Incident Summary #II-1047379-2020 (#18948) (FINAL)

SUPPORTING INFORMATION	Incident Date		August 3, 2020
	Location		Tulameen
	Regulated industry sector		Gas – Propane system
	Impact – Injury	Qty injuries	2
		Injury description	Two individuals deceased
		Injury rating	Fatal
	Impact – Damage	Damage description	N/A
		Damage rating	None
	Incident rating		Severe
	Incident overview		Two individuals were found inside a shower building on a recreational property unresponsive. The building was equipped with a propane-fueled on-demand tankless water heater. The water heater was installed inside a small shower building. The heater vented combustion products into the building where it also received its combustion air supply, producing high levels of carbon monoxide as the combustion air was consumed.
INVESTIGATION CONCLUSIONS	Site, system and components		The incident occurred on recreational property. The property consisted of a lot containing a metal storage container, a wooden bunkhouse, and a wooden shower building (Image 1). The site has electrical services provided by the city and gas provided by portable propane cylinders. The shower building was constructed of wood with insulated walls, a tight-fitting wooden door, and one opening window (Images 2 and 3). The room inside the building contained a sink, toilet, and a shower. Hot water is supplied to the sink and shower by a propane-fueled tankless on-demand water heater. The propane-fueled tankless on-demand water heater does not store heated water in an internal storage tank like a standard water heater. Instead when water begins to flow through the appliance, a gas burner fires to heat water that passes through a heat exchanger above the burner. The burner continues operating until the flow of water is stopped. When a propane appliance is installed indoors it requires an outdoor combustion air supply. The air supply is either piped directly to the appliance or supplied to the room it's installed in using a ducting system or a fixed opening in the building. Propane-fueled water heaters installed indoors also require a venting system that effectively removes all of the flue gases safely outdoors. Propane requires a sufficient amount of oxygen for complete combustion. When the minimum amount of required oxygen is not supplied to a gas burner the result is incomplete combustion. A by-product of incomplete combustion is carbon monoxide. Carbon monoxide is a colourless, odourless, tasteless gas that is toxic to humans and animals (Chart 1). Exposure to carbon monoxide interferes with the body's ability to absorb oxygen, which can result in serious illness or death (Chart 2). For more carbon monoxide information, visit Carbon monoxide safety tips.

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Failure scenario(s)	The shower room on the property was entirely enclosed, and other than the door and window, there were no other openings in the room for air intake or ventilation. The water heater was installed inside the room and did not vent the flue gases to the outdoors. The installation was contrary to the warnings on the front and side of the water heater along with the heater's installation manual (Image 9). While the water heater was operating it circulated the flue gases containing carbon monoxide into the mostly-unvented space (Diagram 1) that was also supplying combustion air supply for the appliance. Once the available oxygen supply was reduced, this caused an increase in the rate of carbon monoxide production due to incomplete combustion of the fuel, which rapidly elevated the concentration of carbon monoxide in the room. Two individuals were inside the room with the shower running. After approximately one hour they were found inside the room and unresponsive.
Facts and evidence	**Interview statements** A witness stated that one of the victims was the owner of the property and had constructed the shower building approximately 3-5 years ago. It had a propane-fueled water heater supplying water to the shower and sink. It had been used, without incident, since it was built. A witness confirmed that the two victims were inside the shower room for approximately one hour, the water was heard to be running, and that the victims were found inside unresponsive. Another witness stated that the shower building was originally built with a different water heater. The original water heater had been damaged due to freezing over the winter and was replaced by the owner, in the summer of 2019, with the water heater that was installed at the time of the incident. **Site examination** A site examination, along with testing of the propane-fueled water heater, took place after the incident. The enclosed room inside the shower building was approximately 40 square feet, eight feet high and contained a toilet, a sink, and a shower. The room had a single window that was open with a one-inch gap and had an electrical wire passing through it from a solar panel to a motion-sensing light inside (Image 3). With the door closed, the room has no other openings for air supply or ventilation from the outdoors other than the window. A propane-fueled tankless on-demand water heater was installed on the inside wall mounted between the sink and shower (Image 4). A propane supply hose passed through the exterior wall to the outside for connection to a portable propane cylinder. The propane cylinder still contained a significant amount of fuel. Tags on the water heater identified the product as model JSD36-A, produced by Zhongshan City Electric Appliance Co. Ltd., and manufactured for use with propane gas (Image 5 and 6). No certification marks approving it for use in Canada were found. The water heater has three adjustable knobs and a digital display on the front. One knob labelled "gas regulator" was set to the minimum position. Another knob labelled "water regulator" was set slightly above the minimum position, and a knob labelled "winter/summer" was set to the winter position (Image 7**)**. The digital display and the burner ignition are powered by two "D" cell batteries inside the water heater. The hot water outlet of the heater was connected to the sink faucet and the shower nozzle. The only water supply to the shower nozzle was from the water heater. Temperature control of the shower water could only be adjusted by the "gas regulator" knob.

