THE SEWERAGE AND WATER BOARD OF NEW ORLEANS

CARROLLTON WATER PLANT
TURBINE GENERATOR 5 EXPLOSION INCIDENT
December 14, 2019
CAUSAL ANALYSIS AND RECOMMENDATIONS
FINAL REPORT

30 November 2020

PS-4429639

Contract: 0001505

Submitted by:

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ABS Group

NOTICE

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ABSG Consulting Inc. and its employees, subcontractors, consultants, and other assigns cannot, individually or collectively, predict what will happen in the future. The investigation team made a reasonable effort, based on the information and scope of work provided by personnel, to help identify mechanical and operational deficiencies that caused the Turbine Generator 5 explosion of December 14, 2019.

The Sewerage and Water Board of New Orleans should recognize that there may be other risks not addressed in this report. Regardless of what actions are taken in response to the information contained in this report, the potential exists for accidents and other abnormal events to occur. ABSG Consulting Inc. accepts no liability for any incident or regulatory action (international, federal, state, or local) that occurs with the Sewerage and Water Board of New Orleans power generating turbines, even if all the recommendations resulting from this incident investigation are thoroughly addressed.

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EXECUTIVE SUMMARY

The Sewerage and Water Board of New Orleans (SWBNO) relies upon a set of five turbine generators to power water supply and storm water drainage pumps. On December 14, 2019 Turbine Generator 4 (TG 4) experienced a loss of steam pressure due a loss of compressed air in the boiler room resulting in TG 4 shutting down. It was necessary to bring Turbine Generator (TG) 5 online to replace the power generation that had been provided by TG 4. During startup of TG 5, an explosion occurred resulting in damage to parts of the TG 5 system, minor injuries to some SWBNO personnel, and limited damage to offsite structures.

ABSG Consulting Inc. (ABS Group) was contracted by SWBNO to conduct an investigation of the December 14, 2019 TG 5 explosion with the following objectives:

- Determine causal factors of the December 14, 2019 incident
- Develop recommendations to minimize potential for future occurrence

METHODOLOGY

The causal analysis investigated and analyzed the proximate causes (i.e., equipment and front-line personnel performance gaps, also referred to as causal factors) of the loss event; including their origin, relationship to other causal factors and how they collectively caused the loss event. This investigation scope did not include identification of root causes of each causal factor. Therefore, recommended corrective actions are offered to address identified causal factors only.

CAUSE AND EFFECT TREE

The December 14th TG 5 explosion was analyzed using a Cause and Effect Tree (CAET), which is a logic-based flow chart that describes potential combinations of conditions and events that contributed to the loss event. It indicates how the causal factors combined to cause the loss event. The CAET is useful for documenting the confirming and contradicting evidence for each potential causal factor and establishing the plausibility of each.

DEFINING THE LOSS EVENTS

For purposes of the investigation, a loss event is defined as an unplanned event or incident with consequences that are a deviation from a normal or optimal performance or outcome that might otherwise be expected under similar circumstances. The “loss event” for this investigation was an explosion that occurred during a startup attempt of TG 5 at approximately 13:47 hours on December 14, 2019. During the firing attempt, TG 5 exploded resulting in damage to the turbine. As of the writing of this report (30 November 2020) TG 5 remained out of service.

SCHEDULE

ABS Group prepared a preliminary list of data requested for the investigation and transmitted to SWBNO on February 21, 2020. Investigation milestones occurred on the following dates:

- December 22-23, 2019 — ABS Group incident scene orientation and investigation scoping at SWBNO
- March 20, 2020 — ABS Group receipt of assembled background information from SWBNO
- April 14 – May 05, 2020 — Witness interviews
- May 26 – May 27, 2020 — Documentation of as-found conditions of equipment
- July 14 – July 16, 2020 — TG 5 Startup Simulation Testing
- August 25, 2020 — Briefing of causal analysis results and recommendations

SPECIFIC CAUSAL FACTORS & RECOMMENDATIONS FOR CORRECTIVE ACTION

The causal factors of the loss event as identified based on a CAET analysis of the events is provided below.

Causal Factor 1:

The control air supply to the gas pressure ratio pilot valve (VPR-10) was 30 psi, 10 psi above the specified value of 20 psi +/- 0.5 psi.

Causal Factor 2:

The gas pressure ratio pilot valve fuel gas pressure offset at zero Compressor Discharge Pressure (CDP) was ~20 psi above specified value of 6 psi.

Causal Factor 3:

The gas pressure ratio pilot valve was slow to adjust to inputs and to command the gas pressure ratio (Leslie) valve to close.

Causal Factor 4:

The fuel gas supply ¼-turn shutoff valve may not have been opened until after the operation selector switch was set to auto (i.e., the valve may have been opened out of sequence).

Causal Factor 5:

The gas pressure ratio valve was slow to adjust to the pilot control signals to close.

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CORRECTIVE ACTIONS TO ADDRESS LOSS EVENT CAUSAL FACTORS

The following are recommended procedural and operational changes that the Sewerage and Water Board of New Orleans should consider to address the causal factors identified for the December 14, 2019 TG 5 explosion.

Recommendation #1:

Set and maintain gas pressure ratio pilot valve control air to the correct value.

Causal Factors Addressed:

Causal Factor 1: The control air to the gas pressure ratio pilot valve (VPR-10) was set 10 psi above the specified value of 20 psi +/- 0.5 psi

Recommendation #2:

Develop and use management of change to control and maintain future changes to the control system.

Causal Factors Addressed:

Causal Factor 1: The control air to the gas pressure ratio pilot valve (VPR-10) was set 10 psi above the specified value of 20 psi +/- 0.5 psi

Causal Factor 2: The gas pressure ratio pilot valve zero fuel gas pressure offset was ~20 psi above specified value of 6 psi.

Recommendation #3:

Set and maintain gas pressure ratio pilot valve to proper zero CDP fuel gas pressure offset for operation of TG 5.

Causal Factors Addressed:

Causal Factor 2: The gas pressure ratio pilot valve zero fuel gas pressure offset was ~20 psi above specified value of 6 psi.

Recommendation #4:

Requalify both the gas pressure ratio valve and pilot to specified operation by a certified vendor.

Causal Factors Addressed:

Causal Factor 3: The gas pressure ratio pilot valve was slow to control the gas pressure ratio valve.

Causal Factor 5: The gas pressure ratio valve was slow to adjust to pilot control signal.

Recommendation #5:

Replace both the gas pressure ratio valve and pilot with a modern gas ratio valve and controller.

Causal Factors Addressed:

Causal Factor 3: The gas pressure ratio pilot valve was slow to control the gas pressure ratio valve.

Causal Factor 5: The gas pressure ratio valve was slow to adjust to pilot control signal.

Recommendation #6:

Add the following permissives to begin the startup sequence (e.g., to start the automatic startup sequence when the master control switch is turned to the start position).

- Fuel supply ¼-turn shutoff valve open
- No combustible gas in exhaust duct near combustion chamber prior to onset of firing

Causal Factors Addressed:

Causal Factor 4: The fuel gas supply ¼-turn shutoff valve may not have been opened until after Operation Selector Switch set to auto.

Recommendation #7:

Perform HAZOP of the TG 5 control system to identify and mitigate potential excessive fuel flows during the startup sequence.

Causal Factors Addressed:

Causal Factor 4: The fuel gas supply ¼-turn shutoff valve may not have been opened until after Operation Selector Switch set to auto.

Recommendation #8:

Add the following permissive to begin the startup sequence (e.g., to start the automatic startup sequence when the master control switch is turned to the start position).

- Gas pressure ratio valve closed

Causal Factors Addressed:

Causal Factor 5: The gas pressure ratio valve was slow to adjust to pilot control signal.

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1 INTRODUCTION

The Sewerage and Water Board of New Orleans (SWBNO) relies upon a set of five turbine generators to power water supply and storm water drainage pumps. A summary of the SWBNO power generation turbines is provided in Table 1[1]. On December 14, 2019, Turbine Generator (TG) 4 experienced a loss of steam due to loss of compressed air from the boiler room resulting in TG 4 shutting down. It was necessary to bring TG 5 online to replace the power generation that was being provided by TG 4. During startup of TG 5, an explosion occurred resulting in damage to the TG 5, injuries to the operators in the vicinity of the turbine, and damage to nearby community residential structures.

Table 1. SWBNO Power Generation Assets

Turbine	TYPE	Year	Frequency (Hz)	Power Rating, megawatts (MW)
Turbine Generator 1	Steam turbine	1909	25	6
Turbine Generator 3	Steam turbine	1929	25	15
Turbine Generator 4	Steam turbine	1915[1]	25	20
Turbine Generator 5	Dual fuel turbine	1958[2]	25	20
Turbine Generator 6	Dual fuel turbine	1981	60	20
			25	6

[1] Refurbished 2017
[2] Forced Outages 2017 and 2019

ABS Group was contracted by SWBNO to determine the causal factors of the TG 5 explosion that occurred during startup of the turbine on December 14, 2019 and to develop recommendations based upon the causal factors to minimize the potential for future recurrence.

1.1 THE LOSS EVENT

On December 14, 2019 at approximately 13:47 hours, an explosion during startup of TG 5 occurred during the first firing attempt at the SWBNO Carrollton Water Plant resulting in damage to parts of the turbine. As of the delivery of this report (30 November, 2020) TG 5 remained out of service.

1.2 THE INVESTIGATION TEAM

An investigation team was organized that included personnel from ABS Group and SWBNO. The ABS Group investigation team members and the SWBNO investigation project manager are identified in Table 2.

[1] Sewerage & Water Board System Overview Presentation, January 2018.
[2] Sewerage & Water Board Power Generation and Drainage System FAQs, 14 August 2017.

Table 2. Incident Investigation Team

Name	Organization	Title
Ben Harrison, P.E.	ABS Group	Lead Investigator
Charles Vergara	ABS Group	Supporting Investigator
Lee Vandenheuvel	ABS Group	Investigations Manager
Darrell Barker, P.E.	ABS Group	Project Manager Customer Service Representative
Tommy Moore	SWBNO	SWBNO Project Manager

1.3 INVESTIGATION AND DATA COLLECTION

ABS Group personnel met with SWBNO personnel at the Carrollton Water Plant in New Orleans on December 22, 2019, eight days after the December 14 incident, to establish the scope of the investigation and to gain a fundamental understanding of the events leading up to the incident. On March 2, 2020, ABS Group received notice from SWBNO to proceed with the following activities:

- Determine causal factors of the December 14, 2019 incident
- Develop recommendations to minimize potential for future occurrence

Investigation milestones occurred on the following dates:

- March 20, 2020 Receipt of assembled background information from SWBNO
- April 14 – May 05, 2020 Witness interviews (performed remotely)
- May 26 – May 27, 2020 Documentation of as-found conditions of equipment (onsite)
- July 14 – July 16, 2020 TG 5 Startup Simulation Testing (onsite)
- August 25, 2020 Briefing of causal analysis results and recommendations (remotely)

ABS Group interviewed eleven SWBNO personnel six from Operations, one from the Mechanical Shop, three from the Electrical Shop, and one from the Instrument Shop. Operations interviews included the operator starting TG 5 on the date of the incident, the supporting operators who were shutting down TG 4 on the date of the incident, and the operator who started the TG 5 successfully on December 12th (the last successful startup of TG 5 prior to the incident).

1.4 METHODOLOGY

The causal analysis investigated and identified the failures (i.e., equipment performance gaps and front-line personnel performance gaps) contributing to the explosion of TG 5 on December 14, 2019 (the loss event). These performance gaps are referred to as causal factors (CF). Once these causal factors are identified, factors contributing the performance gaps are developed through analysis of the data and interviews with personnel. These contributing factors are often referred to as intermediate causes and typically include performance gaps in design, maintenance, documentation, materials/parts, hazard/defect identification, procedures, human factors, training, supervision, communication, personnel performance, and external factors. The investigation team used ABS Group's proven

SOURCE™ (Seeking Out the Underlying Root Causes of Events) methodology for the causal analysis[3]. Root cause determination was not part of the scope of this effort, but the underlying methodology is similar.

1.5 CAUSE AND EFFECT TREE

One analysis technique used for evaluation of the TG 5 explosion was a Cause and Effect Tree (CAET). This technique lays out the causal and intermediate factors on a logic tree that describes potential combinations of conditions and events that contributed to the loss event. The branches in the CAET are colored-coded based upon the plausibility of the event. Plausibility is the likelihood that the postulated event occurred and contributed to the incident. Red events are very highly plausible, and green are very low as shown in Figure 1. Plausibility is based upon:

- Confirming Data – supports the occurrence and contribution of the potential cause – pushes towards red
- Contradicting Data – refutes the occurrence and contribution of the potential cause – pushes towards green

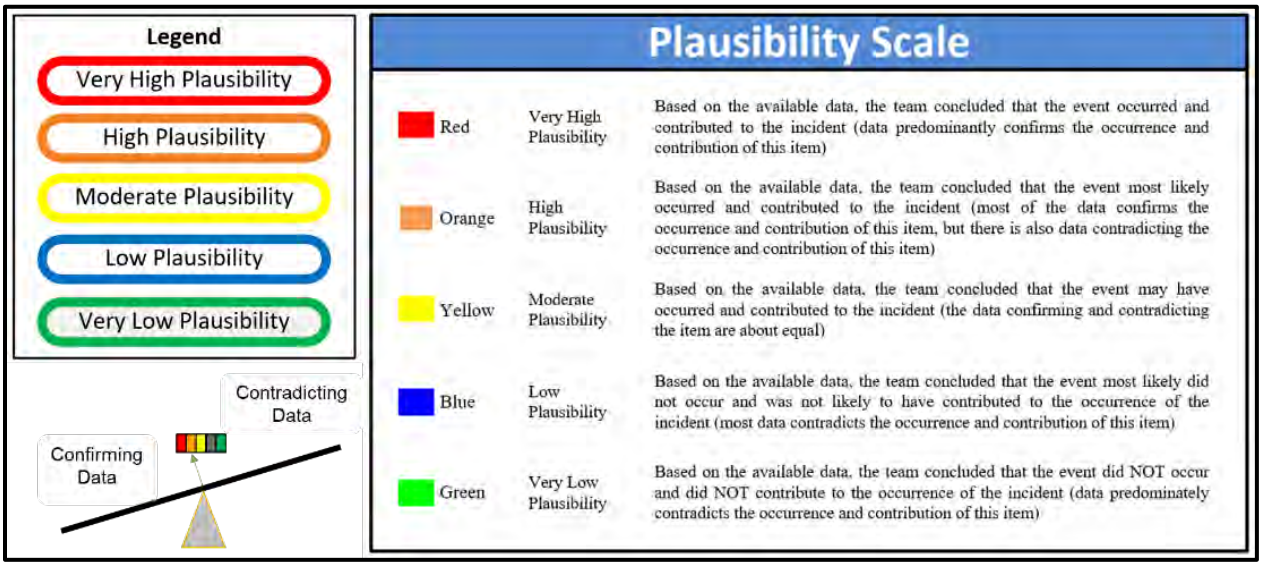


Figure 1. CAET Plausibility

Causes are tied to effect(s) through AND gates and OR gates. AND gates are utilized whenever a combination of events is required to cause the effect that is above the AND gate. The effect carries the lowest plausibility of the connected causes because all of the connected causes are required to occur to create the effect. OR gates are utilized whenever any one of the possible causes may result in the effect above the gate; therefore, the effect shows the highest plausibility of any of the potential causes since any single cause may result in the effect.

[3] Vanden Heuvel, Lee et al., "Root Cause Analysis Handbook", ABS Consulting, Rothstein Associates Inc Publishers, 2008.

The top of the CAET for this loss event is shown in Figure 2. The box colors indicate the plausibility of the event listed in the box occurred and contributed to the loss event. The detailed CAET considered a wide range of potential contributing events, including equipment failures and personnel performance failures. An intermediate level CAET is shown in Figure 3 and a detail level in Figure 4. The complete detailed CAET provided in larger format is included in Appendix B.

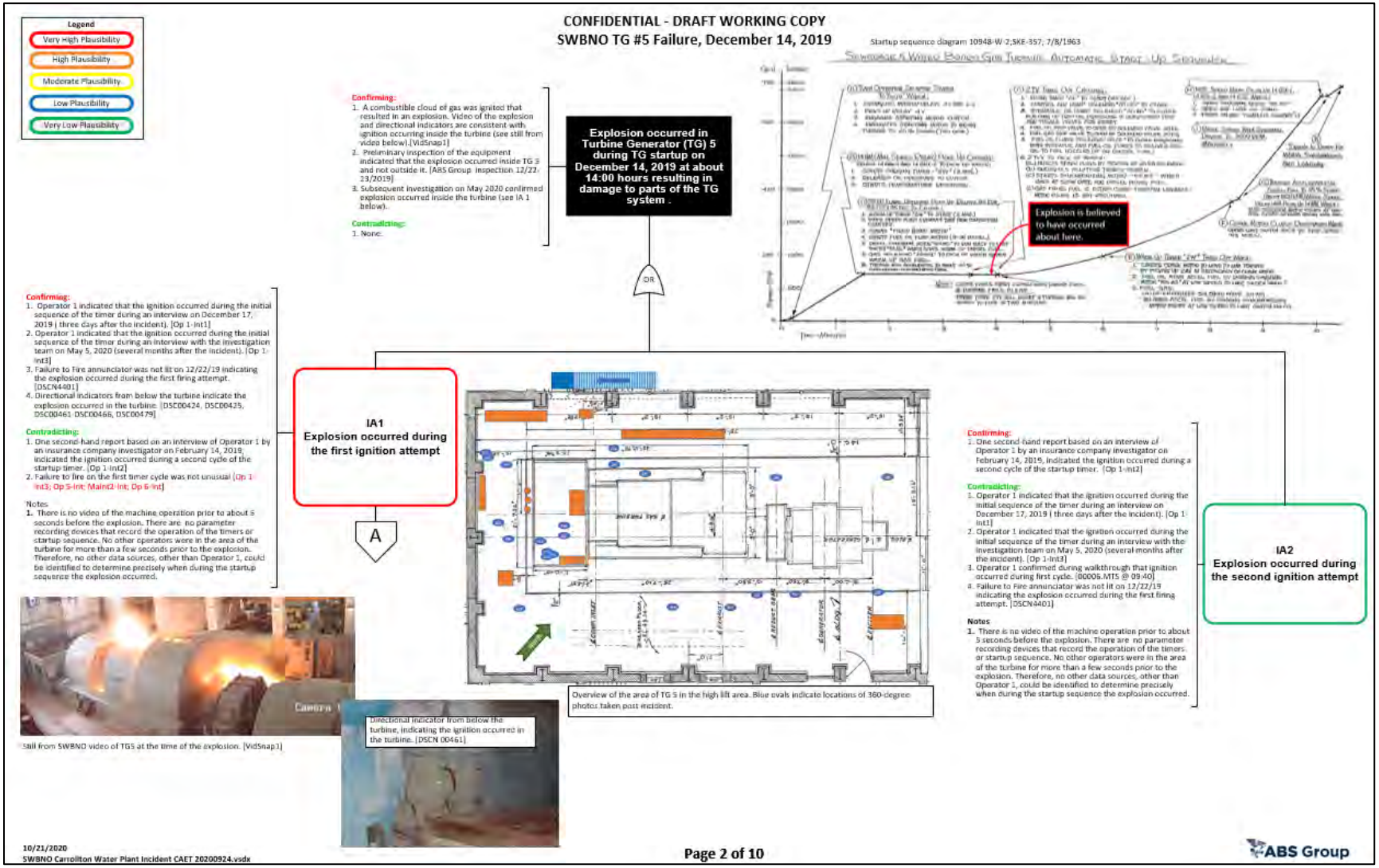


Figure 2. Top Level Cause and Effect Tree

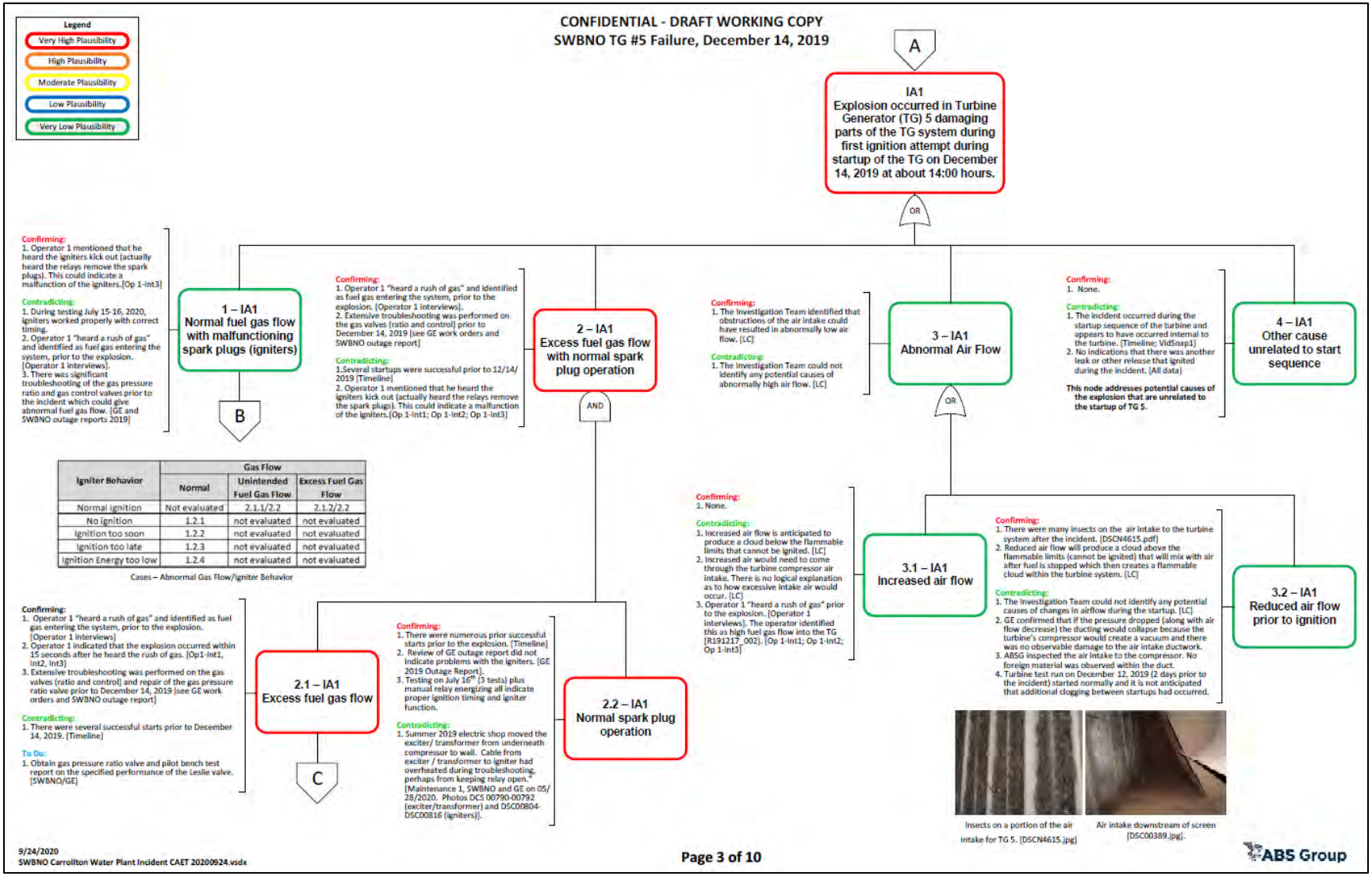


Figure 3. Intermediate Level Cause and Effect Tree

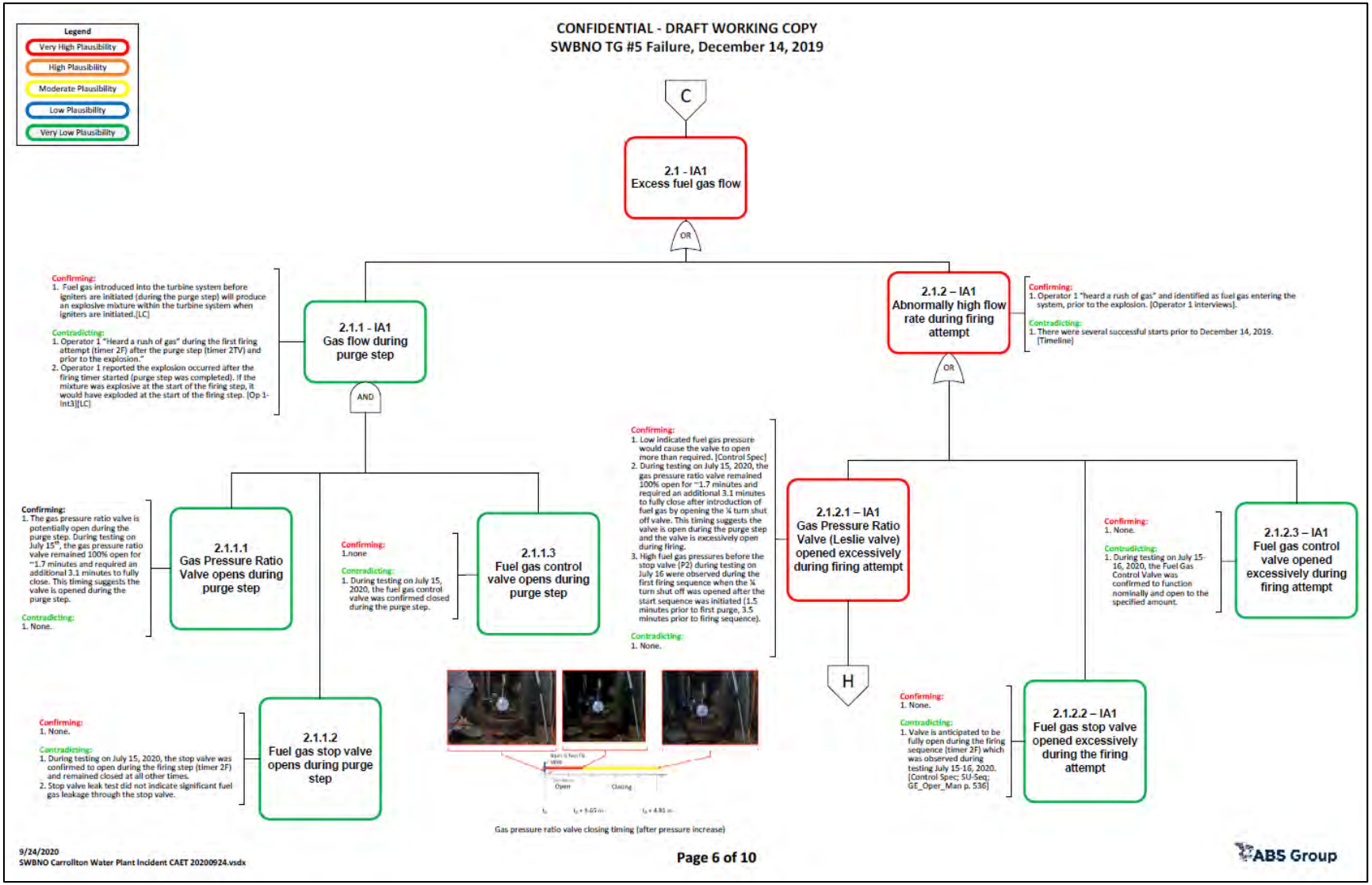


Figure 4. Detailed Level Cause and Effect Tree (Partial)

1.6 TIMELINES

The second technique used in the causal analysis is an event timeline. The timeline establishes the temporal relationships of equipment and personnel and is important to understand the causes for the explosion. A detailed timeline is provided in Appendix A.

1.7 ANALYSIS

The project team used the data collected to confirm or contradict each of the potential causes developed in the CAET. Analyses were conducted principally in the following areas:

- TG 5 Controls
- TG 5 Operation
- TG 5 Combustion
- Combustion Air
- Combustion Fuel Gas
- Ignition

A matrix of combustion abnormalities was created to summarize the evaluation of combination scenarios as depicted in Table 3 for igniter behavior and fuel gas flow.

Table 3. Turbine Generator 5 Combustion Scenario Matrix (CAET Branches)

Spark Plug Behavior	Gas Flow		
	Normal	Unintended Fuel Gas Flow	Excess Fuel Gas Flow
Normal Ignition	Not Evaluated	2.1.1/2.2	2.1.2/2.2
No Ignition	1.2.1	Not Evaluated	Not Evaluated
Ignition Too Soon	1.2.2	Not Evaluated	Not Evaluated
Ignition Too Late	1.2.3	Not Evaluated	Not Evaluated
Ignition Energy Too Low	1.2.4	Not Evaluated	Not Evaluated

An evaluation of each of these topics is provided in Section 5. Data and results of the analysis is included in the appendices.

2 TURBINE GENERATOR 5 DESCRIPTION AND STARTUP PROCESS

Turbine Generator 5, Serial No 127724, was approved for construction in 1959 and in 1960 General Electric (GE) published instruction GEI-40960[4], which contains the instructions and recommended procedures for the operation, service, and maintenance of the turbine. GEI-40960 describes TG 5 as an open simple-cycle, one-shaft design with in-line arrangement of its components. The unit consists of three basic components; the axial-flow compressor, the combustion chambers, and the turbine, as depicted in Figure 5, which is connected to generator serial number 8300411.

The gas turbine-generator is started by a cranking motor. When the cranking motor gets the unit up to approximately 20% speed (750 rpm), the turbine initiates a purge sequence and then spark plugs are initiated and fuel is introduced into the combustion chamber where the spark plugs ignite the fuel/air mixture. The cranking motor assists the turbine up to 50% to 60% of rated speed at which time the cranking motor clutch is disengaged. The unit then accelerates to operating speed on governor control and is available for loading.

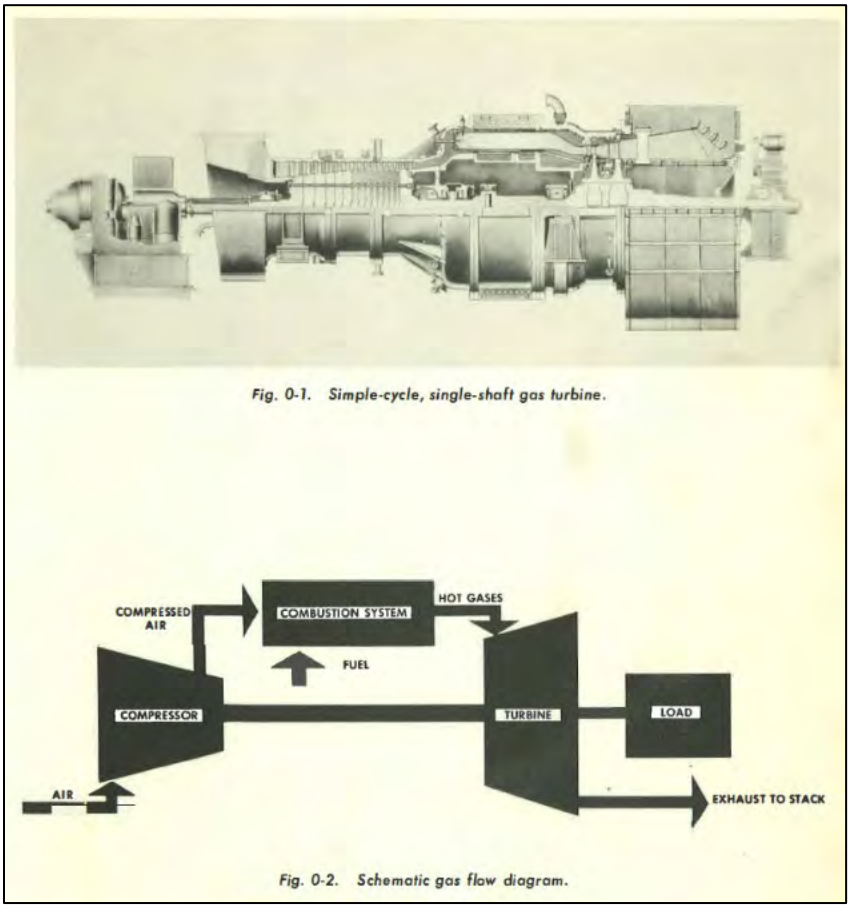


Figure 5. Turbine Generator 5 Cutaway and Schematic Gas Flow Diagrams

[4] GEI-40960, "Gas Turbine-Generator Unit 20,200 KW Gas Turbine No. 127724, Generator NO. 8300411", Sewerage and Water Board of New Orleans Purchaser's Order NO 198-W, Gas Turbine Department General Electric, Schenectady, N.Y., 1960.

