SAFE WORKING TIMES FOR VERY HOT, HUMID CONDITIONS

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INTRODUCTION

As part of the preservation program for a 2500-yea-old wooden boat, its water content is being maintained by subjecting the entire structure to a continuous water spray. In due course the spray water will be enriched with polyethylene glycol in ever-increasing concentrations. The wax will gradually replace the water in the matrix of the wood thus preventing further decay.

The boat is permanently housed within a specially constructed, totally enclosed environment (the "boat lab") in which archaeologists are required to carry out periodic checks on the progress of the conservation program. Because of the constant water spray, the staff must wear personal protective equipment (PPE) to maintain their health, welfare and safety. Special-to-purpose PPE has been built that will keep the user dry and provide breathing-quality air as protection against the microbiological and chemical hazards associated with the preservation process. Operating procedures have been devised to enable the staff to work safely, but one aspect of their future working conditions required particular attention.

As the concentration and molecular weight of the polyethylene glycol increases, friction between the liquid and the sprayer orifices will raise the temperature of the spray water. It is estimated that during the 10-year spray program, the ambient temperature inside the boat lab will increase from its present 30°C to about 60°C. This additional hazard requires that the PPE must also prevent skin burning and provide cooling for the body to prevent the otherwise-inevitable rapid rises in deep-body and skin temperatures.

The purpose of the experiment was to develop guidelines to establish safe working times for the conditions of air temperatures up to 60°C; relative humidity 100%; irrespirable atmosphere and desirable duration of work 60 minutes.

METHODS

Overview. To quantify safe working times, a simulation of the task and the workspace was made in a controlled-climate chamber. Thermal strain (rectal and mean skin temperatures) was measured in the archaeologists assigned to the preservation program.

Tasks. Before the experiment, the routine tasks carried out in the boat lab were analyzed. From these observations, a sequence of similar activities that would be easy to reproduce in the simulated boat lab was devised. The metabolic heat production of each subject carrying out each of these activities was measured at about 100 $W \cdot m^{-2}$ (time-weighted average) using open-circuit spirometry.

Test exposures. Two subjects undertook a test exposure in the mornings; 2 others in the afternoon (ambient conditions are described below). In every test exposure, subjects were instrumented and always performed the same sequence of tasks. The other 2 subjects were dressed in the PPE (detailed below), and acted as 'safety men' to assist the subjects in the simulated boat lab if necessary. The duration of exposures was 100 min, unless pre-defined withdrawal criteria were reached.

Subjects. The 4 male subjects who volunteered were the archaeologists who, in the course of their normal duties, would be expected to work in the boat lab. Their anthropometric details were as follows: mean age 32 (range = 23 to 38) years; height 1.74 (1.66 to 1.83) m; weight 75.73 (65.0 to 85.2) kg; DuBois surface area 1.90 (1.72 to 2.05) m^2; Durnin and Womersley body fat content 20.0 (15.7 to 21.8) %.

