

HPA Compendium of Chemical Hazards

Carbon monoxide

Key Points

Fire

- Flammable gas
- May react violently with other substances
- Use fine water spray with normal fire-fighting clothing and breathing apparatus
-

Health

- Toxic by inhalation
- May cause harm to the unborn child
- Following acute exposure symptoms such as headache, dizziness, confusion, disorientation, memory loss, fainting, seizures, cerebral oedema, coma and death may arise
- Tachycardia, tachypnoea, hypotension, vasodilation, cyanosis, shock and cardiac arrest may occur
- Long-term neurological effects may occur following an acute exposure, including cognitive and behavioural changes
- Chronic exposure to low concentrations of carbon monoxide may lead to tiredness, lethargy, headaches, nausea, dizziness, personality changes, memory problems, Parkinsonian symptoms, visual loss and dementia, as well as loss of visual, auditory or cognitive function
- Low birth weight, perinatal death and behavioural deficits may occur in children exposed to carbon monoxide during pregnancy

Environment

- Unlikely to pose a significant risk to the environment

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Carbon monoxide

General information

Key Points

Fire

- Flammable gas
- May react violently with other substances
- Use fine water spray with normal fire-fighting clothing and breathing apparatus

Health

- Toxic when inhaled
- Following short-term exposure symptoms such as headache, dizziness, confusion, disorientation, memory loss, fainting, coma and death may arise
- Effects such as fast heart rate and breathing, low blood pressure and cardiac arrest may also occur
- Long-term effects may occur such as behavioural changes
- Long-term exposure to low concentrations of carbon monoxide may cause tiredness, headaches, sickness, dizziness, personality changes, memory problems, visual and hearing loss
- Carbon monoxide may cause harm to the unborn child

Environment

- Unlikely to pose a significant risk to the environment

Background

Carbon monoxide is a colourless, tasteless, odourless, non-irritating gas produced during incomplete combustion of gas or fossil fuels due to there being insufficient oxygen present.

In the home, incorrectly installed, poorly maintained and ventilated cooking and heating appliances, such as those using gas, coal, wood or paraffin are the main sources of carbon monoxide. As well as these domestic sources, the most significant exposure to carbon monoxide comes from cigarette smoking and car exhausts.



Production of carbon monoxide increases when cars are moving slowly hence levels of carbon monoxide in the atmosphere are higher near busy roads during peak times when the flow of traffic is slow. Carbon monoxide production increases when the engine is cold, as catalytic converters take time to reach the operating temperature and thus petrol engine cars in closed garages are dangerous even with a catalytic converter. Levels may also increase in winter due to periods of still cold air as this affects the dispersal of carbon monoxide, as it is usually rapidly dispersed away from roads and destroyed by photochemical reactions over a period of months.



In smokers, cigarettes are the major source of carbon monoxide. The amount of carbon monoxide in the blood of smokers is greater than that caused from breathing in contaminated air, even in polluted areas.



When breathed in, carbon monoxide enters the blood through the lungs and attaches to the body's oxygen carrier, haemoglobin. This reduces the amount of oxygen that can be carried round the body. Carbon monoxide also impairs the release of such oxygen as it is transported. Exposure to higher concentrations for a short period of time can cause headaches, dizziness, nausea, vomiting, confusion, collapse and coma. When individuals are removed from the source of carbon monoxide these symptoms usually subside. Exposure to lower concentrations of carbon monoxide for a longer period may affect learning, manual dexterity, driving performance and attention level.

People who have diseases that affect the delivery of oxygen to the heart or brain, such as those with coronary heart disease, angina or anaemia are particularly at risk from carbon monoxide poisoning as the amount of oxygen being carried to the heart or brain is further reduced by carbon monoxide.

Carbon monoxide is transported across the placenta which reduces the oxygen supply to the baby. Therefore exposure to elevated levels of carbon monoxide during pregnancy may result in a decrease in birth weight and possibly behavioural problems. Such effects are more likely in smokers because smoking is a significant source of carbon monoxide.

Frequently Asked Questions

What is carbon monoxide?

Carbon monoxide is a colourless, tasteless, odourless gas. Exposure to high levels can kill.

How will I be exposed to carbon monoxide?

