Incident Summary #II-1311229-2022 (#25700) (FINAL)

SUPPORTING INFORMATION	Incident Date		January 8, 2022
	Location		Delta
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	0
		Injury description	N/A
		Injury rating	None
	Impact – Damage	Damage description	Furnace produced high levels of carbon monoxide that accumulated to dangerous levels inside a home.
		Damage rating	Moderate
	Incident rating		Moderate
	Incident overview		A natural gas furnace in a residential home produced elevated levels of carbon monoxide. Hazardous levels of carbon monoxide were measured inside the home while the occupants were away.
INVESTIGATION CONCLUSIONS	Site, system and components		Residential gas furnaces use the heat produced from the combustion of a gas/air mixture to heat the home. The combustion occurs at the entrance to a heat exchanger. The flue gases produced by combustion pass through the inside passages of the heat exchanger and are carried safely to the outdoors through a venting system connected to the furnace. A blower fan draws air from inside the home and passes it around the outside of the heat exchanger. Heat transfers through the heat exchanger shell to the air on the outside which is then distributed throughout the home through a ducting system (Image 1). High efficiency furnaces incorporate a secondary heat exchanger in addition to the primary heat exchanger. A draft inducer fan first draws the flue products through the primary heat exchanger then through the secondary one before forcing them to the outdoors through the venting system. The secondary heat exchanger allows additional heat to transfer to the heating air, reducing the amount of heat lost through the exhaust to the outdoors and increasing the appliances heating efficiency. A by-product of removing more heat from the flue products is the generation of condensation, which accumulates inside the venting system and secondary heat exchanger. High efficiency furnaces are designed to allow the condensate to drain back through the furnace and be piped to a separate drain in the home. The condensate created in a high efficiency furnace is acidic and corrosive to most metals. The venting systems, condensate drains, and secondary heat exchangers are required to be made of materials that are not affected by the corrosive properties of the condensate. The design of furnace involved in this incident uses carbon steel secondary heat exchanger tubes lined with thermoplastic polypropylene on the inside to protect the steel from the corrosive condensate.

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	Residential gas furnaces incorporate electrical safety circuits designed to shut the furnace off in unsafe conditions. The electrical safety circuits have switches which monitor aspects of the furnaces performance and will interrupt the electrical circuit if any of the monitored values go outside the switches set parameters. When the electrical safety circuit is interrupted, the furnace will stop operating. A flame rollout switch is one component of a safety circuit and is installed just upstream of the gas burners. If flames "rollout" from the burner tubes, the switch will overheat and open the electrical circuit to shut off the furnace. A flame rollout switch must be manually reset if it trips by pressing a button on the outside of the switch. The switches are designed this way because flame rollout is evidence of a serious problem with a furnace or venting system and examination should be done by a qualified individual to identify the issue and not allow the furnace to operate until it is repaired. Natural gas requires a minimum amount of air to burn completely. When the minimum amount of air is not present, the result is incomplete combustion. One of the by-products of incomplete combustion is carbon monoxide (CO). Carbon monoxide is a colourless, odourless, tasteless gas that is toxic to humans and animals (Table 1). Exposure to carbon monoxide interferes with the body's ability to absorb oxygen, which can result in serious illness or death. (For more information on carbon monoxide check out "CO Safety Tips") Another by-product of incomplete combustion are organic compounds know as aldehydes. While carbon monoxide is odorless, aldehydes have a sharp penetrating odor. The odor of aldehydes differs from odorants added to natural gas for detection. Aldehydes, much like carbon monoxide, are toxic to humans and animals.
Failure scenario(s)	The furnace in the residential home had been in operation for approximately 13 years. The design of the furnace's secondary heat exchanger allowed the protective polyethylene coating on the inside to fail causing corrosion holes and a restriction in the airflow of the combustion products through the heat exchanger. The restricted airflow led to incomplete combustion and the production of high levels of carbon monoxide and aldehydes. The carbon monoxide and aldehydes were able to enter the home and accumulate to hazardous levels.
Facts and evidence	Fire department call sheet document • The fire department responded to reported smell of gas from neighbours. • They noticed a strong smell coming from the side wall vent termination of the furnace on the outside of the house. • The gas utility technician arrived and measured 200ppm of CO inside the house. • They did not receive a response from any occupants and there was no open access into the home. • They breached the back door and confirmed there were no occupants in the home.

