Non-Condensable Gas System Explosion at PCA DeRidder Paper Mill

DeRidder, Louisiana

Incident Date: February 8, 2017
3 Killed and 7 Injured

Key Issues

- Process Safety Management System
- Inherently Safer Design
- Process Hazard Analysis
- Ineffective Safeguards
- Hot Work Safety Management

"[A] source of ignition is often said to be the cause of a fire. But when flammable vapour and air are mixed in the flammable range, experience shows that a source of ignition is liable to turn up, even though we have done everything possible to remove known sources of ignition . . . ."

— Trevor Kletz, *Learning from Accidents*

Report Number: 2017-03-I-LA
April 2018

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Dedication

The U.S. Chemical Safety and Hazard Investigation Board dedicates this report to the workers killed by the explosion at the Packaging Corporation of America facility in DeRidder, Louisiana on February 8, 2017.

Jody L. Gooch

William Rolls Jr.

Sedrick Stallworth

TABLE OF CONTENTS

ABBREVIATIONS AND INITIALISMS

ANSI	American National Standards Institute
API	American Petroleum Institute
BLEVE	Boiling Liquid Expanding Vapor Explosion
CCPS	Center for Chemical Process Safety
CDT	Central Daylight Time
CFR	Code of Federal Regulations
CNCG	Concentrated Non-Condensable Gas
CSB	U.S. Chemical Safety and Hazard Investigation Board
EPA	U.S. Environmental Protection Agency
ERT	Emergency Response Team
HAZOP	Hazard and Operability Study
HHC	Highly Hazardous Chemical
HVLC	High Volume Low Concentration
IEC	International Electrotechnical Commission
ISA	International Society of Automation
ISO	International Organization for Standardization
LEL	Lower Explosive Limit (also known as Lower Flammable Limit)
LFL	Lower Flammable Limit (also known as Lower Explosive Limit)
LLC	Limited Liability Company
LOC	Limiting Oxidant (Oxygen) Concentration
LOPA	Layers of Protection Analysis
LVHC	Low Volume High Concentration
MACT	Maximum Achievable Control Technology
MAWP	Maximum Allowable Working Pressure
MOC	Management of Change
NCG	Non-Condensable Gas
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
OSHA	U.S. Department of Labor Occupational Safety and Health Administration
OSHRC	U.S. Occupational Safety and Health Review Commission
PAI	Permit Authorizing Individual
PCA	Packaging Corporation of America
PES	Programmable Electronic System
PHA	Process Hazard Analysis
PPE	Personal Protective Equipment
PRD	Pressure Relief Device
PSI	Process Safety Information
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
psig	Pounds per Square Inch Gauge
PSM	Process Safety Management
RAGAGEP	Recognized and Generally Accepted Good Engineering Practice
RBPS	Risk Based Process Safety
RMP	Risk Management Plan Rule
SDS	Safety Data Sheet
SIS	Safety Instrumented System
SMS	Safety Management System
TAPPI	Technical Association of Pulp and Paper Industry

TIP	Technical Information Paper
TRS	Total Reduced Sulfur
UEL	Upper Explosive Limit (also known as Upper Flammable Limit)
UFL	Upper Flammable Limit (also known as Upper Explosive Limit)

1 EXECUTIVE SUMMARY

1. On Wednesday, February 8, 2017, at approximately 11:05 am, a foul condensate tank, part of a non-condensable gas system, exploded at the Packaging Corporation of America (PCA) containerboard mill in DeRidder, Louisiana. The explosion killed three people and injured seven others. All 10 people were working at the mill as contractors. The explosion also heavily damaged the surrounding process. The foul condensate tank traveled approximately 375 feet and over a six-story building before landing on process equipment.

2. At the time of the incident, the mill was undergoing its annual planned maintenance outage, also referred to as a shutdown. The foul condensate tank likely contained water, a layer of flammable liquid turpentine on top of the water, and an explosive vapor space containing air and flammable turpentine vapor.

3. Although some oxygen in the vapor space of the foul condensate tank is normal, by design the flammable vapor inside the tank should be kept above its explosive limit, also known as its upper explosive limit. The oxygen present should be insufficient to support combustion. Air likely entered the foul condensate tank through a vacuum relief device on the tank's roof. During typical operation, automatic controls continually cycled the liquid level inside the tank, creating routine periods of low pressure. These low-pressure conditions were relieved by the vacuum relief device, which pulled air into the tank. During the annual outage, air also likely entered the tank as its contents cooled. This cooling created another low-pressure condition within the tank. These sources of air ingress allowed air to mix with turpentine vapor and thereby form an explosive mixture in the tank's vapor space.

4. On the day of the incident, contractors supporting the annual outage work made repairs by welding, (a type of hot work) on water piping above and de-coupled (disconnected) from the foul condensate tank. This hot work appears to be the probable source of ignition, although other possible ignition sources could not be definitively excluded.

5. Federal regulation requires many types of chemical facilities that process highly hazardous substances to have a process safety management system in place to protect the workforce and the public from catastrophic incidents. Most of these rules apply to only a few processes within the DeRidder mill; specifically, the Occupational Safety and Health Administration Process Safety Management standard applied to only two processes at the DeRidder mill. These protective rules did not apply to the foul condensate tank, nor to most of the non-condensable gas system (process equipment that included the foul condensate tank).

6. Although not required by Federal regulation, good-practice guidance recommends developing and implementing a robust safety management system to manage the hazards related to generating, collecting, and treating of non-condensable gases. PCA did not voluntarily apply its process safety management system to the non-condensable gas system. Such an approach could have helped PCA to identify, evaluate, and control the non-condensable gas system process hazards that led to the explosion.

7. The U.S. Chemical Safety and Hazard Investigation Board (CSB) determined that air entered the foul condensate tank and mixed with the tank's flammable turpentine vapor. This created an explosive atmosphere within the tank. Ongoing hot work repairs above the tank likely ignited this vapor and caused the explosion.

8. The CSB documented its causal determination throughout this report based on a review of the evolution of mill activities related to its non-condensable gas system, which includes the foul condensate tank; a history of similar explosions in various process industries; and an analysis of all available physical, documentary, and testimonial evidence.

9. The CSB determined that the conditions enabling the explosion to occur could have been mitigated by a broader application of the company's process safety management systems and by the use of other established industry good safety practices. Specifically, PCA did not take the following actions:

   - Evaluate the majority of the non-condensable gas system, including the foul condensate tank, for certain hazards. The DeRidder mill never conducted a process hazard analysis to identify, evaluate, and control process hazards for the non-condensable gas system.
   - Expand the boundaries of its process safety management program beyond the units covered by safety regulations.
   - Effectively apply the hierarchy of controls to the selection and implementation of safeguards that the company used to prevent a potential non-condensable gas explosion.
   - Evaluate inherently safer design options that could have eliminated the possibility of air entering the non-condensable gas system, including the foul condensate tank.
   - Establish which mill operations group held ownership of, and responsibility for, the foul condensate tank.
   - Apply important aspects of industry safety guidance and standards, including the Technical Association of the Pulp and Paper Industry Technical Information Paper 0416-09, National Fire Protection Association Standard 69, National Fire Protection Association Standard 68, and International Society of Automation Standard 84. All of these standards seek to prevent or control explosions, such as non-condensable gas explosions.

10. As a result of its investigation, the CSB is issuing safety guidance to the pulp and paper industry and a safety recommendation to PCA. The CSB is also reiterating a previous recommendation issued to the Occupational Safety and Health Administration, as a result of the CSB's 2002 investigation of Motiva Enterprises, to cover atmospheric storage tanks under the Process Safety Management standard.

2 BACKGROUND INFORMATION

2.1 INDUSTRY AND CORPORATE OVERVIEW

1. PCA corporate headquarters is in Lake Forest, Illinois. The company employs approximately 14,000 employees [1, pp. 1-7]. On February 8, 2017 (the day of the incident), PCA owned and operated five containerboard mills, three paper mills, and 94 corrugated products manufacturing plants.

2. The PCA DeRidder mill is an integrated containerboard mill that brings wood onsite, chips and pulps the raw materials, and makes containerboard paper. As shown in **Figure 1**, PCA containerboard mills are located in the following cities [2, p. 13]:

- Counce, Tennessee
- DeRidder, Louisiana
- Valdosta, Georgia
- Tomahawk, Wisconsin
- Filer City, Michigan

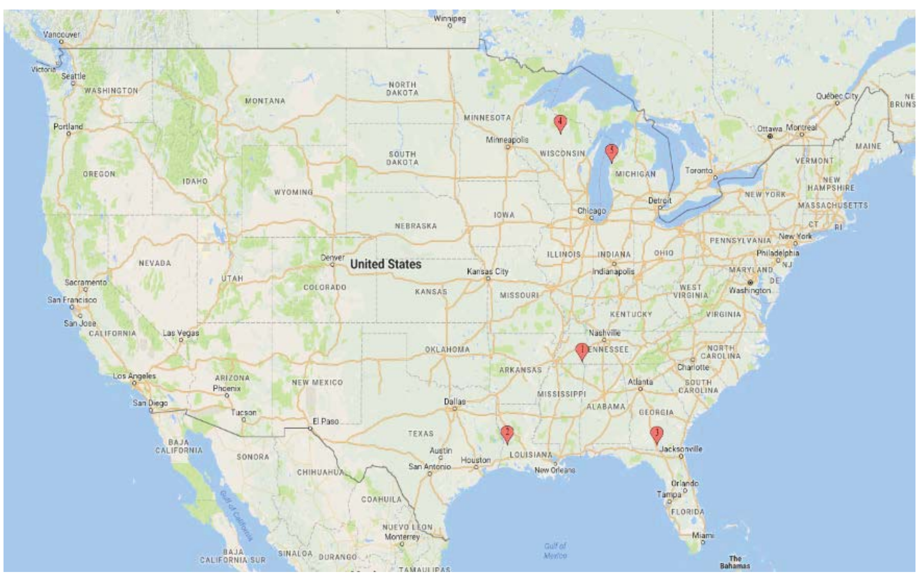

Figure 1. Map Showing the Five PCA Containerboard Facilities. This map shows the site of PCA containerboard facilities in the United States. Map created from www.mapcustomizer.com using Google Maps.

3. The DeRidder mill was built in 1969 [3], [4]. In October 2013, PCA acquired Boise Inc., the former owner and operator of the DeRidder mill. This acquisition furthered PCA's capability to manufacture both packaging and paper products [1, pp. 20-21].

2.2 DeRidder Mill Overview

2.2.1 Mill Overview

4. The PCA DeRidder mill produces different grades of containerboard. PCA customers use the containerboard to produce a wide variety of different packaging products, including boxes to protect and transfer manufactured goods and cardboard displays to advertise products in retail locations.

5. The PCA DeRidder mill consists of a pulp mill area, where pulp is made from softwood chips and recycled corrugated cardboard, and a paper mill area, where containerboard paper is produced from the pulp (**Figure 2**).[a]

Figure 2. Overhead Photograph of the PCA DeRidder Mill. The larger complex at the bottom right of the photograph is primarily the paper mill area. Photograph: Google Earth.

6. The pulp mill is composed of various smaller processing areas. The following two areas are most relevant to the February 8, 2017 incident:

- Powerhouse, which generates energy to run the mill.
- Pulp mill, which provides pulp for the production of paper.

[a] The United Steelworkers represent a number of operations personnel at the DeRidder mill.

2.2.2 Process Description

7. The pulping[a] process produces vapors that contain methanol, turpentine,[b] water, and other noncondensable gases. Some of these noncondensable gases include odorous sulfur compounds. Liquid made up of water and these odorous sulfur compounds formed by processing or condensing this byproduct vapor is known as "foul condensate."

8. The foul condensate tank, which was the tank involved in the incident, has a capacity of approximately 100,000 gallons, and is part of the process equipment that recovers turpentine and water from the pulping process. Turpentine is a byproduct of the process, and PCA sells it to customers.

9. To recover the turpentine, the vapors enter a turpentine-stripping column (**Figure 3**). The process removes turpentine vapor from the top of the column, and foul condensate liquid exits the bottom of the column. This foul condensate then flows into the foul condensate tank.

10. The foul condensate tank provides a means to regulate flow fluctuations between the upstream turpentine-stripping column and a downstream foul condensate-stripping column (**Figure 3**).[c] Per environmental regulation,[d] the foul condensate-stripping column removes contaminants. It also recovers water for other uses in the mill.

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[a] Pulping involves breaking down "wood or other lignocellulosic materials … physically and/or chemically such that … fibers are liberated and can be dispersed in water and reformed into a web [128, p. 55]."

[b] Turpentine is a naturally occurring resin found in living trees and is composed of a mixture of volatile extractives. It is sold for solvents and limited disinfectants used in household pine oil cleaners. The U.S. pulp industry recovers about 30 million gallons of turpentine annually [128, p. 107].

[c] Flow regulation helps prevent upstream fluctuations from adversely affecting the operation of downstream equipment.

[d] 40 C.F.R. Part 63 Subpart S. See also *The Basics of Foul Condensate Stripping* [6, pp. 1-2].

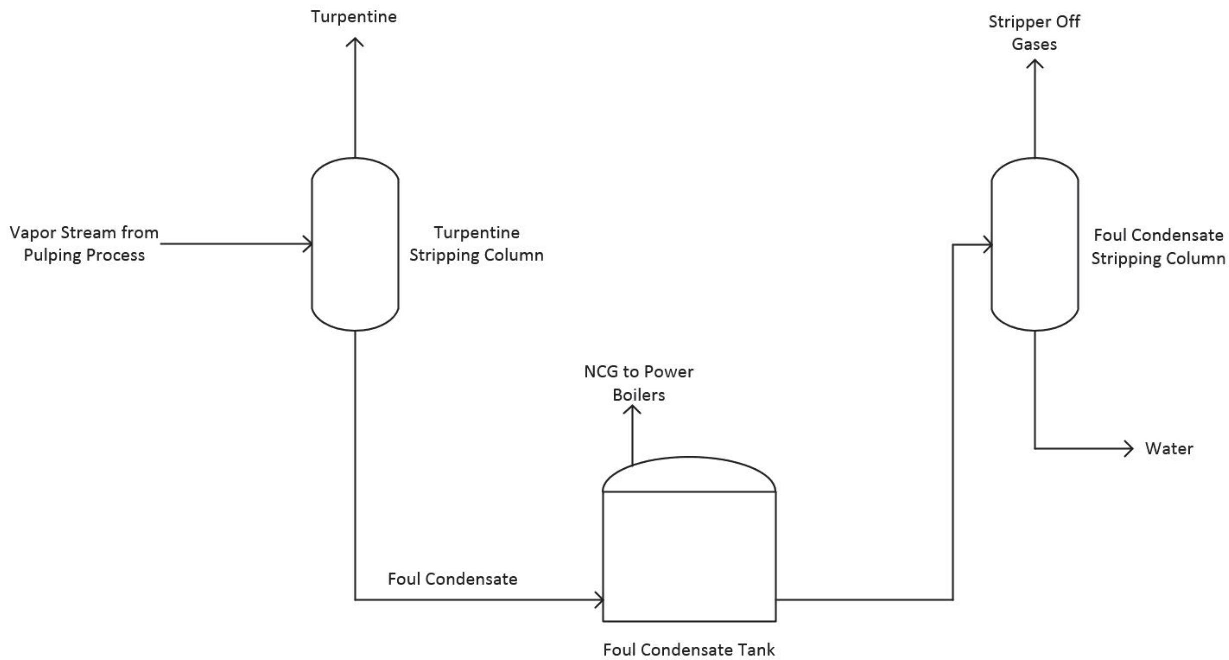

Figure 3. Simplified Flow Diagram of the Foul Condensate Tank. The foul condensate tank is fed by the turpentine-stripping column and then sends foul condensate to the foul condensate-stripping column.

11. The foul condensate is primarily water but also contains flammable compounds, including methanol, turpentine, and odorous sulfur compounds referred to as total reduced sulfur (TRS). The TRS compounds include hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide [5, p. 1].

12. At normal operating conditions, PCA keeps the foul condensate tank at approximately 185 degrees Fahrenheit (ºF) and at or near atmospheric pressure.[a]

13. As shown in **Figure 4**, vacuum equipment called ejectors[b] use steam to create a slight vacuum[c] on the vent piping from the foul condensate tank to draw off methanol, turpentine, and TRS gases, collectively referred to as non-condensable gases (NCG).[d] In addition to being flammable in the presence of sufficient oxygen, NCG are highly toxic, and exposure can potentially result in injury

[a] The foul condensate tank is designed for 8-inches of water pressure and 10-inches of water vacuum. The foul condensate tank was not insulated. The bottom 10-feet of tank and the area near the ladder were coated to reduce heat transfer and to protect personnel from the hot surface.

[b] See video Ejector – Steam Jet Ejectors – Well Operating [144].

[c] Creating a "slight vacuum" means reducing the pressure below atmospheric conditions.

[d] Non-condensable refers to a gas that does not condense to liquids under the pulp mill process conditions. The pulp and paper industry uses "noncondensable," "non-condensable," and "non-condensible" as synonyms. Unless referring to a specific title or a quotation, this report uses the spelling "non-condensable."

and death [5, p. 2]. Environmental regulations require the collection and combustion of NCG [6, pp. 1-2].[a]

14. NCG from the foul condensate tank are collected in a concentrated NCG (CNCG) system, which consists of a piping header attached to various units producing NCG (**Figure 4**). CNCG are NCG that are collected in concentrated form. The CNCG system operates at a slight vacuum to collect NCG and direct them to power boilers for destruction and energy recovery.

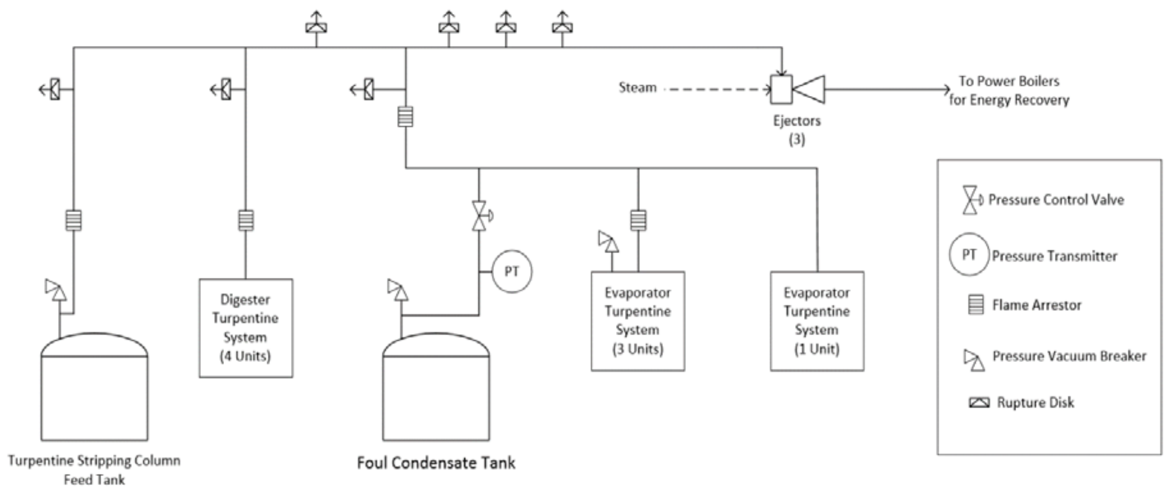

Figure 4. Simplified Flow Diagram of the CNCG System. The CNCG system collects NCG from various units at the mill, including the foul condensate tank, and sends them to the power boilers for energy recovery.

15. Clean condensate piping (water piping) also connects to the foul condensate tank. The mill uses this water piping to periodically clean the inside of the tank so that workers can enter the foul condensate tank to perform inspection or maintenance. Repairs to this water piping were in progress at the time of the February 8 incident. At that time, the water piping was disconnected from the foul condensate tank by an air gap between the flanges and a closed valve (**Figure 13**).

16. Like many integrated containerboard mills, the PCA DeRidder mill generates hazardous by-products as well as purchases and uses various hazardous chemicals. Hazardous chemical by-products include NCG compounds: methanol, turpentine, hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide. The DeRidder mill also purchases various chemicals including chlorine.

[a] 40 C.F.R. Part 63 Subpart S (2017).

2.2.3 NON-CONDENSABLE GAS INDUSTRY SAFETY GUIDANCE

17. The Technical Association of the Pulp and Paper Industry (TAPPI) is an industry association that publishes, among other documents, a number of voluntary safety standards and guidance for the pulp and paper industry [7].

18. TAPPI published a technical information paper (TIP) concerning the collection and burning of NCG, TIP 0416-09, *Collection and burning of concentrated non-condensible gases: regulations, design and operation* [5].

19. CNCG refer to NCG that are sufficiently concentrated to be above their upper explosive limit (UEL), a concentration of flammable gas that is too rich to burn [6].[a] The NCG in the foul condensate tank at the DeRidder mill are CNCG and are intended to operate at conditions that are too rich to burn.

20. TIP 0416-09 highlights the hazards surrounding air entering a CNCG system, stating, "CNCG is normally not [explosive] due to lack of sufficient oxygen to support combustion. Thus, CNCG systems must be designed and operated to prevent ingress of air. No open flames or welding should be allowed on or around the vessels or process lines of a CNCG system [5, p. 2]."

21. TIP 0416-09 also emphasizes that "during upset conditions, especially during start-ups and shutdowns, it is possible for air to enter the system, creating a potentially [explosive] mixture [5, p. 6]."

22. TIP 0416-09 also states:

> During the design phase, operation and maintenance should be considered. Appropriate operating procedures should be developed and training provided. … [T]he CNCG system has unique elements requiring routine inspection, i.e., pressure and vacuum relief devices, flame arresters, water traps/seal pots, vapor condensers and the like [5, p. 8].

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[a] The upper explosive limit (UEL) or upper flammability limit (UFL) is the highest concentration of a combustible material in a mixture that will propagate a flame. The lower explosive limit (LEL) or lower flammability limit (LFL) is the lowest concentration of a combustible material in a mixture that will propagate a flame. The UEL is also known as the UFL [145]. A combustible material is therefore explosive (flammable) in concentrations between these upper and lower limits [26, p. 8]. Air is the typical oxidizer used to measure explosive and flammability limits. The concept of explosive and flammability limits applies to other oxidizers, but the specific values from air measurements do not apply and testing is needed to establish the limits at the specific conditions of interest.

2.2.4 NON-CONDENSABLE GAS: EXPLOSION HAZARD

23. NCG can be flammable in the presence of air. Furthermore, NCG mixed with air can become explosive if contained within a pipe or vessel.[a] Typical NCG flammability properties are show in **Figure 5**.[b]

	Flammable Limits		Flame Speed ft/sec (m/sec)	Auto-Ignition Temperature °F (°C)
	Lower (volume%)	Upper (volume%)		
Hydrogen sulfide	4.3	45.0	1.5 (0.46)	500 (260)
Methyl mercaptan	3.9	21.8	1.8 (0.55)	
Dimethyl sulfide	2.2	19.7		400 (206)
Dimethyl disulfide	1.1	8.0		572 (300)
Alpha-pinene	0.8	6.0	2.0 (0.62)	487 (253)
Methanol	6.7	36.5	1.5 (0.50)	867 (464)

Figure 5. NCG Flammability Properties in Air [5, p. 2].[c] Note: alpha-pinene is a component of turpentine.[d]

24. As noted in **Figure 5**, the flame propagation speed for sulfur gases and methanol is slower relative to that for turpentine, represented by alpha-pinene. Although the flame speed for turpentine is a matter of dispute among experts, turpentine has the fastest speed of all of the components of NCG [5, pp. 4-5].[e]

25. As a result, explosions involving turpentine are typically more severe than explosions involving the other NCG components, including TRS – the sulfur gas components of NCG – and methanol [5, pp. 3-5], [6], [8]. For this reason, the removal of turpentine from systems designed to capture NCG is critically important.[f]

26. An energy source is necessary to ignite a mixture of NCG with sufficient oxygen. Pulp and paper mills have multiple potential ignition sources, including: static sparks, hot equipment, welding, brazing, and various other electrical sources [5, pp. 3-5], [6].

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[a] "Flammable and explosive, when applied to gases or vapours mean the same — a fire turns into an explosion when the gases that are formed by burning cannot get away and the pressure rises [79, p. 5]."

[b] The auto-ignition temperature of a chemical is the "lowest temperature at which a fuel/oxidant mixture will spontaneously ignite under specified test conditions [145]."

