Incident Summary #II-1304266-2021 (#25455) (FINAL)

SUPPORTING INFORMATION	Incident Date		December 16, 2021
	Location		Surrey
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	0
		Injury description	N/A
		Injury rating	None
	Impact – Damage	Damage description	A residential furnace heat exchanger failed and produced high levels of carbon monoxide (CO). Redundant safety features (flame rollout switch, air proving switch) failed to control the hazard. This resulted in carbon monoxide exposure inside the home.
		Damage rating	Moderate
	Incident rating		Moderate
	Incident overview		A natural gas furnace in a residential home-produced elevated levels of carbon monoxide. Hazardous concentrations of CO migrated to inside the home.
rINVESTIGATION 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 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 via a ducting system, (Diagram 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 condensate drains and drain traps must be designed maintained to ensure they effectively drain the condensate from the heat exchangers. If condensate is unable to drain, it could accelerate the corrosion and failure of the secondary heat exchanger.

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	The design of the 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. 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 open 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. A blockage of the flue passages or venting system can cause the burner flames to roll out the front of the 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 (Chart 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 known 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. The Natural Gas code and the furnace manufacturer's published instructions require the termination of the furnace to vent horizontally out the side of a building and maintain 12" of clearance to building openings such as opening doors, windows and non-mechanical air-supply inlets when the appliance input is rated from 10,000 btu/h to up to and including 100,000 btu/h. The furnace vent materials manufacturer states in their installation manual that horizontal wall penetrations should be straight out, and the exhaust should not be directed into window wells.
Failure scenario(s)	A natural gas furnace was operating in a residential home. The furnace's secondary heat exchanger had corroded, creating holes in the heat exchanger and restricting the airflow of the combustion products through the furnace. 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 by recirculation of flue gas from the outdoors through air intake grills and building openings.

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Facts and evidence	A 100,000 btu/h Carrier model 58MCB100 (Photo 2) high efficiency natural gas furnace had been installed in a residential home. The original gas installation permit indicates the furnace was installed in the home in April 2010. The furnace had been operating in the home for just over 11 years prior to the incident. The owner stated that they had purchased the home 6 years ago and CO alarms in the house had been alarming multiple times before the furnace stopped working. They had not had any routine maintenance conducted on the furnace during their time in the home. The only time the furnace quit working was mid December 2021 due to an inducer motor failure. The flame rollout switch had never tripped. The furnace had been producing a strong smell around the furnace and at the vent outlet on the side of the house for some time. A gas technician stated that when he investigated the furnace, he found evidence of staining in the bottom of the furnace cabinet indicating leaking condensate and a strong smell of aldehydes around the furnace and in the flue gas. **Furnace testing and examination** The furnace was tested under controlled conditions and CO was measured in the flue gas and in the home. No incorrect installation characteristics were found. The components of the safety circuit were intact and operational including the pressure switches and flame rollout switch however the flame rollout switch failed to stop the operation of the furnace. CO was measured in the flue gas at the termination at the side of the home. Within 5 seconds of the burners firing CO levels at this location were measured in excess of 1400ppm. CO measurements of 90ppm was measured outdoors at the fresh air intakes for the home located 24 feet away horizontally from the furnace vent termination (Photo 9). 168ppm CO was measured outdoors at the ventilation air grill to the fireplace cavity (Photo 10-11) and 84ppm CO was measured from the area around the gas fireplace indoors with the gas fireplace off. CO measurements were taken from the heating air plenum directly above the furnace heat exchanger after ten minutes of furnace operation and the CO measurements were 4ppm. The same area of the gas fireplace was tested again with the fireplace operating and the furnace shut off and no CO was measured. The hot water tank was electric and no other gas appliances were operating in the home at the time of the testing, no other sources of carbon monoxide were identified other than the furnace. The furnace had sufficiently sized and unobstructed combustion air ducting provided to the mechanical room and the venting system was intact without any cracks, holes or other openings that may have allowed carbon monoxide to enter the home. The furnace was found to be installed level front to back on both sides. This would allow for proper drainage of the condensate from the secondary heat exchanger. Investigation of the furnace found the condensate trap was plugged and when the hose was removed 11 litres of condensate was drained from the secondary heat exchanger. The heat exchanger assembly showed the primary heat exchanger did not have any holes, cracks, or signs of corrosion. While removing the secondary heat exchanger, corrosion and holes were observed on the inlet side to the heat exchanger tubes. Photos show light shining through the holes in the heat exchanger (Photo 5-6).