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Gas utility technician statements

- They were called to the site for what was believed to be a smell of natural gas reported by a neighbour.
- The neighbour was located on the opposite side of the house from the horizontal vent termination of the furnace.
- It was determined that the smell was not leaking natural gas but aldehydes due to incomplete combustion coming from the flue gas of the operating natural gas furnace.
- They measured CO in the flue gas of the running furnace exceeding 1000ppm.
- A measurement was taken through the front door mail slot and CO was detected between 50-100 ppm indoors.
- At the back of the home the fire department was able to move a main floor window enough to insert the test probe of the CO measuring tool and CO was detected at 200ppm at that location indoors.
- The fire department forced entry not the home to check for any occupants.
- No occupants were found inside the home
- After the house was ventilated, they found that the furnace was not shutting off and the inside of the house was still very warm.

Contractor statements

- They were contracted to replace the failed furnace after the incident.
- When they arrived, the furnace was off and there was a strong smell of aldehydes inside the home and particularly around the furnace.
- They did not observe any incorrect installation criteria with the original furnace including furnace leveling.
- The existing venting system to the old furnace was entirely visible inside the mechanical room and was observed to be entirely intact without any indications of possible vent leakage paths into the home.
- The condensate drain was found to be not plugged and there were signs of condensate leakage from the internal heat exchanger down into the heating ducting.

Site examination

- The vent termination for the furnace was installed on the side of the home with compliant clearance to all building openings including doors, windows, and air intakes.
- All doors and windows on the side of the home were closed.
- Staining and corrosion from corrosive furnace condensate were observed in the heating ducting underneath the furnace.
- An open combustion air intake grill for the mechanical room was found approximately 6 feet below the furnace vent termination which would make it an unlikely path for the flue gas containing carbon monoxide to re-enter the home as warm flue gas rises when it exits the vent.

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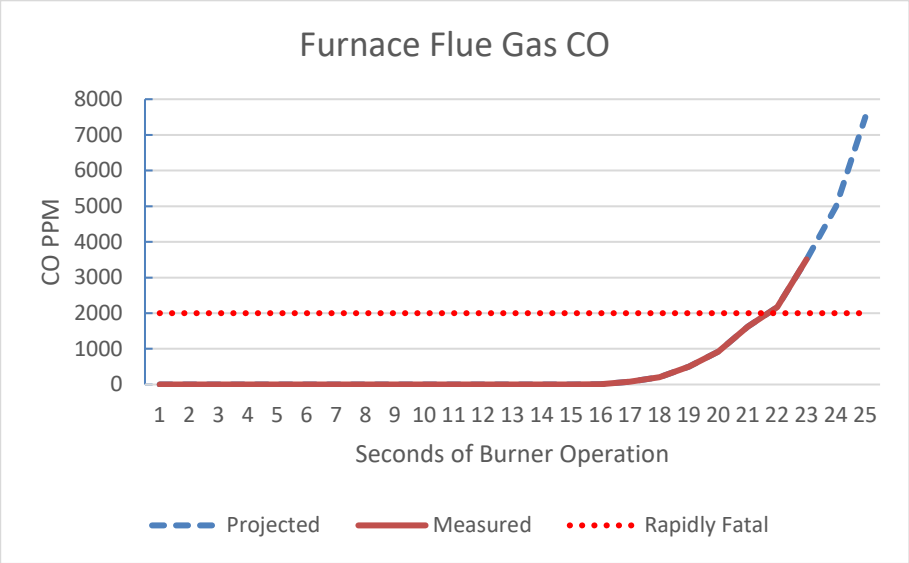
Furnace testing and examination

- The furnace was removed and reconnected in a testing facility for functional testing.
- Gas input and manifold pressures were set to factory settings.
- A testing probe was inserted in the flue gas pipe of the furnace.
- With the burners ignited, the CO measured in the flue gas remained 0 ppm for the first 15 seconds then rapidly increased to the maximum upper limit of the testing equipment measured reading of 3508 ppm within 8 seconds



For more details of the failure mechanism associated with the components found in this and similar makes and models of furnaces, read the full report on the Carrier Gas furnace investigations conducted by Technical Safety BC.