Carbon monoxide is produced when fossil fuels burn without enough air. Indoors, one of the main sources of exposure to carbon monoxide is from faulty, incorrectly installed, poorly maintained, or poorly ventilated cooking or heating appliances which use fossil fuels. Cigarette smoke is also a major source of exposure. Exposure to low levels of carbon monoxide can occur outdoors, as it is also produced by vehicle exhausts.

How will I know that I have been exposed to carbon monoxide? What does it taste/smell/look like?

Carbon monoxide is colourless, tasteless and odourless, so you will not necessarily know that you have been exposed to it.

What are the health effects of carbon monoxide?

At high concentrations, carbon monoxide can kill. People who are exposed to carbon monoxide may experience headaches, dizziness, nausea (feeling sick) and tiredness. High concentrations can cause people to become confused, they may collapse and become unconscious. When individuals are removed from the source of carbon monoxide these symptoms usually improve. Exposure to lower concentrations of carbon monoxide for a longer period may affect young people's school work and an adult's ability to concentrate and think clearly.

Are children more at risk from carbon monoxide than adults?

Children may suffer health effects in a shorter period of time than an adult breathing in the same concentration of CO.

Can carbon monoxide harm unborn children and can it lead to child development problems?

If a pregnant woman is exposed to carbon monoxide, the birth weight of her baby may be decreased, and it is possible that the child may develop behavioural problems. Effects may occur at lower levels in smokers who continue to smoke during pregnancy. Cigarette smoke is a major source of exposure to carbon monoxide and is known to cause a decrease in birth weight.

Can carbon monoxide cause cancer?

It is not thought that carbon monoxide can cause cancer.

What symptoms should I look for if I think I have been exposed to carbon monoxide?

Headaches, tiredness, difficulty in thinking clearly and feeling sick are common symptoms of carbon monoxide poisoning. Symptoms of carbon monoxide poisoning can also be similar to those for food poisoning and flu.

What should I do if I think I am being exposed to carbon monoxide?

Stop using all your cooking and heating appliances. You should move away from the source of exposure (for example a faulty domestic appliance) to a well-ventilated area. Open your windows and move outside. **If you think you have been exposed to carbon monoxide and feel unwell or are worried call NHS Direct on 0845 46 47, or in an emergency call 999.** When people are removed from the source of carbon monoxide exposure, their health usually improves and their symptoms subside, but it is still important to seek medical advice. You should call a suitably qualified and registered engineer to check all your cooking and heating appliances before returning home.

What can I do to protect myself from carbon monoxide?

Have all cooking and heating appliances which use fossil fuels (such as gas, oil and coal) serviced regularly by a qualified and registered engineer, for example Gas Safe Register (for gas appliances), HETAS (for solid fuel appliances) and OFTEC (for oil appliances). It is important to make sure that you have adequate ventilation when using these appliances, therefore chimneys and flues should be kept clean by being swept from top to bottom at least once a year by a qualified sweep and should not be blocked. Fitting an audible carbon monoxide alarm that meets British or European Standards (BS Kitemark or EN 50291) will help to protect you from exposure to high levels of carbon monoxide. The alarm will not go off if you are being exposed to lower levels of carbon monoxide so it should not be used as a substitute for regular servicing of appliances.



Carbon monoxide

Incident management

Key Points

Fire

- Flammable gas
- May react violently with other substances
- In the event of a fire involving carbon monoxide, use fine water spray with normal fire-fighting clothing and breathing apparatus

Health



- Toxic by inhalation
- May cause harm to the unborn child
- Inhalation of carbon monoxide may lead to headache, nausea, irritability, weakness and tachypnoea followed by dizziness, ataxia, agitation, impairment of consciousness and respiratory failure

Environment

- Avoid release into environment
- Inform Environment Agency of substantial release incidents

Hazard Identification

Standard (UK) Dangerous Goods Emergency Action Codes^(a)

UN		1016	Carbon monoxide, compressed	
EAC		2SE	Use fine water spray. Wear normal fire kit in combination with breathing apparatus*. Spillages and decontamination run-off may be washed to drains with large quantities of water. Substance can be violently or explosively reactive. There may be a public safety hazard outside the immediate area of the incident**.	
APP		-	-	
Hazards	Class	2.3	Toxic gas	
	Sub risks	2.1	Flammable gas	
HIN		263	Toxic gas, flammable	




UN – United Nations number; EAC – Emergency Action Code; APP – Additional Personal Protection; HIN - Hazard Identification Number

* Normal fire fighting clothing i.e. fire kit (BS EN 469), gloves (BS EN 659) and boots (HO specification A29 and A30) in combination with self-contained open circuit positive pressure compressed air breathing apparatus (BS EN 137).

