlier, the environmental variables concerned with convective heat exchange between the worker and the ambient environment are dry bulb air temperature (t_a) and the speed of air movement (V_a). When air temperature is higher than the mean skin temperature ($\bar{t}_{sk}$ of 35°C or 95°F), heat is gained by convection. The rate of heat gain is dependent on temperature differential (t_a - $\bar{t}_{sk}$) and air velocity (V_a). Where t_a is below $\bar{t}_{sk}$, heat is lost from the body; the rate of loss is dependent on t_a - $\bar{t}_{sk}$ and air velocity.

Engineering approaches to enhancing convective heat exchange are limited to modifying air temperature and air movement. When t_a is less than $\bar{t}_{sk}$, increasing air movement across the skin by increasing either general or local ventilation will increase the rate of body heat loss. When t_a exceeds $\bar{t}_{sk}$ (convective heat gain), t_a should be reduced by bringing in cooler outside air or by evaporative or refrigerative cooling of the air, and as long as t_a exceeds $\bar{t}_{sk}$, air speed should be reduced to levels which will still permit sweat to evaporate freely but will reduce convective heat gain (see Table VI-1). The effect of air speed on convective heat exchange is a 0.6 root function of air speed. Spot cooling (t_a less than $\bar{t}_{sk}$) of the individual worker can be an effective approach to controlling convective heat exchange, especially in large workshops where the cost of cooling the entire space would be prohibitive. However, spot coolers or blowers may interfere with the ventilating systems required to control toxic chemical agents.

2. Radiant Heat Control

Radiant heat exchange between the worker and the hot equipment, processes, and walls that surround the worker is a fourth power function of the difference between skin temperature ($\bar{t}_{sk}$) and the temperature of hot objects that "see" the worker (t_r). Obviously, the only engineering approach to controlling radiant heat gain is to reduce t_r or to shield the worker from the radiant heat source.

To reduce t_r would require (1) lowering the process temperature which is usually not compatible with the temperature requirements of the manufacturing processes; (2) relocating, insulating, or cooling the heat source; (3) placing line-of-sight radiant reflective shielding between the heat source and the worker; or (4) changing the emissivity of the hot surface by coating the material. Of the alternatives, radiant reflective shielding is generally the easiest to install and the least expensive. Radiant reflective shielding can reduce the radiant heat load by as much as 80-85%. Some ingenuity may be required in placing the shielding so that it doesn't interfere with the worker performing the work. Remotely operated tongs, metal chain screens, or air or hydraulically activated doors which are opened only as needed are some of the approaches.

3. Evaporative Heat Control

Heat is lost from the body when sweat is evaporated from the skin surface. The rate and amount of evaporation is a function of the speed of air movement over the skin and the difference between the water vapor pressure of the air (p_a) at ambient temperature and the water vapor pressure of the wetted skin assuming a skin temperature of 34°-35°C (93.2°-95°F). At any air-to-skin vapor pressure gradient, the evaporation increases as a 0.6 root function of increased air movement. Evaporative heat loss at low air velocities can be greatly increased by improving ventilation (increasing air velocity). At high air velocities (2.5 m/sec or 500 fpm), an additional increase will be ineffective except when the clothing worn interferes with air movement over the skin.

Engineering controls of evaporative cooling can therefore assume two forms: (1) increase air movement or (2) decrease ambient water vapor pressure. Of these, increased air movement by the use of fans or blowers is often the simplest and usually the cheapest approach to increasing the rate of evaporative heat loss. Ambient water vapor pressure reduction usually requires air-conditioning equipment (cooling compressors). In some cases the installation of air conditioning, particularly spot air conditioning, may be less expensive than the installation of increased ventilation because of the lower airflow involved. The vapor pressure of the worksite air is usually at least equal to that of the outside ambient air, except when all incoming and recirculated air is humidity controlled by absorbing or condensing the moisture from the air (e.g., by air conditioning). In addition to the ambient air as a source of water vapor, water vapor may be added from the manufacturing processes as steam, leaks from steam valves and steam lines, and evaporation of water from wet floors. Eliminating these additional sources of water vapor can help reduce the overall vapor pressure in the air and thereby increase evaporative heat loss by facilitating the rate of evaporation of sweat from the skin [114].

B. Work and Hygienic Practices and Administrative Controls

Situations exist in industries where the complete control of heat stress by the application of engineering controls may be technologically impossible or impractical, where the level of environmental heat stress may be unpredictable and variable (as seasonal heat waves), and where the exposure time may vary with the task and with unforeseen critical events. Where engineering controls of the heat stress are not practical or complete, other solutions must be sought to keep the level of total heat stress on the worker within limits which will not be accompanied by an increased risk of heat illnesses.

The application of preventive practices frequently can be an alternative or complementary approach to engineering techniques for controlling heat stress. Preventive practices are mainly of five types: (1) limiting or modifying the duration of exposure time; (2) reducing the metabolic component of the total heat load; (3) enhancing the heat tolerance of the worker by heat acclimatization, physical conditioning, etc.; (4) training the workers in safety and health procedures for work in hot environments; and (5) medical screening of workers to eliminate individuals with low heat tolerance and/or physical fitness.

