Incident Summary #II-927063-2019 (#15727) (FINAL)

SUPPORTING INFORMATION	Incident Date		October 23, 2019
	Location		Delta
	Regulated industry sector		Gas - Natural gas system Boilers, PV & Refrigeration - Boiler and pressure vessel system
	Impact – Injury	Qty injuries	0
		Injury description	One worker was in the boiler room at the time of the explosion but sustained no reported injuries
		Injury rating	None
	Impact – Damage	Damage description	An explosion damaged a steam boiler and vent stack. The front and rear doors of the boiler bent and deformed, the brick refractory insulation on the rear door cracked and broke into pieces. The boiler vent stack split open and the vent cap on the roof blew off and landed several meters away.**(Images 3-8)**
		Damage rating	Major
	Incident rating		Major
	Incident overview		An explosion occurred inside a steam boiler and vent stack in the mechanical room of a large industrial bakery.
INVESTIGATION CONCLUSIONS	Site, system and components		The firetube steam boiler is designed to provide steam for heating and manufacturing processes. The boiler creates heat from the combustion of a gas/air mixture produced by a natural gas burner and combustion air fan. The products of combustion pass through tubes which are surrounded by water inside the boiler and pass safely to the outdoors through a vent stack pipe. Heat is transferred through the tubes to the surrounding water converting it to steam. The facility relies on one steam boiler for production without a permanent system to supply steam if the boiler is shut down for inspection, maintenance or repair. The boiler uses an interrupted gas pilot flame to ignite the main burner. An electronic spark ignitor rod, which is set to a specific gap, is used to ignite the gas pilot flame. After the pilot flame is lit, the main gas valve opens to ignite the main burner flame. Once the main burner flame is lit the pilot extinguishes. The gas burner is comprised of a metal ring providing a precise gap for the gas to exit around a center air diffuser. Combustion air, supplied from a blower, travels through the center diffuser which uses a circular plate to impart a swirling motion to the air providing a thorough and efficient mixture with the fuel from the burner ring. The operation of the gas burner is controlled by a digital burner management control system. The digital controller provides the proper burner sequencing, ignition and flame monitoring, and works in conjunction with external limit and operating controllers to provide safe burner operation. If a condition occurs outside of the monitored control systems set parameters, the controller will go into a safety shutdown, stopping the boiler from operating and displaying a lockout message on the control display **(Image 2)**. When this occurs the controller will require to be manually reset before the boiler can be restarted. The manual reset feature is a

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	means to alert the operator of an unsafe condition and allow for diagnosis and repair so the boiler can be safely put back into operation. The owner of the boiler has a service and maintenance program. The program includes a logbook to record the three daily safety checks and a computer program that automatically creates work orders for scheduled maintenance items. The work orders are created at timed intervals aligned with the manufacture's specifications. The work orders are carried out by qualified employees and signed off by a maintenance supervisor. If a work order is not completed within an allotted timeframe then the work order gets escalated to a higher priority.
Failure scenario(s)	Required routine maintenance procedures were skipped which resulted in an excessive ignitor spark gap along with a degraded pilot gas regulator which contributed to an unstable pilot flame. The burner ring housing, inside the boiler, had deteriorated from flame impingement which produced a large hole in place of the precise gap resulting in an uneven distribution of gas and an inconsistent air/fuel ratio in the combustion chamber. March 13, 2019 - The deteriorated burner ring was identified during the boiler's annual maintenance inspection by a contractor, but was put back into service due to the repair parts being unavailable for immediate replacement. The contractor provided a recommendation to repair the deteriorated burner ring "*as soon as possible*". The boiler was not repaired and remained in operation for another seven months further degrading the burner ring assembly. October 19, 2019 - The boiler stopped operating resulting in a boiler control safety shutdown and lockout. The controller was manually reset and the boiler was restarted and put back into operation. October 21, 2019 - The boiler stopped operating again resulting in a boiler control safety shutdown and lockout. The controller was manually reset and the boiler restarted. The pilot and main burner ignition characteristics were viewed from the door sight glass and an unstable pilot flame was observed. The boiler was cycled again, this time with stable pilot and main burner ignition, and the boiler was put back into operation. October 23, 2019 - The boiler stopped operating and the boiler control system went into a safety shutdown and locked out due to a failure of the main burner flame to ignite during its trial for ignition period. A maintenance mechanic reset the controller, and restarted the boiler. Through the site glass on the rear of the boiler the mechanic observed the main flame extinguish while transitioning from low to high fire and the boiler locked out once more. The maintenance mechanic reset the boiler control a second time and the boiler fired and began producing steam. Less than an hour after the boiler was restarted and resumed operation, unburnt gas accumulated inside of the boiler and vent stack. The air/fuel mixture found a source or ignition causing an explosion.
Facts and evidence	Review of the maintenance records for the last two years of the boiler's operation identified multiple work orders for scheduled maintenance procedures that were skipped and signed off by the maintenance supervisor. Notes on the work orders indicate the procedures were skipped as to not interrupt the facilities production **(Figure 1)**. The skipped maintenance procedures were for boiler electrode

