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FIRE-RELATED MEDICAL SCIENCE

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Space crews must quickly extinguish in-flight fires in order to prevent serious burns and smoke inhalation. Otherwise, fire victims may require medical skills and supplies that exceed the capabilities and resources of the surviving crewmembers.

Man's efforts to combat or escape fires are usually futile when flames develop in oxygen-rich atmospheres, for the simple reason that lethal temperatures are produced within 60 sec of the onset of combustion (refs. 88 to 90). Even in an atmosphere of 20 percent oxygen - 80 percent nitrogen, dangerous temperatures can evolve in an astoundingly short period of time. Earth-based engineering studies (ref. 91) have shown that the threshold temperature for skin injury develops within 30 to 90 sec of ignition, depending on the configuration of the test chamber. High temperatures evolve more quickly when the fire chamber is sealed than when its hatches are open to ambient air. This is shown in figure 1, which plots selected data from figure 5 of the preceding report Inerting and Atmospheres. The difference in skin injury between 30 sec of exposure (hatches closed) and 90 sec of exposure (hatches open) could mean the difference between death and survival of those fighting the fire.

Brief exposures to fire may be lethal within 1 to 5 min when the ambient temperature exceeds 200 °C (fig. 2). The postulated mechanism of death, hyperthermia, is lethal to test animals when rectal or heart-blood temperature exceeds 42.5 °C. The final cause of death is either circulatory failure, from ventricular fibrillation, or agonal collapse of blood pressure (ref. 92).

Inadequate respiratory protection, space sickness, and panic may predispose crewmembers to incapacitation, injury, and death by smoke inhalation. Smoke inhalation has been a leading cause of death in victims of urban fires (refs. 93 and 94). Massive exposures may interfere with lung function when smoke particles mix with secretions to plug the airways. Otherwise, particulates act as irritants, obscure vision, and induce panic (ref. 95). Firefighters have been exposed to a number of harmful gases in smoke, including carbon monoxide, acrolein, hydrochloric acid, and other asphyxiants/irritants (table I). Smoke suffocates victims since it is deficient in oxygen and contains high concentrations of carbon dioxide (refs. 96 and 97). However, carbon monoxide accounts for the majority of deaths occurring within six hours of exposure to cellulosic fires. It asphyxiates the body by blocking oxygen's reactions with hemoglobin and cellular proteins. Hydrogen cyanide, also an asphyxiant, has not been a prevalent cause of early deaths (ref. 98). Acrolein is considered to be the most serious irritant found in smoke, because of its potency in producing intolerable lacrimation and nasal irritation (refs. 95 and 96). The release of acrolein depends on fire temperature and fuel composition (ref. 98).

Spacecraft interiors may contain synthetic polymers that yield high concentrations of toxic gases when burned. There is already an account of the release of lethal concentrations of nitrogen dioxide from x-ray film burned in

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the Cleveland Clinic fire (refs. 95 and 98). Halogenated acids, such as hydrochloric acid, may act as strong sensory irritants when released by the combustion of halogenated polymers. Isocyanates, ammonia, and cyanides have been produced by the burning of nitrogenous polymers.

Any flame might cause an explosion by igniting reactive substances (e.g., propellant fumes) that accumulate in spacecraft atmospheres (ref. 99). Tissues that line gas-filled spaces in the body are particularly vulnerable to injury by blast waves (table II). Consequently, the lung may sustain sufficient damage to impede oxygenation of hemoglobin and release bubbles of air into the arterial blood stream (ref. 100). The bubbles interfere with heart and brain activity by obstructing nutrient blood flow through the tissues. More frequently, however, blast waves cause serious injury by tossing the body against firm surfaces or releasing high-speed fragments that penetrate the tissues.

Structural failures in burning buildings can impede the movement of victims or injure firefighters; but in the weightless conditions of space travel, weakened structures would not shift as a result of gravitational forces.

The time-of-useful-function indicates how long victims have to escape a fire before their only hope for survival is rescue (ref. 93). Medical scientists have studied the ability of experimental animals to escape fires as a biological end-point of combustion toxicology tests. For example, toxic gases may impose one or more forms of hypoxia, which impair animal coordination. Overwhelming irritation of the eyes and airways may also impair escape (ref. 98). But, combustion products can diminish mental acuity and degrade human judgment before there is overwhelming irritation and neuromuscular incoordination. Rather than studying the escape behavior of animals, why not evaluate the early effects of smoke inhalation on human performance?

