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Standard for Managing Exposure to Significant Carbon Monoxide Emissions – Community Health

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VERSION 3.0

Working in conjunction with Communities, Government, Agencies and Business.

The *Standard for Managing Exposure to Significant Carbon Monoxide Emissions – Community Health* is authorised and endorsed by the following:

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Section 1 - Background

Overview and Purpose

This *Standard for Managing Exposure to Significant Carbon Monoxide Emissions – Community Health* (the Standard) outlines the science and the Victorian approach for protecting community health during large, extended or complex fires that produce significant levels of carbon monoxide (CO) in the outdoor environment. This may include, but is not limited to, fires in coal mines, peat bogs, landfill sites or large mulch piles.

This Standard has been developed to provide background information for decision-making to assist any agency, including the Incident Controller and agency commanders, to manage the health and safety of communities near large, complex incidents that can produce significant levels of CO in the outdoor environment. It informs agency-specific protocols, operating procedures, training procedures and decision support tools.

Carbon monoxide (CO) is an odourless, colourless, non-irritating gas found in emissions from any incomplete combustion process, including all types of fires. CO replaces oxygen (O_2) in the blood. The risk of harm from CO inhalation depends on the concentration of CO in the air, the duration of exposure, and underlying health conditions (i.e. susceptibility to hypoxia). These relationships are not linear. This Standard explains the mechanism of CO toxicity, including the important relationship between the CO concentration in air (as parts per million or ppm), the duration of CO inhalation (hours), the rate of uptake in the body (rest versus physical exertion) and the detrimental effect on the body's ability to use O_2 effectively (due to increased carboxyhaemoglobin blood levels, or % COHb).

This Standard provides the context and background for Incident Controllers and agencies to understand and respond to the potential risks to community health of increased CO exposure in outdoor environments caused by an incident. This may require issuing advice to limit physical exertion, particularly for people with heart disease, or precautionary actions such as sheltering indoors or, in worst-case conditions, temporarily relocating (or formal evacuation) until air quality is safe to return. This Standard is not an operational protocol and does not provide a step-by-step guide. The Standard is operationalised in separate cross-government joint standard operating procedures, including SOP J03.19 and SOP J03.12.

This Standard contains important safety provisions that will only be fully effective with the cooperation of all responders and agencies and the willingness of the community to follow the advice or warnings issued by the Incident Controller.

Strategic Intent

Consistent with the Emergency Management Manual Victoria, a set of State Emergency Management Priorities underpin and guide all decisions made during emergencies.

The State Emergency Management Priorities of greatest relevance to this Standard include:

- the protection and preservation of life is paramount. This includes the safety of emergency services personnel and safety of community members, including vulnerable community members and visitors/tourists located within the incident area.
- issuing community information and community warnings detailing incident information that is timely, relevant and tailored to assist community members make informed decisions about their safety.

Governance and Authorising Framework

The Standard is authorised in accordance with the statutory responsibilities of the:

- Emergency Management Commissioner, Emergency Management Victoria (EMV) with respect to responders and community safety under the *Emergency Management Act 2013*
- Chief Executive Officer, Environment Protection Authority, Victoria (EPA) with respect to the statutory objective in the *Environment Protection Act 2017 to* protect human health and the environment by reducing the harmful effects of pollution and waste, and
- Chief Health Officer with respect to the protection of public health in accordance with the *Public Health and Wellbeing Act 2008.*

The Standard is supported by the following legislation and documents:

- *Emergency Management Act 1986 and Emergency Management Act 2013*
- *Emergency Management Manual Victoria*
- *Environment Protection Act 1970; Environment Protection Act 2017**
- *Public Health & Wellbeing Act 2008; State Health Emergency Response Plan 2017**

(* - new or revised since the 2015 version of the Standard)

Latest review (August 2019)

This Standard supersedes the Standard for Managing Significant Carbon Monoxide Emissions (July 2015) and earlier versions

The latest review has amended the Standard in line with:

- EPA's role under the *Environment Protection Act 2017* (proclaimed on 1 July 2018), including the new objective of the EPA to 'protect human health and the environment by reducing the harmful effects of pollution and waste' and creation of the role of the Chief Environmental Scientist.
- EPA is therefore a support agency to the Incident Controller during major incidents requiring air quality monitoring, interpretation of data and forecasting, assessment of potential impacts of smoke on community health and the communication of health protection messages for issuing by the Incident Controller.
- Separating the Standard into one for community health, and one for responder health as it relates to carbon monoxide exposure.

Section 2 - Significant Carbon Monoxide Emissions – Protecting Community Health During Emergencies

Understanding the hazards of carbon monoxide exposure

Carbon monoxide (CO) is an odourless, colourless, tasteless, non-irritating gas formed as a by-product of incomplete combustion. It is present in emissions from all types of fires. The amount of CO in smoke is greatest from fires with partial (often low temperature) combustion of materials including coal, peat, landfill and large mulch piles, and the amount of CO in air is greatest closest to the fire.

