U.S. Chemical Safety and Hazard Investigation Board

Case Study

Williams Geismar Olefins Plant

Reboiler Rupture and Fire
Geismar, Louisiana

Incident Date: June 13, 2013
Two Fatalities, 167 Reported Injuries
No. 2013-03-I-LA

KEY ISSUES:
- Overpressure Protection
- Process Hazard Analysis
- Management of Change
- Pre-Startup Safety Review
- Operating Procedures
- Hierarchy of Controls
- Process Safety Culture

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DEDICATION

This CSB Case Study is dedicated to the two men, listed below, who lost their lives as a result of this incident, as well as to the numerous workers injured on June 13, 2013.

Zach Green, 29

Scott Thrower, 47

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1.0 INTRODUCTION

"We would never knowingly tolerate a situation in which accidental operation of a valve resulted in the overpressuring of a vessel. We would install a relief valve. In the same way, accidental operation of a valve should not be allowed to result in explosion […]." Trevor Kletz, What Went Wrong? – Case Histories of Process Plant Disasters and How They Could Have Been Avoided, 5th ed., 2009

TABLE OF CONTENTS

This case study examines the June 13, 2013 catastrophic equipment rupture, explosion, and fire at the Williams Olefins Plant in Geismar, Louisiana, which killed two Williams employees. The incident occurred during nonroutine operational activities that introduced heat to a type of heat exchanger called a "reboiler" which was offline, creating an overpressure event while the vessel was isolated from its pressure relief device. The introduced heat increased the temperature of the liquid propane mixture[1] confined within the reboiler shell, resulting in a dramatic pressure rise within the vessel due to liquid thermal expansion. The reboiler shell catastrophically ruptured, causing a boiling liquid expanding vapor explosion (BLEVE)[2] and fire.

Process safety management program weaknesses at the Williams Geismar facility during the 12 years leading to the incident caused the reboiler to be unprotected from overpressure. These weaknesses include deficiencies in implementing Management of Change (MOC), Pre-Startup Safety Review (PSSR), and Process Hazard Analysis (PHA) programs. In addition, the company did not perform a hazard analysis or develop a procedure for the operational activities conducted on the day of the incident. This incident illustrates the importance of:

- Using the hierarchy of controls when evaluating and selecting safeguards to control process hazards;
- Establishing a strong organizational process safety culture;
- Developing robust process safety management programs; and
- Ensuring continual vigilance in implementing process safety management programs to prevent major process safety incidents.

Following the incident, Williams implemented improvements in managing process safety. To prevent future incidents and further improve process safety at the Geismar plant, the U.S. Chemical Safety and Hazard Investigation Board (CSB) recommends that Williams strengthen existing safety management systems and adopt additional safety programs. The CSB also issues recommendations to the American Petroleum Institute (API) to help prevent future similar incidents industry-wide.

1 The process fluid in the reboiler contained an estimated 95% propane, with the balance composed mostly of propylene and C4 hydrocarbons, such as butane.

2 See section 4.0 for a technical explanation of the BLEVE mechanism, and a detailed sequence of events leading to the explosion.

2.0 BACKGROUND

2.1 WILLIAMS BACKGROUND

The Williams Companies, Inc. ("Williams") is an energy infrastructure company headquartered in Tulsa, Oklahoma. Founded in 1908, Williams owns interests in natural gas and natural gas liquid (NGL) pipeline and processing facilities throughout North America, and conducts most of its operations through subsidiary companies. One of its subsidiary companies is Williams Olefins LLC, which owns and operates the Williams Geismar Olefins Plant.

2.2 GEISMAR OLEFINS PLANT

The Williams Geismar Olefins Plant, which employs approximately 110 people, is located in Geismar, Louisiana, approximately 20 miles southeast of Baton Rouge. The Lummus Company designed and built the olefins plant in 1967, and Allied Chemical first operated it. In 1985, Union Texas Petroleum purchased the plant from Allied Chemical and sold it to Atlantic Richfield Company (ARCO) in 1998. Williams then purchased the facility in 1999. At the time of the incident, Williams Olefins LLC and Saudi Basic Industries Corporation (SABIC) jointly owned the plant, and Williams Olefins was the sole operator.

The Williams Geismar Olefins Plant produces ethylene and propylene for the petrochemical industry.[3] The plant originally produced 600 million pounds of ethylene annually. Over the years, the production capacity increased to 1.35 billion pounds of ethylene and 80 million pounds of propylene per year. At the time of the incident, approximately 800 contractors worked at the Williams Geismar facility on an expansion project, with an end goal of increasing the production of ethylene to 1.95 billion pounds per year.

2.3 PROCESS OVERVIEW

The June 13, 2013 incident occurred when a reboiler, a heat exchanger that supplies heat to a distillation column,[4] catastrophically ruptured. The reboiler that failed, EA-425B ("Reboiler B") was one of two reboilers (Reboiler A and Reboiler B) that supplied heat to the propylene fractionator—a distillation column that separates propylene and propane. The process fluid on the shell-side[5] of these reboilers is heated by hot "quench water," [6] flowing through the tubes. Reboiler B had been offline for 16 months while Reboiler A was in operation, but was clean and available for use when Reboiler A eventually fouled (see Section 2.4).[7] Figure 1 is a simplified flow diagram highlighting the location of the propylene fractionator relative to the overall olefins production process.

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3 Williams corporate website. https://co.williams.com/operations/ngl-petchem/olefins/ (accessed August 17, 2016). Olefins, also known as "alkenes," are hydrocarbons that contain a carbon-carbon double bond. The primary olefins produced by the Williams Geismar facility are ethylene ($H_2C{=}CH_2$), and propylene ($CH_3CH{=}CH_2$). Ethylene is a basic chemical used in the production process of a variety of products including plastics, soaps, and antifreeze. A primary use of propylene is the manufacturing of plastic materials and antifreeze.

4 A distillation column is a type of process equipment that separates a feed mixture based upon the mixture components' boiling point temperatures. Components with lower boiling point temperatures, the more volatile components, leave the upper portion of a distillation column, while components with higher boiling point temperatures, the less volatile components, leave the lower portion of a distillation column.

5 The propylene fractionator reboilers are shell and tube heat exchangers. This type of heat exchanger has a large cylindrical exterior or "shell," with a bundle of tubes inside of the shell.

6 "Quench water" is water that is used to cool furnace effluent gases through direct contact with the gases. It is a "process water" stream because it directly contacts and often contains residual material from the furnace effluent gases.

7 Fouling historically occurred on the process water (quench water) side of the reboilers. Fouling is a term used to describe a buildup on equipment surfaces of undesired material that has an adverse impact such as reducing heat transfer efficiency.

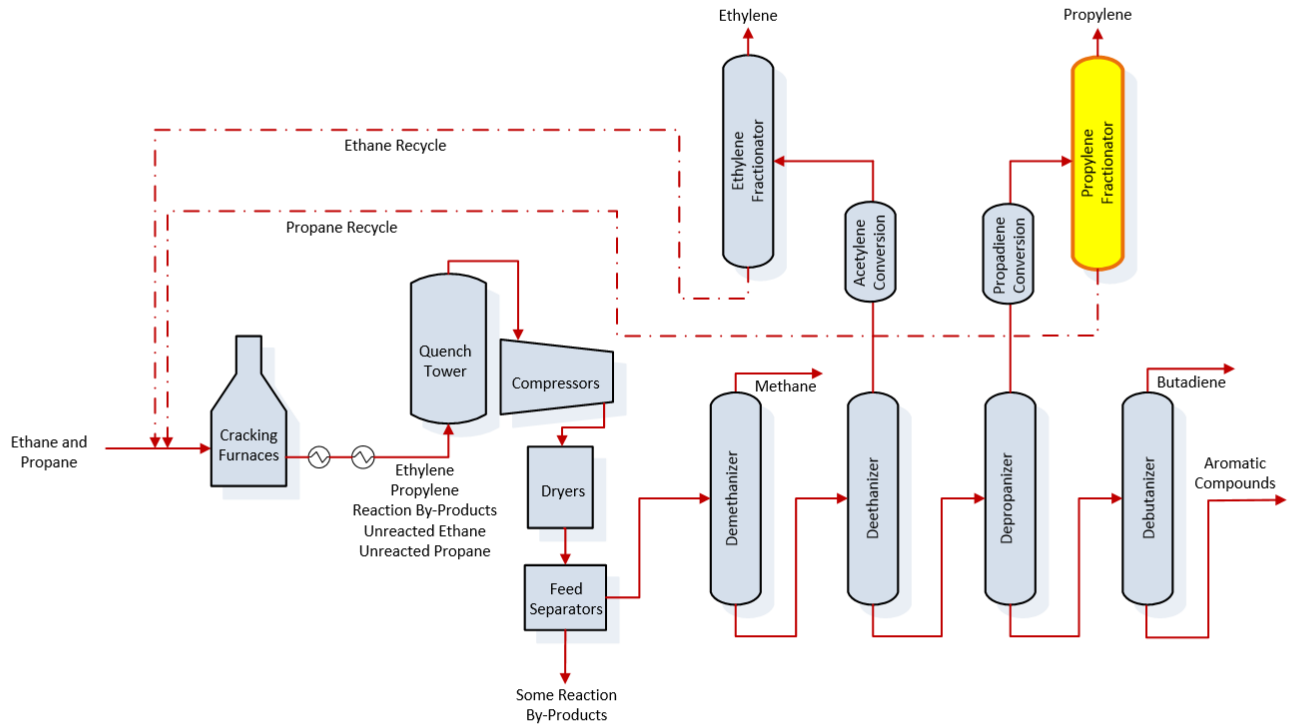

FIGURE 1

Simplified flow diagram of the olefins process. The incident occurred when a propylene fractionator reboiler that had been offline for 16 months catastrophically ruptured. The propylene fractionator is highlighted in yellow.

2.3.1 Olefins Production Process Description

At the beginning of the olefins production process, ethane and propane enter "cracking furnaces"[8] where they are converted to ethylene and propylene, as well as several byproducts including butadiene, aromatic compounds,[9] methane, and hydrogen (Figure 1). The furnace effluent gases leave the cracking furnaces and enter heat exchangers that reduce the temperature of the gases. The furnace effluent gases then enter the quench tower for further cooling by direct contact with quench water, which is sprayed downward from the top of the tower. After additional processing, the cooled gases go to a series of distillation columns, such as the propylene fractionator, which separate the reaction products into individual components. The ethylene, propylene, butadiene, and aromatic compound products are then transported and sold to customers. Unreacted ethane and propane are recycled back to the beginning of the process.

The quench water that directly contacts the heated furnace effluent gases is part of a closed-loop water circulation system. As the heated furnace effluent gases are cooled in the quench tower, heat transfers to the quench water. The heated quench water then serves as a heat source in various heat exchangers within the process, heating process streams while also reducing the temperature of the quench water. Finally, a cooling water system further cools the quench water before it circulates back to the quench tower (Figure 2).

[8] "Cracking" is the breaking apart of molecules to form different molecules.
[9] Examples of aromatic compounds, also called arenes, include benzene and toluene.

Because the quench water directly contacts process gases, oily tar products[10] contained in the gas condense into the quench water. The quench water settler removes most of the tar material (Figure 2); however, some oily material remains in the quench water. Over time, some of this material adheres to and builds up on the inside of process equipment such as heat exchanger tubes, resulting in a decrease in both heat transfer efficiency and quench water flow rate. The buildup of such material is called "fouling." When quench water flow through the process periodically decreased due to fouling, Williams operations personnel would evaluate the quench water system by analyzing, among other things, flow rates through pumps and heat exchangers to identify the fouled piece of equipment likely causing the decrease in quench water flow. Williams personnel were performing this type of nonroutine operational activity when the incident occurred on June 13, 2013.

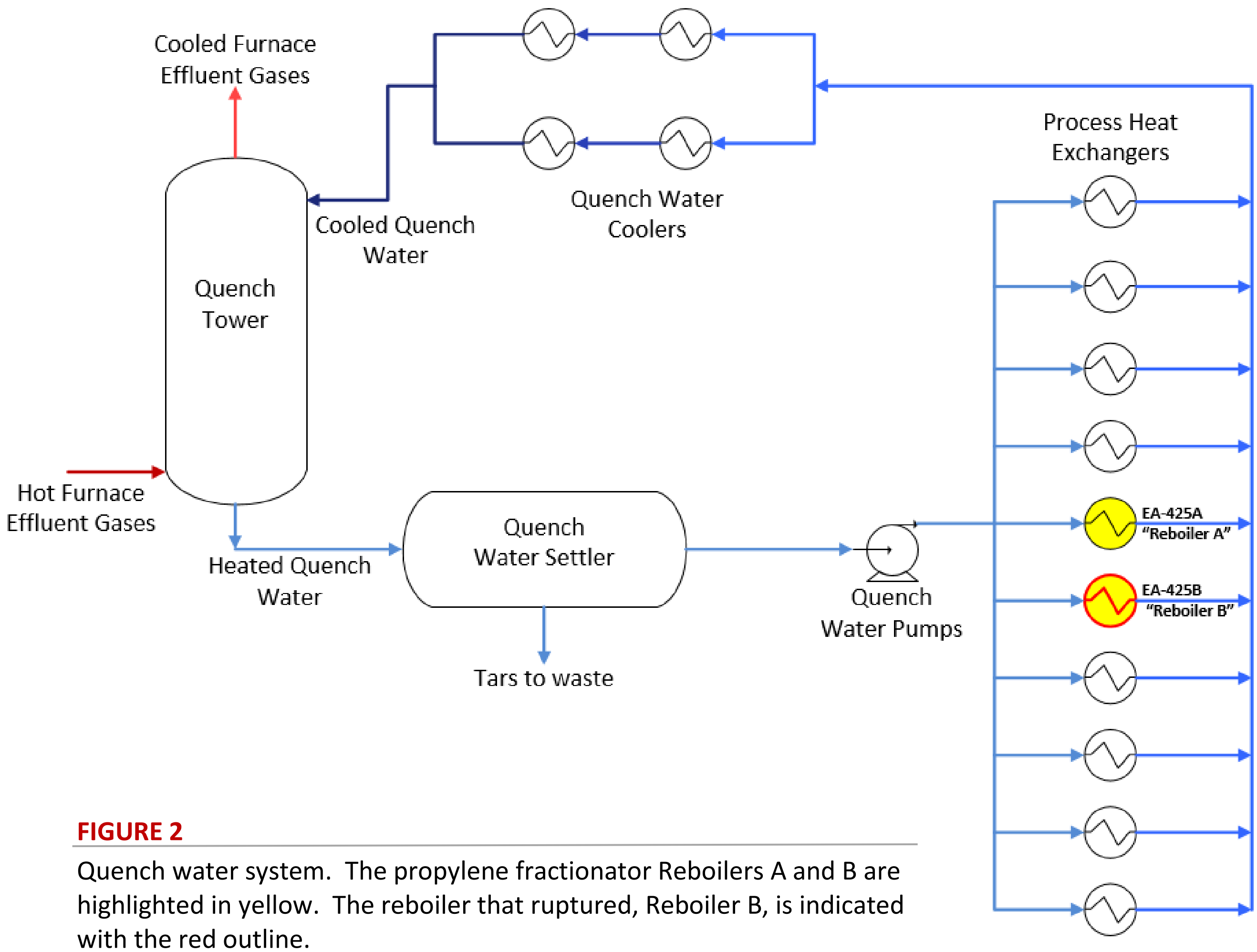

FIGURE 2

Quench water system. The propylene fractionator Reboilers A and B are highlighted in yellow. The reboiler that ruptured, Reboiler B, is indicated with the red outline.

[10] The tar products form in the cracking furnaces.

2.4 Propylene Fractionator Reboilers

The propylene fractionator Reboilers A and B are shell and tube heat exchangers,[11] where tube-side hot quench water vaporizes shell-side hydrocarbon process fluid, which is approximately 95% propane with the balance composed mostly of propylene and C4s[12] (Figure 3[13] and Figure 4). (This report refers to the propane mixture as "propane.") Quench water enters the propylene fractionator reboilers at approximately 185 °F and partially vaporizes the shell-side propane, which enters the reboiler at a temperature of approximately 130 °F.

The original propylene fractionator design had both reboilers continuously operating. This process design required periodic propylene fractionator downtime when the reboilers fouled and required cleaning. In 2001, Williams installed valves on the shell-side and tube-side reboiler piping to allow for continuous operation with only one reboiler operating at a time. The other reboiler would be offline but ready for operation (see Section 5.1), isolated from the process by the new valves. This configuration allowed for cleaning of a fouled reboiler while the propylene fractionator continued to operate. Unforeseen at the time due to flaws in the Williams process safety management program (discussed in subsequent sections in this report), these valves also introduced a new process hazard. If the new valves were not in the proper position (open or closed) for each phase of operation, the reboiler could be isolated from its protective pressure relief valve located on top of the propylene fractionator (Figure 4).

