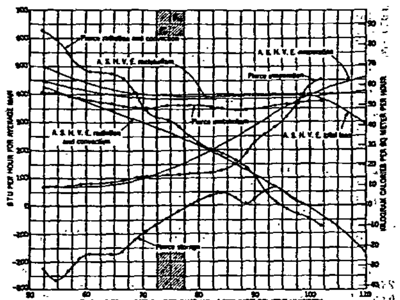

Fig. 2 .... Relation Between Metabolism, Storage, Evaporation, Radiation Plus Convection, and Temperature for the Clothed Subject

ject, and below 85 F for the lightly clothed subject, evaporation loss is minimal and constant. Burch[12] has shown that this insensible perspiration reflects the permeability of the skin to the moisture of the body. Above these temperatures, control is obtained by the availability of sweat for evaporation. The difference in the curves above 75 F is probably largely determined by the difference in clothing and activity.

LOW TEMPERATURE HAZARDS

Human performance in extreme cold depends ultimately on the maintenance of physiological thermal balance. The ability to do so depends, in turn, primarily on extent of cold exposure, heat production (including level of activity), and heat conservation (including insulation and clothing). From a practical standpoint −30 F is probably the lower limit for efficient prolonged outdoor operations. At −60 F many kinds of outdoor activities become exceedingly difficult, but by no means impossible.[13]

Knowledge of both the magnitude[14,15,16] (including environmental low temperature radiation exchanges as well as air movement and water vapor content) and duration of environmental exposure is essential in evaluating the psychological and physiological adjustments of man to cold. Man may become *habituated* to cold, i.e., learn how to survive during cold periods,[17] and he may also become acclimatized, i.e., physiological changes may be produced in the man so as to make him more tolerant to cold.[18] Available information indicates that man habituates, rather than acclimatizes, to cold.

There are few, if any, specific evidences of large physiological changes indicating acclimatization in man,[19] even in groups of people habitually exposed to cold environments, such as the Eskimos and Indians in Alaska. Recent studies of primitive peoples, such as the Australian aborigines, have found that these people allow excessive body cooling during sleep (2–4 F deg) which may be interpreted as representing true physiological acclimatization to cold.[20] However, physiological changes in man resulting from prolonged cold exposure are small, compared with the importance of factors such as accustomization experience, training, fitness, etc. The maintenance of high skin temperature and blood flow of the face and hands during extreme cold exposure in cold-acclimatized individuals[19] is another example of beneficial physiological change which allows sacrifice of body heat to preserve important body parts from frost-bite.

The caloric requirement of man in the Arctic or in the Antarctic is not appreciably different from that of man living in the temperate climates. The slight difference observed[21,22] is no more than what could be accounted for by the added caloric requirement caused by the *hobbling* effect of the winter clothing and the greater energy expenditure required by movement through snow, etc.

However, prolonged cold exposure of nude men to cold was far more severe than that encountered in normal Arctic living, and produced changes in hormonal balance, and dietary intake. Continuous exposure of nude men to an ambient temperature of 8 F for 3 to 9 days, caused a two-fold increase in metabolic rate, a significant increase in pulse rate, and marked loss in body protein which persisted several days after the subject had returned to normal room temperature.[23] Under these conditions, food intake is most important. A reduction in calories from 3000 to 1500 per day caused a marked reduction in physical work capacity, as judged by an all-out treadmill test.[24] On the other hand, no appreciable deterioration occurred in physical work capacity when 3000 calories and 70 g protein were given daily for 9 days at 8 F. Cold injury occurred in the feet of these subjects, but was most pronounced in the subjects receiving a diet deficient both in calories and protein.

HIGH TEMPERATURE HAZARDS

Exposure of men to extreme high temperature is limited by two different physiological responses: (1) elevated skin temperature resulting in pain and tissue damage, and (2) elevated body temperature and the associated syndromes of heat exhaustion, heat cramps, and heat stroke. The first of these limitations is most easily observed when the skin temperature is raised rapidly to levels of 113 F (45 C) or higher, by means of infrared radiation or by contact with hot liquids, gases, or solids. The second effect is that most commonly associated with working conditions in hot climates or in industrial and military situations requiring work in hot, humid spaces.