Oxygen (O_2) is absorbed from the lungs when we breathe and combines with haemoglobin (Hb) in the blood for transport to all organs and tissues. CO is also absorbed into the blood by breathing CO-containing air, where it displaces the O_2 and forms carboxyhaemoglobin (COHb). Since CO binds to haemoglobin 200 times better than O_2, CO exposure quickly reduces the O_2-carrying capacity of the blood. Organs with a high O_2 requirement, such as the heart and the brain, are especially sensitive to the reduced O_2 due to COHb[1]. Once exposure to CO ceases, the blood COHb level reduces by half approximately every five hours if breathing air, or 80 minutes when breathing 100% oxygen, until it reaches the background level.

Small quantities of CO are produced in the human body naturally, leading to a background level of approximately 0.4 – 0.7% COHb in healthy non-smokers[2]. Smokers have a higher level, and in some instances in heavy smokers, blood COHb levels may be up to 10%.

Everyone is susceptible to CO exposure[3], but the health risk is greater for certain groups of people who show health effects at lower blood COHb levels. In addition, physical activity increases the rate of breathing and will increase the amount of inhaled air containing CO.

High risk groups include people who:

- have cardiovascular or heart conditions
- are pregnant – because of potential harm to the foetus from low levels of O_2
- have anaemia - because of lowered O_2-carrying capacity of the blood
- have breathing disorders or lung disease
- are smokers - because they may already have high blood levels of COHb.

Symptoms of acute CO exposure depend on the blood COHb level, which varies with the following:

- The concentration of CO in air that is breathed
- The duration of exposure
- The degree of physical exertion
- Individual susceptibility
- Pre-inhalation blood COHb level (for example in people who smoke).

[1] Committee on Acute Exposure Guideline Levels, Committee on Toxicology; National Research Council Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8 (2010)

[2] World Health Organisation, Regional Office for Europe. Air Quality Guidelines for Europe, Second Edition. (WHO Regional Publications, European Series, No. 91. 2000)

[3] S Bull; HPA Compendium of Chemical Hazards: Carbon monoxide (UK Health Protection Agency 2016)

Table 1 lists the symptoms that may occur at various blood COHb levels. Reversible symptoms of CO exposure may be treated by stopping exposure: moving into fresh air or by breathing O_2-enriched air.

Table 1: Acute symptoms (adverse health effects) associated with increasing CO blood concentrations (as %COHb)[4]

COHb Concentration (CO in the blood)	Symptoms
< 2.5 %	No significant health effects Physiological background level in the body
2.5 – 5 %	Exacerbation of existing cardiovascular disease No significant health effects expected in rest of population, including children
5 – 10 % (common in smokers)	Increase in cardiac symptoms in people with coronary artery disease Subtle neurobehavioral symptoms in adult non-smokers Headache and nausea in children
10 – 20 %	May be lethal in people with coronary artery disease. Headache ("frontal tightness"), possible shortness of breath during exertion in healthy adult population. Cognitive development deficits in children
20 – 30 %	Throbbing headache, nausea, flushing Stillbirth
30 – 40 %	Severe headache, dizziness, nausea, rapid breathing
>40 %	Collapse, coma, convulsion, death

**Note: This is given as a guide only and there may be considerable variation depending on individual characteristics. Blue highlights that people with coronary artery disease are a susceptible group. Green highlights children as a susceptible group.*

Figure 1 illustrates the relationship between CO air concentrations (ppm - each line on the curve represents a different ppm), duration of continuous exposure (minutes) and COHb in the blood (% COHb saturation). It uses the internationally accepted Coburn-Forster-Kane model and equations.

COHb in blood (% COHb saturation) reaches different plateau concentrations after a certain duration of continuous exposure at different CO air concentrations.

Extensive research on the effects of CO exposure on human health concludes that a blood concentration at or below 2.5% COHb is not of concern in susceptible non-smoking individuals, including people with heart disease (ATSDR, 2012).

[4] Adapted from Chemical Hazards Compendium, Carbon Monoxide: Toxicological Overview, Public Health England Nov 2016; and the Agency for Toxic Substances and Disease Registry; Toxicological Profile for carbon monoxide (US Department of Health and Human Services, June 2012) and Committee on Acute Exposure Guideline Levels, Committee on Toxicology; National Research Council Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8 (2010)

Background blood CO concentrations in people who smoke range between 3 to 8% COHb, and up to 10% in heavy smokers.

At 4% COHb, reversible impacts may occur in some people, but this level does not impede the ability to escape during an emergency.