The safety precautions listed on the product tag attached to the side of the water heater stated: “The water heater must be ventilated outside the bathroom” (Image 5). The water heater had a prominent marking across the front of the cover which stated: “No installation in your bathroom” (Image 8). The heater installation manual stated that the “Gas water heater shall be installed outside” (Image 9).

Testing and analysis

An examination inside the heater found the gas burner and heat exchanger free of soot and debris. When the burner were fired during testing they appeared sharp and blue without any visible signs of incomplete combustion.

Tests were conducted measuring the carbon monoxide levels in the water heater flue gas and the concentrations within the enclosed shower room (Appendix A**)**.

Analysis of the test data found that the input setting of the water heater and amount of time the heater operated were critical factors in the amount of time it took to elevate carbon monoxide to dangerous levels of concentration in the shower room.

When the gas input was set to low and the door was open providing the heater with its required amount of combustion air, the carbon monoxide levels measured in the flue gas produced a typical and expected result. When the gas input to the heater was manually turned up to the midway or high point using the “gas regulator” knob, the carbon monoxide levels measured in the flue gas quickly exceeded the allowable limits set by Canadian standards. Canadian standards allow a *maximum* of 400 ppm carbon monoxide “air free” to be produced in the flue gas of a gas-fired water heater.

A carbon monoxide “air free” measurement is used by Canadian standards. It refers to the concentration of carbon monoxide in flue gases undiluted by other gases in the flue. The value is computed using an equation that takes into account the oxygen concentration in the flue gas. Carbon monoxide air-free measurements are higher than regular carbon monoxide measurements like the ones recorded during testing.

The only water supply to the shower nozzle was from the water heater. The temperature of the water was adjusted using the “gas regulator” dial on the front of the machine, which was found at the lowest temperature setting. It can be reasonably assumed that the heater was set to low during the incident.

While the burner did not initially produce hazardous levels of carbon monoxide at the low input setting, testing showed that the environment inside the shower room remained stable for the first 13 minutes of operation then rapidly elevated over the next four minutes to levels immediately dangerous to life and health. This is due to the depletion of oxygen in the room from the operation of the gas burner.

The depletion of oxygen in the room caused incomplete combustion and a rapid increase in the carbon monoxide levels of the flue gas. With the heater input set to low, test data indicates that rapidly fatal concentrations of carbon monoxide were in the room within 18 minutes and 22 seconds. The test results illustrate what reasonably occurred in this incident.

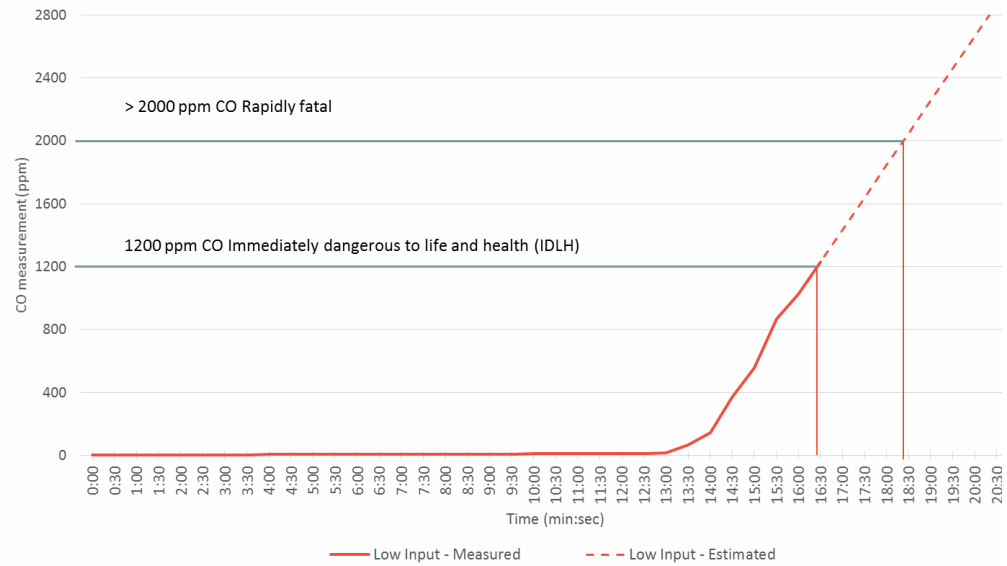


Figure 1 – *Carbon monoxide concentrations inside the shower room with gas input on "low"*

