HUMAN RESISTANCE

AGAINST

THERMAL EFFECTS, EXPLOSION EFFECTS, TOXIC EFFECTS AND OBSCURATION OF VISION

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Report title:

HUMAN RESISTANCE AGAINST THERMAL EFFECTS, EXPLOSION EFFECTS, TOXIC EFFECTS, AND OBSCURATION OF VISION

Client: STATOIL

Client specification:

Report summary:

A human impact load study was carried by DNV Technica and Scandpower on behalf of Statoil in september 1993. The main objective of the study was to carry out a state of the art study on human impact loads and provide a consistent set of human impact load criteria for use in the fatality assessment in offshore and onshore risk analyses. Human impact load criteria for the following loads was established:

- High air temperature
- Thermal incident fluxes
- Explosion loads
- Toxic gases
- Obscuration of vision

It should be noted that the different effects should be seen in light of each other in order to identify the most critical one. However, often fatal situations are a result of a combination of the above mentioned parameters, together with panic among personnel.

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1. INTRODUCTION

A study of environmental impact on humans was carried by DNV Technica and Scandpower on behalf of Statoil in september 1993. The main objective of the study was to carry out a state of the art study on environmental impacts on humans and provide a consistent set of criteria for use in fatality assessments in offshore and onshore risk analyses. Impact criteria for the following loads were established:

- High air temperature
- Thermal incident fluxes
- Explosion loads
- Toxic gases
- Obscuration of vision

It should be noted that the different effects should be seen in light of each other in order to identify the most critical one. However, fatal situations are often a result of a combination of the above mentioned parameters, together with panic among personnel.

Probit functions, table values and charts which can be used to calculate the fatality rate for given loads and exposure times are presented in the following. It is important to use the results from the probit functions, table values and charts as guidance in the fatality assessment, rather than absolute values.

In the fatality assessment load and exposure time are important parameters. Consequence calculations should form the basis for the assessment describing loads as a function of distance and exposure time taken into account shielding effects. Possibilities for personnel to escape from the accident venue, effect of protective measures as clothes and smoke masks are important aspects to address in the fatality assessment. In general offshore personnel will have less possibilities to escape from a large accident compared to onshore personnel. However, in general onshore personnel are lightly clothed compared to offshore personnel, making them more vulnerable to e.g radiation in the immediate vicinity of the accident.

2. DEFINITIONS

LD_{xx}:

The time related dose (heat radiation over time) which would be lethal to xx percent of the population.

Thermal dose:

The thermal dose is defined by the following equation:

$$\text{Thermal dose} = I^n * t \qquad \text{(Eq. 2.1)}$$

where I is the incident flux (kW/m^2), t is the exposure time (seconds) and n is a constant equal to 4/3.

LC_{xx}:

The time related dose (Concentration over time) which would be lethal to xx percent of the population.

Toxic dose:

$$\text{Toxic dose} = C^n * t \qquad \text{(Eq. 2.2)}$$

where C is the concentration in ppm, t is the exposure time in minutes and n is a constant.

Probit:

The range of susceptibility in a population to a harmful consequence can be expressed mathematically using a criterion in the form of an equation which expresses the percentage of a defined population which will suffer a defined level of harm (normally death) when it is exposed to a specified dangerous load. This is a "Probit" equation which has the form:

$$Pr = a + bLn(I^n * t)$$

where Pr is the probit (or the probability measure), a,b and n are constants. I is the radiation intensity given in kW/m^2 and t is the exposure time in seconds. The probit, Pr, can be related to percent fatalities using published tables. Table 2.1, Ref. [1], gives the relationship between the probit Pr and percent fatalities.

TABLE 2.1: Relationship between the Probit Pr and Percent Fatlities

3. THERMAL EFFECTS

3.1 General

The main effects of high air temperature or incident heat fluxes is of physiological and pathological art. The impact criteria contained in this section relate to impact from short and long duration of high air temperature which may cause heat stress resulting in fatal outcome and of thermal radiation which may cause first, second, third degree burns or fatal outcome.

Inside living quarters, control rooms or other compartments where personnel should be safe in a fire situation, the air temperature may become too high leading to physiological effects on humans such as difficulties with breath resulting in incapacitation, high pulse or core temperature leading to collapse. In most cases the air temperature inside the enclosures will not be sufficiently high for that pathological effects such as skin burns to be dominant. However, during escape or at the evacuation stations personnel may be directly exposed to the fire and thermal radiation may be more critical than the air temperature and pathological effects will be dominant.