[c] Values are at atmospheric pressure.

[d] As a mixture of volatile extractives, turpentine is mainly composed of monoterpenes including alpha-pinene and beta-pinene [128, p. 107].

[e] See also *The Basics of Foul Condensate Stripping* [6, p. 2], Table II, Heat Value of Pollutants (showing "Net Heat of Combustion" highest for alpha-pinene at 17,200 British Thermal Units per pound (BTU/lb)).

[f] Literature found a closed-cup flash point of crude turpentine taken from a turpentine recovery system was 80 ºF (27 ºC) [146, p. 3].

27. Although helpful in evaluating NCG explosion hazards, the properties listed in **Figure 5** are theoretical. To gain practical insight into NCG explosion hazards, TAPPI developed the information shown in **Figure 6** using test data and scientific assumptions [5, pp. 4-5].[a]

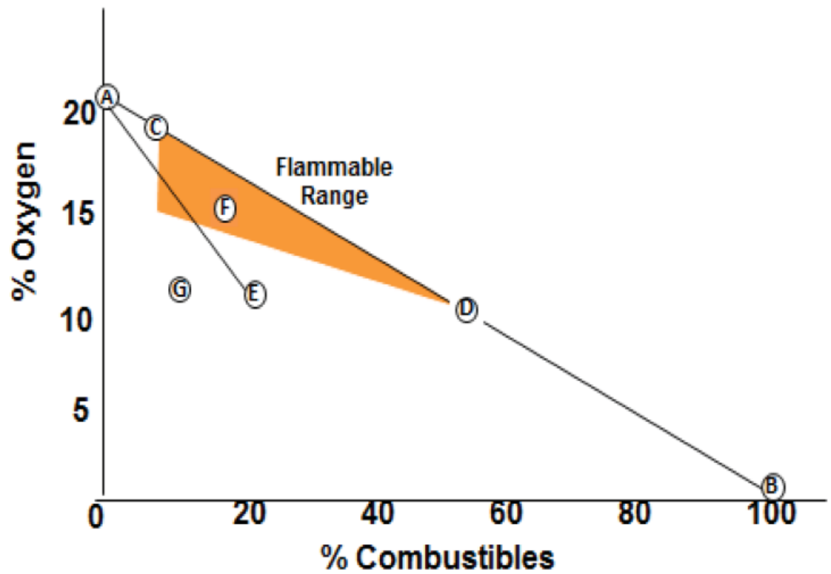

Figure 6. Typical Flammable Range of NCG. The highlighted area between points C and D represents mixtures of NCG and oxygen that are flammable [5, pp. 4-5], [6]. The flammable range can change substantially with the addition of turpentine.

28. Points C and D in **Figure 6** represent the upper and lower boundary limits of the flammable range of a mixture containing NCG and oxygen.

29. In **Figure 6**, Point A represents nothing but air in the system and Point B represents nothing but NCG in the system. Neither point is flammable as Point A is too lean (not enough fuel) and Point B is too rich (not enough oxygen) to burn.

30. Point F in **Figure 6** represents a mixture of NCG and oxygen that is flammable. Point G represents a mixture of NCG and oxygen that is non-flammable because it is too lean.

31. Point E in **Figure 6** is representative of an NCG concentration level outside of the flammable range; however, if oxygen enters the system, the mixture can move into the flammable range, as indicated by the line between Point E and Point A [5, pp. 4-5], [6].

[a] The standard says that the figure "is based on typical test data and the assumption that mixed TRS gases, which also contain other combustibles such as MeOH [methanol] and turpentine, are flammable over the range of 2% to 50% for all combustibles [5, pp. 4-5]."

2.2.5 SAFEGUARDS TO PREVENT NON-CONDENSABLE GAS EXPLOSIONS

32. Paper mills apply a variety of safeguards to prevent NCG explosions including seals to prevent air ingress and flame arrestors to halt flame propagation and protect equipment. The DeRidder mill applied a number of such safeguards, including pressure vacuum breakers and rupture disks.

33. To prevent an explosion, mills must keep NCG systems outside of the explosive range. Although previous designs kept NCG below the lower explosive limit (LEL),[a] the current practice is to keep NCG above its UEL in systems collecting CNCG. To maintain NCG above its UEL, companies must design these systems to prevent the entry of air. To ensure this, all parts of the CNCG system need to be sealed from the atmosphere.[b]

34. Rupture disks are also located in the CNCG piping systems to prevent explosion overpressure damage.[c] In addition, because the CNCG system operates under a slight vacuum, the sealed system could experience low-pressure scenarios. This conclusion is also true for upset conditions, such as a shutdown or a startup. Therefore, the CNCG system typically requires both pressure and vacuum relief protection [9]. A pressure vacuum breaker normally provides such protection (Section 4.4.1).

35. CNCG system piping is typically equipped with flame arrestors near the gas source, such as the foul condensate tank, and at the gas discharge, such as the boilers used at the PCA DeRidder mill to destroy the NCG.[d] Flame arrestors in the CNCG header system are designed to prevent fire in this piping from spreading to other connected units and, if unchecked, possibly causing a catastrophic fire and explosion as a flame front propagates through the piping and ignites additional fuel sources.

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[a] "Attempts to collect and burn NCG were first tried in the late 1950's. The initial systems collected the gases in pipelines, using fans as motivators to move gases. These systems usually diluted the gases with air to bring the TRS concentrations below their lower explosive limits. This was not always successful, especially with concentrated gases coming from digesters and evaporators, and many early systems experienced fires or explosions [87, p. 1]."

[b] 40 C.F.R. Part 63 Subpart S (2017).

[c] The rupture disks used on the CNCG system were designed to protect the CNCG system piping from overpressure scenarios. The rupture disks were not designed to protect units such as the foul condensate tank from overpressure scenarios.

[d] See video animation of flame arrestors used to protect NCG piping systems and equipment [81].

3 THE INCIDENT

1. At approximately 11:05 am central daylight time (CDT) on February 8, 2017, a tank containing foul condensate (**Figure 7**) exploded at the PCA DeRidder mill in DeRidder, Louisiana.

Figure 7. Pre-Incident Photograph of the DeRidder Mill Foul Condensate Tank. Welding work was being conducted above the tank on the pipe rack at the time of the incident. Photograph: PCA.

2. The explosion separated the tank, referred to as the foul condensate tank, from its base and launched it from its ground-level position up and over a six-story structure, landing approximately 375-feet away (**Figure 8** and **Figure 9**).

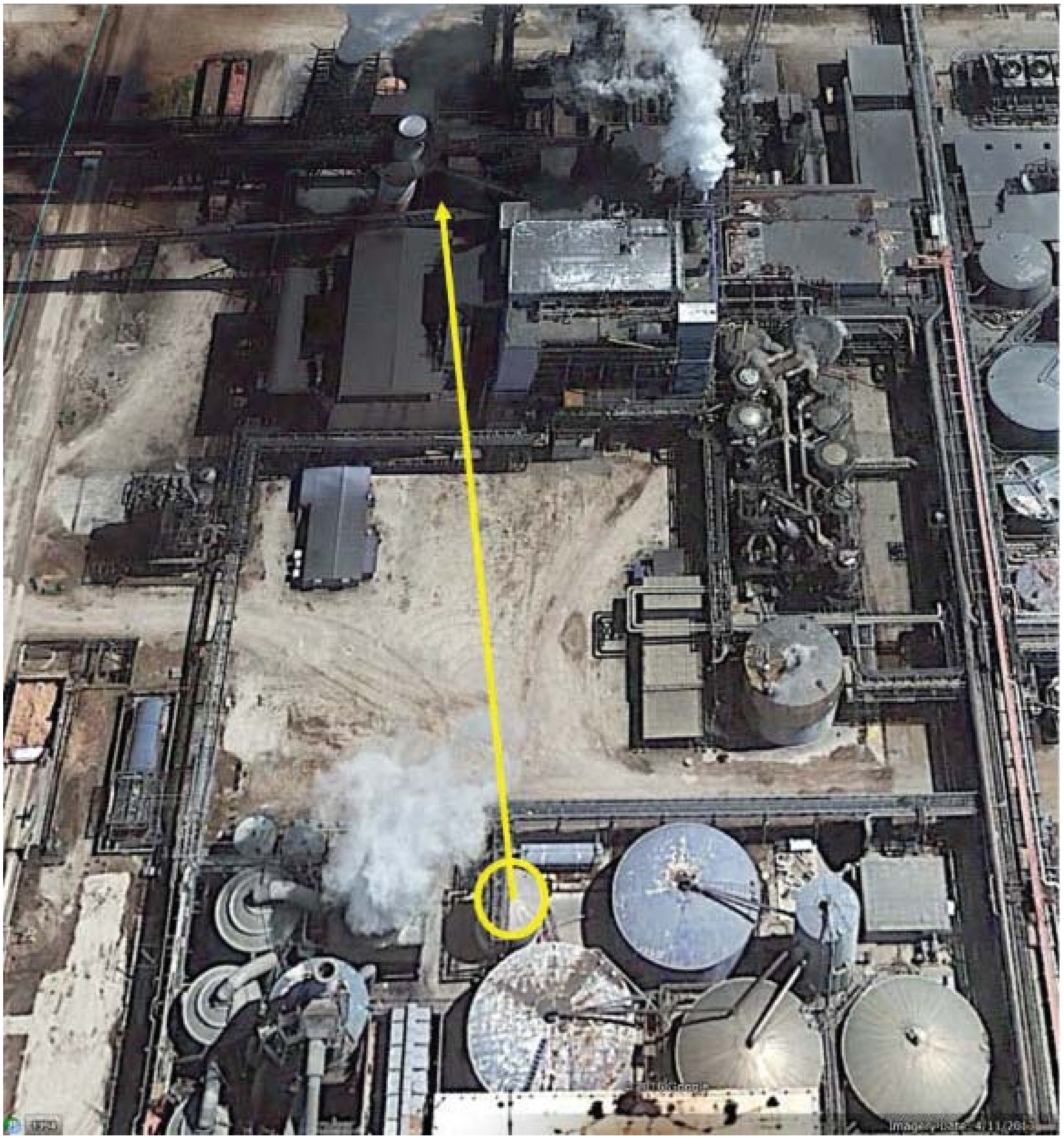

Figure 8. Overhead Photograph of the PCA DeRidder Mill. The yellow circle shows the pre-incident location of the foul condensate tank and the yellow line indicates the path traveled by the tank following the explosion. The tank landed at the base of a powerhouse stack, as indicated by the arrow. Photograph: Google Earth.

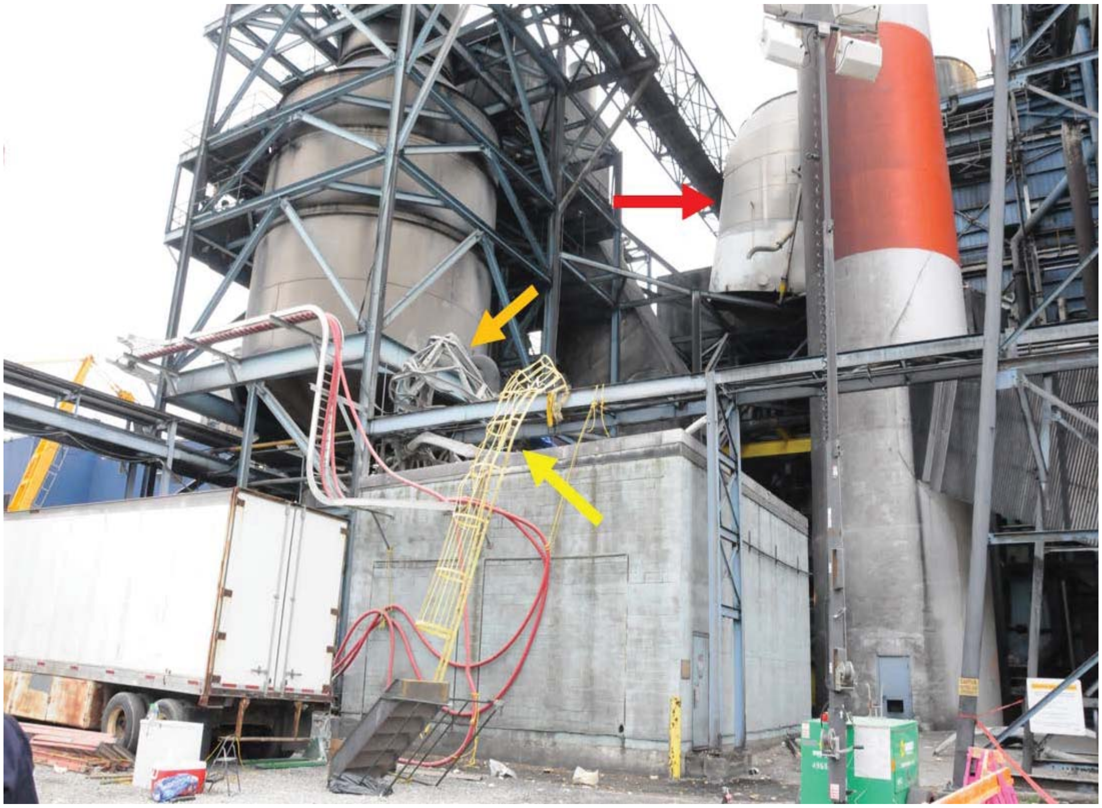

Figure 9. Post-Incident Photograph Showing the Location of the Foul Condensate Tank and Associated Structures. The foul condensate tank is indicated by the red arrow. The ladder previously attached to the tank is indicated by the yellow arrow. The pipe rack, which had previously been located above the tank, is indicated by the orange arrow. Photograph: CSB.

3. The explosion killed three people and injured seven others. All 10 workers were contractors working near the foul condensate tank. Their injuries included contusions and burns [10]. At least one contract worker had burns consistent with those caused by hot liquid.

4. The explosion damaged the pipe rack structure, its associated piping located above the tank (Figure 10), a work platform at the top of a powerhouse stack, and ductwork attached to the precipitator in the powerhouse area. Other areas of the mill also sustained damage.

Figure 10. Photograph Showing Explosion Damage at the PCA DeRidder Mill in DeRidder, Louisiana. The bottom right corner of the photograph shows the foul condensate tank's base upside-down. The explosion separated the tank from its base. Photograph: CSB.

5. Three days before the February 8, 2017 incident, the mill began its annual outage[a] for the repair and maintenance of equipment. The annual outage began on February 5 and was scheduled to end on February 12.

6. The outage plan called for numerous contract workers to perform a variety of tasks within the mill. Although the outage did not include work on the foul condensate tank, multiple contractors were near the tank at any given time during the entire outage either performing work or passing through the area.

7. For the 2017 annual outage, PCA did not empty the liquid in the foul condensate tank. On the day of the incident, the 30-foot tall tank contained a liquid level of about 10 feet,[b] and PCA employees thought that the remaining 20 feet of vapor space contained primarily NCG and water vapor with insufficient air to support combustion. CSB interviews with DeRidder mill employees indicate that the tank was left with a liquid level because:

- Improvements made in the process eliminated the need to de-inventory the tank for the annual outage.

[a] Also referred to as a "shutdown" or a "turnaround."

[b] The diameter of the foul condensate tank was 24 feet. During the annual outage, PCA took the steam ejectors, used to create a slight vacuum on the CNCG system, offline on the afternoon of February 7, 2017. The liquid in the tank corresponded to approximately one third of the 100,000-gallon foul condensate tank.

- There were no known risks among mill personnel of leaving liquid in the tank.
- The company did not have plans to work directly on the tank during the outage.
- There were resource limitations as mill staff had numerous other tasks to complete during the annual outage.

8. During the outage, there was no planned or actual work directly on the foul condensate tank. However, work was planned on water piping located above the foul condensate tank. Months earlier, that piping shifted off its supports and cracked at the intersection of an eight-inch line and a three-inch line that was connected to the foul condensate tank (**Figure 11**), resulting in a significant leak that was visible in a pre-incident video taken by a mill employee who planned the repair work (**Figure 12**).

Figure 11. Pre-incident Photograph of the Cracked Three-inch Piping Connection on the Eight-inch Water Piping (yellow circle). This photograph shows a temporary repair to slow the leak, installed in October 2016. Witnesses stated that workers repaired this crack before the explosion. Workers disconnected the water piping from the valve (just to the right of the yellow circle) to create an air gap and to separate the repair area from the foul condensate tank. The red arrow shows the adjacent vent piping from the foul condensate tank to the CNCG system. The valve on the foul condensate side of the air gap, which was never located, was reportedly closed leading up to the incident. The vapor inside the foul condensate tank and the vent piping likely contained an explosive mixture of NCG and air when this repair work took place. Photograph: PCA.

Figure 12. Pre-Incident Photograph of the Water Leak. The water piping (yellow circle) had cracked at the connection point between the eight-inch vertical water piping and the three-inch horizontal piping entering the foul condensate tank. Water was leaking from the crack (red arrows). Photograph: PCA.

9. To repair the water piping, a crew of contractors needed to disconnect the piping, move it back into place, fix the piping crack, and attach guides to the overhead piping rack to prevent the piping from slipping off of its pipe rack in the future (**Figure 13**). The planned repair required welding. Workers consistently informed the CSB that before starting welding operations, PCA closed and locked the valve on the foul condensate tank side of the water piping. The valve was never located after the explosion.[a]

[a] Blinding, a more robust isolation approach, was not used for the foul condensate side of the water piping. Blinding generally refers to the closure of piping or vessel flanges by fastening a solid plate between flanges or at the open end of a single flange that completely covers the bore and is capable of withstanding the maximum expected system pressure with no leakage beyond the plate [73, p. 32].

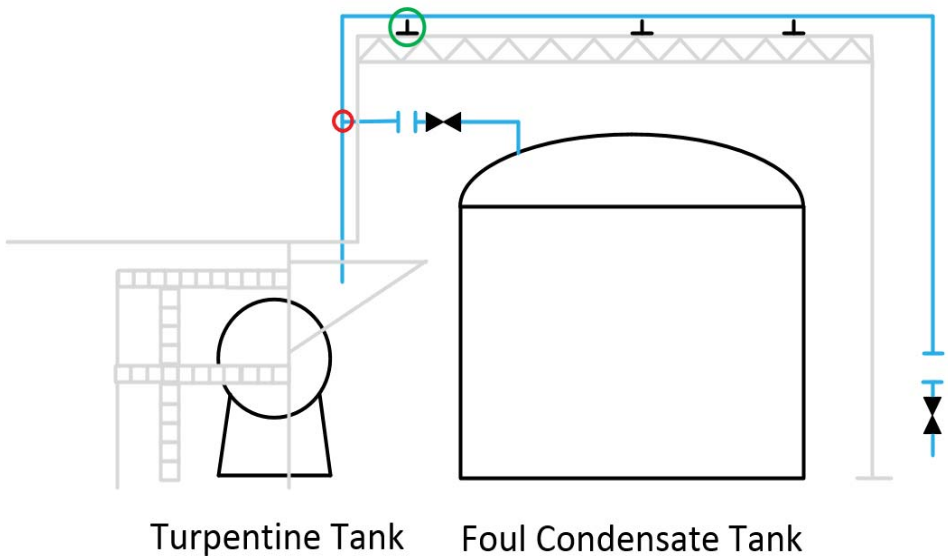

Figure 13. Simplified Drawing of the Scope of Work Conducted on the Water Piping. The scope of work on the water piping required three tasks: (1) disconnect and move water piping back onto its piping rack, (2) fix a crack in the water piping at the intersection of the three-inch line that connected to the foul condensate tank (smaller red circle), and (3) weld a guide onto the piping rack to prevent the water piping from slipping off of the pipe rack in the future (larger green circle).

10. On February 7, 2017, PCA operations personnel isolated the water piping by closing and locking valves in the system, as shown in **Figure 13**. Contractor personnel disconnected the water piping at its flanges and performed the first of three tasks by placing the piping back into position. PCA did not require - and the contract workers did not install - a positive isolation device, such as a blind flange, on the open end of the valve after disconnecting it from the water piping. The work performed on February 7 did not require welding or other methods of hot work.

11. PCA designates one of its operations personnel to serve as a safety coordinator for outages. The safety coordinator receives training to conduct tasks such as: lockout/tagout, confined space entry, and issuing hot work permits.

12. On the morning of February 8, a PCA DeRidder safety coordinator initiated a hot work permit for the water piping welding repairs, a routine procedure for what appeared to be a typical outage work task. Another PCA employee used a gas detector to check for the presence of flammables around and inside the water piping. With no indications of a flammable atmosphere in the water piping or the platform around the hot work area, PCA issued the hot work permit for the work at approximately 8:00 am. The permit focused on the water piping, pipe bridge, and surrounding platform, however, the permit did not consider the potential hazards within adjacent vessels or piping, such as inside the foul condensate tank. The PCA employees involved in issuing the hot work permit were familiar with the operation of the process, but they did not know that the vapor inside the tank was explosive.

13. At the time of the incident, workers had already moved the eight-inch water piping back into its proper place on the rack and repaired the crack in the three-inch water piping, and they were finalizing the work needed to weld guides onto the pipe rack to secure the piping on its supports.[a] Two welders and a pipefitter, who were killed in the subsequent explosion, were on the pipe rack and in the adjacent structure (**Figure 14**).[b]

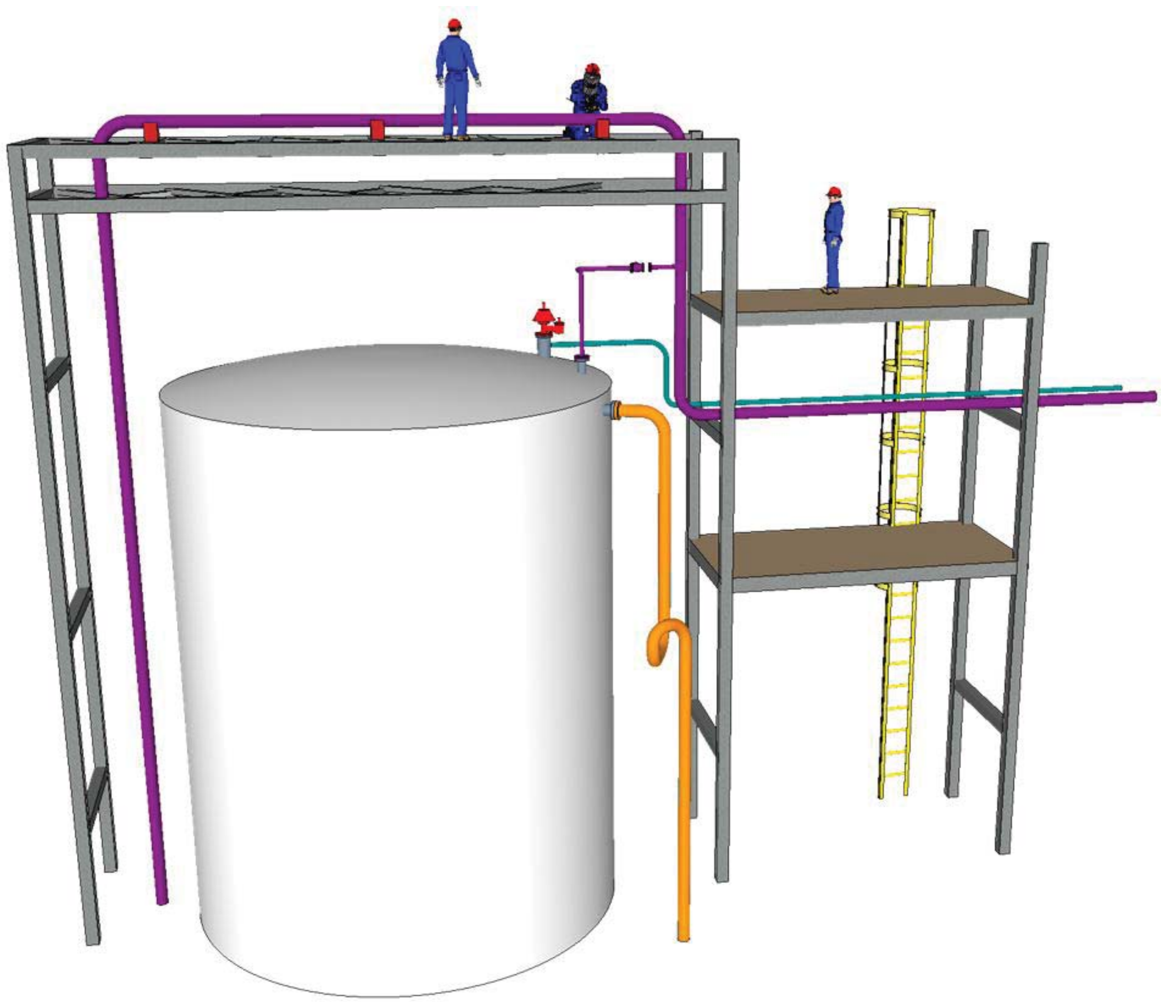

Figure 14. Simplified Drawing of the Work on Water Piping Just Prior to the February 8, 2017 Incident. The location of the workers is approximate and is based on witness interviews. The water piping is indicated by the purple line running over the foul condensate tank. The guides on the pipe rack are in red and sit on top of the pipe rack. The pressure vacuum breaker and the NCG piping are indicated by the red device on top of the tank and the turquoise line, respectively. Although not shown, workers wore appropriate protective equipment, including fall protection. Source: CSB.

