Incident Summary #II-1136528-2021 (#20560) (FINAL)

SUPPORTING INFORMATION	Incident Date		January 26, 2021
	Location		Surrey
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	3
		Injury description	Three individuals were found in medical distress due to exposure to carbon monoxide (CO) in a residential home. The occupants were reported to have lost consciousness or were unresponsive. The three individuals were taken to hospital and were treated for CO poisoning.
		Injury rating	Major
	Impact – Damage	Damage description	NA
		Damage rating	None
	Incident rating		Major
	Incident overview		A natural gas fired boiler used for hydronic heating in a residential home produced high levels of CO. The CO was able to infiltrate into the occupied space causing hazardous exposure to occupants of the home.
INVESTIGATION CONCLUSIONS	Site, system and components		The home utilizes a natural gas fired boiler as the main source of heat. The boiler uses the combustion of natural gas to heat water which is circulated to radiators within the home providing heat for the spaces. The flue gas from combustion is drawn through natural convection up a venting system designed to safely exhaust it to the outdoors through the roof. The boiler in the home uses a standing pilot burner which ignites the main burners when there is a call for heat. The pilot burner does not shut off after a heating cycle and is designed to remain lit 100% of the time the boiler is in operation. The gas burners in the boiler, including the pilot burner, use gas orifices which allow precise volumes of gas to pass through them. The gas mixes with air to provide an air/fuel ratio which allows for complete combustion of the fuel. Natural gas 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. By-products of incomplete combustion can be soot and CO. CO is a colourless, odourless, tasteless gas that is toxic to humans and animals (Chart 1). Exposure to CO 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. A draft hood is incorporated into the venting system for the boiler. During normal operation, when the hot flue gas rises up the flue pipe through natural convection, air is drawn into the draft hood diluting the flue gas and ensuring the combustion chamber of the boiler remains at a neutral pressure. A safety device known as a spill switch is installed at the draft hood of the venting system. It is designed to sense if flue gas spills out of the draft hood into the occupied space and will shut off the appliance by interrupting the electrical supply to the gas valve.

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	A motorized damper in the vent system is normally closed when the boiler is not firing. The damper closes the vent opening increasing efficiency of the appliance by reducing heat loss up the flue pipe. The damper motor has an internal switch which allows the appliance to operate when the damper is in the fully opened position. If the damper does not fully open the electrical circuit is interrupted and the gas valve will not operate the main burners.
Failure scenario(s)	It was reported that in the past the boiler in the home had been making a “booming” sound when it ignited. The likely cause of the sound was the boiler experiencing delayed ignition of the main burners from the pilot burner. Delayed ignition occurs when gas from the main burners fails to ignite immediately from the pilot flame and accumulates in the combustion chamber prior to ignition which would then cause a “booming” sound when it eventually ignited. Delayed ignition can be repaired by repositioning a pilot burner or cleaning a dirty pilot orifice to allow the pilot flame to smoothly light off of the main burner gas. Orifices in pilot assemblies like the one found in the boiler should not be enlarged from the factory sizes. The gas orifice in the pilot burner was found to have been manually enlarged to create a larger pilot flame. The orifice opening was increased beyond the size set by the manufacturer which allowed a greater volume of gas to pass through than what the pilot burner was designed for. The pilot burner was unable to mix a sufficient amount of air with the gas and produced in a large lazy yellow flame and incomplete combustion of the gas. The incomplete combustion created soot and carbon which accumulated in the venting and on the heat exchanger above the burners (Image 6). The soot and carbon restricted the flow of flue products through the heat exchanger which reduced the air being drawn in for the main burners causing incomplete combustion and thereby accelerated the soot and carbon accumulation which compounded the problem. Incomplete combustion of the main burners caused high levels of CO to be produced in the flue gas while restriction through the heat exchanger enabled the flue gas containing CO to infiltrate into the occupied space of the home. Two days prior to the incident, the boiler had quit working. The outdoor temperatures were low and the home had become cold. The evening of the incident a plumber repaired the boiler by reattaching a wire that had become disconnected and placed it back into operation. The boiler ran for longer than usual heating cycles while it was heating the cold home. The extended run time of the boiler resulted in the concentrations of CO in the ambient air of the home to reach levels that caused the occupants to lose consciousness. The occupants were unaware of the hazard as CO is colourless and odourless. The home did not have any CO detectors installed to alert the occupants of the hazard.
Facts and evidence	**Site examination** Site visits were conducted by investigators after the incident. The following was observed during examination of the gas equipment: • The home was heated by a natural gas fired boiler • The boiler had electrical wires known in industry as “jumpers” bypassing the venting spill switch and the damper motor end switch (Images 2-3)

