Incident Summary #II-999966-2020 (#16950) (FINAL)

SUPPORTING INFORMATION	Incident Date		February 21, 2020
	Location		Surrey
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	0
		Injury description	None
		Injury rating	None
	Impact – Damage	Damage description	A residential furnace heat exchanger failed, and produced of high levels of carbon monoxide (CO), as detected at furnace vent termination at side of home. PVC appliance air inlet pipe overheated, melted and charred.
		Damage rating	Moderate
	Incident rating		Moderate
	Incident overview		A natural gas furnace in a residential home produced elevated levels of carbon monoxide that was. was distributed from the furnace vent termination at the side of the home and directed toward the neighbour's house.
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 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 thought-out 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 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.

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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 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. 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")
Failure scenario(s)	A natural gas furnace was operating in a residential home. The furnaces secondary heat exchanger had corroded. The corrosion restricted the airflow of the combustion products through the furnace. The restricted airflow led to incomplete combustion, the production of high levels of carbon monoxide and caused the burner flames to rollout of the burners. The flame rollout overheated the metal burner box causing the PVC air inlet pipe to overheat, melt and char (Image 5).
Facts and evidence	A Carrier model MVB080 (Image 2) high efficiency natural gas furnace and heat pump had been installed in a residential home. The original gas installation invoice indicates the furnace was installed in the home in November 2005. The furnace had been operating in the home for just over 14 years prior to the incident. When the furnace was installed, the owners signed up for a club membership with the installing contractor. The club membership included free annual safety inspections and service maintenance. When the technicians completed the inspection and service maintenance they provided the owner a service report documenting their actions, measurements and findings. Investigation of the service reports provided by the owner show that between 2005 and 2015 the furnace had been serviced eight times by five different qualified technicians. Some of the maintenance and inspection items included in the services were: Measuring inlet and manifold gas pressures, air flow temperature rise and flame signal, checking and cleaning air filters, pressure ports, condensate drain lines and gas burners. This indicates that the furnace was installed, maintained and operating in accordance with the manufacturers specifications.

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During the furnace service on June 2015 the technician found that the furnace was tripping on a high limit switch and high levels of carbon monoxide were measured in the furnace flue gas. The furnace was shut off and the owners were informed not to use it until it could be repaired or replaced as it was unsafe. The secondary heat exchanger was found to be corroded and causing restrictions which led to incomplete combustion and the high levels of carbon monoxide being produced. The secondary heat exchanger was replaced under the manufacturers extended parts and labour warranty. The replacement secondary heat exchanger was of the same design and materials as the original failed component.

The owners continued the club membership with annual safety inspections and service maintenance until July 2017 when the last service report was completed. The owners contacted another heating company in October 2017 when the heating system quit working. The new heating company's invoice states "Tested furnace and went through furnace and it appears to be working 100%" only a repair needed to be done to the heat pump to get the system operating. The same heating company was called twice in 2018, first to replace a condensate pump for the furnace, then a second time to replace the heat pump outdoor compressor and indoor furnace coil with new air conditioning only components.

In February 2020, just under 5 years after the secondary heat exchanger was replaced under warranty, the owner contacted the new heating company to complete a safety inspection and service maintenance of their furnace. When the technician arrived the owner complained of a bad smell from the furnace exhaust. When the technician examined the furnace the PVC air inlet pipe was found to be melted and charred (Image 5) and a carbon monoxide concentration of 775 parts per million (ppm) was measured at the furnace exhaust which terminated horizontally at the side of the home (Image 11). The furnace was disconnected due to the unsafe condition and was subsequently replace with a new furnace.

Examination of the furnace after removal identified that the inlets to the replacement secondary heat exchanger tubes were corroded and the polypropylene liners were delaminating restricting the airflow (Image 9). Multiple holes were also found in the primary heat exchanger (Image 8) and hot spots or burn marks were found on the burner box identifying the presence of flame rollout (Image 6) which had caused the burn damage to the PVC air inlet pipe..

Evidence Examination

The furnace was examined by engineers to determine the cause of failure. It was determined that the restricted airflow due to corrosion damage had reduced the amount of air at the point of combustion in the burner box (Image 8). The unbalanced air/fuel ratio produced elevated levels of carbon monoxide in the flue products.

When the furnace was operating the restricted flue passages caused the flames to roll out of the burner tubes inside of the burner box. The flame rollout had burned the PVC air inlet pipe at the opposite side of the burner box from where the flame rollout safety switch was installed (Image 7). The flame rollout occurred in a location of the burner box that did not cause the safety switch to overheat and allowed the furnace to continue to operate in an unsafe condition.