	Evidence Examination The inlets to the furnace's secondary heat exchanger tubes had corroded and the interior polypropylene lining had delaminated which restricted the airflow through them. The restricted airflow reduced the amount of air at the point of combustion in the burner box. The unbalanced air/fuel ratio caused incomplete combustion that produced elevated levels of carbon monoxide in the flue products. During operation of the furnace, the burner characteristics were observed, and the restricted flue passages in the secondary heat exchanger were seen causing the flames to slightly roll out of the burner tubes inside of the burner box. The flame rollout switch was not triggered by the amount of flame rollout and allowed the furnace to continue to operate in an unsafe condition. The furnace venting terminated horizontally on the side of the home (Photo 9). The vent termination had a 90-degree elbow on it that pointed down towards a window well. The owner stated that the window had been closed all winter and was never open when the CO alarms in the home activated. The termination was 24" away from the ventilation air grill for the gas fireplace cavity and 32" away from the top of the window opening which met the minimum requirements of 12" dictated by the gas code and the manufacturer. The side of the home where the vent terminated was separated from the neighboring property by a 5' high solid wooden fence. The vent pointing down and the fenced area beside the home allowed the flue gas containing very high levels of CO to gather and accumulate instead of dissipating and allowed hazardous levels of CO to migrate back into the home through the building openings. Dilution of the flue gas as it mixed with the outside air was not enough to eliminate the hazard of exposure due to the excessive concentration of CO in the flue gas of the operating furnace.
Causes and contributing factors	The cause of the incident was the furnace secondary heat exchanger design and use of polypropylene laminated steel materials. Rapid and excessive corrosion of these materials restricted airflow through the furnace resulting in high production of CO due to incomplete combustion. The horizontal venting arrangement out the side of the home with a downward facing elbow in a fenced area contributed to the incident by allowing flue gas to be recirculated in the home. The high concentration of CO in the flue gas produced a hazardous condition inside the home, exposing the occupants to CO. Failure to have the furnace maintained contributed to the incident by allowing the condensate drain to plug up accelerating the failure of the secondary heat exchanger.