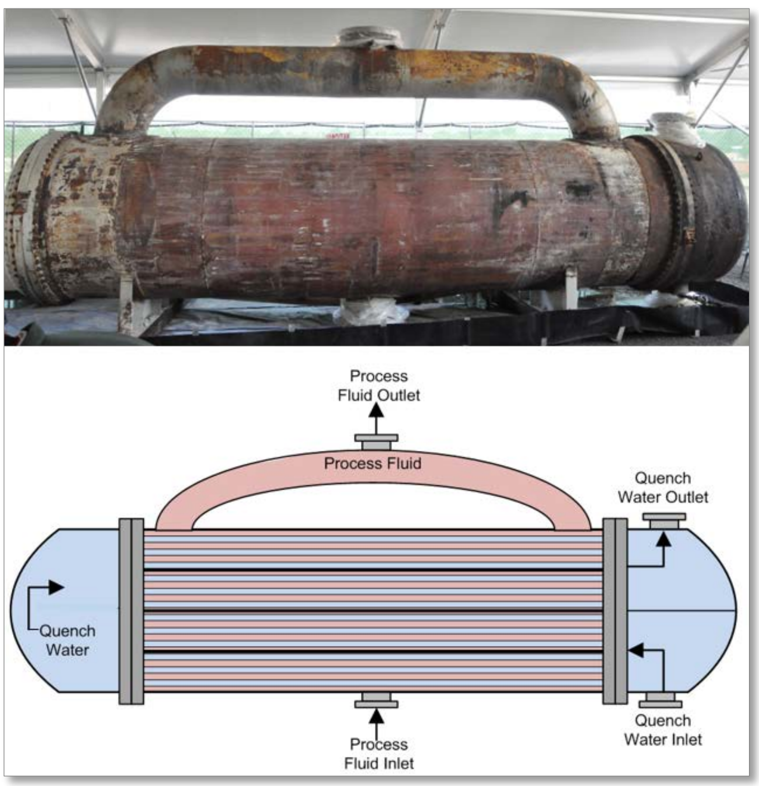

FIGURE 3

Propylene fractionator reboiler.

[11] The heat exchangers are 24 feet 8 inches long end-to-end. Each exchanger shell (the portion of the heat exchanger that holds the tube bundle) is approximately 18.5 feet long and over 5 feet in diameter. The tubes are each ¾-inch in diameter, and each heat exchanger contains 3,020 tubes. To put this in perspective, if one were to lay each tube from one heat exchanger end-to-end in a straight line, the tubes would span over 10.5 miles.

[12] C4s are hydrocarbon molecules that contain four carbon atoms. For example, butane (C_4H_{10}) is a C4 molecule.

[13] Depicted in Figure 3 as a two-pass heat exchanger for purposes of simplicity, the reboilers were six-pass heat exchangers.

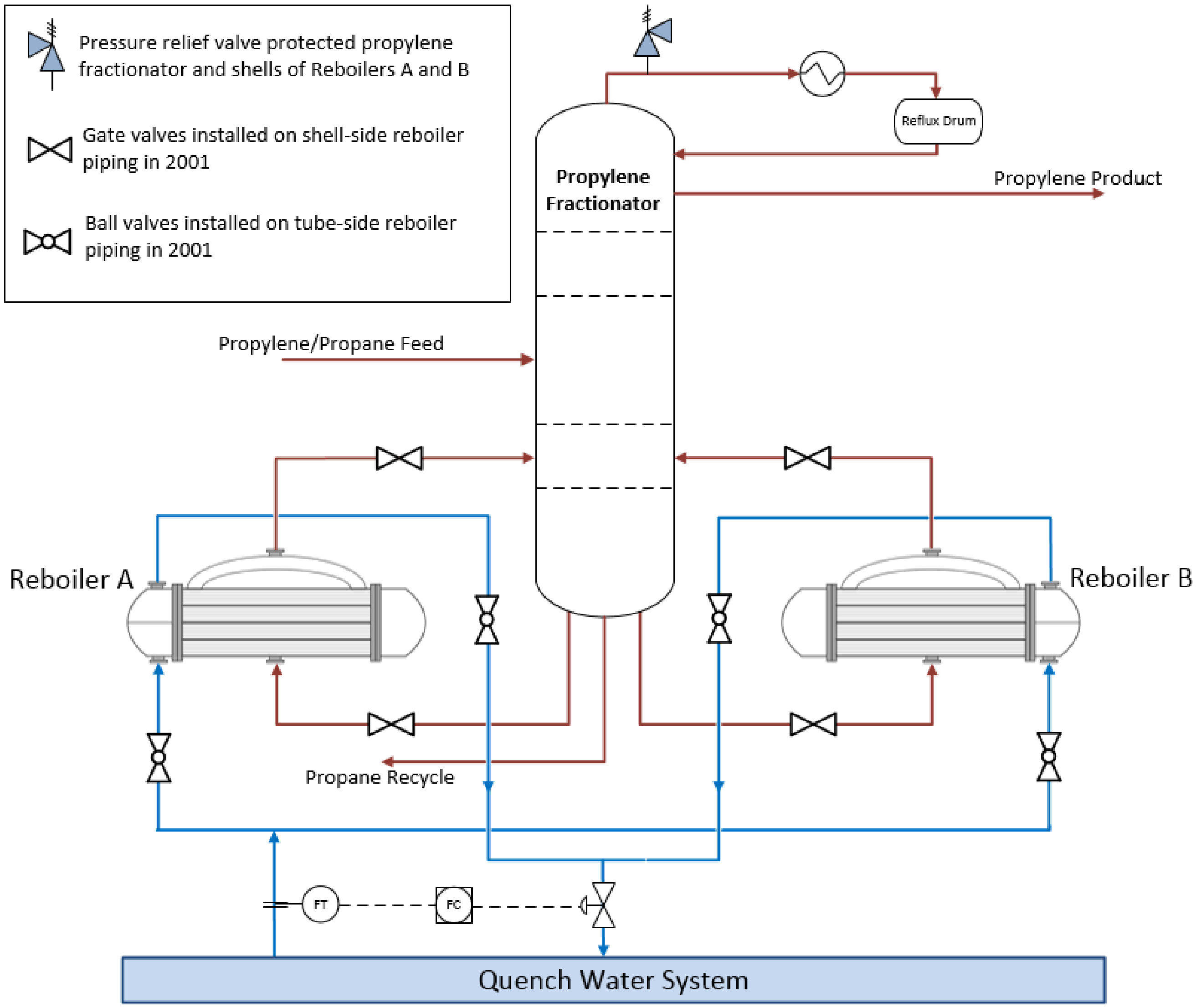

FIGURE 4

Propylene fractionator schematic. This schematic represents the equipment configuration at the time of the incident. The valves (gate valves) isolating the reboilers from the pressure relief valve at the top of the propylene fractionator were not part of the original design, and were installed in 2001. Section 5.1 provides additional information about these valves.

3.0 THE INCIDENT

On June 13, 2013, during a daily morning meeting with operations and maintenance personnel, the plant manager noted that the quench water flow through the operating propylene fractionator reboiler (Reboiler A) had dropped gradually over the past day (Figure 5). The group then analyzed plant data and noticed the entire quench water circulation rate seemed to be impaired. An operations supervisor, who Williams often relied on to troubleshoot and mitigate operational problems, informed the group that he would try to determine what caused the drop in flow. After evaluating the quench water system in the field, the operations supervisor informed several other personnel that fouling within the operating reboiler (Reboiler A) could be the problem and they might need to switch the propylene fractionator reboilers to correct the quench water flow. The operations supervisor attempted to meet with the operations manager to discuss switching the reboilers—a typical chain of communication—so that they could begin getting the necessary maintenance and operations personnel involved who needed to perform the work. The operations manager was not available, however, and the operations supervisor decided to return to the field and continue evaluating the quench water system.

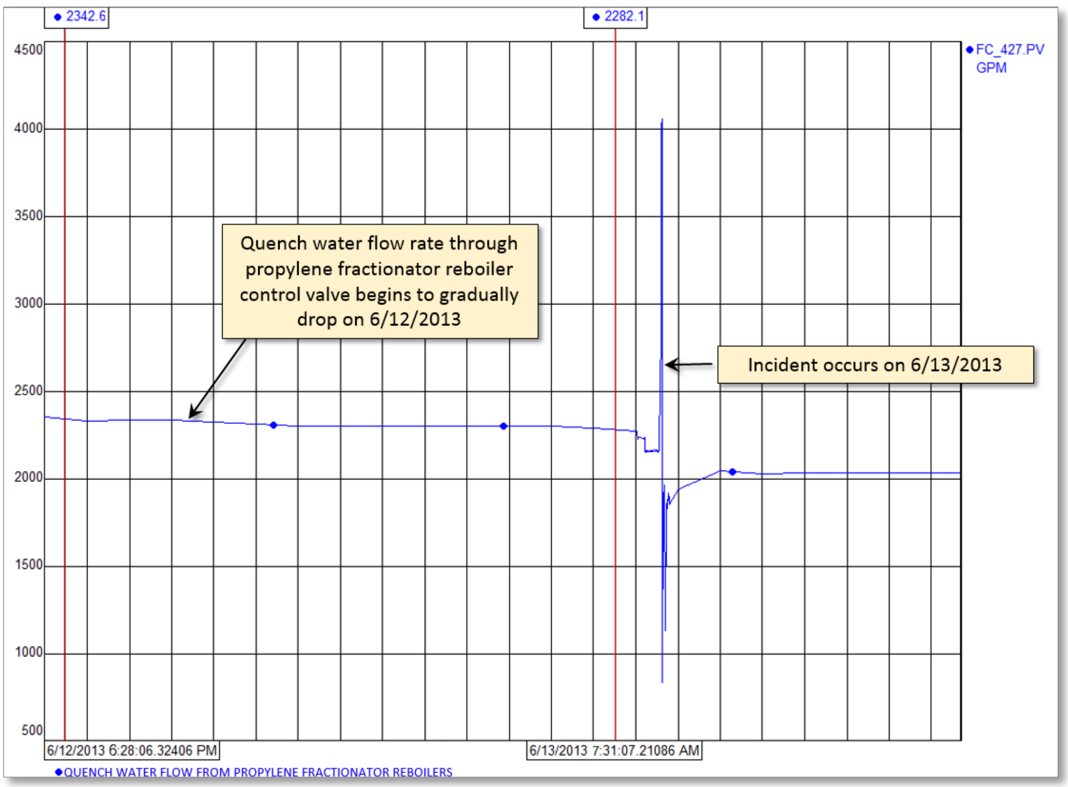

FIGURE 5

Graph of quench water flow rate through propylene fractionator Reboiler A prior to incident. Williams personnel identified that quench water flow rate had dropped.

The CSB determined that at 8:33 am, the operations supervisor likely opened the quench water valves on the offline reboiler, Reboiler B, as indicated by the rapid increase in quench water flow rate shown in Figure 6. Approximately three minutes later, Reboiler B exploded (Figure 7). Propane and propylene process fluid erupted from the ruptured reboiler and from the propylene fractionator due to failed piping. The process vapor ignited, creating a massive fireball. The force of the explosion launched a portion of the propylene fractionator reboiler piping into a pipe rack approximately 30 feet overhead (Figure 8).

A Williams operator working near the propylene fractionator at the time of the explosion died at the scene. The operations supervisor succumbed to severe burn injuries the next day. The explosion and fire also injured Williams employees and contractors who were working on a Williams facility expansion project—167 personnel reported injuries.[14] The fire lasted approximately 3.5 hours, and Williams reported releasing over 30,000 pounds of flammable hydrocarbons during the incident.[15] The plant remained down for 18 months and restarted in January 2015.

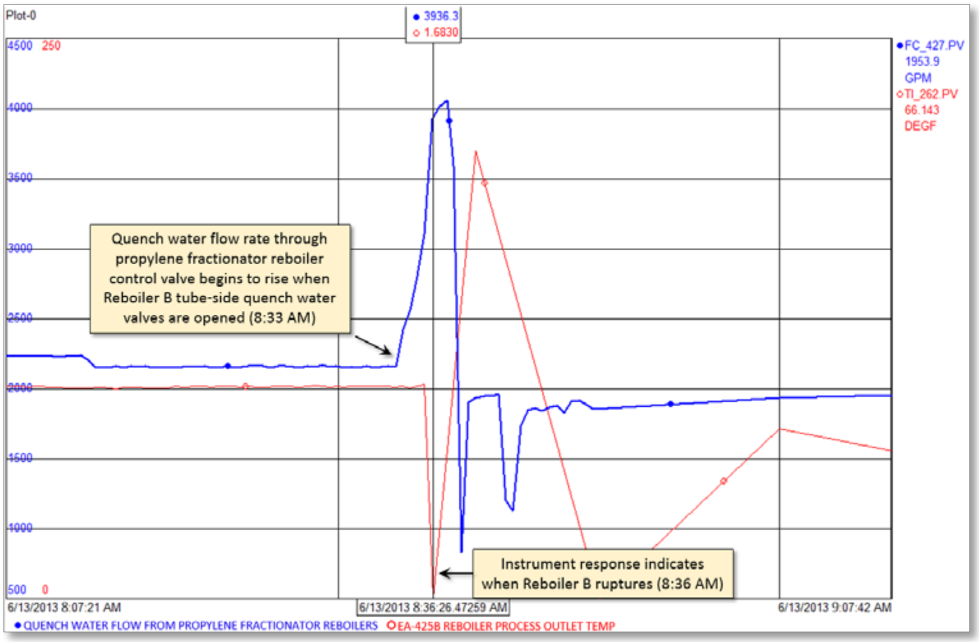

FIGURE 6

Graph of quench water flow rate immediately prior to incident. Quench water flow rate rises when Reboiler B tube-side quench water valves are opened. Reboiler B ruptures approximately three minutes later.

FIGURE 7

Post-incident photo of the ruptured Reboiler B.

[14] Of the 167 workers who reported injuries, three were Williams employees and 164 were contractors.
[15] Louisiana Department of Environmental Quality Incident Report. See http://edms.deq.louisiana.gov/app/doc/view.aspx?doc=8925500&ob=yes&child=yes at p 2 (accessed August 28, 2016).

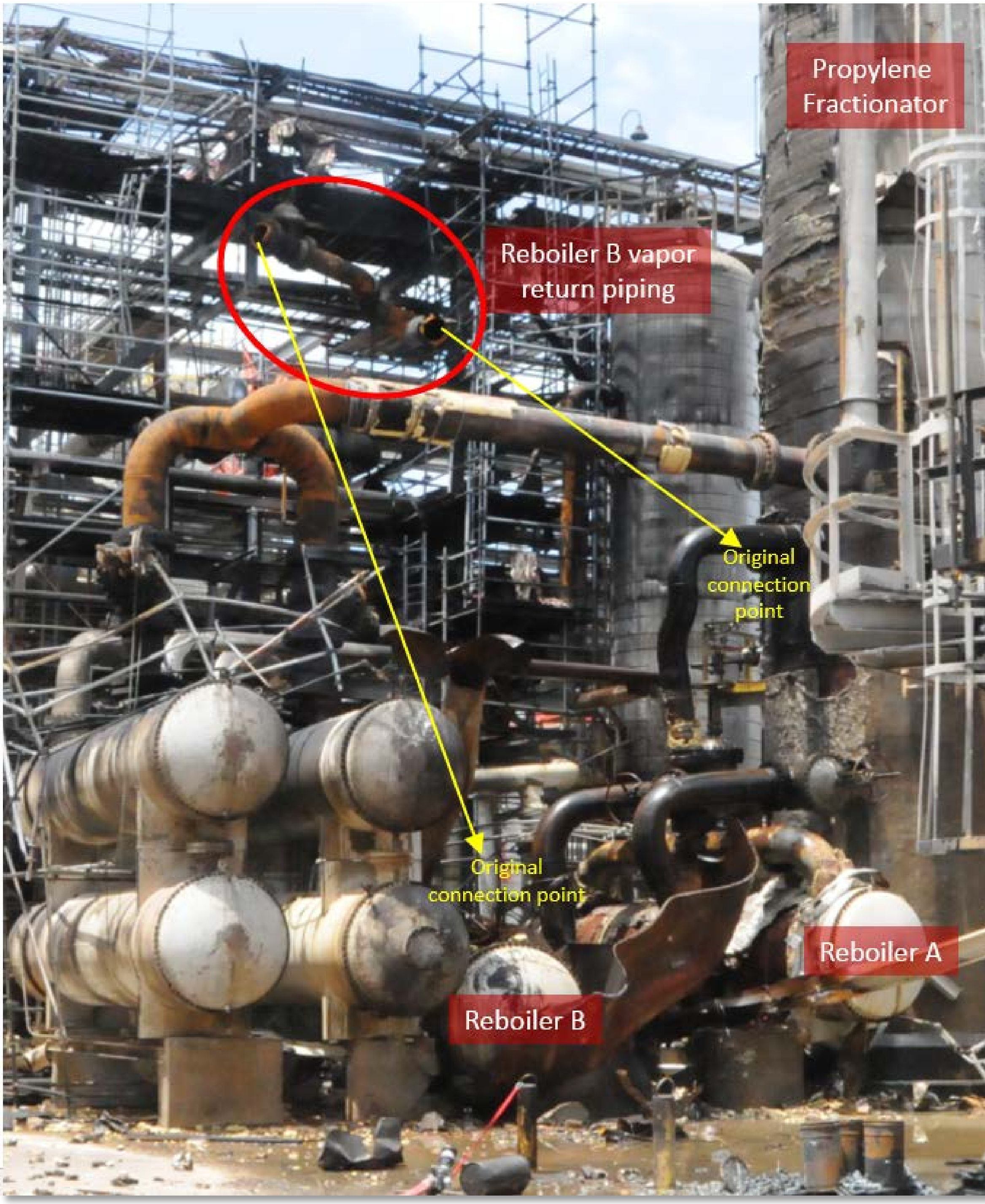

FIGURE 8

Post-incident photo of the propylene fractionator reboilers and surrounding area. The Reboiler B vapor return piping can be seen overhead in the pipe rack (red circle). The approximate original configuration of the piping and equipment is shown in Figure 9 and Figure 14.