Type of fire, the distance from the fire and the timeof exposure are very important parameters in the assessment of fatalities. On an offshore platform it is believed that personnel will be exposed to a fire for a longer time due to short distances and more time is needed to evacuate the platform than on an onshore installation. However, in general offshore personnel are more protectively clothed than onshore personnel, making them more resistant against thermal radiation.

The majorities of the data are given for lightly clothed personnel which is representative for onshore personnel. However, some data are also presented for well clothed personnel which is representative for offshore situations.

Thermal effects is described in detail in Appendix A.

3.2 Physiological Effects

Most physiological effects of thermal radiation onto man involve voluntary exposures which are relatively lengthy, i.e. at least several minutes. However, inside living quarters, control rooms or other types of compartments exposed to fire where personnel may stay for a period of time, they will be exposed to low thermal radiation levels and instead high air temperature may become the most critical parameter.

Personal trapped inside a helicopter due to a fire following a helicopter crash may be on excample of a fire where high temperature and not heat radiation becomes critical.

Table 3.1 adopted from Ref. /A.2/ indicates some Physiological Effects of elevated temperature levels on the human individual based on full-scale fire tests.

TABLE 3.1: Elevated Temperature Response on Human Individuals, Ref. /A.2/

Temperature (^oC)	Physiological Response
127	Difficult breathing
140	5-min tolerance limit
149	Mouth breathing difficult, temperature limit for escape
160	Rapid, unbearable pain with dry skin
182	Irreversible injury in 30 seconds
203	Respiratory systemes tolerance time less than four minutes with wet skin

Elevated temperatures have influence on the pulse rate, Ref. /A.3/. The pulse rate climbs steadily with time and air temperature. The pulse jumps from normal 84 to 120 beats a minute when the air temperature increases to 100 ^oC. It further increases to 150 beats/minute after 10 minutes at an air temperature of 113 ^oC.

In general the maximum air temperature that can be tolerated by the human respiratory tract is approximately 203 ^oC, Ref. /A.3/. Above air temperatures of 150 ^oC, the impact is dominated by pain from skin burns, which occur in less than 5 minutes. Between air temperatures of 70 - 150 ^oC, the impact is dominated by difficulties to breath. It is believed that below 70 ^oC the situation inside a compartment will not be fatal, but may of course lead to an uncomfortable situation for personnel. No probit function has been developed on this matter, hence special assessment must be made to calculate the fatality rate among trapped personnel inside compartments if the temperature inside rises to between 70 - 150 ^oC. The average time to incapacitation has been proposed as follows for temperatures between 70 - 150 ^oC, Ref. /A.3/:

$$t = 5.33*10^8/[(T)^{3.66}] \qquad \text{(Eq. 3.1)}$$

where

t = exposure time (minutes)
T = temperature (^oC)

This equation is also illustrated in Figure 3.1.