Failure analysis conducted by the independent laboratory engineers, who concluded that the secondary heat exchanger failed due to corrosion caused by rapid degradation of the polypropylene lining. The failure had occurred within only 5 years of operation.

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Causes and contributing factors	The cause of the incident was due to furnaces secondary heat exchanger design and use of polypropylene laminated mild steel material that contributed to rapid and excessive corrosion which restricted airflow allowing for the production of carbon monoxide due to incomplete combustion. A contributing factor to incident was the failure of the flame rollout switch to stop the operation of the furnace.

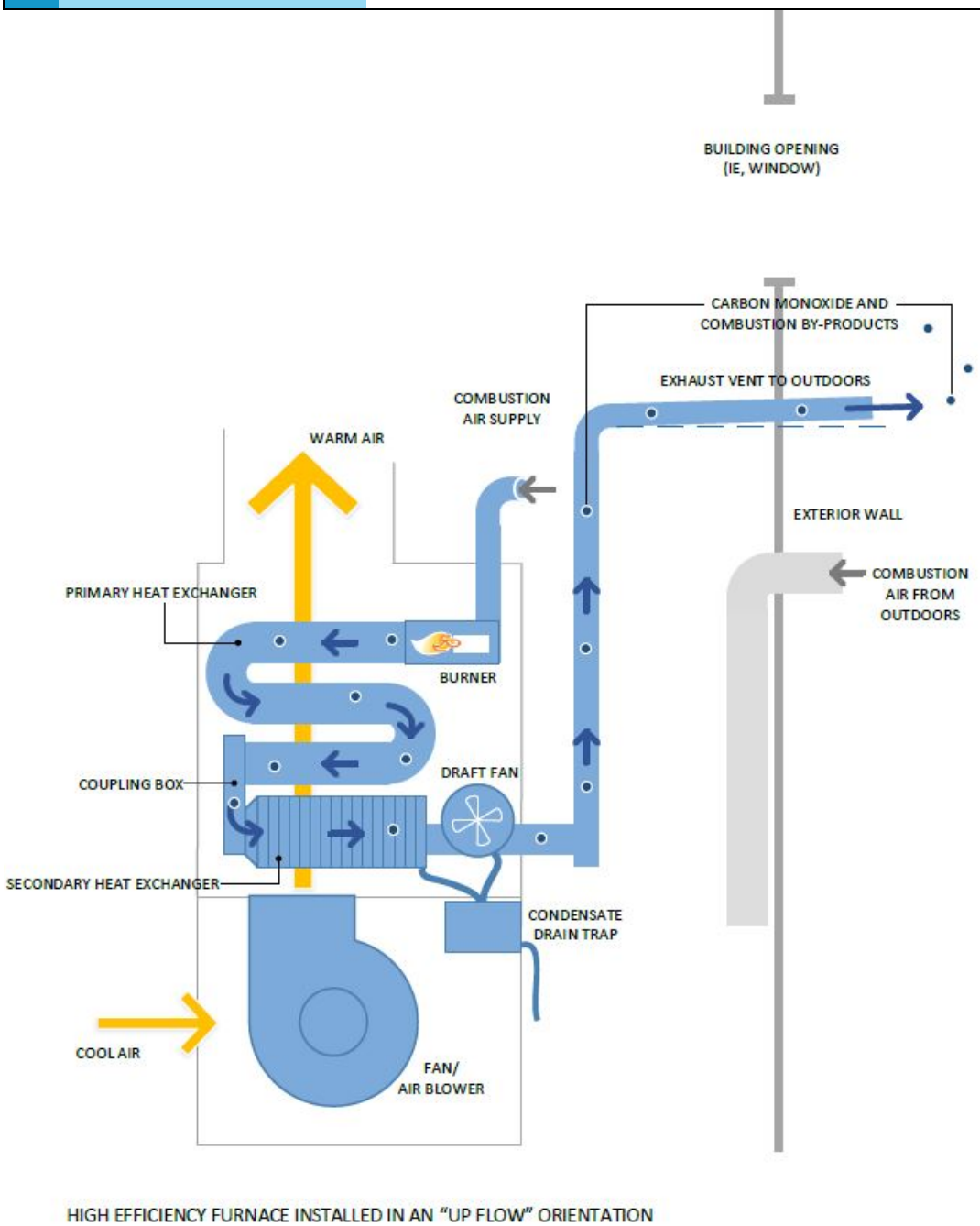

Diagram 1 – Showing typical furnace operation. Arrows show direction of flue gas flow. Dots represent CO.

