Incident Summary #II-1114872-2020 (#20141) (FINAL)

SUPPORTING INFORMATION	Incident Date		December 10, 2020
	Location		Langley
	Regulated industry sector		Gas - Natural gas system
	Impact – Injury	Qty injuries	1
		Injury description	An occupant of a neighbouring home received a small abrasion to the head by a wall hanging which fell off the wall due to the explosion.
		Injury rating	Minor
	Impact – Damage	Damage description	A residential gas fired boiler exploded causing catastrophic damage to the boiler. The mechanical room door broke into several pieces, the back wall of the mechanical room pushed outward into an interior bedroom splitting a wooden leg of a bed against the wall. A hole was blown in the drywall ceiling above the boiler into the attic space.
		Damage rating	Major
	Incident rating		Major
	Incident overview		A gas fired heating boiler in a residential townhome experienced an overpressure condition. The pressure relief valve failed to relieve the excessive pressure resulting in an explosion.
INVESTIGATION CONCLUSIONS	Site, system and components		The residential townhome utilizes a natural gas fired boiler and hydronic in floor heating system as the main source of heat. The boiler is installed in a mechanical room separate from the living space and only accessible from the garage. The boiler uses the combustion of natural gas to heat water. The water is circulated by a pump from the boiler then through the floor of the home providing heat for the spaces. The cooled water then returns to the boiler to be reheated. The closed heating water loop of the hydronic heating system incorporates a feed water components designed to add water to the system if the pressure inside dips below a set point. The feed water system is made up of a back check valve which allows the water to enter the system and not escape, a pressure reducing regulator which controls the set point the water will enter the system, and manual shutoff valves to isolate the system for component service and replacement (Image 1). The boiler incorporates a heat exchange to transfer the heat from the combustion to the water inside. The heat exchanger is made up of three separate cast iron sections which are bolted together to form one unit (Image 6). The pressure in the hydronic system is designed to operate at a maximum allowable working pressure (MAWP) of 30 pounds per square inch (psi). A pressure relief valve (PRV) is installed in the water system as a safety device to relieve excess pressure due to thermal expansion of the water and to protect the heating system components from pressures exceeding their MAWP. The set relief pressure of the PRV should not exceed the MAWP of the system components. The PRV incorporates a lever on the top which can be used to manually open the valve (Image 11). The lever is used for valve maintenance to ensure the mechanism is functioning and to clear the waterway of naturally occurring mineral deposits which may adhere to the valve and render it inoperable.

Incident Summary #II-1114872-2020 (#20141) (FINAL)

	Automatic air vents are installed in multiple locations in the hydronic heating system (Image 1). The purpose of these vents is to release any air or vapour in the system to allow for complete filling of water and allow the pump to circulate the heated water correctly. The air vents in this system operate by use of a plastic float. When air accumulates in the body of the valve the float drops opening a vent to release the air to atmosphere. When the air is vented the incoming water raises the float shutting the vent valve. The air vents in this system have a maximum temperature rating of 240°F (116°C) Residential hydronic systems may incorporate an optional external low water cut-off (LWCO) switch. A LWCO is a safety device which will stop the operation of the boiler if the water in the system drops below the monitored level. A boiler operating without water in the system can create a dangerous “dry fire” condition. In a dry fire condition the heat exchanger is unable to transfer the heat to water inside and may become extremely hot. If water contacts the extremely hot heat exchanger it could rapidly convert to steam. When heated water converts to steam the change in phase from a liquid to a vapour incorporates a large increase in volume by 1700 times. If the increase in volume is contained within a closed system, it can result in a tremendous increase in pressure. LWCO switches are not required on residential systems with boilers of this size (<3 sq. meters heating surface area).
Failure scenario(s)	The boiler in the home had been in service for approximately 30 years. The current occupant had owned the home for approximately 8 years and in that time had not had service or maintenance performed on the boiler or hydronic heating system components. The PRV for the boiler had been in service for approximately 20+ years and corrosion had seized the mechanism rendering the valve inoperable. The circulating pump had seized and quit circulating water through the heating system. The water level in the system lowered as it converted to steam and was released to atmosphere in the mechanical room through the air vents. The water fill system failed to add additional water to the system when the level dropped. The water level in the boiler lowered below the temperature sensing bulbs of the aqua-stat and high limit safety switches. Without water transferring heat to the sensing bulbs, the switches failed to operate as intended. The boiler did not incorporate an optional LWCO switch to stop the operation of the boiler when the water level got too low. This allowed the boiler to continue to fire without satisfying the thermostat or tripping the high limit switch. The water inside the heat exchanger evaporated, leading to a dry fire situation resulting in an extremely hot heat exchanger. The seized pump may have restarted sending water from the system piping into the hot heat exchanger. The rapid expansion from water to steam created a large pressure increase inside the system. The corroded PRV failed to release the excessive pressure resulting in an explosion of the heat exchanger.
Facts and evidence	Residents from the townhouse stated the complex was approximately 30 years old and the unit the incident occurred in was one of the first built. All of the 72 units were originally installed with the same make and design of boiler and hydronic heating system.