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inspections and a main gas valve leak test. There was no evidence of boiler electrode inspection work orders being completed for two years prior to the incident.

The skipped maintenance procedures resulted in a spark gap of 5/16" that was measured after the incident **(Image 9)**. The spark gap exceeds the 3/32" gap size outlined in the work order instructions and the maximum size of 3/16" stated in the boiler manual. The annual service and maintenance inspection in March 2019 by the boiler contractor also failed to identify or adjust the excessive pilot spark gap.

The work orders for the boiler electrode inspections identify that the frequency of the inspections is every 16 weeks and require the boiler to be shut down and burner removed with an estimated boiler down time of 30 minutes.

The Senior Engineering Manager stated that the decision to stop production is made between himself and the Production Manager. A decision was made to not stop production for the skipped scheduled maintenance procedures because they believed the only problem that may arise would be the boiler would quit working. They were relying on the boiler safety system to shut the boiler off and lock out to avoid an unsafe condition. They did not consider the possibility of a hazardous situation occurring due to the skipped maintenance procedures.

The Engineering Supervisor stated that two days prior to the incident, the boiler went into a safety shutdown on a main flame trial for ignition failure. After he reset the boiler and forced a re-lite, he witnessed the pilot flame "*extinguish completely for a fraction of a second three times while the ignitor was sparking. The pilot flame returned after the third extinguish just in time for the main gas valve [to open].*" The extinguishing pilot flame indicates a potential issue with the pilot gas pressure regulator not supplying a consistent supply of gas to the pilot burner.

An independent boiler contractor company was hired to complete the annual service and maintenance for the boiler in March 2019. When the technician arrived to the facility, the boiler had already been shut down and opened up by the facilities employees. The technician's service report noted that the gas housing (burner ring) was damaged **(Images 10-11)** and recommended the replacement of it "*as soon as possible*". The technician contacted his office to see if a new burner ring was in stock for replacement that day, but one was not available and needed to be ordered. The technician stated that he was told that he had to have the boiler operating by the end of the day so production could resume. He stated that he felt a lot of pressure to put the boiler back into operation after identifying the deteriorated burner ring. He feared he may get in trouble, or the company he worked for may lose the service contract if he did not re-install the deteriorated part and put the boiler back into operation. He felt concerned with the financial ramifications to the customer and the hundreds of shift workers that would not be able to work if the boiler wasn't running and production had to stop. He made the decision to reinstall the deteriorated burner ring and worked onsite for 11 hours so he could place the boiler back into operation and production could resume. The technician's service report, noting the findings and the recommendation for the burner ring replacement, was emailed to the customer. The boiler remained in operation in that hazardous state for over seven months until the incident occurred.

The Senior Engineering Manager stated that although they had a copy of the service order and they were aware of the recommended repair, the requested quote for the repair of the burner ring was never given to them from the contractor. The boiler contractor company failing to provide the quote for the repair may have contributed to the repair not being done.