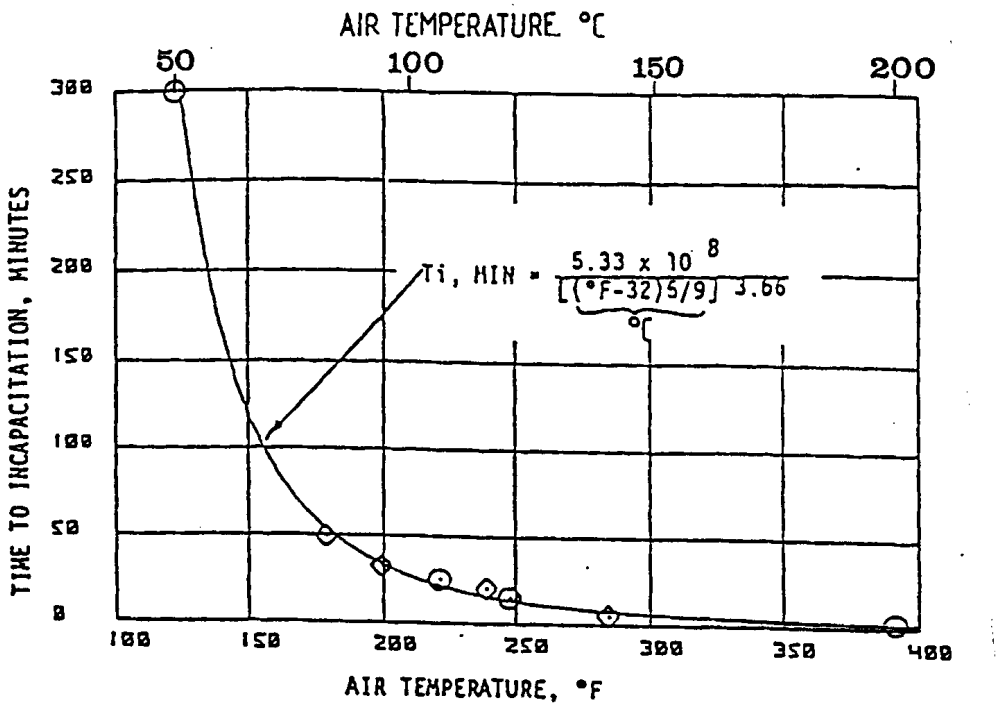

FIGURE 3.1: Air Temperature Hazard Limit Curve, Ref. /A.3/

With temperatures of 70 ^{o}C and 150 ^{o}C inside a compartment, time to incapacitation may be 94 minutes and 6 minutes respectively based on the above presented equation and curve.

3.3 Pathological Effects

Pathological effects on humans are relevant to address in the immediate vicinity of the accident, on unshielded escape ways and evacuation stations and inside enclosures if radiation becomes a dominant factor (above 150 ^{o}C). Pathological effects covered in this section are:

- Pain
- First degree burns
- Second degree burns
- Third degree burns
- Fatal burns.

Thermal doses required to reach second degree burns and third degree burns are approximately the same doses as 1% fatality and 50 % fatality respectively to averagely dressed exposers.

The severity of an injury from heat is determined by the depth of skin to which a temperature difference of 9 K has occurred. The following burn types are reached for different depths of skin:

First degree burns	< 0.12	mm
Second degree burns	< 2	mm
Third degree burns	> 2	mm

Thickness of skin varies from more than 5 mm on the back to only 0.5 mm on the eyelids, but on average is between 1-2 mm.

In the assessment of fatality rates on an offshore or onshore installation it is important to take into account the following factors:

- Information prior to fire (alarms)
- Development of accidents
- Personnel reaction time
- Emergency procedures
- Escape time,
- Shielding effects,
- Radiation levels as a function of time,
- Total exposure time,
- Other critical aspects like visibility, toxic gases, explosion loads etc.

In Table 3.2 ranges of thermal doses required to give pain and burns are given, based on the different sources presented in Appendix A. For a given radiation level or a given exposure time, time or necessary radiation level to pain, first, second or third degree can be calculated by use of the thermal doses presented in Table 3.2 and equation 2.1 in Chapter 2.

TABLE 3.2: Ranges of Thermal Doses required to give Pain, Burns and Fatal Outcome

Effect	Thermal dose ($s^*[kW/m^2]^{4/3}$)	Comments/references
Pain	108 - 127	Ref. /A.4/, bare skin
	85 - 129	Ref. /Gas De France/, bare skin
Significant injury level/ First degree burns	600 - 800	Ref. /A.7/, bare skin
	250 - 350	Ref. /Gas De France/, bare skin
	210 - 700	Ref. /A.12/, bare skin
Second degree burns/ 1 % lethality level for average clothing	900 - 1300	Ref. /A.9/,bare skin
	500 - 3000	Ref. /A.12/, bare skin
Third degree burns/ 50 % lethality level for average clothing	> 2000 - 3000	Ref. /A.12/, bare skin

The fatality rate when personnel is exposed to thermal radiation over a given period of time can be calculated by use of probit functions. Several probit functions have been developed based on experiments carried out on animals and humans. The most known probit functions are the Eisenberg function, Ref. /A.8/, for naked skin and the TNO function, Ref. /A.11/, for naked skin. The Eisenberg probit function is based on experiments carried out at nuclear explosions. The TNO model is based on the Eisenberg probit function adjusted for experiments carried out at hydrocarbon fires.

Compared to the probit function from Eisenberg the TNO model for naked human skin comes up with higher fatality rate. The thermal dose required for a given lethality level is in general lower for hydrocarbon fires than for nuclear explosions, because radiation from hydrocarbon fires is long waved penetrating deeper into the skin compared to the radiation from nuclear explosions which is short waved. It is believed that the TNO model is more suitable for use in the estimation of fatality levels than the Eisenberg model in typical offshore and onshore risk analyses where personnel are directly exposed to the fire, because the TNO model is based on hydrocarbon fires. However, the calculated fatality rates should be used as guidance in the fatality assessment more than as absolute values.