Spacecraft fire safety may be improved by the use of a fire-retardant atmosphere in occupied spaces. Low concentrations of oxygen can protect humans from fire damage by reducing the rate and spread of combustion, but care must be taken to avoid the hypoxic effects of oxygen-lean atmospheres. Crews could live and work in 11 percent oxygen if barometric pressure were adjusted to maintain the partial pressure of oxygen (P_{O2}) above 16 kPa (0.16 atm) (fig. 3). Eleven percent oxygen should prevent most types of fires, since 15 percent oxygen retards the combustion of paper and 13 percent oxygen extinguishes pentane flames (refs. 89, 91, and 101). Studies at the Naval Submarine Medical Research Laboratory are defining (a) a safe, minimum P_{O2} at normobaric pressures; (b) a maximum barometric pressure for use without risk of nitrogen narcosis/decompression sickness; and (c) the health effects of breathing trace levels of atmosphere contaminants in low concentrations of oxygen. To date, the results indicate that seated humans can perform mental tasks in atmospheres containing 11.5 percent oxygen. Although this strategy of fire safety is under consideration for submarines, it could be adapted to spacecraft once operational procedures define a maximum hyperbaric pressure and fire research defines the effects of reduced oxygen concentrations on combustion in low-gravity environments. Additional research is necessary to define man's tolerance of fire-inert atmospheres in the space station.

GLOSSARY

ANEMIC HYPOXIA - a deficiency of oxygen due to reduced content of hemoglobin (e.g., hemorrhage) or inhibition of oxygen uptake by hemoglobin (e.g., the action of carbon monoxide).

ASPHYXIA (SUFFOCATION) - the consequence of hypoxia combined with an increased tension of carbon dioxide in the blood and tissues.

BRONCHOCONSTRICTOR - a gas that induces resistance to air flow through the respiratory passages, either by consequences of nerve stimulation or release of histamine (e.g., ammonia, sulfur dioxide).

HISTOTOXIC HYPOXIA - the blockade of oxygen utilization caused by the poisoning of cellular respiration (e.g., the action of hydrogen cyanide).

HYPERTHERMIA - an abnormally high body temperature.

HYPOXIA - the failure of tissues, for any reason, to receive an adequate supply of oxygen.

HYPOXIC (ARTERIAL) HYPOXIA - the consequence of reduced oxygen tension/content in arterial blood, due to (a) low partial pressure of oxygen in breathing gas, (b) abnormal lung function, or (c) shunting of venous blood into arterial stream.

IRRITANT - a gas that inflames tissues by direct contact, ordinarily the surfaces of skin and mucous membranes.

PULMONARY IRRITANT - a gas that stimulates sensory nerves in the lower respiratory tract and causes pulmonary edema (e.g., nitrogen oxides).

RESPIRATORY IRRITANT - a gas that acts as a SENSORY IRRITANT, PULMONARY IRRITANT, and BRONCHOCONSTRICTOR (e.g., chlorine).

SENSORY IRRITANT - a gas that stimulates sensory nerves in the face and upper respiratory tract, causing discomfort and slowing of the ventilation rate (e.g., acrolein, HCl).

SMOKE - a complex mixture of the airborne solid and liquid particulates and gases evolved when a material undergoes pyrolysis or combustion. The composition of smoke depends on the conditions of combustion.

STAGNANT (CIRCULATORY) HYPOXIA - a deficiency of oxygen caused by the slowing of blood flow through tissues.

TABLE I. - COMBUSTION PRODUCTS ENCOUNTERED BY URBAN FIREFIGHTERS

[The data were tabulated from ref. 96.]

Combustion product	Concentration		Limits of exposure, ppm	
	ppm	mg/m^3	IDLH[a] (30 min)	STLC[b] (10 min)
Acrolein	0.1	14	5	30 to 100
HCN	.1	4	50	350
NO_2	.2	10	50	>200
HCl	1	200	100	>500
CO	5	5 000	1 500	5 000
Benzene	.2	175	2 000	20 000
CO_2	1000	75 000	50 000	100 000
Particulates	20	18 000	------	--------

[a]Immediate danger to life or health (IDLH) is the concentration from which an unprotected worker might escape within 30 min without irreversible health effects or any physiologic effects that would impede escape.