1. Limiting Exposure Time and/or Temperature

There are several ways to control the daily length of time and temperature to which a worker is exposed in heat stress conditions.

- When possible, schedule hot jobs for the cooler part of the day (early morning, late afternoon, or night shift).
- Schedule routine maintenance and repair work in hot areas for the cooler seasons of the year.
- Alter rest-work regimen to permit more rest time.
- Provide cool areas for rest and recovery.
- Add extra personnel to reduce exposure time for each member of the crew.
- Permit freedom to interrupt work when a worker feels extreme heat discomfort.
- Increase water intake of workers on the job.
- Adjust schedule when possible so that hot operations are not performed at the same time and place as other operations that require the presence of workers, e.g., maintenance and cleanup while tapping a furnace.

2. Reducing Metabolic Heat Load

In most industrial work situations, metabolic heat is not the major part of the total heat load. However, because it represents an extra load on the circulatory system, it can be a critical component in high heat exposures. A design for rest-work cycles has been developed by Kamon [115]. Metabolic heat production can be reduced usually by not more than 200 kcal/h (800 Btu/h) by:

- Mechanization of the physical components of the job,
- Reduction of work time (reduce work day, increase rest time, restrict double shifting),
- Increase of the work force.

3. Enhancing Tolerance to Heat

Stimulating the human heat adaptive mechanisms can significantly increase the capacity to tolerate work in heat. There is, however, a wide difference in the ability of people to adapt to heat which must be kept in mind when considering any group of workers.

a. A properly designed and applied heat-acclimatization program will dramatically increase the ability of workers to work at a hot job and will decrease the risk of heat-related illnesses and unsafe acts. Heat acclimatization can usually be induced in 5 to 7 days of exposure at the hot job. For workers who have had previous experience with the job, the acclimatization regimen should be exposure for 50% on day 1, 60% on day 2, 80% on day 3, and 100% on day 4. For new workers the schedule should be 20% on day 1 and a 20% increase on each additional day.

b. Being physically fit for the job will enhance (but not replace heat acclimatization) heat tolerance for both heat-acclimatized and unacclimatized workers. The time required to develop heat acclimatization in unfit individuals is about 50% greater than in the physically fit.

c. To ensure that water lost in the sweat and urine is replaced (at least hourly) by hour during the work day, an adequate water supply and intake are essential for heat tolerance and prevention of heat induced illnesses.

d. Electrolyte balance in the body fluids must be maintained to prevent some of the heat-induced illnesses. For heat-unacclimatized workers who may be on a restricted salt diet, additional salting of the food, with a physician's concurrence, during the first 2 days of heat exposure may be required to replace the salt lost in the sweat. The acclimatized worker loses relatively little salt in the sweat; therefore, salt supplementation of the normal U.S. diet is usually not required.

4. Health and Safety Training

Prevention of serious sequelae from heat-induced illnesses is dependent on early recognition of the signs and symptoms of impending heat illnesses and the initiation of first aid and/or corrective procedures at the earliest possible moment.

a. Supervisors and other personnel should be trained in recognizing the signs and symptoms of the various types of heat-induced illnesses, e.g., heat cramps, heat exhaustion, heat rash, and heatstroke, and in administering first-aid procedures (see Table IV-1).

b. All personnel exposed to heat should receive basic instruction on the causes and recognition of the various heat illnesses and personal care procedures that should be exercised to minimize the risk of their occurrence.

c. All personnel who use heat protective clothing and equipment should be instructed in their proper care and use.

d. All personnel working in hot areas should be instructed on the effects of nonoccupational factors (drugs, alcohol, obesity, etc.) on tolerance to occupational heat stress.

e. A buddy system which depends on the instruction of workers on hot jobs to recognize the early signs and symptoms of heat illnesses should be initiated. Each worker and supervisor who has received the instructions is assigned the responsibility for observing, at periodic intervals, one or more fellow workers to determine whether any of the early symptoms of a developing heat illness are present. If a worker exhibits signs and symptoms which may be indicative of an impending heat illness, the worker should be sent to the dispensary or first-aid station for more complete evaluation of the situation and to initiate the medical or first-aid treatment procedures. Workers on hot jobs where the heat stress exceeds the RAL or REL (for unacclimatized and acclimatized workers, respectively) should be observed by a fellow worker or supervisor. Contingency plans for treatment, e.g., cool rest area and transportation to hospital, should be in place.

5. Screening for Heat Intolerance

The ability to tolerate heat stress varies widely even between individuals within a group of normal healthy individuals with similar heat exposure experiences [5,6,116]. One way to reduce the risk of incurring heat illnesses and disorders within a heat-exposed workforce is to reduce or eliminate the exposure to heat stress of the heat-intolerant individuals. Identification of heat-intolerant individuals without the need for performing a strenuous, time-consuming heat-tolerance test would be basic to any such screening process.

