Incident Summary #II-982535-2020 (#16663) (FINAL)

<table>
<tr><td rowspan="10">SUPPORTING INFORMATION</td><td colspan="3">Incident Date</td><td>February 18, 2020</td></tr>
<tr><td colspan="3">Location</td><td>Langley</td></tr>
<tr><td colspan="3">Regulated industry sector</td><td>Gas - Natural gas system</td></tr>
<tr><td rowspan="5">Impact</td><td rowspan="3">Injury</td><td>Qty injuries</td><td>0</td></tr>
<tr><td>Injury description</td><td>None</td></tr>
<tr><td>Injury rating</td><td>None</td></tr>
<tr><td rowspan="2">Damage</td><td>Damage description</td><td>A residential furnace heat exchanger failed, and produced of high levels of carbon monoxide (CO), while a redundant safety feature (flame rollout switch) controlled the hazard by shutting off the furnace.

High level of carbon monoxide produced at furnace vent termination at side of home.</td></tr>
<tr><td>Damage rating</td><td>Moderate</td></tr>
<tr><td colspan="3">Incident rating</td><td>Moderate</td></tr>
<tr><td colspan="3">Incident overview</td><td>A natural gas furnace in a residential home produced elevated levels of carbon monoxide. Carbon monoxide was released from the furnace vent termination at the side of the home and directed toward the neighbour’s house.</td></tr>
<tr><td>INVESTIGATION CONCLUSIONS</td><td colspan="3">Site, system and components</td><td>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, (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 accumulate 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.</td></tr>
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	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. 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 (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 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)	A natural gas furnace was operating in a residential home. The furnaces secondary heat exchanger had corroded. The corrosion created holes in the heat exchanger and restricted the airflow of the combustion products through it. The restricted airflow led to incomplete combustion and the production of high levels of carbon monoxide and aldehydes.
Facts and evidence	A Carrier model MCB080 (Image 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 November 2010. The furnace had been operating in the home for just under 10 years prior to the incident. The owner stated that prior to the furnace quitting, their daughter informed them that while on the rear patio with friends, they could small a very pungent smell coming from the side of the house when the furnace was running. When the furnace eventually quit working they hired a heating company to repair it. When the technician for the heating company investigated the furnace he told them that the furnace was producing high levels of carbon monoxide outside and it had been disconnected and was unsafe to use. There were multiple carbon monoxide

detectors in the home and none of them had alerted from detecting carbon monoxide in the home.

The technician stated that when he first investigated the un-operational furnace he found a tripped rollout switch on the burner box and he observed a strong smell of aldehydes from inside the furnace. He recognised the smell from several other similar style furnaces that he had replaced due to the same failures. The flame rollout switch was reset and the furnace was restarted. Carbon monoxide levels in excess of 1000 parts per million (ppm) were measured outside at the furnace's vent termination. The upper measurable limit of the measuring device was 1000 ppm so the actual concentration of carbon monoxide was undetermined. The maximum allowable exposure limit of carbon monoxide is 100 ppm (or 25 ppm 8-hour TWA) .

During a physical investigation it was observed that the furnace was installed at the correct level of slightly pitched forward as specified in the manufactures installation instructions. Burn marks observed on the outside of the burner box and the plastic sight window showed signs of melting and overheating (Image 4). The PVC venting system was intact but found to be dark and discoloured on the inside. When the furnace was started the burner flames were weak and yellow tipped but not rolling out severely. After a couple of minutes of burner operation carbon monoxide measurements were taken around the main floor of the house and the heating registers in the kitchen and front foyer. No carbon monoxide was detected at these locations of the house. Carbon monoxide was measured at the furnace vent termination at the side of the home and levels in excess of 1000 parts per million (ppm) were recorded. The upper measurable limit of the measuring device was 1000 ppm so the actual maximum concentration of carbon monoxide was undetermined. Physical examination of the burner flames failed to identify any evidence of high carbon monoxide production in the flue gas.

The furnace vent was terminated horizontally at the side of the house. The termination was installed correctly and met the minimum requirements of the B149.1-15 Natural gas installation code along with the requirements of the manufacturers installation instructions. The vent pipe is required to extend between 6-10" beyond the exterior wall a minimum of 12" above exterior grade, and must maintain a minimum clearance of 12 " to the passive combustion air supply to the building (Image 3). The fence added to one side of the vent and the proximity to the combustion air inlet would reduce natural air flow in that area. Under some environmental conditions it is plausible that the very high levels of carbon monoxide present in the flue gas would allow carbon monoxide to migrate into the home through the combustion air supply duct.

