Incident Summary #II-1507023-2023 (#31672) (FINAL)

SUPPORTING INFORMATION	Incident Date		February 8, 2023
	Location		Abbotsford
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	2
		Injury description	Two occupants of a home were exposed to dangerous levels of carbon monoxide. One of the occupants was incapacitated and lost consciousness and both were taken by ambulance to the hospital for treatment.
		Injury rating	Major
	Impact – Damage	Damage description	N/A
		Damage rating	None
	Incident rating		Major
	Incident overview		A natural gas furnace in a residential home, produced high concentrations of toxic carbon monoxide. The carbon monoxide migrated into the home and rapidly reached dangerous levels in the living space. Two occupants of the home were exposed to the carbon monoxide resulting in exposure symptoms and loss of consciousness of one of the occupants.
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. A natural draft furnace uses air from its surrounding area for combustion of the gas. The combustion occurs at the entrance to a metal heat exchanger. The hot flue gasses produced by the combustion rise through natural convection up through the inside of the heat exchanger, and a vertical venting system connected to the furnace, which conveys the flue gases safely to the outdoors. The furnace heats the home by circulating heated air. A blower draws air from inside the home through return air ducting and supplies it into the furnace where it passes around the outside of the heat exchanger. Heat transfers through the heat exchanger to the heating air which is then distributed throughout the home through the heating ducting system. A natural draft gas appliance installed in a room relies on neutral air pressure for safe operation. Neutral air pressure is when the air pressure inside the room is equal to the pressure on the outside. If air from the inside of a room is removed faster than it can be replaced, then the air pressure in the room will be lower that the outside air and it will be at a negative pressure. When a negative pressure environment is created, air will be naturally drawn in through any openings including gas appliance vent piping. When this occurs, it can inhibit the flue gasses from being safely conveyed outdoors through natural convection and allow them to spill into the space. Natural gas requires a correct ratio of air to fuel to burn completely. When the ratio is incorrect, and there is either not enough air or too much fuel, the result can be 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. Exposure to carbon monoxide interferes with the body's ability to absorb oxygen, which can result in serious illness or death. CO concentrations above 1200 parts per million (ppm) are considered immediately dangerous to life or health (IDLH) by the Centers for Disease Control and Prevention (For more information on carbon monoxide see "CO Safety Tips").

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	To ensure proper combustion, the volume of gas supplied to the burners is controlled by the size of the orifice the gas passes through to enter the burner, and the pressure of the gas at the orifice opening. Manufacturers identify on the appliance data tag what orifice size and manifold gas pressure is required to achieve proper combustion at the burners. Manifold gas pressure is typically identified in units of inches per water column (27.69 inches water column (WC) = 1 pound per square inch (PSI)). The B149.1 Natural gas and propane installation code adopted in BC has a code clause for furnace return air ducting that states: "*Furnace return-air ducting installed in an enclosure in which spillage-susceptible appliances are located (including the furnace), shall be sealed to the furnace casing and joints in the ducting shall be sealed to prevent infiltration of air from the enclosure into the ducting."* The rational for this clause stated in the CSA gas code handbook is that: "*If the joints are not sealed and the appliance should spill the products of combustion, it will create a hazardous situation for the other appliances and the occupants*". The furnace manufacturer suggests on their public website that furnaces should have an annual maintenance check and that the average lifespan of a furnace is around 15 – 20 years.
Failure scenario(s)	The residential home had a natural gas forced air furnace for heating that had been manufactured 54 years prior to the incident in 1969 (**Photo 2**). The occupants had been living in the home for approximately 17 years. During that time the only upgrade to the system had been the installation of a modern programable thermostat. No other service, maintenance, or repair work, other than air filter changes, had been done since the occupants had lived there. The furnace was installed in a small mechanical room in the basement of the home that also contained a natural gas hot water tank. Both appliances were natural draft appliances that conveyed the flue gasses up a common vent through natural convection to the outdoors through the roof of the home. The mechanical room was accessed through a small storage closet in the basement. Both the storage closet and the mechanical room have solid doors that remained closed during typical operation with only small gaps on the bottoms of the doors that allowed air to flow through. The manifold gas pressure for the furnace was set higher than the maximum allowable gas pressure specified by the manufacturer **(Photo 4** and **Photo 5)**. This allowed too much gas into the burners and resulted in a rich air-fuel ratio, incomplete combustion, and the production of high levels of carbon monoxide in the flue gas. This had likely been occurring for years as the furnace had not been serviced or repaired while the occupants had been living there. Although high levels of carbon monoxide were being produced, they likely would have been mostly conveyed safety outdoors by the venting system. The air filter on one of the return air ducts to the furnace was not the correct size for the duct and stuck out from an unsealed opening leaving large gaps that allowed the main blower to draw air in from the mechanical room (**Photo 6**). A day and a half before the incident, one of the occupants used a switch on the outside of the furnace (**Photo 3**) to change the main blower operation from intermittent to continuous to circulate air through the home as portions of the basement felt "stuffy". When set to intermittent, the blower fan only operates when the furnace is operating to heat the home. When the blower is set to continuous operation, the blower operates uninterrupted until the switch is set back to intermittent. The continuous operation of the blower fan drew air in, through the openings in the return air duct, from the small mechanical room at a constant state, not allowing the air pressure in the room to