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Statements from the Senior Engineering Manager and Engineering Supervisor state that between October 19–23, 2019 the boiler went into a safety shutdown and locked out four times requiring manual resets to restart the boiler **(Figure 2)**. The burner control lockouts were due to the main flame extinguishing during operation and failures to ignite the main burner off of the pilot flame. The boiler was not shut down to investigate, identify or repair any faults.

A boiler technician with experience installing, servicing and repairing this style of boiler stated that the burner ring provides a precise gap around the outside of the diffuser allowing the gas to pass through it and mix evenly with the air. This provides a uniform air/fuel mixture that can be smoothly ignited from the pilot flame producing a stable main flame. If conditions with the air and fuel inside the boiler are not correct, the flame produced by the burner may come into contact with the metal burner ring. If this happens the metal will overheat, melt and burn back, deteriorating the housing and changing the shape and volume of the opening. When the burner ring deteriorates, a higher volume of the gas will exit through the larger opening, changing how the gas is mixed with the air and potentially altering the air/fuel mixture present at the location of the pilot flame. This could lead to the main flame failing to ignite during the 10 second trial for ignition period programed in the digital burner controller, and result in unburnt fuel accumulating in the flue passages and venting.

After the incident occurred, a mobile temporary boiler was installed so production could resume at the facility. There were no redundant or backup systems in place prior to the incident to allow for production in the facility while the boiler was down for maintenance or repairs.

The manufacturer's operation and service manual includes warnings identified by a symbol which indicates situations that could result in serious personal injury, or death. Two of the warnings in the manual state:

- "**The lockout switch must be manually reset following a safety shutdown. The cause for loss of flame or any other unusual condition should be investigated and corrected before attempting to restart. Failure to follow these instructions could result in serious personal injury or death"**

- **"Do not repeat unsuccessful lighting attempts without re-checking the burner and pilot adjustments. Failure to follow these instructions could result in serious personal injury or death"**

Investigation found the owner and operator of the boiler did not comply with these warnings or instructions prior to the explosion incident.

The manufacturer's operation and service manual provides the following information addressed to owners, operators and/or maintenance personnel:

- **"Operating controls will normally function for long periods of time and we have found that some operators become lax in their daily or monthly testing, assuming that normal operation will continue indefinitely. Malfunctions of controls lead to uneconomical operation and damage and, in most cases, these conditions can be traced directly to carelessness and deficiencies in testing and maintenance."**

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Causes and contributing factors	It's very likely that the decision to continue operating the boiler without completing the recommended burner ring repair, along with the failure to investigate and test the cause of the multiple burner control lockouts in the days prior to the incident, created an irregular air/fuel mixture which failed to ignite from the pilot flame, allowing unburnt gas to accumulate causing the explosion. It's possible that lack of communication regarding the condition of the boiler burner, limited understanding of the potential hazards associated with multiple resets of the safety control, along with pressure to maintain production with only one source of steam were contributing factors to the incident.

