

Extract from the report

**Development and assessment of requirements for using
of closed life-saving appliances in case of distress
at sea - demands on microclimate and statements on
the acceleration behaviour in closed life-saving
appliances**

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on behalf of

Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAUA)
Federal Institute for Occupational Safety and Health (FIOSH)

1. Introduction

In the last years great efforts have been made to develop life-saving appliances further with the purpose to increase the chance of survival in case of distress at sea.

Live-saving means of the new generation compared with older ones are characterised by important characteristics such as higher grade of sealing, higher capsized safety, higher resistance against external effects, partially improved mobility and manoeuvrability. Whereas with life rafts only changes in points are noted, recent conceptions of lifeboats (especially closed, selfrighting, freefall ones) represent an absolutely new quality compared with conventional boats.

This hitherto existing general development unintentionally led to conditions of stay, which may mean extreme strain for man under unfavourable marginal conditions.

2. Purpose

Purpose of the tests was enabling assessment of the conditions for staying in closed life-saving appliances. Therefore, the most important strain quantities and stress factors for man were recorded.

Determined strain factors:

1. gas concentration of carbon dioxide and oxygen
2. vertical accelerations
3. interior temperature
4. relative humidity of air in the interior of live-saving means
5. sound immission
6. not existing sight
7. emission of volatile substance compounds

Measured pathophysiological stress criteria:

Characterisation of respiratory situation:

1. arterial oxygen and carbon dioxide partial pressures
2. parameters of acid-base-household

Characterisation of endocrine answer function on stress situation:

3. blood-picture, blood sugar, stress hormones

Characterisation of cardiovascular system:

4. heartbeat

5. blood pressure

Measured psychological stress indicators

6. performance characteristics

7. particulars of state of health

3. Measured values of strain

3.1 Gas concentration of carbon dioxide and oxygen

The waterproof sealing of life-saving appliances conditioned by construction causes gas concentrations, which may lead to an unacceptable strain for the occupants. Main reason for this is a missing continuous exchange of air. The described possible development of danger is proved by series of measurements in floating, fully occupied and closed state of the life-saving appliances.

In the life raft the values of carbon dioxide increase to $\text{CO}_2 = 4 - 5$ percent by volume, oxygen values decrease to $\text{O}_2 = 14 - 15$ percent by volume after an hour. After $t = 75$ minutes carbon dioxide values up to $\text{CO}_2 = 7$ percent by volume and after $t = 90$ minutes oxygen concentrations $\text{O}_2 < 15$ percent by volume were measured in dependence on measuring position in the lifeboat. Even when the air valves provided were opened and the ventilation number was increased by this, the concentration of carbon dioxide increased to $\text{CO}_2 = 2$ percent by volume in the fully occupied lifeboat after $t = 50$ minutes. The limits (criteria for breaking off) for carbon dioxide of $\text{CO}_2 = 6$ percent by volume and for oxygen of $\text{O}_2 = 15$ percent by volume were reached for

-concentration of carbon dioxide $\text{CO}_2 > 6$ percent by volume after $t = 75$ minutes

-concentration of oxygen O₂ < 15 percent by volume after
t = 97 minutes

when carrying out tests in the lifeboat on June 7th, 1995.

Figure 1 shows the development of carbon dioxide and oxygen concentration as a function of time exemplary. The lifeboat was occupied to its maximum and in floating and in functionally given closed state.