Download the report

Causes and contributing factors

The cause of the incident was the furnace secondary heat exchanger design which used polypropylene laminated steel materials. Rapid and excessive corrosion of these materials restricted airflow through the furnace resulting in production of carbon monoxide due to incomplete combustion, which then entered the home.

A contributing factor was the failure of the flame rollout switch to stop the operation of the furnace while the restricted heat exchanger was causing it to produce very high levels of CO in the flue gas.

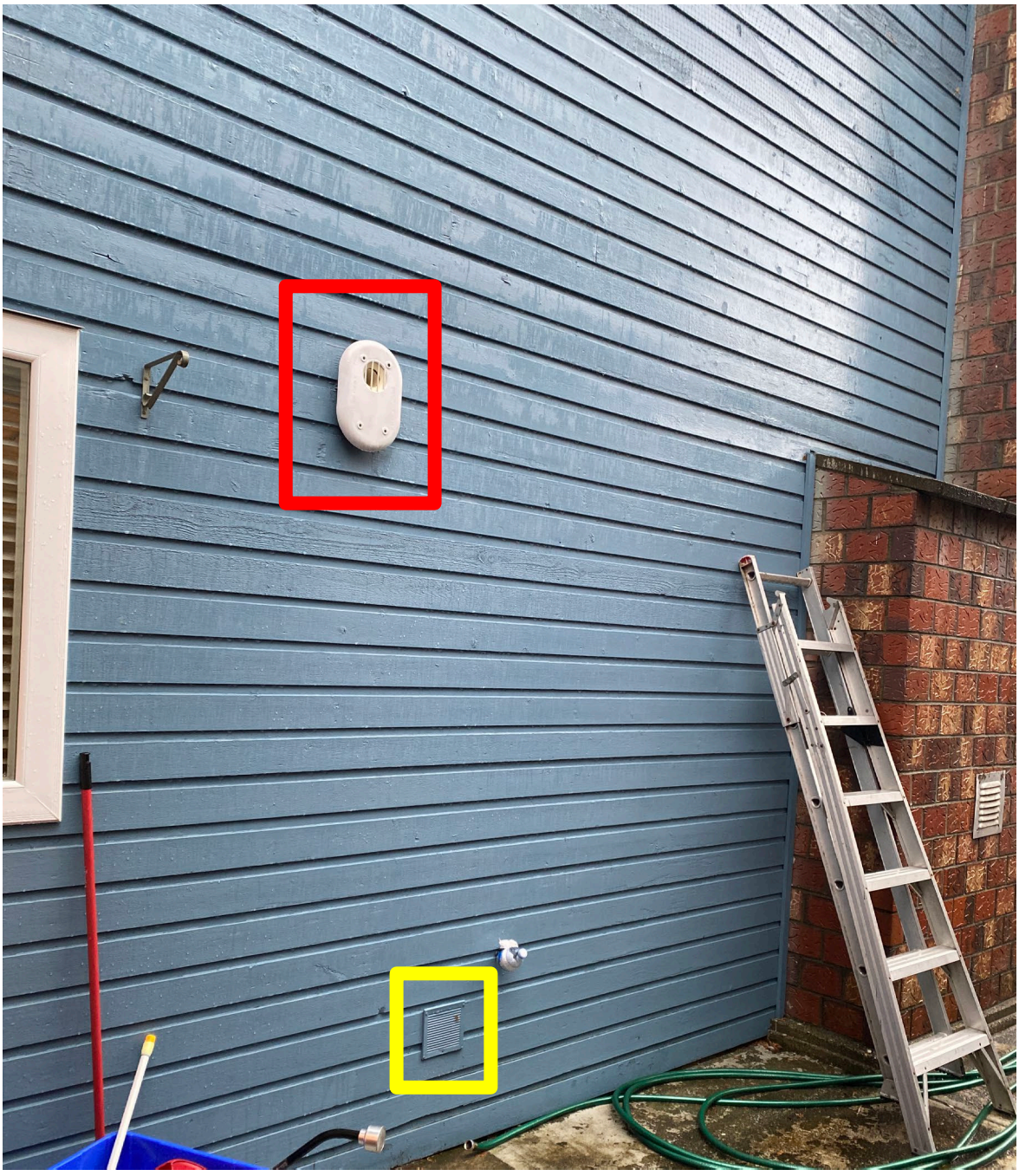


Image 1 - East side of home, red box showing the furnace vent termination. Yellow box showing the combustion air ventilation opening into mechanical room.