[a] Around the time of the incident, the workers were conducting hot work within 35 feet of the explosive atmosphere. Per PCA hot work standards, this work occurred too close to an explosive atmosphere.

[b] A fire watch, tasked with monitoring hot work activities on the ground at the base of the tank, also was injured by the explosion.

14. The CSB was unable to establish conclusively the exact activities taking place at the time of the explosion. Mill surveillance cameras were not positioned to record activities near the foul condensate tank. As a result, no recordings captured the work near the foul condensate tank. Witness statements failed to give a complete picture of the incident. Computer process data for the foul condensate tank indicate a pressure spike on the pressure indicator located on the CNCG header connected to the tank at approximately 11:05 am, which is consistent with witness accounts about when the explosion occurred.

15. The emergency response plan in place at the DeRidder mill was not properly implemented across the entire facility. According to the Occupational Safety and Health Administration (OSHA), a few employees were not evacuated from the facility for more than an hour, no head count was taken of the contractors, and some of the telephones in the mill were not working. As a result, on August 3, 2017, OSHA issued citations to PCA for those violations.

4 TECHNICAL ANALYSIS

4.1 MOST LIKELY INCIDENT SCENARIO

1. A combination of physical evidence, interviews, and process data suggests that pressure swings during normal operation pulled air into the foul condensate tank. Air most likely entered through the tank's pressure vacuum breaker (**Figure 15**), as designed, to relieve the low-pressure condition it was experiencing during swings in the foul condensate tank level. The internal pressure dropped below the minus (-) six-inches of water set pressure of the vacuum breaker. Additional air entered the foul condensate tank during the course of the mill's annual outage. Because the tank had been isolated and was cooling from its operating temperature of 185 ºF, some of the vapor condensed.[a] The ingress of air and the ambient cooling of the liquid brought the tank's atmosphere below the UEL, creating an explosive atmosphere.

Figure 15. Photograph of a Spare Pressure Vacuum Breaker for the CNCG System at the DeRidder Mill. If the foul condensate tank experiences high-pressure (six-inches of water), the left-hand portion of the pressure vacuum breaker opens and releases vapor to the atmosphere. If the tank experiences low-pressure (minus six-inches of water), the portion of the pressure vacuum breaker extending to the right will open and pull air into the tank.[b] Photograph: CSB.

[a] Mill personnel shut off the ejectors on the CNCG system on February 7, 2017 in the afternoon. Therefore, the CNCG system was not pulling a vacuum from the CNCG header.

[b] See Video showing operation of a pressure vacuum breaker [12].

2. In addition to containing numerous volatile components, such as TRS and methanol, the foul condensate that flows into the tank typically includes small quantities of turpentine. In the foul condensate tank, however, turpentine rises and forms an immiscible (second) liquid layer on top of the foul condensate, similar to the behavior of oil and water (**Figure 16**). Because this turpentine layer was not being removed for approximately three months prior to the explosion (Section 4.3.2), a significant quantity of turpentine likely accumulated inside the tank.

Figure 16. Photograph of Immiscible Oil Layer on Top of Water. This photograph shows how oil forms an immiscible liquid layer on top of water similar to how a turpentine layer might appear inside the foul condensate tank. Photograph: CSB.

3. PCA did not conduct a hazard analysis of the foul condensate tank, did not effectively assign or communicate clear ownership of the tank to any operations group (Section 6.1), and did not install instrumentation on the tank that was capable of detecting when the vapor inside the tank entered an explosive range. Therefore, PCA lacked knowledge of both the turpentine accumulation and the air ingress within the tank. Without the capability to know the actual conditions inside the tank, PCA could neither adequately control the hazards of the process nor communicate the risks posed by the tank to PCA DeRidder staff and contractors. Because the mill was unable to monitor the atmosphere within the tank, PCA should have managed the unit as a flammable storage tank.

4. On the basis of interviews and the review of physical evidence, contractors completing repairs above the foul condensate tank likely produced the source of ignition that caused the explosion. Because of a lack of conclusive evidence, a definitive source of ignition cannot be identified, and other potential ignition sources remain (Section 4.5).

4.2 Hot Work Permit for Work on the Water Piping

5. Before conducting any work capable of providing an ignition source, such as welding or brazing, PCA requires its personnel to issue a hot work permit.[a] The permit requires all flammables to be moved 35 feet away from the hot work. If this separation is not possible, the flammables must be shielded to prevent fire or explosion. Once these requirements are accomplished, trained personnel test for flammable atmospheres in the work area before beginning any work that could provide a source of ignition. Hot work permits typically identify the location of the work, date the work is to be done, personnel performing the work, time of permit issue and expiration, brief description of the work, and any special instructions for safely accomplishing the job.[b] The hot work permit issued by PCA on the day of the incident documented this information. PCA's hot work permit program was not designed or intended to identify and control the explosive atmosphere inside the foul condensate tank, despite its close proximity to the planned hot work. Although not required by PCA's hot work program, conducting a hazard analysis as part of a process safety management program before the hot work permitting is more likely to identify explosive atmospheres in nearby equipment.

6. PCA workers performed atmospheric monitoring of the surrounding work area with a combustible gas detector before issuing the hot work permit. PCA workers found the platform around the welding site to be free of flammable vapors; however, no one checked the inside of the foul condensate tank for a flammable atmosphere.[c] Mill personnel were not aware of the potential explosion hazard within the foul condensate tank. Thus, once atmospheric monitoring was complete, a PCA safety coordinator issued the hot work permit for the work at approximately 8 am (**Figure 17**).

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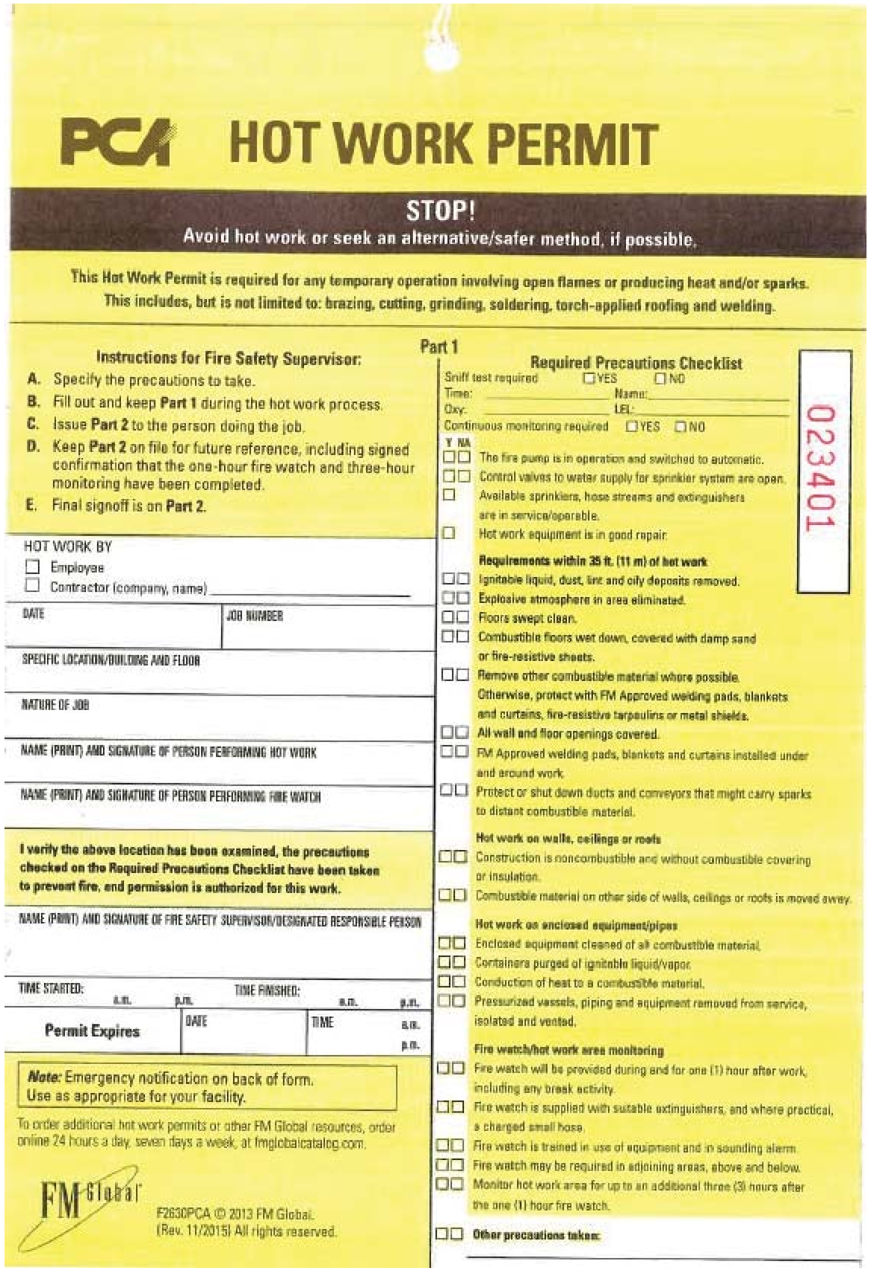
[a] 29 C.F.R. § 1910.119(k) (2013). PCA policy documents required issuing a hot work permit before welding work could begin.

[b] Oil and Gas Well Drilling and Servicing eTool [86]. 29 C.F.R. § 1910.119(k) (2013).

[c] This is not to say that someone should have opened the tank and checked for a flammable atmosphere. Rather, if the possibility exists for a flammable atmosphere inside the tank, the flammable atmosphere must be removed through safer, and established methods such as purging and inerting.



PCA HOT WORK PERMIT

STOP!
Avoid hot work or seek an alternative/safer method, if possible.

This Hot Work Permit is required for any temporary operation involving open flames or producing heat and/or sparks. This includes, but is not limited to: brazing, cutting, grinding, soldering, torch-applied roofing and welding.

Part 1

Instructions for Fire Safety Supervisor:

A. Specify the precautions to take.
B. Fill out and keep **Part 1** during the hot work process.
C. Issue **Part 2** to the person doing the job.
D. Keep **Part 2** on file for future reference, including signed confirmation that the one-hour fire watch and three-hour monitoring have been completed.
E. Final signoff is on **Part 2**.

HOT WORK BY
☐ Employee
☐ Contractor (company, name) ____________

DATE | JOB NUMBER

SPECIFIC LOCATION/BUILDING AND FLOOR

NATURE OF JOB

NAME (PRINT) AND SIGNATURE OF PERSON PERFORMING HOT WORK

NAME (PRINT) AND SIGNATURE OF PERSON PERFORMING FIRE WATCH

I verify the above location has been examined, the precautions checked on the Required Precautions Checklist have been taken to prevent fire, and permission is authorized for this work.

NAME (PRINT) AND SIGNATURE OF FIRE SAFETY SUPERVISOR/DESIGNATED RESPONSIBLE PERSON

TIME STARTED: a.m. p.m. TIME FINISHED: a.m. p.m.

Permit Expires DATE TIME a.m. p.m.

Note: Emergency notification on back of form. Use as appropriate for your facility.

To order additional hot work permits or other FM Global resources, order online 24 hours a day, seven days a week, at fmglobalcatalog.com.

FM Global

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Required Precautions Checklist

Sniff test required ☐YES ☐NO
Time: Name:
Oxy: LEL:
Continuous monitoring required ☐YES ☐NO

Y NA
☐☐ The fire pump is in operation and switched to automatic.
☐☐ Control valves to water supply for sprinkler system are open.
☐ Available sprinklers, hose streams and extinguishers are in service/operable.
☐ Hot work equipment is in good repair.

Requirements within 35 ft. (11 m) of hot work
☐☐ Ignitable liquid, dust, lint and oily deposits removed.
☐☐ Explosive atmosphere in area eliminated.
☐☐ Floors swept clean.
☐☐ Combustible floors wet down, covered with damp sand or fire-resistive sheets.
☐☐ Remove other combustible material where possible. Otherwise, protect with FM Approved welding pads, blankets and curtains, fire-resistive tarpaulins or metal shields.
☐☐ All wall and floor openings covered.
☐☐ FM Approved welding pads, blankets and curtains installed under and around work.
☐☐ Protect or shut down ducts and conveyors that might carry sparks to distant combustible material.

Hot work on walls, ceilings or roofs
☐☐ Construction is noncombustible and without combustible covering or insulation.
☐☐ Combustible material on other side of walls, ceilings or roofs is moved away.

Hot work on enclosed equipment/pipes
☐☐ Enclosed equipment cleaned of all combustible material.
☐☐ Containers purged of ignitable liquid/vapor.
☐☐ Conduction of heat to a combustible material.
☐☐ Pressurized vessels, piping and equipment removed from service, isolated and vented.

Fire watch/hot work area monitoring
☐☐ Fire watch will be provided during and for one (1) hour after work, including any break activity.
☐☐ Fire watch is supplied with suitable extinguishers, and where practical, a charged small hose.
☐☐ Fire watch is trained in use of equipment and in sounding alarm.
☐☐ Fire watch may be required in adjoining areas, above and below.
☐☐ Monitor hot work area for up to an additional three (3) hours after the one (1) hour fire watch.

☐☐ **Other precautions taken:**

023401

Figure 17. Representative Hot Work Permit. This permit is similar to the one used for work on the water piping on the day of the incident. Source: PCA.

7. The appropriate time to identify the explosive atmosphere in the foul condensate tank as a potential hazard would have been during a hazard analysis or when planning the annual outage with a multi-discipline team from the DeRidder mill. Such a team should have had the time, competence, and resources to assess potential process hazards within the mill during the outage rather than relying on a safety coordinator to recognize this hazard just minutes before contractors were ready to begin the repair work. A more robust hazard analysis before or during the planning phase could have identified the foul condensate tank explosion hazard and thereby helped prevent the incident. If the hazard had been identified, the work plan could have been modified to include safety precautions

such as shielding the tank from sparks or slag, or inerting the foul condensate tank to help reduce the potential for an explosion.

8. The actions performed by DeRidder mill staff demonstrate that personnel attempted to make the work on the water piping safe, but they did not identify the explosion danger inside the foul condensate tank. Without proper knowledge of the process hazards inside the foul condensate tank, the safety coordinator and the contractors were unable to implement the safeguards needed to ensure safety during this repair work.

4.2.1 Combustible Gas Monitoring

9. Combustible gas monitoring in the work area before and during hot work activities is crucial to ensuring safety, even in areas where a flammable atmosphere is not anticipated.[a] Because combustible gas monitoring is lower on the hierarchy of controls (Section 4.7), it should be used in conjunction with eliminating the flammable atmosphere, if such elimination is feasible. A properly performed process hazard analysis likely would have identified, and called for elimination of, the flammable atmosphere inside the foul condensate tank during the annual outage.

10. As discussed previously, PCA conducted gas monitoring of the area before starting work. There were no indications that a flammable atmosphere existed in the area. PCA practices and procedures require continuous, combustible gas monitoring when welding, and consistent with this requirement, the contractor assigned a fire watch to the February 8, 2017 work.

11. While work was progressing, the contractor's fire watch conducted gas monitoring for a flammable atmosphere at ground level. Leading up to the explosion, there is no indication that he detected a flammable atmosphere. From his position on the ground, the fire watch could not monitor for flammables above the tank, on or near the catwalk where contractors were standing while conducting hot work, or adjacent to the clean water piping valve leading to the foul condensate tank or the pressure vacuum breaker.[b]

12. No fire watch was assigned to the elevated hot work area, and the three workers who were killed were located on top of the tank and did not perform any independent gas monitoring while finishing the second task related to hot work.

13. Continuous combustible gas monitoring provided a weak safeguard against the February 8 incident, for primarily two reasons. First, continuous monitoring assumes that a leak of combustible gas to the atmosphere would occur in the vicinity of the monitoring location; however, the tank still could

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[a] See, for example, the U.S. Chemical Safety and Hazard Investigation Board's Seven Key Lessons to Prevent Worker Deaths During Hot Work In and Around Tanks [154].

[b] Following NFPA 51B, the safety coordinator could have required additional fire watches [11, p. 12]. FM Global Hot Work guidance also specifies, in Section 2.5.3.2, that a second fire watch can be a good practice requirement under certain circumstances, noting: "Provide a second fire watch when any of the following conditions exist: A. The hot work area and person performing the hot work are not visible from a single vantage point. B. The hot work area is large, multi-level, and/or congested [60, p. 13]."

have exploded without such a leak (Section 4.5), and monitoring near the tank under this scenario could not identify an explosive atmosphere inside the tank. Second, if a leak were to develop from the approximately 100,000-gallon tank, continuous monitoring would need to take place at numerous locations, making the task impracticable for a single fire watch, although, at the very least, continuous monitoring should have been ongoing in the work area.[a]

14. The most effective way to detect the explosive atmosphere would have been to conduct continuous monitoring inside the foul condensate tank using fixed instrumentation. It would have been unacceptable to have an operator conduct monitoring by opening the foul condensate tank. Depending on the pressures inside the tank, air would be pulled into a tank containing NCG or NCG would be released to the atmosphere. Thus, the proper type of monitoring inside the tank would have relied on fixed instrumentation taking samples from within the tank's head space. In addition, and more important, a properly conducted PHA would have alerted personnel to expect the tank to contain flammable gas. With this knowledge, PCA should have purged and inerted the foul condensate tank during the annual outage.

4.2.2 Separation of Combustibles from Hot Work

15. If PCA had identified the explosion hazard associated with conducting hot work above a tank containing an explosive atmosphere, it should have taken steps to eliminate this explosive atmosphere.[b] If this approach had been determined to be impractical, PCA should have attempted to separate the hot work from the foul condensate tank by using appropriate barriers or covers. Interviews conducted with mill personnel by the CSB indicate that PCA treated the foul condensate tank walls as a barrier for the purposes of the hot work. However, this reliance on the tank walls as a barrier proved misplaced.

16. NFPA 51B highlights a 35 Foot Rule in identifying the potential hazard area for conducting hot work:

> All combustibles shall be relocated at least 35 ft (11 m) in all directions from the work site, and . . . [i]f relocation is impractical, combustibles shall be

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[a] OSHA hot work regulation requires a fire watch "whenever welding or cutting is performed in locations whether other than a minor fire might develop," or whenever any special circumstances might exist, such as when, the regulations note: "Combustible materials are adjacent to the opposite side of metal partitions, walls, ceilings, or roofs and are likely to be ignited by conduction or radiation." 29 C.F.R. §§ 1910.252(a)(2)(iii)(A) (2018), 1910.252(a)(2)(iii)(4) (2018). In addition, in accordance with NFPA 51B, the hot work permit issuer could have required additional fire watches, as might be required given the circumstances [11, p. 12]. FM Global hot work guidance then specifies, in Section 2.5.3.2, that a second fire watch can be a good practice requirement under certain circumstances, saying: "Provide a second fire watch when **any** of the following conditions exist: A. The hot work area and person performing the hot work are not visible from a single vantage point. B. The hot work area is large, multi-level, and/or congested [60, p. 13]." Combined, an additional fire watch should have been implemented on the top of the tank, near the hot work operations being conducted. Combined, these regulatory and good practice guidance documents suggest a second fire watch should have been implemented, at a minimum, to monitor for a flammable atmosphere during hot work – and up to 30 minutes after completion [11, pp. 7-8].

[b] The DeRidder Mill's Hot Work Procedure requires the identification and elimination of explosive atmospheres.

protected by a listed welding curtain, welding blanket, welding pad, or equivalent [11, p. 7].[a]

If the hot work is done at an elevation, as was the case at the DeRidder mill, the 35 Foot Rule's radius can be enlarged (**Figure 18**) [11, p. 13].

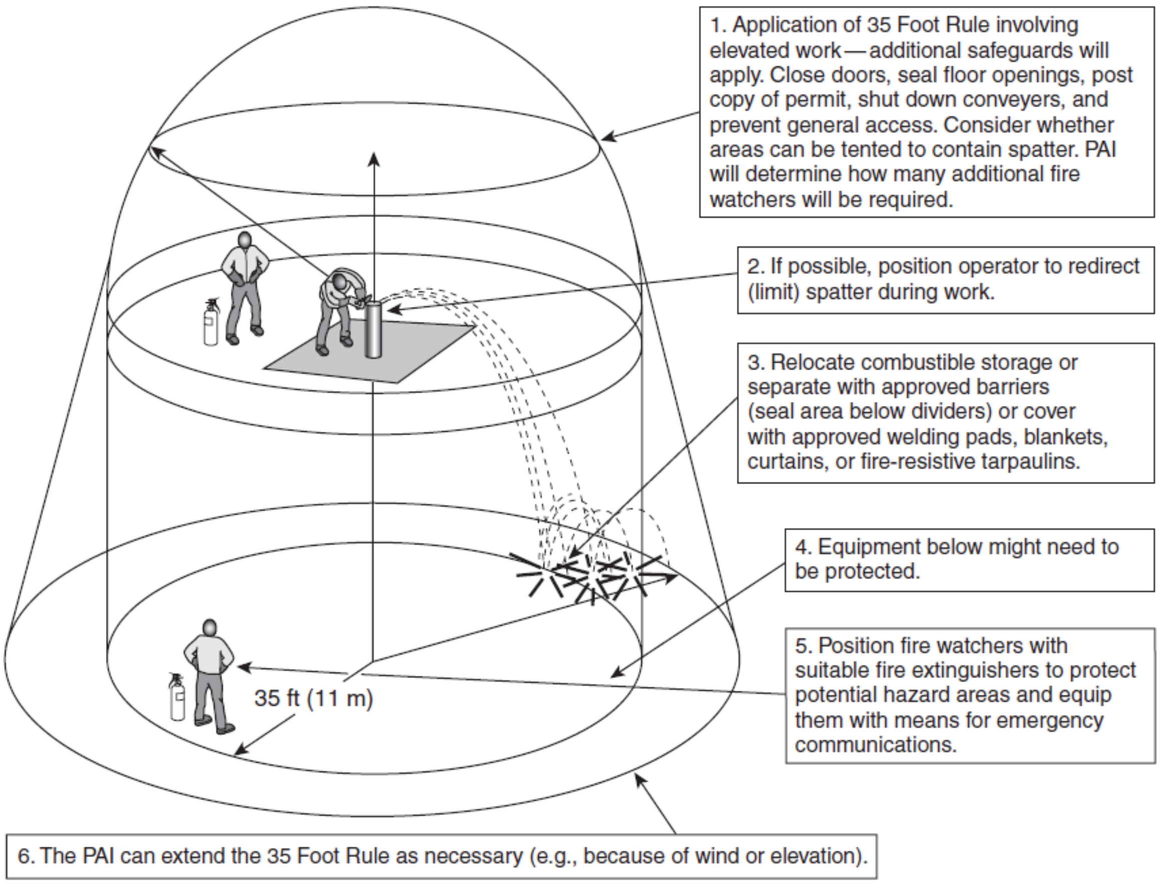

Figure 18. Illustration of the 35 Foot Rule Applied to Elevated Work. NFPA uses the initialism PAI for Permit Authorizing Individual – to indicate the individual designated by management to authorize hot work. Diagram: NFPA.

17. The foul condensate tank sat within 35 feet of the hot work, and the exterior of the tank served as the primary barrier between the flammable atmosphere and the hot work. This situation was inappropriate because the tank could have leaked or the tank exterior could have provided for heat conduction had a source of ignition come into contact with the tank (Section 4.5). Proper barriers that could have been used to insulate the tank from a source of ignition include: welding pads, blankets, curtains, or fire-resistive tarpaulins. During welding, a fire blanket appears to have been used. It was placed over part of the top of the tank. However, this fire blanket did not protect the entire tank from an ignition source.