** People should stay indoors with windows and doors closed, ignition sources should be eliminated and ventilation stopped. Non-essential personnel should move at least 250 m away from the incident.






^a Dangerous Goods Emergency Action Code List, The Stationery Office, 2009.

Chemical Hazard Information and Packaging for Supply Classification^(a)

Classification	F+	Extremely flammable	
	Repr. cat. 1	Category 1 reproductive toxin	
	T	Toxic	
Risk phrases	R61	May cause harm to the unborn child	
	R12	Extremely flammable	
	R23	Toxic by inhalation	
	R48/23	Danger of serious damage to health by prolonged exposure through inhalation	
Safety phrases	S53	Avoid exposure – obtain special instructions before use	
	S45	In case of accident or if you feel unwell seek medical advice immediately (show the label where possible) This material and its container must be disposed of as hazardous waste	

^a Annex VI to Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging of Substances and Mixtures- Table 3.2.
<http://esis.jrc.ec.europa.eu/index.php?PGM=cla> (accessed 11/2011)

Globally Harmonised System of Classification and Labelling of Chemicals (GHS)^{(a)}*

Hazard Class and Category	Flam. Gas 1	Flammable gas	
	Press. Gas	Compressed gas	
	Repr. 1A	Reproductive toxicity, category 1A	
	Acute Tox. 3 *	Acute toxicity (oral, dermal, inhalation), category 3	
	STOT RE 1	Specific target organ toxicity following repeated exposure, category 3	
Hazard Statement	H220	Extremely flammable gas	
	H360D**	May damage the unborn child	
	H331	Toxic if inhaled	
	H372	Causes damage to organs through prolonged or repeated exposure	
Signal Words	DANGER		

* Implemented in the EU on 20 January 2009.

^a Annex VI to Regulation (EC) No 1272/2008 on Classification, Labelling and Packaging of Substances and Mixtures- Table 3.1.
<http://esis.jrc.ec.europa.eu/index.php?PGM=cla> (accessed 11/2011)

Physicochemical Properties

CAS number	630-08-0
Molecular weight	28
Empirical formula	CO
Common synonyms	Carbonic oxide; Coal gas
State at room temperature	Gas
Volatility	Vapour pressure > 760 mm Hg at 20°C
Vapour density	1.0 at 21°C (air = 1)
Flammability	Extremely flammable
Lower explosive limit	12.5%
Upper explosive limit	74.2%
Water solubility	Slightly soluble in water
Reactivity	Flammable gas under normal conditions
Reaction or degradation products	Data not available
Odour	Odourless
Structure	$C \equiv O$

References^(a,b,c)

^a International Chemical Safety Card (ICSC) Entry for Carbon Monoxide. ICS 0023. International Occupational Safety and Health Information Centre (CIS), 1994.

^b The Dictionary of Substances and their Effects. Ed. S Gangolli. Second Edition, Volume 2, 1999.

^c The Merck Index (14th Edition). Entry 1816: Carbon Monoxide, 2006

Threshold Toxicity Values

EXPOSURE VIA INHALATION		
ppm	mg m⁻³	SIGNS AND SYMPTOMS
~ 100	~ 115	Slight headache, flushing of skin (indefinite exposure)
200 – 300	230 – 345	Headache (5 – 6 hour exposure)
400 – 600	460 – 690	Severe headache, weakness, dizziness, nausea, vomiting (4 – 5 hour exposure)
1100 – 1500	1265 – 1840	Increased pulse and breathing rate, syncope, coma, intermittent seizures (4 – 5 hour exposure)
5000 - 10000	5750 – 11500	Weak pulse, depressed respiration / respiratory failure, death (1 – 2 minutes exposure)

Reference^(a)

^a Carbon monoxide (MEDITEXT® Medical Management). In: Klasco RK (Ed): TOMES® System. Thomson Micromedex, Greenwood Village, Colorado (accessed 08/2010).

Published Emergency Response Guidelines

Emergency Response Planning Guideline (ERPG) Values^(a)

	Listed value (ppm)	Calculated value (mg m ⁻³)
ERPG-1*	200	230
ERPG-2**	350	403
ERPG-3***	500	575

* Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odour.

** Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.

*** Maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hr without experiencing or developing life-threatening health effects.

Acute Exposure Guideline Levels (AEGLs)^(b)

	ppm				
	10 min	30 min	60 min	4 hr	8 hr
AEGL-1[†]	-	-	-	-	-
AEGL-2^{††}	420	150	83	33	27
AEGL-3^{†††}	1700	600	330	150	130

[†] The level of the chemical in air at or above which the general population could experience notable discomfort.

^{††} The level of the chemical in air at or above which there may be irreversible or other serious long-lasting effects or impaired ability to escape.

^{†††} The level of the chemical in air at or above which the general population could experience life-threatening health effects or death.

^a American Industrial Hygiene Association (AIHA). Emergency Response Planning Guideline Values and Workplace Environmental Exposure Level Guides Handbook, Fairfax, VA, 2010. (accessed 01/2011).

^b U.S. Environmental Protection Agency. Acute Exposure Guideline Levels, <http://www.epa.gov/oppt/aegl/pubs/chemlist.htm> (accessed 01/2011).

Exposure Standards, Guidelines or Regulations

Occupational standards

WEL^(a)	LTEL (8 hour reference period): 30 ppm (35 mg m ⁻³)
	STEL (15 min reference period): 200 ppm (232 mg m ⁻³)

Public health guidelines

DRINKING WATER QUALITY GUIDELINE	No guideline value specified
AIR QUALITY GUIDELINE^(b)	100 mg m ⁻³ (90 ppm) for 15 minutes 60 mg m ⁻³ (50 ppm) for 30 minutes 30 mg m ⁻³ (25 ppm) for 1 hour 10 mg m ⁻³ (10 ppm) for 8 hours
SOIL GUIDELINE VALUE AND HEALTH CRITERIA VALUES	No guideline value specified

WEL – Workplace exposure limit; LTEL - Long-term exposure limit; STEL – Short-term exposure limit

^aList of approved workplace exposure limits (as consolidated with amendments October 2007). <http://www.hse.gov.uk/coshh/table1.pdf> (An update to EH40/2005: Workplace Exposure Limits 2005. The Stationery Office, London) (accessed 01/2011)..

^b Air Quality Guidelines for Europe. World Health Organization Regional Office for Europe, Copenhagen WHO Regional Publications, European Series, No. 91, Second Edition, 2000 (accessed 01/2011)..

Health Effects

Major route of exposure^(a)

- Toxic by inhalation.

Immediate signs or symptoms of acute exposure^(a)

- Inhalation causes headache, nausea, irritability, weakness and tachypnoea followed by dizziness, ataxia, agitation, impairment of consciousness and respiratory failure. Cerebral oedema and metabolic acidosis may develop in serious cases.
- Less common features include skin blisters, rhabdomyolysis, acute renal failure, pulmonary oedema, myocardial infarction, retinal haemorrhages, cortical blindness, choreoathetosis and mutism.
- While the majority of people exposed to carbon monoxide recover uneventfully, others develop neuropsychiatric features. The onset of these features may be delayed and are more common in those over the age of 40 years and include memory impairment, disorientation, apathy, mutism, irritability, inability to concentrate, personality change, Parkinsonism, including urinary and/or faecal incontinence and gait disturbance are and parietal lobe lesions.

TOXBASE - <http://www.toxbase.org> (accessed 01/2011)

^a TOXBASE: Carbon monoxide (E), 04/2009.

Decontamination and First Aid

Important Notes

- Ambulance staff, paramedics and emergency department staff treating chemically-contaminated casualties should be equipped with Department of Health approved, gas-tight (Respirex) decontamination suits based on EN466:1995, EN12941:1998 and prEN943-1:2001, where appropriate.
- Decontamination should be performed using local protocols in designated areas such as a decontamination cubicle with adequate ventilation.
- Flammability warning: prevent exposure to all sources of ignition such as naked flames, electrical equipment, oxidising chemicals and the smoking of tobacco products.

Dermal exposure

- Not applicable

Ocular exposure

- Not applicable

Inhalation^(a)

- Remove patient from exposure.
- Ensure a clear airway and adequate ventilation.
- Give oxygen in as high concentration as possible.
- Perform a 12 lead ECG and monitor cardiac rhythm.
- Apply other supportive measures as indicated by the patient's clinical condition.

Ingestion

- Not applicable.