4.0 TECHNICAL ANALYSIS

The CSB commissioned metallurgical testing of the ruptured Reboiler B by agreement among Williams, OSHA, and the CSB.[16] The metallurgical testing found that the propylene fractionator Reboiler B failed, resulting in the formation of a crack, at a high internal pressure estimated to be between 674 and 1,212 pounds per square inch gauge (psig). The CSB concluded that a pressure of this magnitude was likely the result of liquid thermal expansion in the liquid propane-filled and blocked-in Reboiler B shell, which overpressured the heat exchanger while it was isolated from its pressure relief device.[17] The initial crack formation quickly progressed to catastrophic vessel failure, which resulted in a boiling liquid expanding vapor explosion (BLEVE) (see Section 4.2 for a technical description of the BLEVE mechanism).

4.1 FAILURE OF REBOILER B

As explained above, following the 2001 valve installation, Williams Geismar operated one propylene fractionator reboiler at a time, keeping the other reboiler offline—in a configuration Williams called "standby." After the operating reboiler fouled, Williams operations staff would put the standby reboiler online. They would then shut down, drain, blind,[18] and clean the fouled reboiler. Next, they would remove the blinds and pressurize the reboiler with nitrogen,[19] leaving the inlet and outlet block valves isolating the standby, nitrogen-filled reboiler shell from the propylene fractionator process fluid. The reboiler remained on standby, typically for a couple of years, until the second, now operating reboiler fouled.

4.1.1 STANDBY REBOILER B CONTAINED LIQUID PROPANE

Williams performed maintenance on Reboiler B in February 2012. Following this maintenance activity, workers left Reboiler B on standby, reportedly filled with nitrogen and isolated from the process by a single closed block valve on the inlet piping and a single closed block valve on the outlet piping. The CSB determined that between the 2012 maintenance activity and the day of the incident—a period of 16 months—flammable liquid propane accumulated on the shell side of the standby Reboiler B (Figure 9).[20] The propane could have entered the standby reboiler via a mistakenly opened valve, leaking block valve(s), or another unknown mechanism.[21] (Depending on the scenario that allowed propane to enter the reboiler, the nitrogen could have compressed and/or been pushed from the reboiler into the process.) Williams had not installed instrumentation to detect process fluid within the reboiler. As a result, Williams personnel did not know that the standby Reboiler B contained liquid propane.[22]

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[16] The metallurgical report is located in Appendix C.

[17] See Appendix B.

[18] A blind is a metal plate inserted between flanges to ensure positive isolation of a vessel from the process.

[19] Nitrogen is often used to fill a standby vessel because it is an inert gas. It is used to reduce the oxygen concentration in equipment in order to eliminate the possibility of a flammable mixture within the vessel or process.

[20] Discussed in Appendix B, the reboiler was at least 65.5 vol% full of liquid propane.

[21] Large gate valves such as the ones installed on the Williams reboilers are known to leak. The American Petroleum Institute (API) specifies allowable leakage rates through closed valves. For 16-inch and 18-inch valves such as the inlet valve and outlet valve on the propylene fractionator reboilers, API specifies an allowable leakage rate of 64 and 72 bubbles of gas per minute, respectively, during leak testing of the valves. (See API Standard 598, 9th ed. *Valve Inspection and Testing*, September 2009, p 10.) The reboiler block valves were leak tested following the incident. Their leakage rate was within that allowed by API Standard 598. While valve leakage likely allowed some process fluid to enter Reboiler B while it was on standby, a different mechanism could have introduced the bulk of the process fluid to the standby reboiler.

[22] Records indicate that Williams filled the Reboiler B shell with nitrogen, to a pressure of approximately 50 psig, during a 2012 maintenance activity. Reboiler B did not have a pressure gauge installed on its shell to allow for periodic monitoring. A pressure gauge could have alerted the operations supervisor that the Reboiler B shell was at a pressure of at least 124 psig (the equilibrium vapor pressure of the process fluid at ambient temperature). This could have served as an indication that process fluid had entered the Reboiler B shell.

KEY LESSON

Closed gate (block) valves leak, and they are susceptible to inadvertent opening. Both scenarios can introduce process fluids to offline equipment. More robust isolation methods, such as inserting a blind, can better protect offline equipment from accumulation of process fluid.

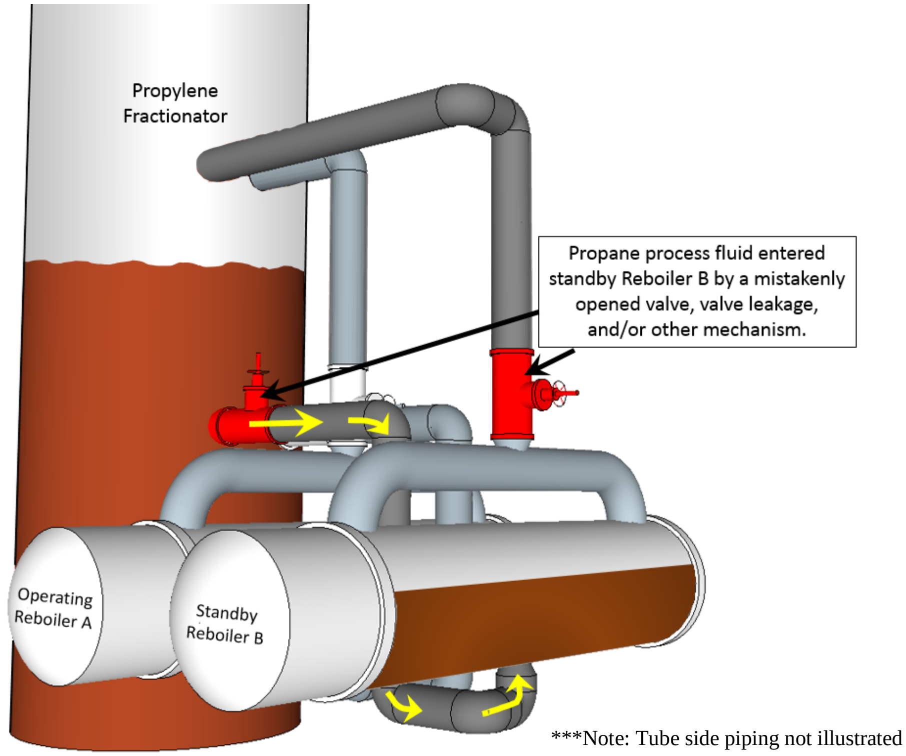

FIGURE 9

Propane process fluid mixture entered standby Reboiler B by a mistakenly opened valve, valve leakage, and/or another mechanism.

4.1.2 Failure of Reboiler B Due to Liquid Thermal Expansion

Post-incident field observations identified that the Reboiler B tube-side hot quench water valves were in the open position (Figure 10). The shell-side process valves were closed, which isolated the shell of Reboiler B from its protective pressure relief valve on the top of the propylene fractionator (Figure 4). This valve alignment shows that heat was introduced into a closed system (i.e., the blocked-in Reboiler B shell).

When the Reboiler B hot quench water valves were opened, the liquid propane within the standby Reboiler B shell began to heat up. This caused the liquid propane to increase in volume due to liquid thermal expansion,[23] filling any remaining occupiable vapor space within the shell. When the liquid could no longer expand due to confinement within the blocked-in Reboiler B shell, the pressure rapidly increased[24] until the internal pressure exceeded the shell's mechanical pressure limit (Figure 11), and the reboiler shell failed.[25]

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[23] Thermal expansion is the increase in volume of a given mass of a solid, liquid, or gas as it is heated to a higher temperature.

[24] The liquid propane expanded and pressurized the reboiler faster than the vessel contents could escape through the leaking block valves.

[25] The 2008 Goodyear Tire and Rubber Company explosion, investigated by the CSB, also occurred when heat was introduced to a heat exchanger that did not have an open path to its pressure relief device. That incident killed one person and injured six others. See the CSB's final investigation report on the incident: Chemical Safety Board Website. *Heat exchanger rupture and ammonia release in Houston, Texas*. http://www.csb.gov/goodyear-heat-exchanger-rupture/ (Accessed August 17, 2016).

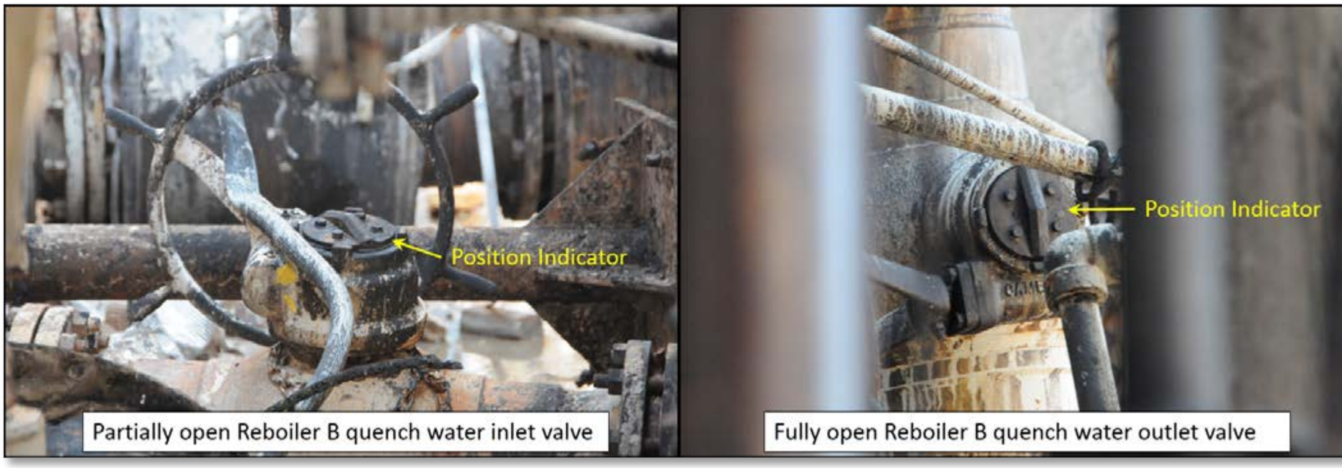


FIGURE 10

Post-incident, the Reboiler B quench water inlet ball valve was found partially open (left), and the Reboiler B quench water outlet ball valve was found fully open (right). When the position indicator is parallel to the pipe, the valve is open; when the position indicator is perpendicular to the pipe, the valve is closed.

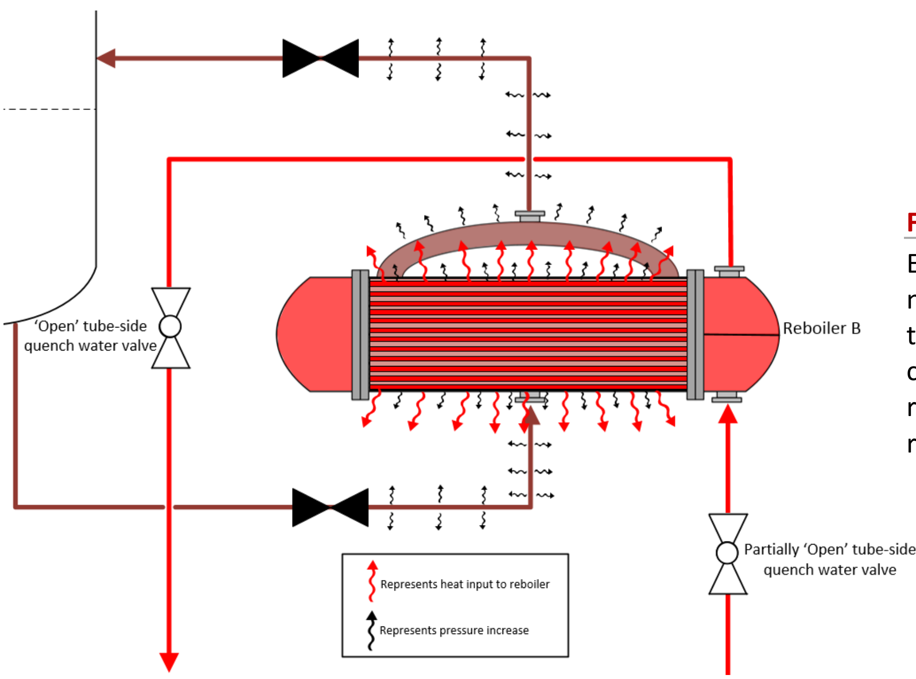


FIGURE 11

Expanding shell-side liquid propane could not sufficiently increase in volume due to the lack of overpressure protection and the closed shell-side process valves. As a result, shell-side pressure increased until reboiler shell failed.

"Equipment or pipelines which are full of liquid under no-flow conditions are subject to hydraulic expansion due to increase in temperature and, therefore, require overpressure protection. Sources of heat that cause this thermal expansion are solar radiation, heat tracing, heating coils, heat transfer from the atmosphere or other equipment. Another cause of overpressure is a heat exchanger blocked-in on the cold side while the flow continues on the hot side." Center for Chemical Process Safety (CCPS), Guidelines for Engineering Design for Process Safety, 2nd ed., 2012

What is a BLEVE?

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.[i] This explosive release creates an overpressure wave that can propel vessel fragments, damage nearby equipment and buildings, and injure people. If the pressurized liquid is flammable, a fireball or vapor cloud explosion often occurs. BLEVEs often result in the failed vessel flattened on the ground.

Fireball from propane BLEVE experiment.[ii]

Vessel flattened on ground following BLEVE.[iii]

i. Birk, A.M.; Davison, C.; Cunningham, M.; Blast Overpressures from Medium Scale BLEVE Tests. *Journal of Loss Prevention in the Process Industries*, 2007, vol. 20, pp 194-206.
ii.http://me.queensu.ca/People/Birk/Research/ThermalHazards/bleve/FieldTrials2000-2002.html (accessed August 17, 2016).
iii. Birk, A.M.; VanderSteen, J.D.J.; Davison, C.; Cunningham, M.H.; Mirzazadeh, I.; *PRV Field Trials – The Effects of Fire Conditions and PRV Blowdown on Propane Tank Survivability in a Fire, TP 14045E*, Transport Canada, 2003.

4.2 Boiling Liquid Expanding Vapor Explosion (BLEVE)

The high pressure generated from liquid thermal expansion of the propane cracked the reboiler shell. The shell contents began to vaporize near the crack opening, and a jet release of liquid and vapor accelerated out of the crack. The pressure loading on the open edges of the crack caused the crack to continue to grow along the vessel length. As the crack opening increased in size, the liquid and vapor jet release also rapidly grew. The continued internal pressure caused the reboiler shell to fail suddenly and catastrophically, splitting wide open (Figure 7 and Figure 12).

With the shell confinement suddenly gone, the bulk of the shell contents abruptly lowered to atmospheric pressure. At atmospheric pressure, the liquid propane was above its boiling point (i.e. in a superheated state). (The atmospheric boiling point of the propane mixture was approximately -43 °F,[26] and the liquid propane mixture was at a much higher temperature.) The propane explosively released into the surrounding area: propane vapor violently expanded and the superheated liquid rapidly vaporized. This type of explosion is known as a BLEVE.[27]

The propane then found an ignition source and ignited, creating a massive fireball. The blast effects flattened the reboiler shell (Figure 12).

[26] Found using Aspen HYSYS simulation of Williams' design composition of the propylene fractionator bottoms.
[27] Center for Chemical Process Safety (CCPS). *Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards*, 2nd ed.; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p 311.