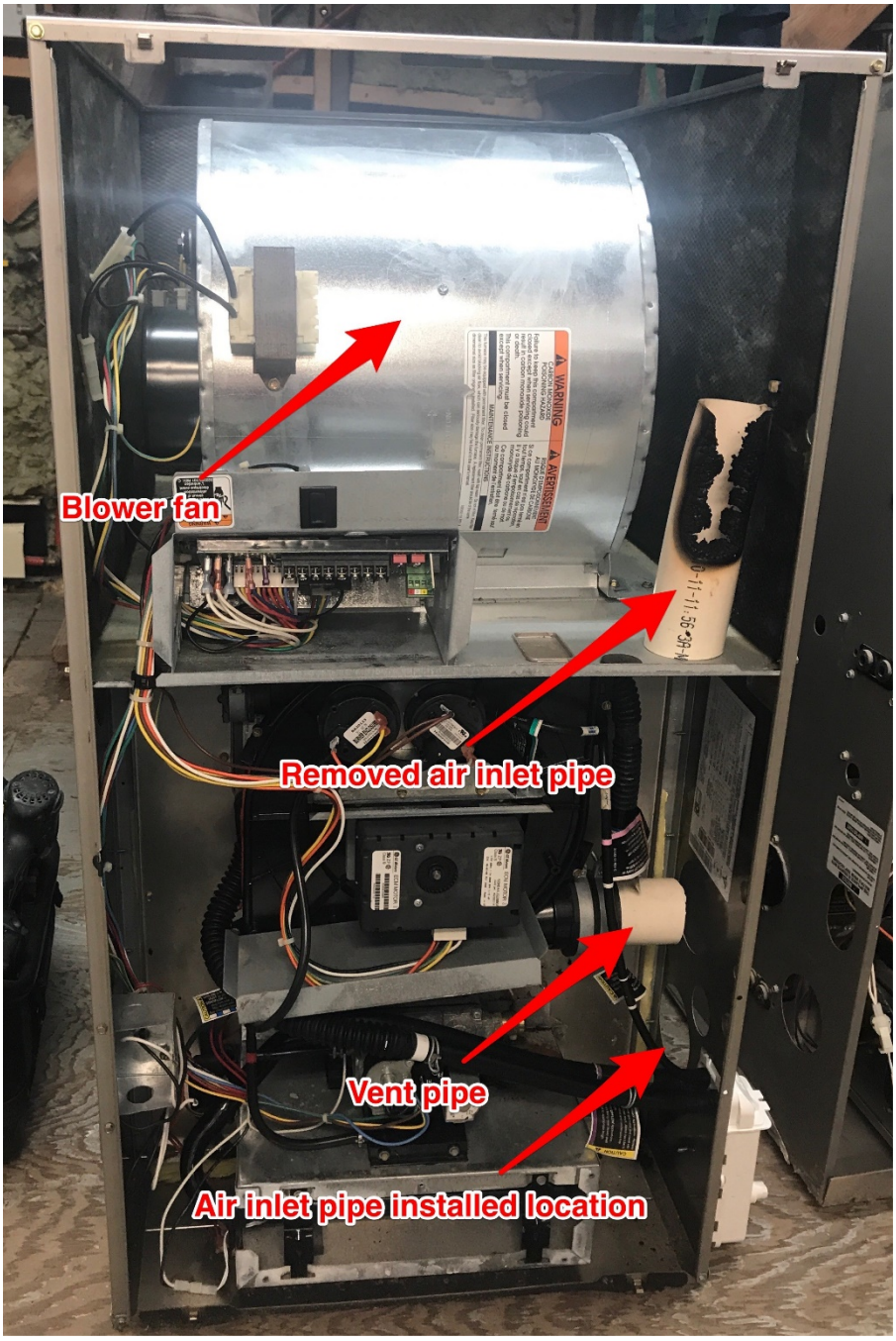

Image 1 – Furnace after removal. Burn damage visible on the air inlet pipe which had been removed from its installed location.