TOXBASE - <http://www.toxbase.org> (accessed 01/2011)

^a TOXBASE: Carbon monoxide (E), 04/2009.

Carbon monoxide

Toxicological overview

Key Points

Kinetics and metabolism

- Following inhalation, carbon monoxide binds with haemoglobin to form carboxyhaemoglobin
- When bound, it reduces the rate at which oxygen is delivered to the tissues, thereby causing hypoxia
- Once exposure has ceased, haemoglobin will bind to oxygen to form oxyhaemoglobin and carbon monoxide is eliminated unchanged via the lungs

Health effects of acute exposure

- Following acute exposure effects such as headache, dizziness, confusion, disorientation, memory loss, fainting, seizures, cerebral oedema, coma and death may arise
- Tachycardia, tachypnoea, hypotension, vasodilation, cyanosis, shock and cardiac arrest may also occur
- Long-term neurological effects may occur following an acute exposure, including cognitive and behavioural changes

Health effects of chronic exposure

- Chronic exposure to low concentrations of carbon monoxide may lead to tiredness, lethargy, headaches, nausea, dizziness, personality changes, memory problems, as well as impairment of visual, auditory or cognitive function
- Low birth weight, perinatal death and behavioural deficits may occur in children exposed to carbon monoxide during pregnancy

Toxicological Overview

Summary of Health Effects

Adverse health effects of carbon monoxide exposure are related to the concentration of carboxyhaemoglobin in the blood. In general, carboxyhaemoglobin concentrations below 2 % are not associated with any adverse effects; 20 - 30 % causes neurological symptoms such as headache, dizziness, weakness, nausea, confusion, disorientation and visual disturbances; over 50 % causes convulsions, respiratory arrest and death.

Following carbon monoxide exposure, tachycardia and tachypnoea may occur as compensatory mechanisms. Hypotension, vasodilation, cyanosis, shock and cardiac arrest may also occur. A decreased maximal oxygen consumption and decreased duration of exercise occurs in patients with impaired blood supply to the heart at lower carbon monoxide concentrations, and in healthy individuals at higher concentrations. Patients with angina are the most sensitive risk group for carbon monoxide intoxication.

The central nervous system is particularly sensitive to carbon monoxide-induced hypoxia and acute effects such as headache, dizziness, confusion, disorientation, memory loss, fainting, seizures, cerebral oedema, coma and death may arise. There is evidence from neurobehavioural studies in volunteers that prolonged exposure to low levels (5-20 % carboxyhaemoglobin), below those causing clinical symptoms, may produce cognitive impairment. Neurological symptoms following severe exposures of acute toxicity may also appear 2 – 40 days after exposure, including headache, lethargy, irritability and lack of concentration.

A range of severe neurotoxic effects may occur following severe poisoning with carbon monoxide including Parkinsonian symptoms, dementia and psychosis. They may not all be related to carbon monoxide-induced hypoxia.

Chronic exposure to carbon monoxide may cause tiredness, lethargy, headaches, nausea, dizziness, personality changes and memory problems.

Studies in patients exposed to carbon monoxide as part of combustion products of wood and coal had a higher frequency of sister chromatid exchanges compared to controls, although effects could not be directly attributed to carbon monoxide. Overall, data on the mutagenicity of carbon monoxide is poor. In addition, no data are available on the carcinogenicity of carbon monoxide.

Pregnant women, the fetus in utero and the newborn infant are at an increased risk from carbon monoxide exposure. Maternal smoking may result in low birth weight, perinatal deaths and behavioural effects in young children.

Kinetics and metabolism

Following inhalation, carbon monoxide diffuses rapidly across the alveolar and capillary membranes of the lungs. Once absorbed, it diffuses through the plasma, passes the red blood cell membrane and enters the red blood cells, where approximately 80 – 90 % binds with haemoglobin in the same way as does oxygen, to form carboxyhaemoglobin. This binding decreases the oxygen carrying capacity of the blood and interferes with oxygen exchange at tissues [1, 2]. The affinity of haemoglobin for carbon monoxide is 234-fold higher than that for oxygen hence the amount of oxygen in the blood becomes greatly reduced. Furthermore, once carbon monoxide is bound it alters the dissociation curve of oxyhaemoglobin, reducing the rate at which oxygen is delivered to the cells. This impaired delivery of oxygen can interfere with cellular respiration and causes tissue hypoxia [2, 3].