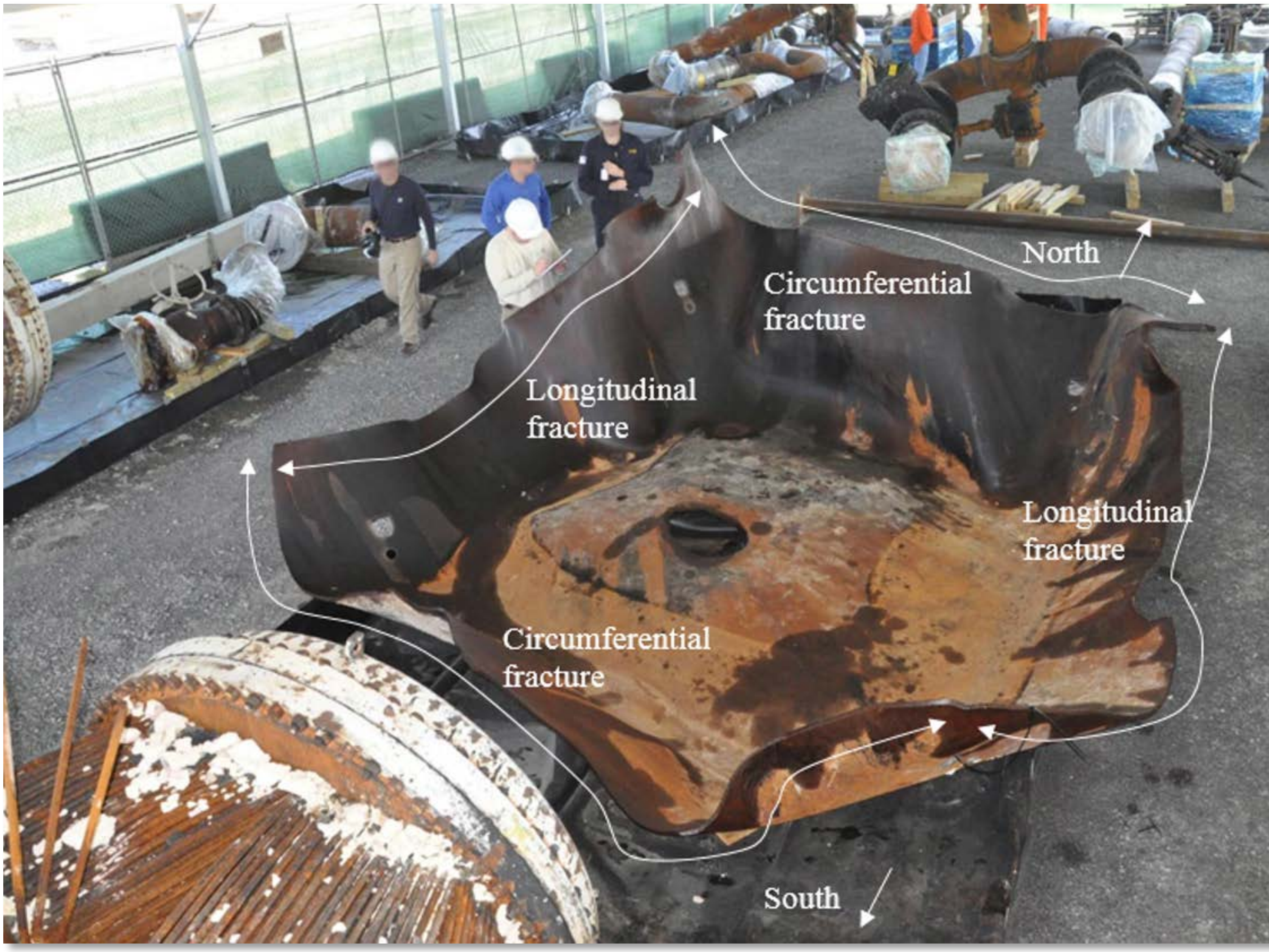


FIGURE 12

Post-incident photo of Reboiler B shell. The pressure forces during the event flattened the cylindrical steel reboiler shell.

Process Safety Culture

In recent years, process safety culture has been a topic of increased focus within the chemical process industry. "Safety Culture" is often simply described as "the way we do things around here," or "how we behave when no one is watching." The chemical process industry has defined process safety culture as "[t]he common set of values, behaviors, and norms at all levels in a facility or in the wider organization that affect process safety."[i]

A significant determinant of an organization's process safety culture is the quality of its written safety management programs (e.g., process safety management procedures, including PHA, MOC, PSSR, operating procedures; and written corporate policies) and how well individuals within the organization, ranging from the CEO to the field operator, implement those programs. The Center for Chemical Process Safety has labeled these two facets as "Conduct of Operations" and "Operational Discipline," respectively.[ii]

Improving an organization's process safety culture starts with management. Managers can help to set a high bar for the organization's commitment to effectively implementing safety management programs and company expectations.

i. Center for Chemical Process Safety (CCPS). *Conduct of Operations and Operational Discipline—For Improving Process Safety in Industry*; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2011.
ii. *Ibid.*

5.0 Analysis of Williams Geismar Process Safety Management Programs

As will be explained in this section, the ineffective implementation of the Williams Geismar process safety management programs[28] (Figure 13 shows a timeline of the program deficiencies during the 12 years leading to the incident), as well as weaknesses in Williams' written programs themselves, were causal to the incident. Weaknesses in these programs resulted from a culture at the facility that did not foster and support strong process safety performance. Discussed in the following sections, Williams Geismar's process safety management program deficiencies that contributed to the incident include:

(1) Williams did not perform adequate Management of Change (MOC) or Pre-Startup Safety Reviews (PSSRs) for two significant process changes involving the propylene fractionator reboilers—the installation of block valves and the addition of car seals (see Section 5.1 and Section 5.2.2.1).[29] As a result, the company did not evaluate and control all hazards introduced to the process by those changes. Not identifying and controlling the new process overpressurization hazard was causal to the incident;

(2) Williams did not adequately implement action items developed during Process Hazard Analyses (PHAs) or recommendations from a contracted pressure relief system engineering analysis (see Section 5.2 and Section 5.4). Consequently, Williams did not effectively apply overpressure protection by either a pressure relief valve or by administrative controls to the standby Reboiler B; and

(3) Williams did not perform a hazard analysis and develop a procedure prior to the operations activities conducted on the day of the incident (see Section 5.3).

[28] Process safety management programs have been developed and described in industry good practice guidance (such as books published by the Center for Chemical Process Safety) and are required by both OSHA as part of its Process Safety Management (PSM) regulation and by the Environmental Protection Agency (EPA) as part of its Chemical Accident Prevention provisions (commonly referred to as its Risk Management Program (RMP) regulation). See 29 C.F.R. § 1910.119. Process Safety Management of Highly Hazardous Chemicals and 40 C.F.R. Part 68, Subpart D - Program 3 Prevention Program.

[29] A car seal is a mechanical device that physically locks a valve in the open or closed position to prevent manipulation by an unauthorized person. A car seal is an administrative control. Nonmandatory Appendix M-5 of ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, allows for the use of administrative controls such as car seals to ensure an open path between a pressure vessel and its pressure relief device(s).

When the quench water valves were opened, therefore, there were no safeguards to prevent high pressure on the shell side of the reboiler. Since the reboiler lacked adequate overpressure protection, introducing heat to the standby reboiler initiated the overpressure event that caused the reboiler to rupture catastrophically.

"The process safety culture of an organization is a significant determinant of how it will approach process risk control issues, and process safety management system failures can often be linked to cultural deficiencies. Accordingly, enlightened organizations are increasingly seeking to identify and address such cultural root causes of process safety performance problems." CCPS, Guidelines for Risk Based Process Safety, 2007.

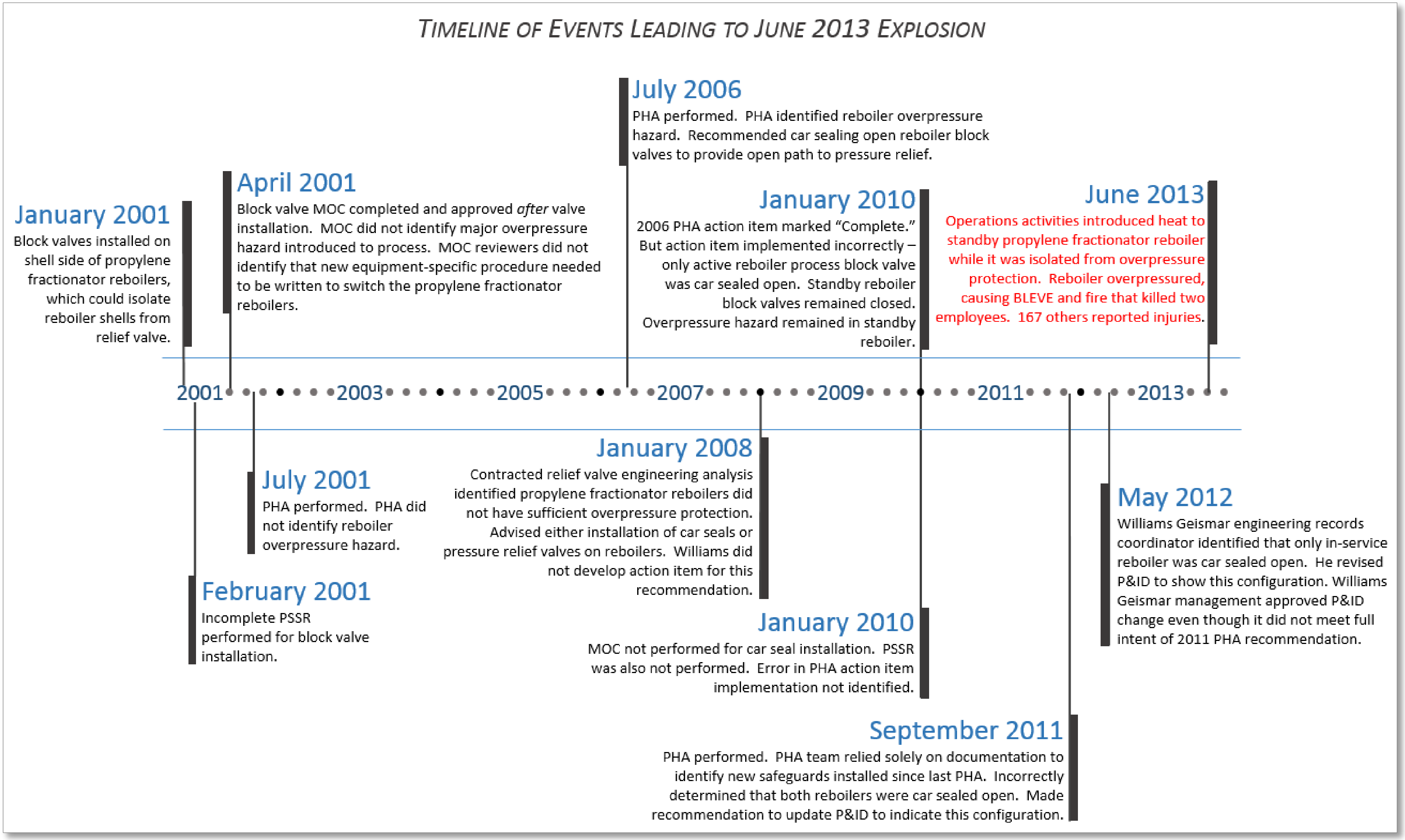
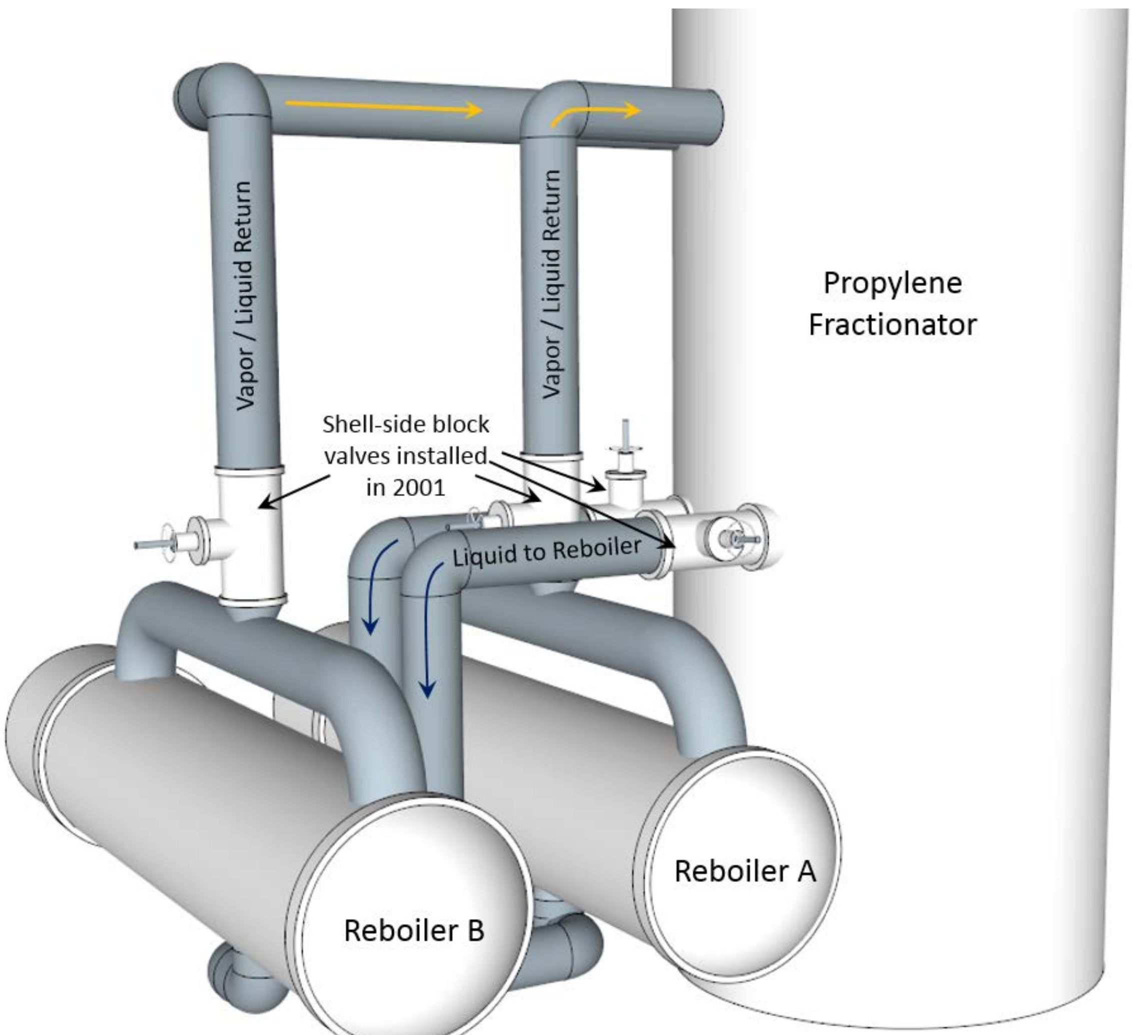


FIGURE 13

Timeline of events leading to the June 2013 incident.

5.1 Reboiler Valves Installation

The original 1967 design of the propylene fractionator required both Reboiler A and Reboiler B in service at the same time. This design had no valves between the reboilers and the propylene fractionator, protecting the two reboilers from overpressure with the relief device located on top of the propylene fractionator. In subsequent years, Williams determined that the propylene fractionator could operate with only one reboiler in service. Operating with a single reboiler allowed continuous propylene fractionator operation and avoided shutdowns when the reboiler tubes fouled and required cleaning. To implement single reboiler operation, in 2000 Williams Geismar management approved a $270,000 investment to install valves on both the process side and quench water side of six of the quench water heat exchangers, including the propylene fractionator's Reboiler A and Reboiler B. In 2001, Williams installed the valves (Figure 14); however, Williams did not identify the overpressure hazard that resulted from this change.



***Note: Tube-side piping not illustrated

FIGURE 14

Illustration of the propylene fractionator reboilers prior to the incident, with shell-side piping shown. The four shell-side process valves were installed in 2001.

KEY LESSON

Robust Management of Change (MOC) practices are needed to ensure the review analyzes hazards in the entire process *affected* by the change. Similar to PHAs, conducting MOC reviews as a multidisciplinary group—composed of individuals with different experiences and different areas of expertise—can assist in identifying hazards introduced by a process change. Companies must conduct MOCs *before* implementing a change in the field, and should not treat them as a paperwork or check-the-box exercise.

5.1.1 Valve Installation Management of Change

Industry good practice guidance advises—and the OSHA PSM regulation and the EPA RMP regulation require—chemical process facilities to conduct a Management of Change (MOC) review before making a change to a covered process, such as a change in equipment.[30] Among other requirements, OSHA and EPA require that a facility's MOC reviews consider the impact of the change on safety and health, and whether operating procedures need modifications. OSHA and EPA also require that companies train affected employees on the change prior to startup or implementation.[31]

In 2001, Williams performed one MOC to cover the installation of valves on the six quench water heat exchangers identified in the 2000 proposal, including the propylene fractionator Reboiler A and Reboiler B. The Williams MOC process required the Operations Department, Maintenance Department, Technical Department, Environmental Department, Safety Department, and Project Engineering Department to consider the potential safety implications of installing the valves. They did this by answering checklist questions used to prompt targeted analysis for each department. Department managers were required to respond to each prompt by checking "yes," "no," or "n/a" (not applicable). While MOC checklists can ensure consideration of common hazards and typical change requirements, the Williams MOC reviewers nevertheless did not identify the serious overpressure hazards introduced by installing valves on the reboilers.[32]

[30] 29 C.F.R. § 1910.119(l) and 40 C.F.R. § 68.75.
[31] 29 C.F.R. § 1910.119(l)(3) and 40 C.F.R. § 68.75.
[32] Installing block valves into a process can introduce overpressure hazards to process equipment. The ASME Boiler and Pressure Vessel Code allows block valves to be installed in a relief path where there is normally process flow, as long as the user provides a method of overpressure protection, such as applying administrative controls, mechanical locking elements, valve failure controls, and valve operation controls to provide an open path between the vessel and its pressure relief device(s). See American Society of Mechanical Engineers. *ASME Boiler and Pressure Vessel Code*, 2015. Section VIII, Division 1, UG-135 and Nonmandatory Appendix M-5.7(3).

5.1.1.1 MANAGEMENT OF CHANGE PERFORMED AFTER VALVE INSTALLATION

The MOC process at Williams intended to provide a method[33] to identify and control[34] all possible hazards presented by a process change *before* making the process change in the facility.[35] Williams, however, did not perform an MOC before installing and commissioning the new block valves on the reboilers. In fact, Williams did not perform the MOC until after the plant was operating with the new valves.[36] The MOC was an after-the-fact activity for Williams to address a regulatory requirement rather than an effective tool used to identify and control new process hazards prior to installing the new equipment.

When "it is difficult to get all of the required authorizations prior to implementation of the change […] [a]bove all, this indicates that there is a potential process safety culture issue that must be addressed. Site management should not tolerate the startup of a change prior to obtaining the necessary authorizations." CCPS, Guidelines for Management of Change for Process Safety, 2008.