[a] This quote uses "ft" as an abbreviation for feet and "m" as an abbreviation for meters.

18. Although PCA did not apply its process safety management system to the CNCG system, it still should have assessed whether a flammable atmosphere existed within at least a 35-foot radius of the work, per internal and external standards [11],[a] which mill personnel failed to do. PCA failed to eliminate the flammable atmosphere inside the tank and also failed to adequately separate the hot work from the flammable atmosphere by using a barrier, such as a fire blanket between the tank and the hot work. After PCA did not implement either safeguard effectively, it should not have issued a permit for the hot work on February 8.

4.3 Sources of Fuel

4.3.1 Non-Condensable Gas

19. As part of the process, some NCG evolves from the foul condensate liquid within the foul condensate tank to occupy the vapor space above this liquid. These NCG are continuously evacuated by the CNCG collection system. During the outage, however, the vacuum system was off, which could allow NCG to accumulate in the vapor space of the tank. As stated previously, NCG are a flammable gas that includes, among numerous other components, methanol, turpentine, and sulfur compounds referred to as TRS. The TRS compounds include hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide.

20. During normal operation, the CNCG system is not considered explosive because the foul condensate tank should not contain enough oxygen to support combustion [5, p. 2]. At the time of the incident, however, air ingress into the vapor space of the foul condensate tank likely provided enough oxygen to mix with the flammable NCG and support an explosion (Section 4.4).

4.3.2 Excess Turpentine

21. In addition to containing NCG and oxygen, the foul condensate tank also likely contained a larger than anticipated quantity of turpentine because the weir within the tank (installed to remove turpentine) had not been operational for approximately three months. This presents certain process hazards as TIP 0416-09 states, "[t]urpentine is able to reach a flammable concentration more readily than TRS, and most explosions in CNCG systems have been attributed to turpentine. Thus, it is very important to keep turpentine out of the CNCG system [5, pp. 2-3]."[b]

22. During normal operating conditions, a small quantity of turpentine is expected to collect in the foul condensate tank. Because turpentine is a valuable byproduct of the pulping process, the PCA

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[a] 29 C.F.R. § 1910.252 (2012).

[b] Although all turpentine cannot be kept out of the CNCG system, companies should seek to minimize the quantity of turpentine to as low as reasonably practicable.

DeRidder mill design included equipment to recover it via an internal weir within the tank (**Figure 19**).[a]

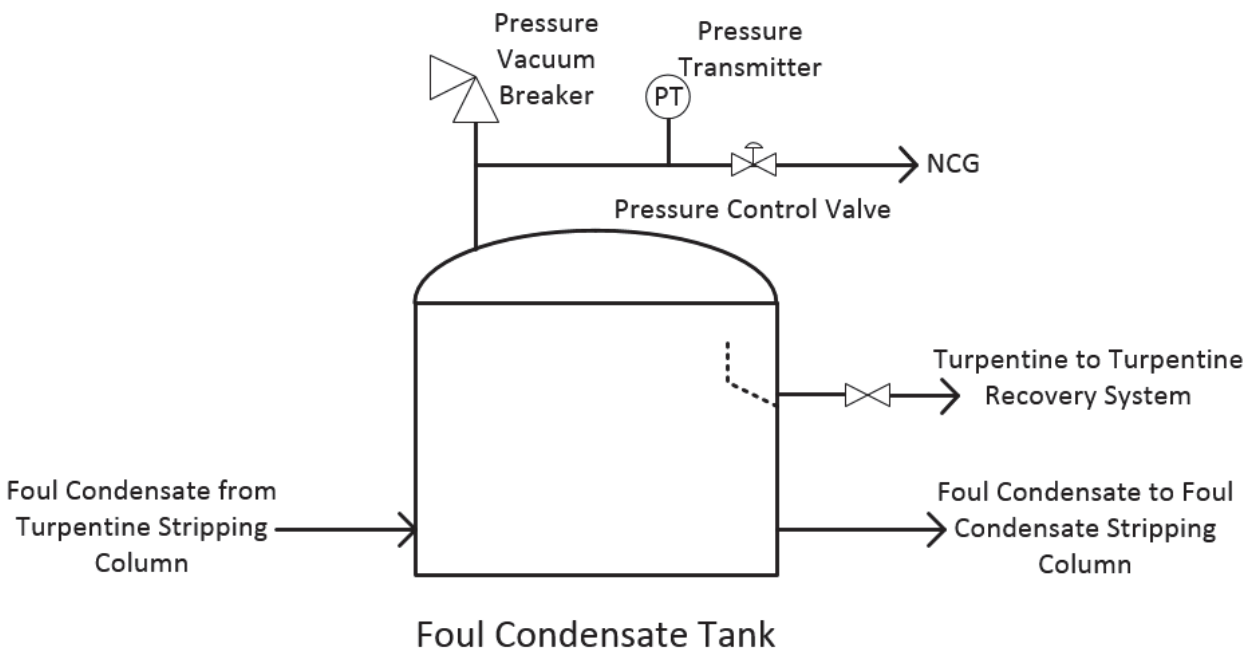

Figure 19. Simplified Drawing of the Weir Within the Foul Condensate Tank. The weir is indicated by the dotted line. The top of the weir sits approximately 20 feet from the base of the foul condensate tank. As the liquid inside the tank rises above 20 feet, liquid is "skimmed" into the weir and sent to a turpentine recovery system.

23. Because turpentine is less dense than water and forms an immiscible layer, it will float and collect on the surface of the foul condensate liquid (**Figure 16**). To enable the recovery and control the accumulation of turpentine, the foul condensate tank was equipped with an internal weir to skim turpentine off the surface of the foul condensate liquid as the liquid inside the tank reached a height of 20 feet. Automatic controls cycled the tank level from 16 to 20 feet every one to two hours, to skim accumulated turpentine from the top of the foul condensate liquid (**Figure 20**).

[a] The foul condensate tank weir is composed of an internal wall and reservoir that allows the top portion of liquid to overflow and thus remove any immiscible (second liquid layer) of turpentine that may accumulate. The weir is essentially a second smaller tank within the tank.

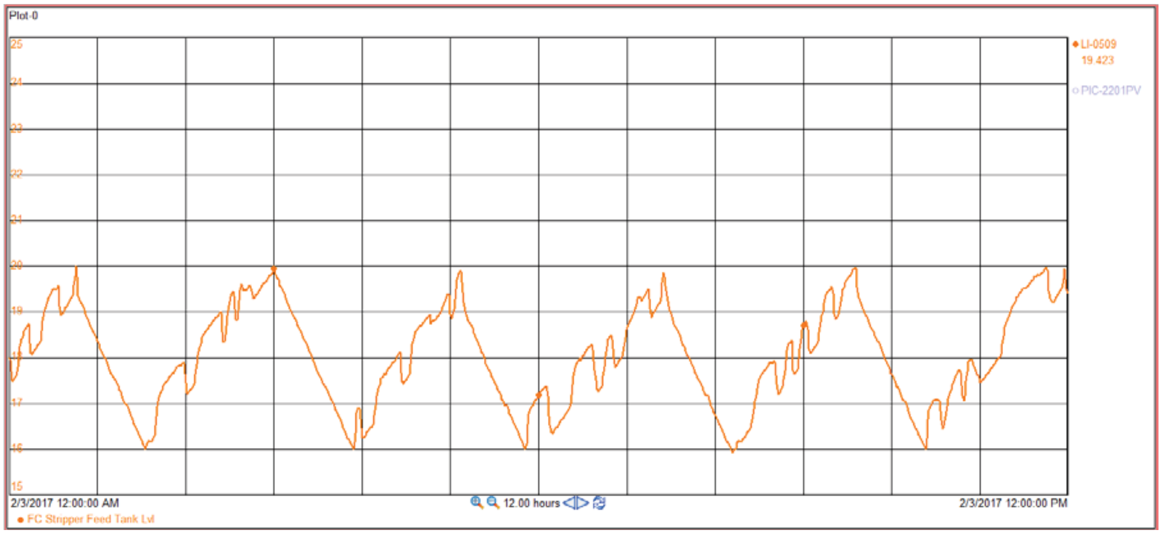

Figure 20. Plot of the Foul Condensate Tank Level Showing the Typical Cycle to Skim Turpentine by Using the Tank's Internal Weir. The tank level has a range of 15 to 25 feet of liquid. Automatic controls were installed to cycle the tank level from 16 to 20 feet to skim turpentine into the tank weir system.

24. Although the tank level continually cycles to skim turpentine from the top of the foul condensate liquid, the CSB investigation revealed that a valve remained closed in the piping designed to direct any skimmed turpentine to the mill's turpentine recovery system. As a result, the mill did not use the downstream turpentine recovery system for approximately three months (**Figure 21**).[a] Because this valve remained closed, turpentine collection in the foul condensate tank was not controlled, and PCA removed the turpentine only when the tank was periodically emptied.

[a] Based on interviews and physical evidence, there appeared to be a lack of understanding surrounding the foul condensate tank's turpentine skimming function and PCA lacked documentation that indicated when skimming was to take place.

Figure 21. Closed Valve on the Piping from the Foul Condensate Weir to the Turpentine Recovery System. This photograph from the mill's 2010 inspection file shows that the valve is in the closed position. Post-incident, this valve also was found in the closed position. The CSB learned that the PCA DeRidder mill had not used the foul condensate tank's weir system to remove turpentine. Photograph: PCA.

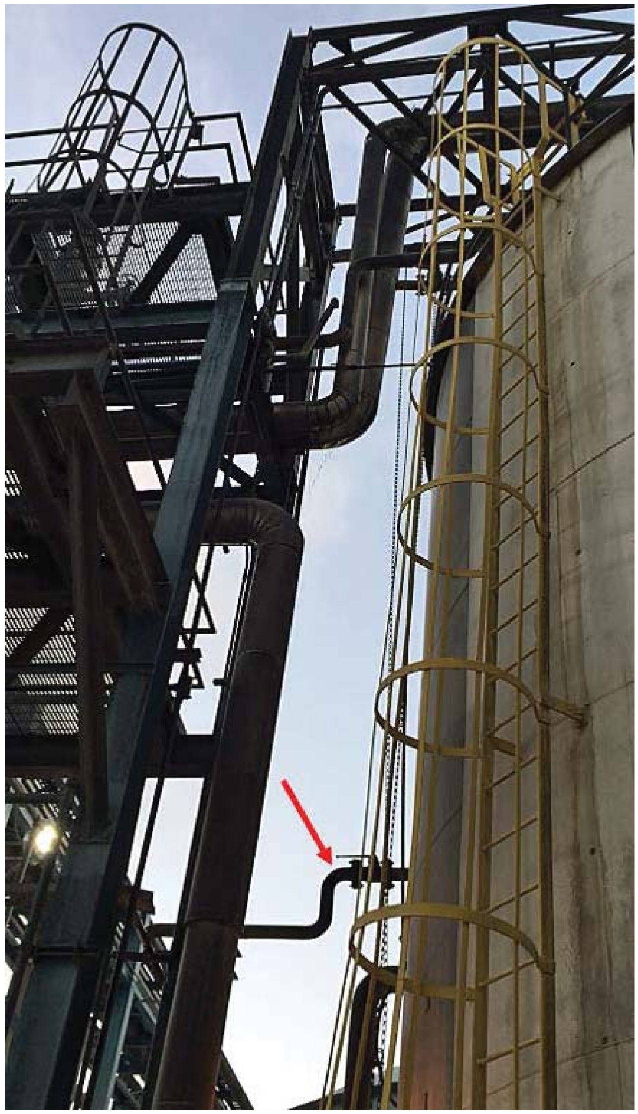

Figure 22. Pre-Incident Photograph of the Foul Condensate Tank. The line from the weir inside the tank to the turpentine recovery system is indicated by the red arrow. The valve at the foul condensate tank is kept open, but the valve at the turpentine recovery system (**Figure 21**) is kept closed. Photograph: PCA.

25. As discussed previously, explosions involving turpentine are typically more severe than explosions involving other NCG [8]. Interviews, physical evidence, and company records indicate that before the incident, the mill last drained the foul condensate in November 2016.[a] As a result, turpentine likely was accumulating inside the foul condensate tank for approximately three months leading up to the February 8, 2017 incident.

[a] "TRS is known to adsorb onto, and then desorb from metal walls [87]." Therefore, "welding should be done immediately after purging and testing for combustibles [87]."

4.4 SOURCES OF AIR

26. Multiple sources of air ingress into process equipment and the CNCG system exist at the DeRidder mill. This includes the process design, such as the pressure vacuum breakers. It also includes the process chemistry that contains small quantities of oxygen. Operation or maintenance issues also can result in air ingress through pressure relief systems and water seals. Furthermore, for some of these potential sources of air ingress, such as the foul condensate tank pressure relief system, air ingress potentially occurred more than once every hour. In designing and operating a CNCG system the pulp and paper industry should apply robust and effective safeguards such as those detailed in TAPPI TIP 0416-09.

4.4.1 PRESSURE VACUUM BREAKER

27. The foul condensate tank and other units within the CNCG system can experience high pressure or vacuum conditions. To prevent the tank from experiencing physical damage during a high or low-pressure event, the tank and other units are equipped with pressure vacuum breakers (**Figure 23** and **Figure 24**).

Figure 23. Image of a Pressure Vacuum Breaker. If the vessel experiences an over pressure event, the top portion of the pressure vacuum breaker releases to the atmosphere. If the vessel experiences an under pressure event, the portion of the pressure vacuum breaker extending to the right will pull air into the vessel. Photograph: Finekay [12].

Figure 24. Post-Incident Pressure Vacuum Breaker. The foul condensate tank's pressure vacuum breaker is shown post-incident. Photograph: PCA.

28. The tank's pressure vacuum breaker is located on the roof of the tank and is designed to relieve pressure or vacuum conditions if they exceed a safe operational limit (**Figure 25**).

Figure 25. Relief/Protection Functions of the Pressure Vacuum Breaker. The image at the left shows that as pressure in the vessel increases, a pressure pallet lifts and relieves tank pressure to the atmosphere. The image at the right shows that as a vacuum is drawn into the vessel, the vacuum pallet lifts and air is drawn into the vessel from the atmosphere. Image: Groth Corporation [13].

29. Although the foul condensate tank turpentine-skimming weir did not remove turpentine because of the closed valve to the turpentine recovery system, before the incident, PCA continued to use the

automatic controls that cycle the liquid inside the tank above and below the weir.[a] With the valve to the turpentine recovery system closed, this level cycle provided no known operational benefit, but adversely affected the tank pressure. As shown in **Figure 26**, the pressure at the foul condensate tank connection to the NCG collection piping increased when the tank liquid level increased, and the pressure decreased when the tank liquid level decreased. Process control data from the PCA DeRidder mill show that these pressure swings cycled between the two set pressures of the pressure vacuum breaker of plus and minus six-inches of water. During a level increase, the pressure increased and lifted the pressure relief side of the pressure vacuum breaker, sending flammable and toxic NCG to the atmosphere. Conversely, when the foul condensate liquid level decreased, the vacuum breaker opened, pulling air into the foul condensate tank.

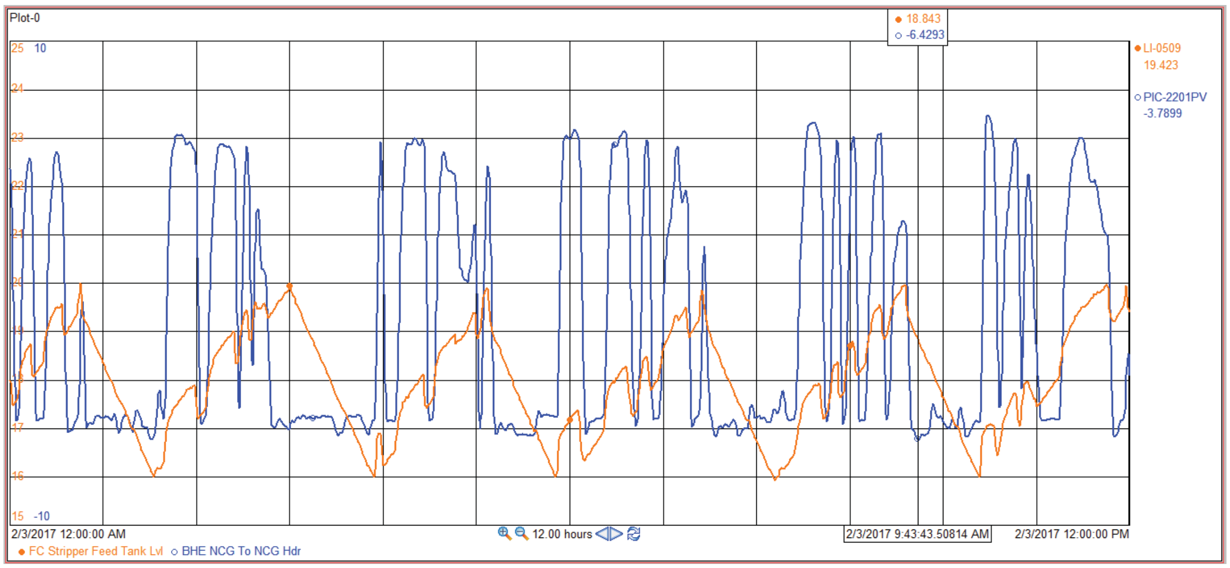

Figure 26. Process Data Trend Showing Typical Pressure and Level of the Foul Condensate Tank During Operation. The tank level is shown by the orange trend line with a range of 15 to 25 feet of liquid. The tank pressure is represented by the blue trend line and ranges from approximately -six to + six inches of water, which are the set pressures of the pressure vacuum breaker (the limits of the graph are 10 inches of water vacuum to 10 inches of water pressure).[b]

30. During the 12 hours of operation captured in **Figure 26**, process data indicate that the pressure vacuum breaker opened enough for air to enter the foul condensate tank at least 14 times. As the tank level decreased from 20 to 16 feet, the internal pressure decreased, pulling as much as 1,800 cubic feet of air through the vacuum breaker and NCG from the CNCG piping into the foul condensate tank. Drawing air into the foul condensate tank increased the oxygen concentration in

[a] To cycle the foul condensate tank level, automatic controls periodically diverted the feed flowing into the foul condensate tank.

[b] To get a more complete air ingress picture, Figure 28 shows the foul condensate tank close to atmospheric pressure, when the vacuum ejectors were off. The foul condensate tank pressure transmitter indicated a pressure between 0.5 and 0.6 inches of water when the tank was near atmospheric pressure, suggesting a slight error in the transmitter calibration. The significance of this is that the vacuum breaker with set pressure of -6 inches of water may open when the pressure transmitter indicates about -5.4 to -5.5 inches of water.

the vapor portion of the tank. By routinely pulling air into the foul condensate tank during normal operation, at least a portion of the vapor inside the tank likely entered its explosive range.

31. When the foul condensate tank level increased from 16 to 20 feet, the internal pressure increased and pushed vapor out of the tank. Some of this vapor exited the vent piping towards the ejectors, but vapor also likely exited to the atmosphere through the pressure relief side of the pressure vacuum breaker. PCA restricted the movement of the pressure control valve in the vent piping to the ejectors. The pressure control valve was limited to an operating range of 5 to 15 percent open. The limitation on how far this control valve could open in turn restricted how much vapor could pass from the foul condensate tank to the ejectors.

32. Because of the continual cycling of the level – drawing air into the foul condensate tank as the level decreased and pushing vapor out of the tank as the level increased – the mixture of vapor and oxygen in the tank began to move toward a flammable range. PCA, however, had not installed instrumentation to analyze the composition of the foul condensate tank vapor space, contributing to PCA not understanding that the vapor space could be explosive.

33. When the mill shut down on February 5, 2017 for the annual outage, the liquid flowing into and out of the foul condensate tank stopped, and the tank level cycling also stopped (**Figure 27**). PCA also shut off the ejectors on the CNCG header on February 7, 2017 (**Figure 28**), stopping the CNCG system from pulling a vacuum.

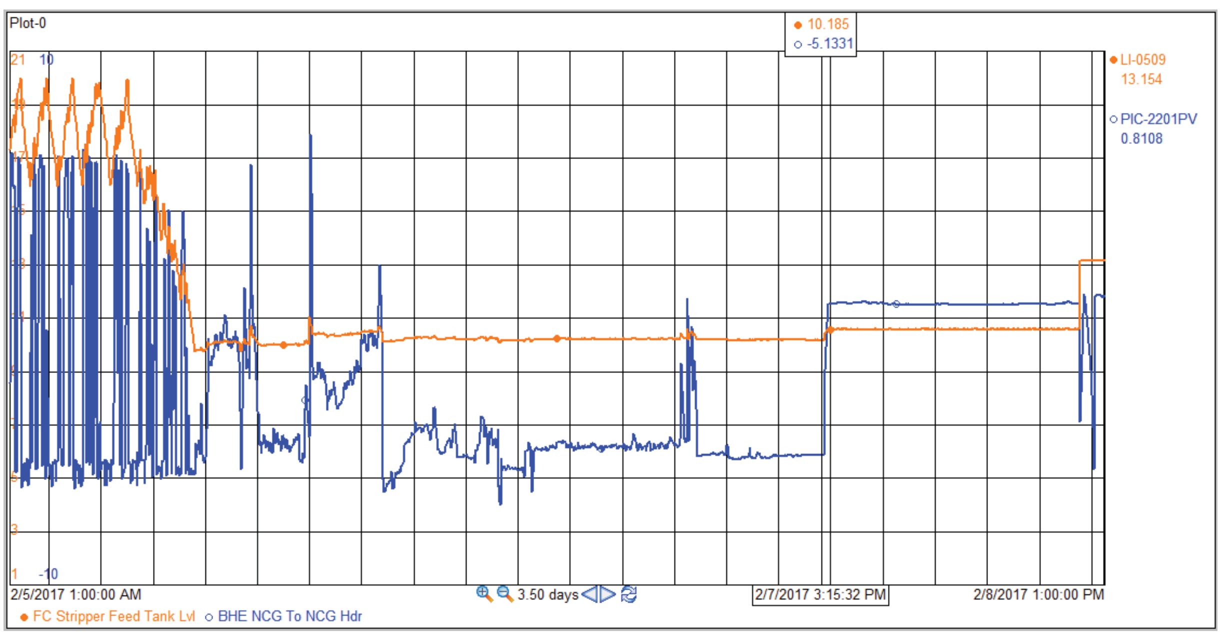

Figure 27. Process Data Trend Showing the Foul Condensate Tank Pressure and Level. These process data trend lines show the foul condensate tank pressure (blue) and level (orange) from just before the outage (while the tank level was still cycling from 20 to 16 feet), to just after the explosion. In this trend, the range of the foul condensate tank level is 1 to 21 feet, and the range of the foul condensate tank pressure is from minus (-) 10 to 10 inches of water. This trend graph shows that PCA shut off the vacuum ejectors on February 7 after 3:15 pm.