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- Soot and carbon were observed on the pressure tank next to the draft hood, inside the venting system, the damper and behind the burner cover plate (Image 5)
- Heavy sooting and carbon deposits were observed above the main burners restricting the flue passages through the heat exchanger (Image 6)

Interview statements

Statements from interviews with occupants of the home:

- One occupant identified their family member as a plumber (the plumber) who originally installed the boiler approximately 12 years ago
- To their knowledge the plumber was the only one who had ever worked on the boiler
- The boiler had been making big “booming” sounds a year or two ago and the plumber had repaired it and the sounds stopped occurring
- Two days prior to the incident the boiler had quit working and the home had become cold
- The plumber arrived the evening of the incident, repaired the boiler and put it back into operation
- A few hours later one occupant of the home was found unresponsive on the main floor
- While attending to the unresponsive individual, two other occupants of the home began to lose consciousness until first responders arrived
- When the first responders arrived their personal CO detectors alarmed indicating hazardous levels of CO in the home
- The home did not have any CO detectors installed at the time of the incident

Statements from interviews with the plumber:

- The day of the incident they went to the home at the request of their family member to inspect the boiler
- The boiler wasn’t working and the home was cold
- A low voltage wire on the boiler was found to be disconnected
- They reattached the wire and put the boiler back into operation
- They were only there for 15-20 minutes to complete the repair and left the home after the boiler was put back into operation
- They installed the boiler in the home approximately 12 years ago
- They have been a plumber since 1996 and have worked for several companies
- They have had their own plumbing/heating company and have worked with heating boilers for the past 10+ years
- They were unaware of the boiler previously making big “booming” sound or repairs that may have been done to correct it
- They were unaware of previous problems with the damper motor, venting spill switch, wiring or repairs that may have been done to correct them
- They were unaware of wire jumpers that were installed bypassing the damper motor and spill switch
- They were unaware of the oversized pilot burner orifice or soot and carbon buildup in the venting and heat exchanger
- They were unaware that the boiler produced high amounts to CO and flue products spilled into the home

Testing and analysis

Notification from the gas utility company indicated that one of their technicians was dispatched to the home after first responders identified the presence of CO inside. The technician measured the highest reading of 1200 parts per million (ppm) CO in the ambient air in the area of the boiler, which is a CO level considered to be immediately dangerous to life and health, (Chart 2).

Examination and testing of the gas appliances in the home was conducted after the incident by an independent third party contractor. The examination and testing revealed the following:

- Two gas fireplaces upstairs had been shut off and not used in 20+ years
- The natural gas hot water heater was operating correctly and was not a source of CO in the home
- No other potential sources of CO were identified other than the boiler
- The pilot burner flame for the boiler was extremely large and produced a lazy yellow flame (Image 7)
- The orifice for the gas pilot burner had been enlarged from an original factory size of 0.018” to 0.0465” (#56 drill size)
- The enlarged pilot orifice size increased the pilot burner input from the original factory rating of 823 btu/hr to 5490 btu/hr
- Their expert opinion was that the enlarged pilot flame would be the source of the soot and carbon deposits found inside the boiler and venting system

A combustion analysis test of the boiler flue gas was conducted. With only the pilot burner in operation, the CO in the flue gas measured a steady 8 ppm. When the main burners were lit the CO level stayed steady for the first 8 seconds then rapidly rose to beyond the 7200 ppm maximum reading of the instrument in an additional 7 seconds (Figure 1).