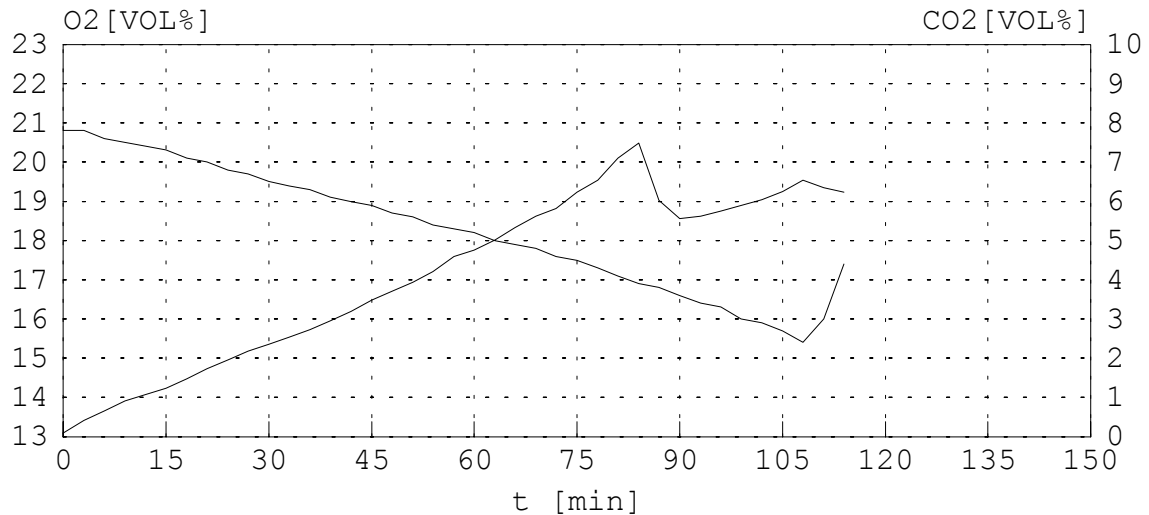


Figure 1 Concentration of oxygen and carbon dioxide as a function of time, place of measurement stern, for the field test in TSL-T 5.7 type lifeboat on June 7th, 1995, occupation with 15 probationers under functionally given closed state, floating.

An assessment of life-saving appliances concerning development of gas parameters carbon dioxide and oxygen is given in advance by the determination of ventilation number n . Such an advance calculation for the concentration of carbon dioxide as a function of the parameters time (t) and ventilation number n) in dependence on the number of occupants constantly supplied quantity of gas (V_{ZU}) and given interior volume of the boat (V_R) is possible with the help of equation 1.

$$C_{CO_2} = \frac{V_{ZU} \cdot 100}{n \cdot V_R} (1 - e^{(-n \cdot t)}) + 0,03 \text{ Vol\%}$$

Figure 2 shows advance calculations for carbon dioxide as a function of time under variation of the parameters ventilation number n and number of occupants.

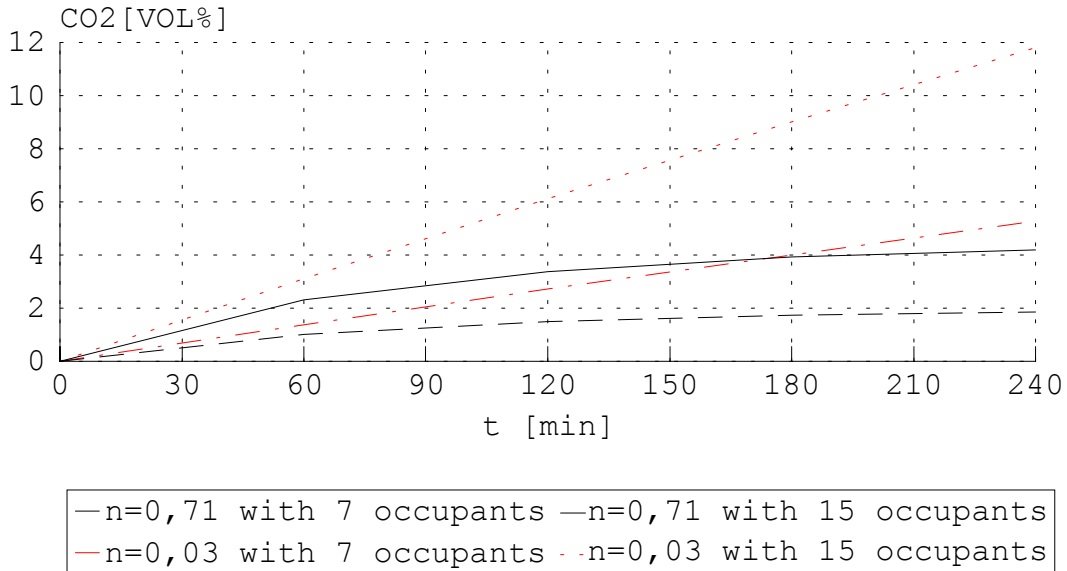


Figure 2 Concentration of carbon dioxide as a function of time under variation of the parameters ventilation number of persons for GSL-T 5.7 type lifeboat

Tendencies determined by this allow an estimation of development of gas concentration under defined conditions.

3.2 Diving and rolling acceleration

Overall acceleration a occurred for the lifeboat reached measured values of $a = 0.04$ to 0.07 g at a frequency of $f = 0.35$ cps under the given marginal conditions. Accelerations measured in the raft lied between $a = 0.04$ and 0.1 g.