As exposure to carbon monoxide continues, the carboxyhaemoglobin concentration increases and reaches equilibrium. For example, exposure to 100 ppm carbon monoxide would result in an equilibrium concentration of carboxyhaemoglobin of 14 % (table 1). Furthermore, the increase in carboxyhaemoglobin concentration is largely dependent on the persons breathing rate, with the uptake of carbon monoxide increasing the faster one breathes [4].

Table 1. Correlation between carbon monoxide concentration in air and blood carboxyhaemoglobin concentration [4]

Carbon monoxide concentration (ppm)	Equilibrium carboxyhaemoglobin concentration (%)
10	1.6
15	2.4
20	3.2
25	3.9
30	4.7
40	6.1
50	7.6
100	14.0

Although carbon monoxide is predominantly bound to haemoglobin, it also binds to other haem proteins such as myoglobin, cytochrome P450, dopamine hydroxylase and cytochrome oxidase [1]. Concentrations of carboxyhaemoglobin in the blood are determined by factors such as the amount of inhaled carbon monoxide, blood production volume, diffusion capacity of the lungs, breathing rate and endogenous carbon monoxide. Pregnant women produce nearly twice as much endogenous carbon monoxide [1].

Carbon monoxide does not accumulate as carboxyhaemoglobin is fully dissociable. Once exposure has ceased, oxygen competes with carbon monoxide for binding sites and the carbon monoxide is lost from haemoglobin in the lungs [2]. Due to the high affinity of carbon monoxide for haemoglobin, the elimination half life is between 2 and 5 hours, the elimination becoming slower as the concentration decreases [1].

Sources and route of human exposure

Inhalation of carbon monoxide is the major route of exposure. Vehicle emissions, cigarette smoke, gas cookers, fires and boilers, paraffin heaters, solid fuel heaters and wood and coal fires are the major sources of carbon monoxide production, hence for the majority of people, the largest exposure occurs in cars or at home [5]. Poorly installed or faulty appliances, resulting in poor combustion of fuel, as well as poor ventilation causing an inadequate removal of waste products results in increased carbon monoxide exposure.

Ambient background levels of carbon monoxide are approximately $0.01 - 0.23 \text{ mg m}^{-3}$ (0.009 – 0.2 ppm). In urban traffic the 8-hour mean concentrations are higher but still less than 20 mg m^{-3} (17.5 ppm) and 1-hour average concentrations are not usually greater than 29 mg m^{-3} (25 ppm). In the average UK home with carbon monoxide sources, peak concentrations of up to 60 mg m^{-3} (52.4 ppm) have been recorded [1, 6]. In homes with faulty appliances or poor ventilation, it has been reported that carbon monoxide concentrations have reached 182 mg m^{-3} (160 ppm) for prolonged periods. Such high exposures are rarely encountered by the general public [6]. The majority of the population are exposed long-term to very low concentrations of carbon monoxide and their carboxyhaemoglobin is largely dependent on their endogenous production.

Outdoor emissions of carbon monoxide have already declined by 33 % between 1990 and 1999, and it is estimated that emissions from transport should decline by 40 % between 1995 and 2005 [7]. Exposure to ambient concentrations of carbon monoxide may particularly affect workers exposed to vehicle exhausts, such as mechanics, garage and petrol station attendants, police, fire fighters, street vendors, street cleaners, cyclists or construction workers. Vehicle drivers are also exposed to carbon monoxide as car interiors produce the highest concentrations of carbon monoxide, on average $10 - 29 \text{ mg m}^{-3}$ (9 - 25 ppm) [1].

In the UK, the Expert Panel on Air Quality Standards (EPAQS) recommended an air quality standard of 10 ppm (8-hour time-weighted average (TWA) [8]. This aims to limit exposure of the population, especially individuals that are susceptible such as those with angina or coronary artery disease. Regular smokers are unlikely to be affected by normal environmental concentrations of carbon monoxide as their blood levels of carboxyhaemoglobin are already higher than would be reached by breathing polluted air [8].

Dermal or ocular exposure to the liquefied gas may occur but the risk is considered to be very low.

Health Effects of Acute / Single Exposure

Human Data

General toxicity

Adverse health effects of carbon monoxide exposure are related to the concentration of carboxyhaemoglobin in the blood.