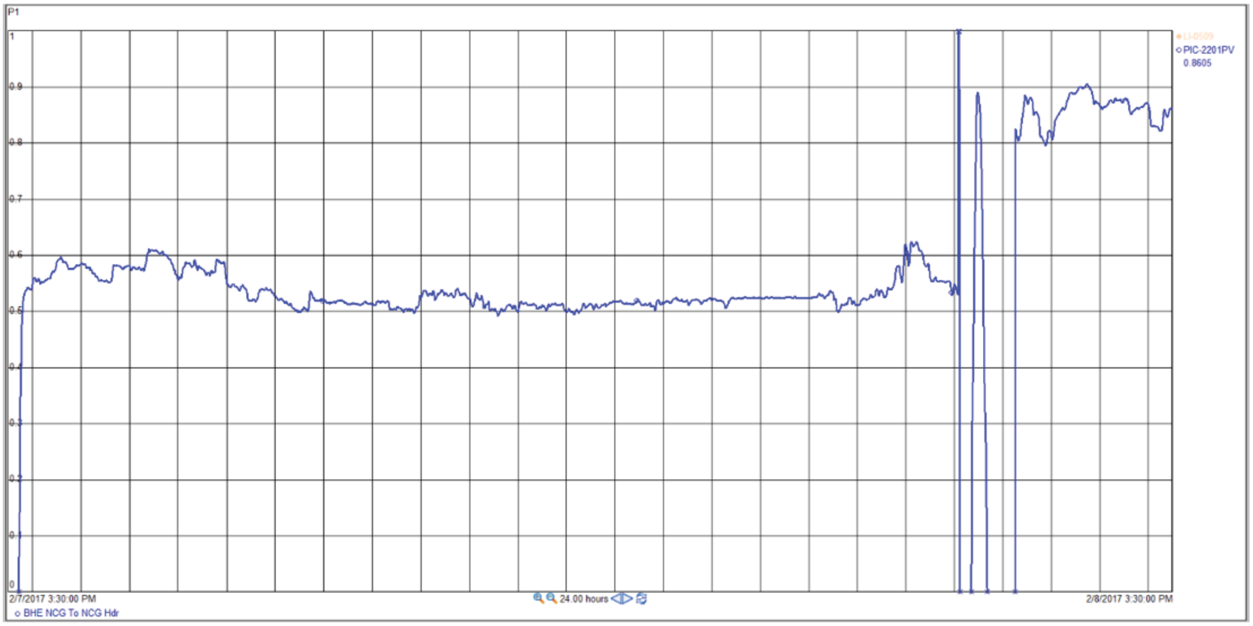

Figure 28. Process Data Trend Showing the Foul Condensate Tank Pressure With the Vacuum Ejector System Off. These data show that when the ejector system was at atmospheric pressure, the foul condensate tank pressure indicated a positive pressure of 0.5 to 0.6 inches of water. After the explosion (right portion of the trend graph), the foul condensate tank pressure indicated a positive pressure of 0.8 to 0.9 inches of water. The slight positive pressure shown is likely due to the calibration of the pressure instrument and the damage from the explosion. With the tank cooling and the ejector system open to the atmosphere, it is unlikely that the pressure was actually above that of the atmospheric conditions.

34. In addition, the normal temperature of the foul condensate tank is approximately 185 °F. The liquid temperature inside the foul condensate tank just before the incident can be roughly approximated between 140 to 150 °F.[a]

35. As the temperature within the foul condensate tank cooled, some internal vapor likely condensed to liquid, which lowered the pressure inside the tank.[b] Air pulled into the foul condensate tank during cooling likely provided additional oxygen to support an explosive atmosphere of NCG and turpentine vapor inside the foul condensate tank.

[a] The foul condensate tank was not equipped with temperature indication. The upper temperature estimate of 150 °F is based on simplified heat transfer calculations and the lower temperature estimate of 140 °F is based on the statement of a worker who observed that on the morning of the incident the tank temperature was too hot to maintain contact with a gloved hand for more than 10 to 15 seconds. See Cal/OSHA Safety Information [75] and OSHA Interpretation Letter [76].

[b] Although the initial concentration of turpentine in the vapor space of the foul condensate tank is unknown, if the vapor were also saturated with turpentine, some of the turpentine would also condense as the temperature gradually decreased from 185 to 140 °F.

4.4.2 Process Chemistry

36. The process chemistry of making pulp does contain small quantities of oxygen [5, p. 3]. It is unlikely, however, that this small quantity of oxygen was enough to support an explosion.

37. Furthermore, some of the oxygen from the process chemistry was removed from the CNCG system by reducing agents such as sodium sulfide [5, p. 3].

4.4.3 Water Seals

38. Because water seals typically operate under a slight vacuum, the integrity of such water seals is critical to prevent the ingress of air into the CNCG system. TAPPI especially calls out the need to monitor water seals on tank overflow piping. For example, if a water seal is not maintained on tank overflow piping, the CNCG system can pull air into the tank through the overflow piping. In addition, without a seal, NCG can escape the CNCG system and pose toxicity hazards to personnel nearby. As will be explained subsequently, however, the foul condensate tank likely had an appropriate water seal at the time of the incident.

39. The foul condensate tank was equipped with overflow piping to protect it from a high liquid level. The design of the overflow piping provided for a liquid seal leg to prevent the ingress of air into the tank while still allowing for proper mechanical integrity protections in the case of an overflow event (**Figure 29**).

Figure 29. Pre-Incident Photograph Showing Overflow Seal Leg. This pre-incident photograph shows the overflow seal leg on the foul condensate tank (red arrow). Photograph: PCA.

40. The PCA DeRidder mill did not equip this water seal with a makeup water line and did not provide instrumentation for operators to monitor its liquid level. Despite the lack of a way to monitor the liquid level of the water seal, pressure data from the tank leading up to the incident nonetheless indicated that the overflow piping on the foul condensate tank had a water seal. This seal was likely self-filling, and the level was maintained by hot vapor within the tank condensing in the cooler uninsulated overflow piping to create a liquid seal.

41. The lack of a small continuous water flow to the foul condensate tank's overflow water seal - and the lack of a sight glass or instrumentation to monitor the seal liquid level - presented a potential process hazard for the PCA DeRidder mill. For instance, during a start-up of the unit after seal piping maintenance, outside of flooding the tank, no way was available to seal the overflow piping until hot vapor condensed and filled the seal loop.

42. Had the foul condensate tank not been intended to operate above the UEL, the lack of a water seal may have been minor, but by operating above the UEL, any means that allows the ingress of air becomes a critical safety system.

4.5 Sources of Ignition

4.5.1 Hot Work

43. Because the atmosphere inside the tank likely contained an explosive mixture of NCG and air, only an ignition source of adequate energy (**Figure 30**) was needed for an explosion to occur. Although the likely ignition source relates to the piping repair work, it is important to point out that ignition sources are both numerous and difficult to control. As process safety expert Trevor Kletz stated:

> [A] source of ignition is often said to be the cause of a fire. But when flammable vapour and air are mixed in the flammable range, experience shows that a source of ignition is liable to turn up, even though we have done everything possible to remove known sources of ignition. [14].

Hot Work Heat Source	Temperature
Electric arc	10,350°F to 21,150°F 5,732°C to 11,732°C
Arc welding slag	6,350°F at welding location 4,900°F at 1.5 ft. away 4,000°F at 16 ft. away 3,510°C at welding location 2,704°C at 0.5 m away 2,204°C at 4.9 m away
Welding spatter	3,350°F near welding rod 2,850°F at 9 ft. below welding rod 1,843°C near welding rod 1,566°C at 2.7 m below welding rod
Oxyacetylene cutting slag	3,800°F 2,093°C
Sparks from grinding wheel on steel	3,362°F in air 1,850°C in air

Figure 30. Temperatures and Hot Work Heat Sources. A range of temperatures are related to various types of hot work heat sources. Source: FM Global [15, p. 2].

44. On the basis of interviews and a review of physical evidence, contractors were likely in the final phases of welding guides onto the pipe rack above the foul condensate tank. If the contractors were performing this work at the time of the incident, the sparks produced from the welding or grinding necessary to complete these repairs could have landed on or near the foul condensate tank.

45. The foul condensate tank may have intermittently vented NCG via the tank's pressure vacuum breaker or the valve on the three-inch water piping.[a] If the sparks from welding or grinding had encountered flammable vapors coming from the tank's pressure vacuum breaker or the three-inch water piping, the sparks might have flashed back into the tank, ignited flammable vapors within the tank, and caused the explosion.[b]

[a] Although the valve on the three-inch water piping was closed at the time of the incident, the valve was never recovered. At the time the hot work permit was issued the area around the valve did not indicate any leakage. Because of the failure to recover the valve, however, verification of a complete seal to the atmosphere was impossible.

[b] At the time of the explosion, an air gap still existed between the foul condensate tank and the water piping. Furthermore, the valve on the foul condensate tank side of the piping was closed. The valve was not recovered during the investigation.

4.5.2 INADVERTENT ARC FROM WELDING EQUIPMENT

46. Some witness statements suggest that the work surrounding welding guides onto the pipe rack was completed and that the workers were lowering various welding tools to ground level at the time of the incident. As the tools were being lowered, it is possible that a welding torch might have fallen and inadvertently created an electric arc on the tank or its vent piping. Such an arc would need to remain active long enough to heat a point of the metal surface above the autoignition temperature of the vapor inside the tank. Post-incident evaluation of the welding machine showed that it likely was running at the time of the explosion. PCA believes that this scenario is the most credible source of ignition.[a]

4.5.3 STATIC CHARGE

47. Although a static charge accumulation scenario was not identified as a likely cause after examining all available physical evidence, the potential still theoretically exists that a static discharge was the cause of the February 8, 2017 explosion.

48. Static electricity from improperly grounded lines and vessels could contribute a spark capable of initiating the incident. The last inspections of the foul condensate tank that evaluated grounding were performed in 2006 (Figure 31). Although this inspection record shows satisfactory grounding in 2006, the ground cable was severed post-incident, so the condition of the tank's grounding cable before the incident could not be determined.

17. MISCELLANEOUS:

1 VESSEL GROUNDING: ☐ N/A ☐ EXCELLENT ☒ GOOD ☐ FAIR ☐ POOR
☐ NEED REPAIR / REPLACEMENT

2 FOUNDATION CONDITION: ☐ N/A ☒ ACCEPTABLE ☐ POOR ☐ SPALLING ☐ WASHOUT
☐ NEED REPAIR / REPLACEMENT

OTHER:

Figure 31. Excerpt from April 2006 Tank Inspection. This excerpt from the April 2006 tank inspection of the foul condensate tank indicates proper grounding. Source: PCA.

49. Another ignition source mechanism is the turpentine-water interface[b] within the foul condensate tank. Because water and turpentine are immiscible and both were likely present in the tank, the shear forces between the two liquids at their interface could have created enough friction to produce

[a] The contract welding company does not concur with PCA's conclusion that hot work or an inadvertent arc were the likely causes of the ignition.

[b] The turpentine-water interface is the point where turpentine and water meet. Given the physical properties of each, the two do not mix. Because turpentine is less dense than water, and insoluble, it floats on top of water.

a static spark [16, p. 5]. However, because of the annual outage the fluid motion within the tank was likely minimal, suggesting that the possibility for generating a spark in this scenario is low.

4.6 Other Potential Theories

4.6.1 Steam Overpressure

50. An alternative theory to explain the incident involved the foul condensate tank experiencing an increase in pressure from steam [10]. This theory involved "an automatic valve left unlocked on top of the [foul condensate] tank [10]." Given the available process data and physical evidence, however, this theory does not appear to be credible.

51. Process data leading up to the incident fail to show any indication of steam over-pressuring the foul condensate tank. Because the liquid inlet and outlet to the tank were closed, the only path for steam to enter the system would have been through the CNCG header system. The process data show no indications of pressure or temperature increases in the CNCG header or the tank itself, but both would be expected with such an event.

52. If pressure from steam had entered the foul condensate tank, the CNCG header would have had physical indications of such an event. For instance, the steam used to pull the vacuum on the CNCG header was at a pressure that would have been sufficient to break multiple rupture disks on the CNCG header and damage the line. Yet, examination of the header and the rupture disks shows no breakage or other damage. Furthermore, valves between the steam and the tank were closed, preventing steam from entering the tank.

4.6.2 Chemical Reactivity

53. Issues surrounding reactive chemistry within the foul condensate tank were also examined as a potential cause of the explosion. A chemical reactivity hazard is defined as "a situation where an uncontrolled chemical reaction could result directly or indirectly in serious harm to people, property, or the environment [17, p. 1]."

54. The CSB used publicly available software [18] to evaluate the reactivity of the chemicals within the tank to determine whether a chemical reaction within the foul condensate tank could have caused the February 8 explosion. The software indicated that the primary hazard within the foul condensate tank was the potential for a flammable atmosphere. Although possible, no other significant reactive hazards likely existed within the tank.

4.7 Hierarchy of Controls

55. The DeRidder mill lacked safeguards that could have helped prevent this incident. Companies should evaluate the most effective safeguard or safeguards for their facilities based on the site-

specific risks identified. Examples of safeguards to prevent or control an explosion in the foul condensate tank[a] could have included the following alternatives:

- Procedures to prohibit hot work near the foul condensate tank while it contained flammable vapor.
- Low-pressure alarms to alert workers of the potential for air ingress.
- Oxygen analyzers to alert workers of dangerous air ingress.
- Interlocks to automatically reduce oxygen concentration by adding gas to prevent the formation of an explosive atmosphere.
- Tank design with a weak roof-to-shell attachment (frangible roof).[b]
- A vessel design for a full vacuum to eliminate significant sources of potential air ingress, such as the pressure vacuum breaker.
- During an outage, draining, purging, and inerting the foul condensate tank.[c]

56. Chemical facilities, such as pulp and paper mills, can prevent air from entering a vessel and moving its contents into an explosive range. By applying controls, such as those mentioned previously, the DeRidder mill could have effectively reduced the risk of an NCG explosion. Note that each safeguard must be evaluated to determine its appropriateness for individual processes and facilities. Some safeguards are incompatible with others.

4.7.1 The Center for Chemical Process Safety (CCPS)

57. In 1985, the American Institute of Chemical Engineers (AIChE) established the Center for Chemical Process Safety (CCPS). The stated purpose of CCPS is "to establish a not-for-profit scientific and educational organization to provide expert leadership and focus to engineering practices and research that can prevent or mitigate catastrophic events involving hazardous materials [19]."

58. The CCPS book *Inherently Safer Chemical Processes – A Life Cycle Approach* defines inherently safer design as the process of identifying and implementing inherent safety in a specific context that is permanent and inseparable [20].

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[a] Notably, several of these safeguards cannot be implemented concurrently on the same equipment; for example, a weak roof-to-shell attachment and increased vacuum rating. However, each safeguard should be assessed to determine whether it is feasible, based on the particular circumstances and needs of the mill in question. For example, see FM Global Property Loss Prevention Data Sheets, *Ignitable Liquid Operations*, 7-32 [156, p. 24].

[b] The foul condensate tank involved in the February 8, 2017 incident lacked a weak roof-to-shell attachment design. API Standard 650, *Welded Steel Tanks for Oil Storage* provides frangible roof design criteria [155]. As a result, without a weak roof-to-shell attachment designed to open under pressure, the explosion separated the tank from its bottom and launched the foul condensate tank nearly 400 feet, with catastrophic results.

[c] "TRS is known to adsorb onto, and then desorb from metal walls." Therefore, "welding should be done immediately after purging and testing for combustibles [87]."

59. In the book *Guidelines for Engineering Design for Process Safety*, CCPS states, "[I]nherently safer design solutions eliminate or mitigate the hazard by using materials and process conditions that are less hazardous [21]."

60. Inherently safer technologies are relative and require comparing one technology with another in regard to a specific hazard or risk [20]. A technology might be inherently safer with respect to one risk but not another risk. For this reason, performing a comprehensive, documented hazard analysis is important to determine the individual and overall risks in a process to minimize the total risks of the hazards presented.

61. An inherently safer systems review details a list of choices that offer various degrees of inherently safer implementation. This review should include the risks of personal injury, environmental harm, and lost production as well as an evaluation of economic feasibility.

62. The CSB often refers to the hierarchy of controls as the appropriate approach for hazard control and applies it in making safety recommendations.[a] As shown in **Figure 32**, the hierarchy of controls is a method to provide effective risk reduction by applying, in order of robustness, inherently safer design, passive safeguards, active safeguards, and procedural safeguards [20]. This strategy promotes a tiered or hierarchical approach to risk management.

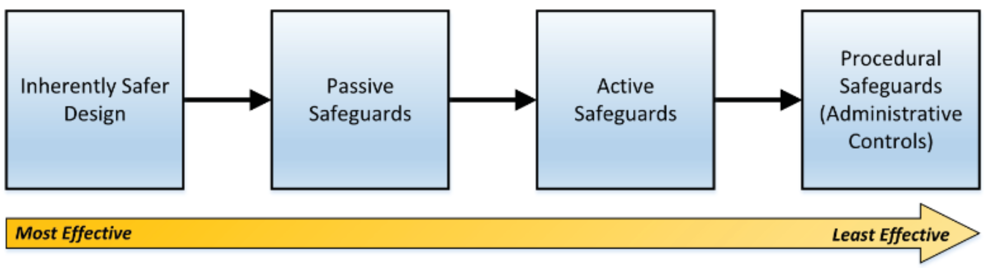

Figure 32. Hierarchy of Controls. When a control is higher in the hierarchy (i.e., further to the left), more effective risk reduction is achieved.

63. As shown in **Figure 33**, the hierarchy of controls applies to the effectiveness ranking of inherent safety principles used to control hazards. Again, when a control is further up (to the left) on the hierarchy, more effective risk reduction is achieved. All concepts in the hierarchy of controls should be included in the process of risk assessment and reduction.

[a] The CSB describes the concept of the "hierarchy of controls" in several previous investigation reports, such as recent CSB final investigation reports for Airgas [150], Williams - Geismar, Louisiana [74], Tesoro - Martinez, California [73], Tesoro - Anacortes, Washington [71], Chevron - Richmond, California [70], and Key Lessons for Preventing Incidents from Flammable Chemicals in Educational Demonstrations [72].

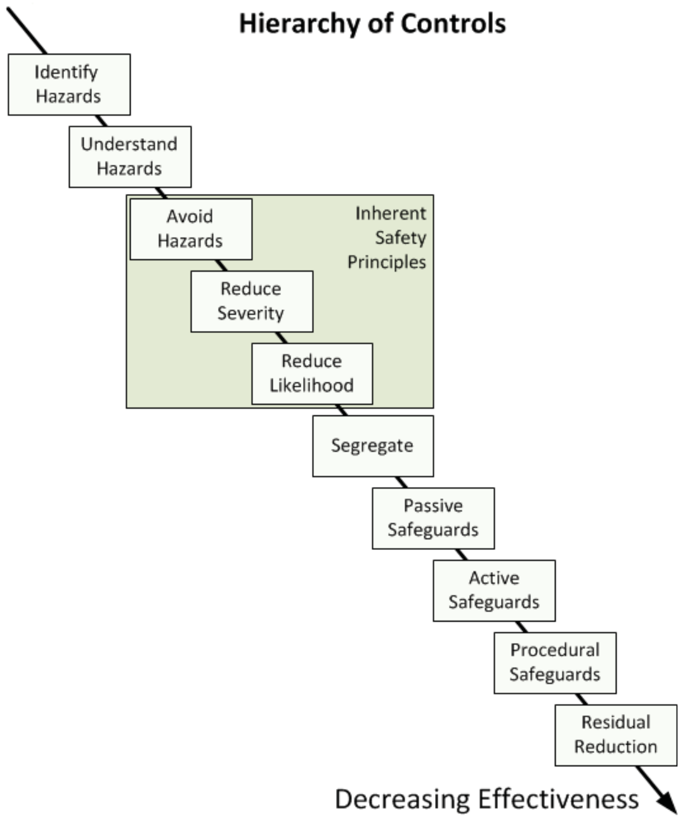

Figure 33. Inherent Safety Principles. The boxes in this graphic reflect the hierarchy of safer controls, from eliminating hazards (near the top left) through personal protective equipment (at the bottom right). Source: Kletz, Trevor; Amyotte, Paul [22].

64. In its *Guidelines for Investigating Chemical Process Safety Incidents*, CCPS discusses the importance of evaluating inherently safer design when developing recommendations. CCPS states:

> Recommendations that lead to inherently safer designs are preferred to those limited to adding-on extra mitigation or prevention features. Inherently safer designs limit reliance on human performance, equipment reliability, or properly functioning preventive maintenance programs for successful prevention of an incident. Inherently safer design changes yield greater economic benefits if they are implemented during the early design phases. Nevertheless, the incident investigation team should consider them when developing recommendations [23, p. 255].

4.7.2 Application of the Hierarchy of Controls at the PCA DeRidder Mill

65. Opportunities might be available to prevent future NCG explosions by applying inherently safer design. For example, PCA's DeRidder mill must decide whether a new foul condensate tank is even needed going forward. Before the incident, PCA used the foul condensate tank to regulate flow fluctuations between the turpentine-stripping column and the foul condensate-stripping column. Post-incident, the DeRidder mill is operating without a foul condensate tank; the mill

made post-incident piping and control modifications to operate without the tank. If operating without the tank proves successful, PCA may permanently eliminate the foul condensate tank and its associated risk of explosion.

66. Alternatively, if PCA decides to replace the foul condensate tank, the company could install a smaller tank designed to handle full vacuum. By continually cycling the tank between 16 and 20 feet of liquid level, the mill was typically operating with only four feet of the available 30 feet of tank height during normal operation, suggesting that the tank was larger than needed. As explained subsequently, a smaller tank designed to withstand full vacuum could significantly reduce air ingress and provide a more cost-effective and inherently safer replacement design.

4.7.2.1 Replace the Foul Condensate Tank with A Vessel Designed for Full-Vacuum

67. A new vessel designed and constructed to withstand full vacuum could eliminate potential sources of air ingress. With a full vacuum design, no pressure vacuum breaker need be installed, and the largest source of air ingress that contributed to the February 8, 2017, explosion could be eliminated through the design. Such a design approach should also consider eliminating or redesigning the tank overflow piping. A recent Bechtel publication, *Design Options for Overfill Prevention for Aboveground Storage Tanks* [24], reviews available designs. Furthermore, API Recommended Practice 2350, *Overfill Protection for Storage Tanks in Petroleum Facilities* [25], also offers overfill protection guidance. By applying these design strategies, the DeRidder mill could eliminate two significant sources of air ingress.

4.7.2.2 Install Explosion Prevention Systems

68. To prevent a foul condensate tank explosion in the future, the DeRidder mill can apply active safeguards, such as oxygen analyzers with a safety interlock, to automatically purge or sweep the tank vapor to prevent the development of an explosive atmosphere inside the tank. Industry safety standards are available and should be applied to both the design and life cycle of the safety interlocks.

4.7.2.2.1 NFPA 69 – Standard on Explosion Prevention Systems

69. NFPA published NFPA 69, *Standard on Explosion Prevention Systems*, to "provide effective deflagration [explosion] prevention and control for enclosures [such as storage tanks] where there is the potential for a deflagration [26, p. 8]."

70. To determine the appropriate level of explosion protection needed for a particular application, NFPA 69 requires a documented hazard analysis and risk assessment of potential explosion scenarios [26, p. 9].[a] The standard provides both performance-based and prescriptive-based design options to comply with NFPA 69 [26, p. 9].

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[a] To address the process hazard analysis requirement, NFPA 69 suggests that one approach would be following the methods provided in the Center for Chemical Process Safety book *Guidelines for Hazard Evaluation Procedures* [26, pp. 38-39].

71. NFPA 69 also includes a life safety objective to protect workers [26, p. 9]. The standard requires explosion prevention and control systems to prevent hazards such as the rupture of a storage tank and consequent injury to personnel [26, p. 9].

72. The performance-based design options in NFPA 69 are high-level explosion prevention safety goals that require competent personnel to ensure the accomplishment of outcomes such as the following:

- Vessels and enclosures such as tanks cannot rupture from an explosion.
- Neither employees nor contractor personnel are exposed to flame, hot gases, hot particles, toxic materials, or projectiles.
- Process equipment is regularly inspected and maintained so that it performs as designed.
- Minimum inspection and maintenance documentation is in place [26, p. 9].

73. The prescriptive-based design options in NFPA 69 provide guidance for designing explosion prevention systems. NFPA 69 specifies methods that focus on preventing combustion within a system as well as techniques to prevent or limit damage from an explosion.[a]

74. NFPA 69 includes the following two methods to prevent combustion explosions [26, p. 9]:[b]

- Limiting the oxygen concentration (fuel rich) – an approach avoiding explosive conditions by controlling the oxygen concentration such that the combustible concentration stays above the upper explosive (flammable) limit.[c]
- Limiting the combustible concentration (fuel lean) – an approach avoiding explosive conditions by controlling the combustible concentration below the lower explosive (flammable) limit.

75. To select the appropriate explosion prevention strategy, NFPA 69 requires users to consider the following factors:

- Effectiveness of each method.
- System reliability.

[a] To improve understanding for a more general audience, this language has been paraphrased. NFPA calls these two methods (1) oxidant concentration reduction and (2) combustible concentration reduction [26, p. 9].

[b] NFPA also provides methods to prevent or limit damage from explosions. These methods include (1) explosion detection and ignition control, (2) explosion suppression, (3) isolation methods, and (4) pressure containment.