If the input to the water heater was increased using the "gas regulator" knob, the water heater began producing high levels of carbon monoxide in the flue gas. The carbon monoxide concentration inside the room rapidly increased to hazardous levels. The room did not need to become depleted of oxygen before the high levels of carbon monoxide were generated when the input is set to a low temperature. When the input was set to a high temperature, testing found that rapidly fatal concentrations of carbon monoxide were in the room in 5 minutes 24 seconds (Appendix A - Table A3).

Conclusion

Tests showed that with the water heater operating at the low input setting and with the door closed, the carbon monoxide concentrations within the shower room remain safe for a relatively short time. Once the available oxygen in the room was reduced, incomplete combustion caused the carbon monoxide concentration to quickly impair the ability to escape and become dangerous to life and health (Chart 2 and Table 1). Testing found that carbon monoxide in the room continued to rise to a rapidly fatal concentration within minutes of the shower being turned on. (Chart 2).

Causes and contributing factors

Installation of the propane-fueled water heater indoors, without a supply of combustion air for the burner or venting of the flue gases to the outdoors, resulted in a rapid accumulation of carbon monoxide inside the shower room, creating a hazardous environment within minutes of the shower being turned on.

Note: Technical Safety BC's scope of investigation and findings are limited to the likelihood of the equipment having produced a carbon monoxide environment consistent with the circumstances of the event. BC Coroners Service will determine the cause of death.

Images, figures, charts, and tables

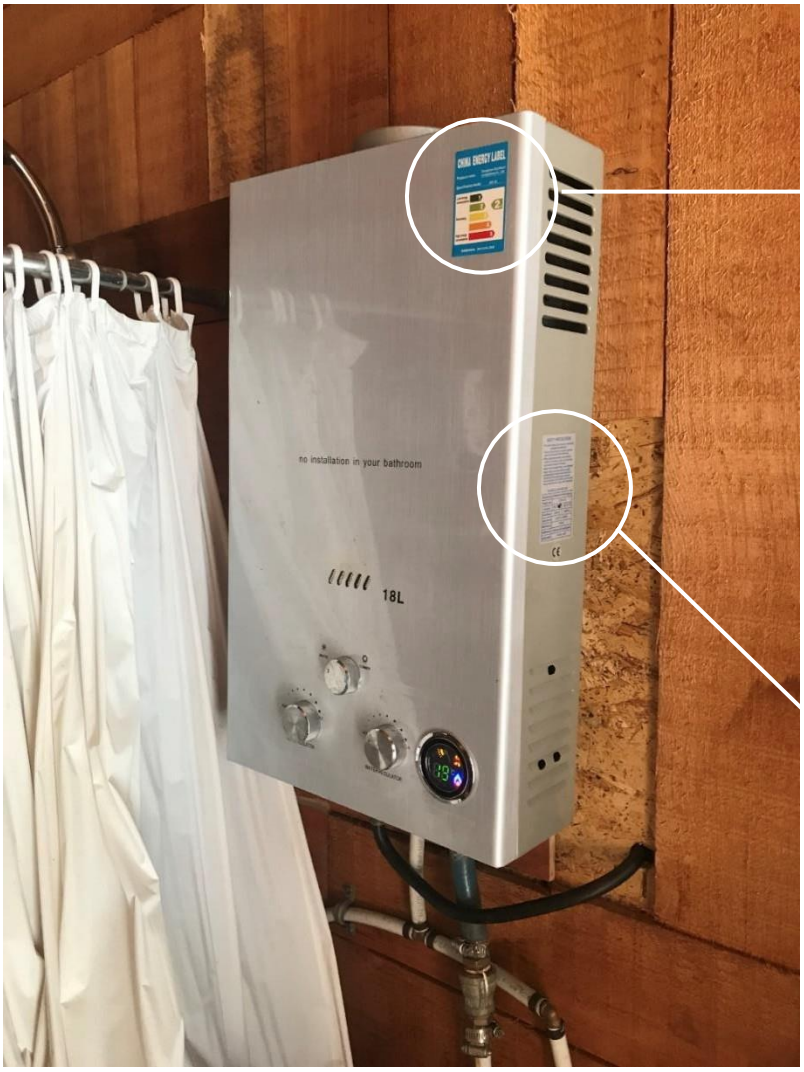
Image 1 – Recreational lot with a wooden bunkhouse (foreground) and the taller wooden shower building immediately behind (arrow).