In general, carboxyhaemoglobin concentrations below 2 % are not associated with any significant health effects; 20 - 30 % causes neurological symptoms such as headache, dizziness, weakness, nausea, confusion, disorientation and visual disturbances; over 50 % causes convulsions, respiratory arrest and death (table 2) [4, 8]. The cherry red skin colour observed when carboxyhaemoglobin concentrations exceed approximately 20 % is rarely observed [5].

Table 2. Summary of toxic effects following acute exposure to carbon monoxide [4, 8]

Carboxyhaemoglobin in blood (%)	Signs and symptoms
<2	No significant health effects
2.5-4.0	Decreased short-term maximal exercise duration in young healthy men
2.7-5.2	Decreased exercise duration due to increased chest pain (angina) in patients with ischaemic heart disease
2.0 – 20.0	Equivocal effects on visual perception, audition, motor and sensorimotor performance, vigilance and other measures of neurobehavioural performance
4.0-33.0	Decreased maximal oxygen consumption with short-term strenuous exercise in young healthy men
20-30	Throbbing headache
30-50	Dyspnoea, dizziness, nausea, weakness, collapse, coma
> 50	Convulsions, unconsciousness, respiratory arrest, death

Cardiovascular toxicity

The heart is one of the most sensitive organs to hypoxia caused by carbon monoxide. As a compensatory mechanism against cellular hypoxia, increased coronary blood flow and tachycardia may occur. At the point where blood flow cannot meet oxygen demand, the myocardium becomes ischaemic resulting in chest pain and reduced myocardial functioning. Other changes such as hypotension, vasodilation, cyanosis, shock and cardiac arrest may occur [6].

Decreased oxygen uptake leading to a decreased work capacity under maximum exercise conditions has been demonstrated in healthy adults with 5 % carboxyhaemoglobin, although

some studies have reported small decreases when exposed to concentrations of 2.3 – 4.3 % [1].

Chronic angina patients are the most sensitive risk group for effects following carbon monoxide exposure. Exposure to 50 ppm for 2 – 4 hours, causing a blood carboxyhaemoglobin concentration of 2 – 5 % aggravates symptoms of angina and the duration of exercise was significantly decreased by the onset of chest pain [9]. Carboxyhaemoglobin concentrations of 50 - 60 % have been associated with death, although some fatalities have been reported in individuals with coronary heart disease with a carboxyhaemoglobin concentration of as low as 10 % [1].

Neurotoxicity

The central nervous system is particularly sensitive to carbon monoxide-induced hypoxia and acute effects such as headache, dizziness, confusion, disorientation, memory loss, fainting, seizures, cerebral oedema, coma and death may occur [1].

Many studies have demonstrated that an increase in carboxyhaemoglobin to above 20 % is associated with a compensatory increase in blood flow in the brain, which may lead to behavioural changes. Elevation in carboxyhaemoglobin concentration produces small decrements in tracking (fine motor behaviour and hand-eye coordination) whereas fine motor control is unaffected by concentrations less than 20 % [1].

Delayed effects following an acute exposure

Carbon monoxide toxicity occurs predominantly due to hypoxia. However, in some cases of severe poisoning symptoms persist when carboxyhaemoglobin levels return to normal. In such cases, neuropsychological sequelae may appear 2 – 40 days after exposure including headache, lethargy and lack of concentration [3, 10]. Glycosuria and heart irregularities have been reported as well as cerebral congestion and oedema, the latter possibly resulting in long-term mental or nervous damage [6]. Other effects include apraxia, visual impairment and in cases of severe poisoning Parkinsonian-type symptoms, dementia and psychosis may occur [3, 10]. The cause of such delayed neurological symptoms are largely unknown, although it has been speculated that free radical production and lipid peroxidation during the reperfusion phase, when oxygen becomes available, may contribute [10].

Although there are no epidemiological data to support lasting effects occurring at low levels of exposure, there is experimental evidence to suggest that carbon monoxide can affect the brain even at very low concentrations, leading to effects on cognitive function prior to the clinical symptoms occurring [3].

Health Effects of Chronic / Repeated Exposure

Human Data

General toxicity

Chronic carbon monoxide poisoning may not necessarily give typical symptoms associated with acute exposure. Chronic symptoms may include tiredness, lethargy, headaches, nausea, dizziness, personality changes, memory problems, Parkinsonian symptoms, visual loss and dementia [1, 11].