Data from laboratory and field studies indicate that individuals with low physical work capacity are more likely to develop higher body temperatures than are individuals with high physical work capacity when exposed to equally hard work in high temperatures. None of the individuals with a maximum work capacity of 2.5 liters of oxygen per minute (L/min) or above were heat intolerant, while 63% of those with $\dot{V}O_2max$ below 2.5 L/min were heat intolerant. It has also been shown that heat-acclimatized individuals with a $\dot{V}O_2max$ less than 2.5 L/min had a 5% risk of reaching heatstroke levels of body temperature (40°C or 104°F) while those with a $\dot{V}O_2max$ above 2.5 L/min had only a 0.05% risk [5,6].

Because tolerance to physical work in a hot environment is related to physical work capacity, heat tolerance might be predictable from physical fitness tests. A simple physical fitness test which could be administered in a physician's office or a plant first-aid room has been suggested [116,117]. However, such tests have not as yet been proven to have predictive validity for use in hot industries.

Medical screening for heat intolerance in otherwise healthy normal workers should include a history of any previous incident of heat illness. Workers who have experienced a heat illness may be less heat tolerant [4].

C. Heat-Alert Program - Preventing Emergencies

In some plants where heat illnesses and disorders occurred mainly during hot spells in the summer, a Heat-Alert Program (HAP) has been established for preventive purposes. Although such programs differ in detail from one plant to another, the main idea behind them is identical, i.e., to take advantage of the weather forecast of the National Weather Service. If a hot spell is predicted for the next day or days, a state of Heat Alert is declared to make sure that measures to prevent heat casualties will be strictly observed. Although this sounds quite simple and straightforward, in practical application it requires the cooperation of the administrative staff; the maintenance and operative workforce; and the medical, industrial hygiene, and safety departments. An effective HAP is described below [77].

1. Each year, early in the spring, establish a Heat-Alert Committee consisting of an industrial physician or nurse, industrial hygienist, safety engineer, operation engineer, and a high ranking manager. Once established, this committee takes care of the following options:

    a. Arrange a training course for all involved in the HAP, dealing with procedures to follow in the event a Heat Alert is declared. In the course, special emphasis is given to the prevention and early recognition of heat illnesses and first-aid procedures when a heat illness occurs.

    b. By memorandum, instruct the supervisors to:

        (1) Reverse winterization of the plant, i.e., open windows, doors, skylights, and vents according to instructions for greatest ventilating efficiency at places where high air movement is needed;

        (2) Check drinking fountains, fans, and air conditioners to make sure that they are functional, that the necessary maintenance and repair is performed, that these facilities are regularly rechecked, and that workers know how to use them;

    c. Ascertain that in the medical department, as well as at the job sites, all facilities required to give first aid in case of a heat illness are in a state of readiness;

d. Establish criteria for the declaration of a Heat Alert; for instance, a Heat Alert would be declared if the area weather forecast for the next day predicts a maximum air temperature of 35°C (95°F) or above or a maximum of 32°C (90°F) if the predicted maximum is 5°C (9°F) above the maximum reached in any of the preceding 3 days.

2. Procedures to be followed during the state of Heat Alert are as follows:

a. Postpone tasks which are not urgent (e.g., preventive maintenance involving high activity or heat exposure) until the hot spell is over.

b. Increase the number of workers in each team in order to reduce each worker's heat exposure. Introduce new workers gradually to allow acclimatization (follow heat-acclimatization procedure).

c. Increase rest allowances. Let workers recover in air-conditioned rest places.

d. Turn off heat sources which are not absolutely necessary.

e. Remind workers to drink water in small amounts frequently to prevent excessive dehydration, to weigh themselves before and after the shift, and to be sure to drink enough water to maintain body weight.

f. Monitor the environmental heat at the job sites and resting places.

g. Check workers' oral temperature during their most severe heat-exposure period.

h. Exercise additional caution on the first day of a shift change to make sure that workers are not overexposed to heat, because they may have lost some of their acclimatization over the weekend and during days off.

i. Send workers who show signs of a heat disorder, even a minor one, to the medical department. The physician's permission to return to work must be given in writing.

j. Restrict overtime work.

D. Auxiliary Body Cooling and Protective Clothing

When unacceptable levels of heat-stress occur, there are generally only four approaches to a solution: (1) modify the worker by heat acclimatization; (2) modify the clothing or equipment; (3) modify the work; or (4) modify the environment. To do everything possible to improve human tolerance would require that the individuals should be fully heat acclimated, should have good training in the use of and practice in wearing the protective clothing, should be in good physical condition, and should be encouraged to drink as much water as necessary to compensate for sweat water loss.

If these modifications of the individual (heat acclimatization and physical fitness enhancement) are not enough to alleviate the heat stress and reduce the risk of heat illnesses, only the latter three solutions are left to deal with the problem. It may be possible to redesign ventilation systems for occupied spaces to avoid interior humidity and temperature buildup. These may not completely solve the heat stress problem. When air temperature is above 35°C (95°F) with an rh of 75-85% or when there is an intense radiant heat source, a suitable, and in some ways more functional, approach is to modify the clothing to include some form of auxiliary body cooling. Even mobile individuals afoot can be provided some form of auxiliary cooling for limited periods of time. A properly designed system will reduce heat stress, conserve large amounts of drinking water which would otherwise be required, and allow unimpaired performance across a wide range of climatic factors. A seated individual will rarely require more than 100 W (86 kcal/h or 344 Btu/h) of auxiliary cooling and the most active individuals not more than 400 W (345 kcal/h or 1380 Btu/h) unless working at a level where physical exhaustion *per se* would limit the duration of work. Some form of heat-protective clothing or equipment should be provided for exposures at heat-stress levels that exceed the Ceiling Limit in Figures 1 and 2.