The TNO model, ref. /A.11/ is as follows:

Naked human skin: $Pr = -12.8 + 2.56(tI^{4/3})$ (Eq. 3.1)

The calculated fatality rates for different thermal incident fluxes and exposure times by use of the TNO probit function presented above are shown in Table 3.3.

TABLE 3.3: Fatality Rate as a Function of Radiation Level and Exposure Time

Exposure time (seconds)	TNO probit model (Naked human skin, Eq. 3.1) Fatality rate (%)		
	10 kW/m^2	20 kW/m^2	30 kW/m^2
10	0	5	39
20	1	53	93
30	11	87	100
40	31	97	100
50	53	99	100
60	71	100	100

If the probit function is not directly used in the fatality assessment, it is recommended to use the following radiation levels for lightly clothed personnel as 100 % fatality limit in the below given exposure time intervals:

16 kW/m^2 - Exposure time less than 0.5 minute
10 kW/m^2 - Exposure time from 0.5 minute to 1 minute
4 kW/m^2 - Exposure time from 1 minute to 2 minutes
2 kW/m^2 - Exposure time from 2 minutes to 10 minutes

The critical radiation levels are based on the TNO probit function assuming that the 50 % fatality limit represents the lethal dose for an average person and that incapacitation occurs close to the lethal dose, i.e. 75 % of the LD_{50} is set as the incapacitation dose here. This corresponds to 81 % of the lethal incident radiation flux.

For clothed personnel the Neisser curve, Ref. /A.12/ is recommended to use assuming that the 50 % fatality limit represents the lethal dose for an average person and that incapacitation occurs close to the lethal dose, i.e. 75 % of the LD_{50} is set as the incapacitation dose. This corresponds to 81 % of the lethal incident radiation flux. It is recommended to use the following radiation levels for clothed personnel as 100 % fatality limit in the below given exposure time intervals:

25 kW/m^2 - Exposure time less than 0.5 minute
13 kW/m^2 - Exposure time from 0.5 to 1 minute
8 kW/m^2 - Exposure time from 1 minute to 2 minutes
4 kW/m^2 - Exposure time from 2 minutes to 10 minutes

The approach assumes a constant heat load over the exposure period. In reality, most fires will initially expand and then decay with time, and thus the radiation received at any given point will also be a function of time. A full integration of the dose received may be performed if greater detail is required.

4. EFFECTS OF EXPLOSIONS

4.1 General

People can survive fairly strong blast waves and in accidental explosions there are very few cases in which the blast effect has killed people directly. Typical injuries following an explosion are caused by

- burn
- hitting fragments
- buildings or other structures falling down or being disintegrated
- persons falling or "flying" and subsequently hitting a solid object (Whole body displacement).

Appendix B presents a detailed presentation of the different effects from an explosion and can be used in a detailed consequence study. Most of the background of the material presented in Appendix B are based on tests performed by explosives and not HC explosions. This must be taken into account when the formulas and figures from Appendix B are used.

Important parameters for determining the effects and the risk from an explosion are

- maximum overpressure
- time to reach the maximum overpressure
- indoor or outdoor exposure of people
- possibility at flying fragments
- designed pressure sustainability of building.

In a risk analysis the most important effects are

- flying fragments hitting personal
- to hole body displacement resulting in impact damage
- damage due to impact coused by collapsed structures

4.2 Overpressure

Figure 4.1 shows lethality as function of overpressure and duration of the blast wave. If the long axis of body is parallel to blast winds and the subject is facing any direction the acceptable overpressure will increase. If the thorax is near a reflecting surface that is perpendicular to the blast winds the acceptable overpressure will decrease.