The startup sequence and operation of control relays is described in GEI-77036A[5], (starting on page 535 of GEI-40960). The start-up sequence in GEI-77036A is not enumerated here; however, the SWBNO Automatic Start-Up sequence diagram, SWNO DWG No 10948-W-2 is provided in Figure 6. The SWBNO startup sequence is dated July 8, 1963 and was produced three years after GEI-77036A[6].

[5] GEI-77036A, "Gas Turbine Generator 20,200 KW", Medium Voltage Switchgear Department, General Electric, Philadelphia, PA, August 1960.
[6] Sewerage and Water Board of N.O. DWG No. 10948-W-2, "Sewerage & Water Board Gas Turbine Start-Up Sequence", July 8, 1963.

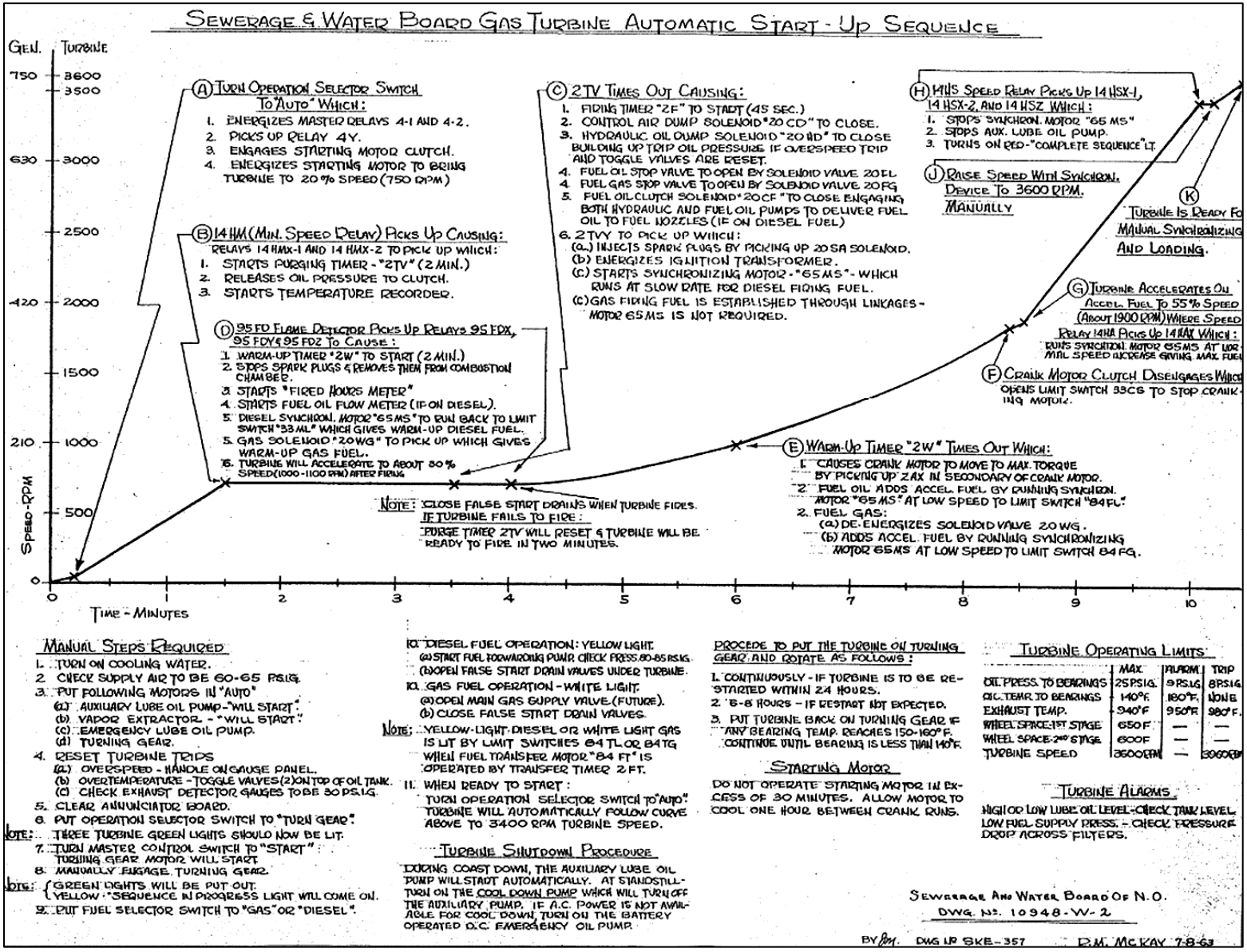


Figure 6. Turbine Generator 5 SWBNO Automatic Start-Up Sequence

2.1 CONTROL SYSTEMS

GEI-40960[4] describes the turbine control system as a mechanical hydraulic control to regulate the speed and load of the unit by controlling the amount of fuel fed to the combustion chambers. The control components, shown in Figure 7, may be described as consisting of the following four basic systems:

- Speed Control System
- Temperature Control System
- Fuel Control System
- Emergency Trip and Protection System

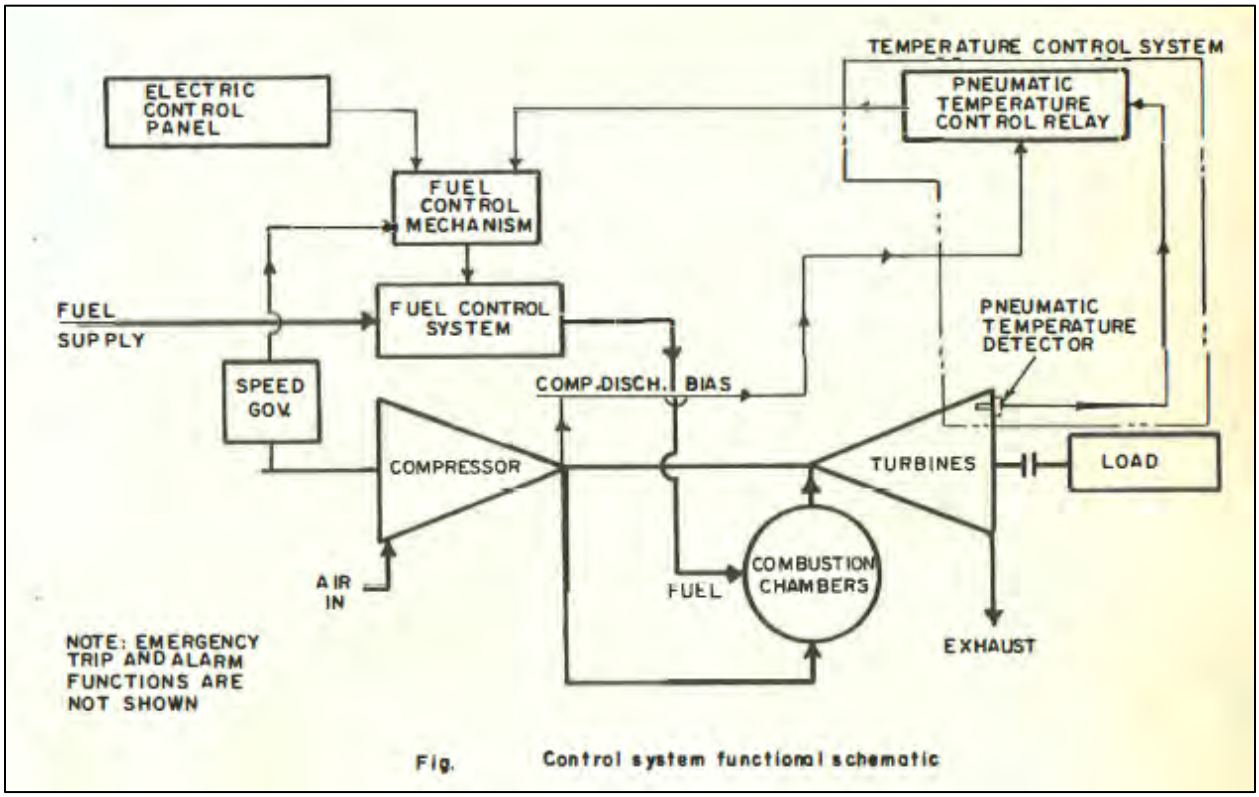


Figure 7. Turbine Generator 5 Control System Schematic Diagram

The starting and fuel limit control is physically part of the fuel control mechanism. Per GEI-40960[4] the starting of the gas turbine is accomplished by means of the minimum fuel relays, the synchronizing device, or speed changer, and the primary relay from signals in the electric control panel.

The primary relay is a hydraulically operated device which amplifies the power of the centrifugal speed governor and integrates their motion through the levers and linkages, shown below in Figure 8, to give the required position signals to the gas control valve.

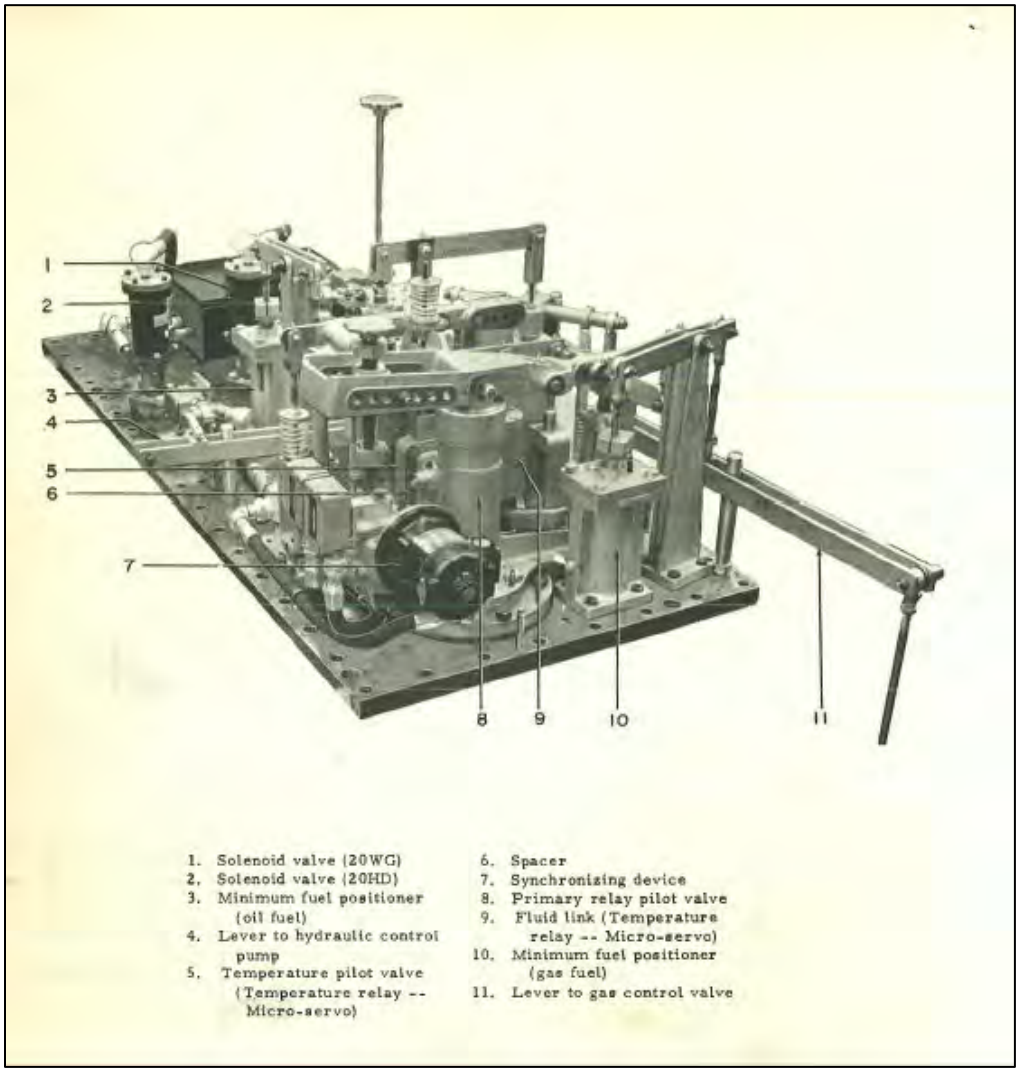


Figure 8. Control Plate and Linkages

2.1.1 ELECTRIC PANEL AND RELAYS

TG 5 control panel is shown below in Figure 9. The control panel incorporates the various switches, relays, timers and other devices which set up the control sequence for starting, accelerating, and running the turbine. The switches and annunciator panel are shown in Figure 9 (a) and the relays and timers in Figure 9 (b). Table 4 provides the layout of the relays and timers.

(a)

(b)

Figure 9. Turbine Generator 5 Control Panel (a) and Relays (b)

Table 4. Turbine Generator 5 Relay Layout (see Figure 9 (b))

4-1	14HM		4-2
4Y	14HMX-1	14HMX-2	2TVY
2FY	95FDX	95FDZ	95FDY
14HSX-1	14HSX-2	3	94
84TLX	84TGX	83FX	63FG-IX
2WX			RPM Indicator
2TV	2F	2W	2FT

2.1.2 PNEUMATIC CONTROLS

Control air is regulated by pressure reducing valves (VPRs), as identified in Table 5. Control air for the temperature control system is in the TG 5 Control Cabinet shown below in Figure 10.

Table 5. Turbine Generator 5 Dry Air VPRs

Name	from	to	P&ID - Sheet	Specified Setting
VPR-2	Referenced on P&ID (916B455-Sheet 7)		916B455-Sheet 7	85 psig
VPR-3	Air Supply	TEMR transmitter	916B455-Sheet 5	20 psig
VPR-4	Air Supply	Butterfly control valve	916B455-Sheet 5	20 psig
VPR-5	Air Supply	Pneumatic Controller	916B455-Sheet 5	20 psig
VPR-6	Air Supply	Pneumatic Controller	916B455-Sheet 5	See Cont. Specs.
VPR-7	Within the pneumatic temperature relay		916B455-Sheet 4	32 psig, $^{+}/_{-}$ 0.5 psi
VPR-8	Air Supply	OT trip	916B455-Sheet 4	62 psig, $^{+}/_{-}$ 0.5 psi
VPR-9	Air Supply	Fuel Gas Control Valve	916B455-Sheet 6	35 psig, $^{+}/_{-}$ 0.5 psi
VPR-10	Air Supply	Gas pressure ratio pilot valve	916B455-Sheet 6	20 psig, $^{+}/_{-}$ 0.5 psi

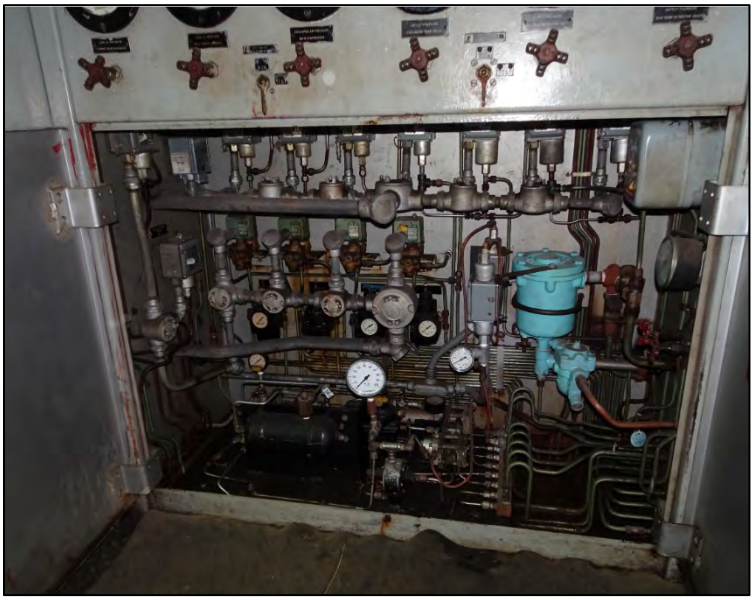


Figure 10. Turbine Generator 5 Control Cabinet

2.1.3 FUEL CONTROL SYSTEM

The fuel control system supplies fuel to the combustion chambers during operation of the turbine after startup in response to turbine speed and turbine temperature based on signals from the speed control system and the temperature control system. During startup of the turbine, the speed changer positions the primary relay directly below the lowest governing speed of the turbine and provides the accelerating fuel strokes require to bring the turbine to the lowest governing speed after startup[4]. This is indicated by the startup position of the fuel gas control valve as set by the primary relay.

The fuel gas is primarily controlled during the turbine ignition by the gas pressure ratio valve (the Leslie valve) and its pilot valve.

2.1.4 COMBUSION SYSTEM COMPONENTS

2.1.4.1 COMPRESSOR AIR INTAKE AND EXHAUST SYSTEM

The Carrollton Water Plant High and Low Lift buildings where TG 5 are located is shown in Figure 11. Eagle Street is located to plant west and Spruce St. to plant south of the building. The air intake is located to plant south of the High Lift Pump Building and compressor intake air is drawn in and ducted into the turbine from the underside as shown in the elevation of the intake ducting in Figure 12. The compressor exhaust is ducted from underneath the outlet of the turbine to plant east to the tall vertical stack as indicated in the turbine compressor exhaust elevation in Figure 13.

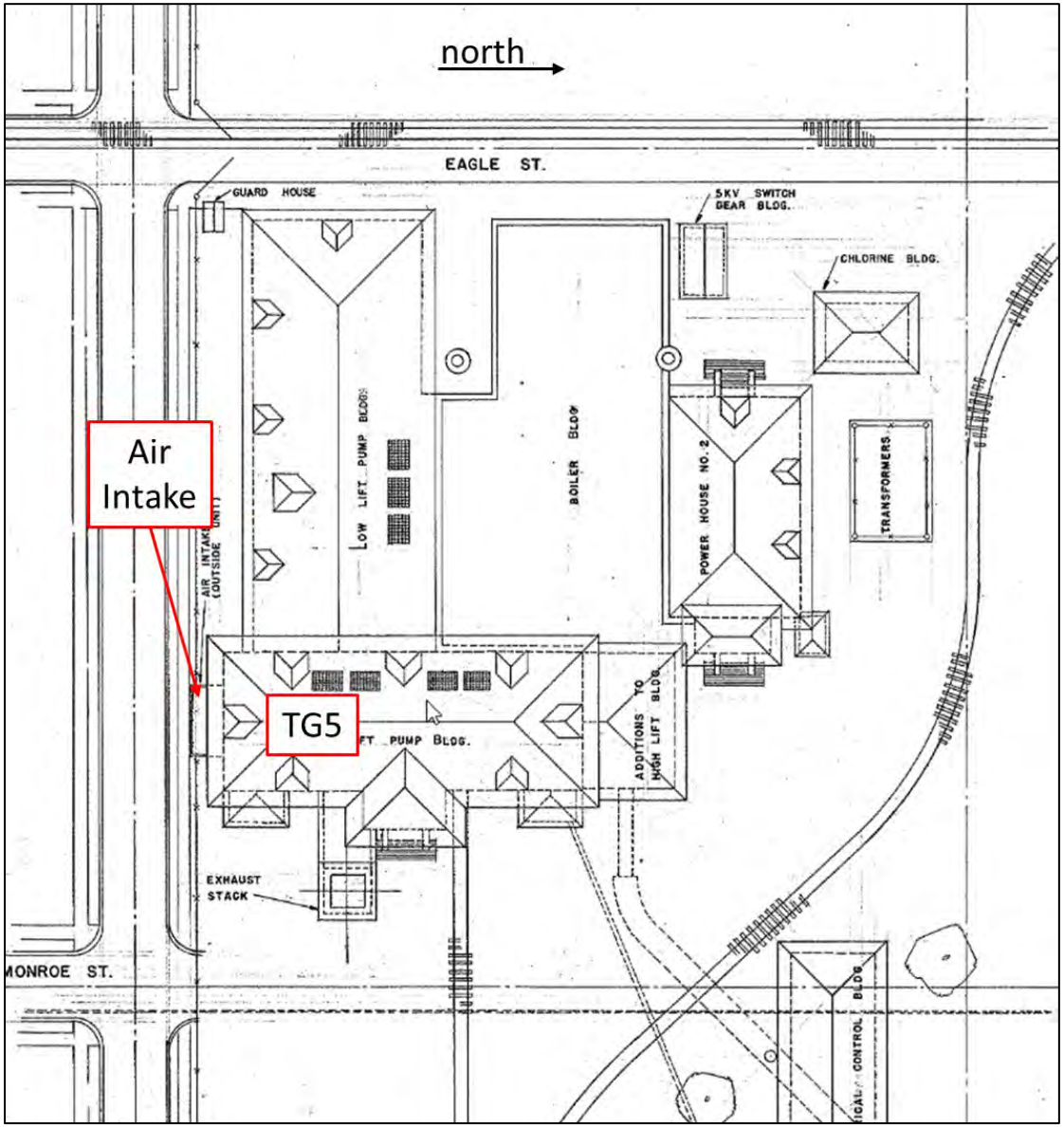


Figure 11. Carrollton Water Plant High and Low Lift Pump Buildings

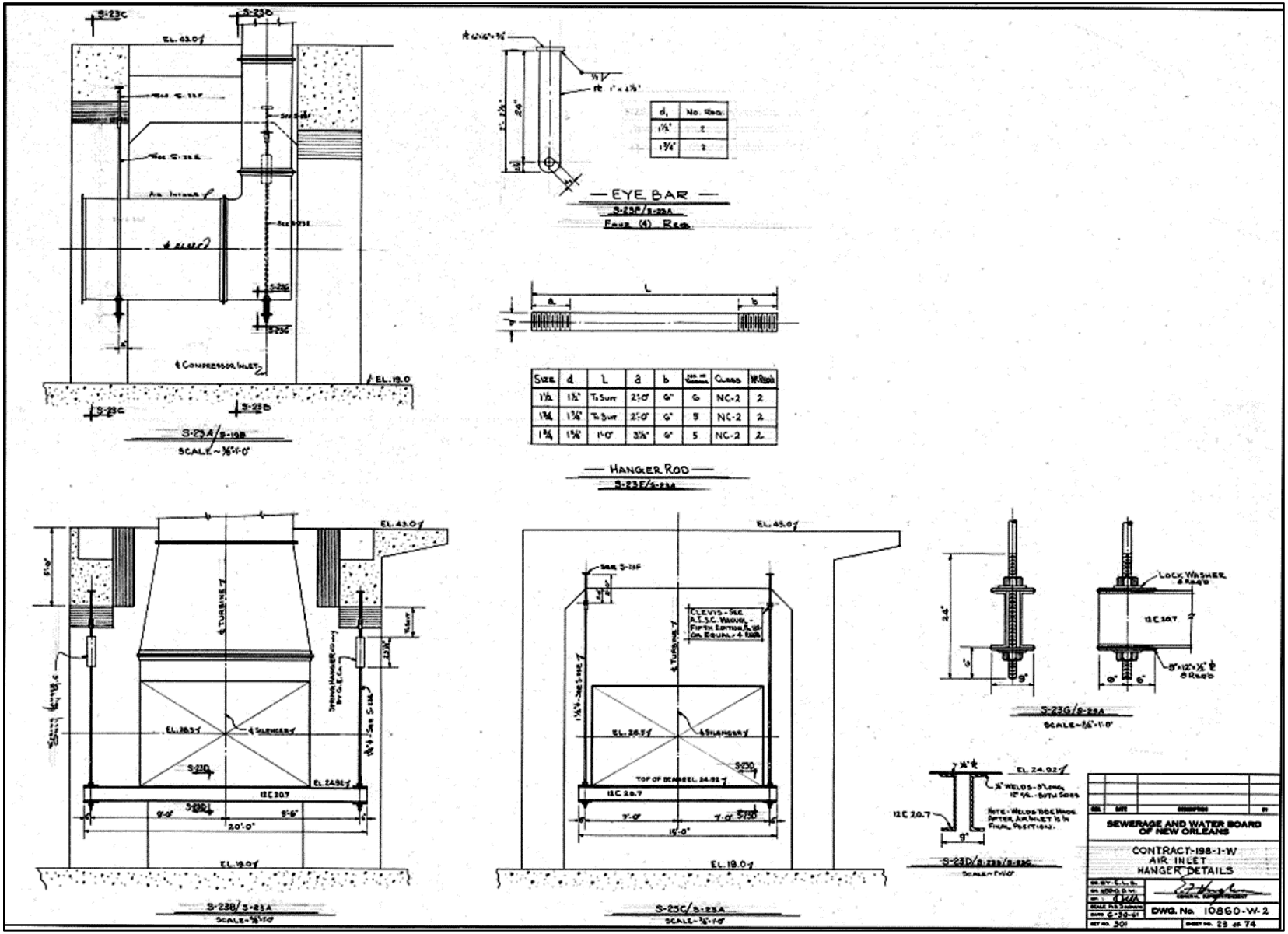


Figure 12. Turbine Generator 5 Compressor Air Intake Elevation

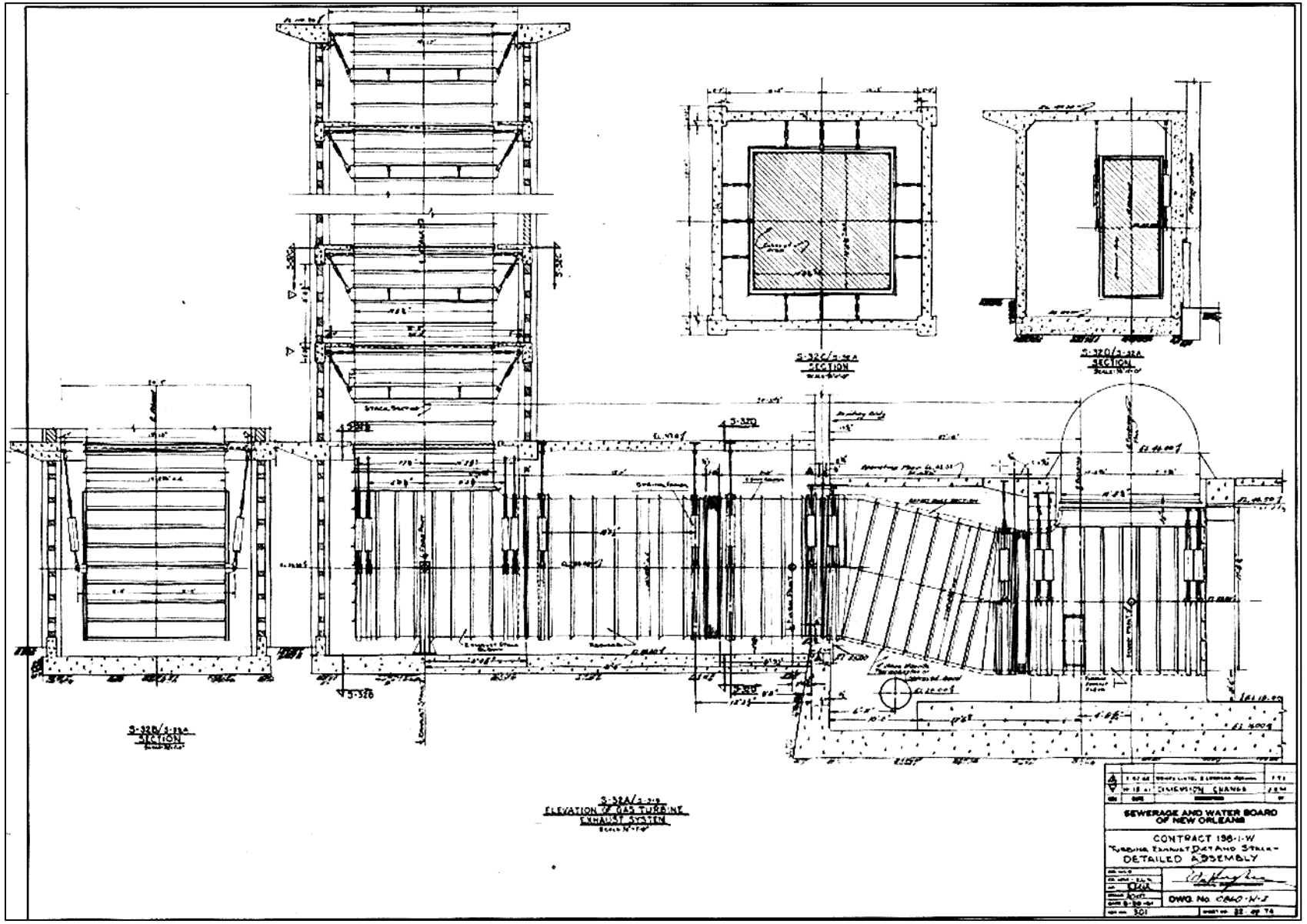


Figure 13. Turbine Generator 5 Compressor Exhaust Ducting Elevation

2.1.4.2 SPARK PLUGS AND FLAME DETECTION

TG 5 has sixteen combustion chambers that are arranged as shown in Figure 14 and are numbered sequentially, counter clockwise (facing downstream) from the twelve o'clock position[4]. Two spark plugs are provided for ignition of the turbine and they are both located on the left hand side as shown in Figure 14. They are in combustion chambers 4 and 5 which are located just above and below the 9 o'clock position. The spark plug position in combustion chambers 4 and 5 is shown in section B-B of Figure 14. The spark plug cross-section is shown in Figure 15 and the spark plugs are shown in position on TG 5 in Figure 16.