Auxiliary cooling systems can range from such simple approaches as an ice vest, prefrozen and worn under the clothing, to more complex systems; however, cost of logistics and maintenance are considerations of varying magnitude in all of these systems. In all, four auxiliary cooling approaches have been evaluated: (1) water-cooled garments, (2) an air-cooled vest, (3) an ice packet vest, and (4) a wettable cover. Each of these cooling approaches might be applied in alleviating risk of severe heat stress in a specific industrial setting [14,26].

1. Water-cooled Garments

Water-cooled garments include (1) a water-cooled hood which provides cooling to the head, (2) a water-cooled vest which provides cooling to the head and torso, (3) a short, water-cooled undergarment which provides cooling to the torso, arms, and legs, and (4) a long, water-cooled undergarment which provides cooling to the head, torso, arms, and legs. None of these water-cooled systems provide cooling to the hands and feet.

Water-cooled garments and headgear require a battery driven circulating pump and container where the circulating fluid is cooled by the ice. The weight of the batteries, container, and pump will limit the amount of ice that can be carried. The amount of ice available will determine the effective use time of the water-cooled garment.

The range of cooling provided by each of the water-cooled garments versus the cooling water inlet temperature has been studied. The rate of increase in cooling, with decrease in cooling water inlet temperature, is 3.1 W/°C for the water-cooled cap with water-cooled vest, 17.6 W/°C for the short water-cooled undergarment, and 25.8 W/°C for the long water-cooled undergarments. A "comfortable" cooling water inlet temperature of 20°C (68°F) should provide 46 W of cooling using the water-cooled cap; 66 W using the water-cooled vest; 112 W using the water-cooled cap with water-cooled vest; 264 W using the short water-cooled undergarment; and 387 W using the long water-cooled undergarment.

2. Air-cooled Garments

Air-cooled suits and/or hoods which distribute cooling air next to the skin are available. The total heat exchange from a completely sweat wetted skin when cooling air is supplied to the air-cooled suit is a function of cooling air temperature and cooling airflow rate. Both the total heat exchanges and the cooling power increase with cooling airflow rate and decrease with increasing cooling air inlet temperature.

For an air inlet temperature of 10°C (50°F) at 20% rh and a flow rate of 10 ft^3/min (0.28 m^3/min), the total heat exchanges over the body surface would be 233 W in a 29.4°C (84.9°F) 85% rh environment and 180 W in a 51.7°C (125.1°F) at 25% rh environment. Increasing the cooling air inlet temperature to 21°C (69.8°F) at 10% rh would reduce the total heat exchanges to 148 W and 211 W, respectively. Either air inlet temperature easily provides 100 W of cooling.

The use of a vortex tube as a source of cooled air for body cooling is applicable in many hot industrial situations. The vortex tube, which is attached to the worker, requires a constant source of compressed air supplied through an air hose. The hose connecting the vortex tube to the compressed air source limits the area within which the worker can operate. However, unless mobility of the worker is required, the vortex tube, even though noisy, should be considered as a simple cooled air source.

3. Ice Packet Vest

The available ice packet vests may contain as many as 72 ice packets; each packet has a surface area of approximately 64 cm^2 and contains about 46 grams of water. These ice packets are generally secured to the vest by tape. The cooling provided by each individual ice packet will vary with time and with its contact pressure with the body surface, plus any heating effect of the clothing and hot environment; thus, the environmental conditions have an effect on both the cooling provided and the duration of time this cooling is provided. Solid carbon dioxide in plastic packets can be used instead of ice packets in some models.

In environments of 29.4°C (84.9°F) at 85% rh and 35.0°C (95°F) at 62% rh, an ice packet vest can still provide some cooling up to 4 hours of operation (about 2 to 3 hours of effective cooling is usually the case). However, in an environment of 51.7°C (125.1°F) at 25% rh, any benefit is negligible after about 3 hours of operation. With 60% of the ice packets in place in the vest, the cooling provided may be negligible after 2 hours of operation. Since the ice packet vest does not provide continuous and regulated cooling over an indefinite time period, exposure to a hot environment would require redressing with backup frozen vests every 2 to 4 hours. Replacing an ice packet vest would obviously have to be accomplished when an individual is not in a work situation. However, the cooling is supplied noise-free and independent of any energy source or umbilical cord that would limit a worker's mobility. The greatest potential for the ice packet vest appears to be for work where other conditions limit the length of exposure, e.g., short duration tasks and emergency repairs. The ice packet vest is also relatively cheaper than other cooling approaches.