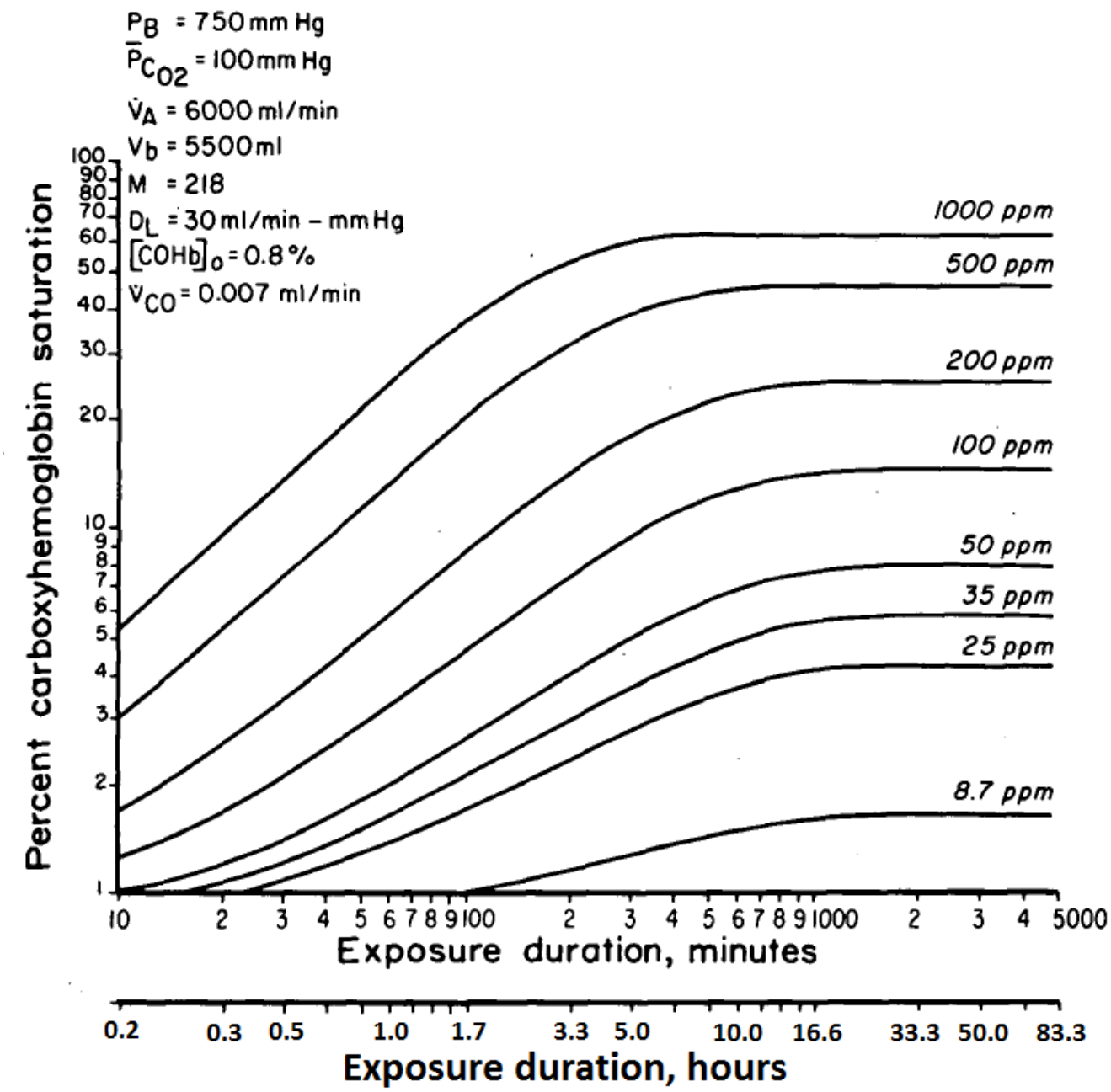

Figure 1. Relationship between CO concentration in air (ppm), duration of exposure (minutes and hours) and %COHb saturation (COHb blood level), noting the horizontal is a log linear scale[5].

[5] From: Peterson, JE and Stewart, RD. "Predicting the carboxyhemoglobin levels resulting from carbon monoxide exposures.' The Department of Environmental Medicine. University of Wisconsin. June 1973. Report no.: CRC APRAC CAPM-3-68; many subsequent references.

Examples to note from Figure 1 to help interpretation include:

- At a CO air concentration of 9 (8.7) ppm, the % COHb saturation remains below approximately 2% indefinitely in non-smokers
- At a CO exposure of 25 ppm, % COHb saturation plateaus at approximately 3% after an exposure of 1,000 min (16.7 hr)
- AEGL-2 concentration-time values (see AEGL explanation later) are calculated so that COHb levels do not exceed 4% (noting this blood level is unlikely to occur at CO air concentrations below 25 ppm).
- A CO exposure of 30 ppm (the Australian Occupational Exposure Standard for an 8-hr work-day) would normally result in a maximum COHb level of 5% at 500 min (approximately 8 hr) exposure time
- At a CO exposure of 35 ppm, COHb would reach approximately 6% after an exposure of approximately 2,000 min (33 hr).