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	equalized in between furnace cycles as it would with intermittent operation. The air was removed more rapidly than it could be replaced naturally causing a negative pressure environment. The morning of the incident, the programable thermostat went from an automated setting of 17ºC to 22ºC at approximately 6am. This started the operation of the furnace which ran for long heating cycles while heating the house up 5ºC to satisfy the thermostat. The negative pressure in the mechanical room allowed flue gases from the furnace to spill out from the combustion chamber and the open draft hood instead of being vented safety outdoors through the vent to the roof. The flue gases containing high levels of carbon monoxide spilled into the mechanical room and were drawn into the return air duct openings, around the incorrect sized air filter, and were distributed throughout the home through the heating air ducting. As the carbon monoxide levels in the combustion air supplied from the mechanical room to the burners increased, the concentrations of carbon monoxide from the burners compounded. The carbon monoxide levels in the ambient air of the home rapidly increased to 1395 parts per million (ppm) over the two hours the furnace was in operation. (*CO concentrations above 1200ppm are considered immediately dangerous to life or health (IDLH) by the Centers for Disease Control and Prevention*). The home did not have carbon monoxide detectors installed that would alarm and warn the occupants of the arising danger. While the CO concentrations were increasing in the home, one of the occupants was exercising on a treadmill in the basement. After they finished exercising, they suddenly experienced flue like symptoms, nausea and fell unconscious in the ensuite of the bedroom. The second occupant of the home found the first occupant, called emergency services, and began feeling similar symptoms as well. Emergency first responders arrived within 6 minutes and upon entering the home were alerted by their personal protective monitors of the presence of carbon monoxide and the occupants were removed to the outdoors and the gas was shut off to the home.
Facts and evidence	<u>Home occupant statements</u>: • They had lived in the home for 17 years and the furnace had run well without any issues, and they had not had the furnace serviced, maintained, or repaired during that time. • They did not have CO detectors in the home and never really considered if they had them or needed them. • The furnace is operated by a programable thermostat that was set to automatically turn down to 17ºC at night and up to 22ºC at around 6am. • A day and a half before the incident they turned on the furnace blower to continuous operation using the switch on the side of the furnace cabinet to help circulate air in the basement that sometimes felt stuffy and to help circulate warm air into the areas of the basement that remained cold. • Doctors at the hospital told them that blood testing showed that they both had 21% of their red blood cells that were not carrying oxygen due to the carbon monoxide exposure. • They did not recall experiencing any similar CO poisoning symptoms in the home when the furnace was operating prior to the incident. <u>Testing:</u> • The furnace was tested and carbon monoxide readings in the flue gas venting were measured exceeding 1400ppm within 10 seconds of operation. • The manifold gas pressure was tested with a digital manometer and measured 5.53” WC, which is 57% higher than the manufacturers specified setting of 3.5” WC. • The gas hot water tank was tested by a gas utility technician and found to be operating properly.