4. Wetted Overgarments

A wetted cotton terry cloth coverall or a two-piece cotton cover which extends from just above the boots and from the wrists to a V-neck when used with impermeable protective clothing can be a simple and effective auxiliary cooling garment.

Predicted values of supplementary cooling and of the minimal water requirements to maintain the cover wet in various combinations of air temperature, relative humidity, and wind speed can be calculated. Under environmental conditions of low humidity and high temperatures where evaporation of moisture from the wet cover garment is not restricted, this approach to auxiliary cooling can be effective, relatively simple, and inexpensive to use.

E. Performance Degradation

A variety of options for auxiliary cooling to reduce the level of heat stress, if not totally eliminate it under most environmental conditions both indoors and outdoors, have been prescribed. However, the elimination of serious heat-stress problems will not totally resolve the degradation in performance associated with wearing protective clothing systems. Performance decrements are associated with wearing encapsulating protective ensembles even in the absence of any heat stress [78]. The majority of the decrements result from mechanical barriers to sensory inputs to the wearer and from barriers to communication between individuals. Overall, it is clear that elimination of heat stress, while it will allow work to continue, will not totally eliminate the constraints imposed by encapsulating protective clothing systems [78].

VII. PREVENTIVE MEDICAL PRACTICES

With proper attention to health and safety considerations, a hot work environment can be a safe place within which to work. A primary responsibility for preventing heat illness resides with the engineer and/or industrial hygienist who recommends procedures for heat-stress controls and monitors workplace environmental conditions. Continuous industrial hygiene characterization of environmental conditions, obtained via either continuous monitoring of the environment or algorithms that relate workplace temperature and humidity to ambient climatic conditions and to the work activity itself, must be available to these personnel. However, because of the complexities of anticipating and preventing heat illness in the individual worker, the physician must be intimately involved in efforts to protect workers exposed to potentially hazardous levels of heat stress in the workplace.

Since an environment that exceeds the Recommended Alert Limit (RAL) for an unacclimatized or the Recommended Exposure Limit (REL) for an acclimatized worker poses a potential threat to workers, the supervising health professional must possess a clear understanding of the peculiar complexities of heat stress. In particular, the physician must be aware of the following:

- The REL represents the most extreme heat-stress condition to which even the healthiest and most acclimatized worker may be safely exposed for prolonged periods of time.

- Among workers who do not have medical conditions that impair heat tolerance, some may be at risk of developing heat illness when exposed to levels below the RAL. In addition, some workers cannot acclimatize to heat-stress levels above the RAL. Empirical data suggest that fewer than 5% of the workers cannot adequately acclimatize to heat stress (see Chapter IV).

- The RAL and REL are TWA values with permissible short-term excursions above the levels; however, the frequency and extent to which such brief excursions may be safely permitted are not known.

Thus, sound judgment and vigilance by the physician, the workers, and their supervisors are essential to the prevention and early recognition of adverse heat-induced health effects.

The physician's role in protecting workers in a hot environment should include the following:

- <u>Work environment not exceeding the RAL</u> In a work environment in which the heat stress experienced by the worker approaches but is kept below the RAL by engineering controls, work practices, and/or personal protective equipment, the physician's primary responsibilities are (1) preplacement evaluation (detection of a worker with a medical condition that would warrant exclusion of the worker from the work setting), (2) supervision during initial days of exposure of the worker to the hot environment (detection of apparently "healthy" workers who cannot tolerate heat stress), and

(3) detection of evidence of heat-induced illness (a sentinel health event [SHE]) in one or more workers that would indicate a failure of control measures to prevent heat-induced illness and related injuries at levels below the RAL).

- Work environment that exceeds the RAL In a work environment in which only acclimatized individuals can work safely because the level of heat stress exceeds the RAL, the physician bears a more direct responsibility for ensuring the health and safety of the workers. Through the preplacement evaluation and the supervision of heat acclimatization, the physician may detect a worker who is incapable of heat acclimatization or who has another medical condition that precludes placing that worker in a hot environment. While a single incident of heat illness may be a SHE indicating a failure of control measures, it may also signify a transient or long-term loss of heat tolerance or a change in the health status of that worker. The onset of heat-induced illness in more than one worker in a heat-acclimatized workforce is a SHE that indicates a failure of control measures. The physician must be cognizant of each of these possibilities.

The following discussion is directed toward the protection of workers in environments exceeding the RAL. However, it also provides the core of information required to protect all workers in hot environments.

A. Protection of Workers Exposed to Heat in Excess of the RAL

The medical component of a program which protects workers who are exposed to heat stress in excess of the RAL is complex. In order to ascertain a worker's fitness for placement and/or continued work in a particular environment, numerous characteristics of the individual worker (e.g., age, gender, weight, social habits, chronic or irreversible health characteristics, and acute medical conditions) must be assessed in the context of the extent of heat stress imposed in a given work setting. Thus, while many potential causes of impaired heat tolerance may be regarded as "relative contraindications" to work in a hot environment, the physician must assess the fitness of the worker for the specific job and should not interpret potential causes of impaired heat tolerance as "absolute contraindications" to job placement.