5.1.1.2 MANAGEMENT OF CHANGE DID NOT IDENTIFY SIGNIFICANT HAZARDS

Installing block valves into a process where they previously did not exist is a significant process change that needs careful safety analysis during the MOC review. But the Williams 2001 MOC review did not identify the significant overpressure hazard introduced by the valves. Figure 15 highlights portions of the Williams MOC that the CSB identified as ineffective assessment of the change presented by the new valves. These weaknesses include:

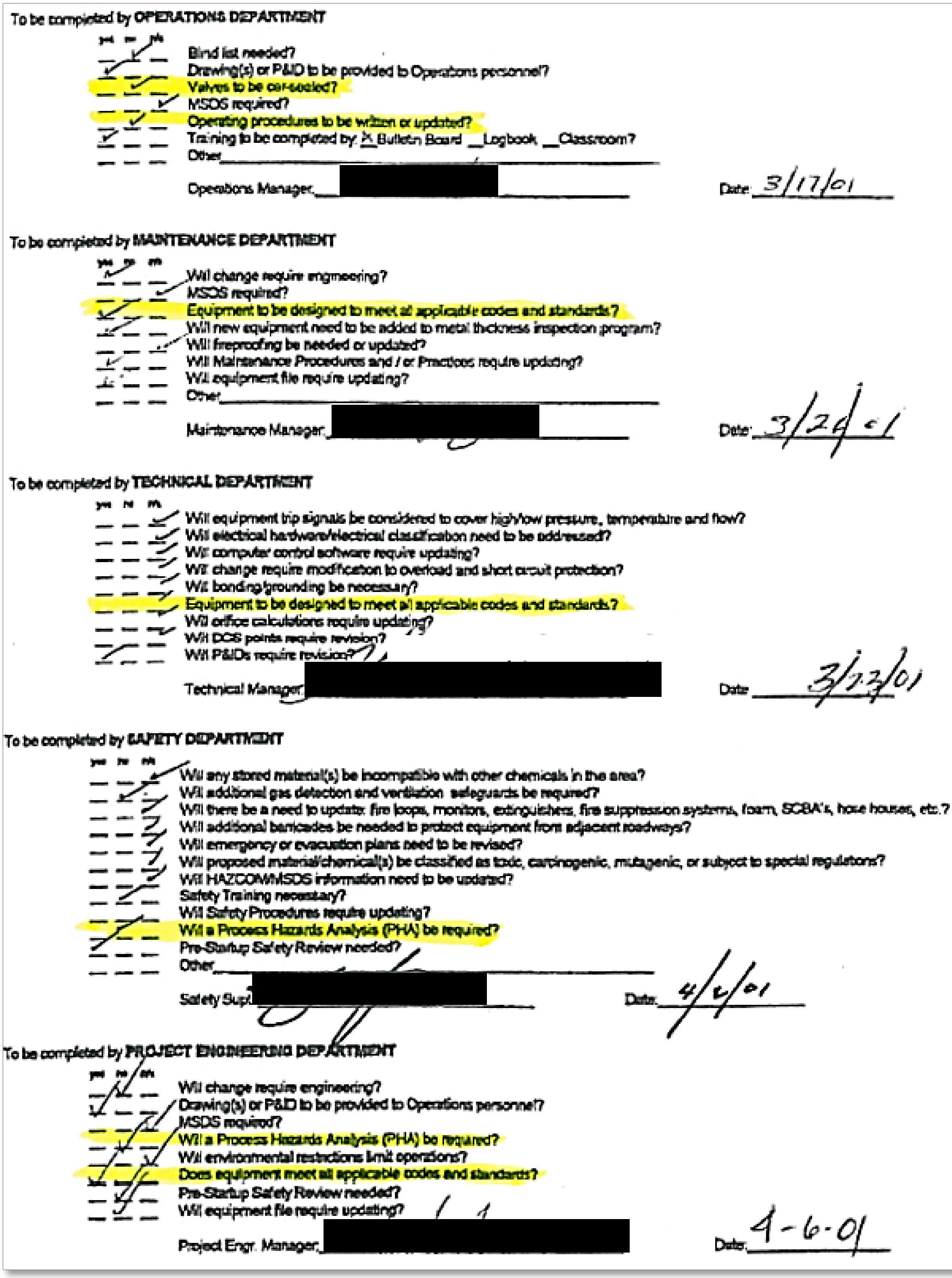
(1) The Williams MOC failed to identify or control the overpressure hazard. The MOC reviewers indicated that the valves did not have to be car sealed open (Figure 15), which would have provided overpressure protection for the reboilers. The option of using a car seal was the only specified overpressure protection method on the MOC checklist, even though in this case installing pressure relief valves could be a better option. Nevertheless, the MOC reviewers did not identify that the reboilers required overpressure protection—through either an open path to a pressure relief device using a car sealed open valve, or by installing a pressure relief device on each reboiler;

[33] The Williams Geismar MOC procedure states, "the purpose of the MOC review process is to include a safety/health, environmental, technical, mechanical, engineering, and operations review of the change. Changes shall be reviewed for impact on safeguards, critical instrument systems, pressure relief systems, equipment inspection programs, operability of equipment, constraints in currently approved process or mechanical design, and operating procedures."

[34] The OSHA PSM and EPA RMP regulations do not specify that the purpose of the MOC is to identify and control hazards introduced by the process change. Rather, the regulations specify that the "impact of change on safety and health" must be considered. Industry guidance publications, as well as Williams' internal MOC procedure, specify that MOCs should identify and control hazards introduced by the change prior to startup.

[35] OSHA PSM and EPA RMP regulations require MOCs prior to the change. See 29 C.F.R. § 1910.119(l)(2) and 40 C.F.R. § 68.75(b).

[36] Plant data indicates the unit was shut down between January 4, 2001 and February 20, 2001. The valves were installed during this period. The PSSR for the valves' installation was performed on February 1, 2001, but the MOC was not initiated until March 2, 2001, and was not approved until April 6, 2001. OSHA PSM requires the MOC prior to implementing the change. See 29 C.F.R. § 1910.119(l)(2).



To be completed by OPERATIONS DEPARTMENT

yes no n/a

Blind list needed?
Drawing(s) or P&ID to be provided to Operations personnel?
Valves to be car-sealed?
MSDS required?
Operating procedures to be written or updated?
Training to be completed by: X Bulletin Board __Logbook __Classroom?
Other__________

Operations Manager [redacted] Date: 3/17/01

To be completed by MAINTENANCE DEPARTMENT

yes no n/a

Will change require engineering?
MSDS required?
Equipment to be designed to meet all applicable codes and standards?
Will new equipment need to be added to metal thickness inspection program?
Will fireproofing be needed or updated?
Will Maintenance Procedures and / or Practices require updating?
Will equipment file require updating?
Other__________

Maintenance Manager [redacted] Date: 3/24/01

To be completed by TECHNICAL DEPARTMENT

yes no n/a

Will equipment trip signals be considered to cover high/low pressure, temperature and flow?
Will electrical hardware/electrical classification need to be addressed?
Will computer control software require updating?
Will change require modification to overload and short circuit protection?
Will bonding/grounding be necessary?
Equipment to be designed to meet all applicable codes and standards?
Will orifice calculations require updating?
Will DCS points require revision?
Will P&IDs require revision?

Technical Manager [redacted] Date: 3/22/01

To be completed by SAFETY DEPARTMENT

yes no n/a

Will any stored material(s) be incompatible with other chemicals in the area?
Will additional gas detection and ventilation safeguards be required?
Will there be a need to update: fire loops, monitors, extinguishers, fire suppression systems, foam, SCBA's, hose houses, etc.?
Will additional barricades be needed to protect equipment from adjacent roadways?
Will emergency or evacuation plans need to be revised?
Will proposed material/chemical(s) be classified as toxic, carcinogenic, mutagenic, or subject to special regulations?
Will HAZCOM/MSDS information need to be updated?
Safety Training necessary?
Will Safety Procedures require updating?
Will a Process Hazards Analysis (PHA) be required?
Pre-Startup Safety Review needed?
Other__________

Safety Supt. [redacted] Date: 4/6/01

To be completed by PROJECT ENGINEERING DEPARTMENT

yes no n/a

Will change require engineering?
Drawing(s) or P&ID to be provided to Operations personnel?
MSDS required?
Will a Process Hazards Analysis (PHA) be required?
Will environmental restrictions limit operations?
Does equipment meet all applicable codes and standards?
Pre-Startup Safety Review needed?
Will equipment file require updating?

Project Engr. Manager [redacted] Date: 4-6-01

FIGURE 15

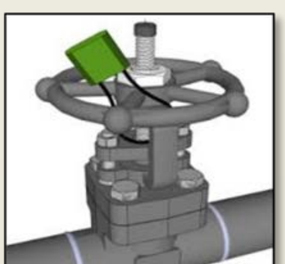
Portion of the MOC performed by Williams for the installation of the valves on Reboilers A and B. Yellow highlights indicate weaknesses in MOC analysis. Note: Image of document is poor quality.

Overpressure Protection Methods

"Overpressure" in equipment occurs when the equipment is subjected to a pressure that exceeds a pre-defined pressure limit, such as the maximum allowable working pressure (MAWP). Such defined pressure limits are used to prevent equipment mechanical failure due to excess pressure. There are several methods to protect equipment from overpressure. One is the use of a pressure relief valve. Pressure relief valves are designed to open and relieve excess pressure by releasing process fluids from equipment when the equipment reaches a specified pressure set point. They are an "active control" that requires no human activation to function.

Photo of a pressure relief valve

Overpressure protection can also be provided to equipment by ensuring an open path to pressure relief by a locked open block valve. Valves are commonly locked open by using a "car seal," a mechanical device that physically locks a valve in the open or closed position to prevent manipulation by an unauthorized person. Car seals are "administrative controls" that rely on human operation. They can be more prone to failure than active controls.



Depiction of a Car Seal[i]

i. Car seal depiction from Total Lockout Website. *Car Seals*. http://www.totallockout.com/online-store/car-seals-2/ (accessed November 19, 2015).

(2) The MOC reviewers incorrectly indicated that existing operating procedures were adequate to account for the new valves, even though there was no procedure specifically for switching the propylene fractionator reboilers. The CSB found that Williams Geismar had relied on its generic procedure, last revised in 1996, to start up any reboiler within the entire facility. Williams considered this generic procedure applicable to start up the propylene fractionator Reboiler B; however, Williams' generic procedure was based on the assumption that all reboilers had the process fluid on the tube side of the reboiler (Figure 16), which was not the configuration of the propylene fractionator Reboiler B. As a result, attempting to use this generic procedure to start up Reboiler B could be confusing to workers and could result in initiating an overpressure scenario on the shell side of Reboiler B—a pressure vessel that was not equipped with a protective pressure relief device. A robust, equipment-specific procedure detailing the steps to switch the propylene fractionator reboilers should communicate the importance of opening the process valves (cold side) before opening the quench water valves (hot side), and should communicate the importance of overpressure protection. The MOC process is intended to trigger—and should have triggered—the development of such a procedure: a procedure that is equipment-specific and addresses the hazards of the operation;

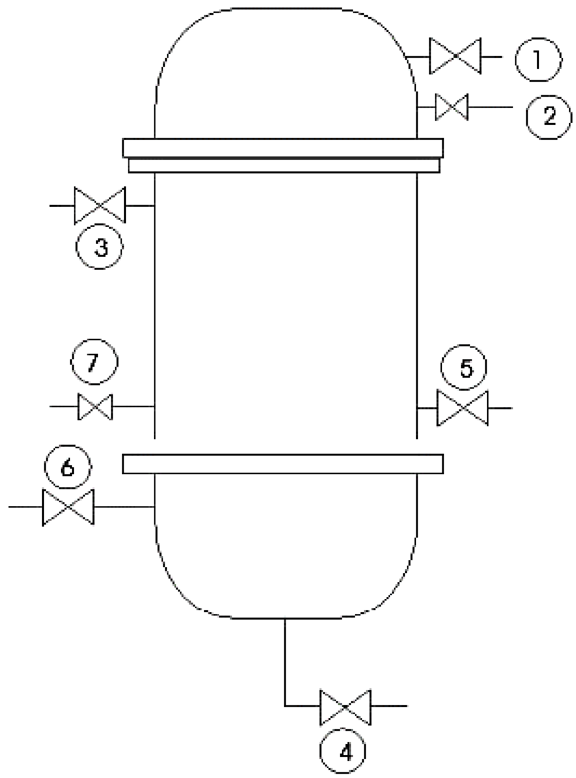
(3) The MOC reviewers improperly indicated that the change did not require a Process Hazard Analysis (PHA), a more robust hazard evaluation option performed at the discretion of the MOC reviewers. The installation of the valves introduced a serious overpressure hazard to the reboilers, and a formal PHA would have been the best opportunity to identify and control that hazard; and

(4) The MOC reviewers selected incorrect responses regarding whether the new equipment met all applicable codes and standards. Reviewers indicated either the valves met all codes and standards, or that the question was not applicable. The addition of the valves without ensuring overpressure protection for the reboilers, however, does not meet requirements within industry codes and standards by the American Petroleum Institute (API), and the American Society of Mechanical Engineers (ASME).[37]

[37] Louisiana has not adopted Section VIII of the ASME Boiler and Pressure Vessel Code; however, Williams Geismar specified in site policy documents that they will follow the Code's requirements.

Williams Olefins 8.1.12.3

Putting a Generic Reboiler in Service



Valve #	Description
1	Process Outlet
2	Tube Side Bleed
3	Shell Side Inlet2-in. Unloading Valve
4	Tube Side Bleed
5	Shell Side Outlet
6	Process Inlet
7	Shell Side Bleed

FIGURE 16

Schematic from the Williams Geismar Generic Reboiler Startup Procedure. This was the applicable procedure to startup the propylene fractionator reboilers. Since the procedure uses the reverse of the Reboiler B configuration, it can be confusing, and workers could initiate a high-pressure scenario on the shell (process) side. Williams had not equipped this reboiler with a protective pressure relief device.

KEY LESSON

Pre-Startup Safety Reviews (PSSRs) are key opportunities to verify effective implementation of design intent, accuracy of process safety information, and proper installation and configuration of field equipment. Companies should conduct thorough and effective PSSRs before placing equipment in service.

The selected responses in the MOC checklist indicate that the reviewers focused largely on managing documentation and maintenance requirements for the new valves, such as needed process safety information updates and inspection requirements, and not on how the addition of the valves could affect the operability and safety of the overall process.

Not only does this "focus-on-the-new-equipment-only" approach to conducting Management of Change not meet the intent of regulatory requirements,[38] it can be dangerous. Williams introduced hazards that it did not fully understand or control.

5.1.1.3 Pre-Startup Safety Review Was Ineffective

Following the installation of the propylene fractionator Reboiler A and Reboiler B valves, Williams performed a Pre-Startup Safety Review (PSSR) as required by process safety management regulations.[39] Conducting the Williams PSSR required filling out a 21-question form. The CSB found that Williams reviewers either did not answer or incorrectly answered key PSSR process safety questions. Figure 17 shows a selection of these questions and their responses.

The Williams PSSR instructions directed the reviewer to "Circle the appropriate response." But each PSSR prompt question did not have a circled answer in the completed and management-approved documentation. The PSSR questions that Williams reviewers did not answer or answered incorrectly were areas that played a direct role in the June 13, 2013 incident. For example:

- No response was given to the question, "Has a process hazard analysis been completed, recommendations resolved, and incorporated in design as deemed appropriate?" A PHA was not conducted, which could have identified hazards introduced by the valves;

---

[38] The OSHA PSM and EPA RMP regulations require that Management of Change procedures shall ensure that the "impact of change on safety and health" is considered and addressed prior to the change. See 29 C.F.R. § 1910.119(l)(2)(ii) and 40 C.F.R. § 68.75(b)(2).

[39] The OSHA Process Safety Management (PSM) regulation requires that "[t]he employer shall perform a pre-startup safety review for new facilities and for modified facilities when the modification is significant enough to require a change in the process safety information." See 29 C.F.R. § 1910.119(i)(1). The EPA RMP regulation requires that "[t]he owner or operator shall perform a pre-startup safety review for new stationary sources and for modified stationary sources when the modification is significant enough to require a change in the process safety information." See 40 C.F.R. § 68.77. Both regulations also state that the pre-startup safety review shall confirm, "safety, operating, maintenance, and emergency procedures are in place and are adequate."

- No response was given to the questions regarding operator training, and PSSR reviewers incorrectly answered “yes” to the questions “Are all necessary operating procedures in place and current for safety, environmental, operating, emergencies, maintenance and technical?” and “Are procedures available for new and modified equipment?” Operations personnel were not effectively trained and procedures were not developed to address the new propylene fractionator reboiler startup requirements; and
- No response was given to the question, “PRV’s [pressure relief valves] lined up and block valves car sealed open? Pressure release systems in place and operational and traced where appropriate?” The company did not provide effective overpressure protection for the propylene fractionator reboilers.

When a company does not effectively implement its written safety management programs—such as only partially completing the PSSR document and incorrectly answering some of the document questions—it indicates a weakness in process safety culture (see Section 9.0). Management’s approval of incomplete documentation can lead to a culture of complacency and, therefore, subpar and incomplete process safety analyses. At a company with a strong commitment to effectively implementing process safety management programs, everyone—from the front line worker to company executives—should perceive incomplete documentation, such as this PSSR document, as unacceptable.