[c] The upper explosive limit (UEL) and upper flammability limit (UFL) represent the highest concentration of a combustible material in a mixture that will propagate a flame. The lower explosive limit (LEL) and lower flammability limit (LFL) indicate the lowest concentration of a combustible material in a mixture that will propagate a flame. A combustible material is therefore explosive (flammable) in concentrations between the upper and lower limits. Air is the typical oxidizer used to measure explosive and flammability limits. The concept of explosive and flammability limits applies to other oxidizers, but the specific values from air measurements do not apply, so testing is needed to establish the limits under the specific conditions of interest.

- Inherent personnel hazards [26, p. 10].

76. Pulp and paper mill NCG systems, such as the design PCA used, seek to avoid explosions by using the fuel-rich approach, limiting the oxygen concentration to maintain the gas concentration above its UEL. When applying this approach, NFPA 69 requires maintaining the system oxygen concentration at a low enough level to prevent an explosion [26, p. 10].

77. In addition, NFPA requires a thorough hazard analysis to determine the type and degree of explosion hazards in the process [26, p. 11 and 38]. NFPA 69 also requires documentation similar to the process safety information requirements of OSHA's Process Safety Management (PSM) standard, demonstrating how the oxygen concentration is monitored and controlled. The standard also requires competent people to develop procedures for startup, normal, shutdown, temporary operations, and emergency shutdown that detail process conditions and ranges for the following:

- Flow.
- Temperature.
- Pressure.
- Oxygen concentration [26, p. 11].[a]

78. NFPA 69 describes an engineering approach to establish the limiting oxygen concentration (LOC), which is the concentration of oxygen below which an explosion cannot occur [26, p. 11]. In addition, to control oxygen concentration below the LOC, NFPA 69 provides guidance on purge gases [26, p. 11].[b, c] For mill sources of NCG that are ultimately combusted in a furnace, purge gases such as methane or natural gas appear to be advantageous [26, p. 39]. NFPA 69 describes the intent of using methane or natural gas and notes that when directing vapors to a combustion device such as a furnace, operation above the upper explosive (flammable) limit (UEL) can greatly reduce the quantity of purge gas needed [26, p. 39]. NFPA also provides requirements for instrumentation including, alarms, control point safety margin, and oxygen analyzer(s) [26, p. 12].

4.7.2.2.2 Safety Instrumented Systems and ISA-84

79. Safety interlocks such as oxygen analyzers, which trigger an automatic purge or sweep of the tank vapor to prevent an explosive atmosphere from developing inside the tank, are called safety instrumented systems (SIS).

80. The International Society of Automation (ISA) develops consensus standards for, among other items, safety instrumentation. ISA84, Electrical/Electronic/Programmable Electronic Systems (E/E/PES) for Use in Process Safety Applications is the ISA committee that developed a three-part

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[a] See Free access to the 2014 edition of NFPA 69 section 3.3.25, page 69-8 and A.3.3.25, page 69-37 for more information on the LOC [26].

[b] A purge gas is an inert or a combustible gas added to a system to render the atmosphere nonignitable [26].

[c] Groth Corporation blanket gas regulator literature provides an example of commercially available equipment to prevent an explosive atmosphere from developing inside a storage tank that contains flammable chemicals [80].

series of standards to help companies safely control hazards [27]. In describing its safety instrumentation standards, ISA84 states:

> This three-part series gives requirements for the specification, design, installation, operation, and maintenance of a safety instrumented system so that it can be confidently entrusted to place and/or maintain a process in a safe state. Through its working groups, ISA84 has also developed several key technical reports to provide guidance on the implementation and use of the three-part series of standards [28].

81. ANSI/ISA-84.00.01-2004 Parts 1-3 (IEC 61511 Mod), *Functional Safety: Safety Instrumented Systems for the Process Industry Sector* (known as "ISA-84," not to be confused with the ISA committee ISA84) is the industry standard for SIS [29].[a] ISA-84 provides a life-cycle approach to ensure that interlocks achieve the desired risk reduction of the hazard [29].

82. ISA-84 "applies to a wide variety of industries within the process sector including chemicals, oil refining, oil and gas production, pulp and paper, non-nuclear power generation," [30, pp. 16-17] and applies "when functional safety is achieved using one or more safety instrumented functions for the protection of personnel, protection of the general public or protection of the environment [30, p. 17]."

83. OSHA identified ISA-84 as recognized and generally accepted good engineering practice (RAGAGEP) in 2000 [31] and reaffirmed that position in 2005 [32].

84. OSHA also addressed the importance and broad application of the ISA-84 safety instrumentation standard – including chemical manufacturing processes that the PSM standard does not regulate, such as NCG systems. As OSHA stated:

> It is also important to note that there are a large percentage of processes which are not covered by PSM which may include SIS [safety instrumented systems] covered by S84.01. The employer may be in violation of the General Duty Clause, Section 5(a)(1) of the OSH Act, if SIS are utilized which do not conform with S84.01 and hazards exist related to the SIS which could seriously harm employees [31].

85. Although OSHA stressed the importance of applying ISA-84 to processes not covered by the PSM standard, PCA did not apply the ISA-84 safety standard to the foul condensate tank or the CNCG header system – actions that could have helped mitigate or helped prevent the type of explosion that

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[a] The precise names of the three standards are: (1) ISA-84.00.01-2004 Part 1 (IEC 61511-1 Mod) Functional Safety: Safety Instrumented Systems for the Process Industry Sector - Part 1: Framework, Definitions, System, Hardware and Software Requirements, (2) ISA-84.00.01-2004 Part 2 (IEC 61511-2 Mod) Functional Safety: Safety Instrumented Systems for the Process Industry Sector - Part 2: Guidelines for the Application of ANSI/ISA-84.00.01-2004 Part 1 (IEC 61511-1 Mod) – Informative, and (3) ISA-84.00.01-2004 Part 3 (IEC 61511-3 Mod) Functional Safety: Safety Instrumented Systems for the Process Industry Sector - Part 3: Guidance for the Determination of the Required Safety Integrity Levels – Informative. See ISA-84 Standards [69, pp. 1-2].

occurred on February 8 because neither unit was equipped with an interlock to prevent such an event.

86. By applying NFPA 69 and ISA-84, PCA could have significantly reduced the risk of an explosion within the CNCG system, including the foul condensate tank.

4.7.2.3 Design the Foul Condensate Tank with a Weak Roof-to-Shell Attachment (Frangible Roof)

87. The National Fire Protection Association (NFPA) published NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, to "provide the user with criteria for design, installation, and maintenance of deflagration[a] [explosion][b, c] vents and associated components [33]." The standard applies "where the need for deflagration venting has been established [33]."

88. **Figure 34** depicts the concept of using deflagration venting or explosion venting to prevent an uncontrolled explosion. The basic idea is that a vessel design can include a section that will preferentially fail first, in order to release the force of an explosion, in lieu of an uncontrolled explosion. Alternatively, the vessel can be equipped with a safety device such as a panel that will burst open to relieve pressure.

[a] A deflagration is a reaction in which the speed of the reaction front propagates through the unreacted mass at a speed less than the speed of sound in the unreacted medium. If the reaction front speed exceeds the speed of sound, it is a detonation [65, p. 20].

[b] Although many people intuitively understand what an explosion is, a detailed technical definition is not so simple. An explosion has three essential characteristics: (1) sudden energy release, (2) rapidly moving blast or shock wave, and (3) blast magnitude large enough to be potentially hazardous [65, pp. 1-2].

[c] "Flammable and explosive, when applied to gases or vapours mean the same — a fire turns into an explosion when the gases that are formed by burning cannot get away and the pressure rises [79, p. 5]."

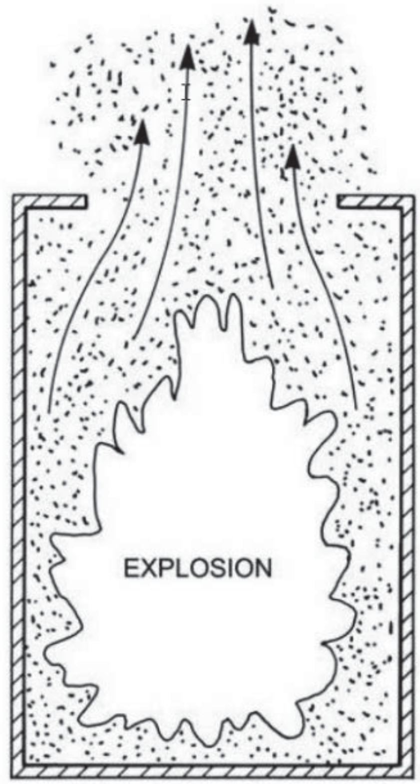

Figure 34. Explosion Venting. This illustration demonstrates deflagration venting. Source: Eckhoff, Rolf K [34, p. 141]

89. NFPA 68 requires users to perform a hazard analysis and risk evaluation to identify the various deflagration hazard scenarios presented [33]. To comply with NFPA 68, the standard provides both performance-based and prescriptive-based design options [33].

90. The performance-based design options in NFPA 68 are high-level safety goals and include management system requirements such as the following:

- Ensuring that vents are designed according to a documented hazard analysis.
- Ensuring a reduction in pressure within a vessel.
- Ensuring that personnel are not exposed to flames, hot gases, hot particles, toxic materials, or projectiles.
- Ensuring that equipment is regularly inspected and maintained so that it performs as designed.
- Providing minimum inspection and maintenance documentation [33].

91. The prescriptive-based design options in NFPA 68 provide guidance for designing explosion protection by applying deflagration venting [33].

92. Designing a new foul condensate tank with a weak roof-to-shell attachment (frangible roof) [a] represents one passive safeguard approach that the DeRidder mill could apply to provide deflagration venting.[b] Effective deflagration venting could prevent the buildup of pressure within the foul condensate tank that led not only to the tank launching approximately 375 feet away but also to the severity of the injuries. Whether a frangible roof could have saved the lives of the three contractors remains an open question, dependent on the preferential direction of the roof opening, location of the contractors at the time of the explosion, and force of the explosion.

4.7.2.4 Implement Administrative Controls

93. Administrative control options such as the following, although less effective than active controls, are also available to help reduce the risk of a future foul condensate tank explosion in the future:

- Prohibiting hot work near the foul condensate tank while it contains a flammable atmosphere.
- Applying labeling to the foul condensate tank to warn of its potentially flammable atmosphere.
- Providing workers with periodic training on the hazards associated with the foul condensate tank.
- Procedures requiring the draining, flushing, purging, and inerting of the foul condensate tank before any hot work is performed nearby.

4.8 Historical Failures to Recognize Explosive Atmospheres Inside Vessels

94. The CSB reviewed several historical incidents relevant to its investigation of the February 8, 2017 foul condensate tank explosion at the DeRidder mill (**Figure 35**). In each case, a failure to recognize that an explosive atmosphere existed inside a vessel led to an explosion, property damage, and, in most cases, injuries and fatalities.

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[a] Commonly referred to as a "frangible roof" in industry, a weak roof-to-shell attachment preferentially fails over other welded joints when subject to overpressure. Video of explosion in storage tank with a frangible roof [77].

[b] The foul condensate tank involved in the February 8, 2017 incident lacked a weak roof-to-shell attachment design.

Year	Location	Killed	Injured	Pulp & Paper	Hazard Recognized	Explosion Prevention Controls	PSM Covered
1990	Channelview, TX	17	0		No	Out of Service	No
1993	Toledo, OR	2	4	✓	No	No	No
1995	Rouseville, PA	5	1		No	No	No
2000	Catawba, SC	2	4	✓	No	No	No
2001	Delaware City, DE	1	8		No	Insufficient	No
2008	Tomahawk, WI	3	1	✓	No	No	No
2017	Pensacola, FL	0	0	✓	No	No	No

Figure 35. List of Historical Explosions. This list includes historical explosions relevant to the February 8, 2017, explosion at the DeRidder mill.[a]

95. Although most of these vessel explosions ignited as the result of hot work, in each case, the hazardous explosive atmosphere could have been prevented by conducting a proper process hazard analysis, thus avoiding the incident. By conducting a rigorous process hazard analysis, companies can identify and control explosive conditions in vessels.

96. Industry standards such as NFPA 69 provide good practice guidance for preventing explosions in vessels such as storage tanks. Companies can prevent dangerous explosive conditions from developing by implementing safeguards such as (1) safety interlocks to provide purge gas inerting[b] or blanketing[c] and (2) oxygen analyzers with alarms that can warn workers, take automatic actions, or both.

[a] The OSHA PSM standard was not applicable until May 26, 1992.

[b] Inerting refers to the use of a nonflammable, nonreactive gas that renders the combustible material in a system incapable of supporting combustion. The current version of NFPA 69 defines inerting as "[a] technique by which a combustible mixture is rendered nonignitible by adding an inert gas [26]."

[c] Blanketing (or padding) is the "technique of maintaining an atmosphere that is either inert or fuel-enriched in the vapor space of a container or vessel [26]."

4.8.1 Atmospheric Tank Explosion Incidents

4.8.1.1 Georgia Pacific Explosion – Toledo, Oregon

97. On February 5, 1993, a storage tank explosion killed two workers and injured four other workers at a Georgia Pacific paper mill in Toledo, Oregon [35]. Oregon OSHA's investigation concluded that the explosion occurred when a worker used a torch to cut a hole into the top of the tank. The company did not test for the presence of an explosive atmosphere inside the tank. Oregon OSHA [36] citations totaled $125,000 [35]. Oregon OSHA cited Georgia Pacific for, among other safety issues, failing to advise workers about flammable materials or hazardous conditions [35]. The CSB did not identify any publicly available information explaining how the explosive atmosphere developed in the tank, although regardless of causation, the facts of this incident point to the need for facility personnel to be aware of all of the hazards inside, and adjacent to, vessels where hot work is being conducted.

4.8.1.2 Bowater Explosion – Catawba, South Carolina

98. On March 14, 2000, a wastewater storage tank explosion during hot work operations killed two workers and injured four other workers at a Bowater paper mill in Catawba, South Carolina [37].[a] South Carolina OSHA's investigation found that "welding was performed on a piping system that contained, among other substances, turpentine and methanol," the same chemicals that likely were present in the tank at the DeRidder mill [37]. In addition, South Carolina OSHA identified that "[t]he piping system was not cleaned, vented or tested on March 14 [37]." South Carolina OSHA concluded that when the welding work began, turpentine vapors ignited, and flames traveled into the tank, causing the explosion [37]. The Bowater incident is similar to the PCA explosion in that the tank was partially full of steam condensate and contained flammable gas from a pulp digestion process, and the company failed to make the equipment safe for hot work by applying regulatory requirements and industry good safety practices.

4.8.1.3 ARCO Chemical Explosion – Channelview, Texas

99. On July 5, 1990,[b] a wastewater storage tank exploded, killing 17 workers at the ARCO Chemical facility in Channelview, Texas (**Figure 36**) [38], [39, p. 1]. ARCO Chemical agreed to OSHA penalties of $3,481,300 stemming from the incident [40].[c] At the time, it "was the largest monetary settlement with OSHA on record for safety violations [39]."

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[a] South Carolina OSHA cited Bowater and fined it $2,520 for allowing the welding activity to take place with flammables present [82].

[b] Because the ARCO Chemical incident occurred before the OSHA PSM rule was promulgated, the incident was not covered by PSM.

[c] The victims included 5 ARCO Chemical employees and 12 contractors [151]. "An area approximately the size of a city block was completely destroyed; no one in the area survived the explosion [151]."

Figure 36. Post-Incident Photograph of the July 1990 Explosion at the ARCO Chemical Facility in Channelview, Texas. The location of the wastewater storage tank is indicated by the red arrow. Photograph credit: [41].

100. The plant's 900,000-gallon atmospheric pressure wastewater storage tank also contained a layer of hydrocarbon liquid, including hydrocarbon peroxides, that released oxygen and flammable hydrocarbon gases into the tank's vapor space [39]. OSHA found that "[e]xcessive liquid hydrocarbons were allowed to accumulate in the tank [40]." The tank was equipped with an oxygen analyzer to monitor the tank's atmosphere and the company added nitrogen to control the oxygen concentration (**Figure 37**) [39]. A compressor directed the vent gases from the storage tank back to the process to recover hydrocarbon gases [39].

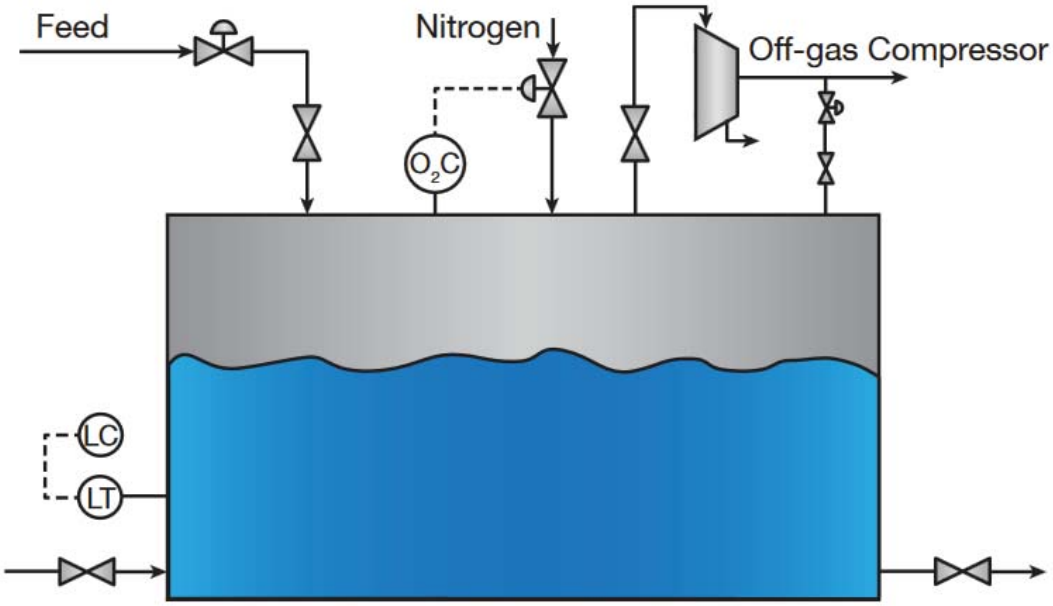

Figure 37. ARCO Chemical Wastewater Tank. "The 900,000-gallon wastewater tank had a nitrogen purge to keep the vapor space inert and an off-gas compressor to draw off hydrocarbon vapors before waste disposal." Credit: [42].

101. During a maintenance activity, the company shut off the nitrogen flow to the wastewater storage tank, which allowed the oxygen concentration to increase and created explosive conditions inside the tank [39, p. 3].[a] Moreover, the oxygen analyzer malfunctioned[b] and failed to detect the dangerous condition, and the tank exploded when restarting the compressor [39, p. 3], [38]. OSHA concluded that "[a]dequate precautions were not taken to prevent an explosive atmosphere/explosion within the vapor space of tank [40]."

102. A more recent article describing lessons learned from this incident concluded, "[T]he workers did not know that a chemical reaction that could produce an oxygen buildup was taking place in the tank. Therefore, the workers did not comprehend the importance of continuing an effective nitrogen purge [42, p. 24]." To address this issue, OSHA recommended that the company perform an analysis of human factors that, among other tasks, would "provide operations and maintenance personnel with an understanding of the hazards created by process reactions, recognition of instrumentation failure, and the actions necessary to reduce the hazards [40]."

103. Post-incident corrections by ARCO Chemical included a focus on making the nitrogen sweep and oxygen analyzer system more robust through improved design and increased redundancy [39], [38]. The company also agreed to revamp its process safety management program, which included performing process hazard analyses and implementing associated recommendations [39, p. 4].

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[a] The nitrogen sweep was shut down approximately 34 hours before the explosion [38].

[b] ARCO Chemical stated, "We now believe that the underlying reason for the explosion was an accumulation of oxygen in the vapor space of the tank, which was not recognized because of an apparent failure of the oxygen analyzer [38, p. 3]."

104. The DeRidder mill could have applied many of the lessons from the ARCO Chemical incident, such as:

- Installing oxygen monitors for the foul condensate tank.
- Using gas to inert the atmosphere and prevent an explosion within the vapor space.
- Providing better operator training to improve worker understanding of the hazards – whether the process unit was in operation or in a maintenance shutdown.

105. Reviewing the company's process safety management program, including the use of a robust hazard analysis and commitment to recommendations identified in that analysis, could have identified these same and other needed measures to improve process safety and helped to prevent a serious incident such as the February 8, 2017 foul condensate tank explosion at the DeRidder mill.

4.8.1.4 PENNZOIL EXPLOSION – ROUSEVILLE, PENNSYLVANIA

106. On October 16, 1995, two wastewater storage tanks that also contained flammable hydrocarbons exploded at a Pennzoil refinery in Rouseville, Pennsylvania, killing five workers and injuring one other worker (Figure 38) [43, p. ii]. Pennzoil agreed to pay an OSHA penalty of $1,500,000 due to the incident [44].

Figure 38. Photographs from the Pennzoil Refinery. These post-incident photographs show the October 1995 explosion at the Pennzoil refinery in Rouseville, Pennsylvania. Photograph credit: [43].

107. The Environmental Protection Agency (EPA) investigated and found that at the time of the incident a welding operation was in progress on a stairway located between two wastewater storage tanks [43, p. ii]. Similar to the tank at PCA, each of the two Pennzoil storage tanks lacked a weak roof-to-shell attachment or other explosion prevention measure, and both tanks failed along the bottom seam and were launched into the air from the force of the explosion [43, p. ii]. The EPA report noted that the explosion in the second tank likely was ignited by the explosion of the first tank.

108. The EPA also found that the tanks lacked adequate protection needed to allow hot work [43, p. 12]. Openings in the tank might have allowed ignition sources to contact flammable vapors [43, p. 12]. These openings included an open manway at the top of the tank [43, p. 20]. In addition, Pennzoil did not appear to recognize the explosion hazard and lacked an engineered system such as a purge gas inerting or blanketing system to prevent an explosive atmosphere inside the tank [43, p. 28].[a]

109. The EPA investigation concluded that among other measures, process safety management systems "should include waste handling operations to ensure that all chemical and process hazards are identified and controlled [43, p. iii]." The EPA investigation also recommended that companies consider developing management systems to identify and control all sources of flammable vapor [43, p. iii].

110. Lessons learned from the Pennzoil incident also could have aided the DeRidder mill. If PCA had applied the DeRidder mill's process safety management system to the foul condensate tank, the explosion hazards could have been identified, and safeguards may have been provided to prevent an explosion.

4.8.1.5 Motiva Explosion – Delaware City, Delaware

111. On July 17, 2001, a 415,000-gallon spent sulfuric acid[b] storage tank that also contained hydrocarbons exploded, killing one worker and injuring eight other workers at the Delaware City refinery in Delaware City, Delaware [45, p. 11]. The tank separated at its bottom, instantaneously releasing its 264,000-gallon inventory of sulfuric acid. The adjacent tank also lost its contents. The EPA estimated that 1.1 million gallons of spent sulfuric acid were released and nearly 100,000 gallons of this acid flowed into the Delaware River, killing fish and other aquatic life. Flammable and combustible material in the spent acid ignited, and burned for one-half hour. Following the incident, Motiva agreed to pay environmental and safety penalties of nearly $24 million, including $175,000 in OSHA penalties [46], [47].[c]

112. The CSB investigation of the Motiva incident found that a welding operation was in progress on a work platform at the top of stairs adjacent to the tank. The CSB concluded that the tank explosion most likely was ignited by a spark from the hot work that either entered the tank's roof and then the vapor space or contacted flammable vapor escaping from one of the holes in the tank [45, p. 13].

113. The vapor space above the liquid surface in the spent sulfuric acid storage tank contained flammable vapor. The CSB noted that spent sulfuric acid from alkylation units normally contains enough flammable hydrocarbon to generate a flammable atmosphere given the presence of oxygen

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[a] The Pennzoil wastewater tank was open to the atmosphere and lacked a pressure-vacuum, which vent typically is used to minimize air intrusion when using an inerting system [43, p. 28].

[b] "Spent H_2SO_4 [sulfuric acid] typically contains 88 to 95 percent acid and up to 5 percent water, with the balance being hydrocarbons, including some light hydrocarbons that can vaporize [45, p. 11]."

[c] In addition, the company agreed to pay $36.4 million to the family of the worker who was killed [78].

[45, p. 16].[a] The investigation also found that the atmosphere within the tank was inadequately inerted.[b] Motiva used carbon dioxide as a purge gas to inert the tank, but design deficiencies resulted in an insufficient flow of carbon dioxide gas to keep the internal atmosphere below the explosive limit [45, p. 16].