A preplacement medical evaluation followed by proper acclimatization training will reduce the likelihood that a worker assigned to a job that exceeds the RAL will incur heat injury. However, substantial differences exist between individuals in their abilities to tolerate and adapt to heat; such differences cannot necessarily be predicted prior to actual trial exposures of suitably screened and trained individuals.

Heat acclimatization signifies a dynamic state of conditioning rather than a permanent change in the worker's innate physiology. The phenomenon of heat acclimatization is well established, but for an individual worker, it can be documented only by demonstrating that, after completion of an acclimatization regimen, the worker can indeed work without excessive physiologic heat strain in an environment that an unacclimatized worker could not withstand. The ability of such a worker to tolerate elevated heat stress requires integrity of cardiac, pulmonary, and renal function; the sweating mechanism; the body's fluid and electrolyte balances; and the central nervous system's heat-regulatory mechanism. Impairment or diminution of any of these functions may interfere with the worker's capacity to acclimatize to the heat or to perform strenuous work in the heat once acclimatized. Chronic illness, the use or misuse of pharmacologic agents, a suboptimal nutritional state, or a disturbed water and electrolyte balance may reduce the worker's capacity to acclimatize. In addition, an acute episode of mild illness, especially if it entails fever, vomiting, respiratory impairment, or diarrhea, may cause abrupt transient loss of acclimatization. Not being exposed to heat stress for a period of a few days, as may occur during a vacation or an alternate job assignment away from heat, may also disrupt the worker's state of heat acclimatization. Finally, a worker who is acclimatized at one level of heat stress may require further acclimatization if the total heat load is increased by the imposition of more strenuous work, increased heat and/or humidity, a requirement to carry and use respiratory protection equipment, or a requirement to wear clothing that compromises heat elimination.

A physician who is responsible for workers in hot jobs (whose jobs exceed the RAL) must be aware that each worker is confronted each day by workplace conditions that may pose actual (as opposed to potential) risks if that worker's capacity to withstand heat is acutely reduced or if the degree of heat stress increases beyond the heat-acclimatized tolerance capacity of that worker. Furthermore, a physician who will not be continuously present at the worksite bears a responsibility to ensure the education of workers, industrial hygienists, medical and health professionals, and on-site management personnel about the early signs and symptoms of heat intolerance and injury. Biologic monitoring of exposed workers may assist the physician in assuring protection of workers (biologic monitoring is discussed in Chapter IV).

B. Medical Examinations

The purpose of preplacement and periodic medical examinations of persons applying for or working at a particular hot job is to determine if the person can meet the total demands and stresses of the hot job with reasonable assurance that the safety and health of the individual and/or fellow workers will not be placed in jeopardy. Examinations should be performed that assess the physical, mental, psychomotor, emotional, and clinical qualifications of such individuals. These examinations entail two parts which relate, respectively, to overall health promotion (regardless of workplace or job placement) and to workplace-specific medical issues. This section focuses only on the latter and only with specific regard to heat stress. However, because tolerance to heat stress depends upon the integrity of multiple organ systems and can be jeopardized by the insidious onset of common medical conditions such as hypertension, coronary artery disease, decreased pulmonary function, diabetes, and impaired renal function, workers exposed to heat stress require a comprehensive medical evaluation.

Prior to the preplacement examination, the physician should obtain a description of the job itself, a description of chemical and other environmental hazards that may be encountered at the worksite, the anticipated level of environmental heat stress, an estimate of the physical and mental demands of the job, and a list of the protective equipment and clothing that is worn. This information will provide the examining physician a guide for determining the scope and comprehensiveness of the physical examination. Specific factors important in determining the individual's level of heat tolerance, the abilities to perform work in hot environments, and the medical problems associated with a failure to meet the demands of the work in hot jobs have been discussed in Chapter IV. A discussion of health factors and medications that affect heat tolerance in a nonworker population can be found in Kilbourne et al. [62].

The use of information from the medical evaluation should be directed toward understanding the potential maximum total heat stress likely to be experienced by the worker on the job, i.e., the sum of the metabolic demands of the work and of using respirators and other personal protective equipment or clothing; the environmental heat load; and the consequences of impediments to heat elimination, such as high humidity, low air movement (enclosed spaces or unventilated buildings), or protective clothing that impedes the evaporation of sweat. The environmental heat load and the physical demands of the job can be measured, calculated, or estimated by the procedures described previously in Chapters III and V. For such measurements the expertise of an industrial hygienist may be required; however, the physician must be able to interpret the data in terms of the stresses of the job and the worker's physical, sensory, psychomotor, and mental performance capabilities to meet the demands [73,118,119].

1. Preplacement Physical Examination

The preplacement physical examination is usually designed for new workers or workers who are transferring from jobs that do not involve exposure to heat. Unless demonstrated otherwise, it should be assumed that such individuals are not acclimatized to work in hot environments.

a. The physician should obtain:

(1) A medical history that addresses the cardiac, vascular, respiratory, neurologic, renal, hematologic, gastrointestinal, and reproductive systems and includes information on specific dermatologic, endocrine, connective tissue, and metabolic conditions that might affect heat acclimatization or the ability to eliminate heat [120,121].