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	Site observations: • There were two other additional air filters observed in the mechanical room that were the same size as the incorrect one installed in the furnace. • The furnace was partially disassembled and examined. The orifice size appeared correct, and the heat exchanger did not show any evidence of blockages, corrosion, cracks, or holes that would allow flue gas to pass into the heating air during typical operation. • Somebody has previously written in marker “Do not operate furnace with this panel off” on the blower cabinet front panel. This may have been done to avoid recirculating of flue gasses into the home. • All other potential sources of CO were identified and ruled out as a cause of the CO in the home. • The venting system was examined and found to be free of blockages and no evidence of openings were found that would have spilled flue gas into the home. Documents: • The fire rescue service’s communications and report confirmed that CO readings were taken by crews walking through the home in full SCBA gear with their gas monitors and high readings were measured in every room of the home with the maximum reading being 1395 ppm of CO in the ambient air. • Fire rescue services arrived on the scene within 6 minutes after being dispatched.
Causes and contributing factors	The incident was caused by the openings in the return air ducting which allowed the spilling and recirculation of the furnace flue gasses, containing high levels of carbon monoxide, throughout the home. Contributing factors to the incident include: • Incorrect gas manifold pressure setting created high levels of carbon monoxide in the flue gas. • Incorrect sized air filter did not allow for the sealing of the return air duct from the mechanical room. • The small mechanical room with solid doors and limited fresh air supply contributed to the creation of a negative pressure in the room and the spilling and recirculation of the carbon monoxide. • There were not any carbon monoxide detectors installed to alert the occupants of the presence of CO in the home.

Photo 1 – The gas furnace in the mechanical room with the front cover removed.