One test had to be stopped because the occupants were overstressed by high diving and rolling accelerations. The values of rolling acceleration a_r were calculated with $a_r = 0.2$ g for this field test. Fore wave period $\bar{T}_{1/3}$ and natural period of vibrations T_Φ of the boat were in the same value range also resonance phenomenon's with high transmission functions are to be mentioned as a reason.

3.3 Microclimate

There is an influence on the microclimate resulting from thermal radiation when using a diesel generator in the lifeboat.

With engine operation under outside temperatures of $t_A = 20^\circ\text{C}$ the temperatures of the interior space locally increased to $t = 38^\circ\text{C}$ in closed state. Relative humidity of air decreased to $U < 50\%$ at the same time.

Even in floating state interior temperatures of $t = 30^\circ\text{C}$ are reached under the same conditions, but with terminal values of relative humidity of air of $U > 90\%$.

The following diagram shows the course of relative humidity of air as a function of time for the floating, functionally closed and maximally occupied lifeboat.

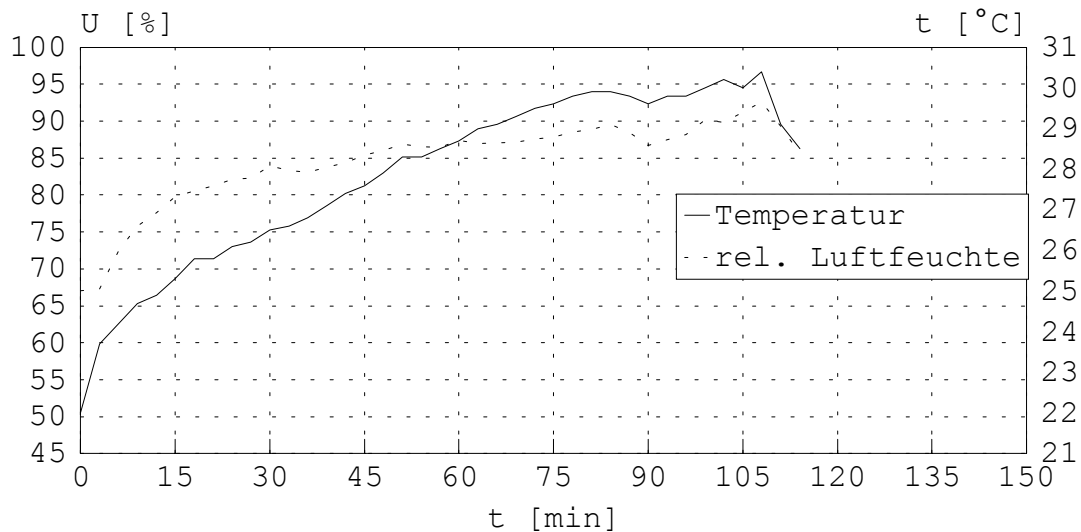


Figure 3 Temperature and relative humidity of air for floating state as a function of time in the lifeboat for the field on June 7th, 1995. Occupation with 15 probationers in functionally given closed state.

3.4 Emission of pollutants

Concerning emission of pollutants it can be assessed qualitatively, that harmful substances emit in an extraordinary high concentration under thermal stress of the exhaust gas insulation (polyester tape, thermal admission $t = 200^{\circ}\text{C}$) and the engine cover (glass fibre reinforced plastic, thermal admission $t = 70^{\circ}\text{C}$). External laboratory testings of the materials (gas chromatography) showed clear emissions of carcinogenic benzene, aliphatic and aromatic hydrocarbon, residual monomers, branched phenols, chlorinated compounds and unsaturated aldehydes.

4. Measurement of stress

4.1 Pathophysiological assessment of stress

The stay of persons in closed lifeboats conditioned by distress at sea leads to evident stress phenomenon's with regulatory effects on the cardiocirculatory system and to changes of blood gas state and acid-base-household in dependence of the length of stay in the closed boat and the strength of the factors acting as stress release from pathophysiological view.

Actually, especially the changes of gas concentration in the air, the microclimatic changes, and the ship motions acting result in an endangering if the lifeboat occupants, if they are not rescued within about three hours. Daze of the lifeboat occupants setting in because of described carbon dioxide concentration paralyses their ability to act and reduces the chance of survival with the oxygen concentration in the air and in the arterial blood of the lifeboat occupants decreasing permanently and carbon dioxide concentration increasing constantly. The respiratory Acidose resulting from this cannot be compensated.