As seen in **Figure 1** from the Coburn-Forster-Kane model, the %COHb depends on both the CO air concentration and the duration of exposure by inhalation. Faster and deeper breathing results in faster CO absorption from the air into the blood and less time needed to reach a given %COHb level at any given CO air concentration; the curves would be shifted to the left. This is the reason for recommending decreased physical activity as an option to reduce CO exposure and the potential for developing symptoms.

Table 2 provides some examples of the acute health effects, including death, of relatively high CO air concentrations over a range of exposure durations. These high concentrations are more likely to occur from faulty equipment or machine exhaust in enclosed spaces, rather than from an outdoor fire. Symptoms will be directly related to the CO blood level (% COHb) as per **Table 1** and are due to lack of O_2 reaching vital organs.

Table 2. Examples of acute health effects of high CO concentration in air (ppm) relative to duration of exposure by inhalation

CO in air (ppm)	Duration of exposure	Symptoms *
35	6 to 8 hr	Headache and dizziness
100	2 to 3 hr	Slight headache
200	2 to 3 hr	Slight headache and loss of judgement
400	1 to 2 hr	Frontal headache
800	45 min to 2 hr	Dizziness, nausea, convulsions within 45 min; death within 2-3 hr
1,600	20 min to 2 hr	Headache, increased heart rate, dizziness and nausea within 20 min; death in less than 2 hr
3,200	5 to 30 min	Headache, dizziness and nausea within 5 to 10 min; death in less than 30 min
6,400	1 to 20 min	Headache and dizziness in 1 to 2 min; Convulsions, respiratory arrest and death in less than 20 min
12,800	3 min	Unconscious after 2-3 breaths; death in less than 3 min

* This table is adapted from several references and is for illustration purposes only.

Community Exposure Guidelines for Carbon Monoxide

Ambient Air Quality Values for CO

The National Environment Protection Measure (NEPM) provides recommended ambient (i.e. outdoor) air quality values for common pollutants in the air we breathe. NEPM concentrations aim to protect populations, including sensitive sub-groups, over a lifetime (assumed 70 years) of exposure and are measured on a continuous basis at EPA air monitoring stations. The NEPM value for CO is an 8-hour average of 9 ppm. Constant exposure to CO at 9 ppm would normally result in COHb blood levels of approximately 2.5% in non-smokers. It is not appropriate to use the NEPM values in an emergency involving short- or medium-term exposures for decision-making for either recommended relocation or formal evacuation for safety reasons.

Occupational Exposure Standard for CO

This information is provided here for reference only. The Australian Occupational Exposure Standard time weighted average inhalation exposure for CO concentrations over an 8-hour shift is 30 ppm. This would normally result in a COHb blood level of less than 5% for a non-smoker. Within an 8-hr shift short excursions (or peaks) in CO air levels are permitted, including a short-term exposure limit (STEL) of 200 ppm for 15 min, 100 ppm for 30 min, and 60 ppm for 60 min. The occupational standard is not protective of the general population (including susceptible groups) during emergency situations.

Guidelines for acute exposure of communities to CO during emergencies

Acute Exposure Guideline Levels (AEGLs) are threshold exposure limits for the general public, including infants and children, and other individuals in susceptible groups. AEGLs describe the risk to the general population resulting from once-in-a-lifetime, or rare, exposure to airborne chemicals during an emergency. The three AEGL levels (1, 2 or 3) represent the severity of adverse health effects of the average contaminant air concentration at increasing exposure times. AEGL average exposure concentrations therefore usually vary with duration of exposure.

The Protective Action Decision Guide for Emergency Services during Outdoor Hazardous Atmospheres (MFESB 2011) sets out a hierarchy[6] of air quality reference values appropriate for protecting the public from short-term exposure to chemicals in the air and AEGLs are the preferred short-term community protection standards for durations up to 8 hr.

The AEGLs for CO are referenced in 'Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8 (US National Academy of Sciences, 2010)' and are listed in **Table 3**.

- AEGL-1 is the airborne concentration above which it is predicted that people may experience discomfort or irritation. AEGL-1 does not exist for CO because it does not cause irritation or discomfort.
- The AEGL-2 aims to protect the general population, including susceptible individuals (most sensitive sub-groups) from the effects of CO exposure[7] (e.g. those with subclinical coronary

[6] In the absence of AEGL values for a particular chemical, the next value in the hierarchy is the ERPG (or emergency response guide) and in the absence of either AEGL or ERPG it is the workplace exposure standard (MFESB 2011)

[7] Committee on Acute Exposure Guideline Levels, Committee on Toxicology; National Research Council Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8 (2010)

artery disease[8]). AEGL-2 concentration-time values have been calculated so that COHb blood levels do not exceed 4% after exposure at the concentrations and times indicated. This blood level is unlikely to occur at CO air concentrations below 25 ppm. This level does not impede the ability to escape during an emergency. Therefore, 4% COHb is the basis of the AEGL-2 concentration-time values.