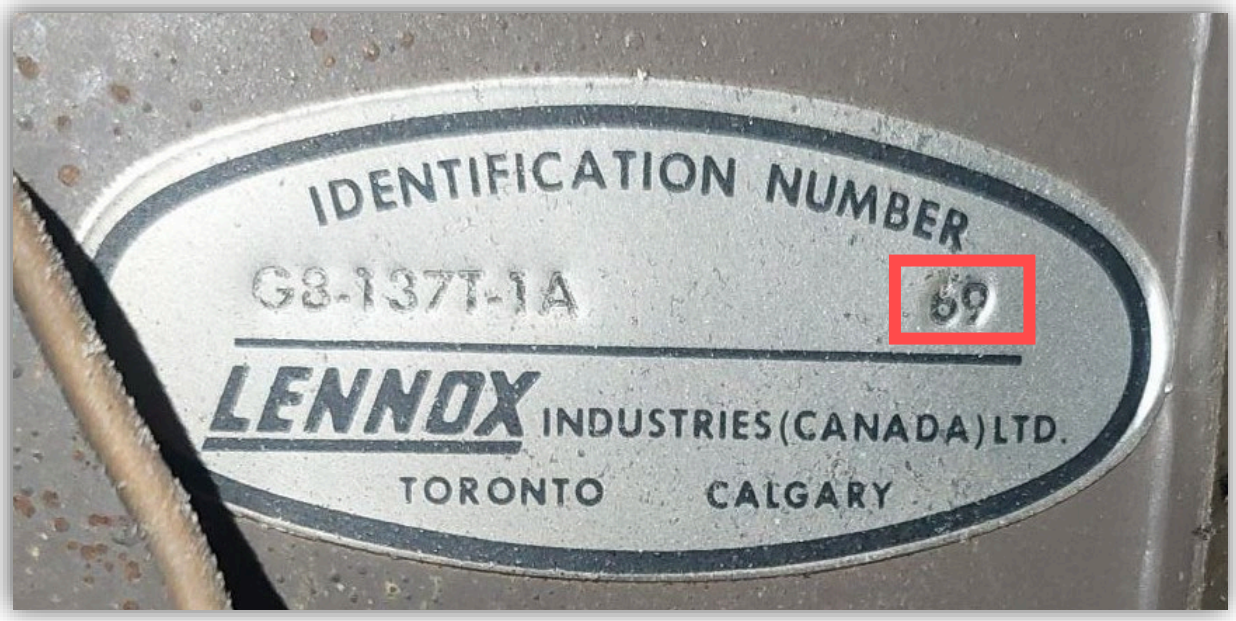

Photo 2 – Furnace identification tag showing it was produced in 1969.

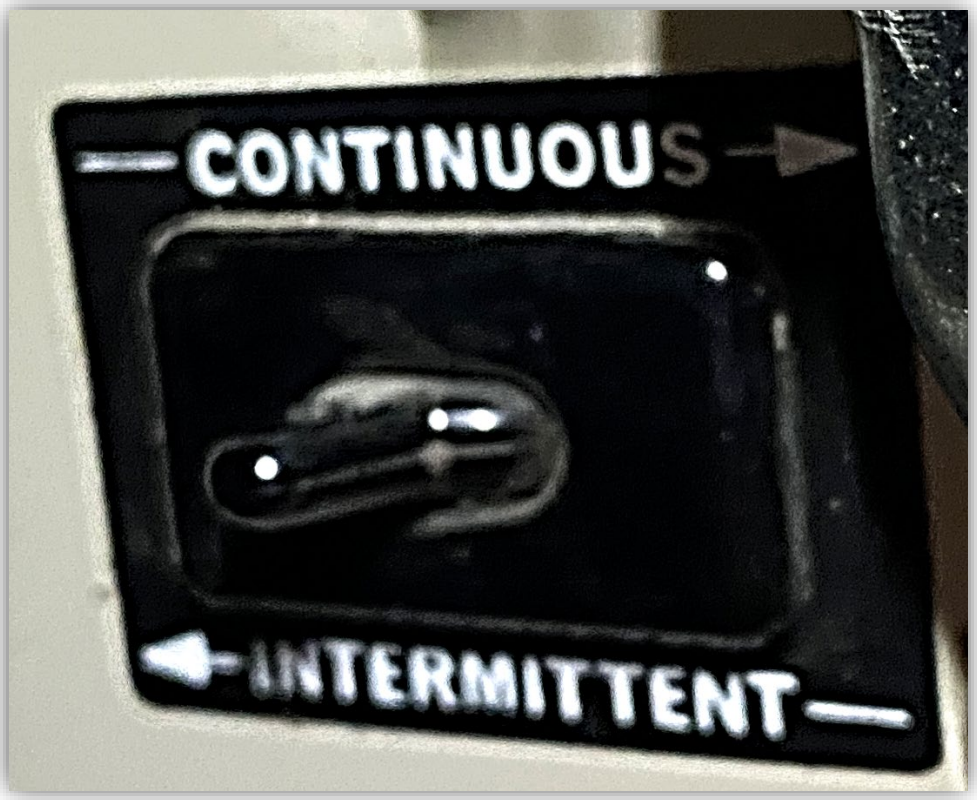

Photo 3 – Fan switch that selects intermittent or continuous blower fan operation.