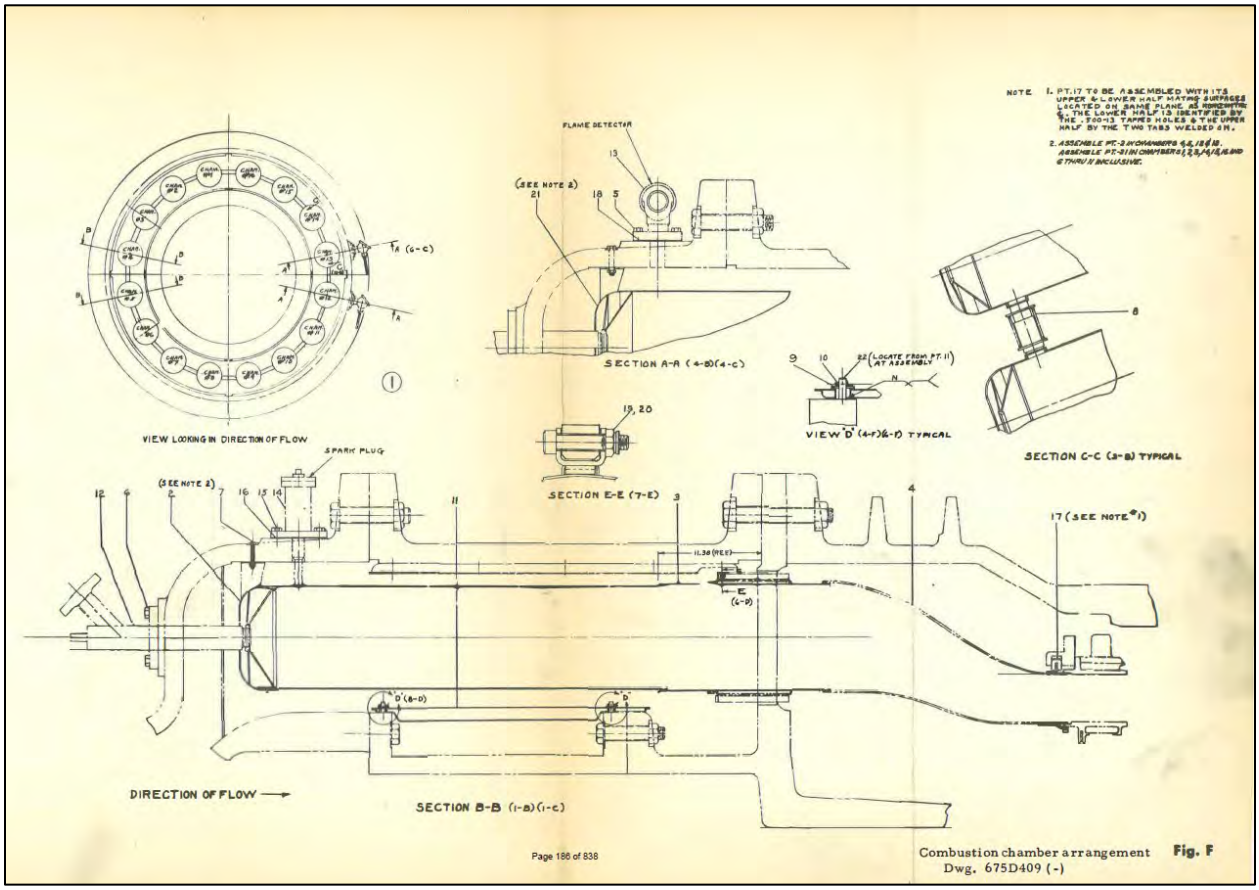


Figure 14. Turbine Generator 5 Combustion Chamber Arrangement

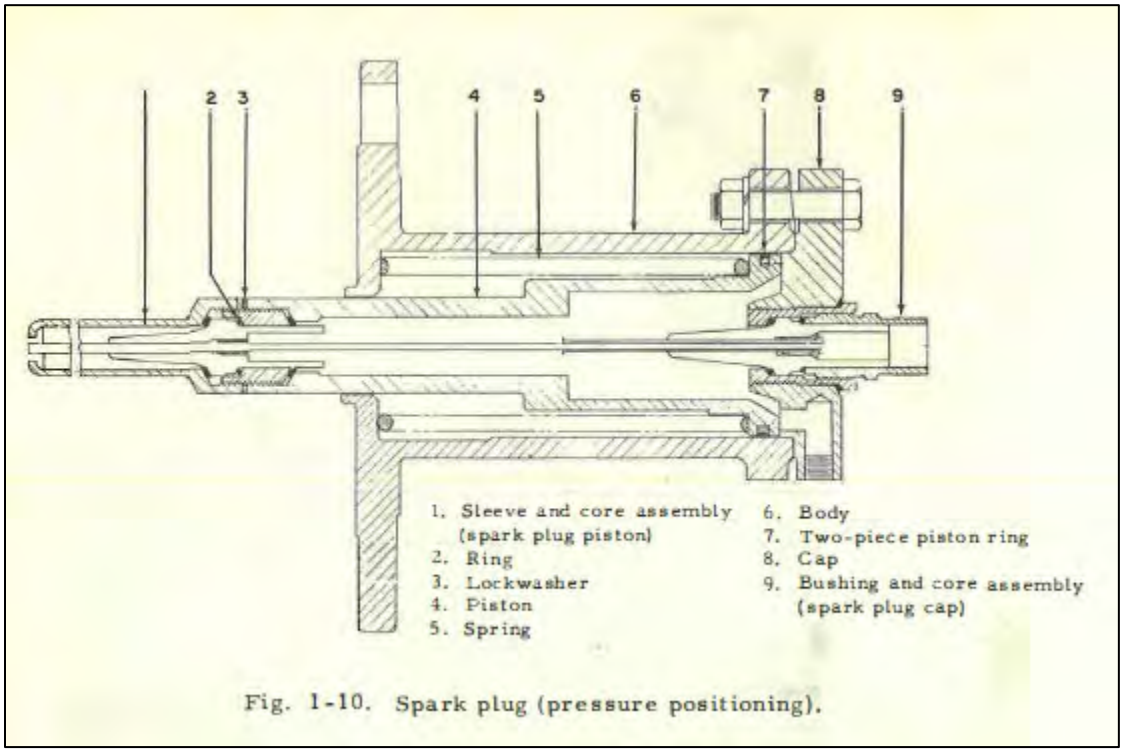


Figure 15. Spark Plug Cross-Section

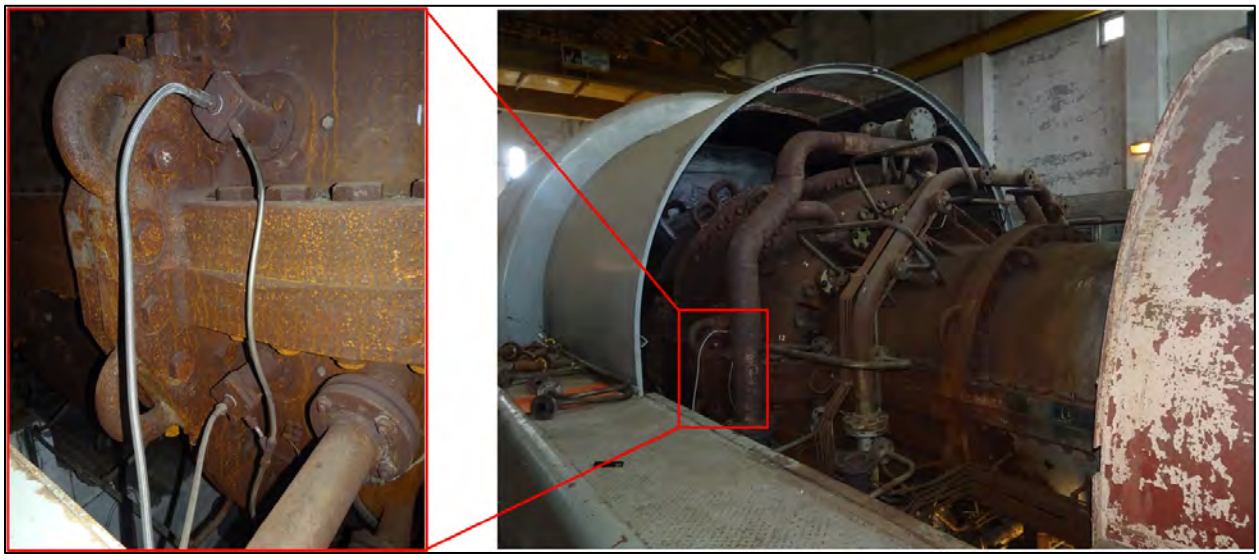


Figure 16. Turbine Generator 5 Spark Plugs

Flame detectors are located on the opposite side of TG 5 from the spark plugs. The flame detectors are located on the right side of the turbine, or the three o'clock position, when looking in the direction of flow and they are indicated in Figure 14 and shown on the turbine in Figure 17. The associated flame detection lights on the control panel are shown below in Figure 18. The flame detector numbers on the

control panel refer to the combustion chamber numbers in Figure 14 where the flame detectors are located.

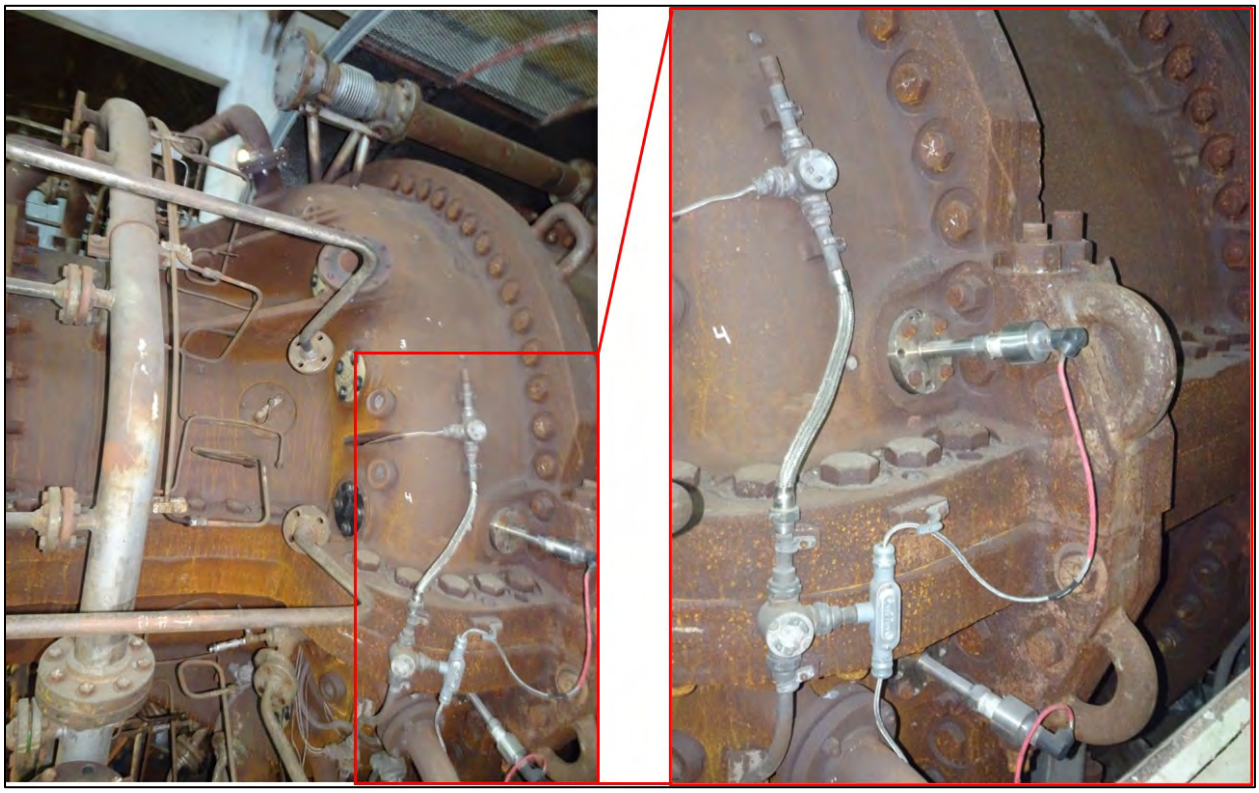


Figure 17. Turbine Generator 5 Flame Detectors

Figure 18. Flame Detector Trouble Lights (top row)

2.1.4.3 FUEL GAS SYSTEM

The fuel gas system, detailed in the Figure 19 piping diagram[7], consists of:

- Fuel gas isolation valve outside of the building (Figure 20)
- Strainer (Figure 21)
- ¼-turn shutoff valve (Figure 22)
- Gas pressure ratio valve and pilot (Figure 23)
- Stop valve (Figure 24)
- Gas control valve (Figure 25)

The fuel gas line is a 4-inch line operating at approximately 200 psi. The fuel gas is strained and then piped to the turbine where it is kept isolated by the ¼-turn shutoff valve in Figure 22 when the turbine is not in operation. Just prior to startup the ¼-turn shutoff valve is opened to provide fuel gas up to the stop valve in Figure 24, which remains closed until Step C (timer 2F) of the firing sequences shown in Figure 6. The gas pressure ratio valve and associated pilot in Figure 23 control the fuel gas pressure before the stop valve during start-up and acceleration of the turbine when the governor, control linkages and fuel gas control valve, in Figure 25, take over regulation of the turbine speed.

[7] GE Schematic Piping Diagrams, 916B455, July 15, 1959.

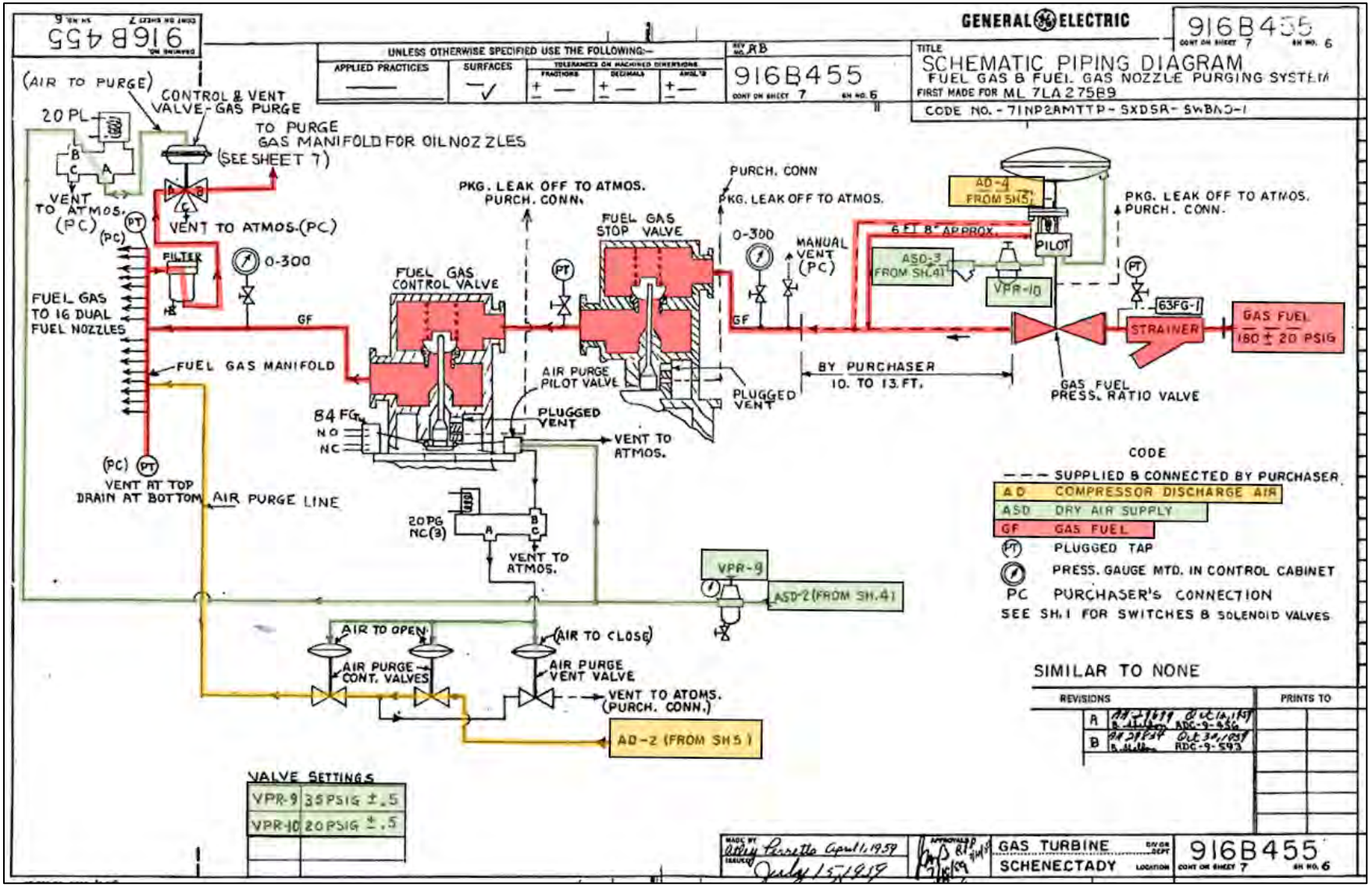


Figure 19. Fuel Gas and Fuel Gas Nozzle Purging Piping Diagram

Figure 20. Fuel Gas Exterior Isolation Valve (Closed Position)

Figure 21. Fuel Gas Strainer

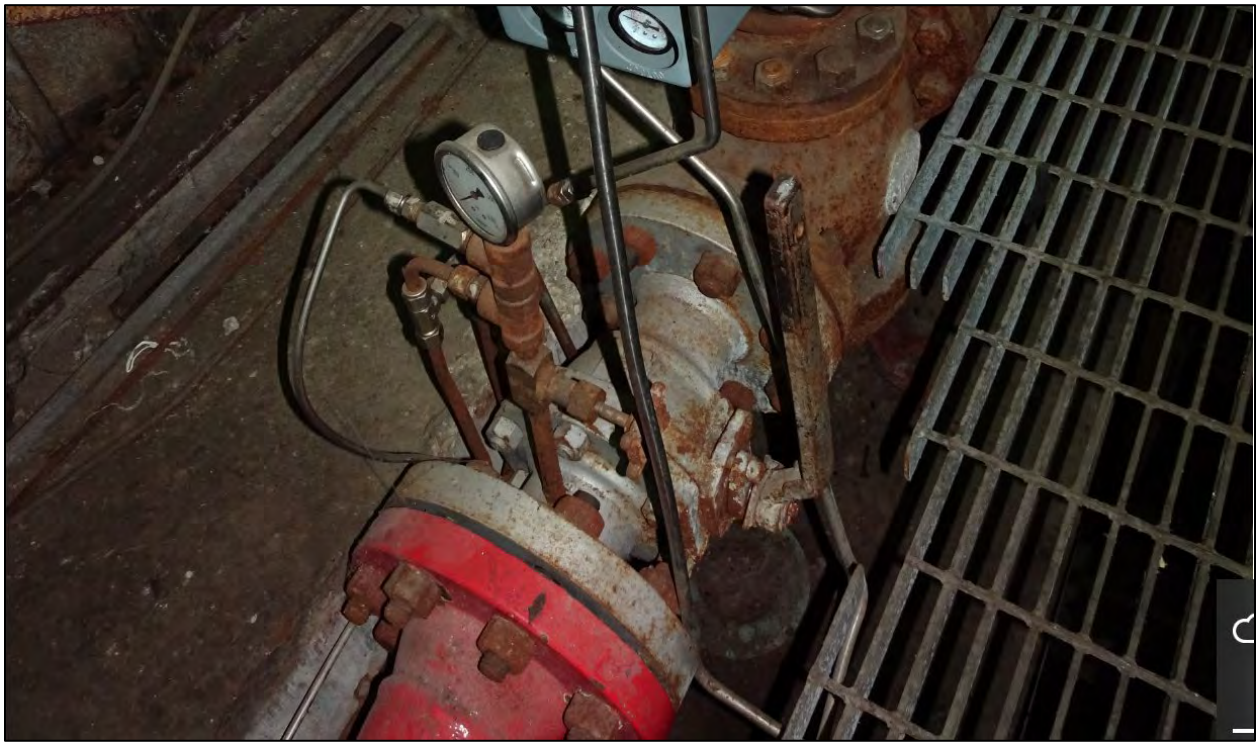


Figure 22. Fuel Gas ¼-Turn Manual Isolation Valve (Closed Position)

Figure 23. Fuel Gas Pressure Ratio Valve (Open Position) and Pilot (Grey)

Figure 24. Fuel Gas Stop Valve (Closed Position)

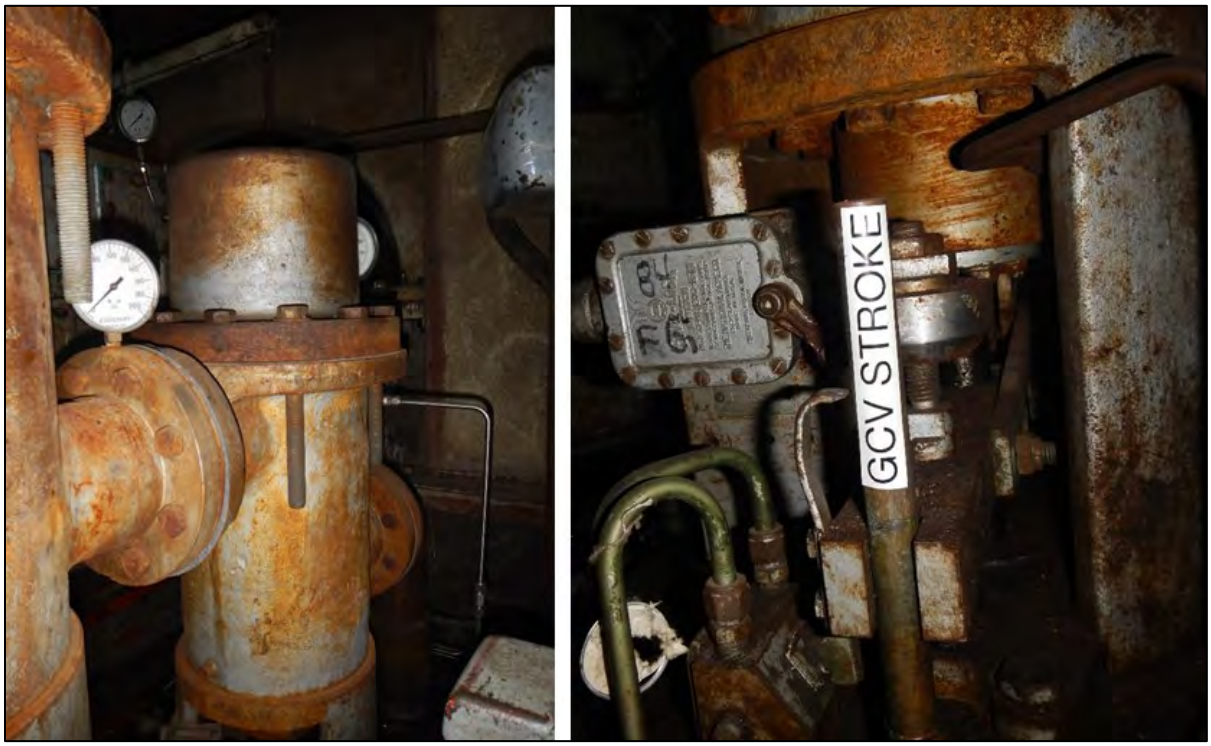


Figure 25. Fuel Gas Control Valve (Closed Position)

3 DATA COLLECTION

The analysis of the December 14, 2019 explosion incident required an extensive amount of data gathering. ABS Group was provided an information package from SWBNO on March 20, 2020 containing:

- Folder 1 – Pre-Event Information
  - Folder 1.1 – GE Outage Report and GE Timesheets
  - Folder 1.2 – Empty / No Content
  - Folder 1.3 – Document with Leslie Diaphragm Replacement CASS Record
  - Folder 1.4 – CASS Work Tickets
  - Folder 1.5 – SWB internal Outage Report and GE Operating Data and Troubleshooting Summary
  - Folder 1.6 – GE SBWNO Forced Outage 2017 Report
- Folder 2 – Contractual Information
  - Folder 2.2 – SWBNO Agreements Since 2017
- Folder 3 – Event Information (Videos and Interviews)
  - Folder 3.1 –Post incident interviews by SWBNO Security
  - Folder 3.2 – Post incident photos by SWBNO Security
  - Folder 3.3 – Surveillance System Videos[8]
- Folder 4 – Engine & Control Data Turbine 5
  - GEI-40960 Gas Turbine-Generator Unit 20,200 KW No 127724
  - Cross-Section Diagram of the Gas Turbine
  - Turbine Drawings (mechanical and electrical)
  - SWBNO DWG. No 10948-W-2 SWBNO Gas Turbine Automatic Start-Up Sequence
- Folder 5 – Scope of Damages Turbine 5
  - Folder 5.1 – Asbestos Abatement Report
  - Folder 5.2 – Drawings of Exhaust Stack
  - Folder 5.4 – Structural Evaluation Report
- Folder 6 – GE Turnover Reports, GE Daily reports Feb 2019 through April 12, 2019

Several videos from various surveillance cameras on the site were provided to ABS Group. The surveillance video file of TG 5 from within the High Lift contained 5 seconds of pre-explosion footage and approximately 75 seconds of post-incident footage.

In addition to the information provided by SWBNO, ABS Group submitted six additional requests for information. Appendix C contains a summary of the status of the RFIs.

ABS Group interviewed eleven SWBNO personnel: six from Operations, one from the Mechanical Shop, three from the Electrical Shop, and one from the Instrument Shop as indicated in Table 6. Operations interviews included the operator starting the turbine on the date of the incident, Operator 1, the supporting operators who were busy shutting down TG 4 on the date of the incident, Operators 2 and 3,

[8] Sewerage and Water Board of New Orleans, Carrollton Water Plant security camera footage, December 14, 2019.

and Operator 4 who started the turbine successfully on December 12th, the last successful startup of TG 5 prior to the incident.

Table 6. Summary of SWBNO Personnel Interviewed by ABS Group

Individual	Department	Title	Role	Date of Interview
Electrician 1	Electrical Maintenance	Utility Maintenance Supervisor	Electrical shop	14-Apr-20
Electrician 2	Electrical Maintenance	Utilities Maintenance Specialist I	Electrical shop	28-Apr-20
Electrician 3	Electrical Maintenance	Utilities Maintenance Specialist I	Electrical shop	28-Apr-20
Instrumentation 1	Instrument	Utilities Maintenance Supervisor	Low voltage systems	5-May-20
Maintenance 1	Mechanical Maintenance	Utilities Maintenances Specialist II	Supported maintenance work during outage	14-Apr-20
Operator 1	Operations	Supervisor III	Operator 1 - Startup December 14	5-May-20 27-May-20
Operator 2	Operations	P.P.O 4th Watch	Assisted Operator 1 – Startup December 14	15-Apr-20
Operator 3	Operations	U.P.W 1st Watch	Assisted Operator 1 – Startup December 14	15-Apr-20
Operator 4	Operations	S.P.E. II	Operator - Startup December 12	27-May-20
Operator 5	Operations	Supervisor IV		16-Apr-20
Operator 6	Operations	Supervisor III	Arrived Shortly After Incident	16-Apr-20

ABS Group visited the SWBNO Carrollton Water Plant on May 26 - 27, 2020 to document the as-found condition of TG 5 and a second visit was conducted from July 14 - 16, 2020 to conduct simulated testing of the TG 5 fuel gas system and start-up sequence.

4 INCIDENT DESCRIPTION

On December 14, 2019 at approximately 13:47 hours, an explosion during the startup attempt of TG 5 occurred at the SWBNO's Carrollton Water Plant. During the first firing attempt, TG 5 exploded resulting in the damage to the turbine, injuries to the operators in the vicinity of the turbine, and damage to nearby community residential structures as a result of the incident. As of the writing of this report TG 5 remained out of service. The fireball emanating from TG 5 casing is shown in Figure 26 and the fireball emanating from the exhaust stack is shown in Figure 27.

Figure 26. Turbine Generator 5 Explosion December 14, 2019 14:37:30

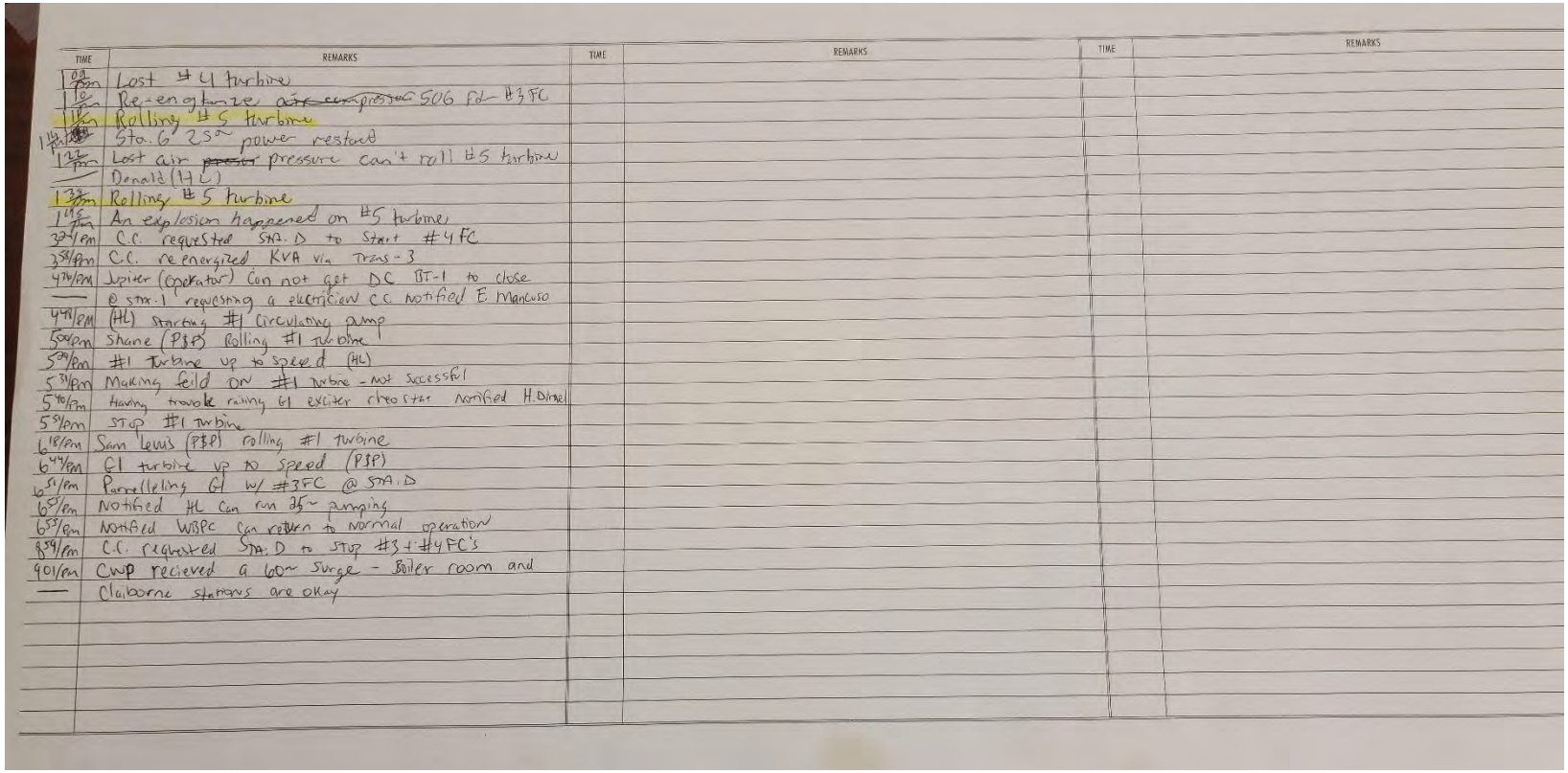
Figure 27. Turbine Generator 5 Explosion Exhaust Stack Fireball

On the day of the incident Operator 3 noticed that the shell temperature on TG 4 was high during his 13:00 round. Operator 2 called the Boiler Room and was notified that the Boiler Room was losing steam pressure and Operator 2 mentioned that approximately 5 minutes later, TG 4 went down due to loss of steam pressure. After the loss of TG 4, Central Control was notified and then Operators 2 and 3 called their supervisor, Operator 1, and requested that Operator 1 come to the Carrollton Water Plant to assist. Operator 1 was not on duty and was offsite at the time. Operator 2 stated that when Operator 1 arrived at the Carrolton Water Plant High Lift they called Central Control to inform them that the Boiler Room did not have steam to restart TG 4 and Central Control instructed the operators to start TG 5. Operator 2 started the following systems on TG 5: vapor extractor, lube oil, cooling water and Operator 3 started the circulating pumps. Operators 2 and 3 could not provide details regarding subsequent start-up of TG 5, they both stated they were busy securing TG 4 at the time. Operator 1 indicated that during the start-up on December 14th the ¼ turn shutoff valve was opened just prior to notifying Central Control the turbine was ready to start. Operators 2 and 3 had the unit on turning gear when Operator 1 arrived. Operator 1 needed to toggle the air and reset the trips prior to being ready to start. Operator 1 stated that the ¼ turn shutoff valve is not opened until just after calling Central and starting the turbine and that after switching the turbine to start everything was coming up normally and there were no abnormal sounds. Once the cranking motor got to speed (~750 rpm as indicated in Figure 6), Operator 1 said the purge timer engaged and then the firing sequence began after completion of the purge. After 10 to 15 seconds, he noticed that the turbine should have fired and he thought something was wrong and went inside of the Accessory Gear Box to take a look at the gas pressure ratio valve. He “could hear and feel a rush of gas” which prompted Operator 1 to leave the room immediately out of concern. After leaving the Accessory Gear Box Operator 1 then waited for the turbine to go through the second purge prior to a second firing attempt; however, he stated that about 20 seconds after leaving the Accessory Gear Box Room the explosion occurred. The approximate time of the explosion was near the end of the first firing sequence as indicated on the start-up sequence plot in Figure 29. A timeline of Operator 1 activity as indicated by SWBNO surveillance camera on December 14, 2019. An abbreviated timeline summarizing these events is provided below in Table 7 and a detailed timeline is provided in Appendix A.