Evidence Examination

The furnace was shut off and removed for replacement. No incorrect installation characteristics were observed prior to the removal of the furnace that may have contributed to a premature failure. The furnace was examined by engineers at a laboratory to determine the cause of failure. 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 (Images 9-11). The unbalanced air/fuel ratio produced elevated levels of carbon monoxide in the flue products.

During operation of the furnace, the restricted flue passages caused the flames to roll out of the burner tubes inside of the burner box. The flame rollout caused an

		increased temperature at the flame rollout safety switch installed on the side of the burner box. The temperature eventually increased to the point the flame rollout safety switch opened the electrical circuit and shut the furnace off. Failure analysis of the heat exchanger was conducted by an independent laboratory, which concluded that the secondary heat exchanger failed due to corrosion caused by rapid degradation of the polypropylene lining.
	Causes and contributing factors	The cause of the incident was the furnace secondary heat exchanger design using polypropylene laminated mild steel materials. Rapid and excessive corrosion of these materials restricted airflow through the furnace resulting in production of carbon monoxide due to incomplete combustion.

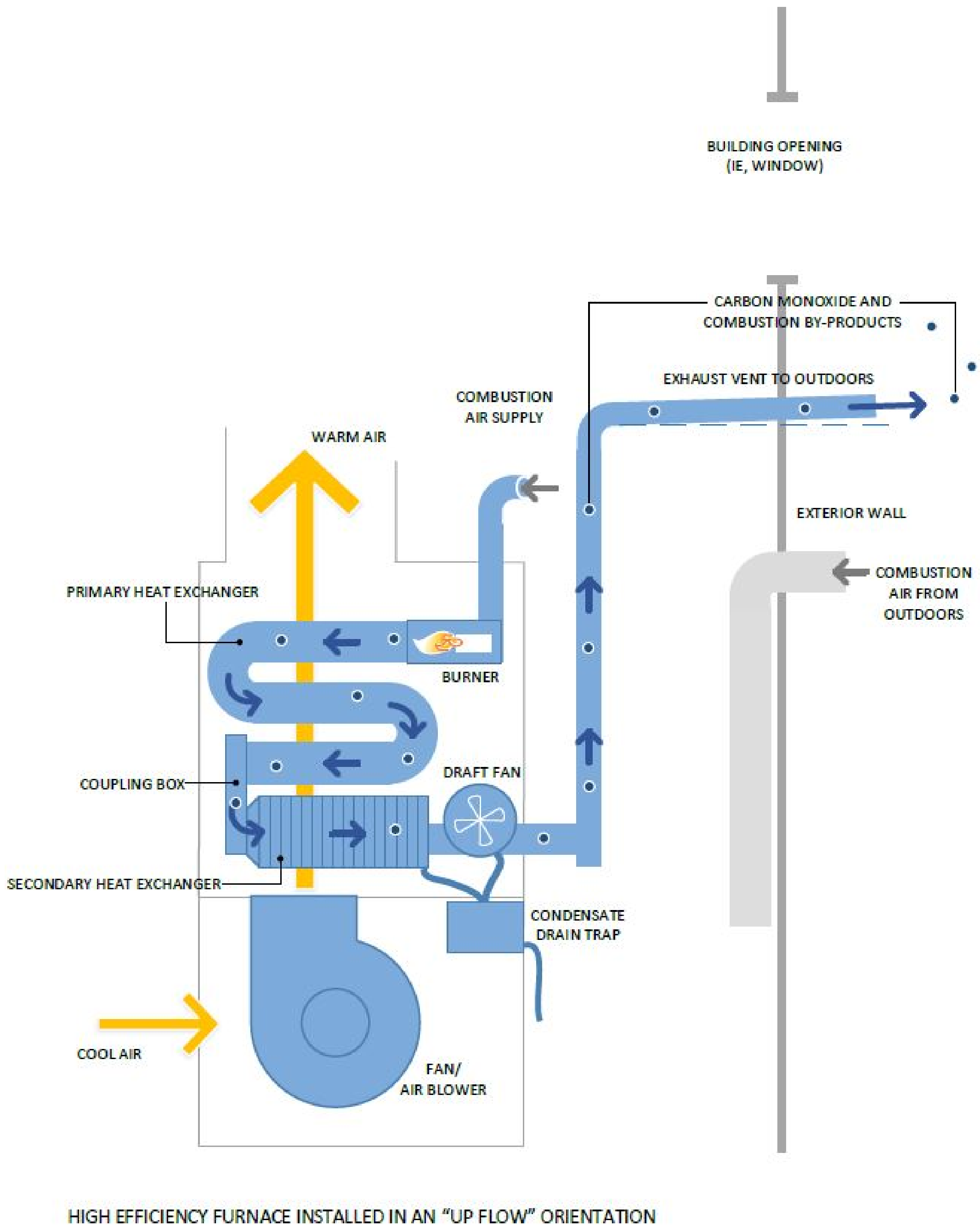

Diagram 1 – Showing typical furnace operation. Arrows show direction of flue gas flow and dark dots represent carbon monoxide.

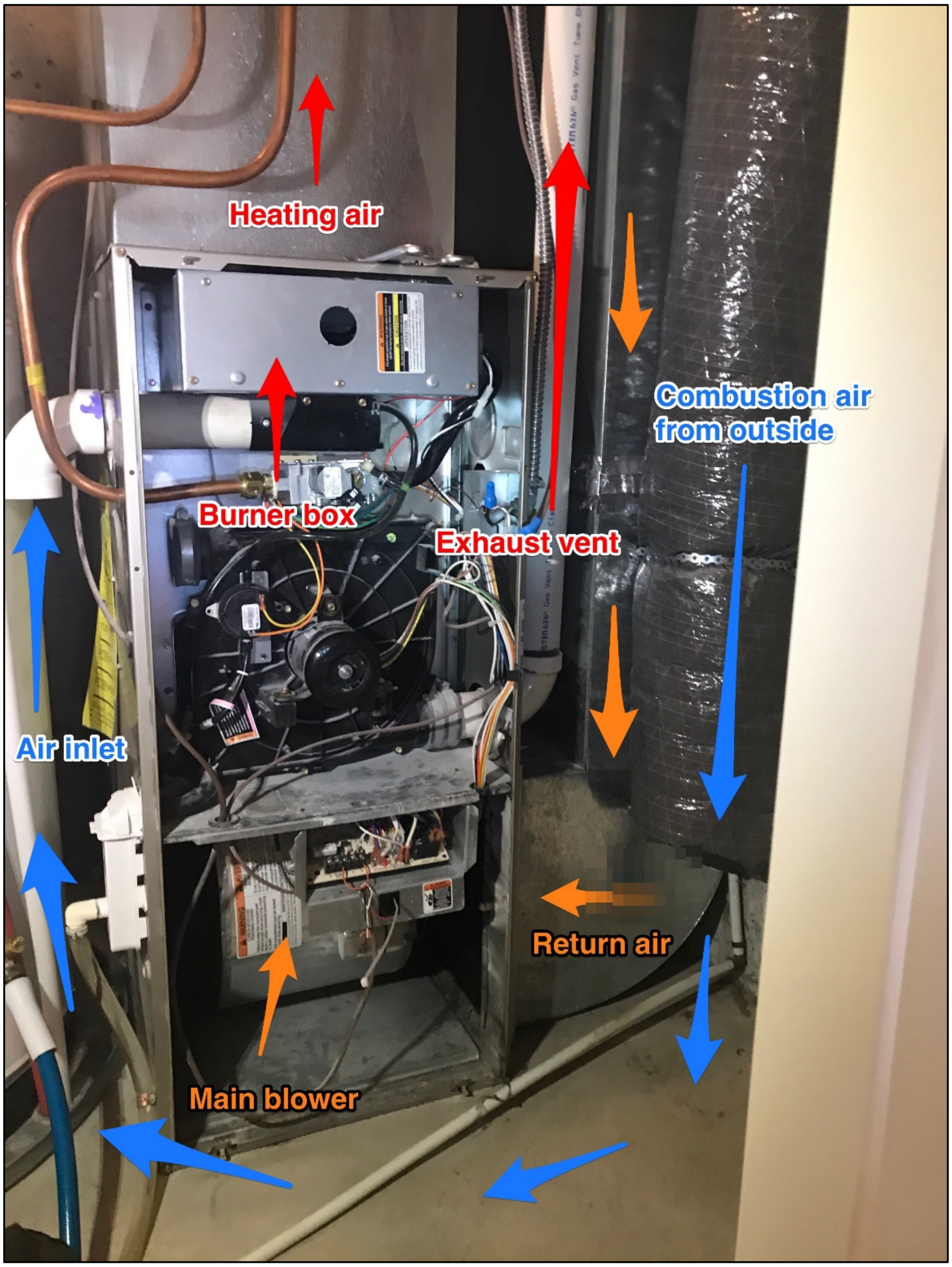

Image 1 – Furnace in house with cover panel removed. Combustion air for gas appliances is supplied via a duct from outdoors. The main blower draws cooler air from inside the home through a return air duct and passes the air over the secondary heat exchanger, then the primary heat exchanger heating the air before distributing it through the heating air ducting.