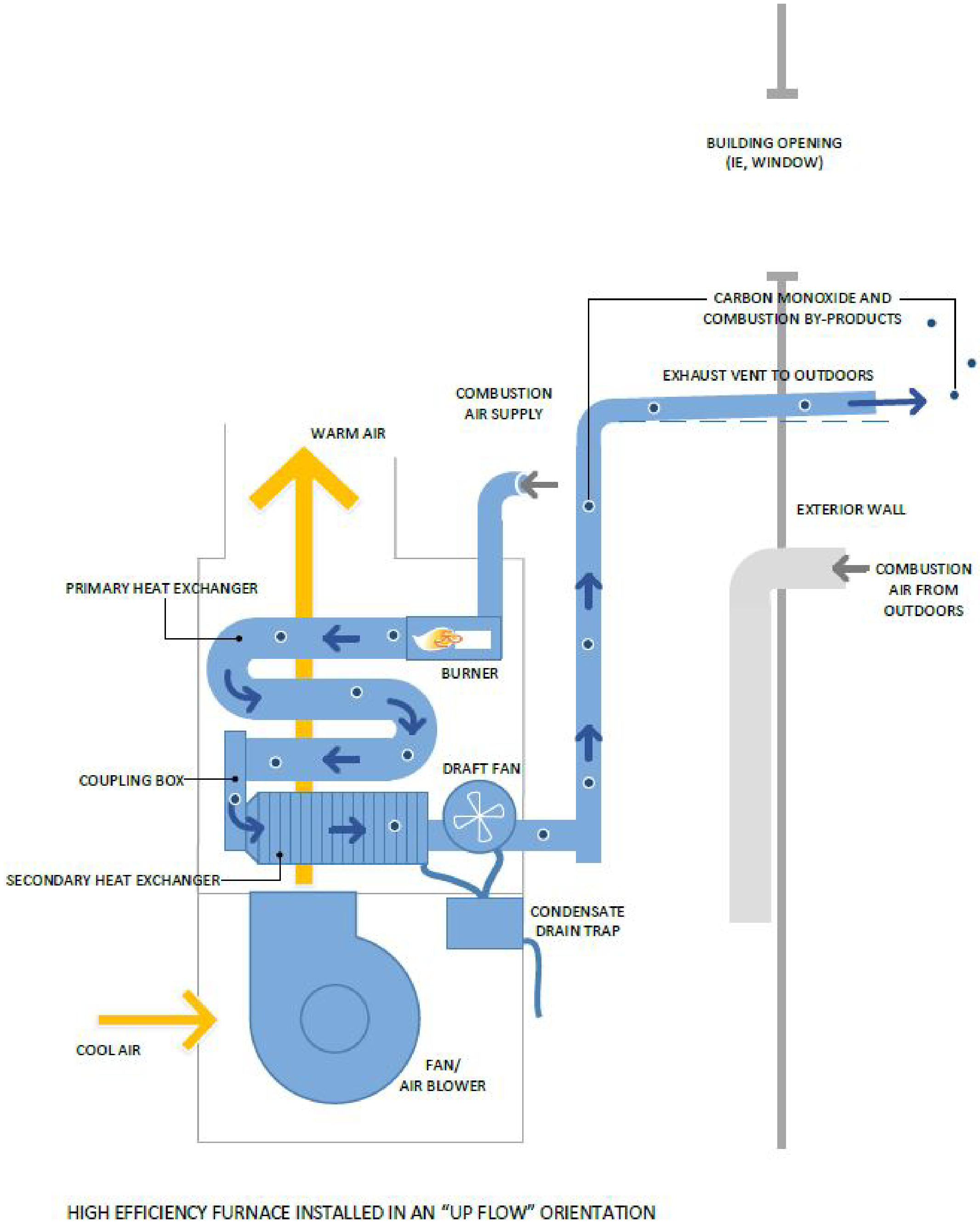

Diagram 1 – Showing typical furnace operation. Arrows show direction of flue gas flow and dots represent CO.