A copy of the Central Control log remarks from December 14, 2019 are provided in Figure 28. The log remarks state that TG 5 was rolled for start-up at 13:38 and the explosion was logged at 13:45. Although the log entry states 13:38 as the time of TG 5 roll, video footage of both Boiler Control and Central Control are consistent with a final call to start the turbine at 13:42, approximately 5 ½ minutes prior to the TG 5 explosion at 13:47:30. The explosion log entry was made (as indicated by the Central Control video) at 13:56 and incorrectly noted the time of the incident as 13:45 rather than 13:47:30 as indicated by numerous security videos.

Table 7. Timeline of Events Related to TG 5 Startup December 14 from Security Footage

Local Time	Incident Time	Activity	Interpretation
13:35:55	(T – 11 min. 35 sec.)	Operator 1 arrives at main security gate	Operator 1 travels to Low Lift Building and parks vehicle Operator 1 walks through Low Lift to the High Lift and meets with Operator 2 and/or Operator 3 to get status of TG 4 and TG 5. Call to Central Control concerning boiler status.
13:36:10	(T – 11 min. 20 sec.)	Operator 1 traveling by vehicle on plant.	
13:38:05	(T – 9 min. 25 sec.)	Central and Boiler Control both on the phone. Call lasts ~50 sec. Central Control log entry made "Rolling #5 Turbine".	
13:39:08	(T – 8 min. 22 sec.)	Central and Boiler Control both on the phone. Call lasts ~15 sec.	
13:42:03	(T – 5 min. 27 sec.)	Central and Boiler Control both on the phone. Call lasts ~10 sec. Last call both receive before the incident.	Probable time of TG 5 start.
13:42:54	(T- 4 min. 36 sec.)	Operator 1 enters High Lift Office and makes a call from the fixed phone on the wall.	TG 5 accelerating on turning gear.
13:43:18	(T – 4 min. 12 sec.)	Operator 1 exits the High Lift Office.	
13:44:25	(T – 3 min. 05 sec.)	Operator 1 enters High Lift Office to make a call from a cell phone	
13:44:45	(T- 2 min. 45 sec.)	Operator 2 or 3 (A second Operator) enters the High Lift Office	TG 5 beginning first purge sequence.
13:46:00	(T - 1 min. 30 sec.)	Operator 1 exits the High Lift Office	
13:47:30	(T – 0 min. 0 sec.)	TG 5 explosion.	TG 5 at end of first firing sequence.



TIME	REMARKS
1[09] pm	Lost #4 turbine
1[1]0 pm	Re-energize ~~air compressor~~ 506 fdr #3 FC
1[1]5 pm	Rolling #5 turbine
1[2]4 pm	Sta. 6 25~ power restored
1[2]7 pm	Lost air ~~press~~ pressure can't roll #5 turbine
——	Donald (HL)
1[3]3 pm	Rolling #5 turbine
1[4]5 pm	An explosion happened on #5 turbine
3[2]4 pm	C.C. requested Sta. D to start #4 FC
3[5]4 pm	C.C. re energized KVA via Trans-3
4[7]0 PM	Jupiter (operator) can not get DC BT-1 to close
——	@ Sta. 1 requesting a electrician C.C. notified E. Mancuso
4[9]1 PM	(HL) starting #1 circulating pump
5[0]4 pm	Shane (P$P) Rolling #1 turbine
5[0]9 pm	#1 Turbine up to speed (HL)
5[3]1 pm	Making field on #1 turbine - Not successful
5[4]0 pm	Having trouble raising G1 exciter rheostat Notified H. Diesel
5[5]1 pm	Stop #1 turbine
6[1]8 pm	Sam Lewis (P$P) rolling #1 turbine
6[4]4 pm	G1 turbine up to speed (P$P)
6[5]1 pm	Parrelleling G1 w/ #3FC @ Sta. D
6[5]7 pm	Notified HL can run 35~ pumping
6[5]3 pm	Notified WSPC can return to normal operation
8[5]9 pm	C.C. requested Sta. D to stop #3 + #4 FC's
9[0]1 pm	CWP recieved a 60~ surge - Boiler room and
——	Claiborne stations are okay

Figure 28. Photograph of Central Control Log Remarks from December 14, 2019

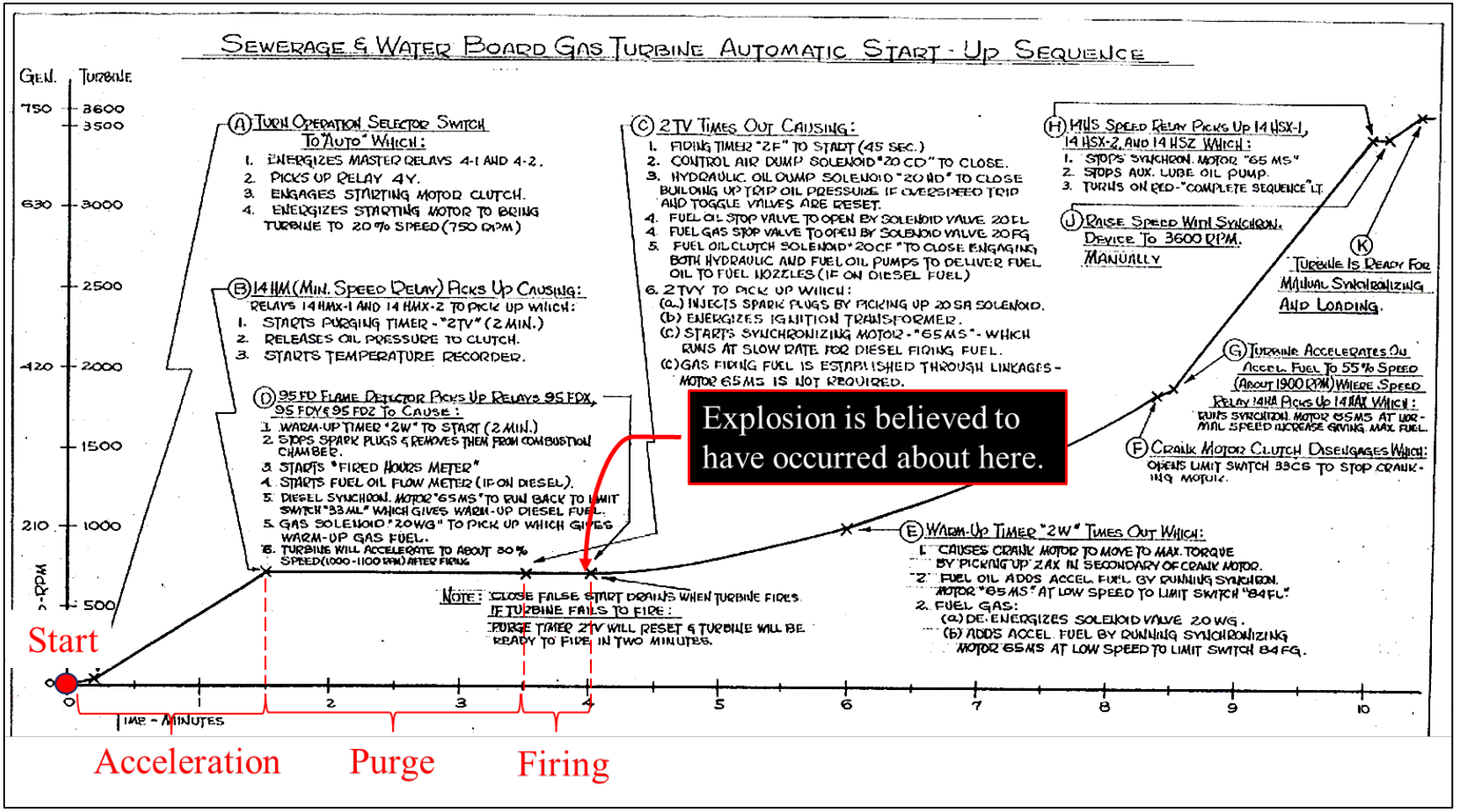


Figure 29. Approximate Time of Explosion During the Start-up Sequence

4.1 EVENTS PRIOR TO THE INCIDENT

Prior to the incident of December 14, 2019 TG 5 had undergone a maintenance outage in 2017[9] and a second outage in 2019[10],[11]. The TG 5 outage in early 2019 consisted of three phases to complete the maintenance and troubleshooting, there was then an extensive operational run from October to December of 2019, and finally preventative maintenance and a test run on December 12th. These events are presented in the Timeline in Appendix A and the key points summarized in the following sections.

4.1.1 MAINTENANCE OUTAGES

An outage occurred in 2017 after oil was observed leaking from bearing cooling ports by SWBNO. During the outage, inspection of the turbine by General Electric lead to a number of maintenance activities and repairs. The turbine returned to operation in spring of 2018[9].

On February 7, 2019 SWBNO electricians found that the TG 5 brushes were not riding on the collector rings properly and it appeared that the generator had thrusted away from the turbine. GE was on site beginning February 12, 2019 for an outage covering three major phases of work[10]:

- Phase 1: Reduction Gear Inspection
  - Feb 10 – Feb. 22, 2019
- Phase 2: Accessory Gearbox Repair and Startup Troubleshooting
  - Feb. 25 – Mar. 16, 2019
- Phase 3: Startup and Controls Troubleshooting
  - March 18 – April 14, 2019

During Phase 1 of the outage[10], after the reduction gear work, the TG 5 liquid fuel system was traced down and the purge check valves were replaced. A liquid fuel run was attempted and failed. The decision was then made to focus on fuel gas operation.

Phase 2 of the outage began after damage occurred to the starting motor clutch hubs[10]. After the repairs, several startup attempts were made, and repairs were made to several electrical controls and mechanical systems. After many failed startup attempts, the turbine was successfully started by bypassing the gas pressure ratio pilot valve with instrument air noting that the gas pressure ratio pilot valve required further inspection and testing. Phase 2 of the outage concluded, and Phase 3 work began. Phase 3 work included repairing the gas pressure ratio pilot valve, which was inspected and repaired by John H. Carter Company[10]. The gas pressure ratio pilot valve required repair of a broken spacer and replacement of the diaphragm[10],[11].

After repair of the gas pressure ratio pilot valve, startup troubleshooting continued. Troubleshooting then occurred with getting the turbine to come up to speed when taking load, Adjustments were made

[9] General Electric, “New Orleans SW&B Forced Outage 2017”, Repair to return to service, June 18, 2019.
[10] General Electric, “2019 Callout Outage – Reduction Gearbox – Starting Clutch – Controls Troubleshooting”, June 15, 2019.
[11] Sewerage & Water Board of New Orleans, “Turbine 5 2019 Outage Report”, October 1, 2019.

to the gas control valve linkages to original specifications and then the adjustments were reversed. At the end of the outage the turbine was proven to start, and hold loads of 0 – 12 MW.

A brief timeline summary of the maintenance activities on TG 5 is provided in Table 8 and a detailed timeline is provided in Appendix A.

Table 8. Summary of Turbine Generator 5 Maintenance

Date	System	Maintenance Activity
March 2017	TG 5 System	Taken out of service for rehabilitation
Feb/March 2018	TG 5 System	Recommissioned following GE work
Feb 10 – Feb 22 2019	TG 5 System GE Phase 1 work	GE FieldCore Mobilized – Reduction Gear Inspection
Feb 10 – Feb 22 2019	TG 5 System GE Phase 1 work	Following the reduction gear inspection • Liquid fuel system was traced down • Liquid fuel check valve replaced • Purge check valve replaced TG 5 failed to run on liquid fuel after several attempts Liquid fuel troubleshooting postponed
Feb 17, 2019	TG 5 System GE Phase 1 work	TG 5 was successfully run on gas fuel at the end of Phase 1
Feb 22, 2019	TG 5 System	Test run on gas • Issue with gas pressure Test run on diesel • Not successful Tried to start on gas after diesel run • Not successful GE begins demobilizing
Feb 25 – Mar 16 2019	TG 5 System GE Phase 2 work	Accessory Gearbox Repair and Startup Troubleshooting GE controls technician arrive to troubleshoot controls
March 15, 2019	TG 5 System	Gas pressure ratio pilot valve regulator • Actuated control valve manually to confirm operation • Regulator that controls the valve not operating properly • Test ran machine and manually actuated the gas control valve by bypassing the regulator
Mar 18 – April 14 2019	TG 5 System GE Phase 3 work	Startup and controls troubleshooting • Repaired the pressure ratio pilot valve (PRV) • Realigned the start motor

Date	System	Maintenance Activity
		Troubleshot startup and fuel controls
Mar 18 – April 14 2019	TG 5 System GE Phase 3 work	The pilot valve (PRV) was inspected and repaired by John H. Carter (Carter) • Removed and sent to Carter on March 18 • Found to have a broken spacer (regulator housing) and diaphragms • Cast aluminum diaphragm spacer worn and cracked • Received from Carter March 23
Mar 18 – April 14 2019	TG 5 System GE Phase 3 work	At the end of the outage, the turbine was proven to start successfully and hold a load range of 0 – 12 MW

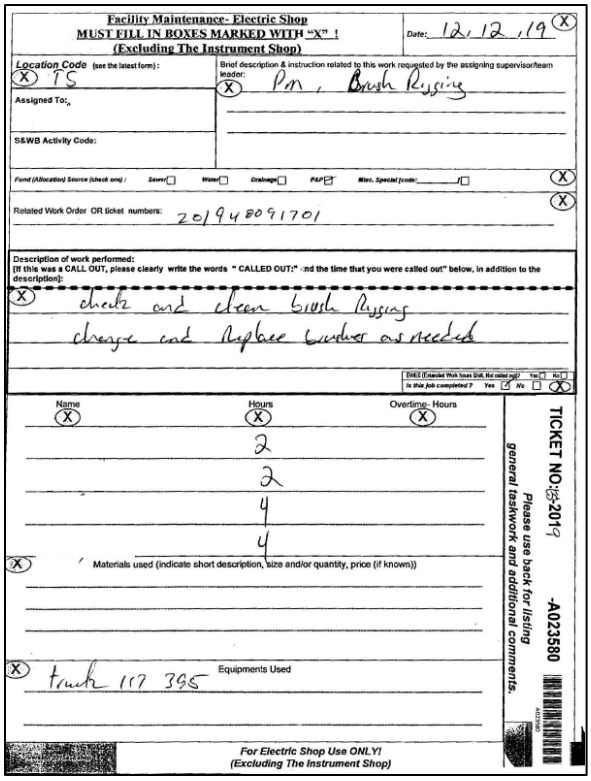
4.1.2 PRE-INCIDENT TG 5 OPERATION AND FINAL PREVENTATIVE MAINTENANCE

TG 5 ran continuously from October 3, 2019 to December 11, 2019 as reported by SWBNO Monitoring and Power Dispatching. On December 11th, TG 5 was shut down for preventative maintenance to:

- Brushes
- Oil changes
- Added hydraulic pressure indicator (analog)

The preventative maintenance that occurred on December 12 and the shop ticket, with the assignment name redacted, is shown in Figure 30.

TG 5 was test run on December 12th between 16:36 and 17:17. Operator 4 was responsible for the test run after the completion of preventative maintenance on December 12th. Operator 4 was training additional operators at the time, explaining the start-up steps to the operators as they were performed. After the ¼-turn shutoff valve was opened on December 12th the operator being trained then reset the annunciator and turbine trips in the control cabinet. Operator 4 described the start-up as not fast or slow, that it started up "just right, like the old days. It came up perfect." Operator 4 also stated (paraphrased), "Since the maintenance and overhaul, the machine has come up faster, not in a bad way, strong and fast like a new turbine. This time it did not come up fast, it came up like it did before. Not weak but like it did before the overhaul." The operator log from the December 12th test run is provided in Figure 31, with the names redacted.



Facility Maintenance- Electric Shop
MUST FILL IN BOXES MARKED WITH "X" !
(Excluding The Instrument Shop)

Date: 12, 12, 19

Location Code (see the latest form): TS

Brief description & instruction related to this work requested by the assigning supervisor/team leader: PM, Brush Rigging

Assigned To:

S&WB Activity Code:

Fund (Allocation) Source (check one): Sewer ☐ Water ☐ Drainage ☐ P&P ☑ Misc. Special (code:) ☐

Related Work Order OR ticket numbers: 20194809 1701

Description of work performed:
[If this was a CALL OUT, please clearly write the words " CALLED OUT:" and the time that you were called out" below, in addition to the description]:

check and clean Brush Rigging
change and Replace brusher as needed

Was this Job completed ? Yes ☑ No ☐

Name	Hours	Overtime- Hours
	2	
	2	
	4	
	4	

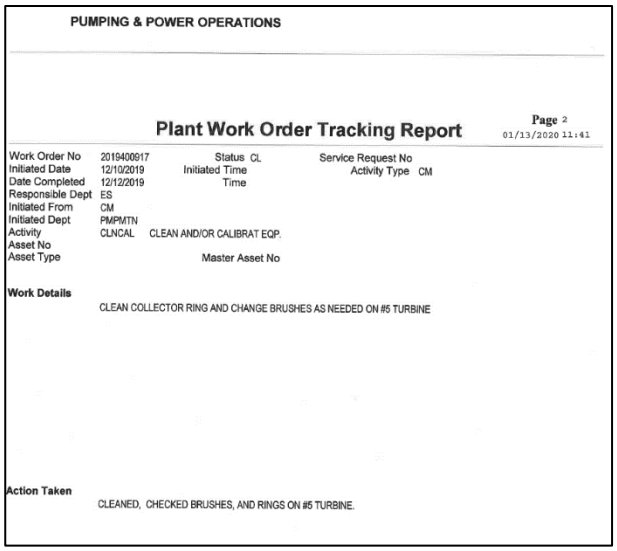
Materials used (indicate short description, size and/or quantity, price (if known))

Equipments Used: Truck 117 395

TICKET NO: 2019 -A023580

Please use back for listing general task/work and additional comments.

For Electric Shop Use ONLY!
(Excluding The Instrument Shop)



PUMPING & POWER OPERATIONS

Plant Work Order Tracking Report

Page 2
01/13/2020 11:41

Work Order No	2019400917	Status CL	Service Request No
Initiated Date	12/10/2019	Initiated Time	Activity Type CM
Date Completed	12/12/2019	Time	
Responsible Dept	ES		
Initiated From	CM		
Initiated Dept	PMPMTN		
Activity	CLNCAL	CLEAN AND/OR CALIBRAT EQP.	
Asset No			
Asset Type		Master Asset No	

Work Details
CLEAN COLLECTOR RING AND CHANGE BRUSHES AS NEEDED ON #5 TURBINE

Action Taken
CLEANED, CHECKED BRUSHES, AND RINGS ON #5 TURBINE.

Figure 30. SWBNO December 12 Turbine Generator 5 Maintenance Ticket and Tracking Report

New Orleans Sewerage and Water Board
Pumping and Turbine Operations

#5 GTG
Start/Stop Log

START DATE: 12-12-19
START NAME: _____ Print _____ Sign
STOP NAME: _____ Print _____ Sign
STOP DATE: 12-12-19

START TIME:	~~4:33pm~~ 4:36pm
FLAME ON:	4:46 pm
UP TO SPEED:	4:53 pm
STOPPED AT:	5:10 pm
FLAME OUT:	5:17 pm
FUEL OIL TEMP: (DIESEL ONLY)	
FUEL OIL USAGE (TOP): (DIESEL ONLY)	
FUEL OIL USAGE (BOT): (DIESEL ONLY)	
ON TURNING GEAR: (COOLDOWN)	
GAS METER START:	00 008441
GAS METER STOP:	00008441

Important:
All data for this log must be complete, accurate and clearly written.

Note:
This log sheet is to remain with the turbine until the unit is stopped.All entries to be completed by Engineer II.

Purpose for this run:

Test---------- [V]
Rainload---- [ ]
Emergency- [ ]

CHART BY D. B. ADAMS
Rev. 3/01

Figure 31. Turbine Generator 5 December 12, 2019 Test Run Log Sheet

5 ANALYSIS

ABS Group conducted a site visit on May 26-27, 2020 to document the as-found condition of the turbine, which had remained mostly undisturbed since the December 14, 2019 incident. ABS Group then returned from July 14-16, 2020 to observe and document TG 5 systems testing including the startup simulation tests. The following systems tests were performed:

- Stop valve leakage test
- Gas pressure ratio valve time to close after opening ¼ turn shutoff valve
- Spark plug performance test by direct signal
- Start-up simulation tests, matrix provided below in Table 9

The results of the as-found documentation, systems testing, and startup simulation tests were utilized to analyze the TG 5 systems including the pneumatic controls, spark plugs, turbine compressor air, and fuel gas system as they related to the CAET scenarios. The results of the analysis of each system is discussed in further detail in the following sections.

Table 9. Start-up Simulation Tests

Scenario	Control Air	CDP	¼-Turn Shutoff	Gas pressure ratio valve @ Start	Note
1	As Found 30-35	0	Open	Closed	
2	As Found 30-35	~5	@ 1m into Purge Timer	In Motion / Open	
3	As Found 30-35	~5	1.5M Before Auto	In Motion / Open	See Startup Figure, 1.5 M is duration of time to crank to 750 rpm and start sequence. Simulate 'Auto' and Open 1/4 turn at same time.
4	As Found 30-35	~5	Beginning of Firing Timer 2F	In Motion / Open	

5.1 PNEUMATIC CONTROLS

During as-found documentation of the turbine and equipment, control air to the turbine was restored and the pneumatic controls identified in Table 5 of Section 2.1.2 were inspected. All VPRs were observed to be within reasonable limits of the specified settings from the schematic piping diagrams with the exception of VPR-10 as shown in the two right hand columns in Table 10. VPR-10 is the control air supply for the gas pressure ratio pilot valve. The specified value is 20 psig $^{+}/_{-}$ 0.5 psi as shown from the schematic piping diagram in Figure 32 and the pressure was observed to be 30 psi at the VPR-10 regulator and 35 psi as measured by the pilot supply pressure gage as shown from photographs taken during the as found inspection in Figure 33.

Table 10. Turbine Generator 5 Dry Air VPRs

Name	From	To	P&ID - Sheet	Specified Setting	As Found Pressure
VPR-2	Referenced on P&ID (916B455-Sheet 7)		916B455-Sheet 7	85 psig	Unobserved
VPR-3	Air Supply	TEMR transmitter	916B455-Sheet 5	20 psig	21 psig
VPR-4	Air Supply	Butterfly control valve	916B455-Sheet 5	20 psig	22 psig
VPR-5	Air Supply	Pneumatic Controller	916B455-Sheet 5	20 psig	21.5 psig
VPR-6	Air Supply	Pneumatic Controller	916B455-Sheet 5	See Cont. Specs.	No gage
VPR-7	Within the pneumatic temperature relay		916B455-Sheet 4	32 psig, +/- 0.5 psi	36 psig
VPR-8	Air Supply	OT trip	916B455-Sheet 4	62 psig, +/- 0.5 psi	66 psig
VPR-9	Air Supply	Fuel Gas Control Valve	916B455-Sheet 6	35 psig, +/- 0.5 psi	34 psig
VPR-10	Air Supply	Gas pressure ratio pilot valve	916B455-Sheet 6	20 psig, +/- 0.5 psi	30 psig at regulator 35 psig at pilot

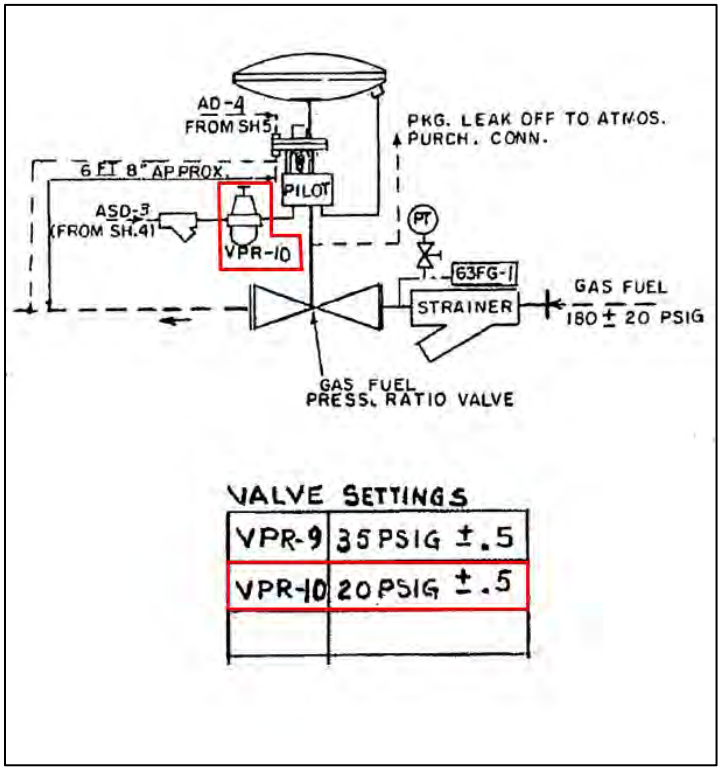


Figure 32. VPR-10 Specified Valve Settings

Figure 33. VPR-10, Gas Pressure Ratio Pilot Valve Control Air Supply, - As-Found Pressure

5.2 ELECTRICAL PANEL AND RELAYS

During the startup simulations the electrical panels, relays and timers functioned as anticipated. Relay 14 HM would stick and not open at the conclusion of some runs requiring an operator to tap on the relay to return the relay to the open position. However, this issue would not affect the startup sequence prior to firing the TG.

5.3 SPARK PLUGS

During startup simulation testing the spark plugs were removed from TG 5 so that they could be observed during each simulation of the start-up sequence. Both spark plugs arced as anticipated during the simulations, as shown in Figure 34, and the air pressure that inserts the plugs into the combustion chamber during normal operation was also observed to be operating normally. The spark plugs operated as anticipated, therefore, normal gas flow with malfunction ignitor was contradicted and determined to have very low plausibility.

Figure 34. Turbine Generator 5 Ignitors During Test Simulation

5.4 TURBINE COMPRESSOR AIR INTAKE

During the first post incident inspection of TG 5 in late December 2019 by ABS Group, an accumulation of insects on the turbine compressor air intake screen was observed. During as-found inspection the compressor air intake duct was opened behind the air intake screen for further inspection. Both the outside and inside of the compressor air intake are shown in Figure 35. During discussions between ABS Group, SWBNO, and General Electric, General Electric confirmed that a significant obstruction of compressor air intake flow would create a pressure drop and likely result in damage to the air intake ducting (e.g., collapsing the ductwork) as a result. Because no foreign objects or insects were observed behind the air intake screen, the insects appeared to have been in place for a substantial amount of time (longer than the period of time between the December 12th and 14th startups), and the lack of observable damage to the compressor air intake ducting, reduced compressor intake air flow was contradicted and determined to have very low plausibility.

Figure 35. Compressor Air Intake Screen and Ducting

5.5 FUEL GAS SYSTEM

Possible causes of excess fuel gas flow during the start-up attempt of December 14th were investigated and included: (1) gas flow during the purge step, and (2) abnormally high fuel gas flow during the firing attempt as shown in the applicable portion of the CAET in Figure 36 (the complete CAET is provided in Appendix B). Both branches require one of the fuel gas system valves to malfunction. Branch 2.1.1, gas flow during the purge, was contradicted because this event required both the gas pressure ratio valve to be open during the purge, which is believed to have occurred, but the fuel gas stop valve and fuel gas control valve must also be open during the purge, neither of which were observed during testing. Further contradicting gas flow during the purge is that Operator 1 stated that the explosion occurred at

the end of the first firing sequence and introduction of fuel gas during the purge or an inadequate purge would likely result in the explosion occurring at the beginning of the firing sequence. Therefore, due to the normal fuel gas stop valve and fuel gas control valve operation and the timing of the event, gas flow during the purge step was contradicted and determine to be very low plausibility.

Abnormally high fuel gas flow during the first firing attempt was determined to be highly plausible due to the gas pressure ratio valve remaining open as a result of slow control by the pressure ratio valve pilot that may be further exacerbated by any delay in opening of the ¼-turn shutoff valve.