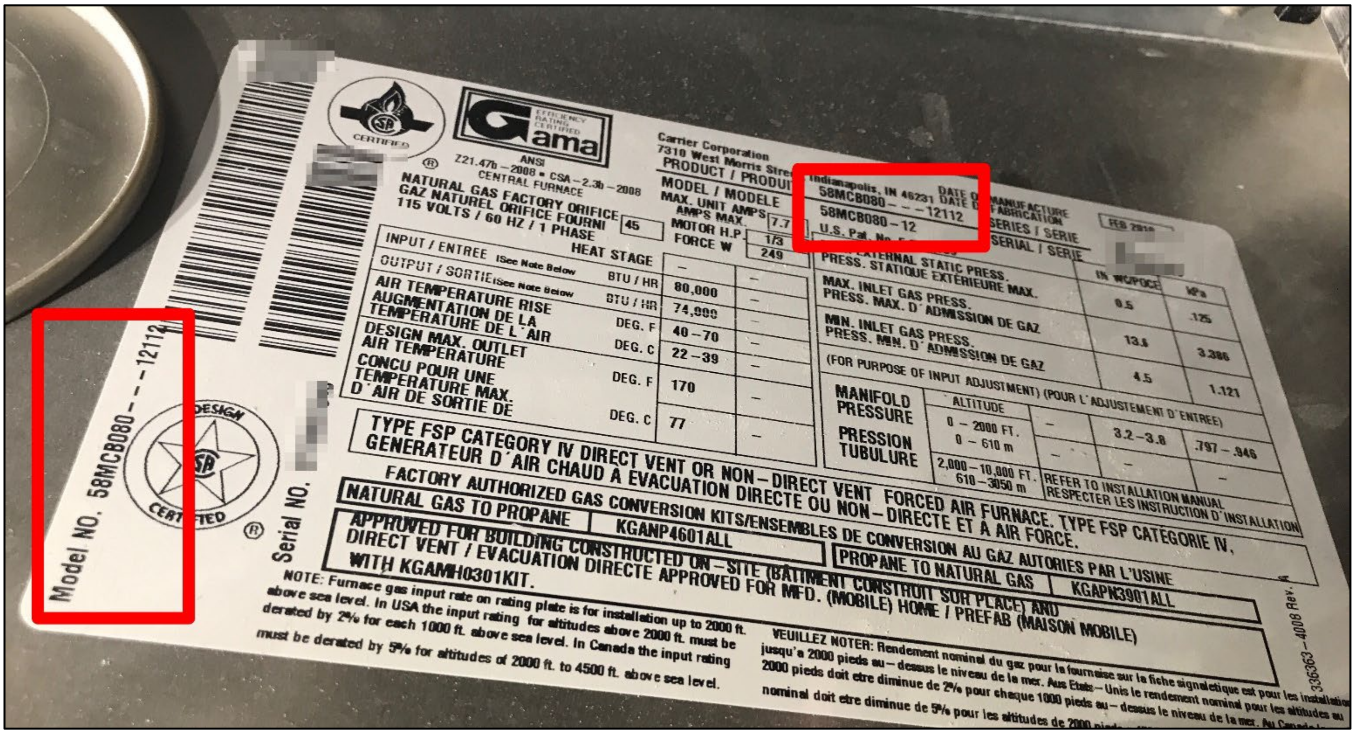

Image 2 – Furnace data tag identifying it as a Carrier model # 58MCB080.

Image 3 - Furnace vent termination extending 9” out from wall and 12” away from “non-mechanical” combustion air supply inlet (A non-mechanical inlet does not have a fan attached, whereas a mechanical combustion air inlet would incorporate a fan, which in turn would need to be a minimum of ten feet away from the furnace vent termination). The fence location restricts natural air flow that would have otherwise helped carry furnace exhaust gas away from home.

Image 4 - Plastic sight window removed from burner box showing signs of melting from insufficient air flow and flame rollout.

Image 5 - Flame rollout switch on burner box with manual reset button in the middle.