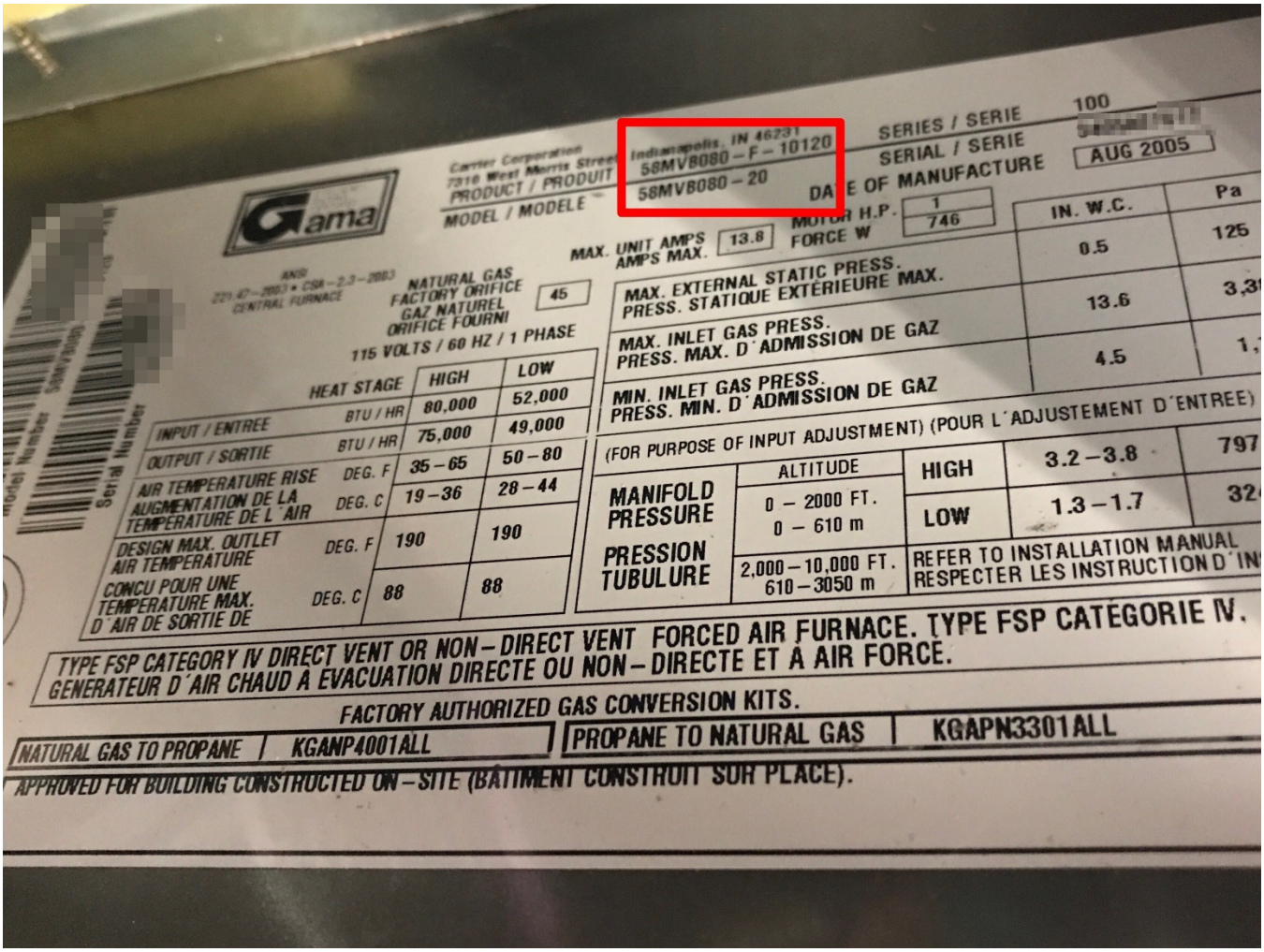

Image 2 – Furnace data tag identifying it as a Carrier model # 58MVB080.

Image 3 - Secondary heat exchanger tubes that were replaced after five years of use.