	Circle the appropriate response		
1. Has a process hazard analysis been completed, recommendations resolved, and incorporated in design as deemed appropriate?	Yes	No	Not Applic.
4. Is operations properly trained to startup and operate the facilities?	Yes	No	Not Applic.
6. Are all necessary operating procedures in place and current for safety, environmental, operating, emergencies, maintenance and technical?	Yes	No	Not Applic.
7. Is operations familiar with any operating changes for new or modified equipment?	Yes	No	Not Applic.
17. PRV's lined up and block valves car sealed open? Pressure release systems in place and operational and traced where appropriate?	Yes	No	Not Applic.
Are procedures available for new and modified equipment?	Yes	No	Not Applic.

FIGURE 17

Selection of responses on the checklist filled out during the PSSR performed following the 2001 reboiler valve installation. Several key process safety questions were not answered or were answered incorrectly.

“[U]nauthorized shortcuts should not be tolerated, even if there are short-term benefits.[…] In the absence of [operational discipline], management personnel intentionally turn a blind eye toward what workers do because they are only interested in achieving the desired results.” CCPS, Conduct of Operations and Operational Discipline, 2011.

KEY LESSON

Overpressure protection is an essential safeguard for all pressure vessels. PHA teams must ensure that all pressure vessels have effective overpressure protection. At a minimum, a pressure relief device is a necessary safeguard to protect process equipment from overpressure scenarios where internal vessel pressure can exceed design code limits.

5.2 Process Hazard Analyses

Both OSHA PSM and the EPA RMP regulations require covered facilities to perform or revalidate a Process Hazard Analysis (PHA) at least every five years to identify, evaluate, and control the hazards involved in the process.[40] Industry good practice publications provide guidance on how to conduct effective PHAs.[41]

Williams performed three PHAs following the installation of the valves on the propylene fractionator reboilers. Williams did not sufficiently implement the recommendations issued in those PHAs and did not effectively mitigate overpressure hazards in the propylene fractionator reboilers. This section analyzes the documented findings, recommendations, and actions taken pertaining to the propylene fractionator reboilers following the three PHAs, which Williams conducted in 2001, 2006, and 2011.

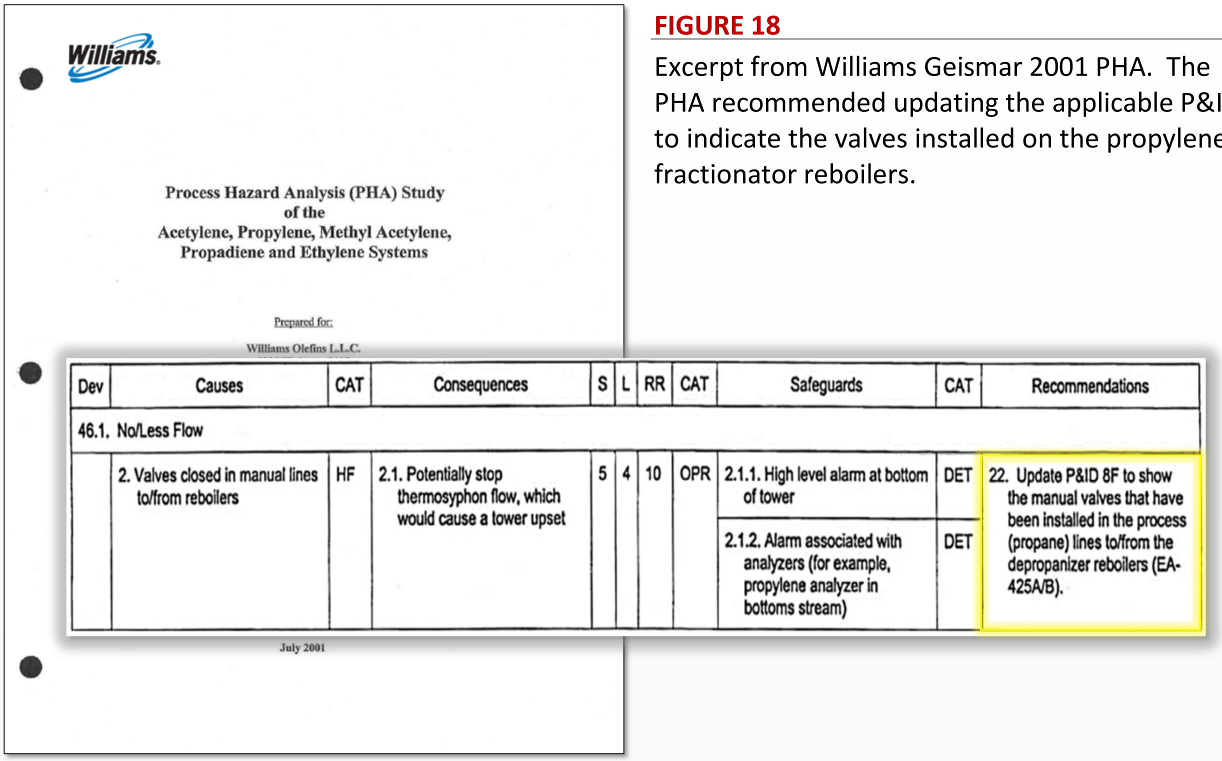
5.2.1 2001 PHA

Williams performed a PHA on the process area that included the propylene fractionator reboilers in 2001—the year Williams installed valves on the propylene fractionator reboiler piping. The 2001 PHA evaluated possible consequences of closing the propylene fractionator reboiler process valves when they should be open. The PHA team did not identify reboiler overpressure as a possible safety consequence. Instead, the team identified a low-severity process upset. The CSB notes that an effective PHA should have identified the more serious safety consequence of reboiler overpressure, as it is a typical potential hazard for a pressure vessel.

The PHA team correctly identified that the piping and instrumentation diagrams (P&IDs) did not show the new valves on the propylene fractionator reboilers. The PHA team recommended updating the relevant P&ID (Figure 18). The CSB notes that the P&ID update should have been required as part of the MOC process. In addition, the PSSR process should have reviewed a marked-up version of the P&ID showing the approved change. Such a review could have identified the significant error with the engineering drawing.

[40] 29 C.F.R. § 1910.119(e) and 40 C.F.R. § 68.67(f).

[41] See CCPS publications including Center for Chemical Process Safety (CCPS). *Guidelines for Hazard Evaluation Procedures*. 3rd ed.; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2008 and Frank, Walter L. and Whittle, David K. *Revalidating Process Hazard Analyses*. American Institute of Chemical Engineers: New York, New York, 2001.



Williams.

Process Hazard Analysis (PHA) Study
of the
Acetylene, Propylene, Methyl Acetylene,
Propadiene and Ethylene Systems

Prepared for:

Williams Olefins L.L.C.

Dev	Causes	CAT	Consequences	S	L	RR	CAT	Safeguards	CAT	Recommendations
46.1. No/Less Flow										
	2. Valves closed in manual lines to/from reboilers	HF	2.1. Potentially stop thermosyphon flow, which would cause a tower upset	5	4	10	OPR	2.1.1. High level alarm at bottom of tower	DET	22. Update P&ID 8F to show the manual valves that have been installed in the process (propane) lines to/from the depropanizer reboilers (EA-425A/B).
								2.1.2. Alarm associated with analyzers (for example, propylene analyzer in bottoms stream)	DET	

July 2001

FIGURE 18

Excerpt from Williams Geismar 2001 PHA. The PHA recommended updating the applicable P&ID to indicate the valves installed on the propylene fractionator reboilers.

5.2.2 2006 PHA

During the 2006 review, the PHA team emphasized evaluating whether equipment had sufficient overpressure protection. The PHA team identified that the propylene fractionator reboilers “potentially don’t have sufficient relief capabilities – could overpressurize equipment” (Figure 19). As a result, the PHA team issued the following recommendation:

> Consider locking open at least one of the manual valves associated with each of the propylene fractionator reboilers (EA-425 A/B) so that the relief valves on top of the propylene fractionator can provide thermal relief protection for these reboilers.

This 2006 PHA recommendation was marked “Complete” more than three years later in January 2010 in Williams’ action item tracking system. This action item, however, was not implemented as the PHA team had intended. The CSB found that only the shell-side outlet valve of the *operating* reboiler was car sealed open. The shell-side valves of the *standby* reboiler remained closed, with no car seals on the manual valves and no protective pressure relief device installed on the shell. This configuration isolated the standby reboiler from the relief device on top of the propylene fractionator, creating a high-risk scenario. This was an implementation error of the PHA recommendation. But as discussed in Section 5.2.2.1, the error remained unidentified because key process safety programs (i.e. MOC and PSSR), which could have identified the implementation error, were not performed.

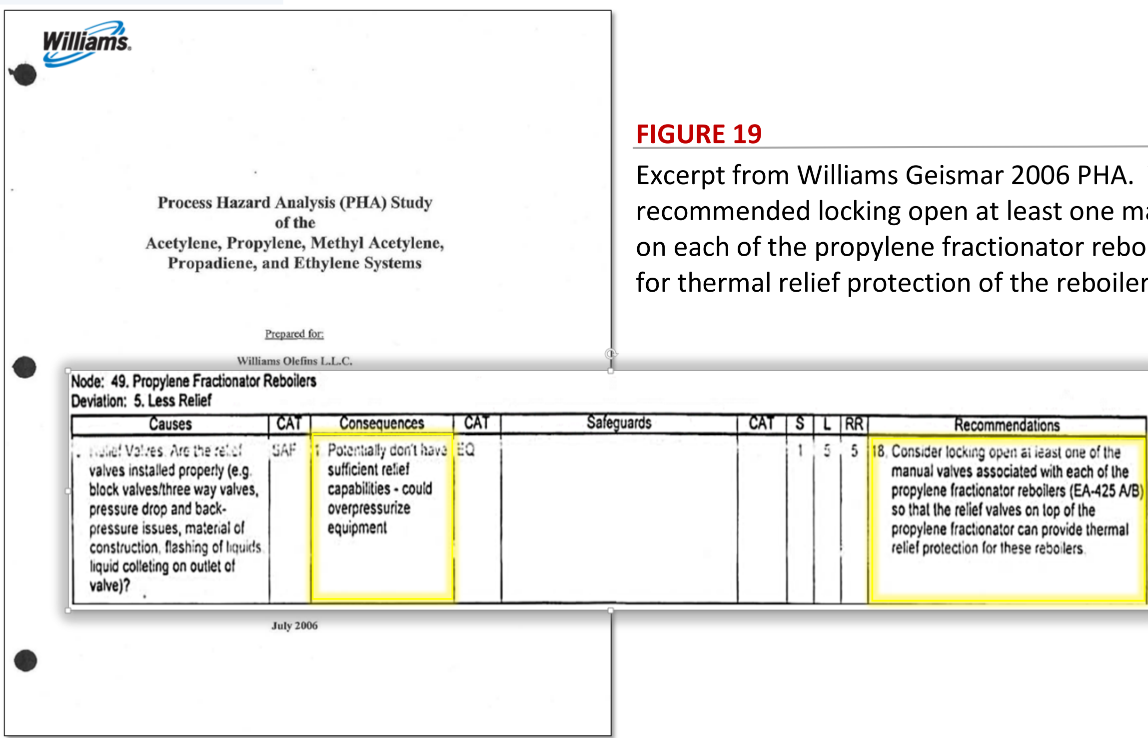
The CSB found that the contracted PHA facilitator was under the incorrect impression that both propylene fractionator reboilers operated at the same time. The CSB was not able to determine why the PHA team did not discuss that in practice only one reboiler operated at a time. This incorrect assumption likely contributed to the PHA team choosing car seals as the recommended overpressure protection strategy, as the shell-side valves would

KEY LESSON

It is important to ensure that the final implementation of PHA action items addresses the original safety concerns identified by the PHA team. Companies should ensure that action items have been effectively implemented and field verified before closing them out.

have to be open for both reboilers to operate. With the knowledge of the current practice—that only one reboiler operated at a time—a recommendation to car seal open both the operating and standby reboilers would be atypical; the standby reboiler would thus not be operating, but still open to the process and filled with process liquid. While unusual, this was a low corrosive and minimally fouling environment, and such a configuration would likely not harm equipment. This configuration, however, would have left an unnecessary inventory of hazardous chemicals in the process. An inherent safety review should identify the opportunity to minimize the hazardous chemical inventory by blinding the standby reboiler from the process.

The CSB notes that pressure relief valves (active safeguards) are a more robust safeguard compared to car seals (administrative safeguards), which are lower on the hierarchy of controls (Section 6.0). Administrative controls such as car seal programs fall low on the hierarchy of controls because of the many types of human factors[42] that can reduce or eliminate their effectiveness. Misunderstanding of what equipment to car seal in order to satisfy the 2006 PHA action item likely contributed to only partial completion of the action item, resulting in only the active reboiler being car sealed open. This misunderstanding likely stemmed from the fact it would have been unusual to car seal open the standby reboiler, and the recommendation to car seal open the standby reboiler was a result of confusion by the PHA team. Had the 2006 PHA team instead recommended installing pressure relief valves on both propylene fractionator reboilers, that action item would have been more difficult to implement incorrectly, as the relief valves would be newly installed, fixed equipment.



Process Hazard Analysis (PHA) Study
of the
Acetylene, Propylene, Methyl Acetylene,
Propadiene, and Ethylene Systems

Prepared for:

Williams Olefins L.L.C.

Node: 49. Propylene Fractionator Reboilers
Deviation: 5. Less Relief

Causes	CAT	Consequences	CAT	Safeguards	CAT	S	L	RR	Recommendations
Relief Valves. Are the relief valves installed properly (e.g. block valves/three way valves, pressure drop and back-pressure issues, material of construction, flashing of liquids, liquid colleting on outlet of valve)?	SAF	1. Potentially don't have sufficient relief capabilities - could overpressurize equipment	EQ			1	5	5	18. Consider locking open at least one of the manual valves associated with each of the propylene fractionator reboilers (EA-425 A/B) so that the relief valves on top of the propylene fractionator can provide thermal relief protection for these reboilers.

July 2006

FIGURE 19

Excerpt from Williams Geismar 2006 PHA. The PHA recommended locking open at least one manual valve on each of the propylene fractionator reboilers to allow for thermal relief protection of the reboilers.

[42] "Human factors" are the environmental, organizational, or job factors, as well as a person's individual characteristics, which can influence a person's actions in a way that can affect health and safety. See Health and Safety Executive (HSE), *Reducing Error and Influencing Behaviour*, 2009, p 5. http://www.hse.gov.uk/pubns/priced/hsg48.pdf (accessed September 7, 2016).

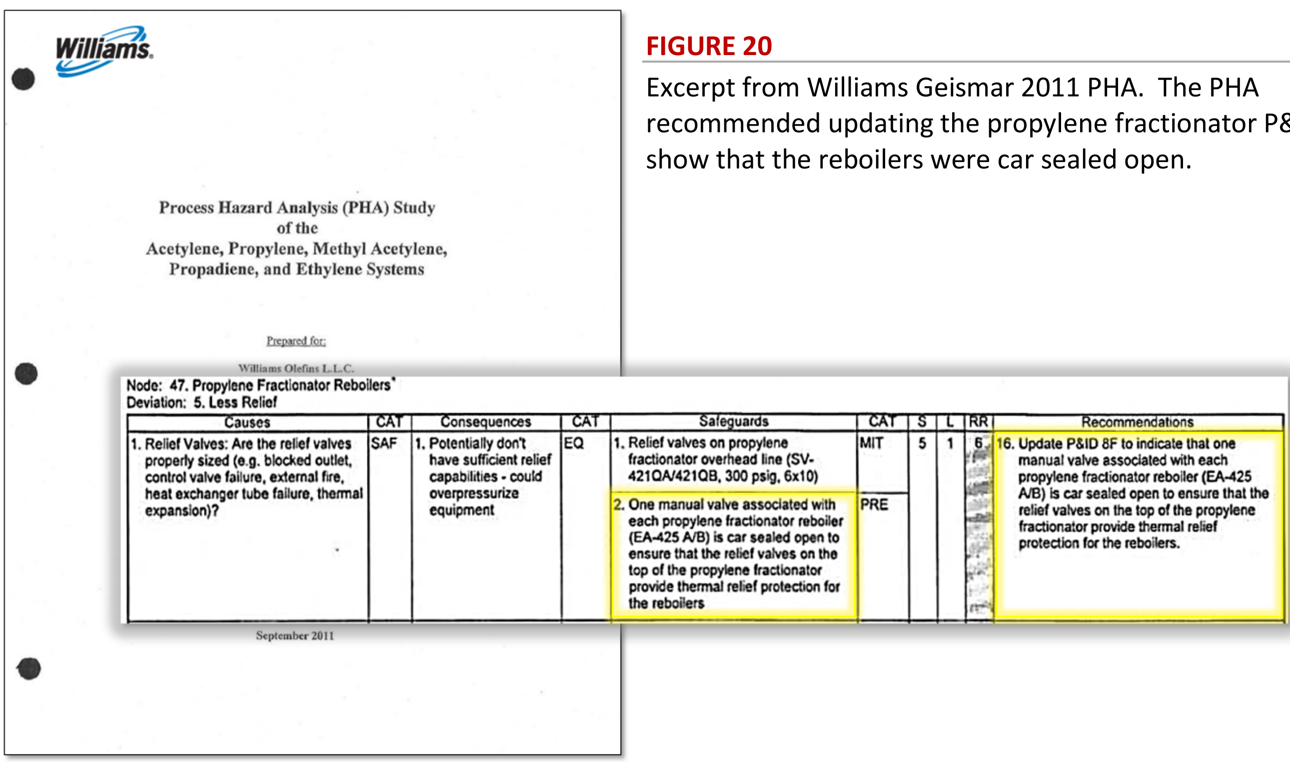
5.2.2.1 Management of Change Not Performed For Car Seal Installation

The installation of a car seal to lock open a propylene fractionator reboiler process valve—as recommended by the 2006 PHA—was a significant process change that required an MOC and a PSSR. But Williams did not perform an MOC or a PSSR for the installation of the car seal.[43] The field verification portion of the PSSR should have provided an opportunity to identify that the PHA action item to car seal open a process valve on *both* reboilers was not complete. Yet, the PSSR was never performed.