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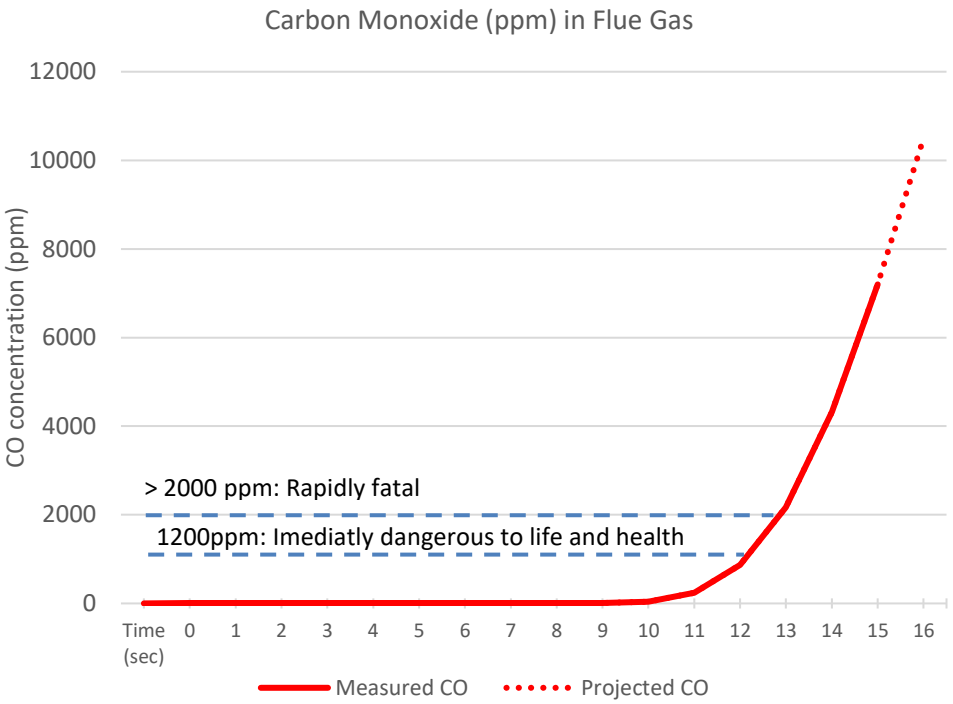

Figure 1 – *CO concentrations in the flue gas of the boiler with the main burners on. Rapidly fatal and immediately dangerous to life and health (IDLH) CO concentrations ref. Chart 2*

During the combustion analysis test, CO was measured in the ambient air in front of the boiler. After the 15 seconds of burner operation, the CO measurements reached a maximum of 181ppm*.

* *Table 1 identifies CO concentrations of this level as being potentially lethal in as little as 4 hours*

Conclusion

The pilot orifice for the boiler had been enlarged, possibly to address the issue of delayed ignition of the main burners that were causing a “booming” noise. This resulted in a very large and lazy pilot flame. The flame generated soot and carbon which collected on the interior of the boiler and venting system. This restricted the flue passages above the main burners through the heat exchanger. The restriction caused an insufficient amount of combustion air to be drawn into the main burners and combustion chamber resulting in the production of extremely high levels of CO and the spilling of flue gas containing CO into the occupied space of the home.

Causes and contributing factors	It is highly likely that the oversizing of the pilot orifice led to a pilot flame that deposited soot and carbon on the inside of the boiler which caused the incident. The absence of CO detectors in the home and lack of regular appliance inspection and maintenance by a qualified individual were contributing factors to the incident.