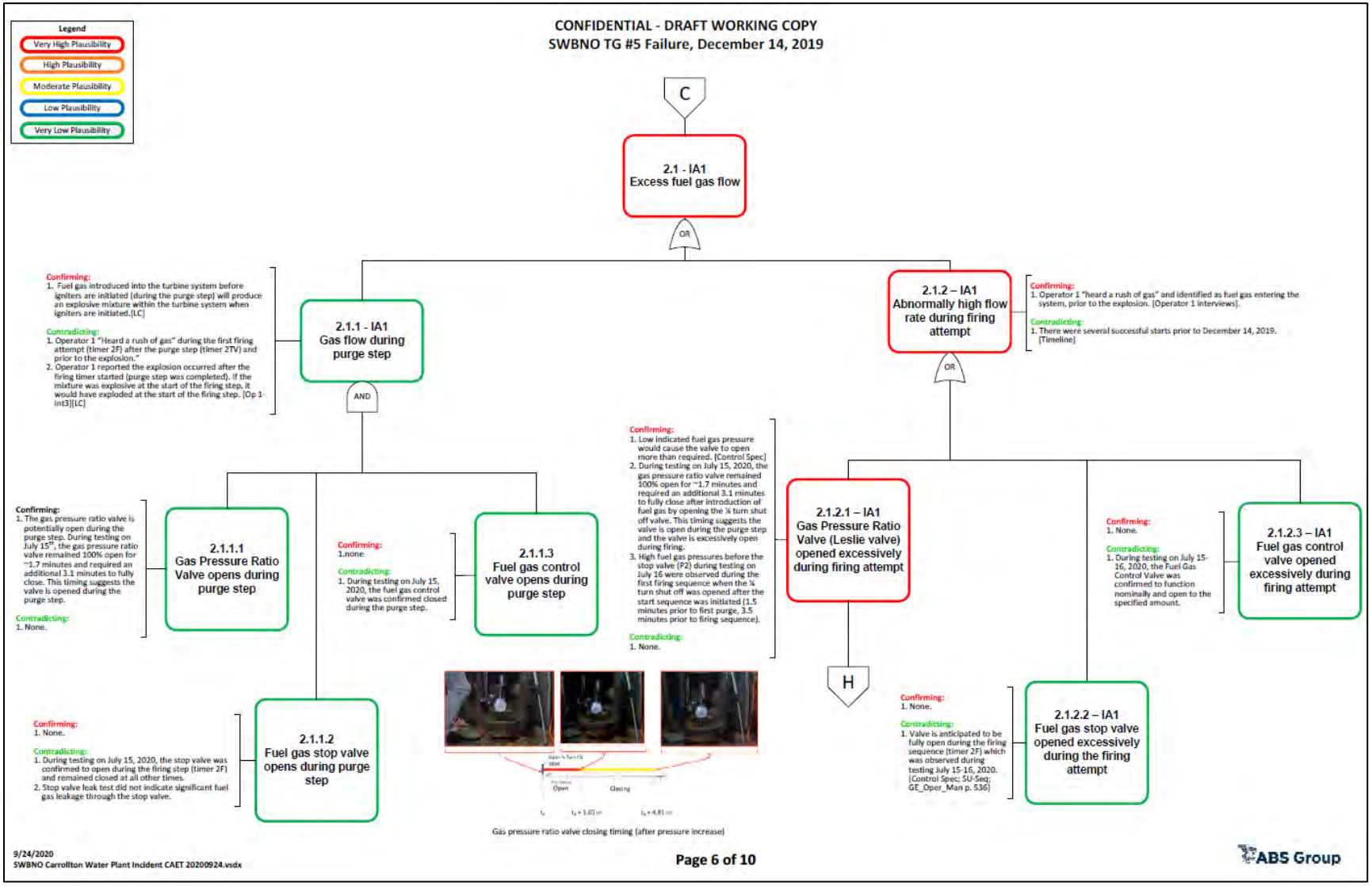


Figure 36. CAET Excess Fuel Gas Flow Major Branches

5.5.1 GAS PRESSURE RATIO VALVE AND PILOT

The gas pressure ratio valve and pilot, shown in Figure 37, regulates the downstream fuel gas pressure before the stop valve, based on compressor discharge pressure (CDP). The pilot valve inputs include: (1) control air supply, specified to be 20 psi +/- 0.5 psi as discussed in Section 5.1, (2) turbine CDP, and (3) downstream fuel gas pressure before the stop valve (P2). The control output is control air to the gas pressure ratio pilot valve to adjust the gas pressure ratio valve position to achieve the regulated downstream fuel gas pressure, P2.

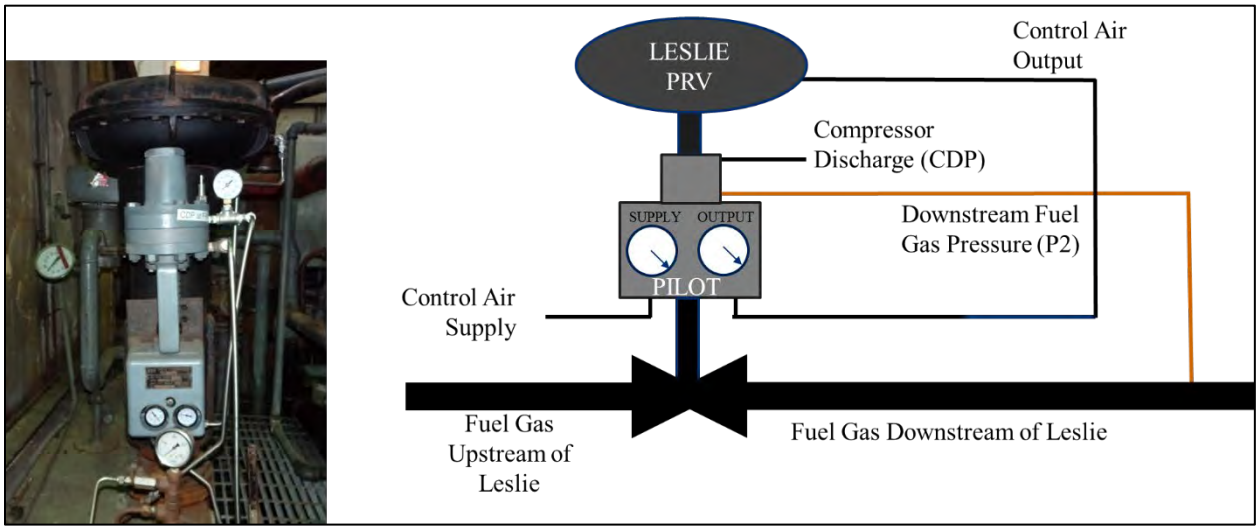


Figure 37. Turbine Generator 5 Gas Pressure Ratio Valve and Pilot

The gas pressure ratio pilot valve controller controls the downstream fuel gas pressure utilizing the following specified linear relationship:

$$P2 = 1.4 \cdot CDP + 5.88 \qquad \text{[Eq. 1]}$$

Where downstream gas pressure is supposed to be regulated to be 5.88 psig when CDP is 0 psig. This offset pressure is referred to as the zero CDP offset. For a non-zero CDP, the downstream fuel gas pressure is specified as 1.4 times the CDP, plus the zero CDP offset. GE Control Specifications 114A9016 define the zero CDP offset and pressure ratio and is provided in Figure 38[12]. The GE outage report Section 3.8[10], provides a condition description of the gas pressure ratio valve pilot and confirms the control specification of 5.88 psi zero CDP offset and notes than several different offsets were tested but ultimately the pilot was set to hold an offset of approximately 6 psi. Appendix 5 of the GE outage report contains a troubleshooting summary and startup and operational readings, shown below in for TG 5, dated April 16, 2019 at the end of Phase 3 of the GE outage work as shown in Figure 40[10].

[12] General Electric, Control Specifications, 114A9016, Dec. 1, 2019.

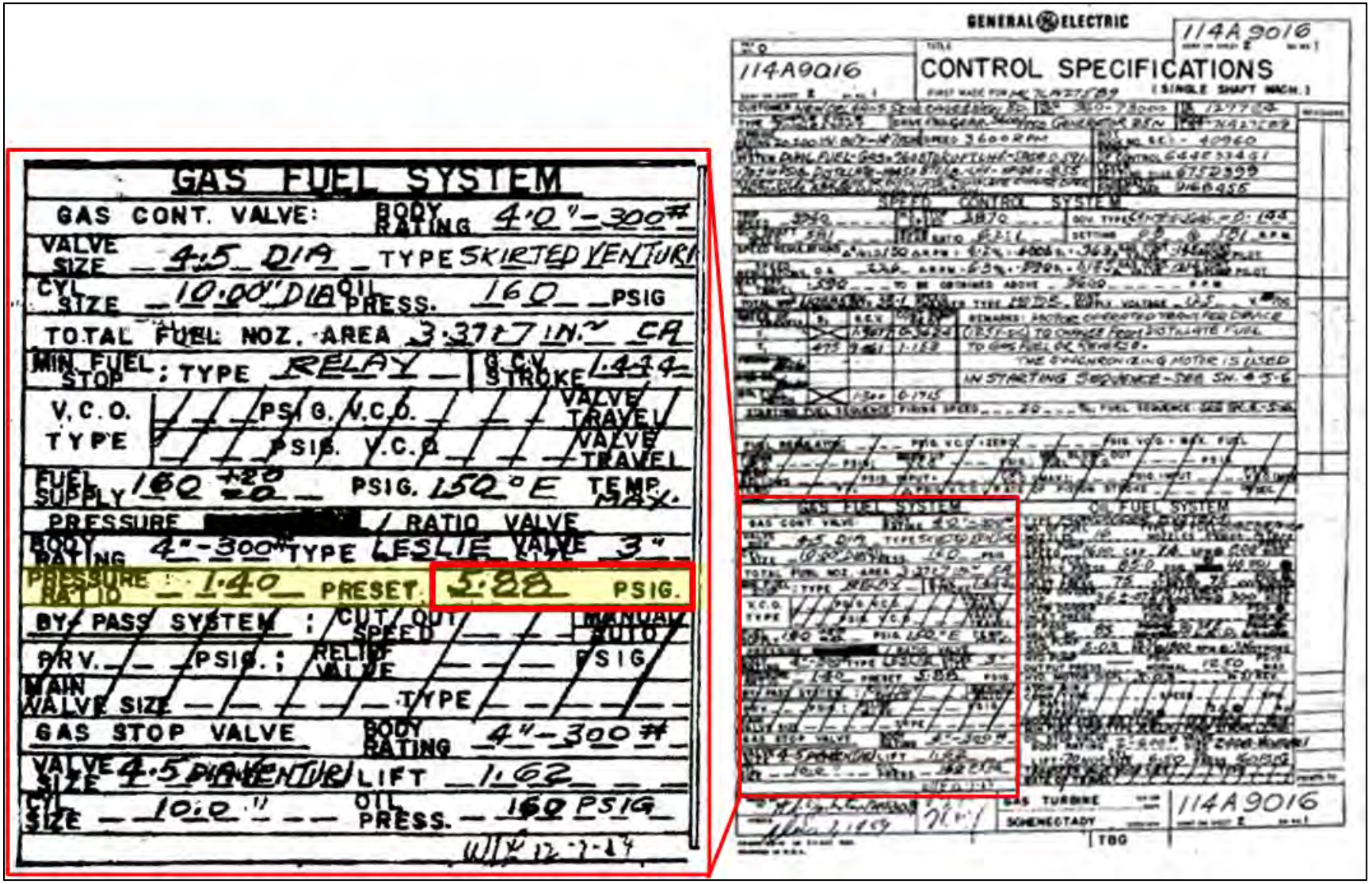


Figure 38. Gas Pressure Ratio Pilot Valve Specified Zero CDP Offset and Pressure Ratio

GE Power Power Services

3.8 PRESSURE RATIO PILOT VALVE (CONTROL VALVE)

Part Condition: Poor

Part Condition Description

The pressure ratio pilot valve controls the pressure ratio valve. The pilot valve has two input signals: Compressor Discharge Pressure and Fuel Gas Pressure before Stop Valve. It compares these two signals with a fixed ratio diaphragm of 1.4:1. Additionally, the pilot valve has a spring built into the valve stem that can be used to adjust the offset of the pressure ratio. Because the pressure ratio is fixed, this spring is the only adjustment on the pilot valve and is meant to make minor adjustments to meet the control specifications.

During startup troubleshooting, the functionality of the pilot valve was questioned, and it was inspected by a technician from John H. Carter. The pilot valve was found to have holes in its diaphragms and a cracked diaphragm spacer. Replacement diaphragms were ordered from Leslie Controls, and John H. Carter completed the valve repair by machining a new spacer. The valve was tested in the John H. Carter shop and is functioning correctly. Additionally, the CDP line that connects to the pilot valve was cleaned out with compressed air and was found to have a fair amount of dirt and debris.

As stated previously, the pilot control valve has only one adjustment. The spring on the valve stem can be adjusted to create an offset pressure. In other words, the pressure that the pressure ratio valve will hold when there is zero CDP (during startup). The control specification calls for an offset of 5.88 psi. During startup troubleshooting, several different offsets were tested, but ultimately the pilot valve was set to hold an offset of approximately 6 psi.

Figure 39. GE Outage Report Pressure Ratio Pilot Valve Condition Description

Turbine Operating Data & Troubleshooting

Date 4/16/2019 Turbine Serial No. 127724 Prepared by C. Beason

Startup & Operation Readings

Fuel Condition	Speed (rpm)	S1 Stroke (inch)	GCV Stroke (inch)	FGP before SV (psi)	FGP after GCV (psi)	CDP (psi)	Lube Oil Press. (psi)	Exhaust Temp Avg	Exhaust Temp. Pr.	CD Totalizer Output	Temp. Relay Output	LP Selector Output
Turning Gear	0	0.0"	0.0"	0	0	0	25	545	30	0	30	35
Acceleration	1900	0.300"	0.75"	0 - 105	0 - 62	0 - 60	150	545	30	0	30	32
FSNL	3620	0.020"	0.35"	105	62	60	160	545	30	0	28	31
5MW Load	3600	0.080"	0.55"	110	70	64	150	545	30	0	28	32
12.3 MW	3870	0.170"	0.677"	125	75-80	75	155	545	40*	0	30	

Figure 40. GE Turbine Startup Record

Startup Troubleshooting Summary

Issue	Cause / Solution
Turbine repeatedly tripping during purge timer	Starting motor misalignment and/or 33CS limit switch giving faulty reading
Synchronizing Motor not raising after warmup timer	84FL limit switch was out of position, not resting on fuel transfer lever
Pressure Ratio Valve not reacting to changes in fuel gas supply pressure during offline vent test	Pressure Ratio Pilot Valve has torn diaphragms and a cracked spacer -- was not properly regulating the CDP to FG pressure ratio. Dirt also found in AD-4 line.
Solenoid Valves not actuating when they should be in sequence	Loose wires were found in junction boxes and poor connections on top of solenoids.
Fuel selector lights for liquid fuel and gas fuel were both illuminated	Fuel selector relay 84TGX had a burnt coil that needed to be replaced
Various timers not operating during the sequence	Several timers had loose wires or broken connectors. Some needed to be replaced all together.
Failure to fire	After the 2TV timer started and ran for 2 minutes the contacts did not change state and send the correct signal to the 2TVY relay and the 2F relay
Light smoke coming from turbine after startup	Auxiliary lube oil pump had been running without vapor extractor for about 2 hours the previous day. Without vapor extractor on to create vacuum pressure, the bearing oil seals will not work.
Turbine could not be raised to 3850 rpm after startup complete	Had to move sync motor stop collar so that max speed with no load is 3850 rpm
Turbine tipping at 1200 rpm without alarms	Motor Control Center door switches can trip turbine during startup. One was repaired and the other was jumpered.

Figure 41. GE Turbine Operation Readings

During the startup simulation testing, the downstream fuel gas pressure was recorded for 0 psig and ~ 8 psig CDP and plotted with the GE Operation readings from Figure 40. The as-found measurements are consistent with the GE operational data from April 16, 2019 that indicate a zero CDP offset of ~ 29 psi or roughly 5 times the specified value of 5.88 psi and not the 6 psi offset mentioned in the outage report. The pressure ratio was ~1.3, which is within 10% of the specified pressure ratio. For reference, the grey line in Figure 40 represents the zero CDP offset and pressure ratio from the control specification. Therefore, the gas pressure ratio pilot valve was providing approximately 5 times the fuel gas pressure before the stop valve (P2) during firing when the CDP is near zero, which is the case as the TG initially fires. The excess fuel gas pressure (P2) was observed in the as-found configuration and although the contribution to the incident was moderate the excess pressure was determined to be a causal factor.

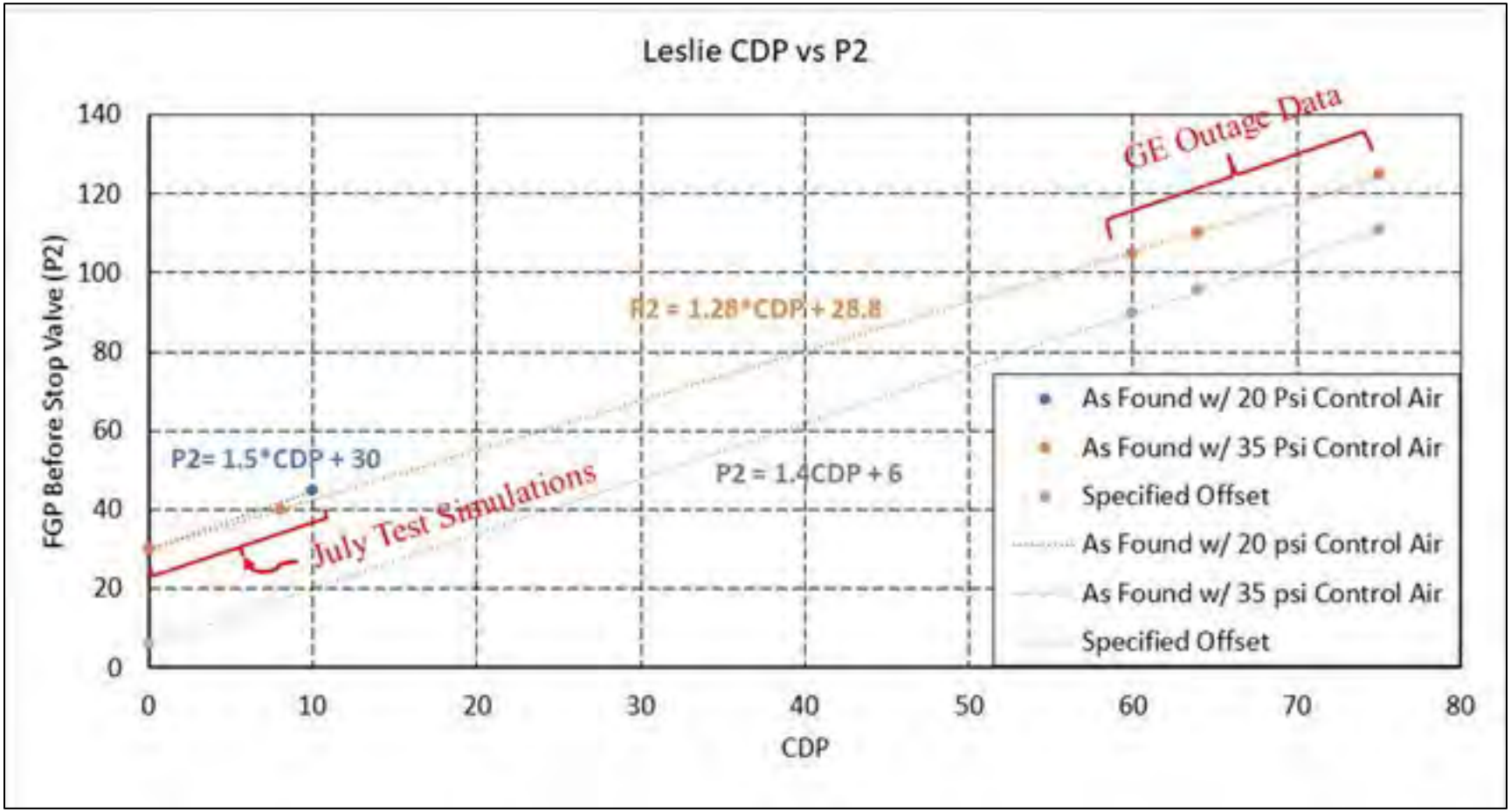


Figure 42. Gas Pressure Ratio Pilot Valve CDP vs Downstream fuel Gas Pressure P2

The gas pressure ratio pilot valve measures CDP and controls the downstream fuel gas pressure before the stop valve with a specified offset of ~ 6 psig and a measured offset of ~29 psig. Regardless of the zero CDP offset, when the ¼-turn shutoff valve is opened immediately prior to starting the turbine just after the operator notifies Central Control, the expected position of the gas pressure ratio valve is 100% open. The gas pressure ratio valve control system is trying to achieve the target pressure of the zero CDP offset, while the actual pressure is 0 psig. When the ¼-turn shutoff valve is opened, the fuel gas pressure before the stop valve will increase immediately to the supply fuel gas pressure, 200 to 220 psig, when the gas pressure ratio pilot should control the gas pressure ratio valve to close due to the excess fuel gas pressure, P2. During testing of TG 5, fuel gas pressure was simulated using an air compressor and the ¼-turn shutoff valve was opened without starting the turbine as indicated in Table 11. The time for the pilot to control the gas pressure ratio valve to fully closed was measured.

After establishing fuel gas pressure by opening the ¼ turn shutoff valve, the gas pressure ratio valve position remained 100% open for ~1.6 minutes and then required an additional ~3.2 minutes to fully close as shown in Figure 43. The total time after opening the ¼ turn shutoff valve until the gas pressure ratio valve achieved the fully closed position was ~4.8 minutes.

Table 11. Gas Pressure Ratio Valve Close Test after Establishing Fuel Gas Pressure

System	Condition 1	Condition 2
1/4 Turn Shutoff	Closed	Open
Stop Valve	Closed	Closed
Gas Pressure Ratio Valve	Open	Measure time to close
CDP	0 psig	0 psig
VPR-10 Supply Control Air (As Found)	30 to 35 psig	30 to 35 psig

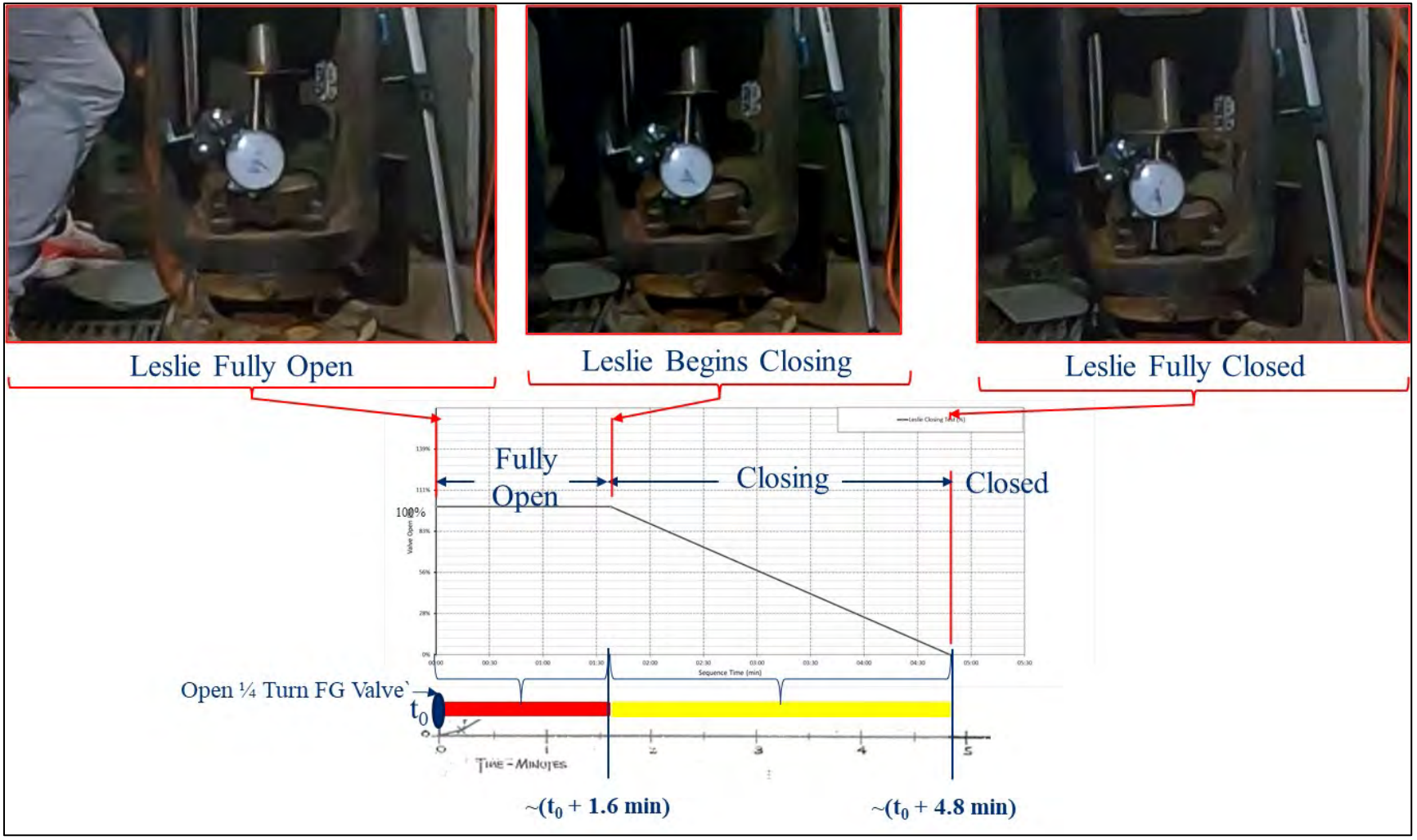


Figure 43. Gas Pressure Ratio Valve Position vs Time after Establishing Fuel Gas Pressure

Three start-up scenarios were simulated during testing as detailed in Table 12. First, the ¼-turn shutoff valve was opened, and the pilot allowed to control the gas pressure ratio valve to the fully closed position prior to initiating the start-up simulation. This is not the standard operating method; however, it does allow the gas pressure ratio valve to achieve the expected pre-start-up position, which is fully closed. Second, the ¼-turn shutoff valve was opened 1.5 minutes prior to the beginning of the purge sequence. This is approximately the time it takes the TG to accelerate to ~ 750 rpm by the cranking motor. This was performed to simulate the SWBNO operating procedure of opening the ¼-turn shutoff valve immediately prior to starting the turbine. Finally, the ¼ -turn shutoff valve was opened late, 1 minute into the purge sequence. Pilot output control pressure signal and the position of the gas pressure ratio valve were plotted versus the sequence time as shown on the start-up diagram in Figure 44.

Table 12. Test Case Scenarios

Scenario	Description	Control Air	CDP	¼-Turn Shutoff Opened	Gas Pressure Ratio Valve Condition @ 1st Firing	Note
1	¼ turn shutoff valve opened well before auto sequence started (not normal practice)	As Found 30-35	0	Prior to Sequence Start	Closed	Gas pressure ratio valve is closed prior to starting sequence (not the normal practice)
2	¼ turn shutoff valve opened at start of auto sequence (normal practice)	As Found 30-35	~5	1.5 min. Before Purge	In Motion / Open	See Startup Figure, 1.5 min. is duration of time to crank to 750 rpm and start sequence. Simulate 'Auto' and Open 1/4 turn at same time.
3	¼ turn shutoff valve opened after auto sequence started (not normal practice)	As Found 30-35	~5	@ 1min. into Purge Timer	In Motion / Open	

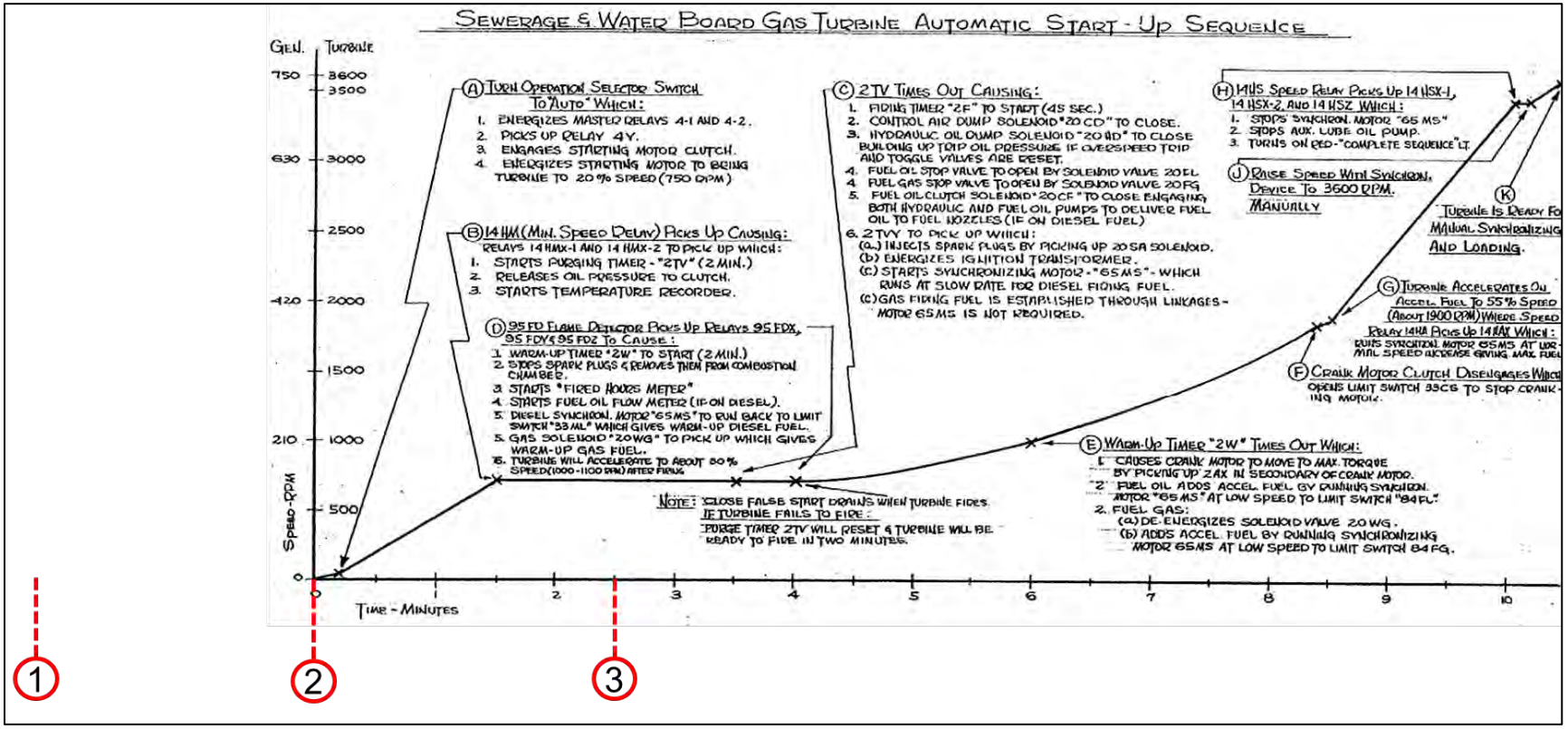


Figure 44. Automatic Start Up and Test Scenario – Establishment of Fuel Gas Pressure

Results for test scenario 1, plotted in Figure 45, indicate that when the pilot is allowed to control the gas pressure ratio valve to a fully closed position prior to start-up of the turbine and prior to the firing sequence that both perform as expected with the pilot controlling the gas pressure ratio to approximately 25% open during the firing sequence.