Incident Summary #II-1114872-2020 (#20141) (FINAL)

The occupant of the home where the incident occurred stated they had lived there for approximately 8 years and in that time they had not had service or maintenance performed on the boiler. They had never operated the lever on the PRV for the boiler and were unaware of the requirement to do so or the potential hazard of the valve not functioning. They had not observed anything unusual with the heating system prior to the incident and had not entered the mechanical room recently.

Site observations and examination of scene photographs showed the explosion had occurred in the mechanical room accessed from the garage. The door to the mechanical room was blocked by objects which needed to be removed to gain full access. The objects had been there for some time identifying that periodic inspection or maintenance of the equipment had not recently taken place. The mechanical room housed a gas fired hot water tank, heating boiler and heating system components. The explosion had broken the top of the mechanical room door above the objects that were leaned up against the door, pushed out the interior wall into the bedroom on the opposite side and created a hole in the drywall in the ceiling above the boiler. There was no evidence of fire or heat damage from the explosion. No evidence could be found of a gas leak or excessive accumulation from the gas system or components. It is highly unlikely that combustible gas was the cause of the explosion.

The data tag attached to the PRV identified it as a Watts 174A Model M3 with a set opening pressure of 45 psi. Manufacturers literature identifies the date code on the valve with a manufacturing date of February 1998.

The PRV specifications sheet identifies the valve as a pressure protection device for all types of hot water heating boiler equipment. It states that each hot water space heating boiler shall be equipped with a PRV set to relieve *below* the maximum boiler working pressure. The manufacturer affixes a safety instruction tag to the valves which identifies a requirement for the valve to be installed in the vertical position and the valve lever to be manually operated “At least once a year by the boiler owner to insure that water ways are clear”. Information on the tag recommends having the PRV inspected by a qualified individual or agency every three years to insure it has not been affected by corrosive water conditions. The tag contains the following warning: “FAILURE TO REINSPECT THIS VALVE COULD RESULT IN UNSAFE PRESSURE BUILDUP WHICH CAN RESULT IN SERIOUS INJURY OR DEATH AND/OR SEVERE PROPERTY DAMAGE”

The boiler user information manual provides a warning instruction to the equipment owner that inspection of the boiler should be done annually by a trained and skilled person from a qualified service agency.

Site observations found the boiler’s three cast iron heat exchanger sections had separated and the center section had fractured into several pieces and separated outwardly from the center. The sections have casting marks identifying the heat exchanger as having a maximum working pressure of 30 psi. The PRV had been installed in the horizontal position contrary to the manufactures safety instruction tag. The PRV is designed to be installed vertically to prevent valve leakage, allow for proper drainage and to operate at its designed set pressure.