Image 1 – Natural gas fired boiler installed on main floor of home

Image 2 – Jumper #1 electrical wire bypassing the draft hood spill switch

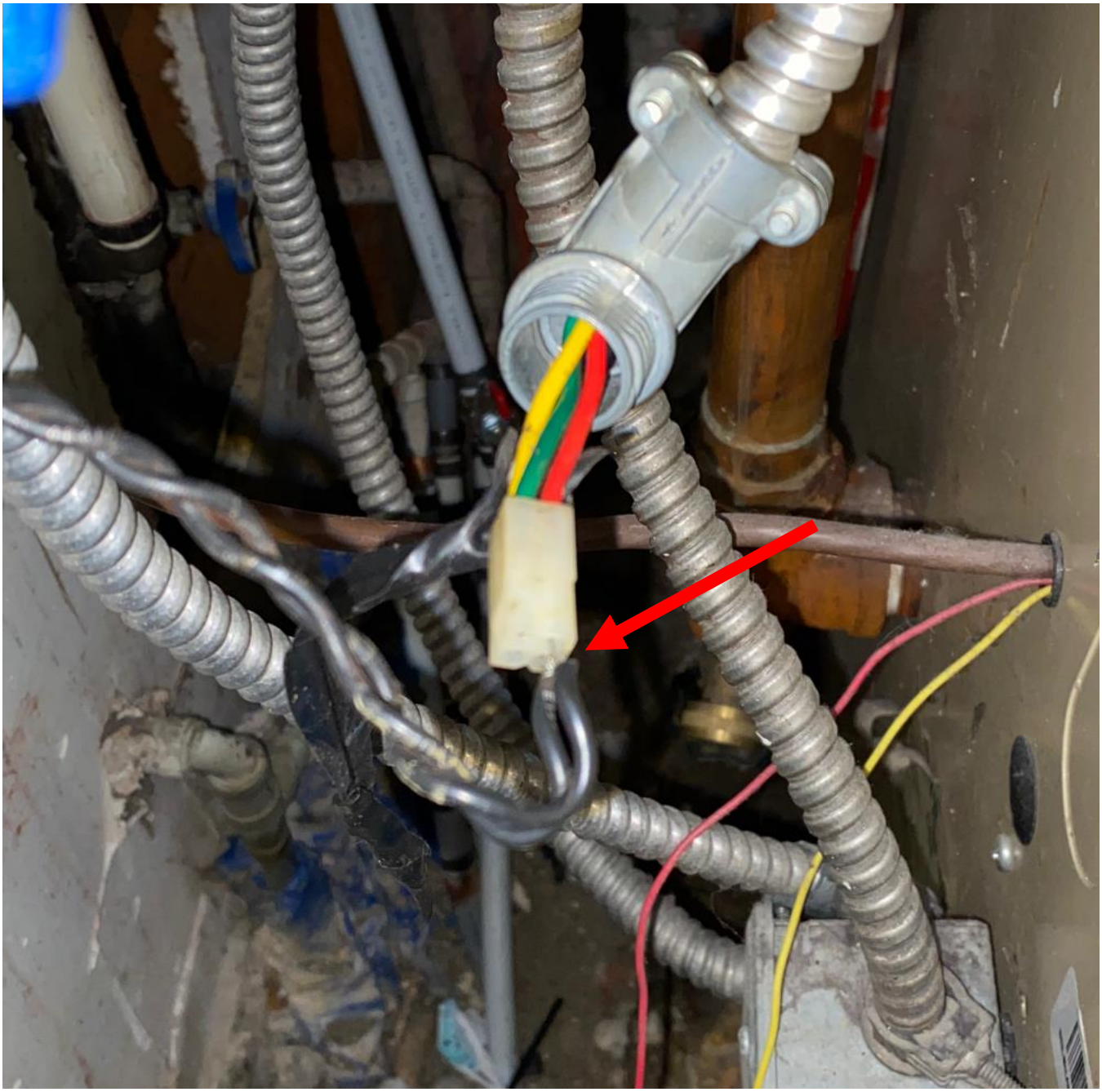

Image 3 – Jumper #2 electrical wire bypassing the damper motor end switch