Image 2 – East side of home red box showing furnace vent termination location away from building openings.

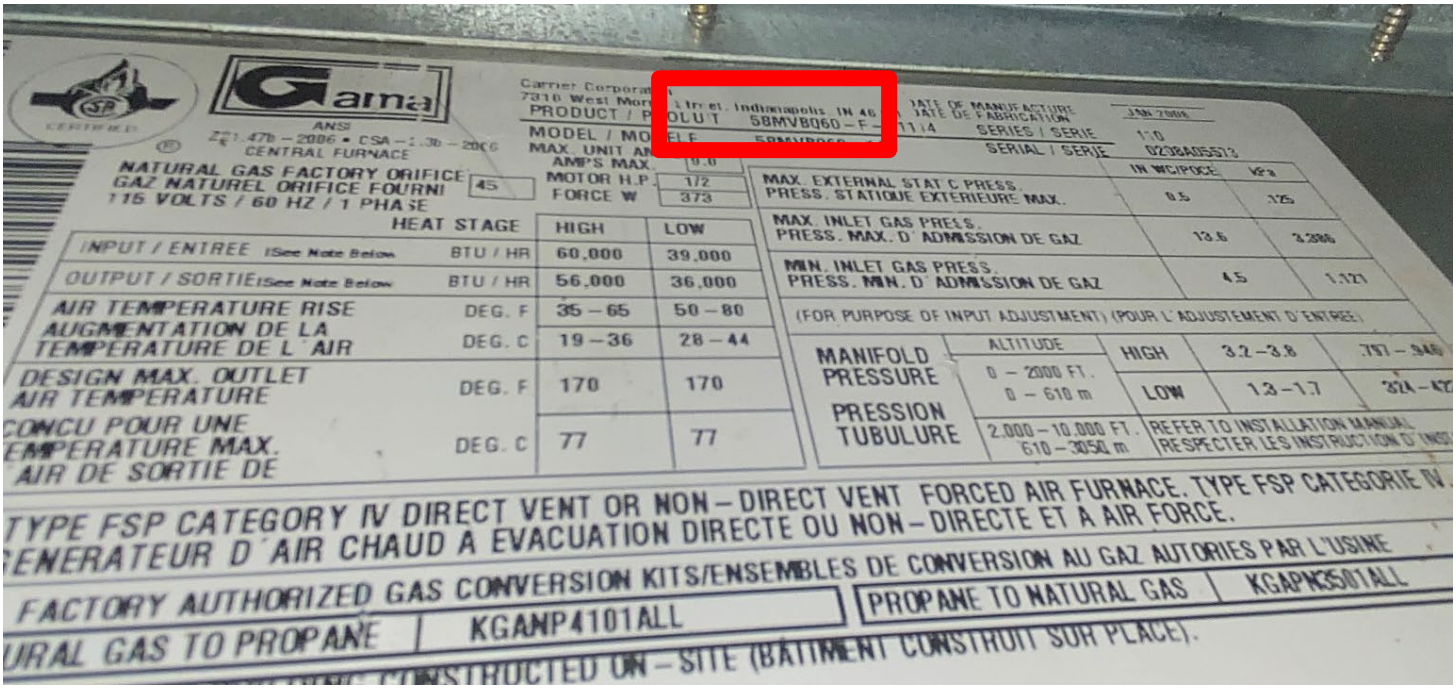


Image 3 – Data tag of furnace identifying it as a Carrier Model # 58MVB060-14

Image 4 – Fully exposed for inspection and sealed furnace venting to outdoor termination.

Image 5 – Heating air ducting exposed after furnace was removed showing corrosion and staining from leaking condensate from the furnace heat exchanger.