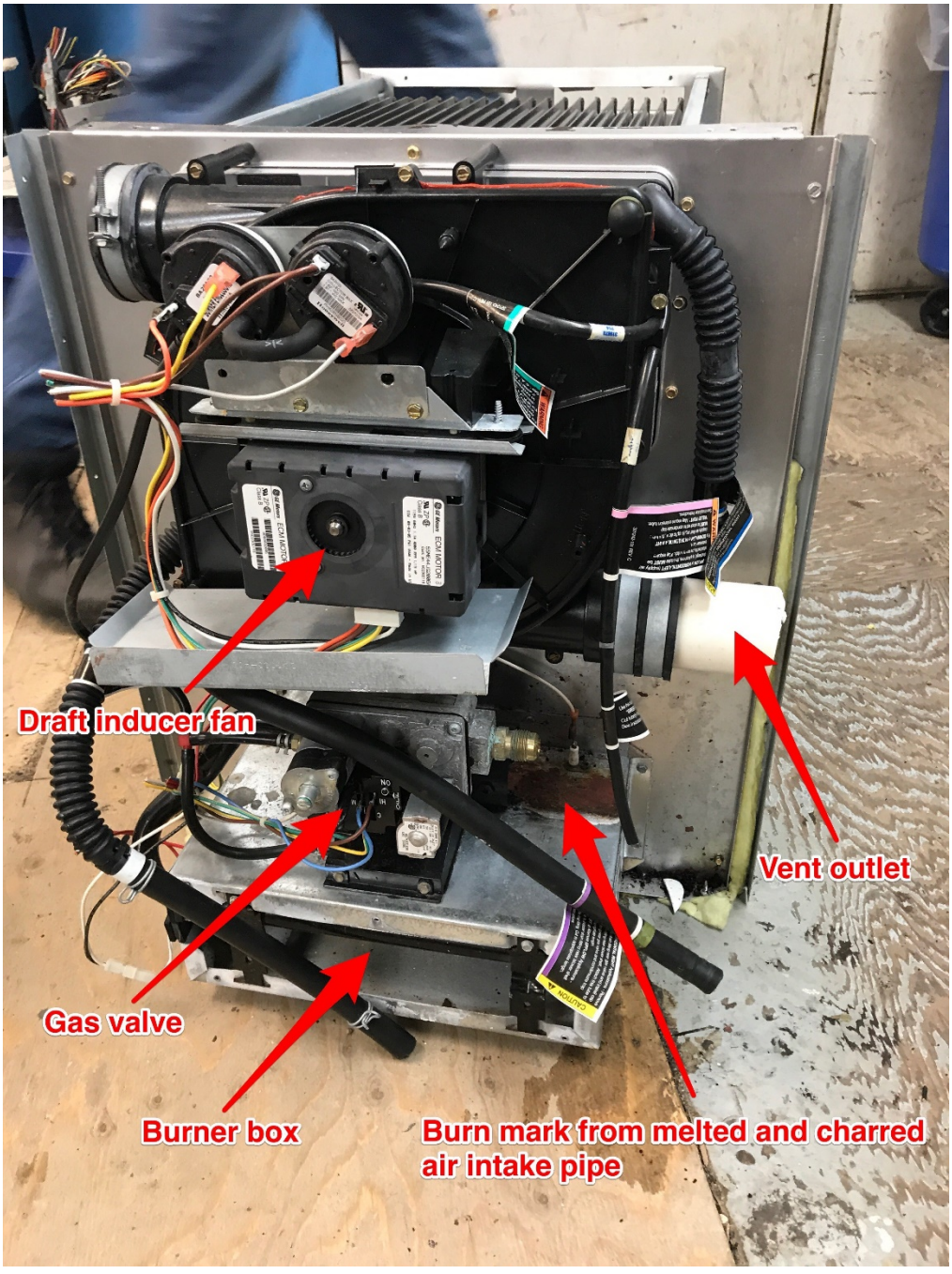

Image 4 – Entire heat exchanger and burner assembly removed from furnace case for examination.