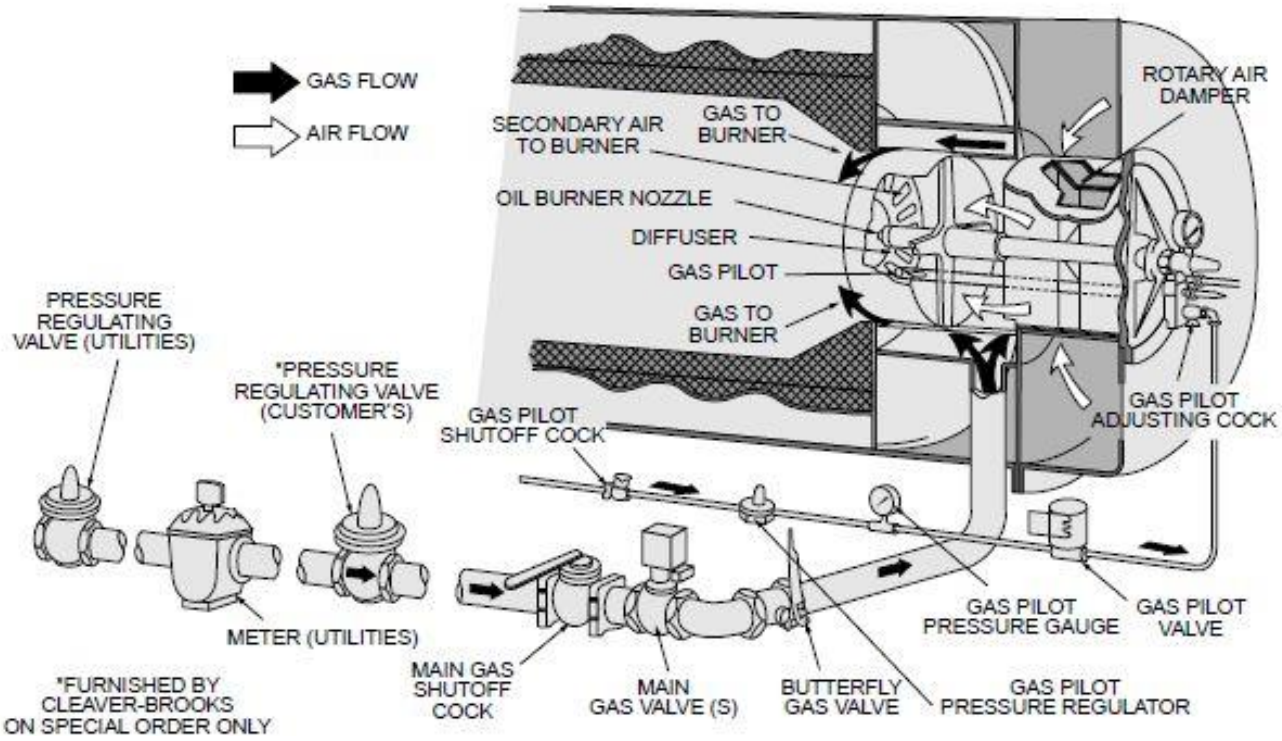

Image 1 - From the boiler manual, showing air and gas flow paths to boiler combustion chamber. The gas flows through the burner ring gap around the diffuser to mix with the air.