The CSB determined that Williams did not perform an MOC for the car seal installation likely because key operations personnel did not understand that an MOC was required. Also, before the June 13, 2013 incident, although prohibited by OSHA PSM regulatory requirements and company policies, at times Williams began fieldwork on a process change without a completed and approved MOC.

5.2.3 2011 PHA

The next PHA of the propylene fractionator was in 2011. This PHA relied on Williams' action item tracking system and MOC database to identify changes made to the process since the last PHA. The Williams PHA action item tracking system incorrectly indicated as "complete" the 2006 recommendation to lock open at least one of the manual process valves on each reboiler. Therefore, the PHA facilitator documented as safeguards in the 2011 spreadsheet that valves on both reboilers were car sealed open to provide relief protection (Figure 20). Williams did not perform a field verification of the documented safeguards as part of the PHA. As a result, they did not identify the discrepancy between documentation and the actual equipment installed in the field.



Williams

Process Hazard Analysis (PHA) Study
of the
Acetylene, Propylene, Methyl Acetylene,
Propadiene, and Ethylene Systems

Prepared for:

Williams Olefins L.L.C.

Node: 47. Propylene Fractionator Reboilers
Deviation: 5. Less Relief

Causes	CAT	Consequences	CAT	Safeguards	CAT	S	L	RR	Recommendations
1. Relief Valves: Are the relief valves properly sized (e.g. blocked outlet, control valve failure, external fire, heat exchanger tube failure, thermal expansion)?	SAF	1. Potentially don't have sufficient relief capabilities - could overpressurize equipment	EQ	1. Relief valves on propylene fractionator overhead line (SV-421QA/421QB, 300 psig, 6x10)	MIT	5	1	6	16. Update P&ID 8F to indicate that one manual valve associated with each propylene fractionator reboiler (EA-425 A/B) is car sealed open to ensure that the relief valves on the top of the propylene fractionator provide thermal relief protection for the reboilers.
				2. One manual valve associated with each propylene fractionator reboiler (EA-425 A/B) is car sealed open to ensure that the relief valves on the top of the propylene fractionator provide thermal relief protection for the reboilers	PRE				

September 2011

FIGURE 20

Excerpt from Williams Geismar 2011 PHA. The PHA recommended updating the propylene fractionator P&ID to show that the reboilers were car sealed open.

[43] Performing an MOC and PSSR for this type of process change was required by OSHA PSM, EPA RMP Regulation, and by the Williams Geismar internal site policy on Management of Change.

Relying on erroneous documentation that the outlet valve for each propylene fractionator reboiler was car sealed open, the 2011 PHA team identified that the applicable P&ID did not show the car seals. Therefore, the PHA team recommended updating the relevant P&ID (Figure 20):

> Update P&ID 8F to indicate that one manual valve associated with each propylene fractionator reboiler (EA-425 A/B) is car sealed open to ensure that the relief valves on top of the propylene fractionator provide thermal relief protection for the reboilers.

In a May 2012 email, the Engineering Records Coordinator communicated to the PSM Coordinator that "[a]ccording to the car seal list only the in service exchanger is to be car sealed open. I will put a note on the P&ID to reflect this." The Engineering Records Coordinator added a note to the applicable P&ID:

> The *in service* EA-425A/B Exchangers 18" block valve will be tagged (CSO) in the field to insure that the reboiler gets thermal protection from SV-421QA/QB.[44] (emphasis added).

This P&ID change did not address the full intent of the recommendation issued in the 2011 PHA because the standby reboiler valve was not car sealed open. Williams management, however, approved this recommendation as complete without verifying that the recommendation was implemented as intended. The PSM Coordinator tracked the status of the 2011 PHA recommendation as "Complete" in the PHA action item tracking spreadsheet, and did not include the additional emailed information provided by the Engineering Records Coordinator in the PHA action item tracking documentation.

Williams did not perform an MOC and PSSR for the installation of the car seal on the in-service propylene fractionator reboiler (see Section 5.2.2.1). Effectively performing these process safety programs could have identified that both reboilers required car seals and ensured accurate process safety information.

"More than ever before, companies recognize that insufficient control of changes plays a major role in accidents. … Experience has demonstrated that inadvertent, unintended, erroneous, or poorly performed changes – changes whose risk is not properly understood – can result in catastrophic fires, explosions, or toxic releases." CCPS, Guidelines for Management of Change for Process Safety, 2008

[44] "CSO" is an acronym for "car sealed open." "SV-421QA/QB" is the tag number for the pressure relief valves on top of the propylene fractionator.

KEY LESSON

Operating procedures need sufficient detail to ensure effective performance of critical steps, including performing steps in the correct order. Affected employees such as operators must receive training on the procedures. Management must establish expectations to maintain and follow accurate procedures.

5.3 Lack of Hazard Analysis And Operating Procedure

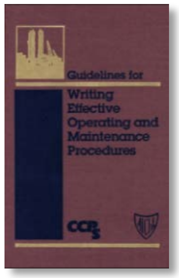
"[T]reating procedures as if they were equipment (just like a pump, valve, reactor, or safety system), is fundamental for building a successful Process Safety Management system. Who would start up a new process without all of the pumps in place and tested? What craftsperson would tackle a pump seal replacement without the required tools and parts? By accepting this idea, that procedures are components, the [concept of requiring effective procedures] will naturally fall into place." CCPS, Guidelines for Writing Effective Operating and Maintenance Procedures, 1996

On the day of the incident, a decreasing quench water flow through the propylene fractionator reboiler (Reboiler A) prompted the operations supervisor to enter the process unit to evaluate the cause of the decreased flow. During this evaluation, evidence indicates that the operations supervisor likely opened the quench water valves (hot side) on the standby reboiler (Reboiler B) while its shell-side process valves (cold side) remained closed, initiating the overpressure event. Prior to manipulating valves in the field, Williams did not conduct a hazard analysis and develop a procedure for the operations activity.[45] The CSB could not conclusively determine the reason for opening these valves.

As demonstrated by this incident, it can be hazardous to conduct field operations—both to personnel performing the operation and to personnel working in the vicinity—without first establishing procedures and evaluating and controlling hazards. As fouling in the quench water system was a known historical issue, Williams should have developed a procedure prior to the day of the incident detailing the method to assess the quench water system to identify the fouled heat exchanger. Furthermore, Williams could have better managed the heat exchanger fouling by establishing a routine maintenance schedule to take off-line and clean this equipment, which was known to foul, prior to the occurrence of any process deviations.

[45] OSHA issued a "Willful" violation to Williams, with a proposed fine of $70,000, for not developing and implementing "written operating procedures that provide clear instructions for safely conducting activities…" This citation was contested by Williams, and was ultimately reduced to a "Serious" violation with a fine of $7,000. This resulted in a total fine amount of $36,000 for the violations identified by OSHA following the incident. (OSHA Inspection Number 915682).

Detailed written procedures can ensure that operations activities are safe and hazards are effectively controlled. In its book *Guidelines for Writing Effective Operating and Maintenance Procedures*, the Center for Chemical Process Safety (CCPS) states:



> *Procedures should identify the hazards presented by the process. Procedures should also state precautions necessary to prevent accidental chemical release, exposure, and injury. Process safety information is an important resource in developing procedures. Using this information ensures that the known hazards are addressed properly.*[46]

When a process condition requires operator activity in the field, such as opening or closing valves, these operation activities can present hazards to workers. Before starting such field operations, a company's process safety management system should ensure a procedure is developed and a thorough hazard evaluation is performed to identify and control hazards.

5.4 Relief Valve Engineering Analysis

The ASME Boiler and Pressure Vessel Code requires that all pressure vessels "shall be provided with overpressure protection […]."[47] Williams contracted an engineering services firm to perform a relief valve engineering analysis of the Williams Geismar facility in 2008 to ensure the valves were properly sized for the equipment they were designed to protect. The analysis identified that the propylene fractionator reboilers did not have sufficient overpressure protection. A finding listed in the contractor's analysis states:

> There are block valves at the inlet and outlet to the shell side of [the propylene fractionator reboilers]. Because those valves are not [car sealed open], [the propylene fractionator relief valves] will not provide overpressure protection to the shell side of the reboilers in the event of a fire or in the event of liquid expanding/vaporizing due to heat input from the hot side. Unless these valves are car sealed open, additional overpressure protection will be needed for the shell side of [the propylene fractionator reboilers].

The engineer who performed the relief valve engineering analysis also directly emailed a Williams project engineer, alerting him of the lack of overpressure protection on the reboilers, and indicating the two options to provide overpressure protection to the reboilers. Figure 21 shows her email.

The CSB learned that Williams did not develop an action item to address this relief valve engineering analysis for the propylene fractionator reboilers. Williams determined their existing plan to car seal open both reboilers, from the recommendation in the 2006 PHA, would address the hazard. Because the company did not fully implement the 2006 PHA action item, this overpressure hazard remained unmitigated (see Section 5.2.2.).

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[46] Center for Chemical Process Safety (CCPS). *Guidelines for Writing Effective Operating and Maintenance Procedures*; American Institute of Chemical Engineers: New York, New York, 1996; p 18.

[47] American Society of Mechanical Engineers. *ASME Boiler and Pressure Vessel Code*, 2015. Section VIII, Division 1, UG-125.

From: [redacted]
To: [redacted]
Cc: [redacted]
Subject: Williams--PSV Study--SV-421QA/QB
Date: Monday, January 21, 2008 12:28:39 PM

[redacted],

I am working on SV-421QA/QB. It protects DA-406 Propylene Fractionator. There are block valves which are not CSO on the inlet and outlet of the reboilers, EA-425A/B; thus SV-421QA/QB will not protect the shell side of EA-425A/B from overpressure caused by fire or heat input from the hot side if the reboilers if the shell side is blocked in. The P&IDs don't show any overpressure protection for the shell side of the reboilers. There are two options to mitigate this problem:
1) Car seal open the valves on the inlet/outlet to the reboilers' shell side
2) Install two new relief valves to protect the shell side of EA-425A/B.
Please advise which option you prefer. I really appreciate your help.
Thanks,
[redacted]

FIGURE 21

Email from engineering services firm engineer to Williams employee alerting that the propylene fractionator reboilers were not protected from overpressure. In figure, "SV-421QA/QB" are the propylene fractionator relief valves. "DA-406" is the propylene fractionator column. "EA-425A/B" are the propylene fractionator reboilers.

KEY LESSON

PHA and MOC teams should effectively use the hierarchy of controls to the greatest extent feasible when evaluating safeguards. Pressure relief devices are typically more robust safeguards than car seals. Pressure relief devices (active safeguards) are higher on the hierarchy of controls than car seals (administrative controls).

6.0 HIERARCHY OF CONTROLS

The Hierarchy of Controls[48] is a method to provide effective risk reduction by applying, in order of robustness, inherently safer design, passive safeguards, active safeguards, and procedural safeguards (Figure 22).[49] This strategy promotes a tiered or hierarchical approach to risk management. The higher in the hierarchy, the more effective the risk reduction achieved. Applying the hierarchy of controls at the design phase is the best opportunity to ensure that process hazards are properly analyzed and risks are effectively reduced, before the design is implemented in the field. After the design phase, when construction is complete and the process is operating, process safety management programs such as MOC and PHA are important opportunities to apply the hierarchy of controls to further reduce risk throughout the life of a process.

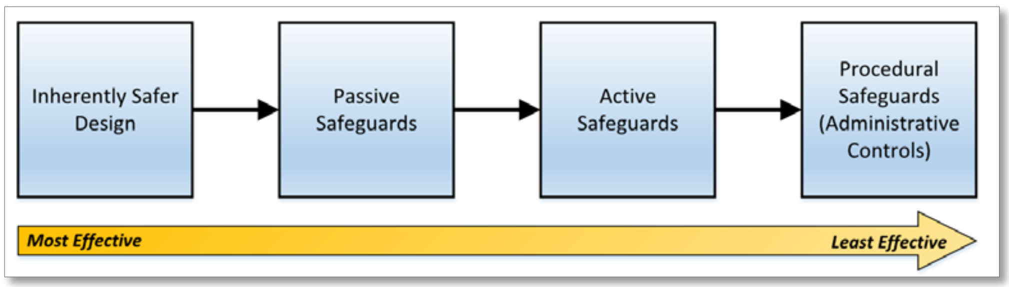

FIGURE 22

Hierarchy of Controls. The higher in the hierarchy (further to the left), the more effective the risk reduction achieved.

Williams did not effectively use the hierarchy of controls in the 2001 design change that added block valves to the propylene fractionator reboilers. Williams also missed key opportunities in its 2001, 2006, and 2011 PHAs to implement the hierarchy of controls when analyzing the risk of overpressure for the propylene fractionator reboilers.[50] Instead of applying inherently safer design, passive safeguards, or active safeguards—design strategies that are higher on the hierarchy of controls—Williams relied upon administrative controls to mitigate a serious overpressure hazard.

The use of a pressure relief valve is an "Active Safeguard"—a safeguard that requires a specific device to function when needed. Car seals, the safeguard chosen by Williams to provide a path to pressure relief for the reboilers, are

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[48] The CSB describes the concept of the "Hierarchy of Controls" in several previous investigation reports. See the CSB final reports on the Tesoro Anacortes Refinery investigation, the Chevron Richmond Refinery investigation, and "Key Lessons for Preventing Incidents from Flammable Chemicals in Educational Demonstrations." (accessed August 17, 2016)

[49] Center for Chemical Process Safety (CCPS). *Inherently Safer Chemical Processes – A Life Cycle Approach*. 2nd ed.; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2009; Section 2.1.

[50] As a result of its investigation of the 2012 Chevron refinery pipe rupture and fire in Richmond, California, the CSB recommended that the State of California update its process safety regulations to require the use of the hierarchy of controls in establishing safeguards for identified process hazards.

"Procedural Safeguards," also known as "Administrative Controls." Procedural safeguards require an action by a person, and are lower on the hierarchy of controls than active safeguards because of the many types of human factors that can reduce or eliminate their effectiveness.

During the 2011 PHA, Williams correctly identified the high potential severity from equipment rupture, but incorrectly assessed the likelihood of an overpressure incident (see severity (S) and likelihood (L) rating in Figure 20). The 2011 PHA team categorized the likelihood of a propylene fractionator reboiler overpressurization as "improbable." Such a low frequency indicates a weak evaluation and poor understanding of the availability of procedural safeguards such as car seals.

CCPS Layer of Protection Analysis guidance suggests that users consider pressure relief valves to have 99 percent availability,[51] while car seal availability is only 90 percent.[52] Therefore, installing a pressure relief valve on the shell side of each propylene fractionator reboiler, the design strategy Williams applied post-incident, is a more robust approach to reduce the likelihood of an overpressure event than the use of car seals, an administrative control that is more prone to failure, and in fact did fail in this case.

"Administrative controls provide another safeguard or layer of protection, but should not be relied on in lieu of practical engineered controls. Administrative approaches that require human action can increase the likelihood of human error." CCPS, A Practical Approach to Hazard Identification for Operations and Maintenance Workers, 2010

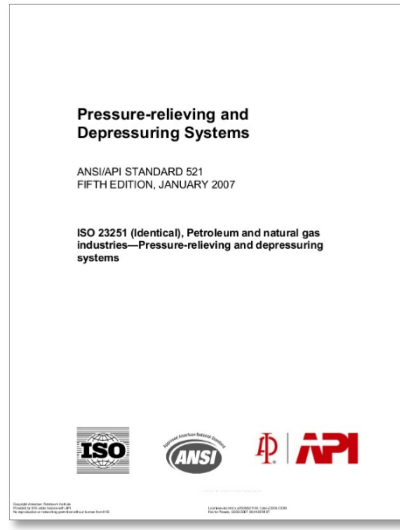
[51] CCPS provides a value of 0.01 as the generic probability of failure on demand for spring-operated pressure relief valves. See Center for Chemical Process Safety (CCPS). *Guidelines for Initiating Events and Independent Protection Layers in Layer of Protection Analysis*; Center for Chemical Process Safety / American Institute of Chemical Engineers: New York, New York, 2014; p 180.

[52] CCPS provides a value of 0.1 as the generic probability of failure on demand for adjustable movement-limiting devices such as car seals. See Center for Chemical Process Safety (CCPS). *Guidelines for Initiating Events and Independent Protection Layers in Layer of Protection Analysis*; Center for Chemical Process Safety / American Institute of Chemical Engineers: New York, New York, 2014; p 260.

7.0 INDUSTRY CODES AND STANDARDS

The American Petroleum Institute (API), the American Society of Mechanical Engineers (ASME), and The National Board of Boiler and Pressure Vessel Inspectors develop codes and standards that detail requirements and recommended practices for overpressure protection of pressure vessels.