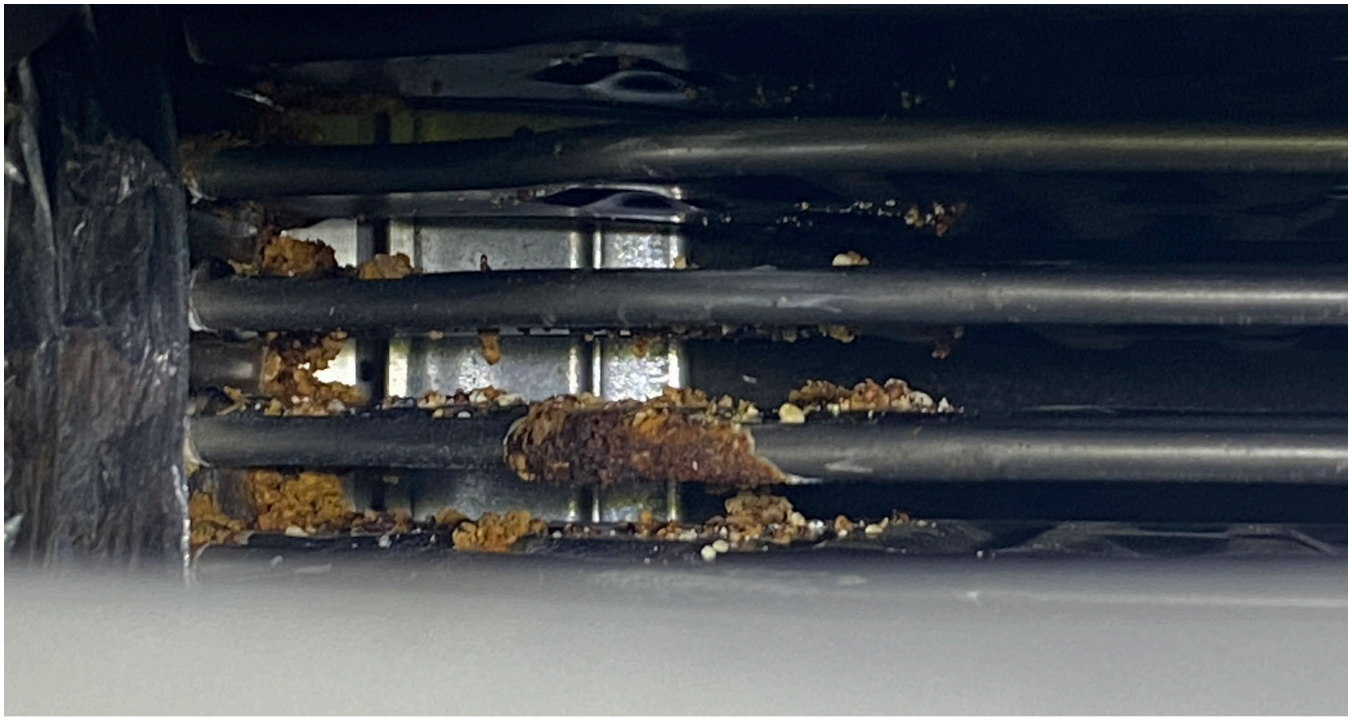


Image 6 – Corrosion on exterior of secondary heat exchanger tubes.