Neurotoxicity

To date it has not been fully elucidated whether chronic exposure to low concentrations of carbon monoxide produces long lasting effects on the brain [3]. A chronic flu-like syndrome has been described in such conditions, including headache, irritability and malaise [10]. It is however difficult to distinguish between the effects of carbon monoxide and damage caused by free radical production during the reperfusion phase when oxygen becomes available again [12].

Recent studies have demonstrated that prolonged exposure to concentrations of carbon monoxide concentrations that do not produce adverse symptoms, may produce subtle effects on the CNS. Neuropsychological symptoms reported included anxiety, psychomotor dysfunction, loss of balance and changes in sleep, memory, vision and smell [3]. Older studies reported an association between exposure to 100 ppm carbon monoxide (causing a carboxyhaemoglobin concentration of 5%) and neurological changes such as loss of visual, auditory or cognitive function [9].

Cardiovascular toxicity

In contrast to acute exposure to carbon monoxide that causes myocardial arrhythmias, chronic exposure to carbon monoxide may lead to the onset of atherosclerosis [10].

Long-term exposure to ambient concentrations of carbon monoxide is unlikely to increase the carboxyhaemoglobin concentrations above 5 %. Patients with inadequate coronary arterial blood flow may experience angina-type symptoms upon exposure to carbon monoxide. In volunteer studies, exposure to carbon monoxide concentrations causing 5 % carboxyhaemoglobin may reduce the time to onset of angina brought on by exercise [10].

Genotoxicity

The genotoxic effect of exposure to combustion products of coal or wood was investigated by analysing the frequency of sister chromatid exchange in individuals presenting with carbon monoxide intoxication. Authors reported a statistically significant increase in sister chromatid exchange frequency in the exposed group compared to controls, although there was no correlation with blood carboxyhaemoglobin hence such effects could not be directly ascribed to carbon monoxide exposure [13]. Overall, there is little data available on the mutagenicity of carbon monoxide in humans [2, 14].

Carcinogenicity

No data are available on carcinogenicity following carbon monoxide exposure [2, 14]. Carbon monoxide is not generally regarded as carcinogenic.

Reproductive and developmental toxicity

Pregnant women, the fetus in utero and the newborn infant are at an increased risk from atmospheric carbon monoxide exposure. During pregnancy the endogenous carbon monoxide may be elevated as much as three-fold and the maternal haemoglobin is often reduced, leading to physiological hyperventilation. As a consequence less oxygen is available to be transported to the fetus. Carbon monoxide readily crosses the placenta by simple diffusion and binds to fetal haemoglobin with a higher affinity than for maternal haemoglobin. Furthermore, carbon monoxide is cleared from fetal blood slower than from maternal blood, leading to the accumulation of carbon monoxide which, at steady state, may be up to 10 – 15 % higher than maternal concentrations [1, 2].

The developing brain appears to be the most sensitive organ to the effects of carbon monoxide. Maternal smoking, resulting in fetal carboxyhaemoglobin concentrations of 2 – 10 % may result in low birth weight, perinatal deaths and behavioural effects in young children [2].

Animal and In-Vitro Data

Genotoxicity

No data are available on the genotoxicity following carbon monoxide exposure. Carbon monoxide would not be expected, from its structure, to have any significant mutagenic properties.

Carcinogenicity

No data are available on carcinogenicity following carbon monoxide exposure [2, 14]. Carbon monoxide is not generally regarded as carcinogenic.

Reproductive and developmental toxicity

Studies in experimental animals have demonstrated that maternal exposure to 150 – 200 ppm carbon monoxide resulting in carboxyhaemoglobin concentration of 15 – 25 % cause a reduction in birth weight, cardiomegaly and delayed behavioural development and cognitive function [1].

Mice exposed to concentrations of 65 – 500 ppm carbon monoxide on days 7 – 18 of gestation showed a dose-dependent effect on the fetus. Exposure to 500 ppm resulted in a significantly increased mortality and exposure to 125 ppm caused a decrease in birth weight. No signs of maternal toxicity were observed [15].

Offspring of rats exposed to 150 ppm for the duration of gestation had minor reductions in birth weights, decreased growth rates and persistent memory deficits that became more

pronounced in adulthood. In addition, exposure of rats to 30 and 90 ppm led to a decrease in pregnancy rate to 69 and 38 %, respectively [15].

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This document will be reviewed not later than 3 years or sooner if substantive evidence becomes available.