Photo 1 – Furnace installed in basement of home in the up-flow position

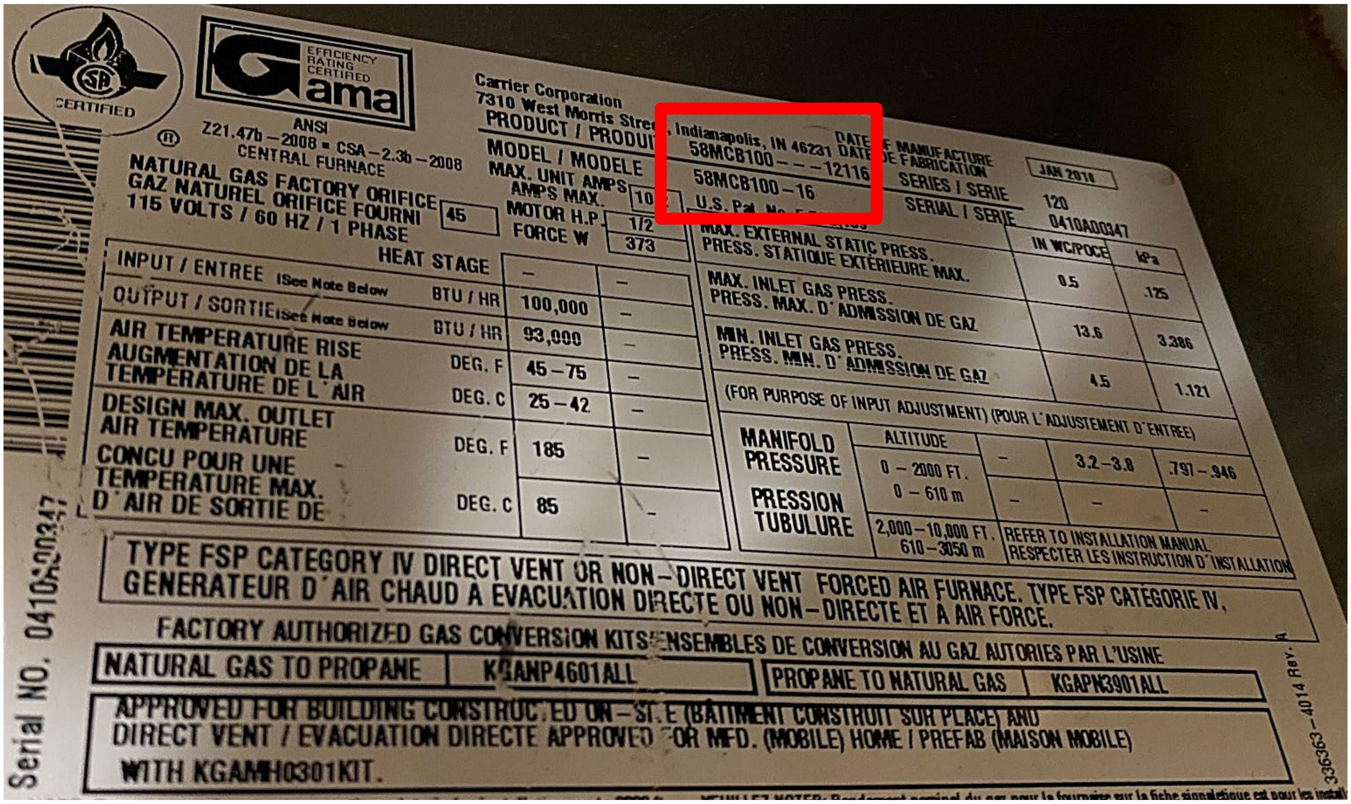

Photo 2 – Furnace data tag identifying it as a Carrier model #58MCB100.