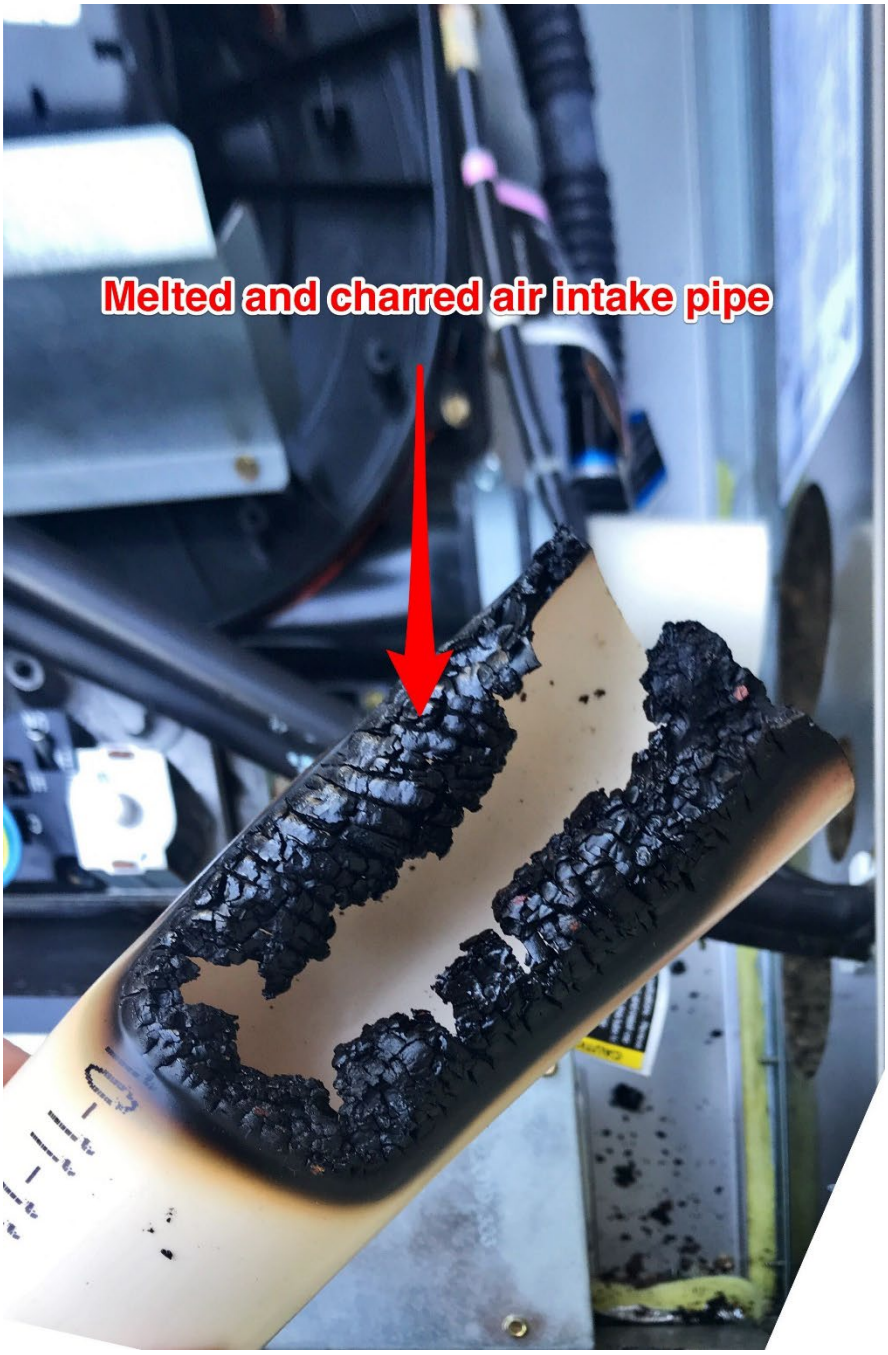

Image 5 – Air inlet pipe removed from furnace.