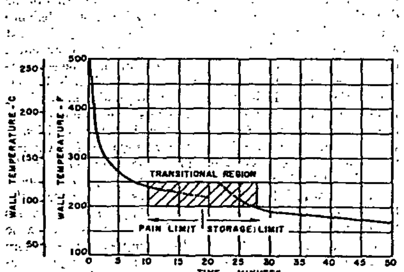

Fig. 3 .... Tolerance Times and Temperature Limits of Unprotected Subjects Exposed to Fast Heat Pulses with an Approximate Definition of the Transitional Region between Pain Limited and Body Heat Storage Limits[25]

Experiments have been carried out on human volunteers exposed nude in a small chamber lined with quartz tube radiators: Measurements were made of mean wall temperature, air temperature, skin temperature, body temperature, and time of exposure *to unbearable pain.* Slowly and rapidly rising radiation pulses were used, and the heat flux to the skin in both cases was about half radiative and half convective, with total heat fluxes to the skin between 1000 and 3000 Kcal/(m²)(hr).[25] Other experiments carried out at lower operative temperatures were limited by the elevation of deep body temperature T_s between 105 and 125 C (221–257 F). Fig. 3 shows the relationship of the limiting exposure time at very high wall temperature to the pain limit and body heat storage limit up to 50 minutes. In the transition region, both pain and heat storage may be factors limiting the exposure time, but sufficient information in this area is lacking. The high infrared radiation or wall temperatures in these experiments must be considered a dangerous situation for a man, and clear-cut end points for exposure *limits* may not be available for every individual. Any covering of the exposed skin serves to protect the individual, and thicker, highly reflecting garments offer additional protection. However, only well ventilated, heavy garments can prevent elevation of body temperature. Fig. 4 indicates the degree of protection that has been obtained for various types of clothing in the pain limiting range of high intensity infrared heating. An important consideration in exposures of this type is the diffuse reflecting power of the skin. Fig. 5 shows a composite of data from many authors for the reflection in the visible and near infrared regions for a fair, blonde type skin, and for a dark, negro skin. The major differences in reflecting power are in the visible and near infrared because for wavelengths longer than 3μ, the human skin is essentially black (reflecting power 1–1.5 percent), regardless of pigmentation.

Wherever S (Equation 1) becomes strongly positive, and body temperature rises progressively, men can continue to work until body temperature reaches 102–105 F.[28] When these body temperatures are exceeded, men work with declining efficiency and may be subject to heat stroke.

Heat exhaustion is a circulatory failure in which the venous return to the heart is reduced so that fainting results.[29] Early symptoms of heat exhaustion may include fatigue, headache, dizziness when erect, loss of appetite, nausea, abdominal distress, vomiting, shortness of breath, flushing of face and

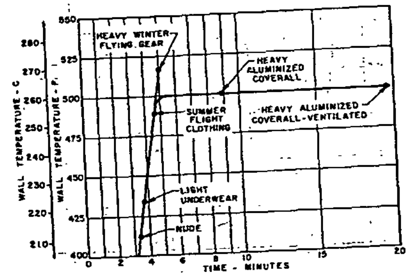

Fig. 4 .... Average Values of Tolerance Limits to a Slow Heat Pulse for Various Clothing Assemblies

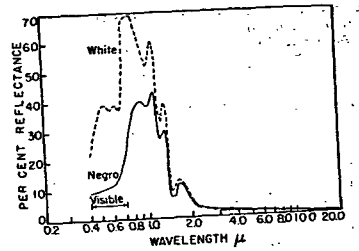

Fig. 5 .... Reflecting Power of Human Skin[27]

neck, pulse rate above 150, glazed eyes, and mental disturbances, such as apathy, poor judgment, and irritability, which usually precede fainting (syncope). Unless the man has another illness, such as heart disease, he will usually recover promptly if he is removed to a cool place and is permitted to lie down for a time.

Heat cramps are painful muscle spasms in the extremities, back, and abdomen, due, at least in part, to excessive loss of salt in sweating. Formerly common in hot industries, this manifestation of illness due to heat is now greatly reduced by drinking water containing 0.1 percent salt, or by proper use of salt tablets. Heat cramps are readily alleviated by intravenous administration of salt solution.

Heat stroke is a serious effect of exposure to great heat. The body temperature climbs rapidly to excessive levels, often above 105 F, when, for unknown reasons, free sweating suddenly stops. At such high temperatures, coma occurs, and death may be imminent. Under these circumstances, emergency measures which quickly reduce body temperatures are necessary, in order to avoid irreparable damage to the brain.[30]

The deleterious physiologic effects of high temperatures exert a powerful influence upon physical activity, accidents, sickness, and mortality. Both laboratory and field data show that physical work in warm atmospheres is a great effort, and that production falls progressively as the temperature rises.

HEAT ACCLIMATIZATION

When men move to deserts or to jungles, some adaptation to the climate takes place. If work is gradually increased day by day, and if the men can get plenty of water and salt, and can sleep each night, acclimatization may be complete in 7 to 10 days. The acclimatized man works with a lower heart rate, lower skin and rectal temperature, and more stable blood pressure than when unacclimatized. The process of acclimatization requires work in the heat.[31] During the recent war, white troops lived and did hard physical work for long periods in tropical conditions, when disease hazards were controlled.

In work tests made at the ASHRAE Research Laboratory,[32] subjects were required to perform light work under very hot conditions for a 4-hr period each day. It was found that the ability of a new subject to endure these conditions showed daily improvement for a period of at least 2 weeks. However, after acclimatization was completed, several days without work had no effect on the endurance of the subject. Individu-