Images, figures, charts, and tables (cont'd)

Image 2 (left) – Exterior of shower building showing door and window

Image 3 (right) – Window with one inch opening and electrical wire from solar panel to motion light inside the shower room

Images, figures, charts, and tables (cont'd)



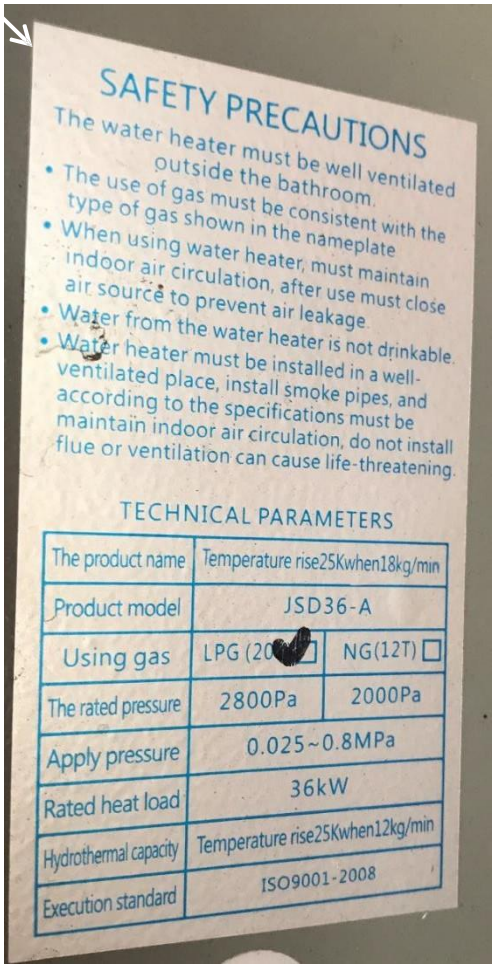


Image 4 (above) – Water heater installed inside shower building without flue vent piping

Image 5 (top right) – Product tag on the front of water heater showing manufacturer name and model number

Image 6 (bottom right) – Product tag and safety precautions on side of water heater

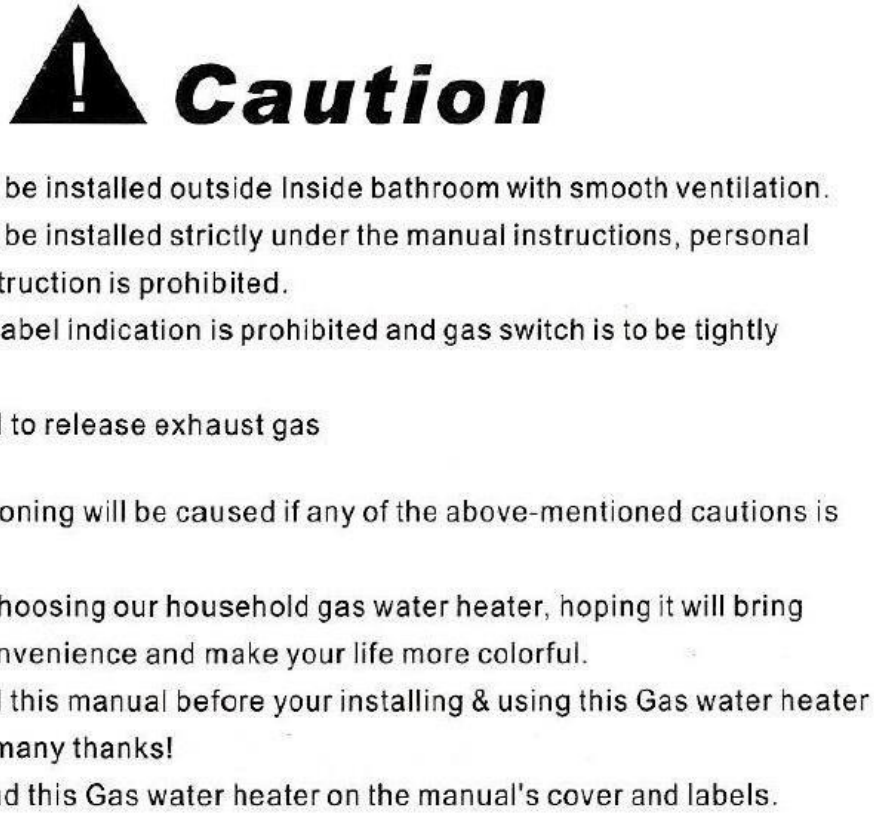
Images, figures, charts, and tables (cont'd)