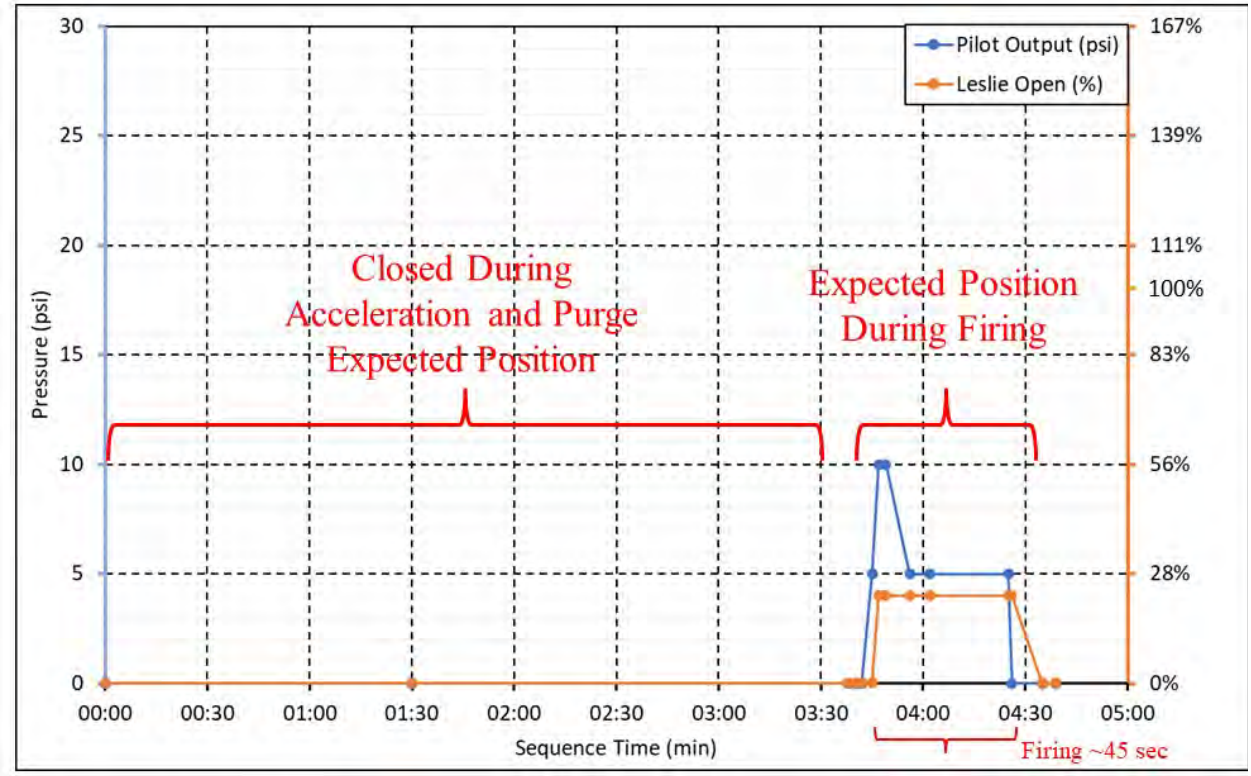


Figure 45. Test Scenario 1 - Gas Pressure Ratio Valve Position and Pilot Output Pressure

Results for test scenario 2, which represents the normal sequence for turbine startup, are presented in Figure 46. This reveals many facets of the as-found operation of the gas pressure ratio pilot. The pilot output control pressure, represented by the blue line in Figure 46, begins at the as-found control air supply pressure of ~ 30 psig and the gas pressure ratio valve remains 100% open until the control air output pressure drops to 18 psig. GEI-40960 page 676[10], reproduced in Figure 47, shows a cross-section of the gas pressure ratio pilot and is stamped with "0-18 operational range 1.4 to 1 ratio". The 1.4 to 1 ratio is understood to be the linear slope of downstream fuel gas pressure to CDP and the 0 to 18 range is suspected to be the range of control pressures to manipulate the gas pressure ratio valve position. In any case, inspection of the scenario 2 test results in Figure 46 clearly indicate the gas pressure ratio valve position does not begin to respond to the pilot control pressures until it falls to 18 psig, consistent with the 0-18 range in Figure 47. The result is that the high input control air pressure identified in Section 5.1, results in the delayed onset of gas pressure ratio valve movement, which is the second causal factor. The third causal factor identified during test scenario 2 is that the pilot is slow to control the gas pressure ratio valve, as indicated by the time required for the pilot to control the gas pressure ratio valve position. This results in the gas pressure ratio valve being opened in excess of that required for firing of the turbine.

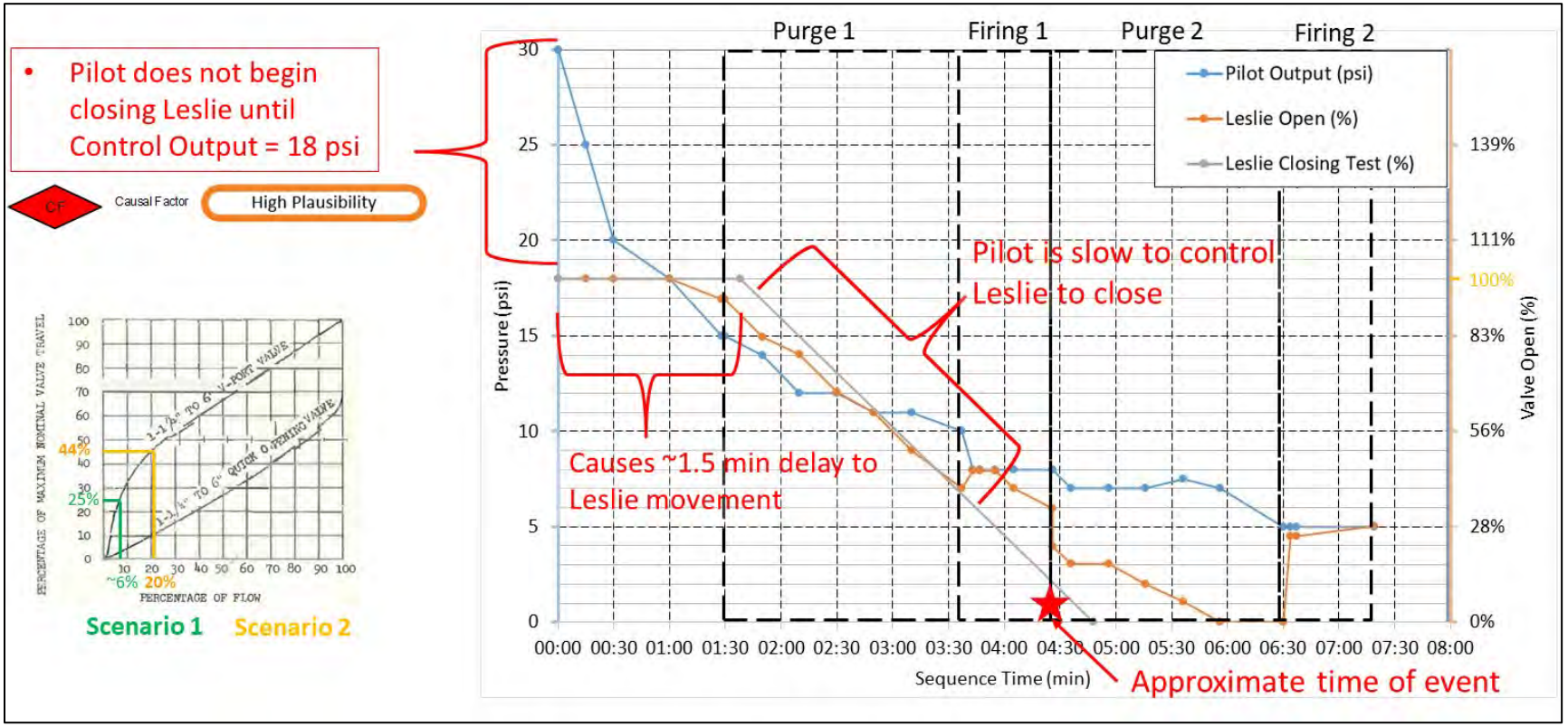


Figure 46. Test Scenario 2 - Gas Pressure Ratio Valve Position and Pilot Output Pressure

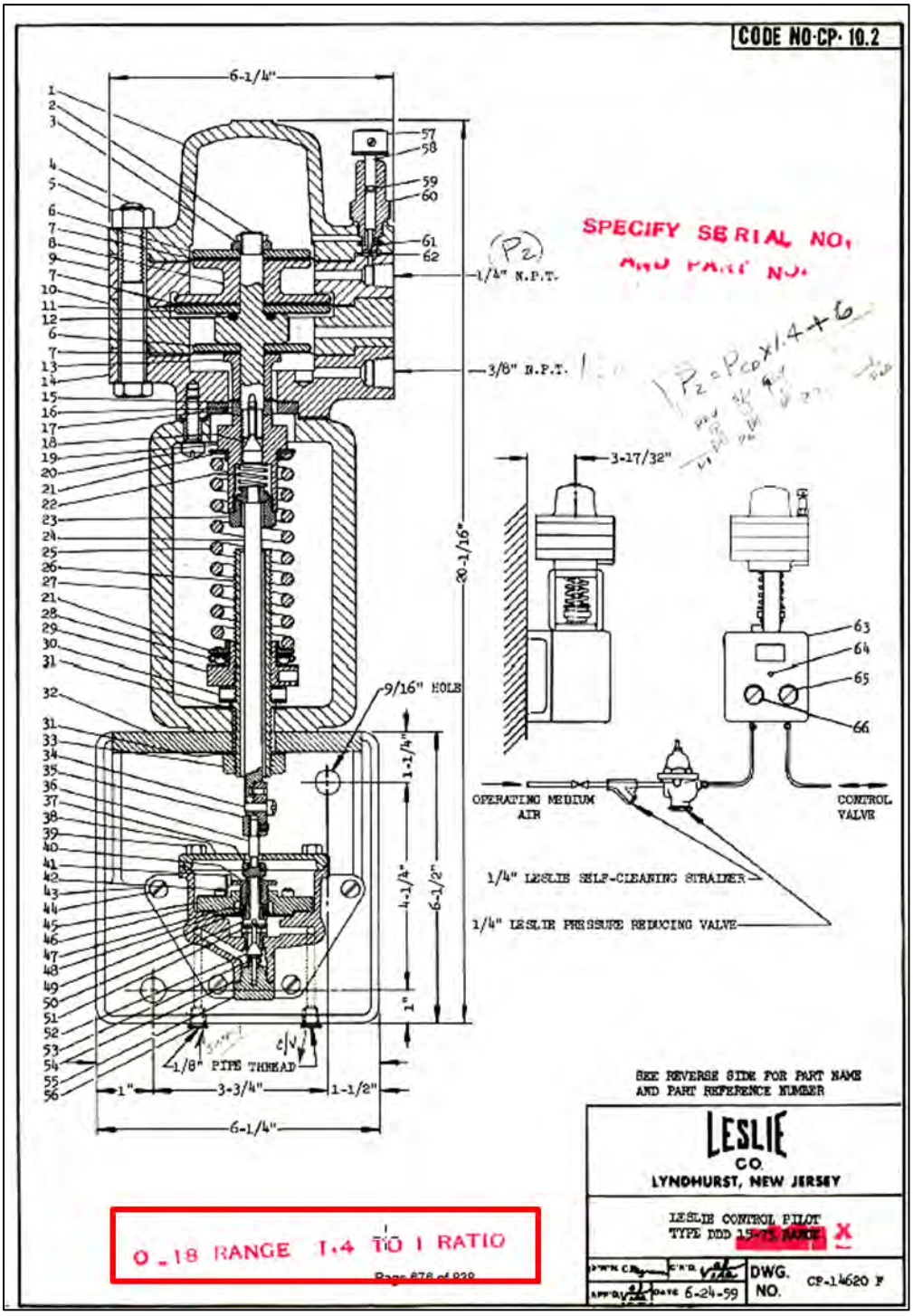


Figure 47. Gas Pressure Ratio Valve Pilot Drawing from GEI-40960

Test scenario 3, opening the ¼ turn valve late, results in an even larger opening position of the gas pressure ratio valve at the onset of firing as illustrated in Figure 48, which is the fourth causal factor.

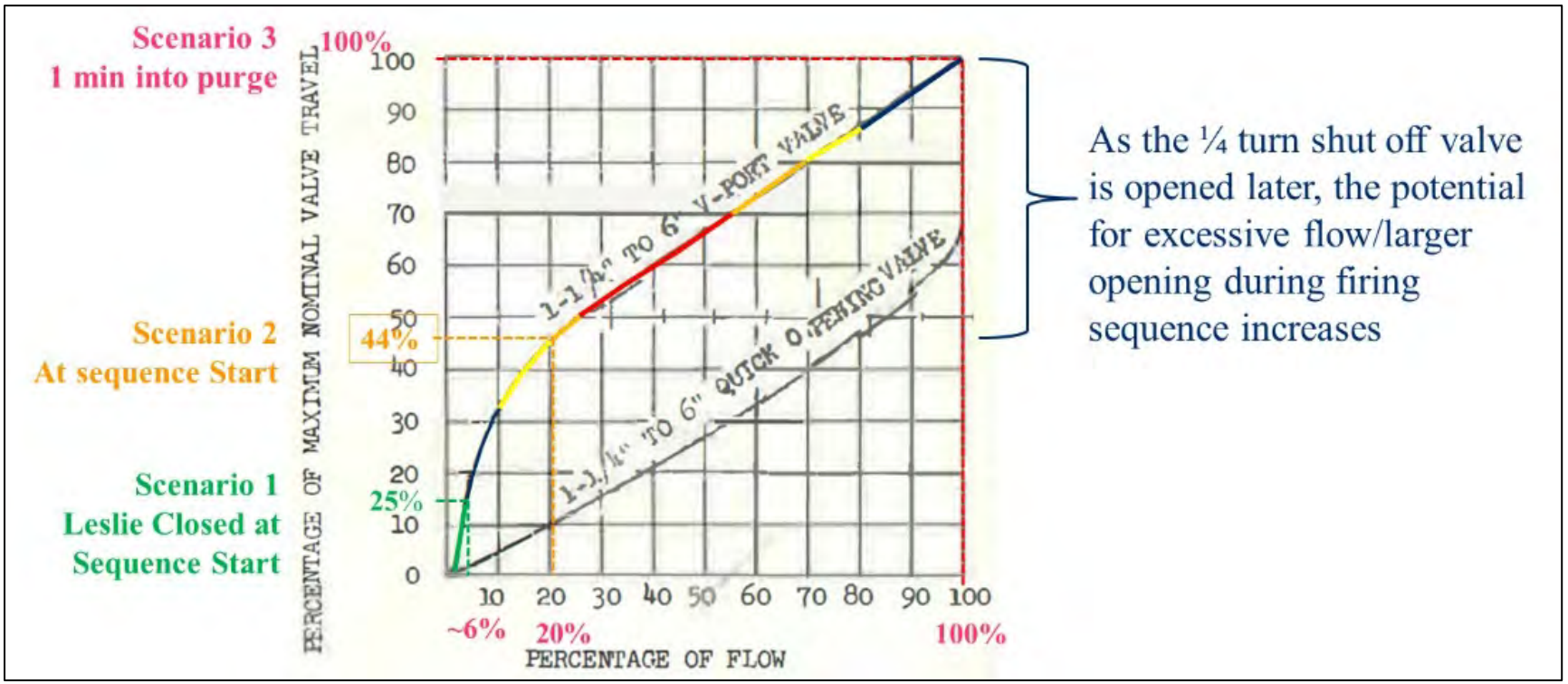


Figure 48. Test Scenarios - Gas Pressure Ratio Valve Travel vs Percentage of Fuel Gas Flow

5.5.2 STOP VALVE

Observation of the fuel gas stop valve performance during start-up simulations indicated that the stop valve opened over a period of approximately 6 seconds during the onset of firing and closed rapidly, less than 1 second, at the end of the firing sequence. The stop valve remained closed during the purge cycles.

A leak test was also performed by opening the ¼-turn shutoff valve, pressurizing the volume upstream of the stop valve, then closing the ¼-turn shutoff valve and monitoring the pressure between the ¼-turn shutoff valve and the stop valve over a period of 10 minutes. Table 13 shows that the rate of pressure decay was approximately 1 psi per minute and a total of 10 psi over the duration of the 10 minute test as shown in Figure 50. The volume of piping between the two valves is relatively small and the rate of gas leakage low.

The fuel gas stop valve performance was nominal. Therefore, malfunction of the fuel gas stop valve was contradicted and determined to be very low plausibility.

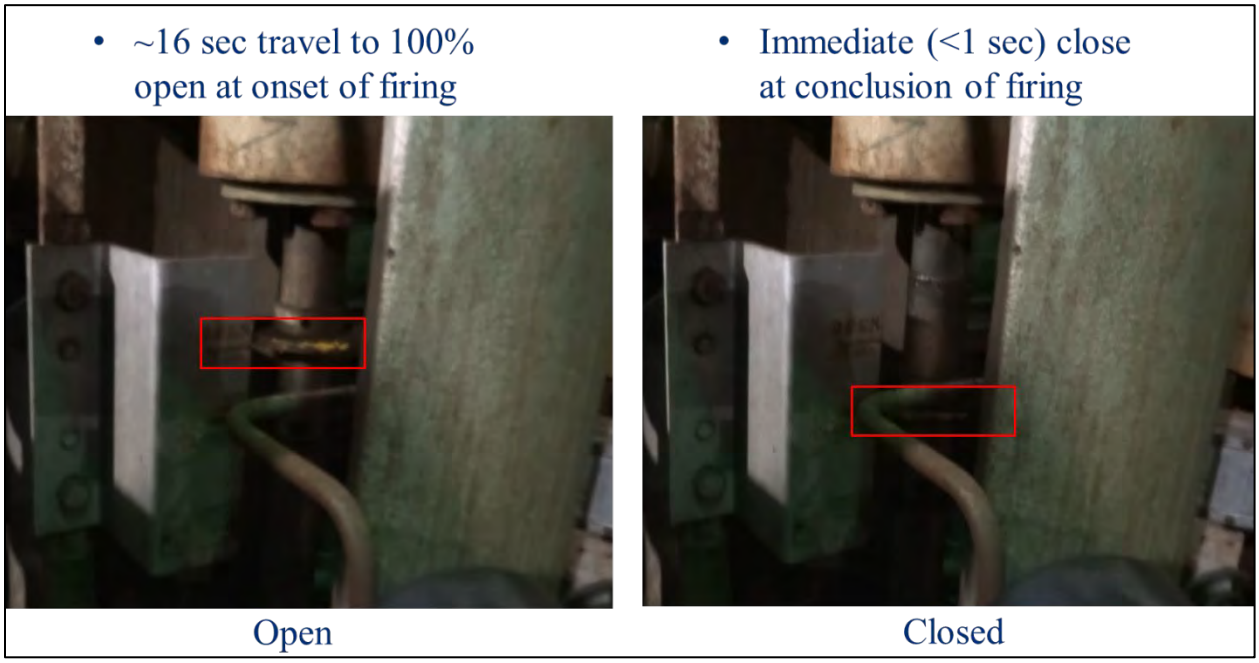


Figure 49. Fuel Gas Stop Valve Operation During Start-up Simulation

Table 13. Fuel Gas Stop Valve Leak Test Results

Time	Pressure Before Stop Valve
0 min	167 psi
2 min	165 psi
5 min	162 psi
10 min	157 psi

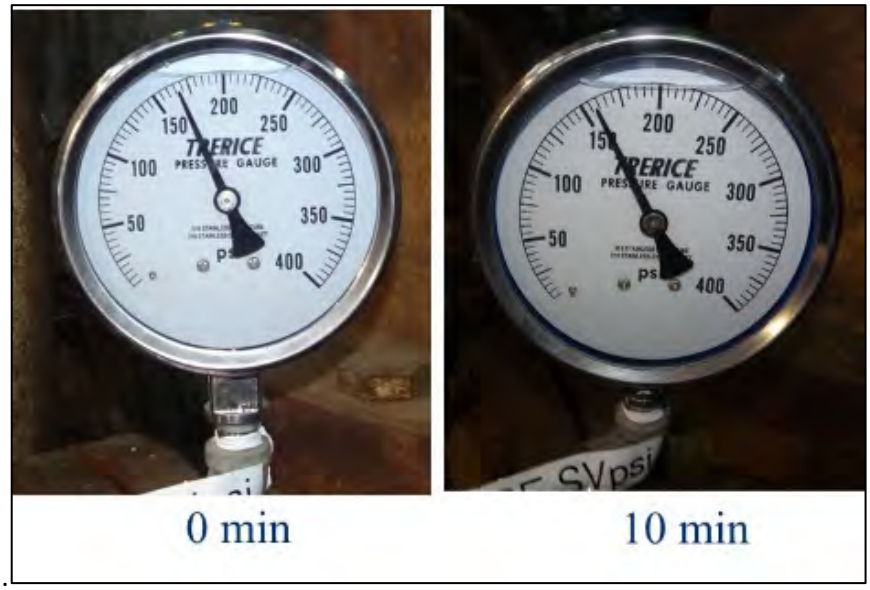


Figure 50. Fuel Gas Pressure Before the Stop Valve During Leak Testing

5.5.3 GAS CONTROL VALVE

A dial indicator was placed on the gas control valve to monitor the movement of the valve during start-up testing. This test was recorded using a camera at 60 fps. The gas control valve is a fast-acting valve with a specified opening position of 0.315 inches during firing of the turbine. The gas control valve was observed to operate nominally during all simulated firing attempts, as shown in Figure 51. Therefore, malfunction of the gas control valve was contradicted and determined to be very low plausibility.

- Fuel Gas Control Valve Travel ~0.3”
- Consistent with the specification

Closed

Open

LINE SETTINGS - GAS & OIL

LINE	FUEL CONDITION		PRIMARY RELAY S_1 SEE NOTE "A"	TEMP. RELAY T_1 SEE NOTE "B"	MIN. FUEL/CTL. OIL	MTD. CONTROL PUMP FG_1	MIN. FUEL CTL. GAS	GAS CONTROL VALVE "V_2"	PRIMARY ELECTRICAL DEVICES ENERGIZED	SECONDARY ELECTRICAL DEVICES ENERGIZED
AA	RESET		0	0	C.O.T.	C.O.T.	C.O.T.	C.O.T.	NONE	NONE
BB	FIRING	OIL	0.083	——	0.349	0.090	0.408	0.053	20CD+20HD+65MS TO84FL	20CF+20FL
		GAS	0	——	0.349	0.010	0.408	0.315	20CD+20HD	20FG
CC	WARM-UP	OIL	0	——	0.349	0.060	0.299	C.O.T.	20CD+20HD+20WG	20CF+20FL
		GAS	0	——	0.349	0.010	0.299	0.230	20CD+20HD+20WG	20FG
DD	ACCELERATION	OIL	0.083	——	0.349	0.090	0.408	0.053	20CD+20HD+65MS TO84FL	20CF+20FL
		GAS	0.307	——	0.349	0.010	0.408	0.900	20CD+20HD+65MS TO84FG	20FG
EE	MIN. FUEL	OIL	0	0	0.349	0.060	0.408	0.053	20CD+20HD	20CF+20FL
		GAS	0	0	0.349	0.010	0.408	0.315	20CD+20HD	20FG
FF	NO LOAD	OIL	0.036	0.008	0.349	0.073	0.408	0.053	20CD+20HD	20CF+20FL
		GAS	0.036	0.008	0.349	0.010	0.408	0.364	20CD+20HD	20FG
GG	1/4 LOAD	OIL	0.436	0.092	0.349	0.218	0.408	0.053	20CD+20HD	20CF+20FL
		GAS	0.436	0.092	0.349	0.010	0.408	1.147	20CD+20HD	20FG
HH	MAX. QUOTED FUEL FLOW	OIL	0.491	0.103	0.349	0.238	0.408	0.053	20CD+20HD	20CF+20FL
		GAS	0.491	0.103	0.349	0.010	0.408	1.252	20CD+20HD	20FG
JJ	MAX. REQ'D. STROKES	OIL	0.590	0.124	0.349	0.274	0.408	0.053	20CD+20HD	20CF+20FL
		GAS	0.590	0.124	0.349	0.010	0.408	1.440	20CD+20HD	20FG

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6 CAUSAL FACTORS AND RECOMMENDATIONS

The CAET was used to identify the most plausible causal factors that led to the TG 5 explosion on December 14. The causal factors and the recommendations are shown in Table 14 below.

Table 14. Causal Factors and Recommendations

Causal Factor	Recommendations
Causal Factor 1 - VPR-10 supply control air to the gas pressure ratio pilot valve set 10 psi above the specified value of 20 psi +/- 0.5 psi	**Recommendation 1:** Set and maintain gas pressure ratio pilot valve control air to correct value **Recommendation 2:** Develop and use management of change to control and maintain future changes of the control system
Causal Factor 2: Gas pressure ratio pilot valve fuel gas pressure offset (~20 psi) above specified value of 6 psi.	**Recommendation 3:** Set and maintain Leslie pilot to proper zero CDP fuel gas pressure offset for operation of the Turbine **Recommendation 2:** Develop and use management of change to control and maintain future changes of the control system
Causal Factor 3: The gas pressure ratio pilot valve pilot is slow to adjust to inputs and control the gas pressure ratio valve.	**Recommendation 4:** Requalify both the Leslie and Pilot to specified operation by a certified vendor. **Recommendation 5:** Replace both the Leslie and Pilot with a modern gas ratio valve and controller.
Causal Factor 4: Fuel gas supply ¼ turn shutoff valve may not have been opened until after operation selector switch set to auto	**Recommendation 6:** Add the following permissives to begin the startup sequence (Set Selector to Auto). • Fuel supply ¼ turn shutoff valve open. • No combustible gas in exhaust duct near combustion chamber prior to onset of firing. **Recommendation 7:** Perform HAZOP of new / modified controls system to identify and mitigate potential excessive fuel flows during startup sequence.

Causal Factor	Recommendations
Causal Factor 5: Gas pressure ratio valve is slow to adjust to pilot control signal.	**Recommendation 4:** Requalify both the gas pressure ratio valve and pilot to specified operation by a certified vendor OR replace both the gas pressure ratio valve and pilot with a modern gas ratio valve and controller. **Recommendation 8:** Add the following permissive to begin the startup sequence (Set Selector to Auto). • Gas pressure ratio valve closed.

7 REFERENCES

1 Sewerage & Water Board System Overview Presentation, January 2018.

2 Sewerage & Water Board Power Generation and Drainage System FAQs, 14 August 2017.

3 Vanden Heuvel, Lee et al., “Root Cause Analysis Handbook”, ABS Consulting, Rothstein Associates Inc Publishers, 2008.

4 GEI-40960, “Gas Turbine-Generator Unit 20,200 KW Gas Turbine No. 127724, Generator NO. 8300411”, Sewerage and Water Board of New Orleans Purchaser’s Order NO 198-W, Gas Turbine Department General Electric, Schenectady, N.Y., 1960.

5 GEI-77036A, “Gas Turbine Generator 20,200 KW”, Medium Voltage Switchgear Department, General Electric, Philadelphia, PA, August 1960.

6 Sewerage and Water Board of N.O. DWG No. 10948-W-2, “Sewerage & Water Board Gas Turbine Start-Up Sequence”, July 8, 1963.

7 GE Schematic Piping Diagrams, 916B455, July 15, 1959.

8 Sewerage and Water Board of New Orleans, Carrollton Water Plant security camera footage from 18 different cameras, December 14, 2019.

9 General Electric, “New Orleans SW&B Forced Outage 2017”, Repair to return to service, June 18, 2019.

10 General Electric, “2019 Callout Outage – Reduction Gearbox – Starting Clutch – Controls Troubleshooting”, June 15, 2019.

11 Sewerage & Water Board of New Orleans, “Turbine 5 2019 Outage Report”, October 1, 2019.

12 General Electric, Control Specifications, 114A9016, Dec. 1, 2019.

APPENDIX A – TIMELINES

No.	Date	Time	Item	Event	Ref.
10	1959		TG 5 System	Design approved for construction	
20	August 1960		Startup Procedure	Procedure developed by GE	5
30	July 8, 1963		Procedure	Startup procedure diagram generated by R.M. McKay, Drawing No. 10948-W-2, SKE-357	6
40	March 2017		TG 5 System	Taken out of service for rehabilitation	
50	Feb/March 2018		TG 5 System	Recommissioned following GE work	
60	February 6, 2019		TG 5 System	Electricians perform PM on the generator.	11
70	February 7, 2019		TG 5 System	SWBNO personnel met GE crew and gave tour	
80	Feb 10 – Feb 22 2019		TG 5 System GE Phase 1 work	Reduction Gear Inspection	10
100	Feb 10 – Feb 22 2019		TG 5 System GE Phase 1 work	GE FieldCore Mobilized • Inspected reduction gear box o Lose babbitt on the gears o Upper halves of 4 reduction gear bearings inspected o Thrust bearing pads inspected • Bearings, journals, oil deflectors cleaned and measured • Reduction gearbox casing and bolt holes cleaned • Gearbox reassembled	10, 11
110	Feb 10 – Feb 22 2019		TG 5 System GE Phase 1 work	Following the reduction gear inspection • Liquid fuel system was traced down • Liquid fuel check valve replaced	10

No.	Date	Time	Item	Event	Ref.
				• Purge check valve replaced TG 5 failed to run on liquid fuel after several attempts Liquid fuel troubleshooting postponed	
120	Feb 17, 2019		TG 5 System GE Phase 1 work	TG 5 was successfully run on gas fuel at the end of Phase 1	10, 11
130	Feb 18-21, 2019		TG 5 System	Oil leak on the gearbox observed. • GE reopened the gearbox • Cleaned surfaces • Applied new sealant and closed	11
140	Feb 22, 2019		TG 5 System	Test run on gas • Issue with gas pressure Test run on diesel • Not successful Tried to start on gas after diesel run • Not successful GE begins demobilizing	11
150	February 23, 2019		TG 5 System SWBNO	Turbine test failed again • Suspected a controls issue • GE looking at providing a controls expert	11
160	February 24, 2019		TG 5 SWBNO	SWBNO Facility Maintenance and Electric Shop cannot find issue with turbine controls Gear reduction gearbox leaking again	11
170	Feb 25 – Mar 16 2019		TG 5 System GE Phase 2 work	GE controls technician arrive to troubleshoot controls SWBNO electrician pointed issue out an issue with door switch on the T5 cranking motor panel door • Switch adjusted to allow for earlier engagement • Switch not part of the problem	11
180	Feb 25 – Mar 16 2019		TG 5 System GE Phase 2 work	The 33CS Starting Clutch Limit Switch was adjusted by SWBNO ~Feb 25th.	10, 11

No.	Date	Time	Item	Event	Ref.
				• On subsequent startup the motor started before the clutch was engaged • Jaw teeth on the clutch hubs were heavily damaged This initiated the Phase 2 Outage work by GE	
190	Feb 25 – Mar 16 2019		TG 5 System GE Phase 2 work	Accessory Gearbox Repair and Startup Troubleshooting	10
200	Feb 25 – Mar 16 2019		TG 5 System GE Phase 2 work	GE FieldCore removed the accessory gearbox cover to access the damaged clutch • Both clutch hubs were removed • #1 gear and shaft removed • Jaw teeth on the clutch hubs were repaired by SWBNO machine shop Feb 27 GE FieldCore then: • Reinstalled the hubs and the #1 gear shaft • Reassemble the Accessory gearbox	10, 11
210	Feb 25 – Mar 16 2019		TG 5 System GE Phase 2 work	Phase 2 startup attempts testing and several repairs to electrical, controls, mechanical issues • First startup attempt March 4 • Fuel transfer relay and two timers replaced with customer spares • A lose ground wire shared by several solenoid valves fixed • Starting motor clutch assembly tested, adjusted to meet specifications • Clutch piston replaced March 8	10, 11

No.	Date	Time	Item	Event	Ref.
				• Instrument Air lines disconnected and blown out • Compressor discharge pressure (CDP) signal air lines disconnected and blown out	
220	March 15, 2019		TG 5 System	Gas pressure control pilot valve • Actuated control valve manually to confirm operation • PIlot that controls the valve not operating properly • Test ran machine and manually actuated the gas control valve by bypassing the regulator	
230	Feb 25 – Mar 16 2019		TG 5 System GE Phase 2 work	After many failed startup attempts the turbine was started by bypassing the pressure ratio valve with instrument air The pilot valve needed further inspection and Phase 2 outage concluded	10
240	Mar 18 – April 14 2019		TG 5 System GE Phase 3 work	Startup and Controls Troubleshooting • Repaired the pressure ratio pilot valve (PRV) • Realigned the start motor • Troubleshot startup and fuel controls	10
250	Mar 18 – April 14 2019		TG 5 System GE Phase 3 work	The pilot valve (PRV) was inspected and repaired by John H. Carter (Carter) • Removed and sent to Carter on March 18 • Found to have a broken spacer (regulator housing) and diaphragms	10, 11