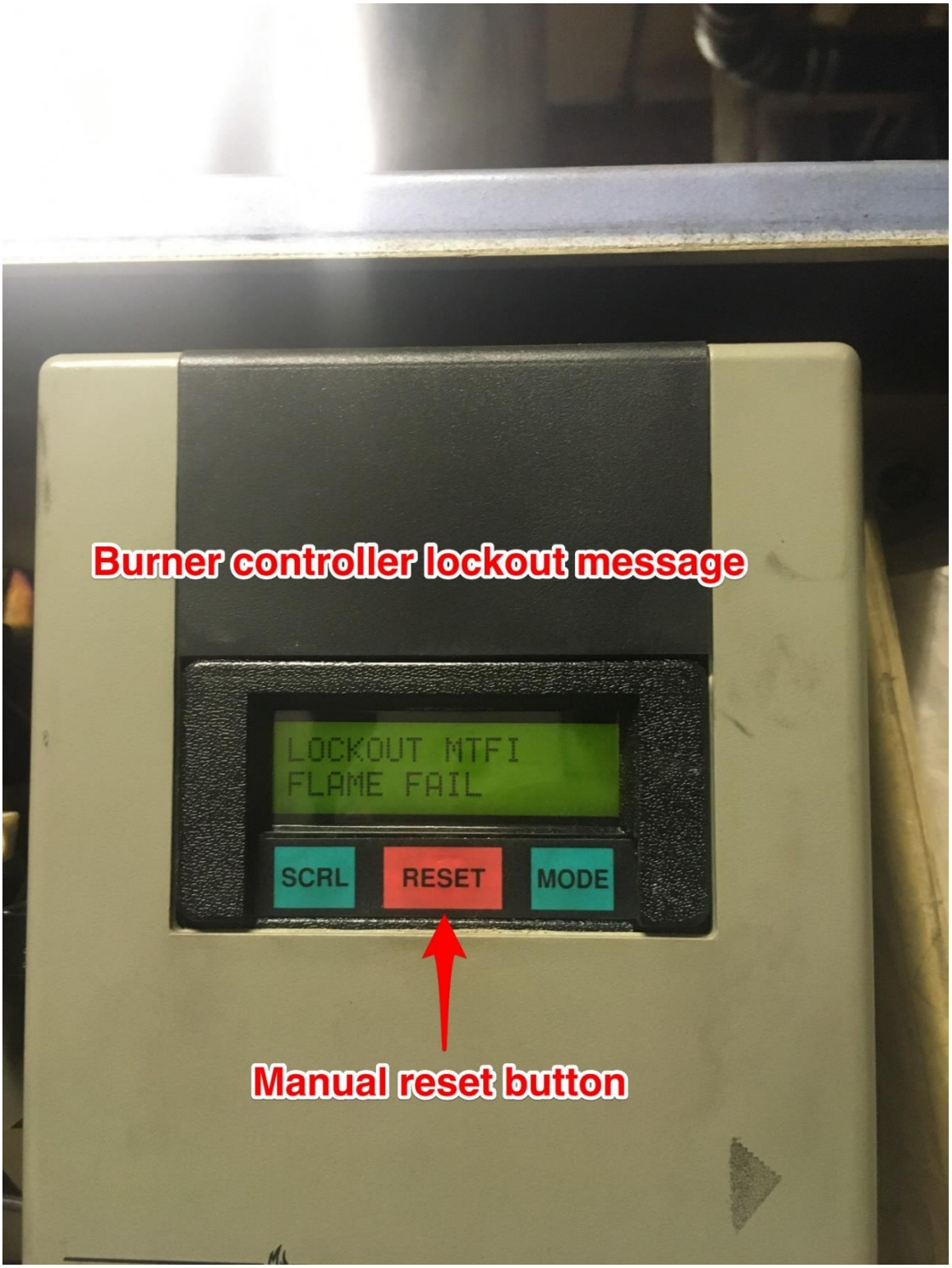

Image 2 - Digital burner controller showing a “main flame trial for ignition failure” after the incident