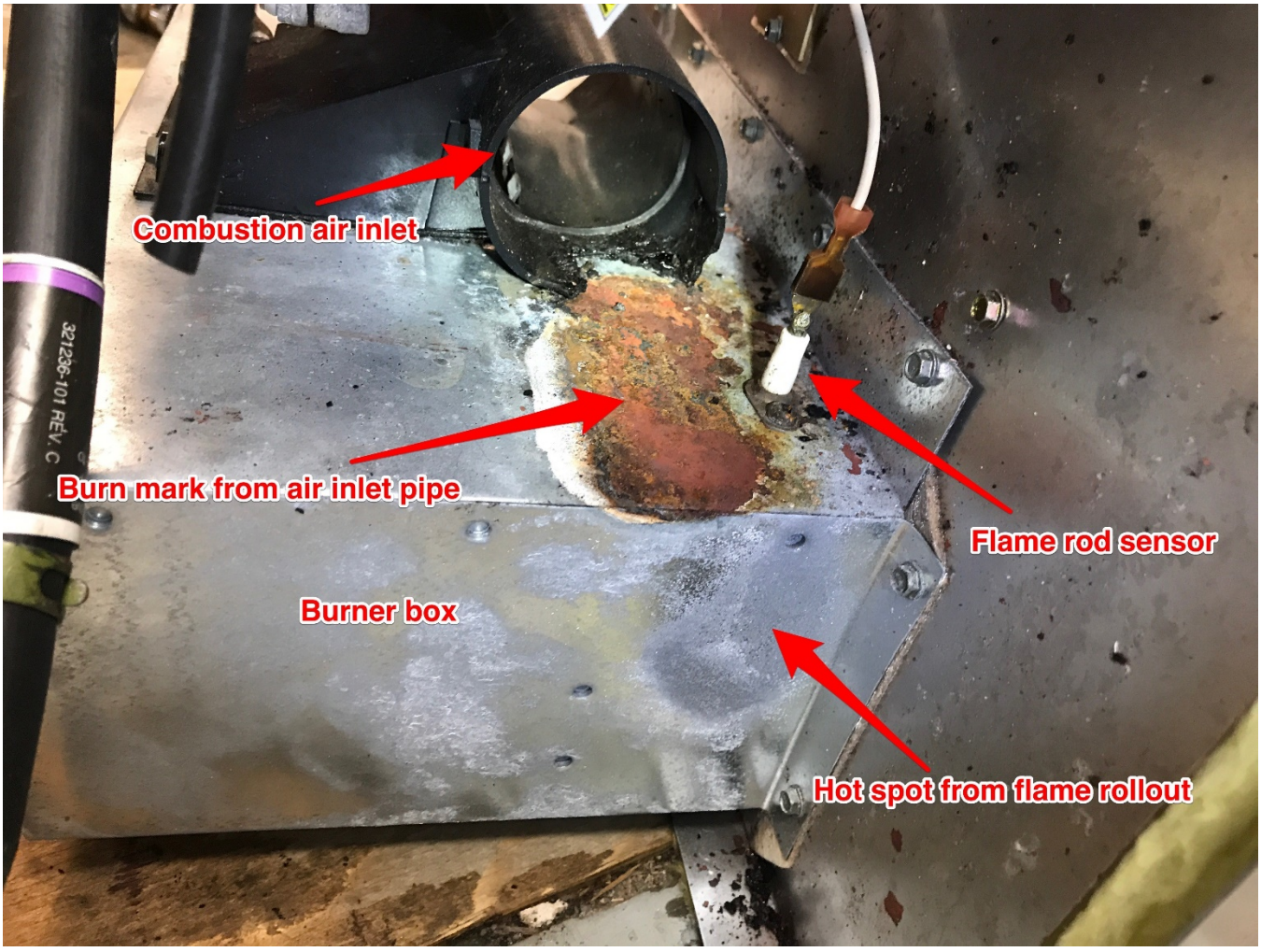

Image 6 – Burner box showing original installed location of air inlet pipe (white PVC pipe had been removed in this photo).

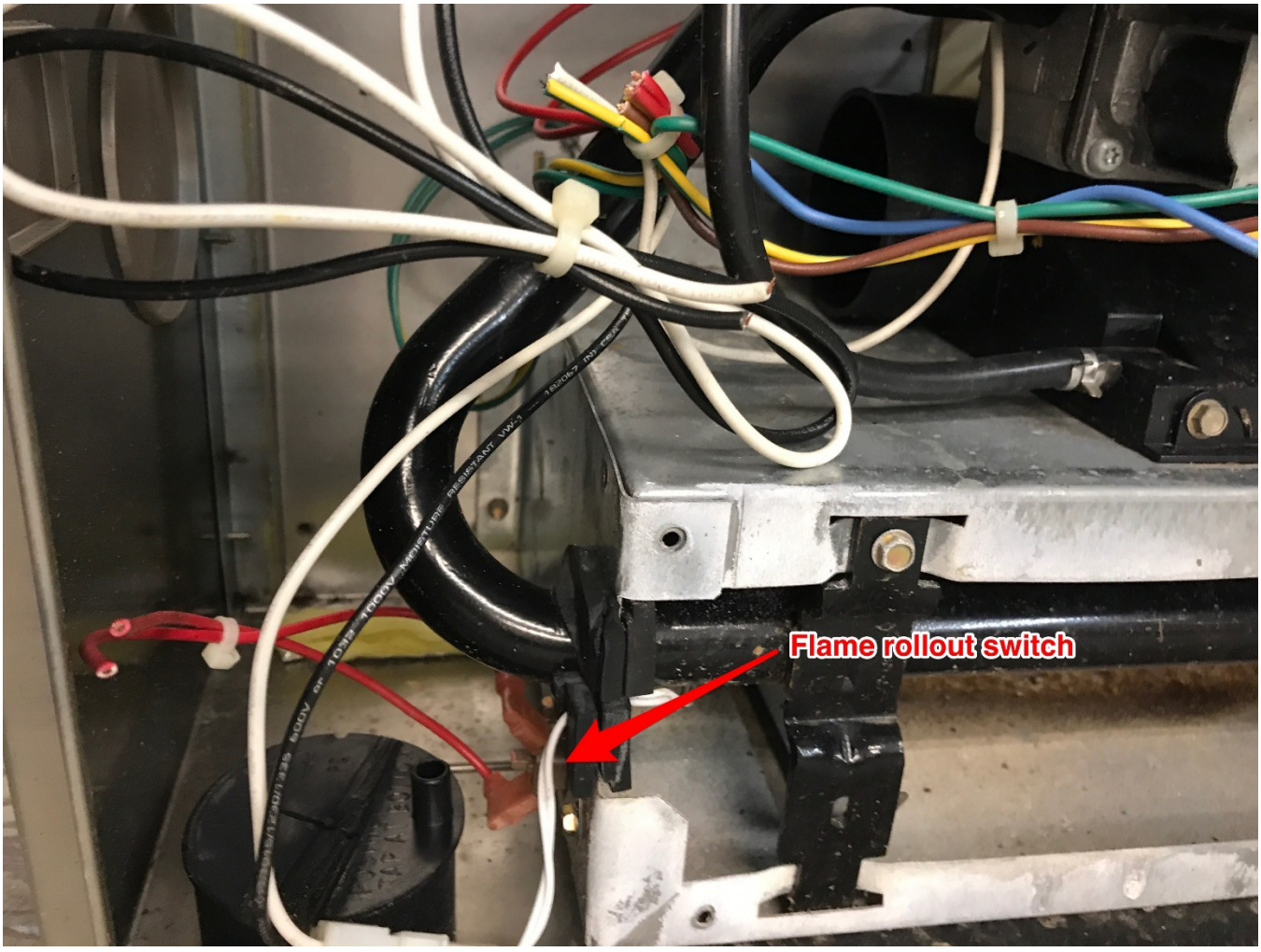

Image 7 – Flame rollout switch on opposite side of burner box from charred air inlet pipe.