- AEGL-3 represents the average concentration-time values above which the general population, including susceptible individuals could experience life-threatening adverse health effects or death.

The AEGL-2 column in **Table 3** shows that an individual generally will not experience any significant adverse health effects from breathing CO at 27 ppm for 8 hr, 33 ppm for 4 hr, 83 ppm for 1 hr, or 420 ppm for 10 min. Air monitoring against AEGL-2 concentration-time values informs decisions to initiate community health protection measures such as sheltering indoors, recommended relocation or formal evacuation until air quality improves. To provide additional health protection for the most susceptible group, the following health advice is recommended at concentration-time values below the AEGL-2: ie to limit physical exertion, particularly for people with heart disease.

It is important to understand that the potential to achieve 4% COHb blood levels is based on continuous exposure to the CO air concentration values in **Table 3** (AEGL-2 or AEGL-3) measured over the respective duration of monitoring. The likelihood of experiencing COHb levels above 4% is driven by the length of time a person is exposed at these levels. For example, 30-min exposure at 150 ppm CO is unlikely to result in COHb levels greater than 4%, and likewise 10-minutes exposure at 150 ppm is not considered to be a community health risk.

Table 3: Community exposure threshold guideline values for CO in a short-term emergency[9]

Exposure period for monitoring CO levels (Duration of CO exposure at the AEGL level)	AEGL-2 * Levels above which health effects may occur in the general population, including susceptible individuals	AEGL- 3 Levels above which irreversible or life-threatening effects may occur in the general population, including susceptible individuals
8 hours	27 ppm	130 ppm
4 hours	33 ppm	150 ppm
1 hour	83 ppm	330 ppm
30 min	150 ppm	600 ppm
10 min	420 ppm	1700 ppm

***** At each AEGL-2 air concentration-time value, it is estimated that blood COHb levels would be 5.3-5.6% in newborns, 4.9-5.2% in children aged 5 years, 4% in adults and 6.2-11.5% in adult smokers. AEGL Reference: Committee on Acute Exposure Guideline Levels, Committee on Toxicology; National Research Council Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8 (2010)

[8] People with coronary artery disease constitute the most susceptible subpopulation. The AEGL-2 value is set at 4% COHb. At or above this exposure level, those with coronary artery disease may experience a reduced time until onset of chest pain during physical exertion. An exposure at this level of 4% COHb may increase the frequency of exercise-induced arrhythmias.

[9] The USEPA AEGL documentation describe this as a once-in-a-lifetime, or rare, exposure.

Section 3 - Application of Community Exposure Guideline Values During Emergencies

Where fires are predicted to result in elevated CO concentrations in air for more than four hours, then the potential risk to nearby communities will be assessed by fire services in consultation with EPA Victoria, based on the fuel source(s) and likely emissions or products of combustion during the fire. This is further illustrated in **Table 4**. The duration of exposure is predicted with available plume modelling, taking into consideration current and forecast fire status, its size and the fire's proximity to the community.

Where there is likely to be community exposure to air contaminants of health concern, the Incident Controller can request air quality to be monitored in the adjacent community. CO concentrations in outdoor air may be continuously monitored at several locations, and the results interpreted scientifically to inform decisions taken by the Incident Controller. As CO air concentrations can fluctuate, with frequent spikes, the monitored values need to be averaged before comparing to a relevant action value. The average CO concentration over a relevant exposure period is compared to the AEGL-2 concentration-time values, along with information about the likely duration of the fire, the fire suppression strategy, and predictions about wind and weather conditions.

Results of CO monitoring are assessed continuously to ensure early health protection advice is issued with enough time to recommend to the community to shelter indoors prior to relevant AEGL-2 thresholds being reached. Further actions such as recommended relocation or formal evacuation may be recommended if the community is likely to be exposed to CO concentrations approaching or at AEGL-2 levels, respectively.

Dispersion and dilution[10] of CO in the air can decrease the amount of CO reaching a community compared to what is measured closer to the fire. CO monitoring continues until fires are sufficiently controlled to ensure protection of community health and safety.

Options for protecting the community

CO air concentration data needs to be monitored continuously, and there needs to be enough time to prepare appropriate community messaging and to implement decisions on a whole-of-population basis.

Warnings are issued one to two hours prior to the anticipated time that an AEGL-2 threshold is predicted to be exceeded, adjusted for the known effectiveness of shelter-in-place strategies to minimise the amount of CO exposure (up to 4 hours depending on the building). This is also important because the process of evacuation of community members is likely to take longer than one hour.