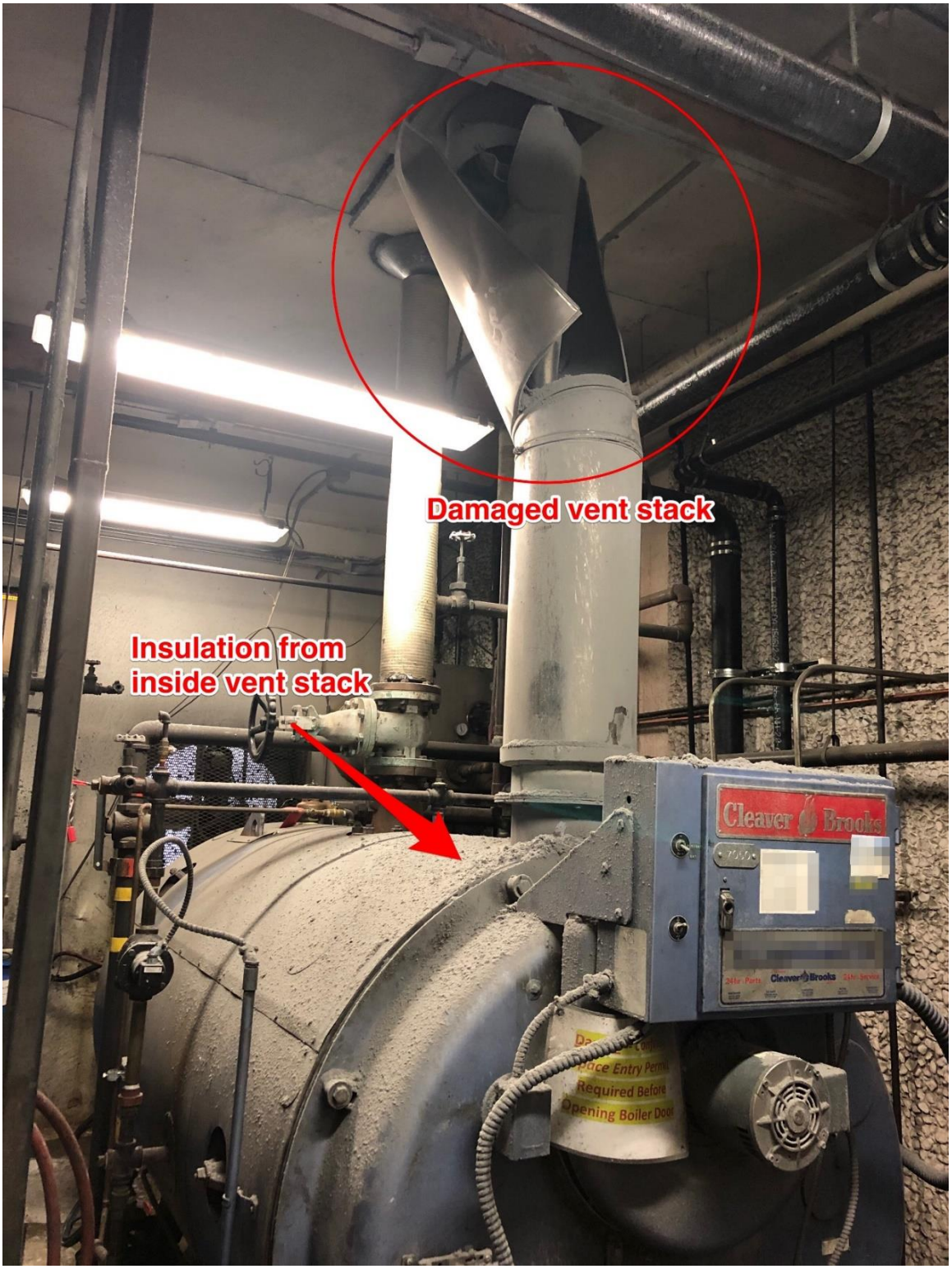

Image 3 - Boiler in mechanical room

Image 4 - Boiler vent stack above boiler

Image 5 - Boiler vent stack at mezzanine above boiler room

Image 6 - Location of vent cap after it was blown off the boiler vent stack by the explosion