Image 7 (left) – Control knob placements in front of the water heater. Knob positions as found on site.

Left knob labelled "gas regulator".

Image 8 (left) – Text (markings) on the front of the water heater cover reads "no installation in your bathroom"

Images, figures, charts, and tables (cont'd)



Caution

- Gas water heater shall be installed outside Inside bathroom with smooth ventilation.
- Gas water heater shall be installed strictly under the manual instructions, personal dismantling or re-construction is prohibited.
- Any other gas beyond label indication is prohibited and gas switch is to be tightly closed after using.
- Flues shall be installed to release exhaust gas

Garbon monoxide poisoning will be caused if any of the above-mentioned cautions is ignored!
Many thanks for your choosing our household gas water heater, hoping it will bring you great comfort & convenience and make your life more colorful.
Please do carfully read this manual before your installing & using this Gas water heater to ensure your safety, many thanks!
Please do carefully read this Gas water heater on the manual's cover and labels.

Image 9 – Warning label from the water heater installation manual

Images, figures, charts, and tables (cont'd)

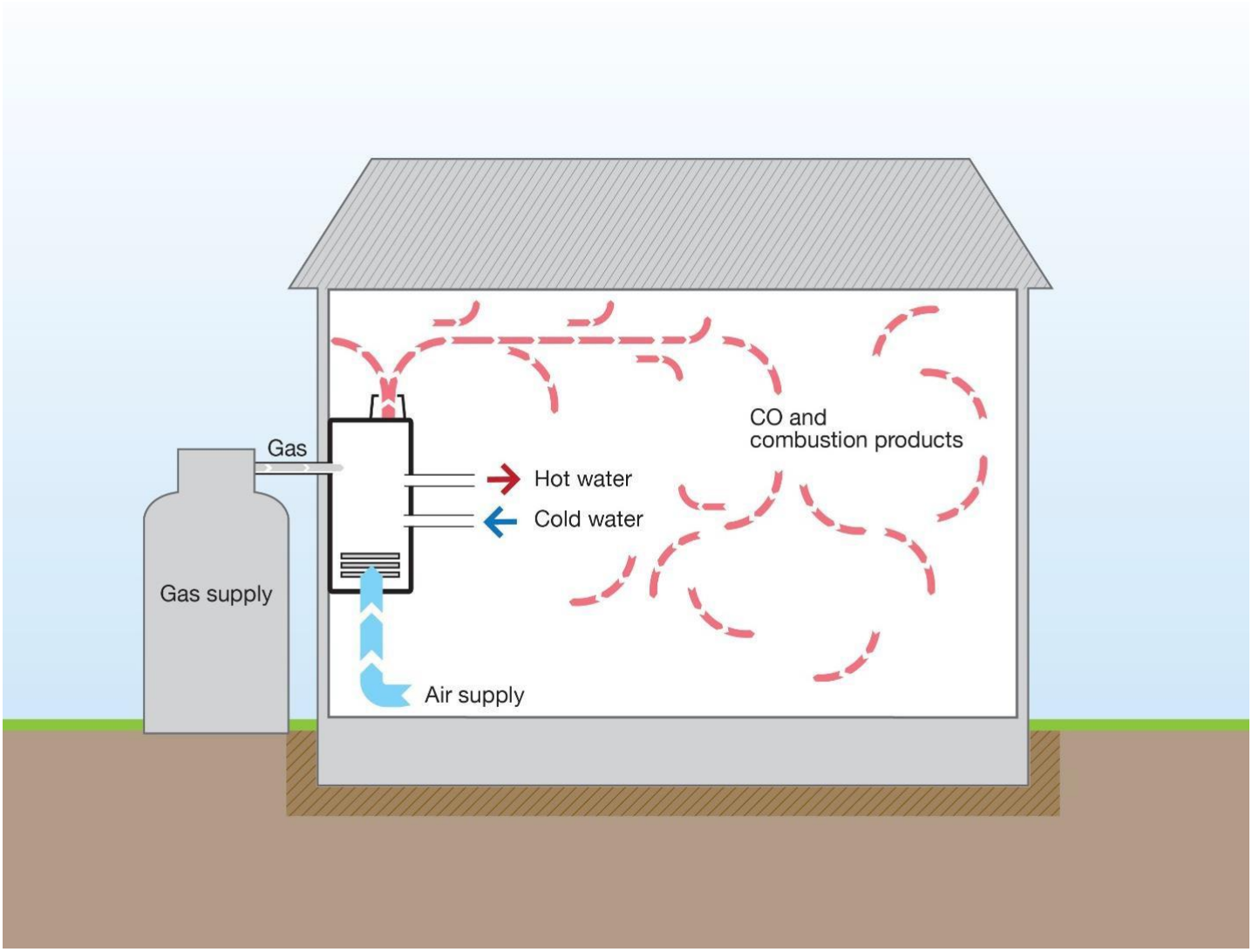


Diagram 1 – Illustration showing an on-demand water heater installed in an enclosed building without flue venting or combustion air openings. Combustion products and carbon monoxide filling the building and contaminating the air supply to the gas burner.

Images, figures, charts, and tables (cont'd)

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.

Chart 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

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

Images, figures, charts, and tables (cont'd)

Acute exposure guideline levels for carbon monoxide

	Duration				
Classification (description)	10 min	30 min	1 hour	4 hours	8 hours
Disabling Irreversible or other serious, long-lasting adverse health effects, or an impaired ability to escape.	420 ppm*	150 ppm	83 ppm	33 ppm	27 ppm
Lethal Life-threatening health effects or death)	1700 ppm	600 ppm	330 ppm	150 ppm	130 ppm

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

Table 1 – Acute exposure guideline levels for carbon monoxide showing health effects based on carbon monoxide concentration levels and exposure duration. Adapted from National Research Council (US) Committee on Acute Exposure Guideline Levels (AEGL)[1]