External components from the hydronic heating system were disassembled for examination and testing.

- An air eliminator located at the highest point in the system was found to have been exposed to high temperatures and the plastic internal float assembly

Incident Summary #II-1114872-2020 (#20141) (FINAL)

had melted and clogged the valve inlet (Images 8-9). The maximum operating temperature of the valve is listed on the cap as 240°F (116°C).

- The circulation pump was connected to its rated voltage and was not operational. The plastic pump impeller showed evidence of exposure to high heat and was discoloured and warped (Image 10). After manually turning the impeller, the motor began rotating. Power to the motor was disconnected then re-energised and the motor failed to rotate once again until the rotor was rotated by hand.
- A ¼ turn ball valve in the system was unable to fully close. The internal plastic sealing disks melted which inhibited the valve from closing fully (Image 13).
- The temperature / pressure gauge for the boiler was damaged from the explosion and showed the pressure needle pinned at 75psi and the temperature gauge pinned off the high end of the scale beyond the highest registered mark of 320° F indicating excessively high pressures and temperatures prior to the explosion (Image 7).

The boiler, PRV and an exemplar boiler from a neighboring townhome of the same vintage, make and model was sent to an independent laboratory for testing and examination. The laboratory examination and testing found:

- The middle section of the cast iron heat exchanger suffered brittle fractures with no evidence of deformation and found no evidence of graphitization at any location.
- The heat exchanger was constructed of typical materials and no defects were found in the fractured boiler pieces.
- The PRV was stuck in the closed position by the accumulation of aluminum oxide corrosion deposits in the spring housing. The non-metallic seating disk material was in a deformed ring shape around the outside of the seating disk holder (Image 12).
- The PRV had a factory set opening pressure of 45 psi, a test was conducted using high pressure air to determine at what pressure the valve would open. The test pressure was increased up to maximum of 90 psi with the valve failing to open. The test did not continue past 90 psi for safety reasons.

The laboratory concluded that The heat exchanger explosion was caused directly by excessive internal pressure which was failed to be relieved by the PRV.

The heating systems in multiple other townhomes in the complex were examined. All of the other PRV's were found to be of the correct pressure rating of 30 psi.

Causes and contributing factors

It is highly likely that the corroded internal spring and relief mechanism of the PRV led to the failure to relieve excess pressure inside the boiler causing the explosion.

The failure of the feed water system and the failure to test the operation of the relief valve annually were contributing factors to the incident.