[b]Short-term lethal concentration (STLC) is a 10-min exposure limit.

TABLE II. - ESTIMATED BLAST EFFECTS IN MAN

[Adapted from ref. 100.]

Effect	Overpressure	
	kPa	psi
Ruptured ear drum	>35	>5
Tiny hemorrhages in lung	80 to 110	12 to 16
Isolated hemorrhage in lung	140 to 210	20 to 30
LD_{50}, boggy lung, emphysema	320 to 340	46 to 50
Death	690 to 830	100 to 120

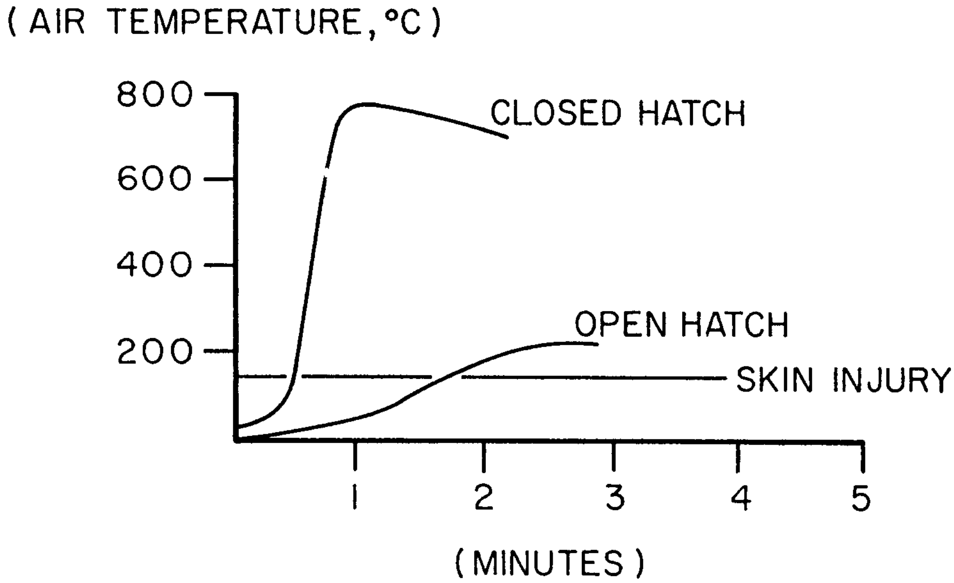

Figure 1. - Effect of chamber configuration on air temperature in submarine hull insulation fires (ref. 91).

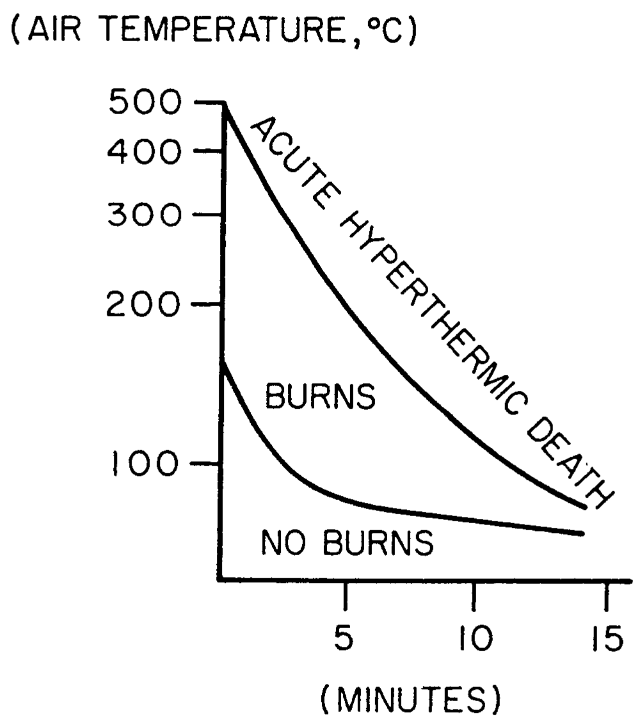

Figure 2. - Temperature-time relationship for heat injuries (ref. 92).