Image 7 - Damage to boiler front door

Image 8 - Cracked and broken rear door refractory insulation

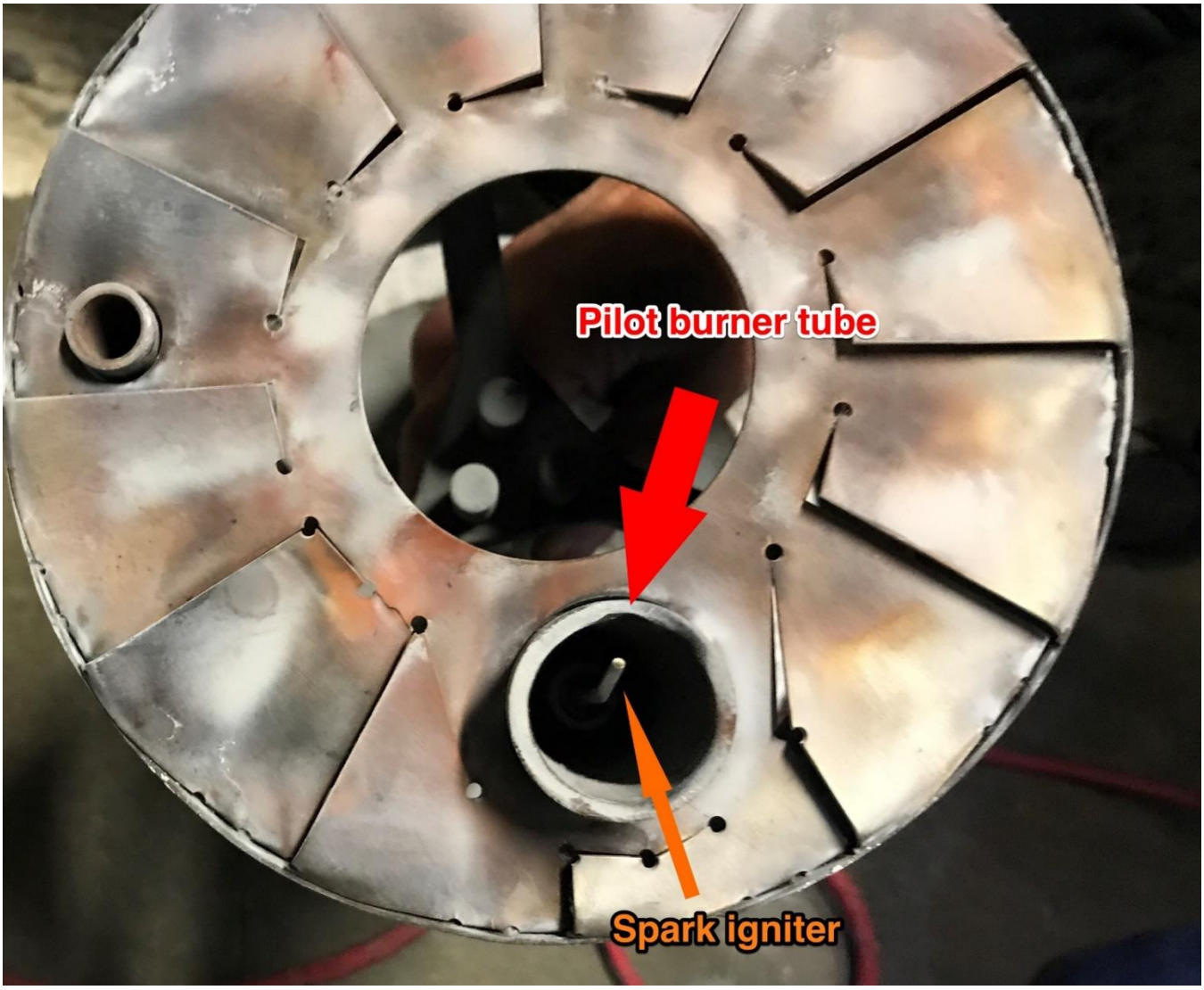

Image 9 – Excessive spark gap in burner tube and diffuser that imparts a rotary swirling motion to the combustion air prior to entering the flame.

Image 10 - Burner housing with deteriorated ring and large gas port opening. The air diffuser gets positioned in the middle circular area of the burner housing.

Image 11 - Burner housing with deteriorated ring and large gas port opening

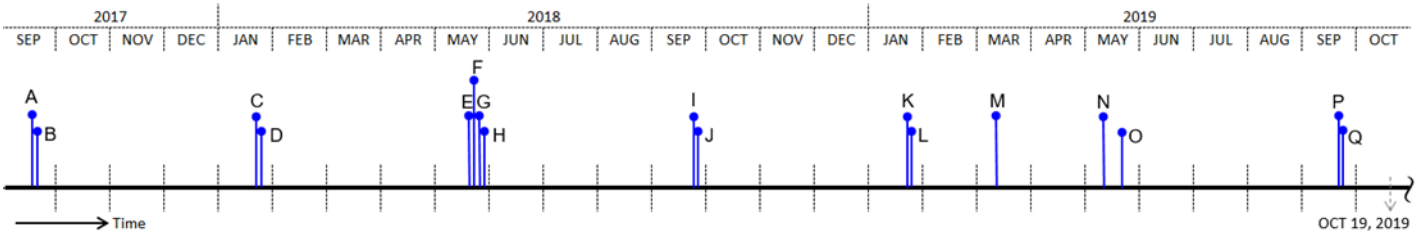

Figure 1 - Event timeline (September 2017 to October 2019). Red X indicates explosion.