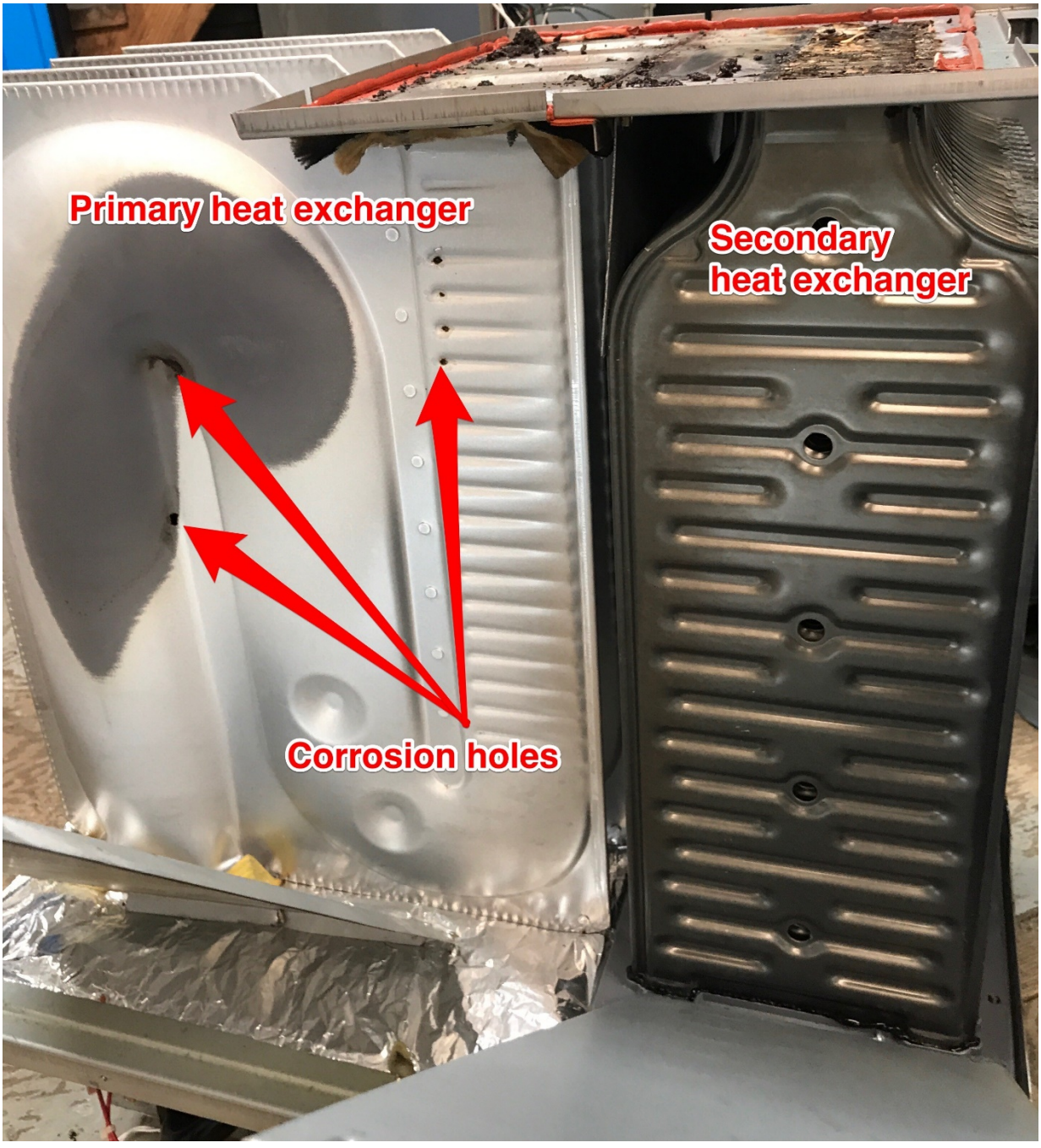

Image 8 – Heat exchangers.

Image 9 – Replacement secondary heat exchanger tubes inlets after under 5 years of operation.

Image 10 - Replacement secondary heat exchanger tube removed for examination.

Image 11 – Carbon monoxide meter registering 755 parts per million (ppm) at the furnace vent termination while the furnace was operating.

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"