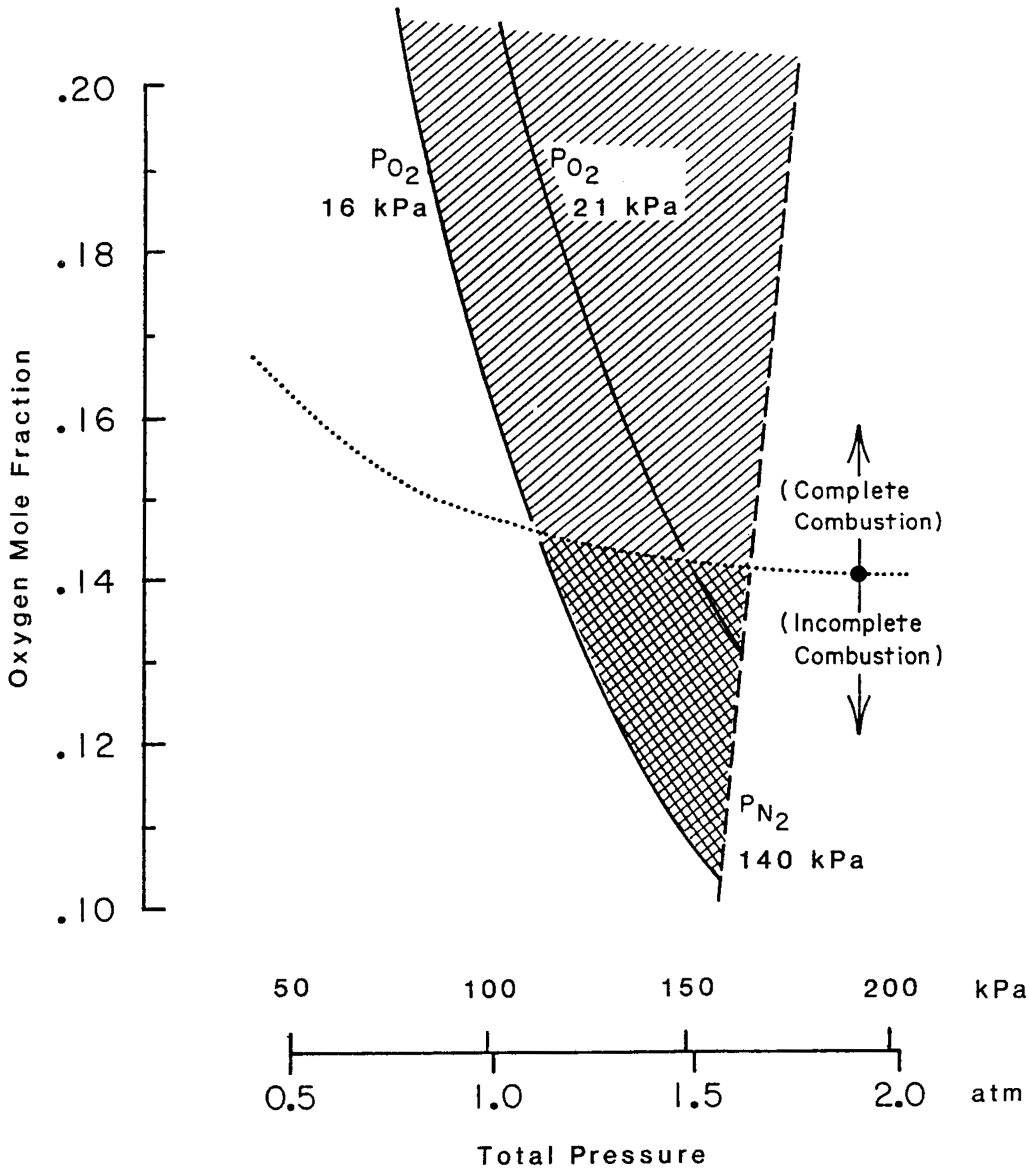

Figure 3. - Human life-support zones and flame retardant atmospheres.