If outdoor CO concentrations are predicted to be a community health risk, options include:

- Advice - Inform community of potential risk of CO exposure with advice to reduce physical activity, minimise exposure, and stay aware of further alerts.
- Warning (shelter indoors) - Warning with instructions to shelter indoors until conditions improve or further advice is received.

[10] JC Wakefield – Chapter 4 Products of Combustion and Toxicity from Specific Types of Fires, Issues in Toxicology No 23, Toxicology, Survival and Health Hazards of Combustion Products, Royal Society of Chemistry 2016

- Emergency Warning - to take shelter indoors or to leave (relocate - specific instructions on where to go, how to get there and what to take are provided in the warning).
- Planned formal evacuation (per SOP J03.12 – evacuation for major emergencies) of CO impacted community, determined by the Incident Controller in consultation with Victoria Police – specific instructions on where to go, how to get there and what to take are provided in the warning.

Triggers for action

A staged approach to protect the community from potential health effects of CO exposure during emergency situations that produce significant CO emissions is described in **Table 4** and **Table 5**.

The lowest trigger for action for community exposure – ie an Emergency Warning to stay/shelter indoors - is informed by measured CO levels in outdoor air of ≥ 70 ppm, averaged over 30 minutes.

Triggers for action to manage potential (ie predicted) exceedance of the following air CO concentration-time values:

- 70 ppm for 1 hr (the AEGL-2 1-hour level of 83 ppm with a safety factor applied)
- 33 ppm for 4 hr
- 27 ppm for 8 hr.

The AEGL-2 equivalent 1-hour average CO air concentration of 83 ppm (in Table 3) has been conservatively reduced to a 1-hour average CO air concentration of 70 ppm[11]. This provides the first margin of safety, beyond that already provided by the AEGLs and the use of predictive plume duration to guide protective actions. A second margin of safety is setting the lowest level for triggering action for community exposure based on a 30-minute average instead of a 1-hour average.

At a 1-hour average CO air concentration of 70 ppm (and similarly a 30-minute average CO air concentration of 70 ppm) it is very unlikely someone would experience health effects associated with CO exposure. Both margins of safety provide encourage time to issue advice and recommended health protection actions in the community before a 1-hour average of 83 ppm is reached.

Tables 4 and **Table 5** incorporate the recommendation to shelter indoors as a protective action for community health. It may take up to four hours for typical homes to lose protection when outdoor air concentrations may equilibrate with indoor levels.

As averaged CO air concentrations are monitored, fire status, weather conditions and plume modelling continue to be reviewed to estimate the likely duration of community exposure to each concentration.

[11] The 2014 Hazelwood open-cut coal mine fire was a hazmat emergency. In planning for the need to undertake a formal evacuation due to CO, a decision was made to reduce the one-hour 83 ppm value (AEGL-2) to 70 ppm. This additional level of community health protection also provided time for agencies to safely enact evacuation (ie JSOP 3.12 – Evacuation for major emergencies). A further decision was made to halve the time period from 1 hour to 30 minutes. Therefore, a 30-minute value of 70 ppm CO would trigger an Emergency Warning to Stay (shelter) indoors.

If the CO air concentration is measured at or greater than 70 ppm for more than 30 minutes, an emergency warning to shelter indoors will be issued with consideration of formal evacuation if it is also predicted that outdoor CO concentrations are likely to continue at this level for 4-6 hours.

If the CO air concentration is measured and/or predicted to be greater than 33 ppm for more than 4 hours or greater than 27 ppm for more than 8 hours, recommended relocation or formal evacuation will be considered. See SOP J03.12 for formal evacuation.

Table 4. Community exposure to CO in outdoor air – Trigger levels to minimise COHb levels in the population (not to exceed the AEGL-2 blood level of 4% COHb).[12]

Incident Controller considerations:

Trigger	Advice	1 hr at 70 ppm	4 hr at 33 ppm	8 hr at 27 ppm
Action	Is this fire or incident likely to last > 4 hr and requires monitoring of CO levels in firefighters? If yes, consider **Advice** informing the community of potential risk of exposure to CO from this event. As part of general smoke and health messages include specific advice for people with heart conditions to avoid exertion and shelter indoors.	If 30-min average CO air value ≥ 70 ppm, review weather predictions. If plume is predicted to be over community and CO levels are likely to reach a 1-hr average of 70 ppm for up to 4 hours, issue **Emergency Warning to stay (shelter) indoors** and ask that people listen for further advice/actions. If – the above – and plume is predicted to continue for 4-6 hr, issue **Emergency Warning (leave) to consider relocation***. If – the above – and plume is predicted to continue for ≥ 6hr, recommend **formal Evacuation** until air quality is safe to return*.	If 1-hr average CO air value ≥33 ppm, review weather predictions. If plume predicted to be over community and CO levels are likely to continue at this level for 2 to 8 hr - issue **Warning to shelter indoors**. If plume predicted to be over community > 8 hr and CO levels are likely to continue at this level, recommend **formal Evacuation** until air quality is safe to return*.	If 3-hr average CO air values ≥27 ppm, review weather conditions. If plume predicted to be over community and CO levels are likely to continue at this level for 6 to 12 hr – issue **Warning to shelter indoors**. If plume predicted to be over community > 12 hr and CO levels are likely to continue at this level, recommend **formal Evacuation** until air quality is safe to return*.