No.	Date	Time	Item	Event	Ref.
				• Cast aluminum diaphragm spacer worn and cracked • Received from Carter March 23	
260	Mar 18 – April 14 2019		TG 5 System GE Phase 3 work	The turbine repeatedly tripped during the purge timer Accessory gearbox cover removed to investigate the clutch assembly Starting motor found to be misaligned with the accessory gearbox • Alignment move was made to bring alignment within specification • Clutch assembly and limit switch were reset and tested independently • Gearbox reassembled	10
270	Mar 18 – April 14 2019		TG 5 System GE Phase 3 work	Several other electrical and controls problems were identified and fixed • Liquid fuel limit switch • Synchronizing motor resistor • Startup timer	10
280	Mar 18 – April 14 2019		TG 5 System GE Phase 3 work	The turbine could still not be manually raised to 3850 rpm at full speed no load (FSNL) because of the stop collar on the sync motor shaft • The range of the sync motor became an issue when the turbine was carrying a 12MW load • Operations needed to raise the speed to sync to achieve additional load • Could not sync additional load because sync motor was maxed out against the stop collar	10, 11

No.	Date	Time	Item	Event	Ref.
				• Adjustments to the fuel gas linkages were attempted unsuccessfully (April 9) • Stop collar was lowered and repined so that the manual speed with no load was 3850 rpm. • Linkage settings reversed on April 11 to prior settings • Fieldcore/GE requested moving 65 MS shaft collar	
290	April 25			Ran Load Test • Measure the S1 (speed control) and V (gas control valve) linkages under load • Insufficient load for test	11
300	April 25			Decent run on Turbine 5 • Got 12.3 MW • Central control had to manually bring the turbine back up to speed after each load increase beyond 8 MW • 3/8" travel left on sync motor • Gas pressure ratio valve is still only open a little more than half stroke but still getting 125 psi of gas pressure at the stop valve	11
310	Mar 18 – April 14 2019		TG 5 System GE Phase 3 work	At the end of the outage, the turbine was proven to start successfully and hold a load range of 0 – 12 MW Without a larger rain event, SWBNO could not provide a heavier load to test the maximum load of the turbine	10

No.	Date	Time	Item	Event	Ref.
320	Oct. 1, 2019			Still have not generated significant load on TG 5 • Still have the 8 MW restriction • Central control still must manually bring up the RPM with the sync motor to maintain anything above 8MW	10
330	Oct. 3 to Dec. 11 2019		TG 5 System	TG Ran continuously	
340	Dec 11		TG 5 System	Shutdown for PM	
350	Dec 12		TG 5 System	Started for testing – brought the machine up to speed, but did not load the machine Operator stated that this startup went very smoothly, 'perfect'. Operator was training two other individuals during this startup.	
360	Dec 12		TG 5 System	Shutdown	
370	Dec 14 (Saturday)		Control air	Air compressor "failed" in Boiler Room	
380	Dec 14		Frequency Converters to #4 Aux and #5 Aux	#5 Auxiliary had not been powered	
390	Dec 14		TG 4 System	No pressure because of loss of steam	
400	Dec 14		TG 5 System	Did not have air pressure initially because of the air system issues that led to TG #4 shutting down. Verified air pressure in order to meet permissive for TG 5	
410	Dec 14		TG 5 System	Begin preparing TG 5 for startup to replace power from TG 4	
420	Dec 14	13:35:55	Operator	Operator 1 arrives at main security gate	8
430	Dec 14	13:36:00	Boiler Control	Boiler control room phone call that ends at 13:38:04	8
440	Dec 14	13:36:08	TG 5 System	Operator 1 driving to back of plant.	8
450	Dec 14	13:36:15	Central Control	Central control on call that ends at 13:36:51	8
460	Dec 14	13:37:17	Central Control	On a call that ends at 013:38:08.	8

No.	Date	Time	Item	Event	Ref.
470	Dec 14	13:39:05	Central Control Boiler Control	Central Control and Boiler Control both on a call that ends at 13:39:22.	8
480	Dec 14	13:29:22	Central Control	A log or note entry is made.	8
490	Dec 14	13:40:05	Central Control	Central control on a call (2 seconds) that ends at 13:40:07	8
500	Dec 14	13:40:07	Central Control	A log or note entry is made.	8
510	Dec 14	13:42:03	Central Control Boiler Control	Central Control and Boiler Control both on a call that ends at 13:42:14.	8
520	Dec 14	13:42:14	Central Control	A log or note entry is made.	8
530	Dec 14	13:42:14	Central Control	A log or note entry is made.	8
540	Dec 14	13:42:54	High Lift Office	Operator 1 enters High Lift Office and makes a call from the fixed phone on the wall.	8
550	Dec 14	13:43:18	High Lift Office	Operator 1 exits the High Lift Office.	8
560	Dec 14	13:44:25	High Lift Office	Operator 1 enters the High Lift Office to use a cell phone.	8
570	Dec 14	13:44:45	High Lift Office	A second operator enters the High Lift	8
580	Dec 14	13:46:00	High Lift Office	Operator 1 departs High Lift Office	8
590	Dec 14	13:47:30	TG 5	TG 5 Explosion	8

APPENDIX B – CAUSE AND EFFECT TREE

DRAFT REPORT

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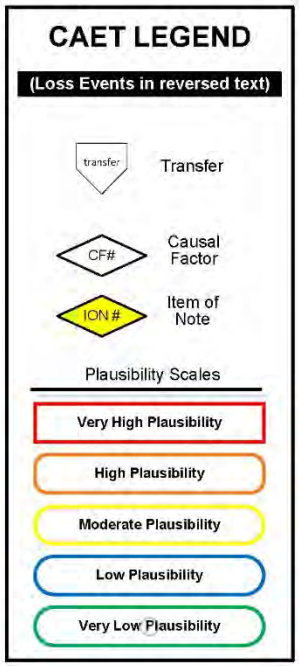
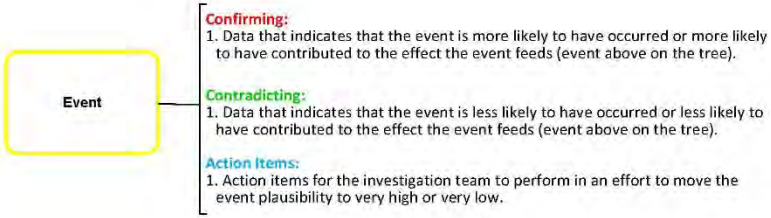
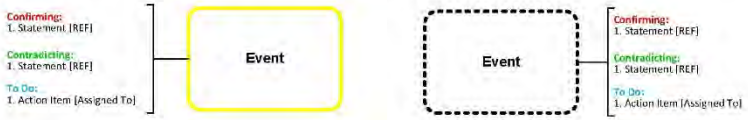
SWBNO TG #5 Failure, December 14, 2019



Plausibility Scale

Red	Very High Plausibility	Based on the available data, the team concluded that the event occurred and contributed to the incident (data predominantly confirms the occurrence and contribution of this item)
Orange	High Plausibility	Based on the available data, the team concluded that the event most likely occurred and contributed to the incident (most of the data confirms the occurrence and contribution of this item, but there is also data contradicting the occurrence and contribution of this item)
Yellow	Moderate Plausibility	Based on the available data, the team concluded that the event may have occurred and contributed to the incident (the data confirming and contradicting the item are about equal)
Blue	Low Plausibility	Based on the available data, the team concluded that the event most likely did not occur and was not likely to have contributed to the occurrence of the incident (most data contradicts the occurrence and contribution of this item)
Green	Very Low Plausibility	Based on the available data, the team concluded that the event did NOT occur and did NOT contribute to the occurrence of the incident (data predominately contradicts the occurrence and contribution of this item)





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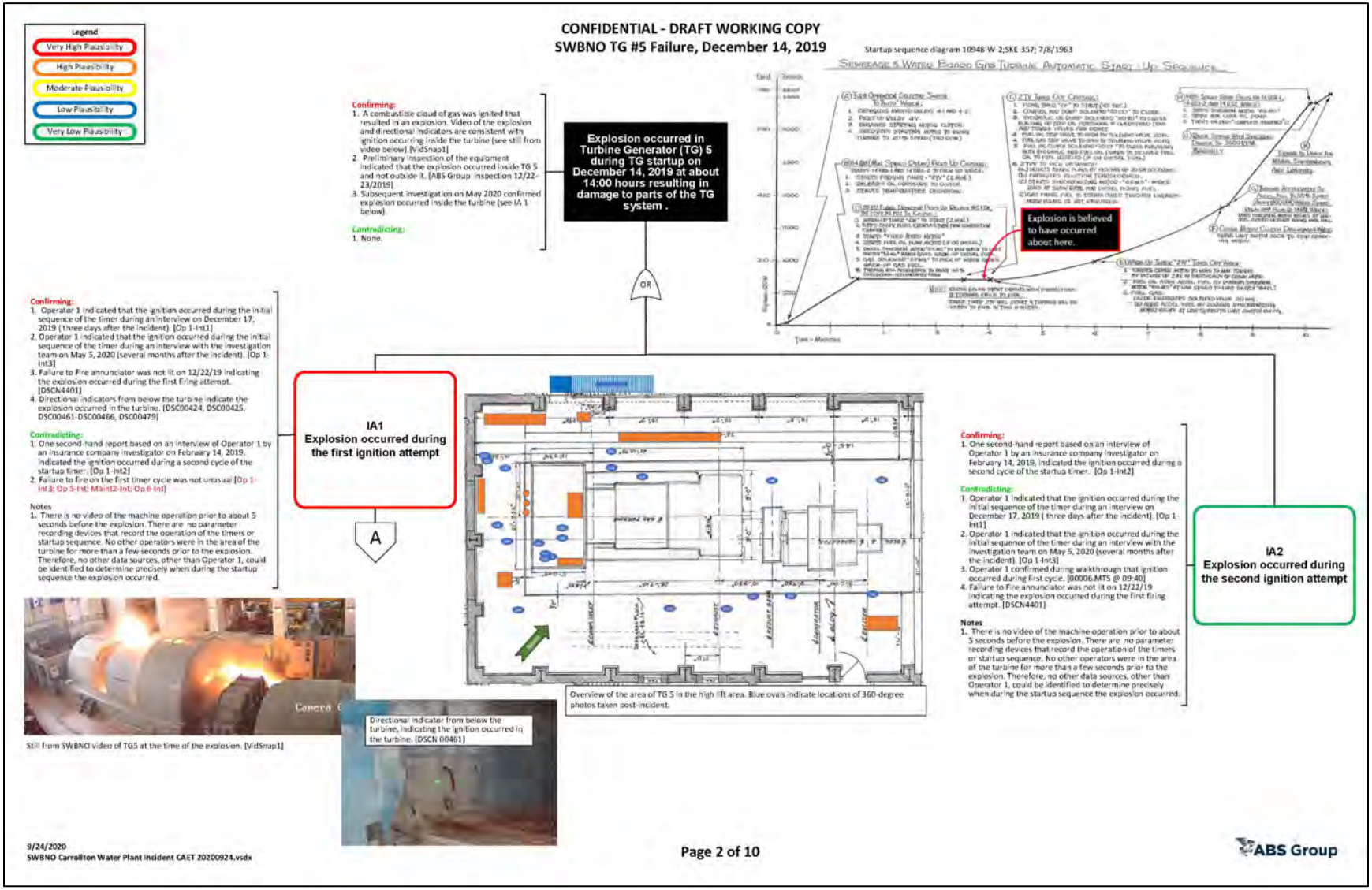
Legend
Very High Plausibility
High Plausibility
Moderate Plausibility
Low Plausibility
Very Low Plausibility
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SWBNO TG #5 Failure, December 14, 2019
Startup sequence diagram 10948-W-2;SKE-357; 7/8/1963
Confirming:
1. A combustible cloud of gas was ignited that resulted in an explosion. Video of the explosion and directional indicators are consistent with ignition occurring inside the turbine (see still from video below).[VidSnap1]
2. Preliminary inspection of the equipment indicated that the explosion occurred inside TG 5 and not outside it. [ABS Group Inspection 12/22-23/2019]
3. Subsequent investigation on May 2020 confirmed explosion occurred inside the turbine (see IA 1 below).
Contradicting:
1. None.
Explosion occurred in Turbine Generator (TG) 5 during TG startup on December 14, 2019 at about 14:00 hours resulting in damage to parts of the TG system .
OR
Explosion is believed to have occurred about here.
Confirming:
1. Operator 1 indicated that the ignition occurred during the initial sequence of the timer during an interview on December 17, 2019 (three days after the incident). [Op 1-Int1]
2. Operator 1 indicated that the ignition occurred during the initial sequence of the timer during an interview with the investigation team on May 5, 2020 (several months after the incident). [Op 1-Int3]
3. Failure to Fire annunciator was not lit on 12/22/19 indicating the explosion occurred during the first firing attempt. [DSCN4401]
4. Directional indicators from below the turbine indicate the explosion occurred in the turbine. [DSC00424, DSC00425, DSC00461-DSC00466, DSC00479]
Contradicting:
1. One second-hand report based on an interview of Operator 1 by an insurance company investigator on February 14, 2019, indicated the ignition occurred during a second cycle of the startup timer. [Op 1-Int2]
2. Failure to fire on the first timer cycle was not unusual [Op 1-Int3; Op 5-Int; Maint2-Int; Op 6-Int]
Notes
1. There is no video of the machine operation prior to about 5 seconds before the explosion. There are no parameter recording devices that record the operation of the timers or startup sequence. No other operators were in the area of the turbine for more than a few seconds prior to the explosion. Therefore, no other data sources, other than Operator 1, could be identified to determine precisely when during the startup sequence the explosion occurred.
IA1
Explosion occurred during the first ignition attempt
A
Overview of the area of TG 5 in the high lift area. Blue ovals indicate locations of 360-degree photos taken post-incident.
Confirming:
1. One second-hand report based on an interview of Operator 1 by an insurance company investigator on February 14, 2019, indicated the ignition occurred during a second cycle of the startup timer. [Op 1-Int2]
Contradicting:
1. Operator 1 indicated that the ignition occurred during the initial sequence of the timer during an interview on December 17, 2019 (three days after the incident). [Op 1-Int1]
2. Operator 1 indicated that the ignition occurred during the initial sequence of the timer during an interview with the investigation team on May 5, 2020 (several months after the incident). [Op 1-Int3]
3. Operator 1 confirmed during walkthrough that ignition occurred during first cycle. [00006.MTS @ 09:40]
4. Failure to Fire annunciator was not lit on 12/22/19 indicating the explosion occurred during the first firing attempt. [DSCN4401]
Notes
1. There is no video of the machine operation prior to about 5 seconds before the explosion. There are no parameter recording devices that record the operation of the timers or startup sequence. No other operators were in the area of the turbine for more than a few seconds prior to the explosion. Therefore, no other data sources, other than Operator 1, could be identified to determine precisely when during the startup sequence the explosion occurred.
IA2
Explosion occurred during the second ignition attempt
Camera
Still from SWBNO video of TG5 at the time of the explosion. [VidSnap1]
Directional indicator from below the turbine, indicating the ignition occurred in the turbine. [DSCN 00461]
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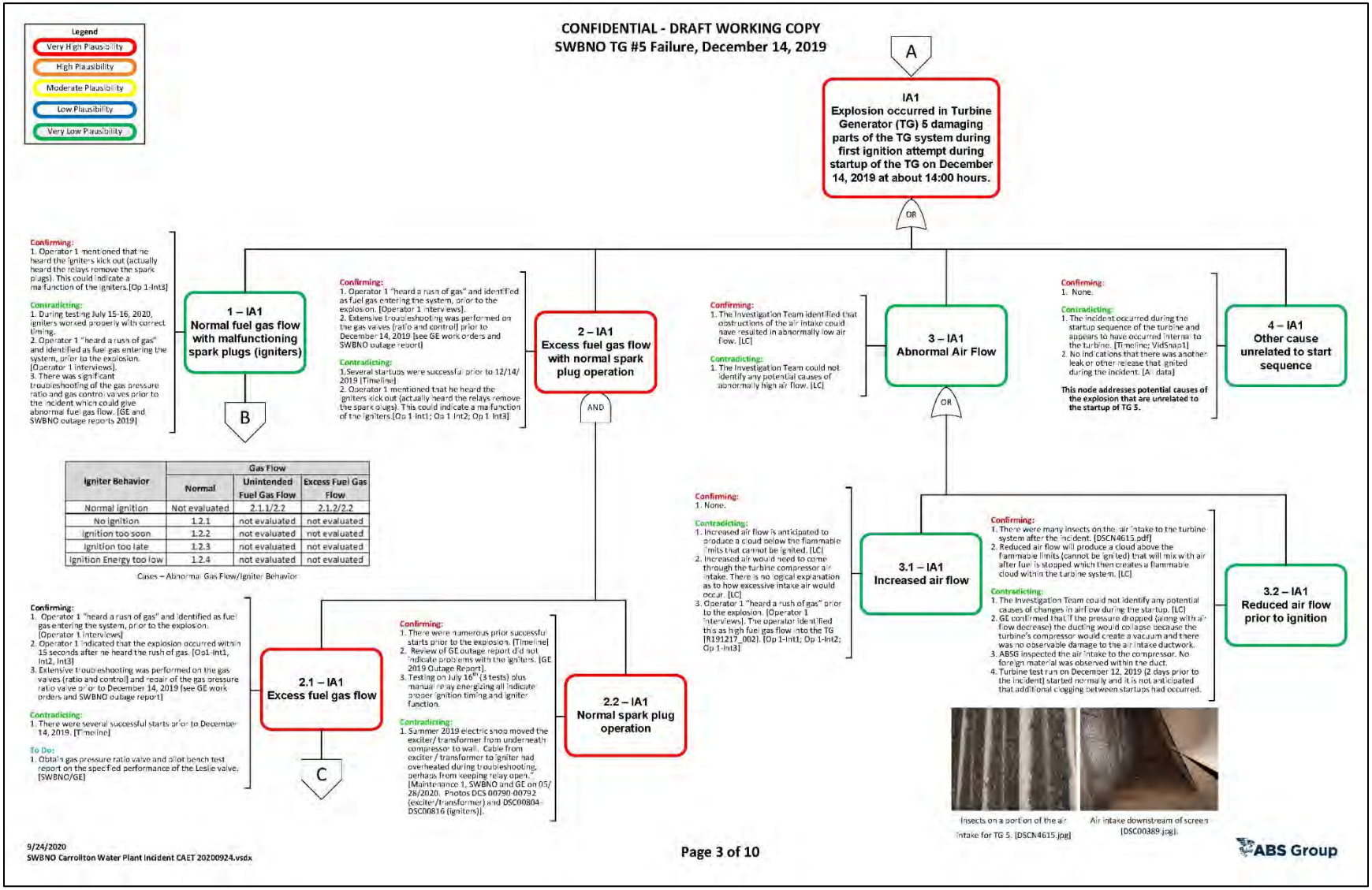
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SWBNO TG #5 Failure, December 14, 2019
A
IA1
Explosion occurred in Turbine Generator (TG) 5 damaging parts of the TG system during first ignition attempt during startup of the TG on December 14, 2019 at about 14:00 hours.
OR
1 – IA1
Normal fuel gas flow with malfunctioning spark plugs (igniters)
2 – IA1
Excess fuel gas flow with normal spark plug operation
AND
3 – IA1
Abnormal Air Flow
OR
4 – IA1
Other cause unrelated to start sequence
B
Confirming:
1. Operator 1 mentioned that he heard the igniters kick out (actually heard the relays remove the spark plugs). This could indicate a malfunction of the igniters.[Op 1-Int3]
Contradicting:
1. During testing July 15-16, 2020, igniters worked properly with correct timing.
2. Operator 1 "heard a rush of gas" and identified as fuel gas entering the system, prior to the explosion. [Operator 1 interviews].
3. There was significant troubleshooting of the gas pressure ratio and gas control valves prior to the incident which could give abnormal fuel gas flow. [GE and SWBNO outage reports 2019]
Confirming:
1. Operator 1 "heard a rush of gas" and identified as fuel gas entering the system, prior to the explosion. [Operator 1 interviews].
2. Extensive troubleshooting was performed on the gas valves (ratio and control) prior to December 14, 2019 [see GE work orders and SWBNO outage report]
Contradicting:
1. Several startups were successful prior to 12/14/2019 [Timeline]
2. Operator 1 mentioned that he heard the igniters kick out (actually heard the relays remove the spark plugs). This could indicate a malfunction of the igniters.[Op 1 Int1; Op 1 Int2; Op 1 Int3]
Confirming:
1. The Investigation Team identified that obstructions of the air intake could have resulted in abnormally low air flow. [LC]
Contradicting:
1. The Investigation Team could not identify any potential causes of abnormally high air flow. [LC]
Confirming:
1. None.
Contradicting:
1. The incident occurred during the startup sequence of the turbine and appears to have occurred internal to the turbine. [Timeline; VidSnap1]
2. No indications that there was another leak or other release that ignited during the incident. [Air data]
This node addresses potential causes of the explosion that are unrelated to the startup of TG 5.
Igniter Behavior
Gas Flow
Normal
Unintended Fuel Gas Flow
Excess Fuel Gas Flow
Normal Ignition | Not evaluated | 2.1.1/2.2 | 2.1.2/2.2
No Ignition | 1.2.1 | not evaluated | not evaluated
Ignition too soon | 1.2.2 | not evaluated | not evaluated
Ignition too late | 1.2.3 | not evaluated | not evaluated
Ignition Energy too low | 1.2.4 | not evaluated | not evaluated
Cases – Abnormal Gas Flow/Igniter Behavior
Confirming:
1. None.
Contradicting:
1. Increased air flow is anticipated to produce a cloud below the flammable limits that cannot be ignited. [LC]
2. Increased air would need to come through the turbine compressor air intake. There is no logical explanation as to how excessive intake air would occur. [LC]
3. Operator 1 "heard a rush of gas" prior to the explosion. [Operator 1 interviews]. The operator identified this as high fuel gas flow into the TG [R191217_002]. [Op 1-Int1; Op 1-Int2; Op 1-Int3]
3.1 – IA1
Increased air flow
Confirming:
1. There were many insects on the air intake to the turbine system after the incident. [DSCN4615.pdf]
2. Reduced air flow will produce a cloud above the flammable limits (cannot be ignited) that will mix with air after fuel is stopped which then creates a flammable cloud within the turbine system. [LC]
Contradicting:
1. The Investigation Team could not identify any potential causes of changes in airflow during the startup. [LC]
2. GE confirmed that if the pressure dropped (along with airflow decrease) the ducting would collapse because the turbine's compressor would create a vacuum and there was no observable damage to the air intake ductwork.
3. ABSG inspected the air intake to the compressor. No foreign material was observed within the duct.
4. Turbine test run on December 12, 2019 (2 days prior to the incident) started normally and it is not anticipated that additional clogging between startups had occurred.
3.2 – IA1
Reduced air flow prior to ignition
Insects on a portion of the air intake for TG 5. [DSCN4615.jpg]
Air intake downstream of screen [DSC00389.jpg].
Confirming:
1. Operator 1 "heard a rush of gas" and identified as fuel gas entering the system, prior to the explosion. [Operator 1 interviews]
2. Operator 1 indicated that the explosion occurred within 15 seconds after he heard the rush of gas. [Op1-Int1, Int2, Int3]
3. Extensive troubleshooting was performed on the gas valves (ratio and control) and repair of the gas pressure ratio valve prior to December 14, 2019 [see GE work orders and SWBNO outage report]
Contradicting:
1. There were several successful starts prior to December 14, 2019. [Timeline]
To Do:
1. Obtain gas pressure ratio valve and pilot bench test report on the specified performance of the Leslie valve. [SWBNO/GE]
2.1 – IA1
Excess fuel gas flow
C
Confirming:
1. There were numerous prior successful starts prior to the explosion. [Timeline]
2. Review of GE outage report did not indicate problems with the igniters. [GE 2019 Outage Report].
3. Testing on July 16th (3 tests) plus manual relay energizing all indicate proper ignition timing and igniter function.
Contradicting:
1. Summer 2019 electric shock moved the exciter/transformer from underneath compressor to wall. Cable from exciter/transformer to igniter had overheated during troubleshooting, perhaps from keeping relay open." [Maintenance 1, SWBNO and GE on 05/28/2020. Photos DCS 00790-00792 (exciter/transformer) and DSC00804-DSC00816 (igniters)].
2.2 – IA1
Normal spark plug operation
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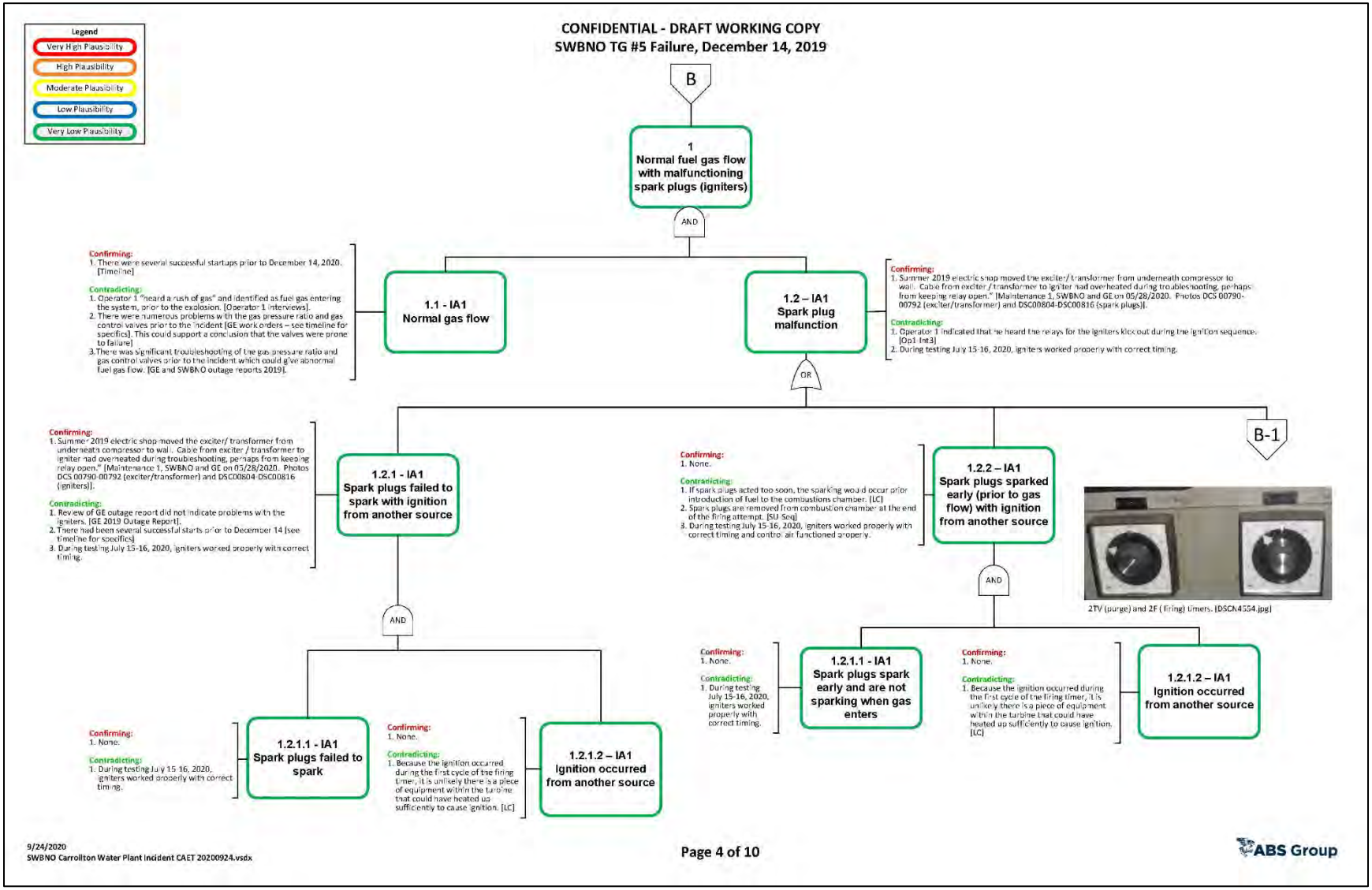
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SWBNO TG #5 Failure, December 14, 2019
B
1
Normal fuel gas flow with malfunctioning spark plugs (igniters)
AND
Confirming:
1. There were several successful startups prior to December 14, 2020. [Timeline]
Contradicting:
1. Operator 1 "heard a rush of gas" and identified as fuel gas entering the system, prior to the explosion. [Operator 1 interviews].
2. There were numerous problems with the gas pressure ratio and gas control valves prior to the incident [GE work orders – see timeline for specifics]. This could support a conclusion that the valves were prone to failure]
3. There was significant troubleshooting of the gas pressure ratio and gas control valves prior to the incident which could give abnormal fuel gas flow. [GE and SWBNO outage reports 2019].
1.1 - IA1
Normal gas flow
1.2 – IA1
Spark plug malfunction
Confirming:
1. Summer 2019 electric shop moved the exciter/ transformer from underneath compressor to wall. Cable from exciter / transformer to igniter had overheated during troubleshooting, perhaps from keeping relay open." [Maintenance 1, SWBNO and GE on 05/28/2020. Photos DCS 00790-00792 (exciter/transformer) and DSC00804-DSC00816 (spark plugs)].
Contradicting:
1. Operator 1 indicated that he heard the relays for the igniters kick out during the ignition sequence. [Op1 Int3]
2. During testing July 15-16, 2020, igniters worked properly with correct timing.
OR
B-1
Confirming:
1. Summer 2019 electric shop moved the exciter/ transformer from underneath compressor to wall. Cable from exciter / transformer to igniter had overheated during troubleshooting, perhaps from keeping relay open." [Maintenance 1, SWBNO and GE on 05/28/2020. Photos DCS 00790-00792 (exciter/transformer) and DSC00804-DSC00816 (igniters)].
Contradicting:
1. Review of GE outage report did not indicate problems with the igniters. [GE 2019 Outage Report].
2. There had been several successful starts prior to December 14 [see timeline for specifics]
3. During testing July 15-16, 2020, igniters worked properly with correct timing.
1.2.1 - IA1
Spark plugs failed to spark with ignition from another source
Confirming:
1. None.
Contradicting:
1. If spark plugs acted too soon, the sparking would occur prior introduction of fuel to the combustions chamber. [LC]
2. Spark plugs are removed from combustion chamber at the end of the firing attempt. [SU Soq]
3. During testing July 15-16, 2020, igniters worked properly with correct timing and control air functioned properly.
1.2.2 – IA1
Spark plugs sparked early (prior to gas flow) with ignition from another source
2TV (purge) and 2F (firing) timers. [DSCN4554.jpg]
AND
AND
Confirming:
1. None.
Contradicting:
1. During testing July 15-16, 2020, igniters worked properly with correct timing.
1.2.1.1 - IA1
Spark plugs failed to spark
Confirming:
1. None.
Contradicting:
1. Because the ignition occurred during the first cycle of the firing timer, it is unlikely there is a piece of equipment within the turbine that could have heated up sufficiently to cause ignition. [LC]
1.2.1.2 – IA1
Ignition occurred from another source
Confirming:
1. None.
Contradicting:
1. During testing July 15-16, 2020, igniters worked properly with correct timing.
1.2.1.1 - IA1
Spark plugs spark early and are not sparking when gas enters
Confirming:
1. None.
Contradicting:
1. Because the ignition occurred during the first cycle of the firing timer, it is unlikely there is a piece of equipment within the turbine that could have heated up sufficiently to cause ignition. [LC]
1.2.1.2 – IA1
Ignition occurred from another source
9/24/2020
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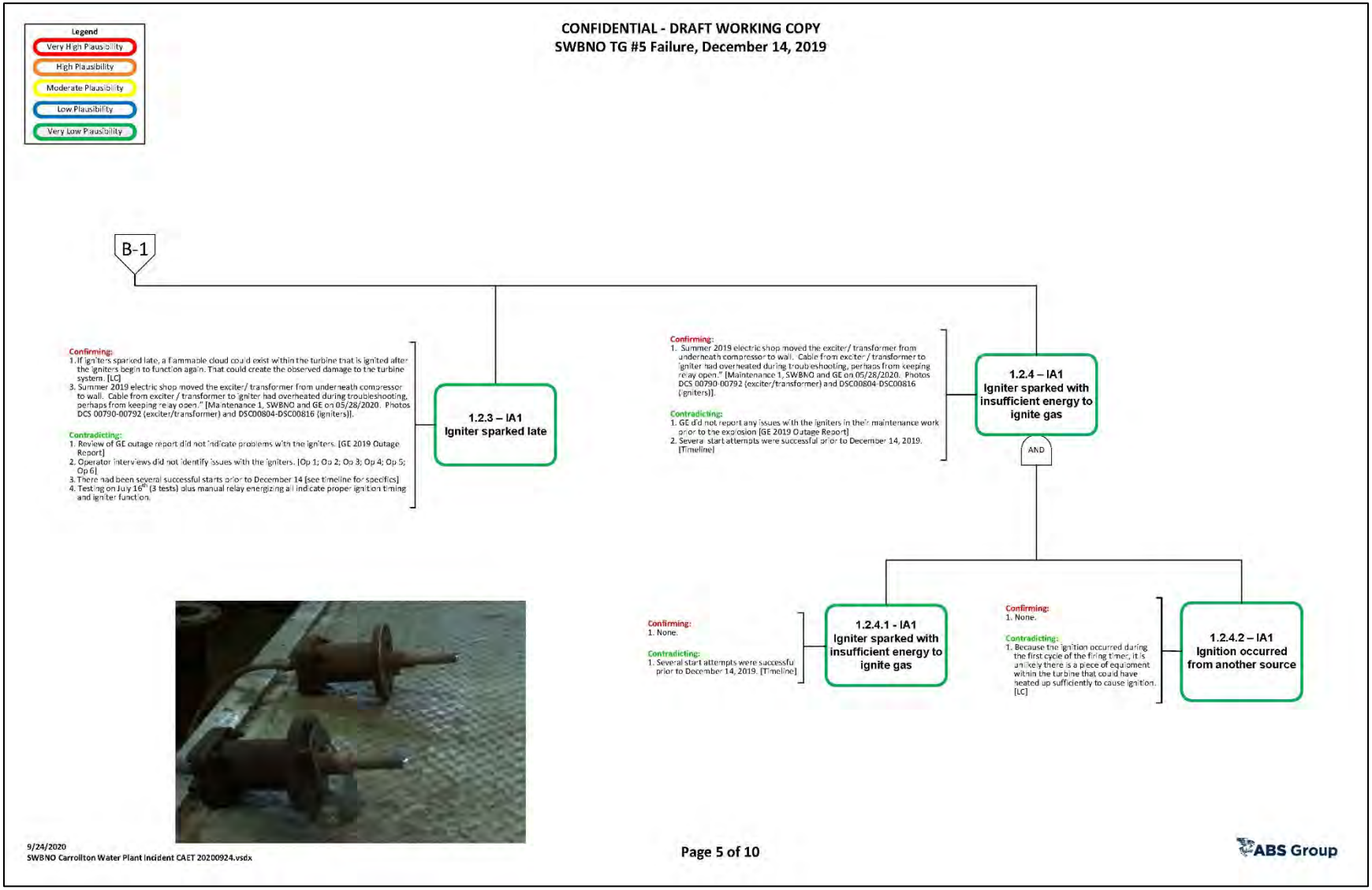
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High Plausibility
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Very Low Plausibility
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SWBNO TG #5 Failure, December 14, 2019
B-1
Confirming:
1. If igniters sparked late, a flammable cloud could exist within the turbine that is ignited after the igniters begin to function again. That could create the observed damage to the turbine system. [LC]
3. Summer 2019 electric shop moved the exciter/ transformer from underneath compressor to wall. Cable from exciter / transformer to igniter had overheated during troubleshooting, perhaps from keeping relay open." [Maintenance 1, SWBNO and GE on 05/28/2020. Photos DCS 00790-00792 (exciter/transformer) and DSC00804-DSC00816 (igniters)].
Contradicting:
1. Review of GE outage report did not indicate problems with the igniters. [GE 2019 Outage Report]
2. Operator interviews did not identify issues with the igniters. [Op 1; Op 2; Op 3; Op 4; Op 5; Op 6]
3. There had been several successful starts prior to December 14 [see timeline for specifics]
4. Testing on July 16th (3 tests) plus manual relay energizing all indicate proper ignition timing and igniter function.
1.2.3 – IA1
Igniter sparked late
Confirming:
1. Summer 2019 electric shop moved the exciter/ transformer from underneath compressor to wall. Cable from exciter / transformer to igniter had overheated during troubleshooting, perhaps from keeping relay open." [Maintenance 1, SWBNO and GE on 05/28/2020. Photos DCS 00790-00792 (exciter/transformer) and DSC00804-DSC00816 (igniters)].
Contradicting:
1. GE did not report any issues with the igniters in their maintenance work prior to the explosion [GE 2019 Outage Report]
2. Several start attempts were successful prior to December 14, 2019. [Timeline]
1.2.4 – IA1
Igniter sparked with insufficient energy to ignite gas
AND
Confirming:
1. None.
Contradicting:
1. Several start attempts were successful prior to December 14, 2019. [Timeline]
1.2.4.1 - IA1
Igniter sparked with insufficient energy to ignite gas
Confirming:
1. None.
Contradicting:
1. Because the ignition occurred during the first cycle of the firing timer, it is unlikely there is a piece of equipment within the turbine that could have heated up sufficiently to cause ignition. [LC]
1.2.4.2 – IA1
Ignition occurred from another source
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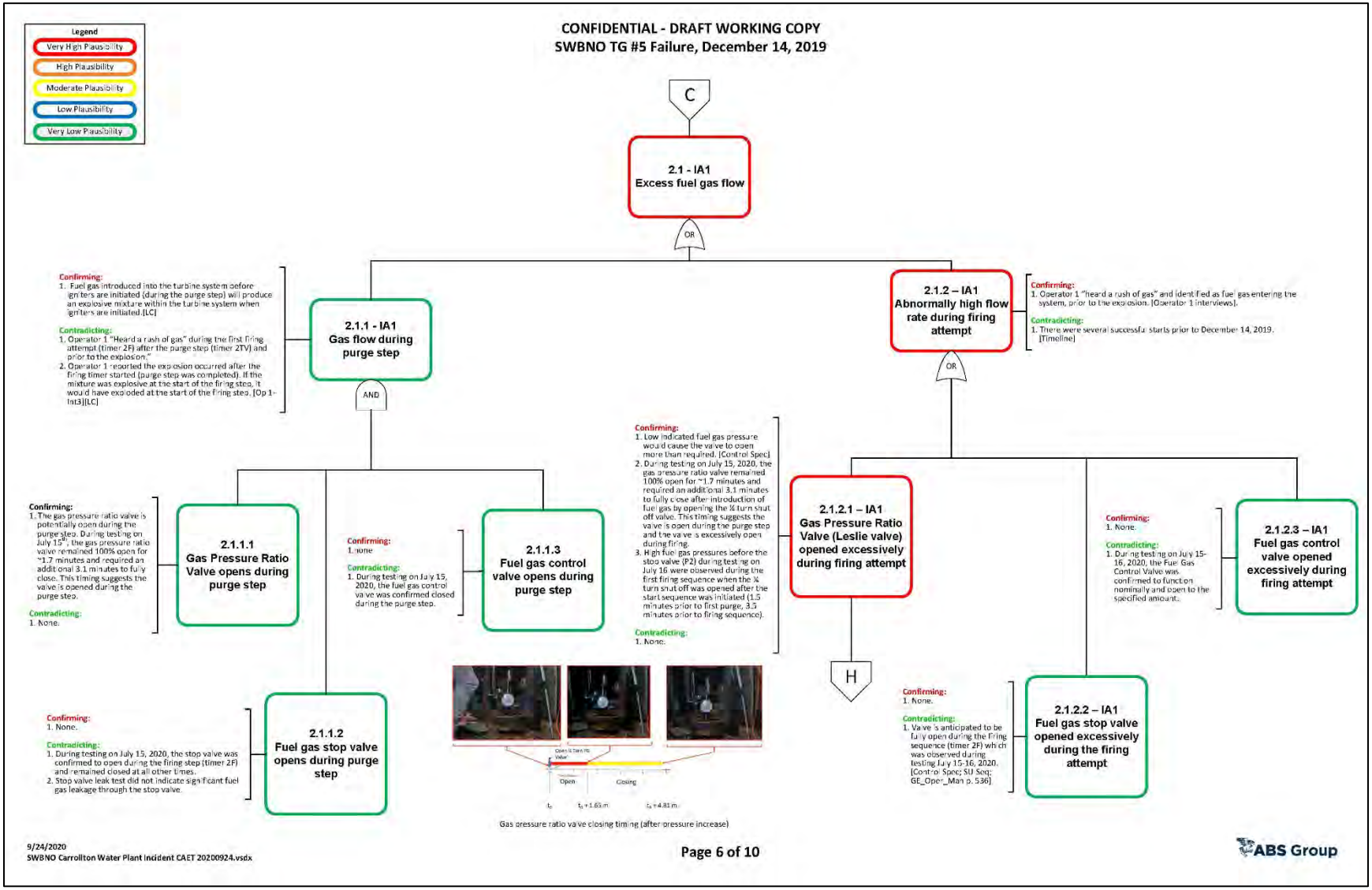