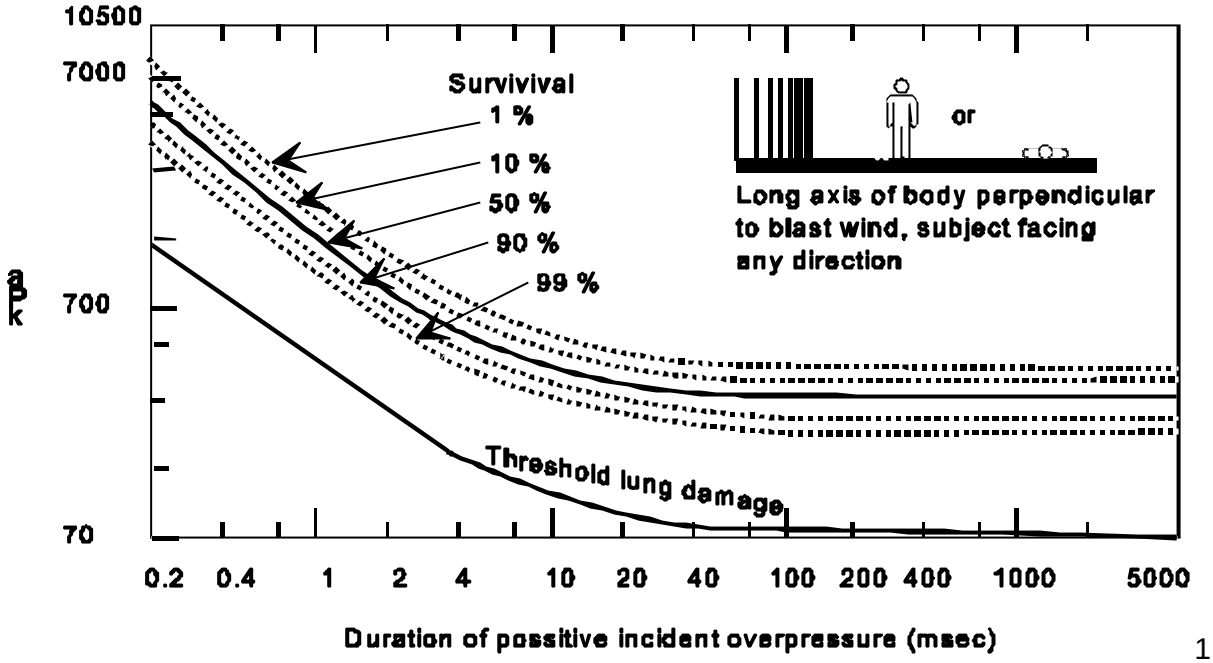

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FIGURE 4.1: Survival Curves for Man

For comparison a blast wave in the order of 25 kPa to 50 kPa is the threshold for eardrum perforation. For more information about lethality see Appendix B.

4.3 Fragments

Flying fragments from en explosion are more dangerous than the bare overpressure. Fragments may be debris from demolished buildings caused by the explosion or loose equipment in the building.

Fragments from glass breakage is a very common type of serious and extreme dangerous type of fragments, possibility for glass fragments must be determined during an analysis of explosion effects. The pressure needed for breakage of conventional glass is:

- 1 % level glass breakage $?p_{peak} = 1.7$ kPa
- 90 % level glass breakage $?p_{peak} = 6.2$ kPa

Table 4.1 shows the expected effects of flying missiles from an explosion.

TABLE 4.1: Injuries from Missiles

Injury	Peak overpressure (kPa / bar)	Impact velocity (m/s)	Impulse (N s/m^2)
Skin laceration threshold	7 - 15 / 0.07 - 0.15	15	512
Serious wound threshold	15 - 20 / 0.15 - 0.2	30	1024
Serious wounds near 50 % probability	25 - 35 / 0.25 - 0.35	55	1877
Serious wounds near 100 % probability	50 - 55 / 0.5 - 0.55	90	3071

4.4 Hole Body Displacement

Explosion effects also involve whole-body displacements and subsequent impact. During the whole-body displacement, blast overpressure and impulses interact with the body in such a manner that it is essentially picked up and translated.

The head is the most vulnerable part of the body for injuries from whole-body displacement. The whole-body displacement (accelerations) is a function of the size, shape and mass of the person and the blast forces.

50 % of the people being picked up and translated with a speed more than 0.6 m/s will suffer minor injuries. One percent of those with a speed of about 4 m/s will suffer injuries like ruptured organs and bone fractures. If thrown against a solid wall about 40 % will suffer major injuries.

Table 4.2 shows the expected effects from hole body displacement.

TABLE 4.2: Criteria for Tertial Damage involving Total Body Impact

Total body impact tolerance	Related impact velocity (m/s)
Most "Safe"	3.05
Lethality Threshold	6.40
Lethality 50 %	16.46
Lethality Near 100 %	42.06

5. TOXIC EFFECTS

5.1 General

Effect of toxic gases can be divided into two categories:

- Local irritant which may cause incapacitation mainly by effects on the eyes and the upper respiratory tract which may impair escape capability and sometimes cause delayed death due to lung damage

- Systematically acting agents which cause damage to the body via the blood and distribution in the body, so called narcotic gases.

