THERMOPHYSIOLOGICAL STUDY OF HUMAN STEAM HAZARD EXPOSURE

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INTRODUCTION

Accidental exposure to direct steam jets or to a hot saturated environment is a potential hazard for some Navy military staff members and nuclear industry employees. Despite an effective potential risk, no job legislation on human exposure to steam was found; only one short article deals with steam engine construction and security. Moreover, only a few old scientific references on steam exposure effects on animals were found (1,2). In recent literature, only physiological and pathophysiological effects of *dry* and humid (but not saturated) heat exposures are well documented (3,4). These arguments point out the lack of medical and physiological knowledge concerning the steam hazard.

Furthermore, different industrial and naval steam protective garments have been tested in our institute with a calorimeter. These garments were inefficient to protect against steam exposure. At the most, they allowed 15 to 60 s of exposure time before a cutaneous second burn injury occurred (safety criteria for nuclear protection).

Different biological risks can appear after steam accidents ***(5).*** The main risk is a thermal one due to direct steam jet exposure and/or to hot saturated vapor environment created by hot steam entry in a closed room. It will affect all the human biological tissues, perhaps with more pronounced lethal effects on specific organs (respiratory airways, nervous structures). Condensation of water occurs on skin, clothing and perhaps in the respiratory airways. Furthermore, a foggy environment would lead to a low visibility and to difficulties in escaping.

Thus, the **final** purpose of our project in process is to create a data collection on biological impact of steam exposure for elaborating efficient protective systems.

To test the thermophysiological impact of steam exposure on the whole body, the first approach was done with a mathematical simulation of the steam accident.

HYPOTHESIS AND METHODS

In a thermophysiological view, the steam stress can be applied to the following: (1) the whole body with a more pronounced effect on nude skin area or (2) a specific area, the cephalic segment that contains all the nerve centers and the respiratory tract, with a short-term lethal effect.

Due to the potential risk of steam exposure, experiments need to be done **on** models, which avoids doing experiments on protected humans. We used the mathematical model, PROTECT, developed for the DGA by the CEPA laboratory (CNRS) for doing first simulations of human steam exposure. We chose the environmental parameters corresponding to measures of the **usual** conditions (iuitial conditions) of a submarine and calculations **of** a mathematical simulation **of** a steam accident in the same submarine.

PROTECT was elaborated fi-om the model of Stolwijk et al. (6) to which was added the possibility of wearing different kinds of clothing or local insulation and the possibility of doing specific ventilation inside the garment. The input parameters are clothing features, environmental conditions and physiological characteristics (work rate, degree **of** training, height and weight). The output parameters are internal and skin temperatures, heart rate, sweat rates, degree **of** dehydration and percentage of wet skin. Validations have been done, in part, by using less stressful conditions than those of this simulation **(7,8).** The results were in good agreement with the findings in these references, partictularily in prediction of tolerance time. The simulation was divided in two periods corresponding to 60-min steady initial conditions for the first period avoiding stability of the different physiological variables and the accidental conditions for the second period. **All** the input parameters of the Simulation are presented in Table 1. The total clothing insulation was 0.6 clo corresponding to a 100% covering of the trunk, legs and feet, and a 50% covering of the arms, with head and hands not covered. Three tenths clo insulation was added to model an undergarment covering 100% of the trunk and 25% of the arms.

Table 1: Input parameters of the simulation of the submarine accident.

	Initial conditions	Accidental conditions
Time duration (min)	60	15
Air temperature (°C)	38.8	70
Radiant temperature ("C)	42	42
Floor temperature ("C)	40	40
Air speed ($m \cdot s^{-1}$)	0.2	0.3
Relative humidity (%)	31	95
Metabolism ($W \cdot m^{-2}$)	116	116
Activity	walking	walking

RESULTS

The results of the simulation are presented in Table 2.