The changes of the acid-base-household may be intensified additionally by vomiting conditioned by sea-sickness.

Figures 4 to 7 show the limits of strain. Furthermore, time functions of stress parameters, which appeared significantly in the field tests carried out, are given. Values were determined via probationers participated taking the mean.

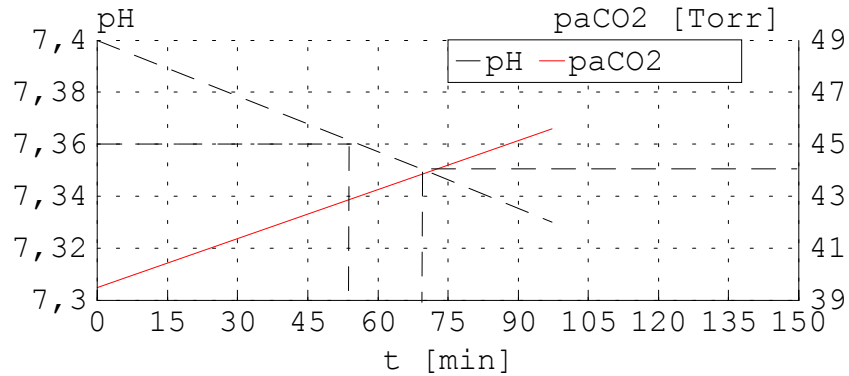


Figure 4 ph-value and carbon dioxide partial pressure as a function of time for the tests carried out in a closed lifeboat on June 7th, 1995, giving exact time of exceeding limiting values (pa CO₂ = 44 torr, pH = 7.36)

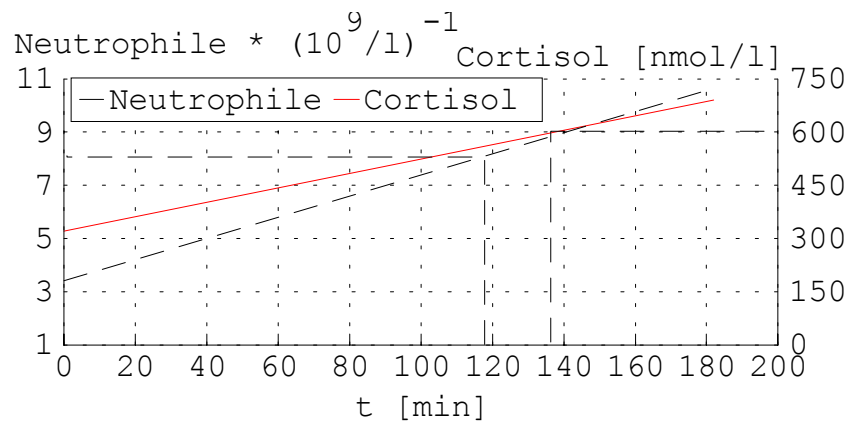


Figure 5 Neutrophile (test on May 30th, 1995) and cortisol (test on June 7th, 1995) as a function of time in a closed lifeboat giving exact time of exceeding limiting values (Neutrophile = $8 * (10^9/l)$, cortisol = 600 nmol/l)

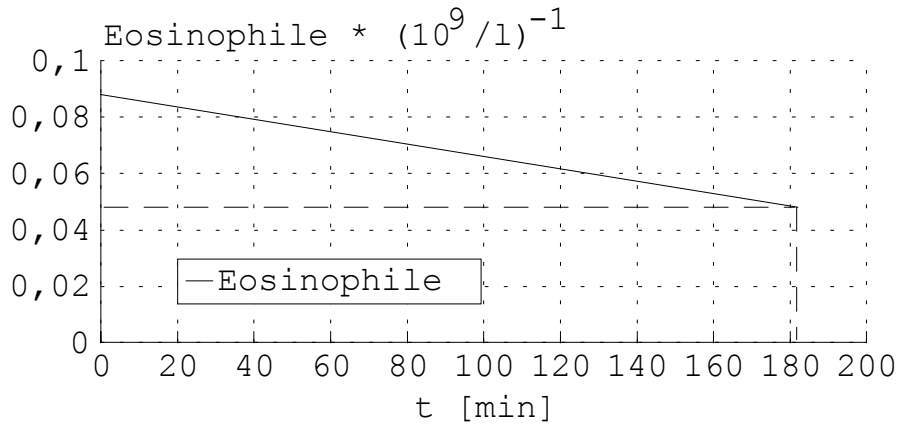


Figure 6 Eosinophile (on May 30th, 1995) as a function of time in a closed lifeboat giving exact time of exceeding limiting values (eosinophile = $0,05 \cdot (10^9/l)$)