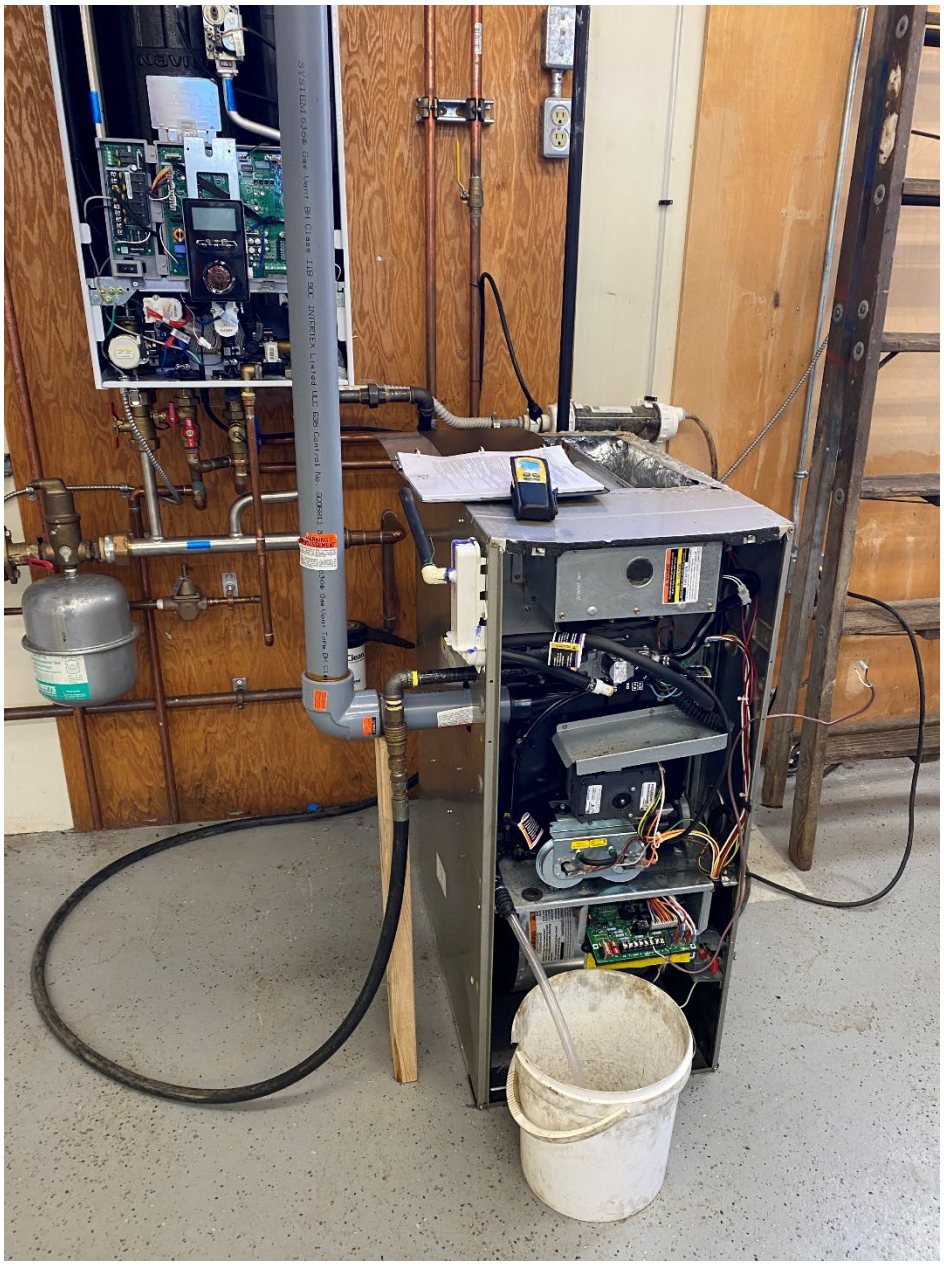


Image 7 – Furnace installed at testing facility.

Image 8 – Test probe installed measuring CO in the furnace flue gas at testing facility.

Properties of Carbon Monoxide

Colourless	Cannot be seen.
Tasteless	Cannot be detected through the sense of taste.
Odourless	Cannot be detected by sense of smell, However, CO can also be accompanied by aldehydes. Aldehydes' odour can somewhat resemble vinegar, which can be detected by the sense of smell, and may also result in a metallic taste in the mouth.
Non-irritating	Carbon Monoxide will not cause irritation. However, aldehydes usually present with higher levels of CO will irritate the eyes, nose, and mucous membranes.
Specific gravity	Slightly lighter than air (Sg 0.975). It may, but not always collect near the ceiling, and mixes freely with air.
Flammable (explosive) limits	CO is flammable between concentrations of 12.5% to 74% when mixed with air. Its ignition temperature is 609ºC (1128ºF).
Toxic	Can cause death if enough is absorbed into the bloodstream.

Table 1 – Properties of carbon monoxide from Technical Safety BC's Carbon Monoxide Handbook

Concentrations (*ppm)	Observations and Health Effects
1 to 3	Normal.
25	Occupational exposure limit averaged over 8 hour period.
30 to 60	Exercise tolerance reduced.
100	15-minute short-term exposure limit (STEL).
60 to 150	Frontal headache. Shortness of breath on exertion.
150 to 300	Throbbing headache, dizziness, nausea, and impaired manual dexterity.
300 to 650	Severe headache; nausea and vomiting; confusion and collapse.
700 to 1000	Coma and convulsions.
1200	Immediately dangerous to life and health (IDLH).
1000 to 2000	Heart and lungs depressed. Fatal if not treated.
Above 2000	Rapidly fatal.

*1 ppm = 1 part of gas per million parts air by volume

Table 2 – Carbon monoxide concentrations and health effects from Technical Safety BC's Carbon Monoxide Handbook