The main toxic gases of fire effluents are carbon monoxide, (CO), carbon dioxide, (CO_2), hydrogen sulphide, (H_2S), nitrogen oxides, (NO_x), ammonia, (NH_3), sulphur dioxide, (SO_2) and hydrogen fluoride, (HF). CO and CO_2 are classified as narcotic gases, while the other are classified as irritants. The individual effects of CO, CO_2 and O_2 depletion are discussed in detail, before the combined effect of all is derived. The effect of irritants are also discussed in this section.

Although CO is not the most toxic of the above mentioned gases, it is present in relatively high concentrations in smoke, and so its effects are usually dominant.

There is a lot of uncertainties in the calculation of amount of smoke produced in a fire situation and amount of toxic gases in the smoke. This depends on type of burning fuel and ventilation conditions.

The proportion of toxic gases in smoke depends on the chemical structure of the burning materials and the degree of ventilation to the fire. The differences between different hydrocarbons are quite small, and ventilation has the main effect. Fires in which the ventilation is restricted occurs only for fires in modules or compartments. These fires will either be fuel controlled or ventilation controlled. In general, reduced ventilation greatly increases the ratio of CO, while the O_2 and the CO_2 remain more or less unaffected.

Typical gas concentrations close to the fire are given in Table 5.1 collated by Bonn, Ref. /C.2/, based on Ref. /C.3/, /C.4/ and /C.5/.

TABLE 5.1: Initial Gas Concentrations in Smoke, Ref. /C.2/

Gas	Concentration in smoke (%)			
	Well ventilated fire		Under ventilated fire	
	Gas fire	Liquid fire	Gas fire	Liquid fire
CO	0.04	0.08	3	3.1
CO_2	10.9	11.8	8.2	9.2
O_2	0	0	0	0

On an onshore installation the possibilities to escape from the accident are greater than on an offshore installation. Based on this offshore personnel will be exposed to toxic gases over a longer time period leading to in general lower acceptable concentrations than on an onshore installation.

The consequences of inhalation of toxic chemicals can only be derived from animal experiments. The uncertainties in translating animal data to data relevant for humans are large and therefore "safety factors" are included in the modelling. In general animals have a higher adsorption rate and humans have a higher respiratory rate in accident situations.

Toxic effects are discussed in detail in Appendix C.

5.2 Effects of CO

Extensive investigations examining human fire fatalities have shown carbon monoxide to be the primary toxicant in many deaths due to smoke inhalation, Ref. /C.6/ and /C.7/. The toxicity of carbon monoxide is due to the formation of blood carboxyhemoglobin, which results in a reduced ability of the blood to transport oxygen to critical body organs referred to as anaemic anoxia. There exist further evidence that relatively low levels of carboxyhemoglobin saturation may have adverse effects on reaction time which is important to escape from a fire. The toxicity of carbon monoxide may be modified by heat stresses. Experiments on test animals under heat stress showed that blood carboxyhemoglobin concentrations at the time of death were much lower than in animals not stressed by heat.

The following physiological effects on human individuals from carbon monoxide is given below based on Ref. /C.9/:

1500	ppm	Headache after 15 minutes, collapse after 30 minutes, death after 1 hour
2000	ppm	Headache after 10 minutes, collapse after 20 minutes, death after 45 minutes
3000	ppm	Maximum "safe" exposure for 5 minutes, danger of collapse in 10 minutes
6000	ppm	Headache and dizziness in 1 to 2 minutes, danger of

death in 10 to 15 minutes

12800 ppm Immediate effect, unconscious after 2 to 3 breaths, danger of death in 1 to 3 minutes

The above presented effects of CO indicates that with several thousand ppm of CO in the atmosphere will cause very critical situations on an offshore installation or an onshore installation.

Several probit functions have been developed based on experiments data from animals. They are presented in Appendix C. However, the following probit function is recommended to use in the fatality assessment, Ref. /C.12/:

$$Pr = -37.98 + 3.7\ln(C^*t) \quad \text{(Eq. 5.1)}$$

In Table 5.2 the lethality levels for different CO concentrations and exposure times by use of the probit equation are presented. In this table also the necessary CO concentrations and exposure time for a 50 % lethality level are presented.

TABLE 5.2: Lethality Level for Different CO Concentrations and Exposure Times by Use of the Recommended Probit Function

Probit Function	Fatality rate (%)			Concentration/exposure time for 50 % lethality	
	2000 ppm 10 minutes exposure	6000 ppm 10 minutes exposure	10000 ppm 10 minutes exposure		
Eq. 5.1	0	1.5	35	2000 ppm	54 min
				4000 ppm	27 min
				6000 ppm	18 min
				8000 ppm	13 min
				10 000 ppm	11 min

Based on a 50 % lethality level it can be concluded that the probit function is more or less consistent with the previous presented threshold limits.