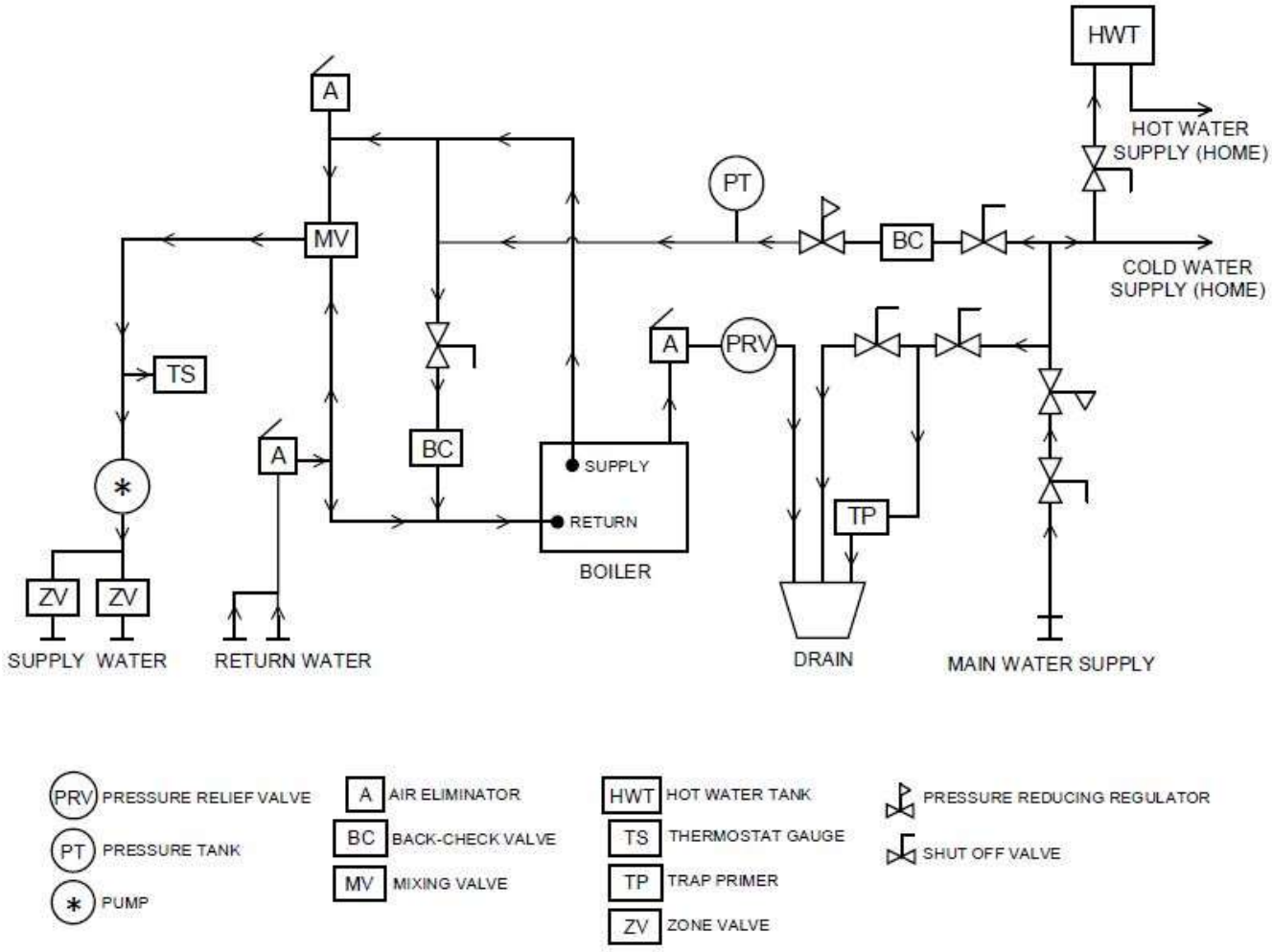

Image 1 – Diagram of hydronic heating system identifying components and water flow

Image 2 – Mechanical room from inside garage showing damaged boiler

Image 3 – Damaged boiler and drywall into attic space above boiler in mechanical room

Image 4 - Damage to interior bedroom wall opposite mechanical room and wooden bed frame