Timeline event descriptions

- **A.** **Work order (WO) (17-002855) Boiler electrode cleaning and adjustment**
  WO Note: “Cannot do during [*Preventative Maintenance*] (PM) period. Always in use.”
- **B.** **WO 17-002855 Signed off by supervisor**
  Decision to continue production and skip maintenance was accepted.
- **C.** **WO 17-004993 Boiler electrode cleaning and adjustment**
  WO Note: “Boiler is always in use during this PM cycle. No opportunity for a shutdown. No event of ignition failure. Boiler inspection is coming soon.”
- **D.** **WO 17-004993 Signed off by supervisor**
- **E.** **WO 17-006973 Boiler electrode cleaning and adjustment**
  WO Note: "Cannot do electrode inspection this PM period. Always running production."
- **F.** **WO 17-006973 Signed off by supervisor**
- **G.** **WO 17-006276 Main gas valve leak test**
  WO Note: “Cannot do this main gas valve check this PM period. Always running production & cannot shut down boiler for gas leak test.”
- **H.** **WO 17-006276 Signed off by supervisor**
- **I.** **WO 17-008899 Boiler electrode cleaning and adjustment**
  WO Note: “Cannot shut down boiler to check electrode. Running productions. No failure to ignite within the last two weeks.”
- **J.** **WO 17-008899 Signed off by supervisor**
- **K.** **WO 17-010711 Boiler electrode cleaning and adjustment**
  WO Note: “Cannot check boiler electrode for this PM period. Running production on three lines, cannot shut down boiler.”
- **L.** **WO 17-010711 Signed off by supervisor**
- **M.** **Service report WO#10687** Annual service and inspection completed by third-party contractor.
  Service report note: “Gas housing damaged and requires replacement as soon as possible, parts need to be ordered… Back door in poor condition, should be replaced or rebuilt. Mod motor making grinding noise and should be replaced.”
- **N.** **WO 17-012492 Boiler electrode cleaning and adjustment**
  No comments or indication that cleaning and/or adjustment was completed.
- **O.** **WO 17-012492 Signed-off by supervisor**
- **P.** **WO 17-014238 Boiler electrode cleaning and adjustment**
  WO Note: “No recent failures of ignition recorded. Cannot perform electrode check due to production, boiler in use.”
- **Q.** **WO 17-014238 Signed off by supervisor**

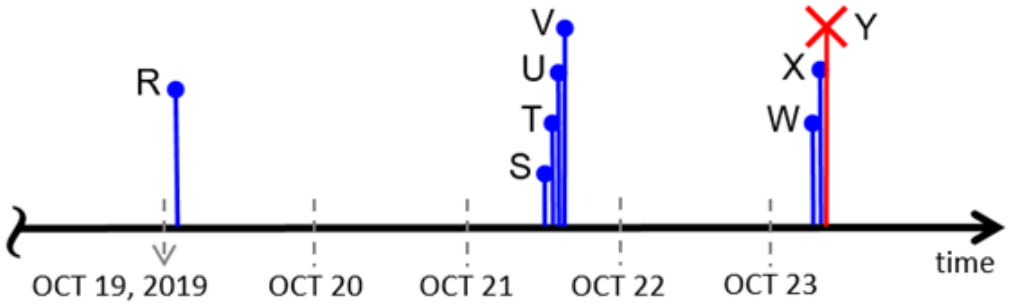

Figure 2 - Event timeline (October 19-23, 2019) Red X indicates explosion

Timeline event descriptions

- **R.** Boiler operation stopped by safety control. Controller manually reset and boiler placed back into operation.
- **S.** Boiler operation stopped by safety control. Controller manually reset and boiler placed back into operation.
- **T.** Engineering supervisor notified the Senior Engineering Manager of the boiler flame failure and lock-out condition.
- **U.** Engineering supervisor observed an inconsistent gas supply to pilot flame and informed the Senior Engineering Manager.
- **V.** Senior Engineering Manager visually observed the gas flame. The boiler was allowed to continue operating without further testing or examination
- **W.** Boiler operation stopped by safety control. Controller manually reset and boiler placed back into operation.
- **X.** Boiler operation stopped by safety control. Controller manually reset and boiler placed back into operation.
- **Y.** Explosion occurred