5.3 Effects of CO_2

While carbon dioxide is not particular toxic at levels normally observed in fires, moderate concentrations do stimulate the rate of breathing. This condition may contribute to the overall hazard of a fire gas environment by causing accelerated uptake of toxicants and irritants. The rate and depth of breathing are increased 50 % by 20 000 ppm carbon dioxide and doubled by 30 000 ppm carbon dioxide in air. At 50 000 ppm, breathing becomes laboured and difficult for some individuals, although this concentration of carbon dioxide has been inhaled for up to one hour without serious

aftereffects.

Table 5.3 illustrates carbon dioxide responses, Ref. /C.15/.

TABLE 5.3: Carbon Dioxide Responses, Ref. /C.15/

Concentration of carbon dioxide (ppm)	Responses
100 000	Approaches threshold of unconsciousness in 30 minutes
120 000	Threshold of unconsciousness reached in 5 minutes
150 000	Exposure limit 1 minutes
200 000	Unconsciousness occurs in less than 1 minute

These values are also referred to in Ref. /C.10/.

No probit functions have been found in the literature describing the lethality level of different CO_2 concentrations and exposure time. Based on this the following 100 % fatal limits of CO_2 are recommended to use for different exposure times:

150 000 ppm of CO_2 Exposure time < 5 minutes
120 000 ppm of CO_2 Exposure time 5 - 30 minutes
100 000 ppm of CO_2 Exposure time > 30 minutes

5.4 Effects of Oxygen Depletion

Oxygen constitutes 21 % by volume of clean air. Decreases in oxygen concentration down to about 15 % are counteracted by the body increasing the flow of blood to the brain, and only minor effects on motor coordination are apparent.

Oxygen concentrations below 15 % by volume produce oxygen starvation effects such as increased breathing, faulty judgement and rapid onset of fatigue.

Oxygen concentrations below 10 % cause rapid loss of judgement and comprehension followed by loss of consciousness, leading to death within a few minutes. This is taken to be the limiting oxygen concentration for escape lasting a few seconds. If escape is not possible within few seconds, incapacitation and death is assumed to occur.

Oxygen concentrations of 10 % and 15 % require a clean air content in the mixing gas of 47 % and 71 % respectively. These would be achieved when the gas is diluted to 52 % and 29 % respectively of its concentration. A gas concentration of 52 % would cause death unless escape is possible in a few seconds.

Table 5.4 indicates the responses of human individuals to different reduced levels of oxygen in air, Ref. /C.15/.

TABLE 5.4: Human Responses due to reduced Levels of Oxygen in Air, Ref. /C.15/

Concentration of oxygen in air (%)	Responses
11	Headache, dizziness, early fatigue, tolerance time 30 minutes
9	Shortness of breath, quickened pulse, slight cyanosis, nausea, tolerance time 5 minutes
7	Above symptoms becomes serious, stupor sets in, unconsciousness occurs tolerance time 3 minutes
6	Heart contractions stop 6 to 8 minutes after respiration stops
3-2	Death occurs within 45 seconds

No probit functions are found in the literature describing the lethality level for personnel when exposed to different concentrations of oxygen in the air and exposure time. Based on this the following fatal limits of O_2 depletion are recommended to use for different exposure times:

10 % of O_2 Exposure time < 5 minutes
15 % of O_2 Exposure time > 5 minutes

5.5 Overall Smoke Effects

The combined effects of CO, CO_2 and oxygen depletion are the main causes of fatalities in smoke. The criteria for them are compared in Table 5.5. For the under ventilated fires, CO has the main effect, which depends strongly on exposure time. For well-ventilated fires, CO production is much reduced and oxygen depletion appear to have main effect.

TABLE 5.5: Smoke Concentration to prevent Escape in Few Minutes

Gas	Smoke concentration (%) to prevent escape in few minutes			
	Well ventilated fire		Under ventilated fire	
	Gas fire	Liquid fire	Gas fire	Liquid fire
CO	-	-	33	32
CO_2	92	85	-	-
O_2	56	56	56	56
Comb. effects	52	48	19	18

Based on this the following concentrations of smoke may cause very critical situations (nearly 100 % fatality rate) among exposed personnel after few seconds:

52 % of smoke in well ventilated gas fuelled fires
48 % of smoke in well ventilated liquid fuelled fires
19 % in under ventilated gas fuelled fires
18 % in under ventilated liquid fuelled fires

The combined effects of CO, CO_2 and oxygen depletion are a difficult task and the above presented values should be used as guidance only to identify the problem.