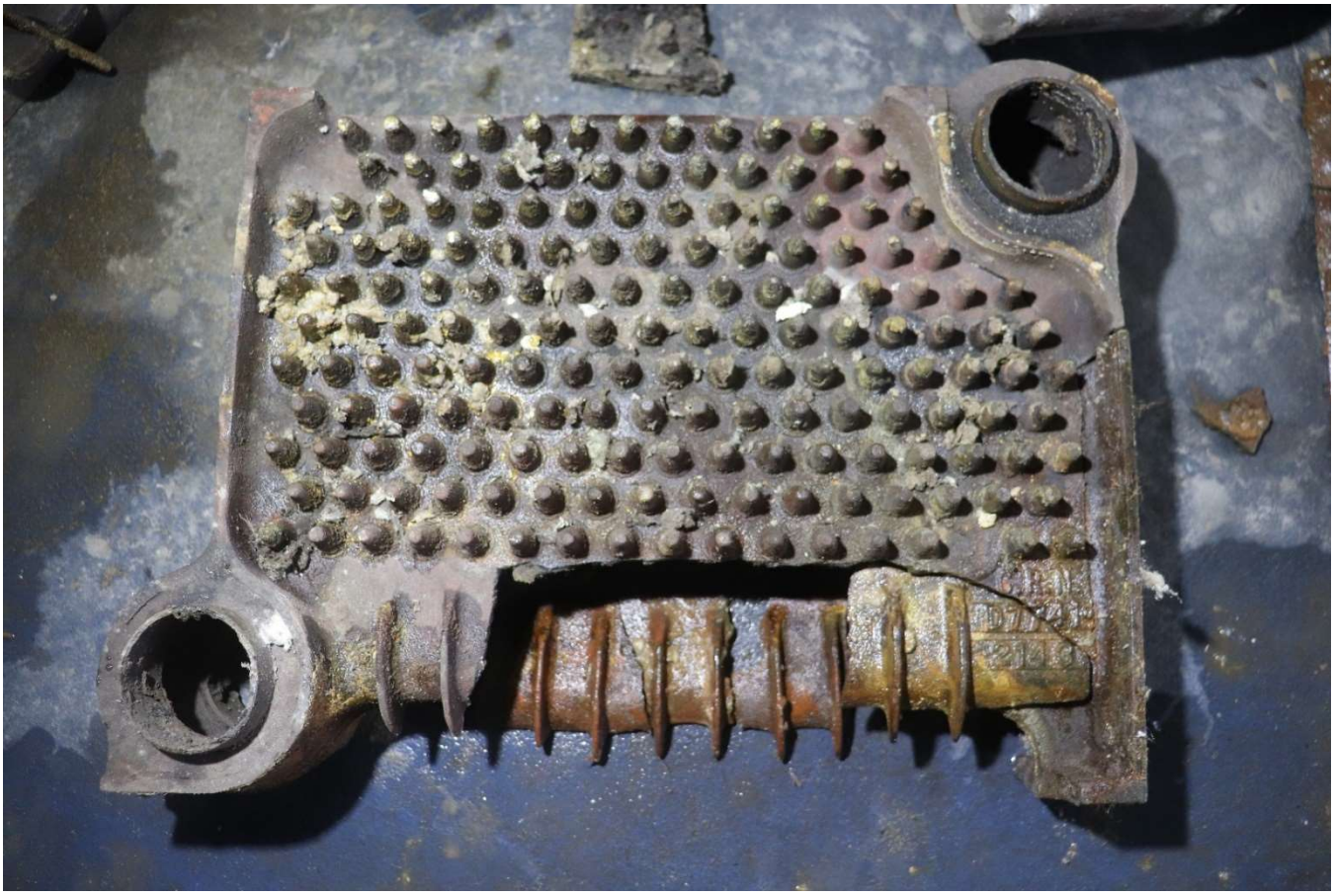

Image 5 – Reassembled portions of fractured heat exchanger

Image 6 - (Top) fractured center heat exchanger section in relation to end sections (Bottom) Exemplar heat exchanger showing sections fully assembled

Image 7 – (Top) Heat exchanger casting showing 30 psi maximum working pressure (Bottom) Temperature/pressure gauge showing needles pinned above 75 psi and 320°F maximum readings

Image 8 – Air vent with melted float

Image 9 – (Top) Air vent inlet plugged with melted float material (Bottom) Exemplar air vent float (left) next to melted air vent float (right)

Image 10 – Circulating pump impeller in two different positions identifying warpage

Image 11 – Pressure relief valve (PRV) showing deformed non-metallic seal and set pressure of 45 psi