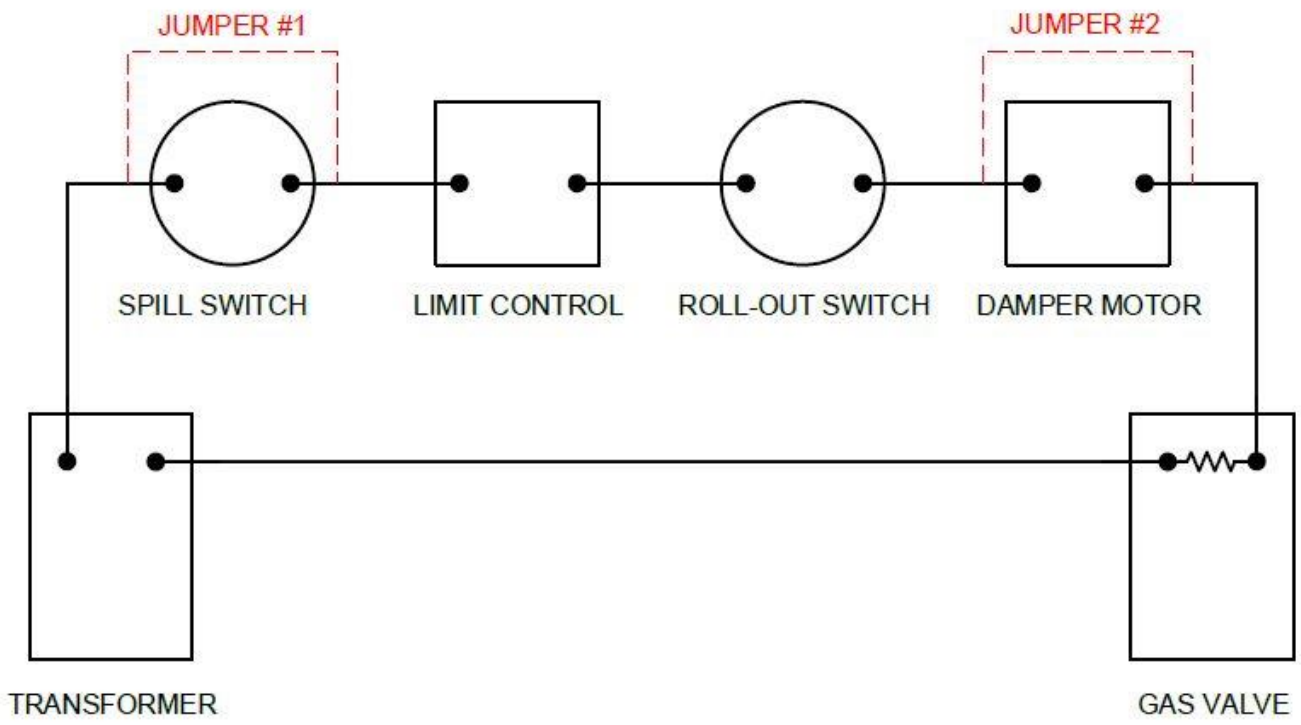

Image 4 – Wiring diagram identifying how the vent spill switch and damper motor position end switch were bypassed with “jumpers” allowing the gas valve to operate