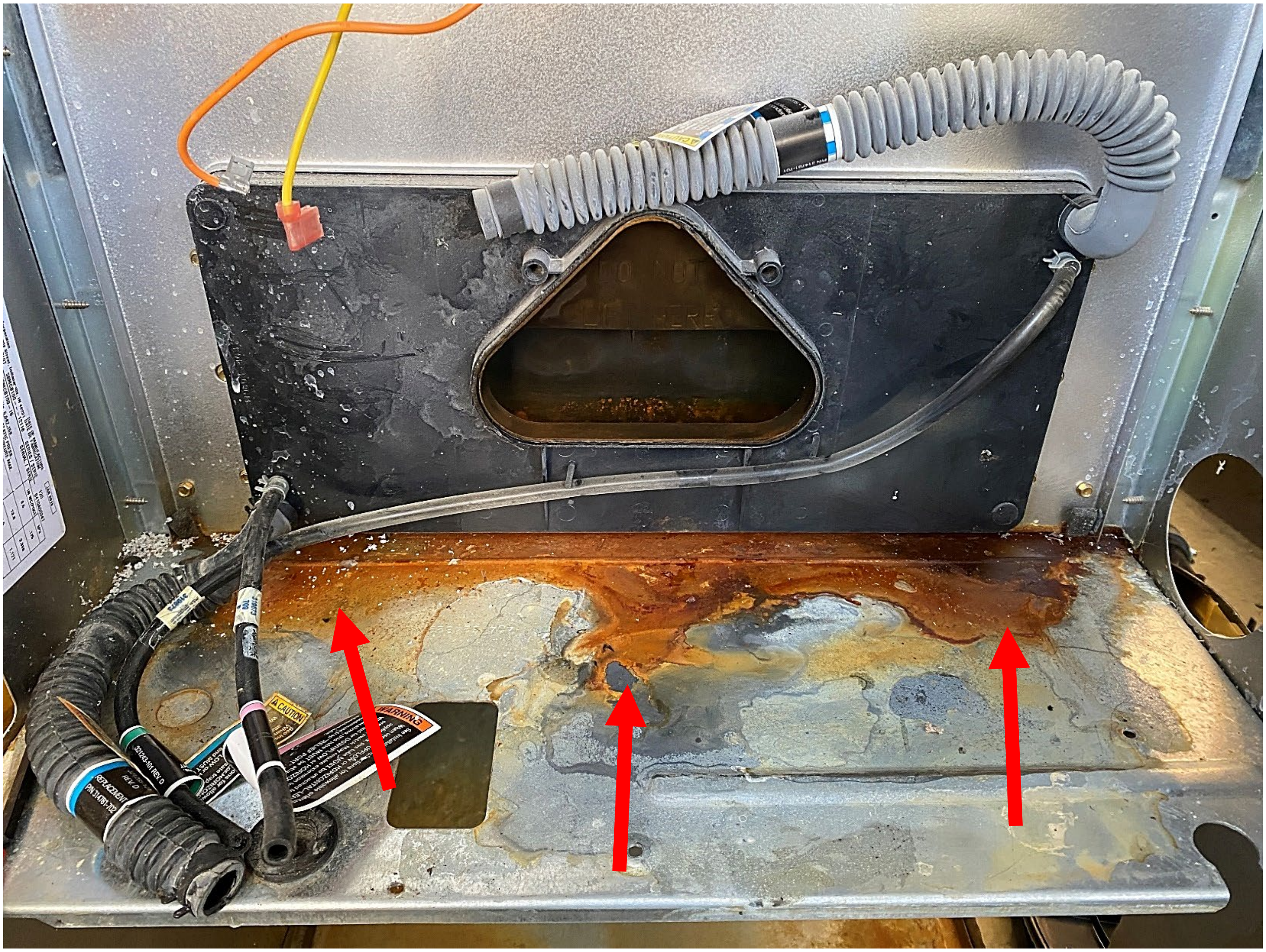

Photo 3 – Red arrows show areas of the furnace case stained and corroded from condensate leakage.

Photo 4 – Corrosion on the exterior of the secondary heat exchanger tube inlets.