[1] National Research Council (US) Committee on Acute Exposure Guideline Levels. Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 8. Washington (DC): National Academies Press (US); 2010. 2, Carbon Monoxide Acute Exposure Guideline Levels. Available from: https://www.ncbi.nlm.nih.gov/books/NBK220007/ (Accessed August 11, 2020.)

Appendix A: Test results and conclusions

Tests

Test A: The flue gas of the water heater was tested for carbon monoxide concentrations. The water heater was tested in the as found condition ("gas regulator" knob set to low, "water regulator" knob set to slightly above minimum and "winter/summer" knob set to winter). The door and window were fully opened to provide sufficient air for combustion. The propane cylinder that was originally connected at the time of the incident was reconnected. No leaks were found in the gas system upon reconnection.

Test #	Conditions/parameters	Result
A-1	Sink hot water valve fully opened. Measurements were taken after the burner was on for 30 seconds.	Stable measurement 9 to 11 ppm carbon monoxide (CO) through test duration
A-2	Shower valve fully opened. Measurements were taken during and after the burner was started up.	Eight seconds after the burner ignited: 0 ppm to 833 ppm CO. CO measurement fell as flame stabilized. 30 seconds after the burner ignited: Stable measurement of 40 to 50 ppm CO.
A-3	Shower valve fully open; measurements were taken after the burner on for 30 seconds while manually increasing the input from low to high using the "GAS REGULATOR" knob.	On low input: CO measurement stabilized between 31 to 34 ppm CO. On maximum input: 1266 ppm CO (maximum measurement) reached in approximately 10 seconds.

Table A1 – Test A and Results Summary

Test B: Carbon Monoxide (CO) concentrations inside the room while the heater was operating. The shower building's door was closed and the window was put back to its as-found position with a one-inch opening. The detectors sampling wand was inserted in the window opening and the air samples were drawn from the end of the wand approximately 12 inches inside the window opening at a height of approximately 6 feet from the floor inside the room. Measurements were recorded every 30 seconds after the burner was fired and the door was closed. The tests continued until the instrument reached its maximum reading level above its operating range and the measurements abruptly stopped increasing. The fuel was then shut off to the heater from the outdoors and the readings were continually monitored until the CO levels began decreasing and it was safe to open the door to ventilate the space. Test results are graphed in Figure A1.