114. Similar to PCA, the acid tank at Motiva "lacked a weak roof seam or other emergency venting provisions, which likely would have prevented it from separating at the floor and catastrophically releasing its contents [45, p. 51]." Combined with inadequate attempts to inert the flammable vapor space and inadequate conformance with regulatory requirements and industry good safety practices with respect to conducting hot work adjacent to a vessel with a flammable vapor space, Motiva's incident presented a significant missed learning opportunity for PCA.

4.8.2 Pressure Vessel Explosion Incidents

4.8.2.1 Packaging Corporation of America Storage Tank Explosion – Tomahawk, Wisconsin

115. In 2008, the CSB investigated an explosion at a PCA mill in Tomahawk, Wisconsin. The incident involved hot work on a storage tank containing an explosive atmosphere. Similar to the PCA DeRidder incident, the 2008 PCA Tomahawk incident could have been prevented if PCA had performed an appropriate hazard review and applied industry safety standards such as NFPA 69.

116. The July 29, 2008, Tomahawk explosion killed three workers at the PCA fiberboard manufacturing facility. The workers were welding to install a temporary metal clamp to stabilize a damaged flange connection. The flange was located on top of an 80-foot-tall storage tank that contained recycled water and fiber waste (**Figure 39**). Although the storage tank was not an atmospheric storage tank, the similarities between the hot work being performed on or near tanks containing flammable gases at both the PCA DeRidder mill and the PCA Tomahawk mill provide further insights into preventing these type of incidents.

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[a] The CSB investigation also noted [45, p. 48] that "[t]he Encyclopedia of Chemical Processing and Design states that because of the possible formation of a hydrocarbon layer in the spent acid, "a [spent sulfuric acid] storage tank should be designed and operated as if it contained volatile hydrocarbons [84]." .

[b] Id; Inerting refers to the use of a nonflammable, nonreactive gas that renders the combustible material in a system incapable of supporting combustion. The current version of NFPA 69 defines inerting as "[a] technique by which a combustible mixture is rendered nonignitible by adding an inert gas or a noncombustible dust [26]."

Figure 39. Post-Incident Photograph at the PCA Tomahawk Mill. This photograph shows the post-incident storage tank at the PCA Tomahawk mill in 2008. Photograph: CSB.

117. The CSB investigated the explosion and determined that anaerobic bacteria inside the tank and water recycle system multiplied over time by feeding on organic waste material. The bacteria likely produced hydrogen, a highly flammable gas, which ignited during welding. PCA did not perform a hazard analysis and did not recognize fiber waste tanks as potentially hazardous before initiating hot work activities.

118. At the time of the incident, three workers were on a catwalk above the tank; one worker had begun welding the flange into place when sparks from the welding ignited flammable vapors inside the tank. The resulting explosion ripped open the tank lid (**Figure 40**), knocking two of the workers to the ground 80 feet below. All three workers died of traumatic injuries. A fourth worker, who had been observing the work from a distance, survived with minor injuries.

Figure 40. Post-Incident Photographs from the PCA Tomahawk Mill. These photographs show views of the top of the storage tank involved in the 2008 explosion at the PCA Tomahawk mill. Photograph: CSB.

119. Similar to the explosion at the DeRidder mill, PCA personnel at Tomahawk lacked knowledge of process hazards, such as the potential for an explosive atmosphere in the storage tank. At Tomahawk, facility personnel were unaware of the potential presence of flammable gas from the decomposition of the organic material in the tank.

4.8.2.2 International Paper Explosion – Pensacola, Florida

120. On January 22, 2017, an explosion occurred within a continuous digester[a] at the International Paper Pensacola mill in Pensacola, Florida, during non-routine operations. The incident involved an air and NCG mixture entering the explosive range in a vessel. Although not a storage tank explosion, the incident suggests that the pulp and paper industry would benefit from more broadly applying its process safety management systems to prevent explosions where air and flammables can combine to develop an explosive atmosphere in process equipment.

121. Although no injuries were reported, the Pensacola mill explosion released a significant portion of the digester's contents including wood, water, and other pulping chemicals, including black liquor,[b] into the community around the mill (**Figure 41** and **Figure 42**) [48]. The clean-up process took two months, and the mill returned to partial operations a month after the explosion [48], [49]. International Paper estimated the total costs of the incident at between $80 and $120 million [50].

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[a] A digester is a pressure vessel used for cooking wood chips until they turn into pulp. The continuous digester system at the International Paper Pensacola mill is a two-vessel vapor phase system, also referred to as a two-vessel steam/liquor phase digester. The digester is equipped with an inverted top separator at the top of the vessel. Wood chips and liquor enter the bottom of this top separator and are conveyed upward and discharged continuously into the top of the digester. Steam and air are added to the digester to cook and pressurize the wood chips.

[b] Black liquor is a byproduct of the paper making process.

Figure 41. Post-Incident Photograph of the International Paper Pensacola Mill in Relation to Adjacent Neighborhoods. Clean-up crews can be seen in the neighborhood at the bottom left of the photograph. Photograph: Pensacola News Journal [48].

Figure 42. Post-Incident Photograph of Debris on a Car. This photograph shows a car covered with process chemicals that were released when a digester at the Pensacola mill exploded on January 22, 2017. Photograph: WEAR Television [51].

122. On the morning of January 21, 2017, the Pensacola mill experienced a total power failure [52, p. 4]. Mill personnel restored power later that evening [52, p. 4]. The digester was isolated, but not emptied during this time [52, p. 4]. During the morning of January 22, 2017, mill personnel attempted to restart the digester system [52, p. 4]. As these efforts progressed, an explosive atmosphere developed within the digester because of a combination of the naturally produced NCG from the pulping process and the introduction of air to maintain pressure while the vessel remained out of operation [52, p. 4]. The introduction of air into the digester combined with the existing NCG and created an explosive atmosphere [52, p. 4].

123. At 7:37 pm on January 22, 2017, the digester exploded [52, p. 4]. With the explosive atmosphere that developed within the digester, the heat added by direct steam injection and the potential of sparks from a rotating top separator provided all the necessary components for an explosion, although the ignition source has not yet been positively identified [52, p. 4]. The explosion created a mechanical failure of the vessel and was immediately followed by a boiling liquid expanding vapor explosion (BLEVE) that threw the top of the digester from the vessel and expelled a significant portion of the digester's contents [52, p. 4].[a]

124. International Paper did not perform a hazard analysis on the digester that contemplated the particular scenario that led to the explosion and therefore did not recognize the potential for the vapor within the digester to enter an explosive range during the restart. International Paper also lacked safeguards, such as operating guidelines, to prevent the formation of the hazardous atmosphere in this upset condition. Moreover, the mill lacked instrumentation on the digester that could have provided a warning about the explosive atmosphere that developed.

125. Post-incident corrections by International Paper focused on preventing air from entering the digester systems when wood chips and liquor were not being fed through the system for an extended period [52, p. 5].

126. International Paper failed to conduct a process hazard analysis for the above-discussed incident, which led to a failure to identify air ingress into a closed system containing NCG. This similarity between the International Paper incident and the PCA DeRidder incident indicate that the pulp and paper industry would benefit from broadly applying its process safety management systems to its process equipment.

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[a] BLEVE, pronounced 'blev-ē, stands for "Boiling Liquid Expanding Vapor Explosion." A BLEVE is the explosive release of expanding vapor and boiling liquid when a container holding a pressure liquefied gas—where the liquefied gas is above its normal atmospheric pressure boiling point temperature at the moment of vessel failure—suddenly fails catastrophically [88].

5 Non-Condensable Gas System Regulatory Analysis

5.1 Regulatory Requirements for the Non-Condensable Gas System

1. Based on a long history of a growing focus on air quality dating back to the mid-1950s, environmental laws require mills such as the DeRidder mill to reduce the quantity of hazardous air pollutants emitted from its processes.[a] Among the various requirements, the DeRidder mill must collect and incinerate pulping process vent emissions, eliminate the use of certain bleaching chemicals, and collect and treat process condensate streams to remove hazardous air pollutants by using biological treatment or steam stripping [53].[b, c]

2. As related to the current investigation, environmental laws and regulations also require that NCG from the DeRidder mill's pulping process be collected and treated to 98 percent efficiency before discharge [54, p. 1].[d] To address these requirements, the DeRidder mill installed the CNCG system in 2000 to collect and burn NCG produced in its pulping process.

5.2 Hot Work Requirements

3. OSHA issues various safety regulations specific to hot work and the pulp and paper industry more generally.[e] If PCA had more broadly applied the safety themes provided by these regulations and strengthened its safety practices, the February 8, 2017 incident could have been prevented.[f]

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[a] See Air Pollution Control Act of 1955, Public Law No. 159, July 14, 1955 (first Federal law focused on air pollution prevention and provided Federal funds for research); Clean Air Act of 1963, Public Law No. 88-206, December 17 1963 (established a Federal program within the U.S. Public Health Service and authorizing research into techniques for monitoring and controlling air pollution); Air Quality Act of 1967, Public Law No. 90-148, November 21, 1967 (increased Federal government investigation and enforcement activities of interstate air pollution transport, initiated ambient air monitoring studies and stationary source inspections, and authorized additional research); Clean Air Act of 1970, Public Law No. 91-604, December 31, 1970; Clean Air Act Amendments of 1990.

[b] 40 C.F.R. Part 63 Subpart S (2017).

[c] Of particular interest in this investigation is the fact that foul condensate stripper vent gas were a fairly new form of foul gas generation following first generation upgrades incorporated in pulp and paper mills after implementation of the CAA in the early 1970s, and it is common for paper mills to combust LVHC streams, such as foul condensate gases, in a dedicated incinerator, a lime kiln, a power boiler (like at PCA-DeRidder), or a recovery boiler MACT I and MACT II Air Compliance: Concepts, Costs, Impacts, 2000 [54, p. 3].

[d] See also Air Pollution Control Act of 1955, Public Law No. 159, July 14, 1955 (first Federal law focused on air pollution prevention, which provided Federal funds for research); Clean Air Act of 1963, Public Law No. 88-206, December 17 1963 (which established a Federal program within the U.S. Public Health Service and authorized research into techniques for monitoring and controlling air pollution); Air Quality Act of 1967, Public Law No. 90-148, November 21, 1967 (which increased Federal Government investigation and enforcement activities related to interstate air pollution transport, initiated ambient air monitoring studies and stationary source inspections, and authorized additional research); and Clean Air Act of 1970, Public Law No. 91-604, December 31, 1970.

[e] 29 C.F.R. § 1910.252 (2017) & 29 C.F.R. § 1910.261 (2017).

[f] OSHA's regulatory scheme also provides requirements for controlling ignition sources in hazardous locations that may have flammable atmospheres. See 29 C.F.R. § 1910.307 (2017).

4. OSHA promulgated a standard specific to hot work titled *Welding, Cutting, and Brazing.*[a] This standard calls for an inspection of the area before conducting hot work and for contractors to be notified about any hazardous conditions.[b] Furthermore, the standard specified that hot work should not be permitted in areas that are not made fire safe (e.g., unless the combustibles have been removed or the combustibles are protected from ignition sources).[c]

5. OSHA also issued a standard specifically created for pulp and paper mills titled *Pulp, Paper, and Paperboard Mills.*[d] Relevant to the PCA investigation, the standard states, "[w]elding on blow tanks, accumulator tanks, or any other vessels where turpentine vapor or other combustible vapor could gather shall be done only after the vessel has been completely purged of fumes. …"[e]

6. Although the welding on February 8 was not performed on a "vessel where turpentine vapor or other combustible vapor could gather," PCA apparently never took the opportunity to assess whether any nearby vessels, such as the foul condensate tank, contained combustible vapors and whether they should be purged before commencing hot work activities.

5.3 Risk Management Program Requirements

7. The Risk Management Program, administered by EPA, establishes requirements for owners or operators of stationary sources to prevent the accidental release of 77 toxic and 63 flammable substances. A Risk Management Program includes a hazard assessment, a prevention program, and an emergency response program, and reporting of summary-level information in a "Risk Management Plan" (RMP).

8. The PCA DeRidder facility has one process, wastewater treatment using chlorine, that is covered by the RMP regulations at 40 C.F.R. Part 68. The DeRidder mill has submitted a Risk Management Plan to EPA. The last update to this Risk Management Plan, provided in February 2015, listed the plant facility name as Boise Packaging and Newsprint. Although two of the NCG components are hydrogen sulfide and methyl mercaptan, which are both RMP regulated toxic substances, they would be subject to RMP regulations only if they were present in a process above 10,000 pounds, the listed threshold quantity for both chemicals. The DeRidder mill does not, however, exceed the requisite threshold quantity of these chemicals to make it subject to the RMP requirements.

5.4 OSHA Process Safety Management Standard Did Not Cover the Non-Condensable Gas System

9. The OSHA Process Safety Management (PSM) standard provides a systematic approach to process safety and the prevention of catastrophic incidents. The PSM standard has broad application to

[a] 29 C.F.R. § 1910.252 (2017).

[b] 29 C.F.R. § 1910.252(a)(2)(iv) & (a)(2)(xiii)(D) (2017).

[c] 29 C.F.R. § 1910.252(a)(2)(xv) (2017).

[d] 29 C.F.R. § 1910.261 (2017).

[e] 29 C.F.R. § 1910.261(g)(22) (2017).

various manufacturing industries, particularly chemicals, fabricated metals, natural gas liquids, farm products, utilities and sanitary services, and pyrotechnics and explosives.

10. The PSM standard requires adherence to various elements of good safety management for processes containing listed toxic, reactive, flammable, or explosive chemicals if they are present in quantities equal or greater to the specific threshold. The PSM standard carves out an exemption, however, for atmospheric storage tanks[a] such as the foul condensate tank.[b]

11. Consequently, even if the foul condensate tank held more than 10,000 pounds of flammable turpentine,[c] the PSM standard would not apply.

12. The PSM standard does consider "any group of vessels which are interconnected and separate vessels which are located such that a highly hazardous chemical could be involved in a potential release"[d] to be part of a PSM covered process, however, the foul condensate tank would still not be covered by the PSM standard. Although the foul condensate tank is "interconnected" to the PSM covered turpentine system (**Figure 43**), which includes a turpentine tank, a 1995 administrative opinion ("the *Meer* decision") held that atmospheric storage tanks containing flammable liquids are exempt from PSM coverage regardless of whether the tanks are "interconnected" to a PSM covered process [55]. Because of the *Meer* decision, OSHA has refrained from applying the PSM standard to atmospheric storage tanks when pursuing enforcement actions [56].

[a] The PSM standard defines "atmospheric tank" as "a storage tank which has been designed to operate at pressures from atmospheric through 0.5 psig (pounds-per-square-inch-gauge, 3.45 Kpa)." 29 C.F.R. § 1910.119(b) (2017).

[b] In pertinent part, the PSM standard exempts "[f]lammable liquids with a flashpoint below 100 ºF (37.8 ºC) stored in atmospheric tanks or transferred which are kept below their normal boiling point without benefit of chilling or refrigeration." 29 C.F.R. § 1910.119(a)(1)(ii)(B) (2017).

[c] Although the quantity of turpentine in the tank was unknown, five inches of turpentine in the tank would exceed the 10,000-pound threshold for PSM coverage.

[d] 29 C.F.R. § 1910.119(b) (2017) (see definition of "Process").

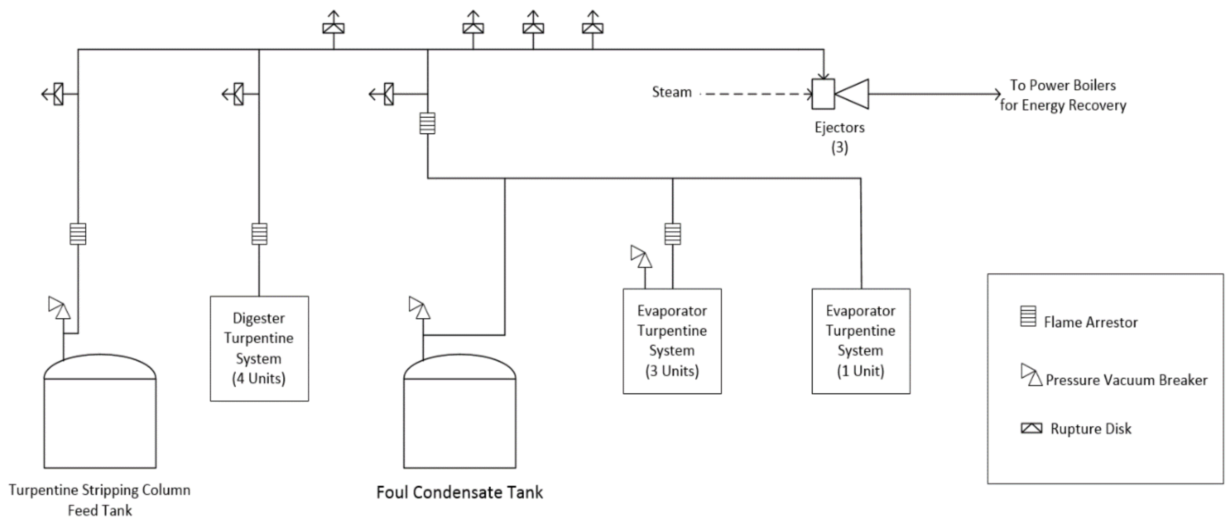

Figure 43. Simplified Flow Diagram of the CNCG System Showing the Interconnection Between the Foul Condensate Tank and the Turpentine System. The turpentine system is composed of the evaporator turpentine system, and the digester turpentine system.

13. Since the *Meer* decision, OSHA has not effectively clarified or challenged the application of the PSM standard to atmospheric storage tanks.[a]

14. According to PCA, because of the lack of PSM coverage, the pulp and paper mill industry consistently draws PSM boundaries to exclude the majority of their CNCG systems, including the foul condensate tank.[b]

5.5 The Foul Condensate Tank Should Be Covered Under the OSHA PSM Standard

15. As discussed in Section 4.8.1.5, the CSB approved its final report on the Motiva Enterprises sulfuric acid tank explosion in August 2002. The CSB investigation of the Motiva incident found that a welding operation was in progress on a work platform at the top of stairs adjacent to the tank. Similar to the agency's findings in the DeRidder incident, the CSB concluded that the explosion at Motiva most likely ignited from hot work during welding repairs adjacent to the tank [45, p. 13]. Due to the *Meer* decision, the PSM standard did not apply to the spent sulfuric acid storage tank [45, p. 14]. The *Meer* decision determined that PSM coverage did not extend to stored flammables in atmospheric tanks even if the tanks are connected to a covered process.

[a] See generally Implementing PSM: Perspective from a Process Engineer Turned PSM Attorney [58]; Akzo-Nobel Chemicals - Limits of a Process [89]; Interpretation of OSHA's Standard for Process Safety Management of Highly Hazardous Chemicals [90]; Determining when a mixture would exceed the threshold quantity in a covered process [91]; and Process Safety Management and Prevention of Major Chemical Accidents [92].

[b] See, e.g., Process Safety Management Process Boundary Determinations [153].

16. The CSB recommended in the Motiva report that OSHA should ensure that the PSM standard covers atmospheric storage tanks that could be involved in a potential catastrophic release as a result of being interconnected to a covered process with 10,000 pounds of a flammable substance.[a]

17. In response to the Motiva recommendation, OSHA stated in a 2003 letter to the CSB that it would issue a revised PSM Compliance Directive[b] specifying that tanks, like the one at Motiva which had a separating or processing function as well as storage, would be regulated under the PSM standard.[c] The CSB argues that this directive would also apply to the foul condensate tank at the DeRidder mill, which also separates hydrocarbons from water through the internal weir system, although at the time of the incident the weir system was not functioning.

18. Over the past several years, the CSB inquired about the progress of OSHA's proposed PSM Compliance Directive revision on multiple occasions without receiving a clear answer until an August 2012 communication from the Assistant Administrator for OSHA, which promised completion of a revision in six to nine months. To date, however, OSHA has not issued a revised compliance directive, although the CSB is advised that OSHA continues to work on updating its standard with respect to *Meer*.

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[a] CSB Recommendation number 2001-05-I-DE-R1.

[b] OSHA compliance (CPL) directives are Federal compliance operating procedures that relate to the enforcement of particular standards.

[c] OSHA stated to the CSB that it was "committed to issuing a compliance directive to address the distinctions between storage tanks and process tanks containing flammable liquids."

6 Packaging Corporation of America Organizational Analysis

1. Because the DeRidder mill did not apply its process safety management system to the foul condensate tank, each of the following organizational deficiencies contributed to the February 8, 2017, explosion:

   - PCA did not perform a hazard analysis on key components of the CNCG system, including the foul condensate tank, to identify, evaluate, and control process hazards.
   - PCA did not identify with sufficient clarity those operations personnel who were responsible for the foul condensate tank, leading to confusion within the mill workforce.
   - PCA did not observe established industry safety standards and good practice safety guidance.
   - PCA did not adequately demonstrate a learning culture with respect to making needed improvements based on lessons learned from past publicized and well-understood industry incidents.

6.1 Gaps in Packaging Corporation of America's Non-Condensable Gas Safety Knowledge and Communication

2. PCA participated in the development of the TAPPI TIP 0416-09, *Collection and burning of concentrated non-condensible gases: regulations, design and operation,* safety guidance, which discusses potential NCG explosion hazards [5, p. 11]. However, this knowledge was not broadly communicated among DeRidder personnel, who in turn were then unable to act on that information, and were unable to communicate the information to welding contractors.

3. At some point before the work on the water piping, PCA developed an electrical area classification diagram for the foul condensate tank. The diagram required electrical equipment used in the designated area around the tank, such as the welding equipment used on February 8, 2017, be made safe prior to its use. Although PCA knew that fire or explosion hazards could exist near the foul condensate tank, the welding contractors appear not to have known the work they were performing was being conducted in a hazardous area.

4. The foul condensate tank was located between two operations areas – the pulp mill and the powerhouse. The tank received foul condensate from the pulp mill, temporarily stored it, and then fed the foul condensate to a stripper in the powerhouse. But PCA did not clearly define tank responsibility and neither the pulp mill personnel nor the powerhouse personnel appeared to know which operations area was responsible for operating and maintaining the foul condensate tank. Over time, this ambiguity led to few operators knowing much about the tank, its contents, and its potential hazards.

5. Although PCA operations personnel understood that components of NCG, such as methanol, hydrogen sulfide, and turpentine, presented flammable hazards, these workers did not appear to understand the potential for an explosion of the magnitude encountered on the day of the incident. This misunderstanding led many operators to believe that an explosion was not possible. Numerous operators demonstrated a general lack of knowledge about the tank, its role in operations, or hazards that it posed.

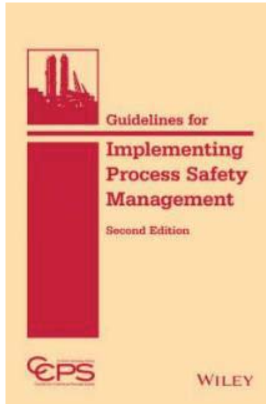
6. Due to a lack of adequate communication from PCA corporate, some PCA DeRidder employees incorrectly believed that the foul condensate tank could not contain an explosive atmosphere. When the CSB asked employees whether air could get into the foul condensate tank or other parts of the CNCG system, most thought that could not happen. Employees stated:

- It's a sealed system …. You have the automatic valve that controls how much it pulls. But … air's not bled into the system. It's a sealed system.
- It shouldn't be possible [to get air into the system]. I wouldn't think. But I don't know. I guess anything's possible.
- Air into the foul condensate tank … I would say no. I mean, anytime you introduce air, you have vacuum problems. Do you see what I'm saying? So any type of vacuum systems is closed, cold air causes vacuum issues. If you introduce any type of cold air, you can't pull the vacuum without a lot of … without a lot of struggle.
- Not that I'm aware of.
- Not to my knowledge. … Correct me if I'm wrong, but … the NCGs are pulling a … vacuum on this tank. So outside of that, which it wasn't pulling a vacuum because it was down, I don't see how you could.
- There's no way … no way that I know of ….

7. Because PCA did not adequately review and communicate potential hazards, DeRidder employees did not understand that the tank routinely pulled in air during the automatic cycling of the level, and did not understand that allowing the foul condensate tank to cool could create enough of a vacuum to draw air into the tank through the vacuum breaker, creating the dangerous condition that led to the February 8, 2017 incident.