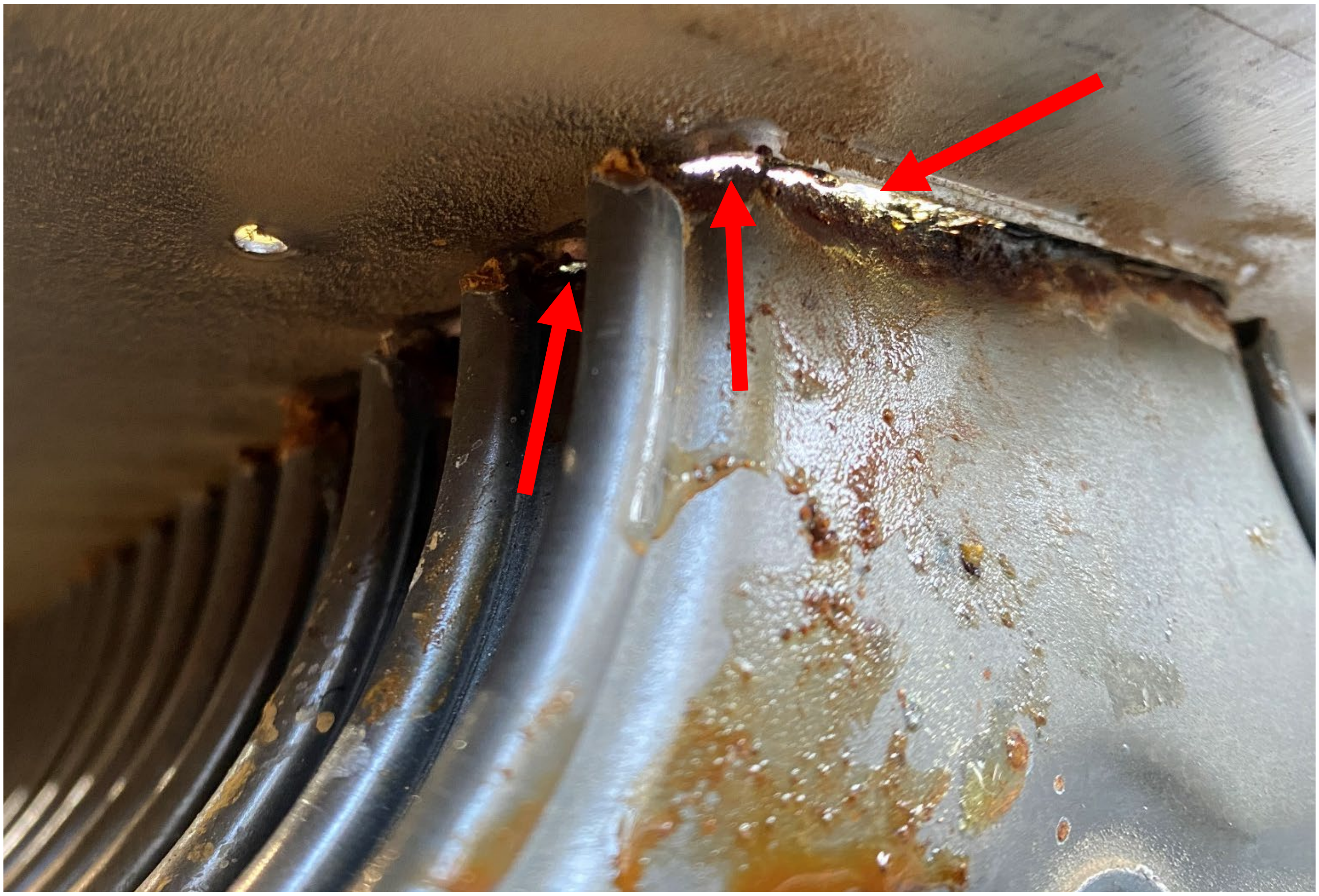

Photo 5 – Red arrows show light passing through holes from corrosion where the tube connects to the coupling box from the exterior.

Photo 6 – Red arrows show light passing through holes from corrosion where the tube connects to the coupling box from the interior.

Photo 7 – Close up photo shows corrosion and delaminated polypropylene liners at the heat exchanger inlet tubes.

Photo 8 – Profile showing the corrosion of the heat exchanger inlet tubes.

Photo 9 – **Red** shows furnace vent termination at side of house. **Blue** shows air intake grills to the house 24 feet away where flue gas containing 90ppm CO was measured migrating into the home.