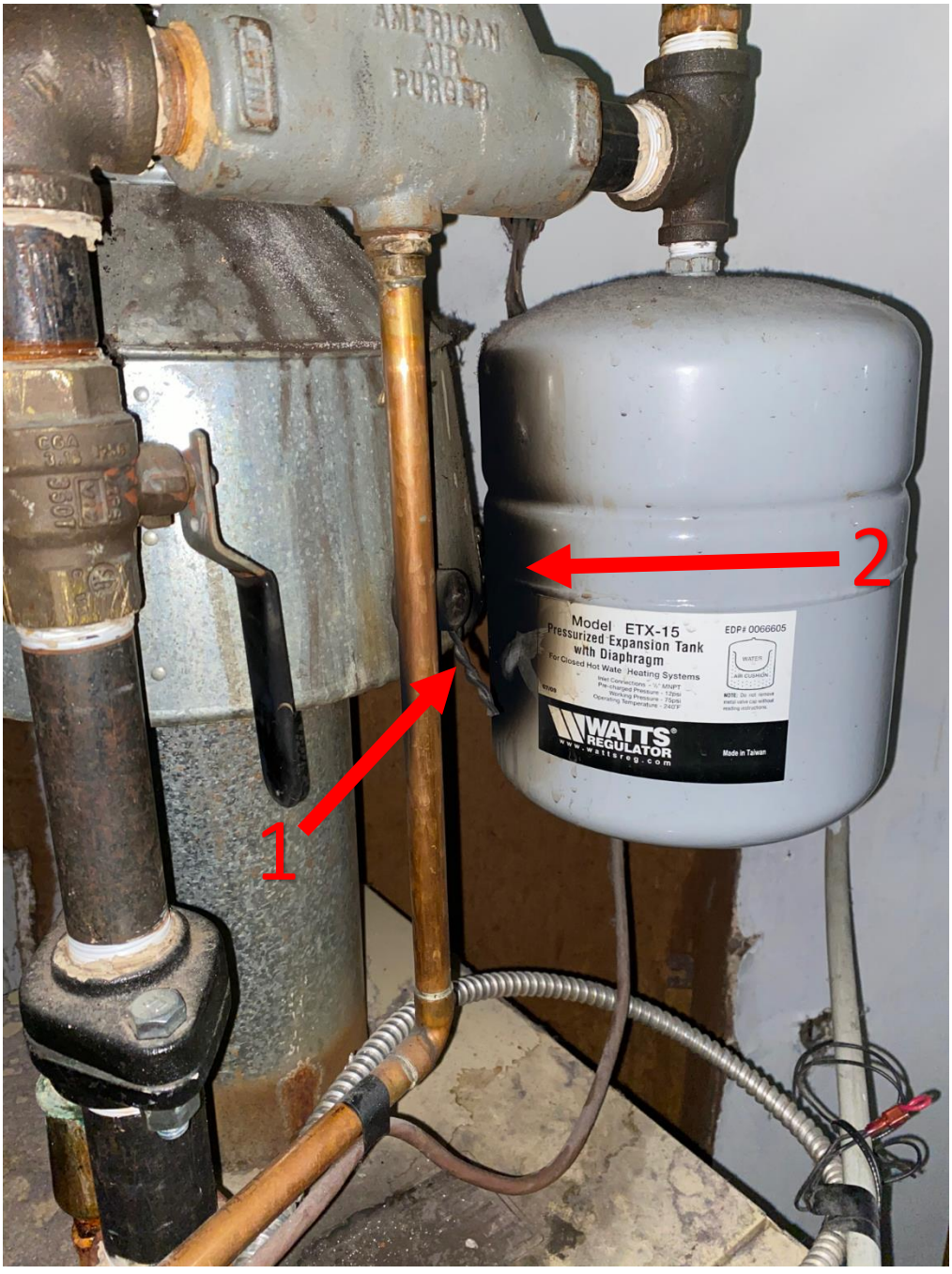

Image 5- Wires to the venting spill switch had been cut (1) and soot visible on expansion tank (2)

Image 6 – Soot and carbon deposits found on the boiler heat exchanger following the incident (left) and after cleaning (right). The soot and carbon deposits restricted the flue gas passage through the heat exchanger.

Image 7 – Boiler pilot flame in operation. The boiler operating manual states that a proper pilot flame is blue with the inner cone engulfing the thermocouple and an overfired pilot flame with lack of primary air will have a large lifting flame with a yellow flame tip as seen in the image and here: Pilot flame video.

Image 8 – Pilot orifice showing the enlarged size of the gas flow opening

Image 9 – Pilot orifice with a #56 orifice drill (0.0465”) inserted to measure the size of the enlarged gas flow opening

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

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.)