***** Moving people to cleaner air, depending on the circumstances and the population affected. For example, since a blood concentration at or below 2.5% COHb is not of concern in susceptible non-smoking individuals, including people with heart disease (ATSDR, 2012), and constant exposure to CO at 20 ppm or lower is

[12] Note: This chart is not the same as that which applies to firefighters exposed to CO. This is because firefighters will be working in shifts where exposure times are managed depending on the levels of CO in air, they have workforce oversight, and they have the opportunity for monitoring personal exposure, with access to personal protective equipment. These management options are not available for the public.

unlikely to result in a COHb level greater than 2.5%, relocation to an area with an average CO of less than 20 ppm is considered.

Table 5: Advice and Warnings Matrix for CO Readings, including evacuation

Warnings Matrix for CO Readings							
	Predicted Duration (hours) of ACTUAL Impact of Plume (How long the plume is in the area)						
CO Readings (ppm)	**30 min**	**>1-2**	**>2-4**	**>4-6**	**>6-8**	**>8-12**	**> 12**
70*	**EW_{Stay}**	**EW_{Stay}**	**EW_{Stay}**	**EW_{Leave}**	**EVAC**		
33	**A**	**A**	**$W_{Shelter}$**	**$W_{Shelter}$**	**$W_{Shelter}$**	**EVAC**	
27	**A**	**A**	**A**	**A**	**$W_{Shelter}$**	**$W_{Shelter}$**	**EVAC**

Assumptions
Meteorological forecasts of wind speed, direction and duration inform the estimated duration of exposure (ie predicted duration of plume containing CO)
Sheltering indoors provides 4 hours protection before indoor CO and outdoor CO concentrations are the same
CO readings (i.e. monitored levels) are based on average measurements over a minimum of 30 to 60 minutes
Available data is constantly monitored and actions occur well before above thresholds are reached
Evacuation (prepare to/ evacuate now) - is based on monitored CO levels that are predicted to continue beyond the period of protection provided by sheltering indoors.
Outdoor monitoring CO levels that warrant formal evacuation are likely to be a rare occurrence.
Clean air in relation to CO is defined in this Standard as 20 ppm (1 hour) or less. 'Clean air' to identify where people should relocate to and a 'clean air' threshold to inform a risk assessment for planned return.

***** *Note that the AEGL-2 equivalent 1-hour average CO air concentration of 83 ppm has been conservatively reduced to a 1-hour of 70ppm to ensure an extra margin of safety, beyond that already provided by the AEGLs and the use of predictive plume duration to guide public health actions. Further protection is made by the initial time point being 30 minutes for issuing EWStay (for 70 ppm) or Advice for 33 ppm (30 min) or 27 ppm (30 min).*

Options for CO Monitoring

CO is measured for a number of purposes, using different techniques. Examples include:

Atmospheric monitoring:

- Hand-Held Atmospheric Monitoring: equipment used by emergency responders to survey potentially hazardous atmospheres for 'spot' measurements
- Fixed Atmospheric Monitoring: equipment deployed by or on behalf of the EPA in locations representative of public exposure with the capability to be monitored remotely

Personal monitoring:

- Personal Atmospheric Monitoring: equipment worn by first responders in the breathing zone for the purposes of assessing personal exposure against workplace exposure standards

- Personal Biological (Health) Monitoring: assessment involving the analysis of blood for workers or community (pulse CO-Oximetry), or exhaled breath samples from workers for a hazardous substance or its metabolites (breakdown products in the body).

General Roles and Responsibilities

Agencies

The following is a high-level description of general roles and responsibilities of agencies involved in protecting the community during large, extended or complex fires where high outdoor CO exposure is possible:

- First responders to a fire event have capacity to deploy mobile air monitoring equipment.
- Incident Controller provides information on first responder assessment of potential CO impacts into the community from the incident to the EPA.
- Incident Controller continues to provide qualitative assessments and available data from equipment deployed by first responders to EPA for assessment and advice. EPA informs DHHS and other stakeholders (as per SOPs).
- Other agencies may be requested to provide advice on predicted weather conditions for smoke impacted communities.
- In the event of actual or predicted adverse conditions, continuous CO monitoring[13] may be initiated to determine CO concentrations in potentially impacted communities to manage potential public health risks.
- Incident Controller leads Emergency Management Team in consideration of whether formal evacuation, or part evacuation of a community is required.
- Incident Controller determines the strategy for protecting the community from CO exposure through issuing information (ie advice) and warnings (if required).
- Information and warnings issued to the community is based on observed and predicted information including:
    - Measured CO concentrations in outdoor air that are adjusted to 30- to 60-minute averages
    - Bureau of Meteorology forecast data
    - Actual and forecast fire behaviour
    - Predicted duration and location of unfavourable conditions and elevated CO levels
    - Size of community impacted.
- At the request of the Incident Controller, Victoria Police prepares a staged evacuation plan for the community (or defined area) likely to be impacted by smoke from fires with the greatest CO-producing potential. Plans are prepared as early in the emergency as feasible.

[13] Because of rapid fluctuations of CO levels, atmospheric monitoring should be continuous to enable interpretation of results. If continuous monitoring is not available, 'spot' monitoring (a single reading, a "snapshot in time") should be repeated at frequent intervals at the same monitoring point in order to provide averaged results or trends in data. The frequency of monitoring should be at not more than 5-minute intervals. CO monitoring results need to be reviewed and verified. Reporting should be either a graph or a time series including all results with time and location of measurement. CO monitoring results need to be interpreted with supporting information including maps of affected community specifying monitoring positions, plume modelling of smoke dispersion, and predictions of local weather for the next 12 to 24 hours. Maps should identify facilities with vulnerable people, such as childcare facilities, schools, health services, and residential aged care facilities.

- The Health Commander (Ambulance Victoria) and DHHS contribute to planning for formal evacuation.
- DHHS in conjunction with local government coordinates relief and recovery arrangements for relocated or evacuated members of the community.

Community actions

The community should be able to access or receive emergency warnings and information from multiple sources and be advised to remain vigilant during the emergency so that they can act in a timely way if told to shelter indoors or leave.

Sources include:

- Local ABC or any commercial radio station
- Television
- Vic Emergency website www.emergency.vic.gov.au
- Social media.

Shelter indoors involves:

- Moving inside into an indoor room with the least number of doors and windows
- Closing all doors and windows
- Sealing gaps under doors or around windows and wall vents with towels, blankets or plastic
- Switching off air-conditioning or heating or turn to recirculate
- Continuing to monitor advice for additional protective actions to take, and for when and how to end shelter-indoors
- Minimise overall exposure by avoiding other sources of CO or indoor air pollution (e.g. smoking cigarettes or cooking food on a gas stove without extraction ventilation).

In a prolonged incident, there may be several occasions where shelter indoors is advised. Between these episodes the air may clear, and outside CO levels decrease to safe levels. Advice will be provided at this time to open doors and windows to air out homes.

Community exposure air quality values for significant outdoor CO emissions longer than 8 hours

This Standard concerns community health and safety during large, complex incidents that have the capacity to produce significant levels of CO in the outdoor environment. The AEGL-2 values for CO are generally applicable to CO exposure in the outdoor environment during an emergency in the community for up to 8 hours.

Community exposure in long-term emergency situations is usually defined as a period of 24 hours or longer. Therefore, if fires lead to prolonged periods (e.g. day or weeks) of consistently elevated exposures to CO, AEGL-2 levels may not be appropriate as these values have been derived for acute emergency situations.

Long-term exposure at environmentally relevant concentrations that are below the AEGL-2 may result in chronic health effects, especially for susceptible individuals. Consideration should be given to the use of a trigger CO concentration in air that results in less than 2.5% COHb, the blood concentration at which there are no observed adverse effects on health for long-term exposure even for susceptible individuals.

Refer to **Table 1** and **Figure 1** to inform decision making in this regard.

References and further reading

ATSDR: Toxicological Profile for Carbon Monoxide. US Department of Health and Human Services. Agency for Toxic Substances and Disease Registry, June 2012

Book: Toxicology, Survival and Health Hazards of Combustion Products (Issues in Toxicology), ed. D Purser, R Maynard and J Wakefield, Royal Society of Chemistry Cambridge UK (2016)

Book: Carbon Monoxide Poisoning, ed. DG Penney, CRC Press (2008)

UK: Public Health England. Compendium of Chemical Hazards: Carbon Monoxide Toxicological Overview, Nov 2016.

USEPA: Committee on Acute Exposure Guideline Levels, Committee on Toxicology; National Research Council: Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8 (2010)

Victoria (MFESB): A Best Practice Approach to Shelter-in-Place for Victoria (MFESB 2011)

Victoria (MFESB): Protective Action Decision Guide for Emergency Services during Outdoor Hazardous Atmospheres (MFESB 2011)

WHO: International Program on Chemical Safety (IPCS): Environmental Health Criteria 213, Carbon Monoxide, World Health Organisation, 1999