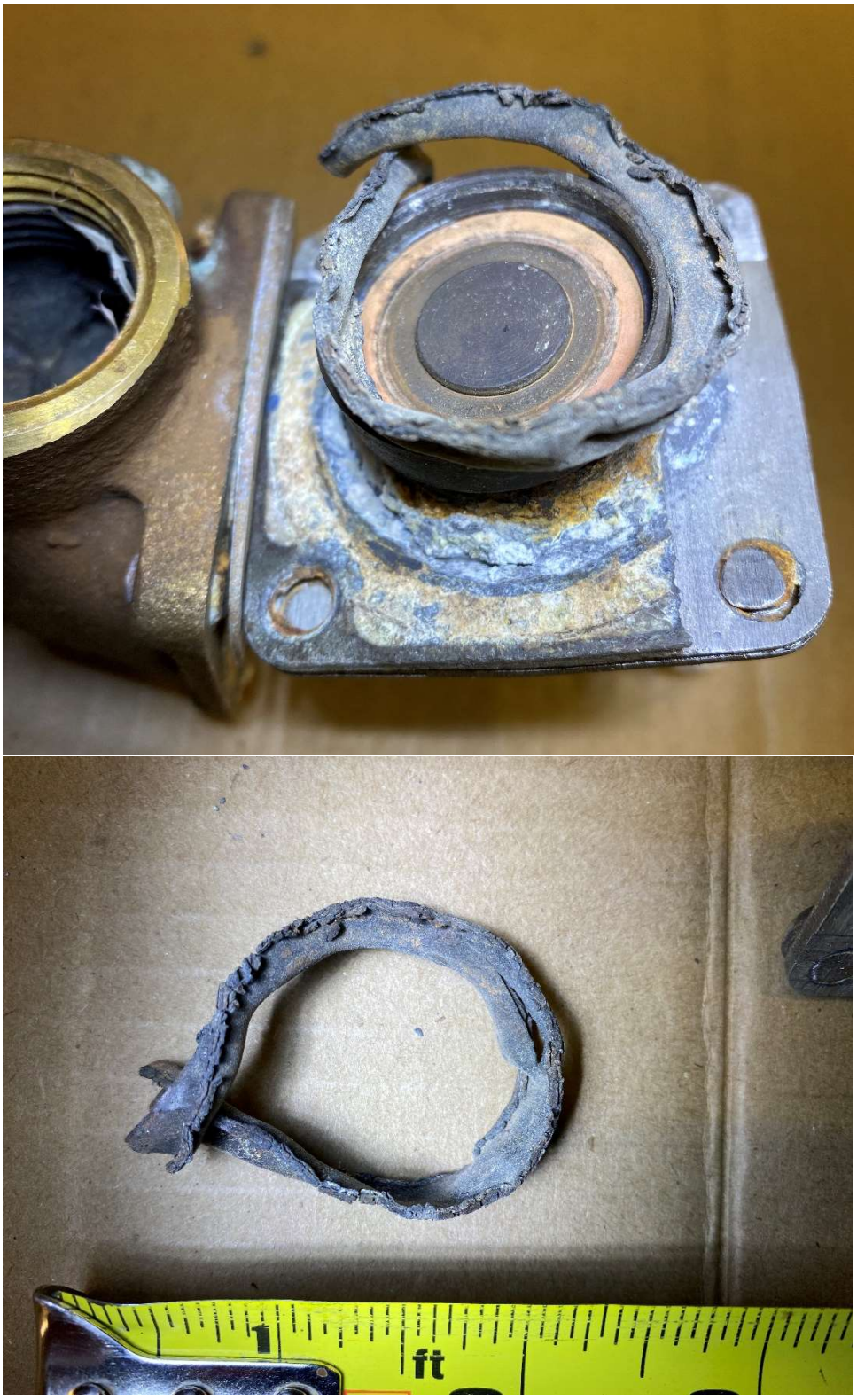

Image 12 – Close up detail of PRV non-metallic disk seal