Test #	Conditions/parameters	Result
B-1	"gas regulator" knob set to maximum high position	Once the burner was fired the CO measurements inside the room quickly rose from 0 ppm to the instrument's maximum reading level at the 5-minute mark.
B-2	"gas regulator" knob set to a midpoint position between high and low	Once the burner was fired the CO measurements inside the room quickly rose from 0 ppm to the instrument's maximum reading level at the 9 minutes 30-second mark.
B-3	"gas regulator" knob set to a low position	Once the burner was fired the CO measurements inside the room remained under 15 ppm for the first 13 minutes. After 13 minutes the CO measurements began to quickly rise and reached the instrument's maximum reading level at the 17 minutes 30-second mark.

Table A2 – Test B and Results Summary

Appendix A: Test results and conclusions (cont'd)

Figures

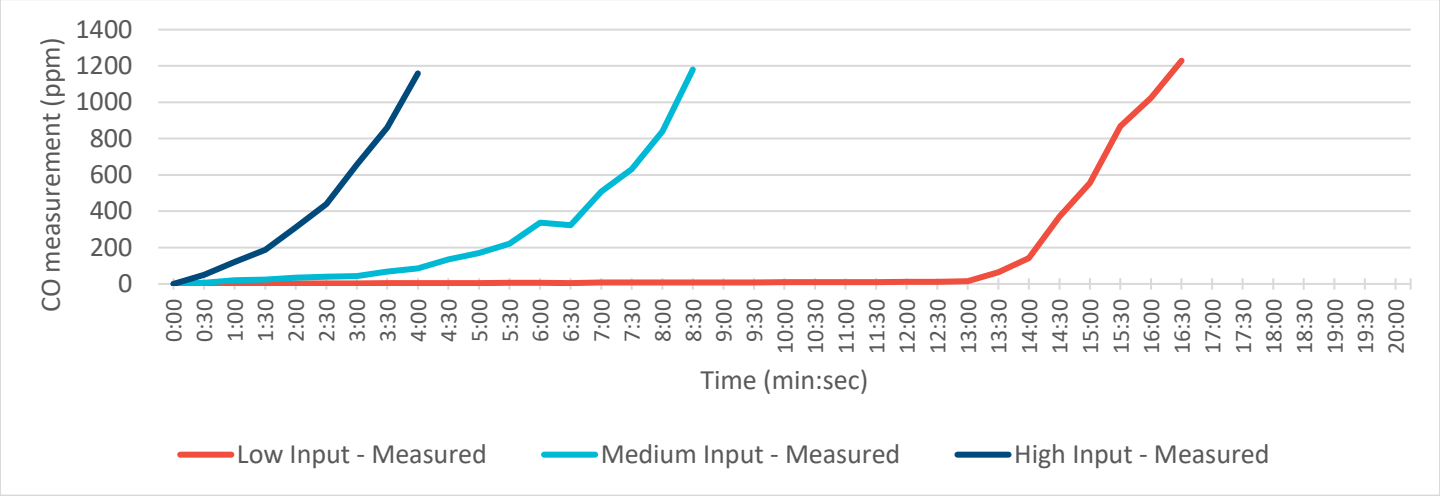


Figure A1 – CO Measurements at High, Midpoint and Low Input Positions (Tests B-1, B-2, and B-3)

As described above, the tests continued until the instrument reached its maximum reading level. The plateau represents this scenario where the instrument could not register readings higher than 1260 ppm. For example, in the low input test, the instrument reached 1260 ppm at the 17-minute mark and the gas supply was shut off at 19 minutes. The door to the shower building was opened at 20 minutes and as fresh air entered the room, CO readings declined. The test concluded at 27 minutes.

Since the test instrument was not able to take readings higher than 1260 ppm, linear extrapolation was used to estimate when the CO concentration in the shower room would reach levels described to be immediately dangerous to life and health (IDLH) and rapidly fatal (1200 ppm and 2000 ppm respectively) at each test scenario. Figure A2 shows the test data and the extrapolated CO values.