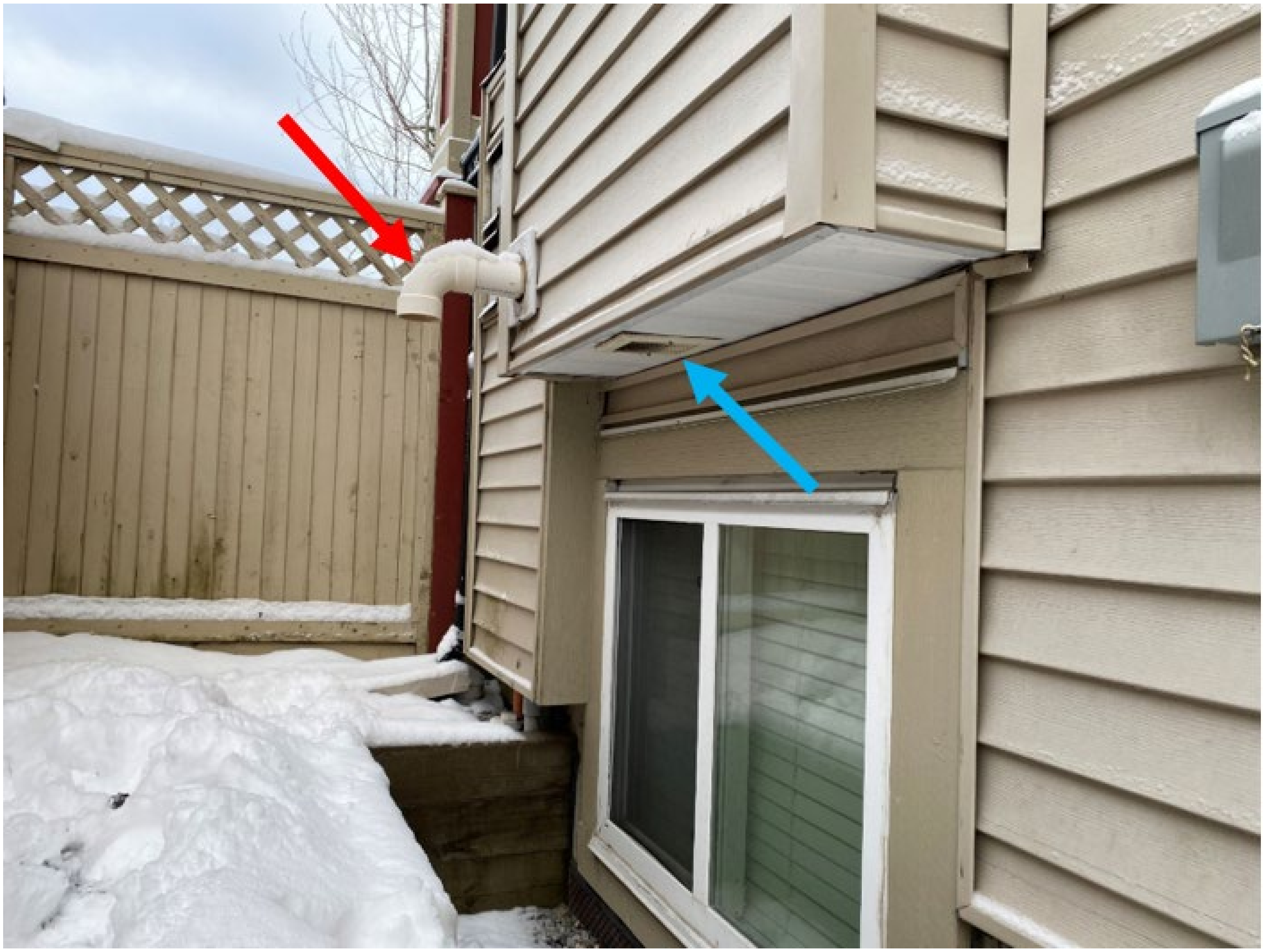

Photo 10 – **Red** shows furnace vent termination with a 90-degree elbow pointing down. **Blue** shows ventilation air opening for gas fireplace cavity.

Photo 11 - The ventilation opening for the gas fireplace cavity that flue gas containing 168ppm of CO was measured migrating into the home.

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 609°C (1128°F).
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"