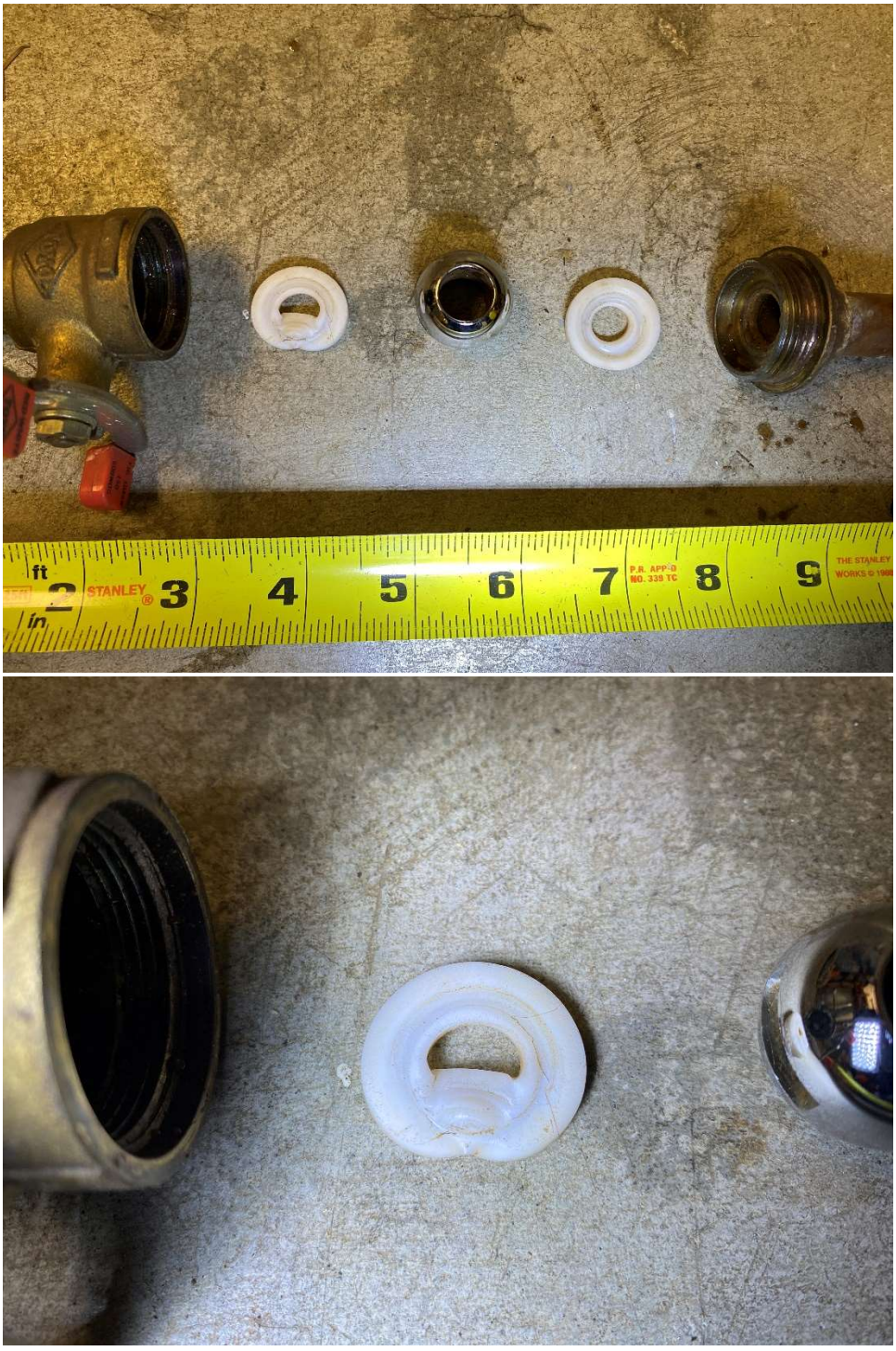

Image 13 – Ball valve plastic sealing disk melted and deformed from high temperature