5.6 Effects of Other Gases

Table 5.6 illustrates the effects likely to be experienced by humans exposed to various concentrations of H_2S.

TABLE 5.6: Effects on People exposed to H_2S

Concentration (ppm)	Effect
20 - 30	Conjunctivitis
50	Objection to light after 4 hours exposure. Lacrimation
150 - 200	Objection to light, irritation of mucous membranes, headache
200 - 400	Slight symptoms of poisoning after several hours
250 - 600	Pulmonary edema and bronchial pneumonia after prolonged exposure
500 - 1000	Painful eye irritation, vomiting.
1000	Immediate acute poisoning
1000 - 2000	Lethal after 30 to 60 minutes
> 2000	Acute lethal poisoning

Several probit functions have been developed based on experiments data from animals. They are presented in Appendix C. However, the following probit function, Ref. /C.21/, is recommended to use in the fatality assessment:

$$Pr = -31.42 + 3.008\ln(C^{1.43}*t) \qquad \text{(Eq. 5.2)}$$

The probit function is to some degree more conservative than the values presented in Table 5.6.

The toxicological effects of NO_x, NH_3, SO_2 and HF are given in Table 5.7.

TABLE 5.7: Toxicological Effects of NO_x, NH_3, SO_2 and HF, Ref. /C.16/

Toxicant	Toxicological Effects
NO_x	Strong pulmonary irritant capable of causing immediate death as well as delayed injury
NH_3	Pungent, unbearable odour; irritant to eyes and nose
SO_2	A strong irritant, intolerable well below lethal concentrations
HF	Respiratory irritants

In Table 5.8 predicted lethal concentrations for humans and published values are given.

TABLE 5.8: Predicted Lethal Concentrations for Humans and published Values, Ref. /C.17/

Toxicant	Human LC_{50} (ppm) predicted from metabolic rate		Human lethal concentrations (ppm) Ref. /16/
	5-min	30-min	
NH_3	55 000		2 000
SO_2	17 000	8 000	600 - 800 (few min)
HF	44 000	4 600	
NO_x	410	180	250 (few min)

Several probit functions have been developed for NH_3, SO_2, and HF. Below probit function for each of these gases are presented to use in the fatality assessment:

NH_3, Ref. /C.18/:
$Pr = -9.82 + 0.71\ln(C^2*t)$, LC_{50} = 15 240 ppm, 5 minutes exposure (Eq. 5.3)

SO_2, ref/C.19/:
$Pr = -15.67 + 2.1\ln(C*t)$, LC_{50} = 3 765 ppm, 5 minutes exposure (Eq. 5.4)

HF, ref/C.20/:
$Pr = -48.33 + 4.853\ln(C*t)$, LC_{50} = 11 845 ppm, 5 minutes exposure (Eq. 5.5)

No probit model is found in the literature for NO_x.

The presented LC_{50} values for NH_3, SO_2, and HF in Table 5.7 is not so conservative as the LC_{50} values received at by use of the probit functions.

6. OBSCURATION OF VISION

The absence of vision may delay or prevent escape from fires and cause people to be exposed to the fire gases for an unacceptable long period of time. While the exposure to high concentrations of toxic and hot gases usually will be significant only in the vicinity of the fire, the effect of reduced visibility may also be significant far away from the fire source. For example, in multi-compartment buildings, the smoke blocking effect may be significant in rooms far away from the room of fire origin.

Moreover, the smoke blocking effect is reported to be the first condition becoming critical of the three hazardous conditions of fires i.e. heat stresses, obscuration of vision, toxic effects.

The hazard of smoke is characterized by three factors. The first threat is reduced visibility due to soot. The second is that hot smoke can cause pain and injuries, and the third is that a concentration of toxic and irritating components can lead to incapacitation or death. The relative order of these factors can be found by comparison of threshold values with actual exposure in a fire scenario.

A visibility of 4-5 m is about the threshold of diminished performance, and this is the smoke level that one should have in mind when designing smoke ventilation systems. A visibility of less than one arm length will be of no help at all when escaping from a fire environment.

Important factors to consider in a risk analysis with regard to obscuration of vision (and time to escape) are

- exposure to smoke
- arrangement of escapeways (layout, sign, illumination, railing, etc.)
- training of personnel
- familiarization with the installation.

Obscuration of vision is described in detail in Appendix D.