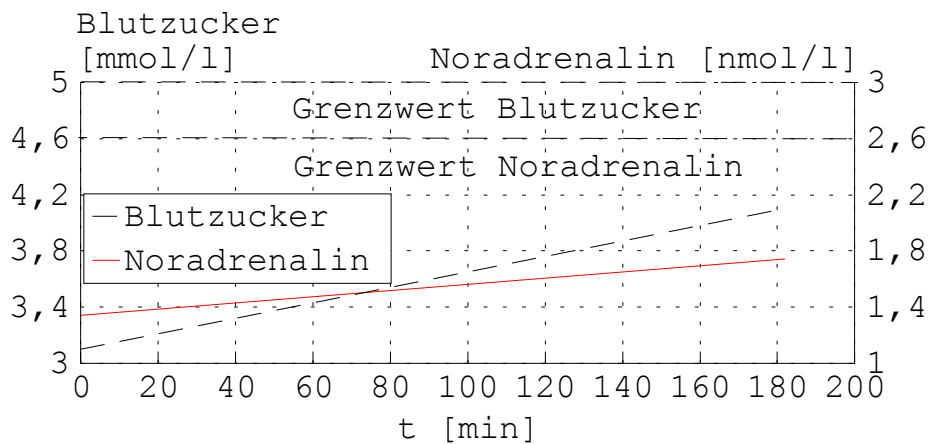


Figure 7 Blood sugar and noradrenaline as a function of time in a closed lifeboat for the test carried out on May 30th, 1995. Statement of limiting values (sugar = 5 mmol/l, noradrenaline = 2.5 nmol/l).

4.2 Psychological assessment

Strains acting on the occupants of the closed lifeboat result in an impairment of data of performance and state of health. Subjective stress (particulars of state of health) can be demonstrated by increased stress experiences (experience of threat) and decrease of mental activity.

At the time the degree of willing engagement diminishes, subjective well-beings impaired and affective participation (excitement) of probationers increases.

How much these particulars of state of health are marked is depending on the situational conditions during the tests of life-saving appliances. Unfavourable data with stress in critical symptom range occur with high accelerations. Effects of strain because of unfavourable climatic influences, especially by high temperatures are to be mentioned in the second place.

The influence of unfavourable oxygen and carbon dioxide concentration was not perceived subjectively but showed objectively in a decrease of concentrative performances. These impairments mainly occur under the following conditions:

- high accelerations in floating state
- unfavourable composition of air
- unfavourable composition of air, high temperatures
- low acceleration, high temperatures in floating state

5. Recommendations for naval construction/determination of limiting values

The described impairment of survival quality by strain factors acting is not compatible with the purpose function of these life-saving appliances to secure survival for occupants during period of stay. As a result of these tests technical changes are to be realised to reduce the determined, most important strain quantities.

The following remarks to limiting values of strain consider the determined importance of the individual strain qualities and allocate problem oriented solution attempts.

The described strain factors in closed life-saving appliances are to be kept below the following recommended limits or are to be eliminated with help of technical alterations.

1. Gas concentration of carbon dioxide and oxygen

Limiting value of $\text{CO}_2 = 4$ percent by volume is to be kept by means of an active ventilation regime.

2. Rolling and diving acceleration

The value of total acceleration of $a = 0.5$ g must not be exceeded. This should be reached by damping self-movement.

3. Gas emission of thermally stressed substances

Regarding naval construction only such substances are to be used preventively, which do not represent a potential for endangering the health of the occupants due to emission of volatile substance compounds.

4. Temperature/relative humidity of air

concerning value pair temperature/relative humidity of air effective temperature (NET) is to be kept **below 30°C** mainly by reducing relative humidity of air as long as it is objectively possible.

5. Loudness level

Sound level is to be kept **below 70 dB(A)**, primary to guarantee linguistic communication.

6. Not existing sight

Reference to real horizon is to be made by means of insertion of transparent areas or an artificial horizon, respectively.