Appendix A: Test results and conclusions (cont'd)

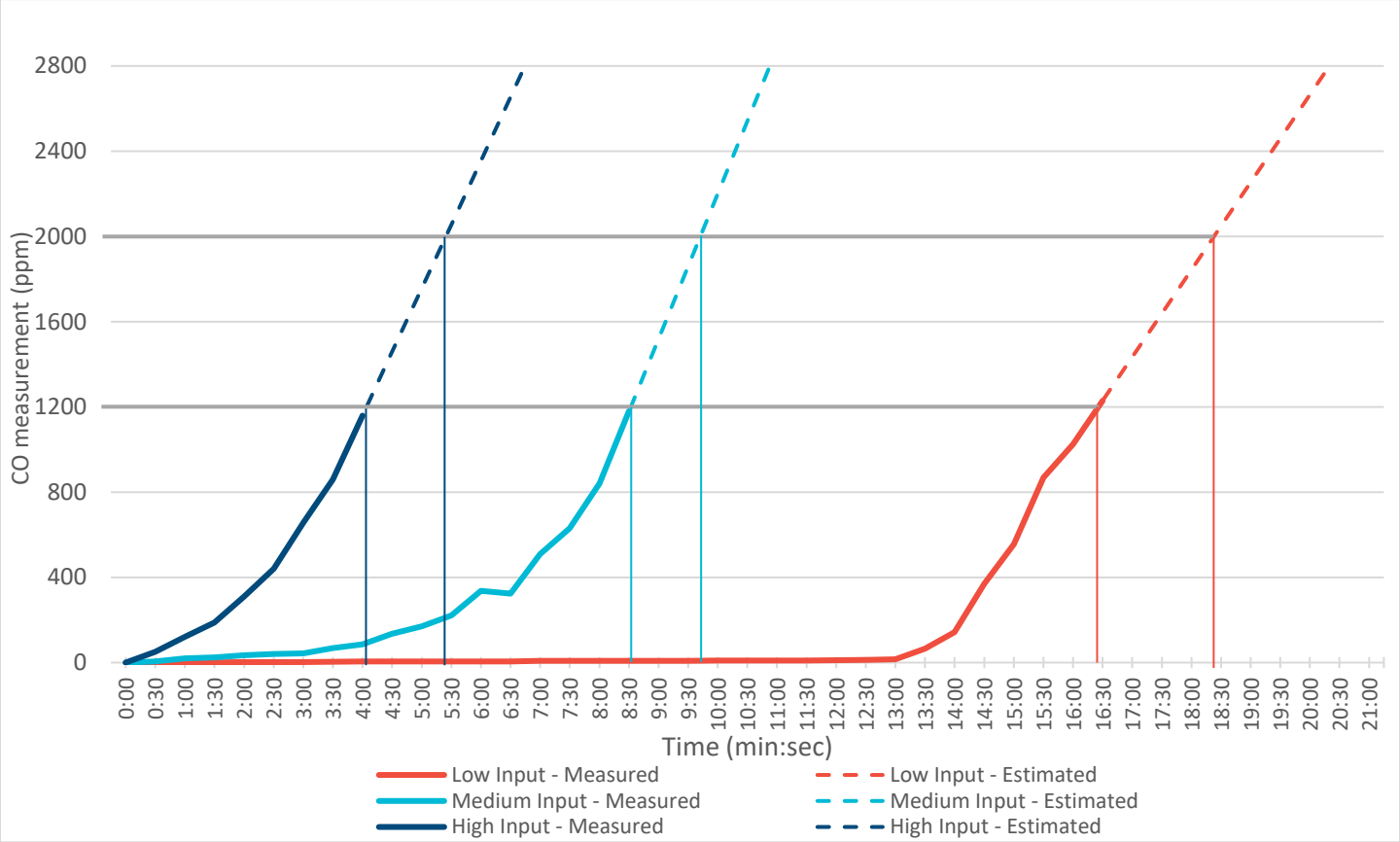


Figure A2 – Test Data with Linear Extrapolation

	Time (min:sec)			
	1200 PPM (CO)	1500 PPM (CO)	2000 PPM (CO)	3000 PPM (CO)
Low Input	16:25	17:09	18:22	20:49
Medium Input	8:31	8:58	9:42	11:10
High Input	4:04	4:34	5:24	7:04

Table A3 – Estimated time to reach 1200 ppm, 1500 ppm, 2000 ppm, and 3000 ppm

Conclusions

1. The water heater's gas regulator was found set in the low position. At the low position, concentrations of 1200 ppm CO were likely reached at 16 minutes and 22 seconds, and concentrations of 2000 ppm CO were likely reached at 18 minutes and 22 seconds. This is consistent with the timeline described by witnesses.
2. If the regulator was set higher than the lowest setting, CO concentrations described as being fatal could have been reached sooner, within approximately 5 minutes and 24 seconds.