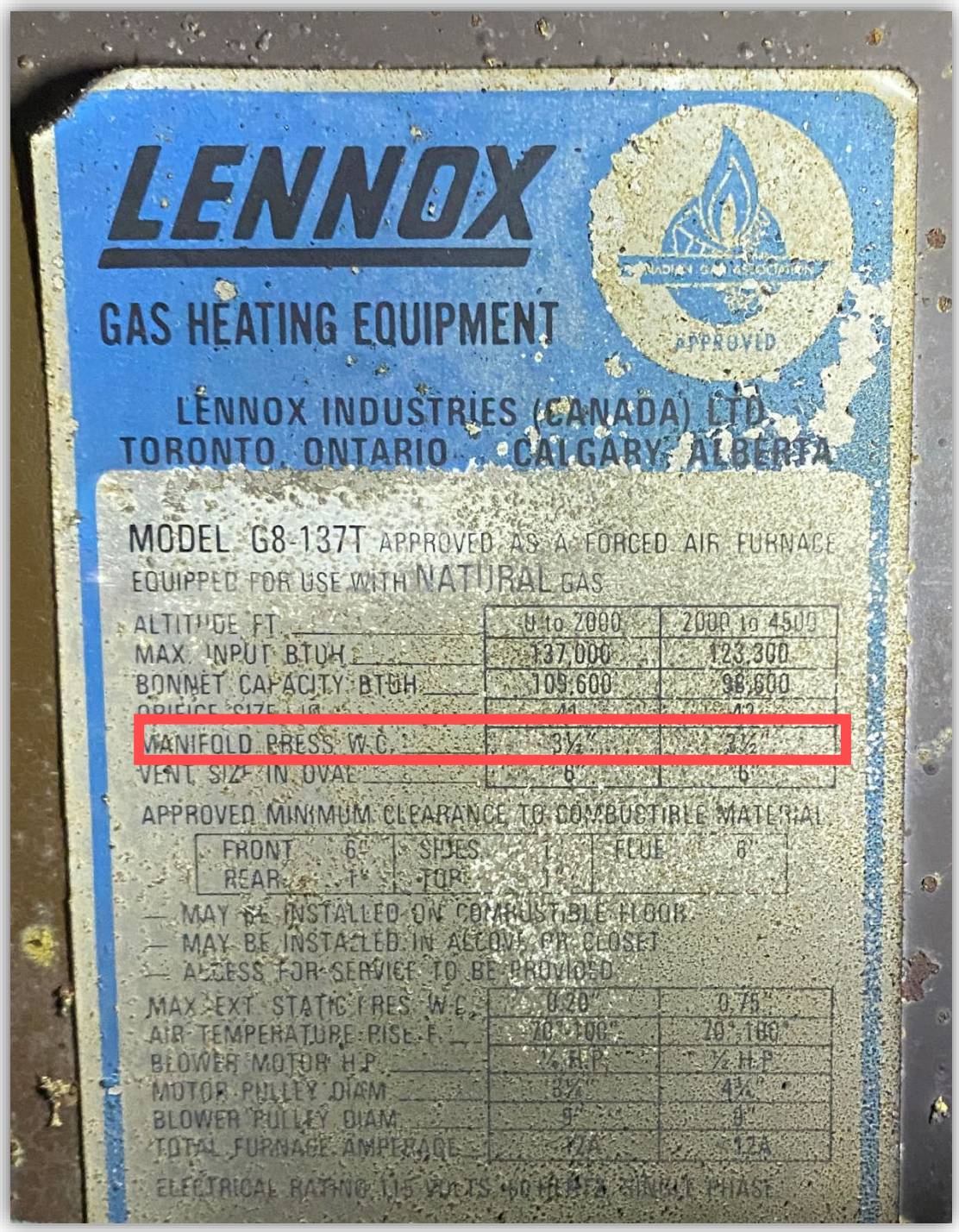

Photo 4 – Furnace data tag. Manifold gas pressure requirement of 3.5” WC.

Photo 5 – Manifold gas pressure measured at 5.53” WC

Photo 6 – Incorrect furnace filter installed. (RED) Opening gaps allowing air to be drawn into the blower from the mechanical room.