(2) A complete occupational history, including years of work in each job, the physical and chemical hazards encountered, the physical demands of these jobs, intensity and duration of heat exposure, and nonoccupational exposures to heat and strenuous activities. This history should identify episodes of heat-related disorders and evidence of successful adaptation to work in heat in previous jobs or in nonoccupational activities [120].

(3) A list of all prescribed and over-the-counter medications used by the worker. In particular, the physician should consider the possible impact of medications that potentially can affect cardiac output, electrolyte balance, renal function, sweating capacity, or autonomic nervous system function including: diuretics, antihypertensive drugs, sedatives, antispasmodics, anticoagulants, psychotropics, anticholinergics, and drugs that may alter the thirst (haloperidol) or sweating mechanism (phenothiazines and antihistamines).

(4) Information about personal habits, including the use of alcohol and other social drugs.

(5) Data on height, weight, gender, and age (see discussion in Chapter IV).

b. The direct evaluation of the worker should include the following:

(1) Physical examination, with special attention to the cardiovascular, respiratory, nervous, and musculoskeletal systems, and the skin.

(2) Clinical chemistry values needed for clinical assessment, such as fasting blood glucose, blood urea nitrogen, serum creatinine, serum electrolytes (sodium, potassium, chloride, bicarbonate), hemoglobin, and urinary sugar and protein.

(3) Blood pressure evaluation.

(4) Assessment of the ability of the worker to understand the health and safety hazards of the job, understand the required preventive measures, communicate with fellow workers, and have mobility and orientation capacities to respond properly to emergency situations.

c. More detailed medical evaluation may be warranted. Communication between the physician performing the preplacement evaluation and the worker's own physician may be appropriate and should be encouraged. For instance:

(1) History of myocardial infarction, congestive heart failure, coronary artery disease, obstructive or restrictive pulmonary disease, or current use of certain antihypertensive medications indicates the possibility of reduced maximum cardiac output.

(2) For a worker who uses prescribed medications that might interfere with heat tolerance or acclimatization, an alternate therapeutic regimen may be available that would be less likely to compromise the worker's ability to work in a hot environment.

(3) Hypertension per se is not to be an "absolute" contraindication to working under heat stress (see VII-B-3). However, the physician should consider the possible effects of

antihypertensive medications on heat tolerance. In particular, for workers who follow a salt-restricted diet or who take diuretic medications that affect serum electrolyte levels, it may be prudent to monitor blood electrolyte values, especially during the initial phase of acclimatization to heat stress.

(4) For workers who must wear respiratory protection or other personal protective equipment, pulmonary function testing and/or a submaximal stress electrocardiogram may be appropriate. Furthermore, the physician must assess the worker's ability to tolerate the <u>total</u> heat stress of a job, which will include the metabolic burdens of wearing and using protective equipment.

(5) For workers with a history of skin disease, an injury to a large area of the skin, or an impairment of the sweating mechanism that might impair heat elimination via sweat evaporation from the skin, specific evaluation may be advisable.

(6) Insofar as obesity can interfere with heat tolerance (see Chapter IV), a specific measurement of percent body fat may be warranted for an individual worker. An individual should not be disqualified from a job solely on this basis, but such a worker may merit special supervision during the acclimatization period.

(7) Women having childbearing potential (or who are pregnant) and workers with a history of impaired reproductive capacity (male or female) should be apprised of the overall uncertainties regarding the effects on reproduction of working in a hot environment (see VII-B-4).

2. Ongoing Medical Evaluation

a. Medical supervision of workers following job placement involves two primary sets of responsibilities:

(1) The monitoring of individual workers for changes in individual health that might affect heat tolerance or for evidence suggesting failure to maintain a safe working environment. The evaluation of these data in aggregate form permits surveillance of the work population as a whole for evidence of heat-related injury that is suggestive of failure to maintain a safe working environment.

(2) The ability to respond to heat injuries that do occur within the workforce.

b. On an annual basis, the physician should update the information gathered in the preplacement examination (see Chapter VII-B-1-a and b) for all persons working in a hot environment. In addition, the physician should ensure that workers who may have been transferred into a hot environment have been examined and are heat acclimatized. A more complete examination may be advisable if indicated by the updated medical history and laboratory data.

Special attention should be directed to the cardiovascular, respiratory, nervous, and musculoskeletal systems and the skin.

3. Hypertension

Limited human data are available that relate to the relationship of hypertension to heat strain. The capacity to tolerate exercise in heat was compared in a group of workers with essential hypertension (resting arterial pressure 150/97 mmHg) with a group of normotensives of equal age, $\dot{V}O_2max$, weight, body fat content, and surface area (resting arterial pressure 115/73 mmHg). During exercise in heat (38°C (91.4°F) t_a and 28°C (82.4°F) t_{wb} at work rates of 85-90 W), there was no significant intergroup difference in t_{re}, $\bar{t}_{sk}$, calculated heat-exchange variables, heart rate, or sweat rate. The blood pressure difference between the two groups was maintained [122]. The study of mortality of steelworkers employed in hot jobs conducted by Redmond et al. on a cohort of 59,000 steelworkers showed no increase in relative risk of death from all cardiovascular diseases or from hypertensive heart disease as a function of the level of the heat stress; however, for workers who had worked for 6 months or less at the hot jobs, the relative risk of death from arteriosclerotic heart disease was 1.78 as compared to those who worked at the hot jobs longer than 6 months [123].