6.2 Process Safety Management

8. In June 2016, the Center for Chemical Process Safety (CCPS) released a new edition of its *Guidelines to Implementing Process Safety Management* [57].



9. CCPS explained the goal of these guidelines, noting: "Ensuring that people can return home healthy and uninjured at the end of each workday, ensuring that our neighbors are unharmed, and having a safe work environment has driven many companies to pursue PSM implementation with the objective of having zero incidents [57]." CCPS stated: "It is that goal for which this guideline was developed - to help companies pursue and achieve the 'perfect process safety' vision of zero harm [57]."

10. In its 2016 publication *Guidelines for Implementing Process Safety Management*, CCPS described the current state of PSM and the global adoption of management systems to control process hazards. CCPS stated:

> Companies have been implementing process safety management (PSM) systems for over 25 years. A variety of PSM structures have been used - some based upon regulatory requirements and many more based upon evolving industry good practices. These PSM systems are designed to manage the hazards and risks associated with processes using hazardous chemicals or energy. Management of these aspects requires a PSM system to focus on nurturing the performance of equipment and people throughout the life cycle of their deployment in a facility. The adoption of PSM systems has gone global, offering many new opportunities to improve upon implementation practices of the past [57].

11. Despite the adoption of process safety management systems by many industry safety leaders, the CSB investigation of the February 8, 2017 incident revealed that the DeRidder mill management did not apply its process safety management system to the CNCG system, which contributed to the explosion.

12. Explosion hazards associated with the foul condensate tank could have been readily revealed by applying a process hazard analysis, one of the basic elements of a process safety management program. Questions such as, "How often do we get low pressure in the foul condensate tank?" or "What if there is low pressure in the foul condensate tank as the result of cooling during a shutdown?" should generate a conversation about how air could enter the vapor space of the foul condensate tank.

13. According to industry good practice guidance, the pulp and paper industry is aware that the normal composition of the vapor in foul condensate tanks is flammable, and that it should be maintained above its upper explosive limit [5, p. 2]. Diluting this flammable gas with air could bring the tank's atmosphere into the explosive range and thus could create a hazard to mill workers.

14. In addition, the foul condensate tank itself was equipped with the capability to remove and recover the turpentine liquid that can gradually accumulate on top of the water inside the tank. A review of this design during an organized, formal hazard analysis could have identified the potential for air intrusion creating an explosive atmosphere requiring the need for robust safeguards to prevent this major accident scenario.

15. The DeRidder mill applied strict lines of demarcation about where application of PSM began and ended. Within the strict PSM boundary, the mill identified process hazards; however, PCA did not implement a uniform hazard recognition approach outside of those boundaries. For example, PCA did not apply PSM to the foul condensate tank despite the fact that the foul condensate tank contained some quantity of turpentine and that the tank was directly connected to the turpentine system. By applying these strict PSM boundaries, a formal hazard analysis was not required and was therefore not performed, and additional effective safeguards were never considered – because the DeRidder mill never evaluated the CNCG system for potential process hazards.[a]

16. Despite the absence of a regulatory requirement to do so, the DeRidder mill should voluntarily broaden the boundary of its process safety management program to include the CNCG header system and interconnected units, including the foul condensate tank, using good practice guidance, such as the CCPS *Guidelines for Risk Based Process Safety*.

17. Although the decision about whether to expand process safety management beyond legally required limits lies with the company,[b] engineering analyses concerning the application of process safety principles and good practices should not be based solely on whether a regulatory requirement demands such action. Rather, as one author wrote: "The process engineer does not stop thinking about safety just because there is no highly hazardous chemical (HHC) in a given process unit of the plant [58]." To an engineer, "PSM is more of a safety philosophy than a set of regulations [58]."

18. Thus, although a process might not be covered by OSHA's PSM standard, the chemicals in use or the process itself could still present sufficient hazards to warrant application of good process safety management principles and techniques.

19. By effectively applying the CCPS *Guidelines to Implementing Process Safety Management*, PCA can develop a management system to manage NCG process hazards and prevent future NCG explosions in the future.

[a] See e.g. *Process Safety Management Process Boundary Determinations* [153].

[b] See e.g., *Guidelines for Risk Based Process Safety* [64, p. 214]; *Process Safety Management Process Boundary Determinations* [153]; and *DOE Handbook: Process Safety Management for Highly Hazardous Chemicals* [152, pp. 13-14].

20. This new PCA management system should ensure an appropriate evaluation of potential consequences and should also require inherently safer design where feasible. In addition, the hierarchy of controls should guide safeguard selection when establishing recommendations to lower the risk of process hazards.

6.2.1 Packaging Corporation of America Hot Work Policy

21. PCA developed a process safety management policy for its containerboard mills. The policy addresses some key aspects of process safety including requirements for conducting process hazard analysis, management of change, and hot work.

22. The DeRidder hot work permit procedure states, "The purpose of this procedure is to protect employees and mill assets against unexpected hazards associated with work that generates a source of ignition."

23. The DeRidder hot work permit procedure contains a section detailing the hot work to be conducted by contracted personnel. If contracted personnel are required to conduct hot work, the policy states, "All air testing [atmospheric monitoring] will be performed by the PCA Technical department or a trained ERT [emergency response team] member of the PCA ERT team." Furthermore, the procedure continues: "The Contractor must be apprised of . . . all hazards and considerations of the area where hot work is performed."

24. The DeRidder procedure requires the elimination of explosive atmospheres within 35 feet of the hot work. The procedure further requires the removal of other combustibles within that same 35-foot zone; alternatively, if that is not possible, the procedure requires protecting combustibles from hot work ignition by the use of fire resistant tarpaulins or metal shields. The procedure also specifically requires the use of fire resistant tarpaulins to be suspended beneath elevated work, an additional safety technique that the contractors should have been required to use at the DeRidder mill on the day of the incident with the contractors performing hot work on an elevated catwalk directly above the tank.

25. The PCA corporate standard operating procedure also specifically identifies the issue of conducting hot work on a nearby vessel such as the foul condensate tank which contains a flammable atmosphere:

> When welding on or in the vicinity of storage tanks and other containers, properly test and continuously monitor all surrounding tanks or adjacent spaces (not just the tank or container being worked on) for the presence of flammables and eliminate potential sources of flammables.

26. On the day of the explosion, DeRidder mill personnel verified that the equipment was properly isolated, and they tested the atmosphere around the water piping for flammable gas. The work area adjacent to the foul condensate tank, where contractors planned to conduct the hot work, was also checked for flammable gas. Because no flammable gas was detected and workers believed that PCA's hot work permit requirements had been met, the hot work permit was issued.

27. PCA did not, however, identify the explosive atmosphere within the foul condensate tank. Because workers did not know about the hazard – that the tank could contain an explosive mixture of flammable vapor mixed with air –no one performed combustible gas monitoring of the tank vapor space. If the explosive atmosphere hazard had been recognized through a process hazard analysis, however, all such hot work should have been prohibited until the foul condensate tank had been made safe by means of inerting the tank before performing the required hot work.

6.2.2 Hot Work Regulations and Industry Safety Standards

28. Regulations and good practice guidance exist for performing hot work safely. To conform to applicable regulations, and to make effective use of good practice guidance, companies must have a thorough knowledge of their processes, combined with a comprehensive understanding of all relevant process safety hazards. To protect workers from future explosions in the future, PCA needs to strengthen its process safety and hot work safety management systems. Training should ensure that workers have a clear understanding of organizational their responsibilities, along with a thorough understanding of relevant process safety hazards. In addition, PCA should thoroughly evaluate process hazards to determine the appropriate conditions needed to allow hot work. The company should also clearly define those conditions in specific procedures and emphasize those procedures in a strong training program.

29. According to hot work guidance produced by the American Petroleum Institute (API) [59], the key to preventing fires and explosions safely while conducting hot work starts long before the job begins. As API notes: "The evaluation of the [hot] work conditions should identify potential hazards. Hot work can be conducted safely when hazards are recognized and proper procedures are used."

30. As worldwide insurer FM Global states: "All hot work fires and explosions are preventable. A hot work fire or explosion is the result of inadequate hot work management allowing ignition sources to come into contact with combustible, ignitable, or flammable material [60]."

31. If the DeRidder mill had properly identified the hazards associated with conducting hot work above the foul condensate tank, a variety of standards, good practice guidance, and regulations would have provided for their proper evaluation and control of those hazards.

32. The need for compliance with pertinent regulations and adherence to good practice safety standards can be difficult to share effectively with workers and contractors across varied job sites. Although workers and contractors may recognize hot work hazards on a particular piping segment or vessel, they may lack knowledge of the hazards concerning nearby equipment.

33. OSHA publishes regulations and helpful guidance concerning hot work. Of particular relevance to the February 8, 2017, DeRidder mill incident is OSHA's standard on welding, cutting and brazing [61].

34. OSHA clearly states that management must advise contractors engaged in hot work about flammable materials or other hazardous conditions that the contractors otherwise might not know

about considering their non-employee status and their potential lack of familiarity with the equipment in the facility.[a]

35. In recognition of the growing trend towards outsourcing hot work projects, the National Fire Protection Association (NFPA) noted parallel concerns with respect to the risks associated with hot work:

> The trend toward outsourcing facility maintenance and renovations can influence the risks associated with hot work. A contractor might have the technical expertise to perform hot work but is not likely to have a full understanding of fire prevention or of the specific combustible hazards within a client property [11, p. 10].

36. Aside from noting typical ignition sources in hot work, such as welding or grinding, API guidance reminds practitioners to be conscious of other potential ignition sources as well.

> Any spark-producing or high-temperature object or activity can be a potential source of ignition. Motor vehicles, drilling, cutting, abrasive blasting and electrical equipment (including cellular or digital phones, two-way radios or digital cameras) should be evaluated before being allowed in an area where flammable vapors may be present. Static electricity can be generated by flow of fluids such as air and steam. Bonding and grounding procedures along with the avoidance of non-metallic static-accumulating equipment are used to prevent static discharge [59, pp. 7-8].

37. In terms of the risks of fires or explosions, knowledge of hazardous conditions is key to hot work safety. At PCA, mill workers and contractors appeared to review the water piping and pipe rack repair work at a specific moment in time – while in the process of writing a hot work permit. Workers should have known about the potential for explosive conditions inside the foul condensate tank long before February 8, 2017, when the safety coordinator issued the hot work permit to authorize the contractors to perform repairs using hot work equipment.

38. An absence of critical process knowledge is a primary cause of the February 8, 2017 incident. Both PCA mill employees and welding contractors were willing to make the scene safe for the needed hot work to be performed, including during repairs on the clean condensate line, as well as when installing the guards on the pipe rack above the foul condensate tank. The issue was, however, that a genuine knowledge gap existed regarding the dangers posed by the foul condensate tank. With the benefit of hindsight, the hazards are clear, but at the time of the incident, the hazards were apparently unknown to the workers.

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[a] 29 C.F.R. § 1910.252(a)(2)(xiii)(D). See also 29 C.F.R. § 1910.252(a)(2)(xv) (Explaining various duties of a supervisor, the regulation requires, in pertinent part: "Fire prevention precautions. Cutting or welding shall be permitted only in areas that are or have been made fire safe. When work cannot be moved practically, as in most construction work, the area shall be made safe by removing combustibles or protecting combustibles from ignition sources."); 29 C.F.R. § 1910.252(a)(2)(xiv)(C)(1)-(3); see generally (A)-(G).

39. Lacking this critical knowledge, DeRidder mill employees were not capable of discussing the potential foul condensate tank explosion hazards with the contractors. As a result, no one was able to implement the potential safeguards needed to make this particular hot work project safe.

7 PACKAGING CORPORATION OF AMERICA POST-INCIDENT ACTIONS

1. In the months following the February 8, 2017 incident, PCA began a safety review of its DeRidder mill. The company has developed several recommendations to address the findings described in this report. The scope of the recommendations is summarized in **Table 1**.

Table 1. PCA-Post Incident Actions. This table summarizes the actions that PCA has taken since the incident at its DeRidder, Louisiana mill.

Topic	Current Status
Tank Flammability	• All tanks and vessels have been evaluated for the potential for a flammable or hazardous atmosphere and have been marked with an orange label indicating this potential. • Evaluating flammable atmosphere prevention mechanisms in the foul condensate tank during all operation conditions, if the tank is replaced. • Evaluating flammable atmosphere prevention mechanisms as they relate to other vessels, storage tanks, and associated piping containing flammable materials at the DeRidder mill, as appropriate.
Foul Condensate Tank Turpentine Removal	• Considering incorporating a system that periodically skims or decants turpentine from the foul condensate tank, if the tank is replaced. Note, however, that a weir is unlikely to be capable of removing 100 percent of turpentine in the tank.
Hazard Analysis	• Conducting formal hazard analysis on the foul condensate tank and associated processes as informed by investigation findings, if the tank is replaced. • Incorporating learnings regarding changing the foul condensate tank conditions of relevant tanks and vessels during shutdowns as a recognized hazard in further process hazard analyses. • Following formal hazard analysis on the foul condensate tank and associated processes, review startup, shutdown, and maintenance procedures for the foul condensate tank

Topic	Current Status
	and other vessels, storage tanks, and associated piping containing flammable material, and apply learnings as appropriate.
Hot Work	• Policies, procedures, and practices revised to ensure all tanks and vessels within 35 feet of any hot work activity will be drained, purged, cleaned, and confirmed free of a hazardous atmosphere before hot work permit is issued. • If the tanks or vessels within 35 feet of any hot work activity cannot be drained, purged, or cleaned they will be filled to the top with water and vented at the top, to eliminate any vapor space within the vessel. • Each vessel within 35 feet of any hot work activity will be continuously monitored by a gas monitor. • Policies, practices, and procedures revised to reflect that all hot work within the PSM boundaries can only be issued by the safety department, and must be signed off by area supervisors and the safety manager or their designees. • Reinforcing expectations with contractors that all contractors performing hot work activities, including monitoring and fire watch responsibilities. • Reinforcing expectations that contractors must have a competent safety person on-site at all times and must submit a safety plan on how work will be performed safely, which will be reviewed with the PCA contract representative and the safety manager, prior to beginning work at the PCA DeRidder mill. • Reinforcing the importance of effective hot work procedures with DeRidder mill PCA contract business partners.

2. As discussed above, PCA has posted labels on any vessel in the mill that may contain a flammable atmosphere. Examples of these labels can be seen in **Figure 44** and **Figure 45**.

Figure 44. Post-Incident Warning Label. This warning label is intended to inform personnel of the potential hazards associated with a flammable atmosphere inside a vessel. Photograph: PCA.

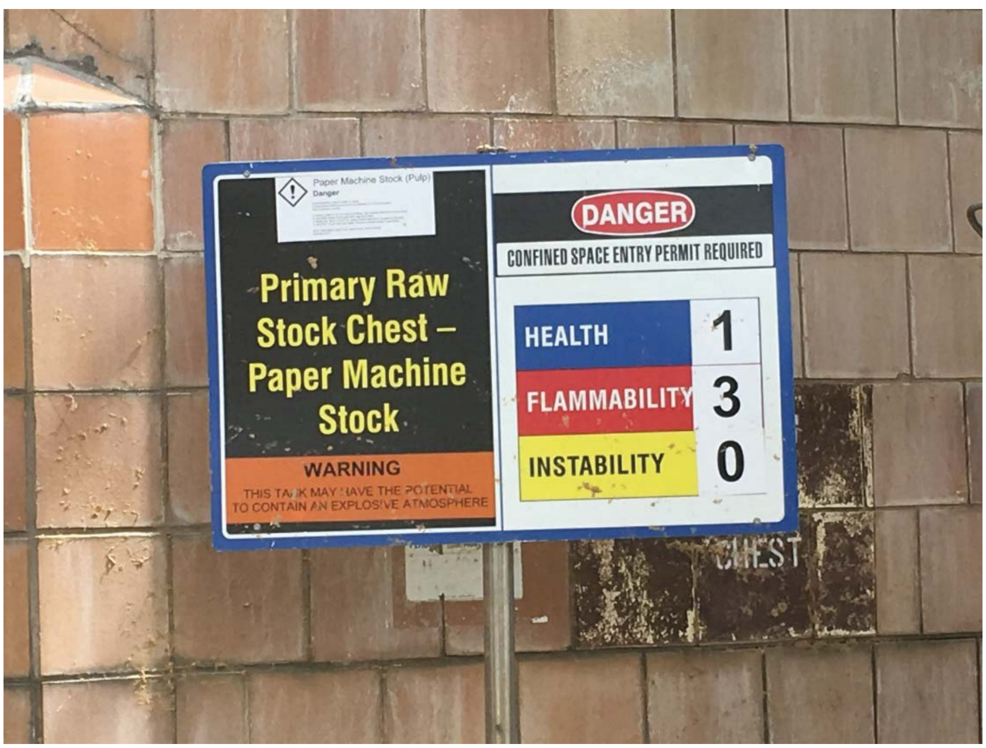

Figure 45. Post-Incident Danger Label. This label is intended to warn mill personnel of the hazards associated with a potential flammable atmosphere inside a vessel. Photograph: PCA.

8 SAFETY GUIDANCE

Based on the findings of this investigation, the CSB provides the following guidance to pulp and paper mills that produce NCG and operate NCG systems, which includes all foul condensate tanks. For these NCG systems:

- Apply effective process safety management systems to NCG system equipment using good practice guidance, such as CCPS *Guidelines for Risk Based Process Safety*, and *Guidelines for Implementing Process Safety Management*;
- Consider further expanding process safety management program boundaries beyond the minimum legal requirements to provide heightened coverage of process safety hazards;
- Apply NFPA 69, *Standard on Explosion Prevention Systems*, to provide effective explosion prevention;
- Where explosions cannot be prevented in accordance with NFPA 69, apply NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, to provide explosion protection;
- Ensure safety instrumented systems (safety interlocks) achieve desired risk reduction by applying the life-cycle approach provide by ISA-84, *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*;
- Apply TIP 0416-09, *Collection and burning of concentrated non-condensible gases: regulations, design and operation,* for effective NCG system design and operation;
- Provide workers with periodic training to ensure they have an understanding of all process safety hazards applicable to areas of their responsibility and job tasks, including the safety conditions needed to permit hot work.

9 RECOMMENDATIONS

9.1 REITERATED RECOMMENDATIONS

2001-05-I-DE-R1

In August 2002, the CSB approved the final report on the Motiva Enterprises Sulfuric Acid Tank Explosion, a report covering hot work conducted above a tank containing flammable vapors, which resulted in one fatality, eight injuries, and offsite environmental impacts.

As a result of the report, CSB recommended that OSHA amend its Process Safety Management (PSM) Standard, 29 C.F.R. § 1910.119, to ensure coverage under the standard of atmospheric storage tanks that could be involved in a potential catastrophic release as a result of being interconnected to a covered process with 10,000 pounds of a flammable substance.

The CSB hereby reiterates this important safety recommendation and urges OSHA to implement this recommendation.

9.2 NEW RECOMMENDATIONS

According to its statutory authority under 42 U.S.C. § 7412(r)(6)(C)(i) and (ii), and in the interest of promoting safer manufacturing operations at U.S. facilities handling chemicals, and to protect workers and communities from NCG explosion hazards, the CSB makes the following safety recommendation:

9.2.1 PACKAGING CORPORATION OF AMERICA

2017-03-I-LA-R1

Apply the CSB safety guidance to PCA pulp and paper mills that produce NCG and operate NCG systems, which includes all foul condensate tanks. For these NCG systems:

- Apply effective process safety management elements using good practice guidance, such as CCPS *Guidelines for Risk Based Process Safety*, and *Guidelines for Implementing Process Safety Management*;
- Consider further expanding process safety management program boundaries beyond the minimum legal requirements to provide heightened coverage of process safety hazards;
- Apply NFPA 69, *Standard on Explosion Prevention Systems*, to provide effective explosion prevention;
- Where explosions cannot be prevented in accordance with NFPA 69, apply NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, to provide explosion protection;

- Ensure safety instrumented systems (safety interlocks) achieve desired risk reduction by applying the life-cycle approach provided in ISA-84, *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*;
- Apply TIP 0416-09, *Collection and burning of concentrated non-condensible gases: regulations, design and operation,* for effective NCG system design and operation;
- Provide workers with periodic training to ensure they have an understanding of all process safety hazards applicable to areas of their responsibility and job tasks, including the safety conditions needed to permit hot work.

10 CAUSAL ANALYSIS

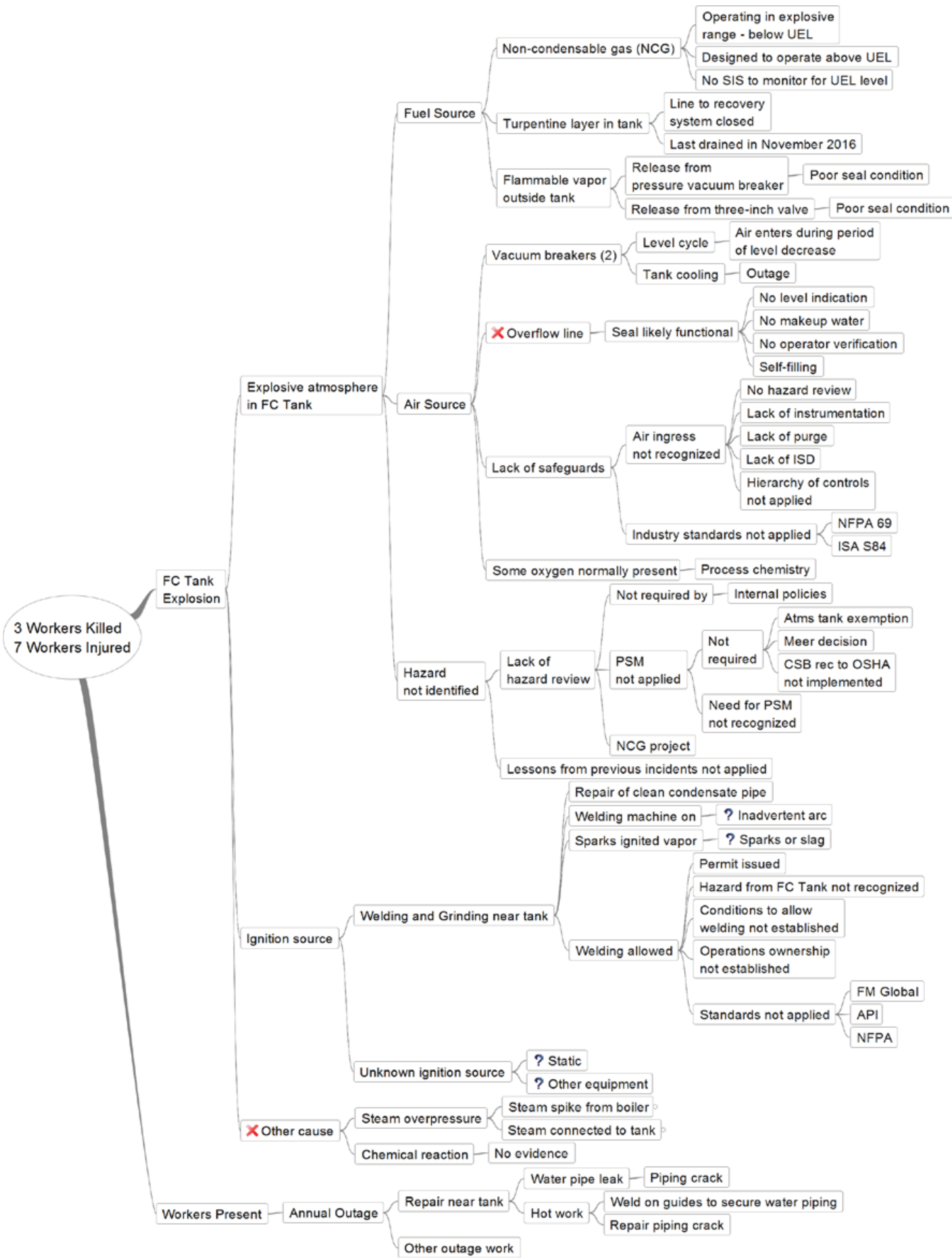

Figure 46. Simplified Causal Analysis Diagram. This diagram shows a simplified causal analysis of the February 8, 2017 incident at the Packaging Corporation of America facility in DeRidder, Louisiana.

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