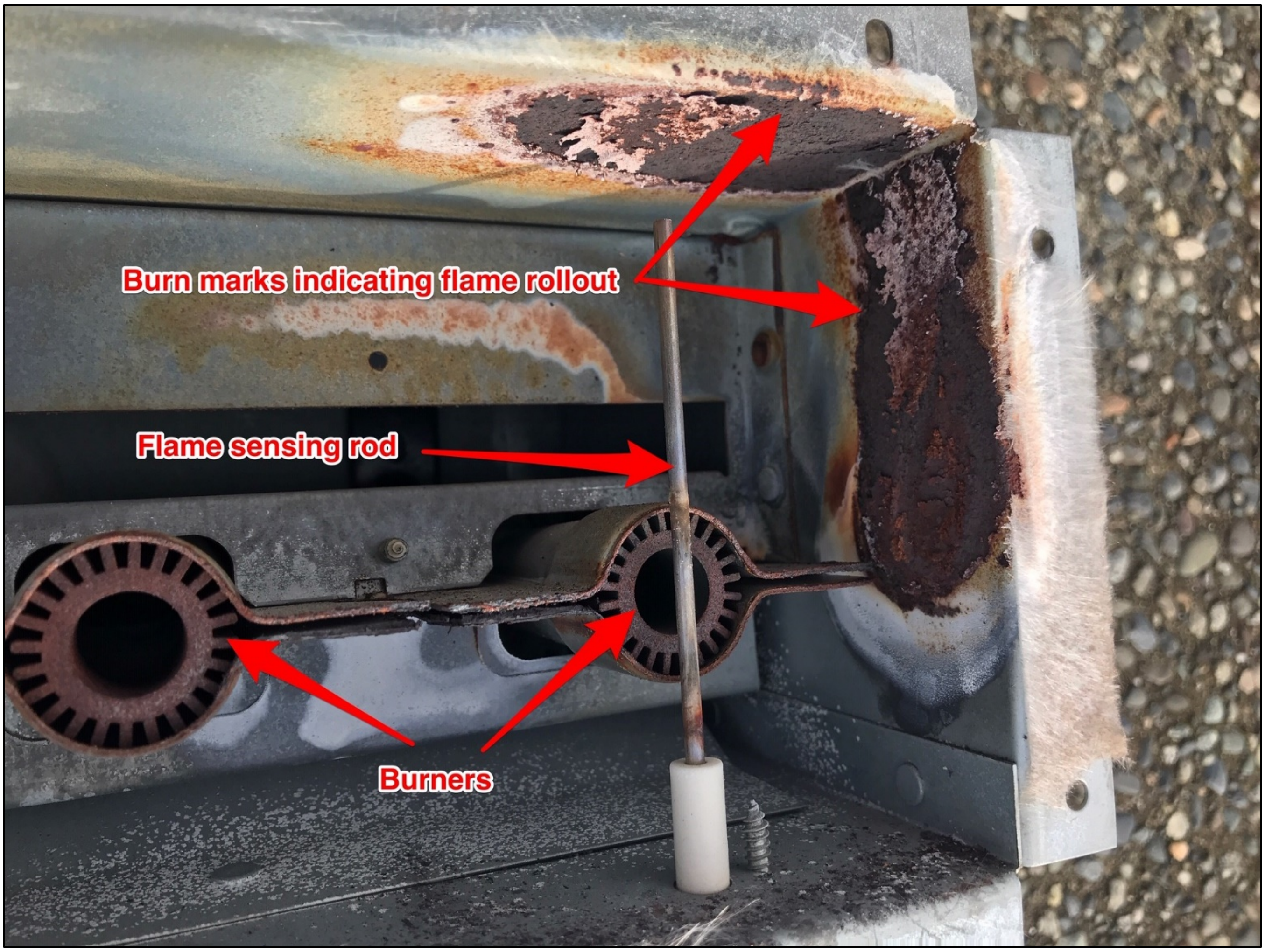

Image 6 - Burn marks from flame rollout on the opposite site of the burner box from the flame rollout switch. Flame sensing rod used to detect flame for the furnaces safety circuit.

Image 7 - The main blower blows air up through the secondary heat exchanger then through the primary heat exchanger above it.

Image 8 – Complete heat exchanger assembly removed from furnace for examination (coupling box cover and baffle removed in this image). The heat exchanger is sitting upside down from its up flow operational position. Combustion products from the gas burners travel through the S-shaped primary heat exchanger to the coupling box and then pass through the secondary heat exchanger tubes before being expelled to the outdoors by the draft inducer fan through the vent piping.