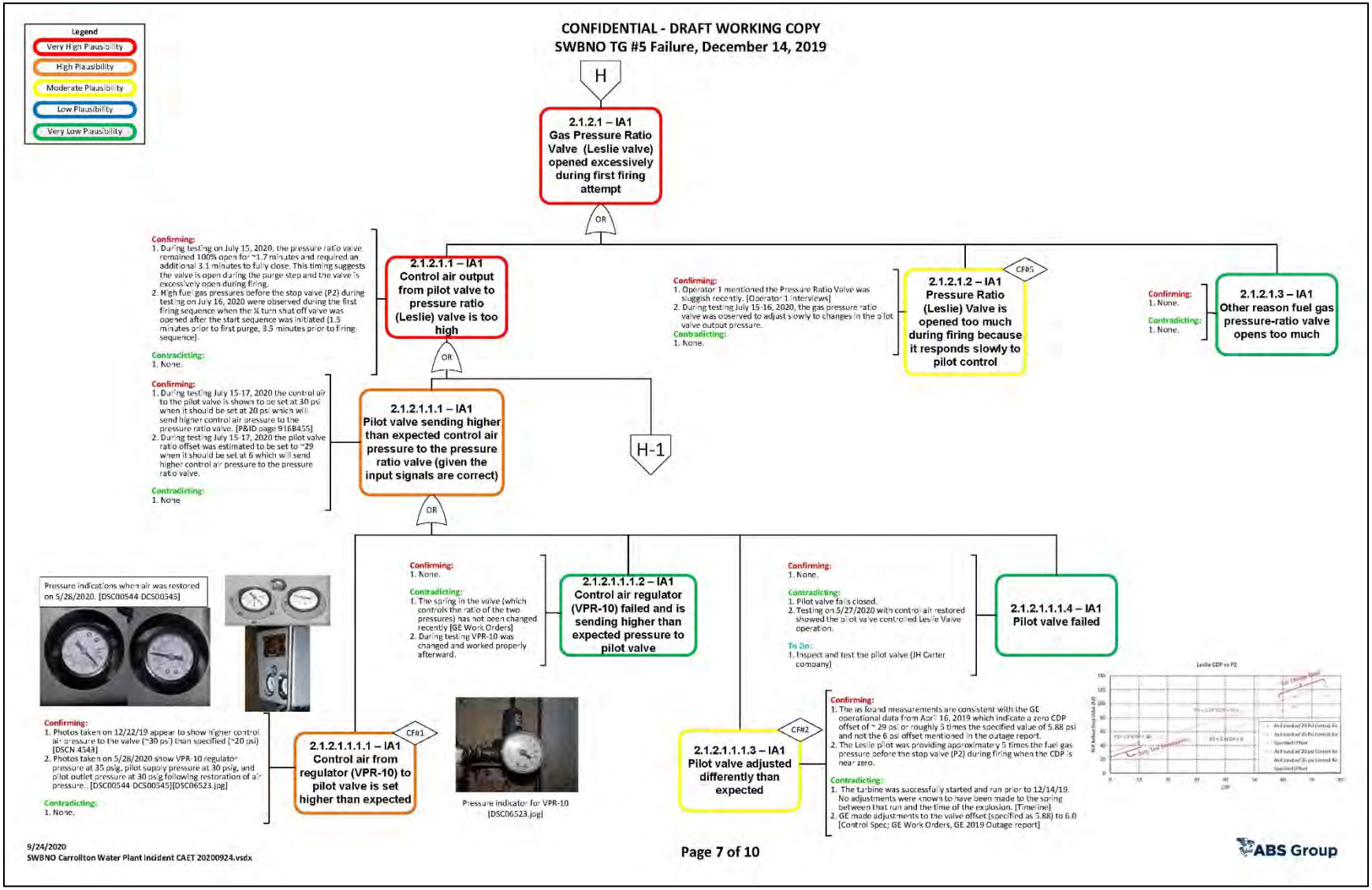
Legend
Very High Plausibility
High Plausibility
Moderate Plausibility
Low Plausibility
Very Low Plausibility
CONFIDENTIAL - DRAFT WORKING COPY
SWBNO TG #5 Failure, December 14, 2019
H
2.1.2.1 – IA1 Gas Pressure Ratio Valve (Leslie valve) opened excessively during first firing attempt
OR
2.1.2.1.1 – IA1 Control air output from pilot valve to pressure ratio (Leslie) valve is too high
Confirming:
1. During testing on July 15, 2020, the pressure ratio valve remained 100% open for ~1.7 minutes and required an additional 3.1 minutes to fully close. This timing suggests the valve is open during the purge step and the valve is excessively open during firing.
2. High fuel gas pressures before the stop valve (P2) during testing on July 16, 2020 were observed during the first firing sequence when the ¼ turn shut off valve was opened after the start sequence was initiated (1.5 minutes prior to first purge, 3.5 minutes prior to firing sequence).
Contradicting:
1. None.
OR
2.1.2.1.1.1 – IA1 Pilot valve sending higher than expected control air pressure to the pressure ratio valve (given the input signals are correct)
Confirming:
1. During testing July 15-17, 2020 the control air to the pilot valve is shown to be set at 30 psi when it should be set at 20 psi which will send higher control air pressure to the pressure ratio valve. [P&ID page 916B455]
2. During testing July 15-17, 2020 the pilot valve ratio offset was estimated to be set to ~29 when it should be set at 6 which will send higher control air pressure to the pressure ratio valve.
Contradicting:
1. None
H-1
Confirming:
1. Operator 1 mentioned the Pressure Ratio Valve was sluggish recently. [Operator 1 interviews]
2. During testing July 15-16, 2020, the gas pressure ratio valve was observed to adjust slowly to changes in the pilot valve output pressure.
Contradicting:
1. None.
CFM5
2.1.2.1.2 – IA1 Pressure Ratio (Leslie) Valve is opened too much during firing because it responds slowly to pilot control
Confirming:
1. None.
Contradicting:
1. None.
2.1.2.1.3 – IA1 Other reason fuel gas pressure-ratio valve opens too much
Pressure indications when air was restored on 5/28/2020. [DSC00544-DCS00545]
Confirming:
1. Photos taken on 12/22/19 appear to show higher control air pressure to the valve (~30 psi) than specified (~20 psi) [DSCN 4543]
2. Photos taken on 5/28/2020 show VPR-10 regulator pressure at 35 psig, pilot supply pressure at 30 psig, and pilot outlet pressure at 30 psig following restoration of air pressure.. [DSC00544-DCS00545][DSC06523.jpg]
Contradicting:
1. None.
CFM1
2.1.2.1.1.1.1 – IA1 Control air from regulator (VPR-10) to pilot valve is set higher than expected
Pressure indicator for VPR-10 [DSC06523.jpg]
Confirming:
1. None.
Contradicting:
1. The spring in the valve (which controls the ratio of the two pressures) has not been changed recently [GE Work Orders]
2. During testing VPR-10 was changed and worked properly afterward.
2.1.2.1.1.1.2 – IA1 Control air regulator (VPR-10) failed and is sending higher than expected pressure to pilot valve
Confirming:
1. None.
Contradicting:
1. Pilot valve fails closed.
2. Testing on 5/27/2020 with control air restored showed the pilot valve controlled Leslie Valve operation.
To Do:
1. Inspect and test the pilot valve (JH Carter company)
2.1.2.1.1.1.4 – IA1 Pilot valve failed
CFM2
2.1.2.1.1.1.3 – IA1 Pilot valve adjusted differently than expected
Confirming:
1. The as found measurements are consistent with the GE operational data from April 16, 2019 which indicate a zero CDP offset of ~ 29 psi or roughly 5 times the specified value of 5.88 psi and not the 6 psi offset mentioned in the outage report.
2. The Leslie pilot was providing approximately 5 times the fuel gas pressure before the stop valve (P2) during firing when the CDP is near zero.
Contradicting:
1. The turbine was successfully started and run prior to 12/14/19. No adjustments were known to have been made to the spring between that run and the time of the explosion. [Timeline]
2. GE made adjustments to the valve offset (specified as 5.88) to 6.0 [Control Spec; GE Work Orders, GE 2019 Outage report]
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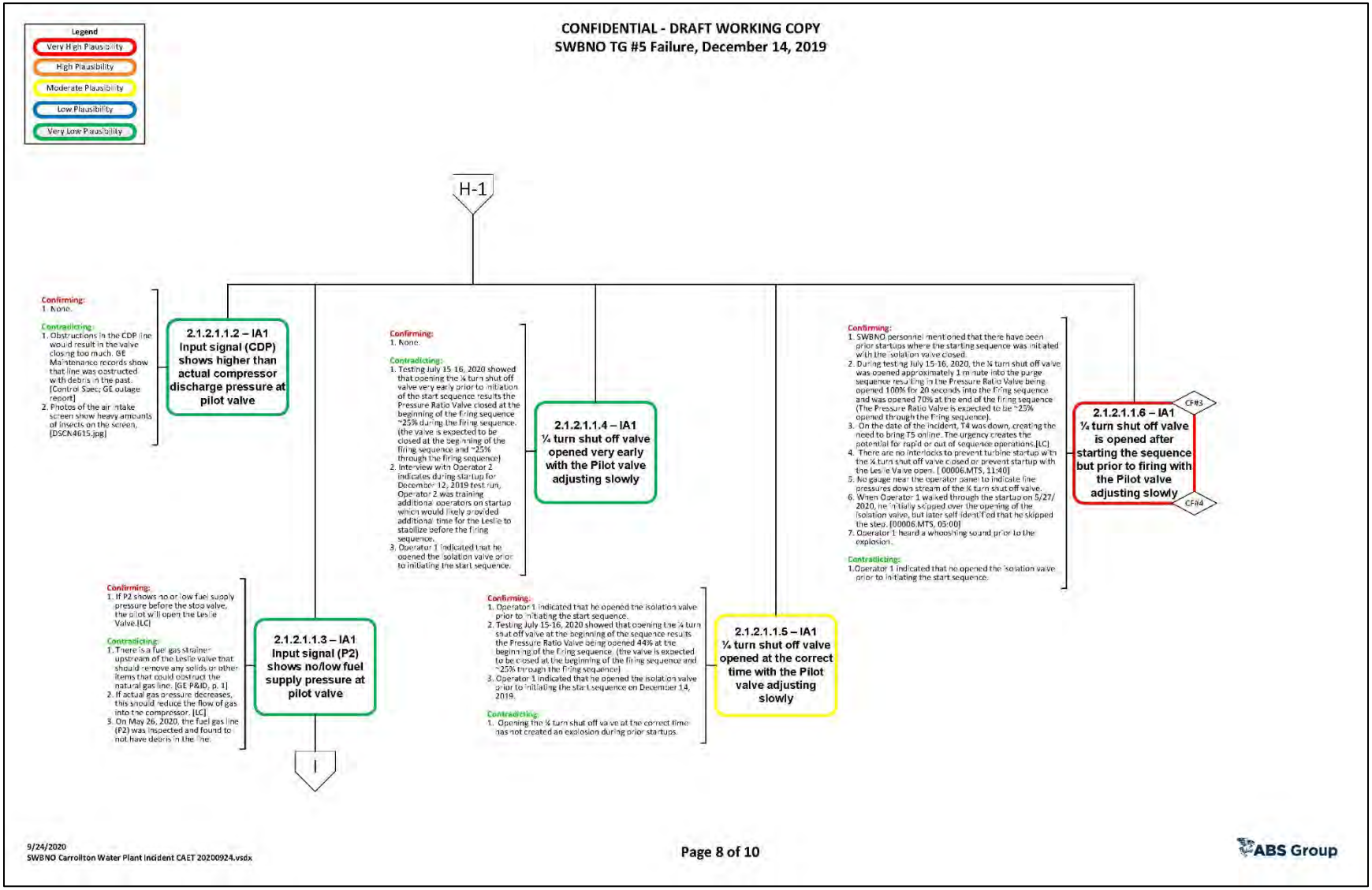

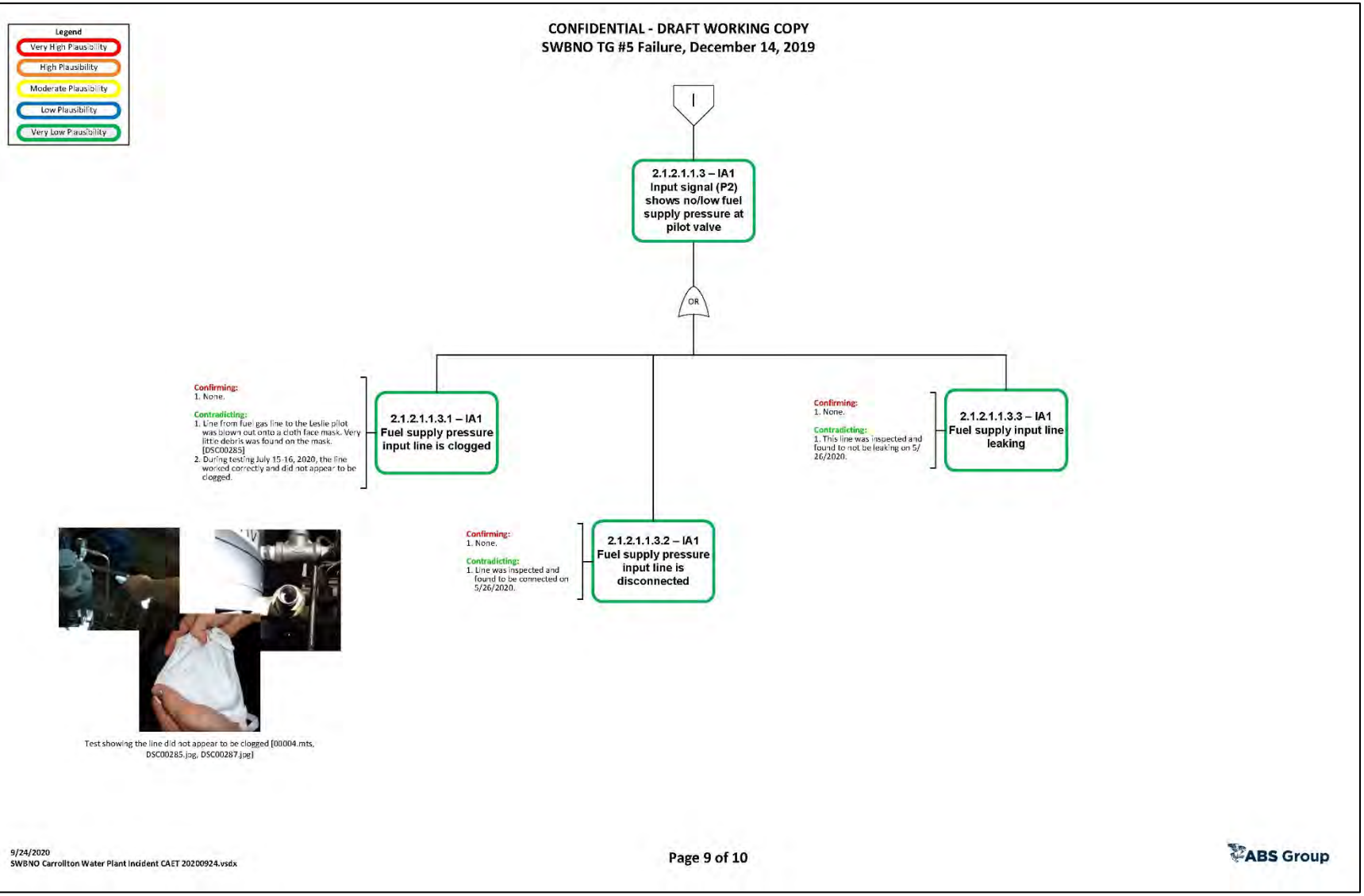
Legend
Very High Plausibility
High Plausibility
Moderate Plausibility
Low Plausibility
Very Low Plausibility
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SWBNO TG #5 Failure, December 14, 2019
2.1.2.1.1.3 – IA1 Input signal (P2) shows no/low fuel supply pressure at pilot valve
OR
Confirming:
1. None.
Contradicting:
1. Line from fuel gas line to the Leslie pilot was blown out onto a cloth face mask. Very little debris was found on the mask. [DSC00285]
2. During testing July 15-16, 2020, the line worked correctly and did not appear to be clogged.
2.1.2.1.1.3.1 – IA1 Fuel supply pressure input line is clogged
Confirming:
1. None.
Contradicting:
1. This line was inspected and found to not be leaking on 5/26/2020.
2.1.2.1.1.3.3 – IA1 Fuel supply input line leaking
Confirming:
1. None.
Contradicting:
1. Line was inspected and found to be connected on 5/26/2020.
2.1.2.1.1.3.2 – IA1 Fuel supply pressure input line is disconnected
Test showing the line did not appear to be clogged [00004.mts, DSC00285.jpg, DSC00287.jpg]
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APPENDIX C – DATA REQUEST SUMMARY

DRAFT REPORT

RFI #	ABSG Item No	Description	Status
1	140	1. Turbine Generator (TG) #5 Control system files and instrument data from the startup(s) of 12-14-19 including the incident.	None
1	110	2. TG #5 Inspection logs.	Received Pre-event Information (1.6)
1	160	3. List of personnel associated with TG #5 operations	Closed
1	191	4. List of personnel involved with TG #5 startup on December 14, 2019	Closed
1	120	5. TG #5 repair and maintenance documents since 2018 restart including but not limited to:	Received Pre-event Information
		a. TG #5 General Electric maintenance and repair documentation for work performed on TG #5 in 2019.	Received Pre-event Information
		b. TG #5 preventative maintenance records from December 2019, prior to incident.	Received Pre-event Information
1	190	6. a. List of General Electric personnel associated with TG #5 repairs	Received Pre-event Information
1	180	b. List of SWBNO Personnel associated with repairs	Closed
1	100	7. TG #5 return to service/startup records (logs, testing reports, etc.)	Received Pre-event Information
1	70	8. List of prior TG #5 issues, especially associated with fuel gas system	Closed
1	150	9. Number of hours TG #5 operated since restart and on what dates.	Open
1	310	10. 1. CCTV and security camera footage	Closed See RFI 4 and 5
2	10	DCS Historical records	Closed
2	20	Activities performed since the incident	Closed

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RFI #	ABSG Item No	Description	Status
2	30	Additional drawings - structural	Received 4-Engine & Control Data Turbine 5
2	40	Additional drawings - control system	Received 4-Engine & Control Data Turbine 5 Electrical diagram of relays
2	41	P&IDs	See RFI #4 GE Schematic Piping Diagrams.pdf
2	50	Could the emergency trip system have prevented ignition? (system description p. 1-17)	Closed
2	60	Preliminary investigation reports	Received MGTA 19-626 2020 02 19 Report of Site Visit.pdf
2	80	Inspection logs (T5)	Received Pre-event Information (1.6)
2	90	Startup logs, test reports, etc.	Open Carried forward to RFI #5
2	130	What was the output of the flame detectors?	Open
2	170	List of personnel associated with the maintenance activities on T5 in the last 6 months	Received 1 Pre-Event Information\1.4
2	200	Maintenance procedures	Closed - Have what is avail.
2	210	Witness statements - paper says 12 were in the area	Open
2	220	Control system description - pneumatics (T5)	Closed
2	230	Control system description - hydraulics (T5)	Closed
2	240	Control system description - igniters (T5)	Closed
2	250	The system description provided refers to Figure F to show details of the igniter. We need Figure F.	Open
2	260	Similarities/differences to other TGs? Any other examples out there?	Closed - Only TG of this type.
2	270	Photographs from others - GE	Closed - Have what we can receive
2	280	Photographs from others - SWBNO	Closed - Have what we can receive
2	290	Radio traffic recordings	Closed

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RFI #	ABSG Item No	Description	Status
2	320 330	Understand timing for the "no start" case	Closed
2	340	Understand why it is "normal" for the system to not ignite on the first attempt	Open
2	350	Interview Operator 1 for the timing and steps taken before/during the incident. (Any other personnel?)	Closed
2	360 370	Confirm the insect clogging would reduce the air intake to the turbine system.	Closed
2	380	Confirm operational timeline, including purge time between start attempts	Received 1 Pre-Event Information
2	390	What does “removed igniters from combustion chamber” mean in the incident sequence? What was done to the igniters? Tested prior to use?	Closed
2	400	Other than Operator #1	Closed
2	410	What maintenance was done? What records are available?	Received 1 Pre-Event Information
3		1. Interviews	Closed
3		2. full length version of High Lift Camera Video Ops-Skylift Right_20191214_134729 - Ops-Skylift Right.avi	Closed, not available
4		1. P&ID of the control air supply that includes all the air compressors that can supply TG #5 and the equipment supplied at TG #5	Walked Down
4		2. Photographs of the control air supply valves and pressure gauges located on the Mezzanine deck below the turbine	Closed
4		3. Photographs of the control air pressure indicator on the top deck located under the oil and gas pressure gauges on southeast side of Accessory Gear Box (small enclosure) behind panel doors, potentially with a blue label	Closed
4		4. Photographs of the control air toggle switches (located near the floor north of the Leslie valve) and pressure indicator on/near the floor north of the door within the Accessory Gear Box	Closed
4		6.Please confirm that we have received all the available camera footage and if there is additional footage	Closed
5	90	1. Startup checklist form utilized by operators during the startup of Turbine 5	Closed
5	90	2. Startup checklist from the December 14th startup that ended in the Turbine 5 explosion	Open

RFI #	ABSG Item No	Description	Status
5	90	3. Startup checklist from the last successful startup of Turbine 5 prior to December 14th.	Closed
5		4. Photographs of the current position of the Leslie Valve indicator disc.	Closed
5		5. Photograph dials and gauges on the Leslie valve (taken straight on reading the gauges)	Closed
6		John H. Carter gas pressure ratio pilot valve bench test report.	Open