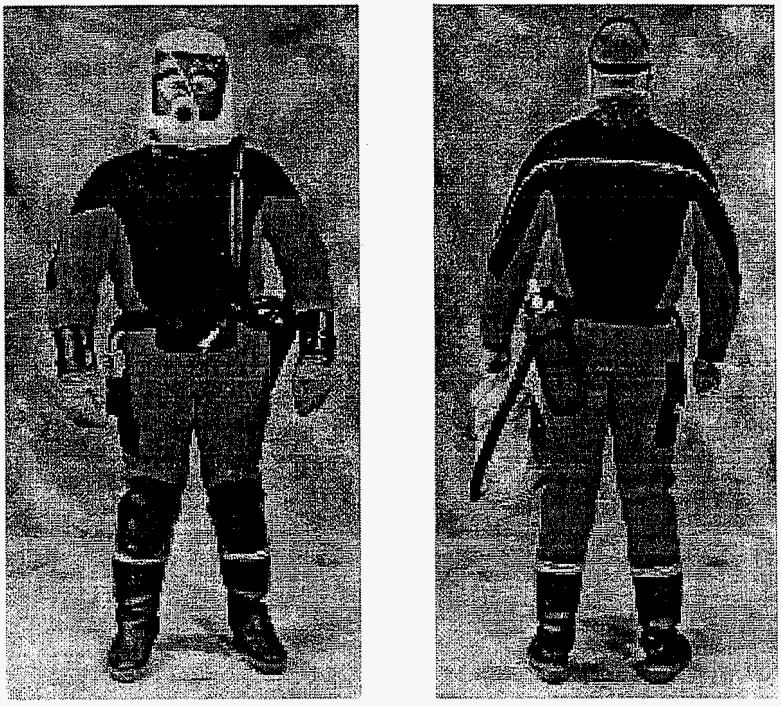
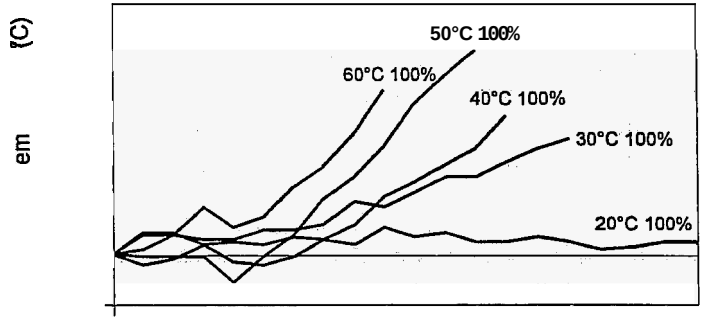


Figure 1. Themulti-layered PPE

PPE. The multi-layered PPE, designed by Life Support Engineering Ltd, Storrington, Sussex, UK is shown in Figure 1 above.

The PPE comprised a polyester pile diving undersuit to provide both thermal insulation and microclimate cooling. On its outer surface the suit had 7 pockets each of which held a gel pack frozen to –30°C, 3 across the upper back, 2 on the chest and 2 on the front of the thighs. Around the neck, the undersuit had a double layer of stretch fabric to protect the skin against burning. Over the under-


(C)
em
50°C 100%
60°C 100%
40°C 100%
30°C 100%
20°C 100%

rose continuously, reaching about 120, 135 and 155 bpm, respectively, at the end of the exposures.

Dehydration and evaporative ratio. Mean dehydration was within acceptable limits for all exposures, being 0.8, 1.0, 1.8, 2.2 and 1.8% of body weight at air temperatures of 20, 30, 40, 50 or 60°C, respectively. The corresponding E/P ratios of 10, 3, 3, 3 and 14% were low, as expected for individuals wearing water-vapor impermeable clothing.

Safe working time. For the team as a whole, maximum safe working times recommended from these data were as follows: at 60°C, 35 min; at 50°C, 40 min; only at 40°C and below was the required working time of 60 min achieved.

DISCUSSION

These data show that the simulated working conditions pose a high risk unless appropriate PPE and safe working practices are employed. We are not aware of reports of heat strain in similar working conditions with which to compare these data, and therefore have set conservative exposure times. Two other factors dictate cautious limits: first, this population will age during the preservation program; second, it is possible that women will join the team. Heat strain is greater in older individuals with lower aerobic fitness and in women (or men) with a lower surface area to mass ratio. The safe working times must therefore be constantly reviewed.

Two avenues of progress are underway. The preservation process is being re-thought to limit the temperature to which the archaeologists are exposed. However, in the event that this is not possible, the suit is being redesigned to provide either more conductive cooling and insulative protection or more evaporative cooling fi-om the head. A personal heat-strain monitoring system is being developed to provide continuous, real-time monitoring for every individual. The records will be archived as part of the archaeologists' personal medical records.

The lessons learned during the development of this working system are applicable to a wider range of workplaces, for example, firefighters, furnace workers and those working in water vapor impermeable suits. However, these working times must be used with caution because they apply only to the limited population tested..