Image 9 – Close up of secondary heat exchanger tube inlets in coupling box showing severe corrosion**.**

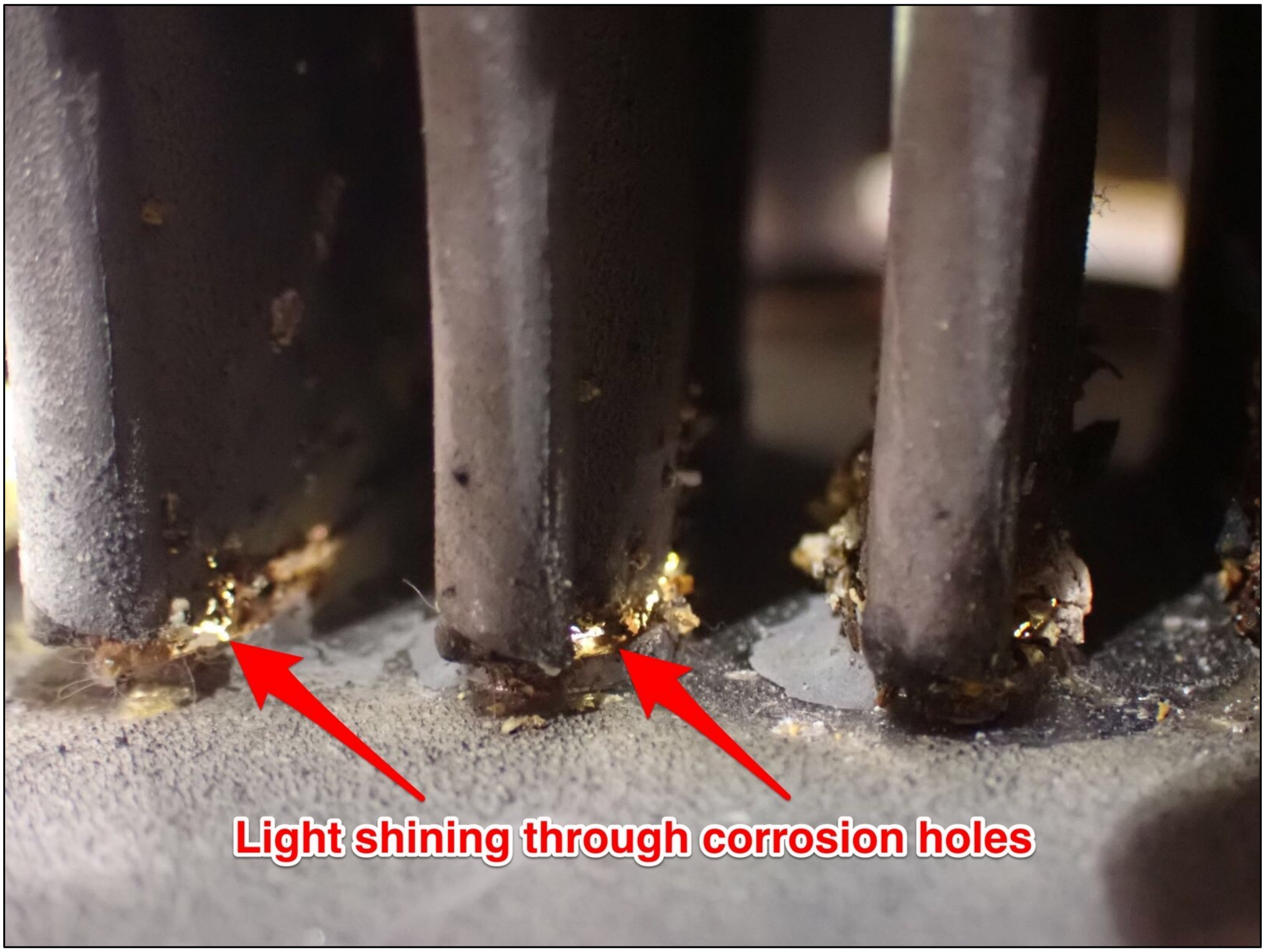

Image 10 – Image take with a flash light shining into the secondary heat exchanger tube inlets showing light passing through corrosion holes in the heat exchanger**.**

Image 11 – Secondary heat exchanger tube inlets with one tube completely removed for examination. Image shows corrosion, delamination of polypropylene liner and restricted passages.

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"