Internal **bodv** temperatures. During the initial conditions, internal and blood temperatures slightly increased due to warm environment and work. After ***60*** min, these two temperatures reached 38.2°C. In vapor saturated environment, these temperatures increased rapidly and exceeded the danger threshold (39°C) in less than ***5*** min. After 15 min in a steam environment, the internal temperature reached **40.7°C** and the blood temperature 41.6°C.

Skin temperatures. After 1 h in the initial conditions, all the skin temperatures were between **37** and 38°C. In accidental conditions, skin temperatures of the uncovered areas (head and hands) reached **45°C (injury** threshold) in less than 3 min, while the other skin temperatures stayed under this threshold during

Table *2:* Physiological results* of the simulation of the submarine accident.

	End of initial condition	End of accidental condition	Difference between the 2 conditions
T_{sl} Head (°C)	**37.3**	**47.1**	**9.8**
T_{sl} Trunk (°C)	**37.8**	**42.0**	**4.2**
T_{sl} Arm (°C)	**37.6**	**44.8**	**7 2**
T_{sl} Hand (°C)	**37.3**	**48.6**	**11.3**
T_{sl} Leg (°C)	**37.8**	**42.0**	**42**
T_{sl} Foot (°C)	**38.0**	**42.8**	**4.8**
T_{sk} (°C)	**37.7**	**43.1**	**5.4**
T_i (°C)	**38.2**	**40.7**	**2.5**
T_{blood} (°C)	**38.2**	**41.6**	**3.4**
HR (beats.min^{-1})	**163**	out of limit	**97**
M_{sw} (g·h^{-1})	**949.4**	**1378**	**428.6**

* T_{sl}: local skin temperature, T_{sk}: mean skin temperature, T_i: internal temperature, T_{blood}: blood temperature, HR: heart rate, M_{sw}: global sweat rate.

the **15 min** of steam exposure. The arms, uncovered at **50%,** presented **a** higher skin temperature than the skin temperature of the totally covered areas.

Sweat rates. Total sweat rate was already above the danger threshold at the end of the first period and increased again during the second period despite a totally wet skin (100%). The local sweat rates showed that the trunk sweated more **than** the other segments.

Heart rate. **During** the initial conditions, *HR* increased, first due to workload, and then due to warm conditions. HR reached **163** bpm at the end of the first period. In steam environment, HR increased rapidly. After **5** min in a steam environment, HR exceeded the limits.

DISCUSSION AND FUTURE PROSPECTS

The results **of** the simulation show that the skin areas that are not covered have a greater increase in temperature. These **skin** temperatures rapidly exceeded the injury threshold due to a direct impact of condensation on skin. Moreover, all the **skin** temperatures were greater than internal ones. The sweat could not evaporate making heat loss impossible and leading to considerable heat gain **(10°C·h-1).** With work and additional heat strain, the *HR* increased rapidly to dangerous levels. Thus, all the results show that the exposure to hot saturated environment presents a higher potential risk, with fast lethal consequences, including a cardiovascular one and other ones, which have generally slower impacts like heat stroke.

Despite a considerable heat strain applied to the human body, our study must take other potential lethal consequences of hot saturated environment exposure into account. Different parameters such as the steam impact on the upper respiratory tract and the psychological stress impact on physiological functions must be observed. Breathing hot steam should produce apnea, bums or condensation in the respiratory airways, among cardiovascular repercussions. All these factors produce a strong cardiovascular strain that would lead to fast death.

This simulation is the first step of our project of studying the biological effects of human steam exposure. The validity of the physiopathological responses in these upper limit conditions of the physiological variables needs to be confirmed. It is hypothesized that steam exposure could lead to specific pathological effects with delayed cutaneous burns and deeper injuries. To determine these injuries, different models (mathematical, mechanical and animal) should be used to observe the impact of steam exposure on biological tissues and physiological functions. All these experiments and simulations should give information about hot steam hazard that should be of interest for designing specific protective garments.

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