4. Considerations Regarding Reproduction

a. Pregnancy

The medical literature provides little data on potential risks for pregnant women or for fertile men and fertile noncontracepting women with heavy work and/or added heat stress within the permissible limits, e.g., where t_{re} does not exceed 38°C (100.4°F) (see Chapter IV). However, because the human data are limited and because research data from animal experimentation indicate the possibility of heat-induced infertility and teratogenicity, a woman who is pregnant or who may potentially become pregnant should be informed that absolute assurances of safety during the entire period of pregnancy cannot be provided. The worker should be advised to discuss this matter with her own physician.

b. Infertility

Heat exposure has been associated with temporary infertility in both females and males, with the effects being more pronounced in the male [124,125]. Available data are insufficient to assure that the REL protect against such effects. Thus, the examining physician should question workers exposed to high heat loads about their reproductive histories, whether they use contraceptive methods, type of contraceptive methods used, whether they have ever tried to have children, and whether female workers have ever been pregnant. In addition, the worker should be questioned about any history of infertility, including possible heat-related infertility. Because the heat-related infertility is usually temporary, reduction in heat exposure or job transfer should result in recovery.

c. Teratogenicity and Heat-induced Abortion

The body of experimental evidence reviewed by Lary [126] indicates that in the nine species of warm-blooded animals studied, prenatal exposure of the pregnant females to hyperthermia may result in a high incidence of embryo deaths and in gross structural defects, especially of the head and central nervous system (CNS). An elevation of the body temperature of the pregnant female to 39.5°-43°C (103.1°-109.4°F) during the first week or two of gestation (depending on the animal species) resulted in structural and functional maturation defects, especially of the central nervous system, although other embryonic developmental defects were also found. It appears that some basic developmental processes may be involved, but selective cell death and inhibition of mitosis at critical developmental periods may be primary factors. The hyperthermia in these experimental studies did not appear to have an adverse effect on the pregnant female but only on the developing embryo. The length of hyperthermia in the studies varied from 10 minutes a day over a 2- to 3-week period to 24 hours a day for 1 or 2 days.

The evidence for teratogenic effects of hyperthermia in humans is less convincing, in part, because it is based mainly on self-reported data obtained months or years after a pregnancy in which increased body temperature occurred during pathologic processes (e.g., acute infection during early pregnancy). However, recent retrospective epidemiologic studies have associated hyperthermia of a day or less, to a week or more, during the first trimester of pregnancy with birth defects, especially defects in CNS development (e.g., anencephaly) [126]. Based on the animal experimental data and the human retrospective studies, it appears prudent to monitor the body temperature of a pregnant worker exposed to total heat loads above the REL, every hour or so to ensure that the body temperature does not exceed 39°-39.5°C (102°-103°F) during the first trimester of pregnancy.

C. Surveillance

To ensure that the control practices provide adequate protection to workers in hot areas, the plant physician or nurse can utilize workplace medical surveillance data, the periodic examination, and an interval history to note any significant within- or between-worker events since the individual worker's previous examination. Such events may include repeated accidents on the job, episodes of heat-related disorders, or frequent health-related absences. These events may lead the physician to suspect overexposure of the worker population (from surveillance data), possible heat intolerance of the individual worker, or the possibility of an aggravating stress in combination with heat, such as exposure to hazardous chemicals or other physical agents. Job-specific clustering of heat-related illnesses or injuries should be followed up by industrial hygiene and medical evaluations of the worksite and workers.

D. Biologic Monitoring of Workers Exposed to Heat Stress

To assess the capacity of the workforce and individual workers to continue working on a particular hot job, physiologic monitoring of each worker or randomly selected workers while they are working in the heat should be considered as an adjunct to environmental and metabolic monitoring. A recovery heart rate, taken during the third minute of seated rest following a normal work cycle, of 90 beats per minute (b/min) or higher, and recovery heart rate taken during the first minute of seated rest minus the third minute recovery heart rate of 10 b/min or fewer, and/or an oral temperature of 38°C (100.4°F) or above indicate excessive heat strain [127,128]. Both oral temperature and pulse rate should be measured again at the end of the rest period before the worker returns to work to determine whether the rest time has been sufficient for recovery to occur. Measurements should be taken at appropriate intervals covering a full 2-hour period for the hottest part of the day and again at the end of the workday. Baseline oral temperatures and pulse rates taken before the workers begin the first task in the morning can be used as a basis for deciding whether individual workers are fit to continue work that day. If excessive heat strain is indicated, the work situation will require reexamination, preferably by the physician and industrial hygienist to determine whether it is a case of worker intolerance or excessive job-related heat stress.