7.1 AMERICAN PETROLEUM INSTITUTE


Pressure-relieving and Depressuring Systems

ANSI/API STANDARD 521
FIFTH EDITION, JANUARY 2007

ISO 23251 (Identical), Petroleum and natural gas industries—Pressure-relieving and depressuring systems

API is an industry trade association that develops standards and recommended practices for the oil and natural gas industry. These publications apply to petrochemical facilities, including the Williams Geismar Olefins Plant. At the time of the June 13, 2013 incident, the fifth edition (2007) of the API Standard 521, *Pressure-Relieving and Depressuring Systems* ("API 521-2007") was the recognized and generally accepted good engineering practice (RAGAGEP) for pressure relieving and disposal systems.

API 521-2007 divided guidelines into four main sections: causes of overpressure, determination of individual relieving rates, selection of disposal systems, and disposal systems. The CSB identifies below weaknesses and ambiguities in the "causes of overpressure" guidelines.

API 521-2007 does not specifically address the hierarchy of controls; however, the standard does address the use of administrative controls and recommends the user apply "good engineering judgment" or "sound engineering judgment."[53] API 521-2007 provides guidance regarding inadvertent closure of a manual block valve on the outlet of an on-stream pressure vessel, which is applicable to the valves on the Williams propylene fractionator reboilers. The guidance presents users with a choice between two seemingly equivalent options: either install a pressure relief device or develop an administrative control. The API 521-2007 guidance states:

> The inadvertent closure of a manual block valve on the outlet of a pressure vessel while the equipment is on stream can expose the vessel to a pressure that exceeds the maximum allowable working pressure. If closure of an outlet-block valve can result in overpressure, a pressure-relief device is required unless administrative controls are in place.[54]

The API 521-2007 guidance cautions the user that catastrophic failure can occur when relying on administrative control, but the guidance is vague:

> If the pressure resulting from the failure of administrative controls can exceed the corrected hydrotest pressure[55] […], reliance on administrative controls as the sole means to prevent overpressure might not be appropriate. The user is cautioned that some systems can have unacceptable risk due to failure of administrative controls and resulting consequences due

[53] API does not define "good engineering judgment" or "sound engineering judgment;" however, it is generally taken to mean that users should apply their engineering knowledge when developing a qualitative basis for a design using the standard.
[54] API Standard 521, 5th ed. *Pressure-relieving and Depressuring Systems*, January 2007, section 4.3.2.
[55] API defines corrected hydrotest pressure as "hydrostatic test pressure multiplied by the ratio of stress value at design temperature to the stress value at test temperature."

> to loss of containment. In these cases, limiting the overpressure to the normally allowable overpressure can be more appropriate.[56]

Given the design of the Williams propylene fractionator reboilers, it was possible to exceed the corrected hydrotest pressure. (The maximum allowable working pressure was 300 psig, and the hydrostatic test pressure was 450 psig. Metallurgical analysis indicates the reboiler shell exceeded this pressure during the event, failing at a pressure of at least 674 psig.)[57] The email shown in Figure 21 provides evidence that the API 521-2007 approach was applied during the relief valve engineering analysis at Williams. The engineering analysis performed on the propylene fractionator reboilers resulted in a choice between either installing car seals or adding pressure relief devices. Williams selected the car seal approach.

In January 2014, seven months after the Williams incident, API published a new (Sixth) edition of API Standard 521, *Pressure-relieving and Depressuring Systems* ("API 521-2014"). The new version of the standard has significant improvements that address the gaps and ambiguities in API 521-2007 that contributed to the Williams incident. As shown below, when evaluating situations like the propylene fractionator reboilers at Williams, API 521-2014 requires a pressure relief device, prohibits reliance on administrative controls, and highlights the importance of the hierarchy of controls.

> The inadvertent closure of a valve on the outlet of pressure equipment while the equipment is on stream can expose the equipment to a pressure that exceeds the MAWP. Every valve (i.e. manual, control, or remotely operated) should be considered as being subject to inadvertent operation. If closure of an outlet valve can result in pressure in excess of that allowed by the design code, a PRD [pressure relief device] **is required**.[58] (emphasis added)
>
> In the case of a manual valve, administrative controls can be used to prevent the closed outlet scenario unless the resulting pressure exceeds the maximum allowed by the pressure design code […].[59]
>
> A hierarchy of measures should be used to ensure equipment is not subject to excess pressure. Such a hierarchy first involves avoiding or reducing risks, then providing engineering controls, and finally providing administrative controls. Avoiding risks includes, for example, setting the MAWP of the equipment above the maximum pressure of all possible sources. Engineering controls include providing pressure relief on the vessel. Administrative controls include provision of block valves of the locked-open design. The user is cautioned that some systems may have unacceptable risk due to failure of administrative controls and resulting consequences due to loss of containment.[60]

Although API 521-2014 made significant safety improvements that address API 521-2007 weaknesses revealed by the Williams incident, additional gaps still exist. For example, in one area of the standard that addresses hydraulic (thermal) expansion, the requirement to use a relief valve is not restated, and the language indicates that

---

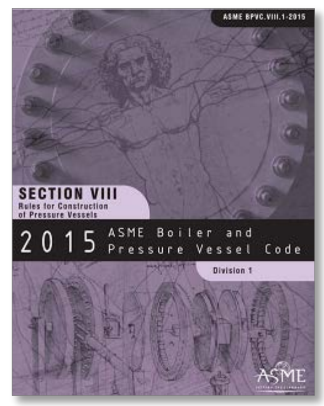
[56] API Standard 521, 5th ed. *Pressure-relieving and Depressuring Systems*, January 2007, section 4.3.2.
[57] See Metallurgical Evaluation of Williams Olefins Ruptured Reboiler EA-425B in Appendix C.
[58] API Standard 521, 6th ed. *Pressure-relieving and Depressuring Systems*, January 2014, section 4.4.2.1.
[59] *Ibid*.
[60] API Standard 521, 6th ed. *Pressure-relieving and Depressuring Systems*, January 2014, section 4.2.1.

administrative controls may be relied upon when a relief valve is not installed on a heat exchanger—even when the corrected hydrotest pressure can be exceeded.

> [C]losing the cold-fluid block valves on the exchanger unit should be controlled by administrative procedures and possibly the addition of signs stipulating the proper venting and draining procedures when shutting down and blocking in. Such cases are acceptable and do not compromise the safety of personnel or equipment, but the designer is cautioned to review each case carefully before deciding that a relieving device based on hydraulic expansion is not warranted because the corrected hydrotest pressure could be exceeded if the administrative procedures are not followed. [61]

This language contradicts the language in the standard requiring a pressure relief device for scenarios that develop pressure greater than allowed by the design code. API should further enhance this standard to help prevent overpressurization incidents caused by failure of administrative controls by clearly requiring a pressure relief device for overpressure scenarios that can result in pressure greater than allowed by the design code.

7.2 American Society of Mechanical Engineers



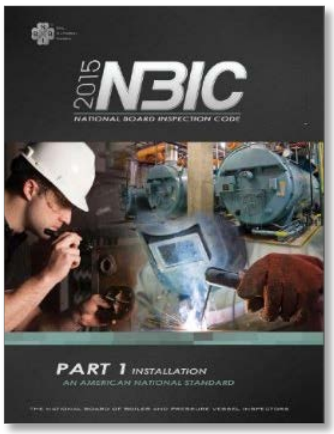
The American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, provides requirements for pressure vessel construction, inspection, and testing, including requirements for overpressure protection. Section *UG-135 "Installation"* details the requirements for placement of pressure relief devices on pressure vessels. UG-135 directs users to Nonmandatory Appendix M for guidance on placement of stop (block) valves between a pressure vessel and its relief device. Nonmandatory Appendix M, Section M-5.7, states that, "Stop valve(s), excluding remotely operated valves and process control valves, may be provided in the relief path where there is normally a process flow [...]."[62]

In order to install a block valve in the path between a vessel and its pressure relief device, the appendix specifies management system and design guidance. In situations where the closure of the stop (block) valve could overpressure a vessel, the appendix allows the user to "apply administrative controls, mechanical locking elements, valve failure controls, and valve operation controls[.]"[63] While Louisiana has not adopted the ASME Boiler and Pressure Vessel Code, Section VIII, Williams Geismar has chosen to comply with the Code's requirements. The CSB encourages all companies to follow the more robust pressure relief requirements in API 521-2014 that require a relief device if the overpressure scenario can result in pressure greater than allowed by the design code.

[61] API Standard 521, 6th ed. *Pressure-relieving and Depressuring Systems*, January 2014, section 4.4.12.1.
[62] American Society of Mechanical Engineers. *ASME Boiler and Pressure Vessel Code*, 2015. Section VIII, Division 1, Nonmandatory Appendix M, Section M-5.7.
[63] *Ibid.*

7.3 THE NATIONAL BOARD OF BOILER AND PRESSURE VESSEL INSPECTORS

The National Board Inspection Code (NBIC), developed by the National Board of Boiler and Pressure Vessel Inspectors, provides rules for installation, inspection, repair, and alteration of pressure vessels. Part 1, Section *4.5 Pressure Relief Devices* details requirements for placement of pressure relief devices on pressure vessels.[64] Section *4.5.3 Location* states:



> The pressure relief device shall be installed directly on the pressure vessel, unless the source of pressure is external to the vessel and is under such positive control that the pressure cannot exceed the maximum overpressure permitted by the original code of construction and the pressure relief device cannot be isolated from the vessel, except as permitted by NBIC Part 1, 4.5.6 e)2).[65]

That section states:

> [W]hen necessary for the continuous operation of processing equipment … a full area stop valve between a pressure vessel and its pressure relief device should be provided *for inspection and repair purposes only.*[66] (emphasis added)

At Williams, because the source of overpressuring the reboilers was internal to the vessel (i.e. hot quench water flowing through the vessel could cause the vessel to overpressure), the NBIC requires installing the pressure relief device directly on the vessel. The design of the Williams reboilers did not meet this design requirement. Louisiana, however, has not adopted this portion of the NBIC and Williams did not list the NBIC as a standard it would voluntarily follow.

[64] Previous versions of the NBIC had similar requirements as the 2015 version.

[65] The National Board of Boiler and Pressure Vessel Inspectors. *National Board Inspection Code*, 2015. Part 1-Installation, Section 4.5.3.

[66] The National Board of Boiler and Pressure Vessel Inspectors. *National Board Inspection Code*, 2015. Part 1-Installation, Section 4.5.6, e2.

8.0 WILLIAMS GEISMAR POST-INCIDENT CHANGES

Williams made positive changes to its Geismar facility process safety management programs following the incident. Williams personnel told the CSB that a significant cultural shift occurred after the incident in understanding the importance of process safety programs in key areas where weaknesses contributed to the incident. The following sections detail some improvements that Williams Geismar implemented following the incident.

8.1 NEW REBOILER DESIGN

Following the June 13, 2013 incident, Williams redesigned the propylene fractionator reboilers to include a pressure relief valve on the shell side of each reboiler (Figure 23). Discussed in Section 6.0, this design strategy of using pressure relief valves, categorized as active safeguards, is higher on the hierarchy of controls than using administrative controls, such as a car seals. This practice also aligns with guidance published by the American Petroleum Institute in API 521-2014 (see Section 7.0), which cautions the user that failure of administrative overpressure protection controls can lead to unacceptable risks. The Williams post-incident design also aligns with guidance published by the NBIC, which requires a pressure relief device installed directly on the reboiler.

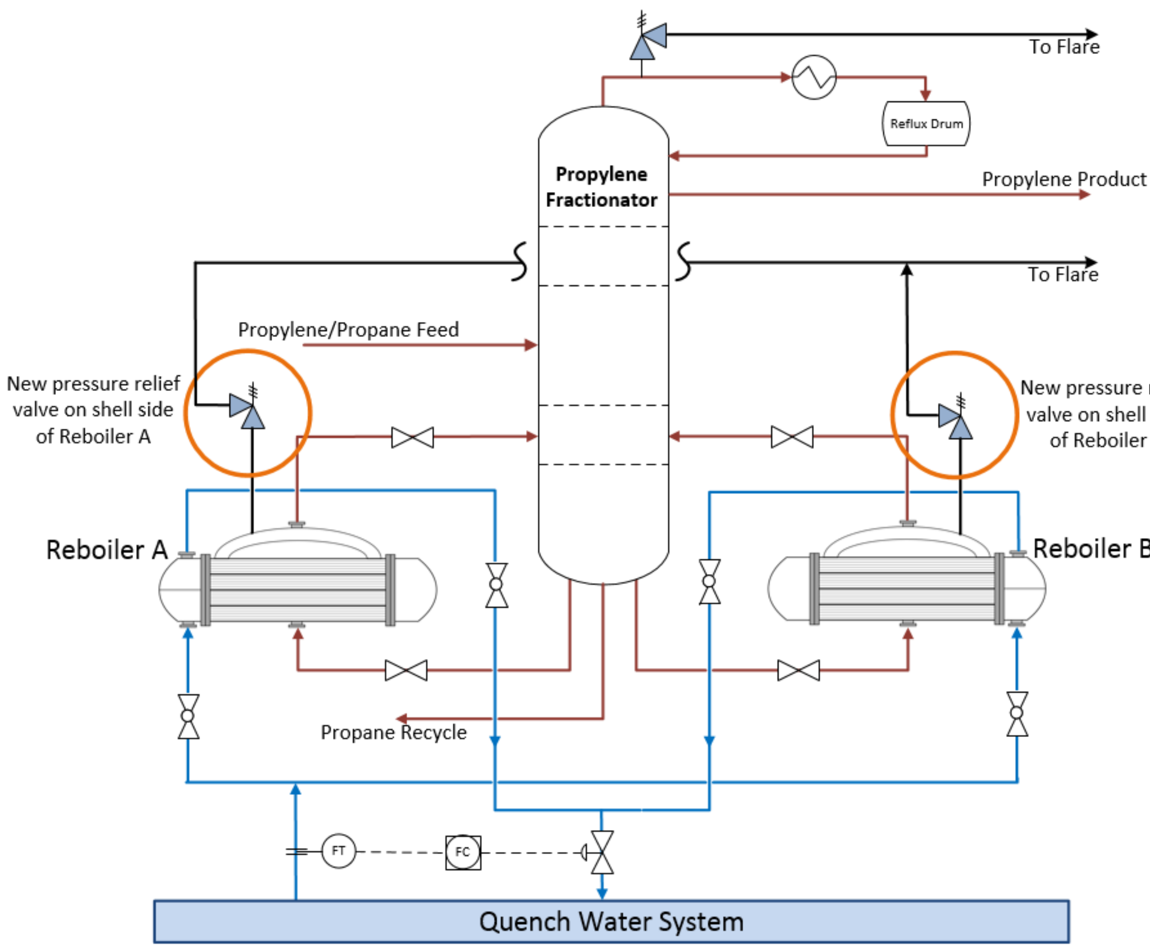


FIGURE 23

Post-incident, the Williams Geismar facility added pressure relief valves to the shell side of Reboiler A and Reboiler B.

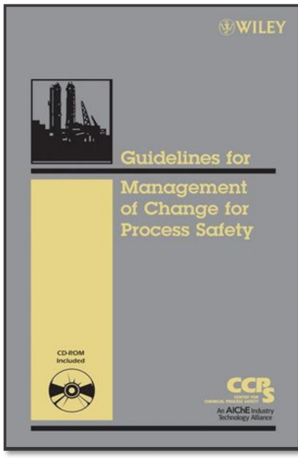
8.2 IMPROVED MANAGEMENT OF CHANGE PROCESS

Before the incident, the Williams Geismar MOC reviews occurred in a sequential process, one person at a time, where the MOC document passed from reviewer to reviewer—a process that often occurred while the reviewers remained in their offices. Following the incident, Williams changed its MOC review to a more collaborative process, requiring an "MOC Review Team" to review every MOC in a group setting. Williams Geismar personnel informed the CSB that this new MOC process facilitates better identification of hazards introduced by proposed changes. An improved MOC process could have helped improve the hazard identification and evaluation process conducted in the 2001 MOC for the installation of the block valves on the propylene fractionator reboilers. A Williams technical employee described to the CSB the new MOC process:

> Pre-incident, an MOC was written, it was brought to [the PSM coordinator] for a number, it was put in a green folder, and it was passed from desk to desk or mailbox to mailbox. It was a fairly long process. If you had questions, you'd have to go track down who had seen that MOC so far and ask them those questions. […] Oftentimes that would result in a do-loop. You'd ask them a question, they'd answer it, that would spar off another question. Now [after the incident], by having everybody just come and sit around a table and discuss the MOC at once, if I ask you a question and you answer it, everyone else around the table that may have the same question hears that answer. And they don't ask the same question, but it may spur another question. So I think we have a lot of really good conversation by having that process in place. It also makes it a lot easier to have broader employee involvement, because every department has to be represented.
>
> Because by having everybody sit around the table and everybody look at the form and discuss it at once, the [MOC] process doesn't take place in a vacuum. It's very transparent and very open and a very collaborative process. And so you do have some level of hazard analysis that takes place right there at that MOC review team meeting. And if it looks like we're getting to the point of actually conducting a semi-HAZOP, then we can say, no, let's refer this now to a PHA and let's do a full-blown HAZOP on [the proposed change]. But I definitely think you get a much better hazard review in that collaborative [MOC] process.

The CCPS book *Guidelines for the Management of Change for Process Safety* also advises readers that the team-based MOC approach can be a more effective MOC approach for identifying the potential safety and health effects of a proposed change (Figure 24).[67]

[67] Center for Chemical Process Safety (CCPS). *Guidelines for the Management of Change for Process Safety*; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2008; p 157.



Problem:	Reviews of the potential safety and health effects of the proposed changes are not very thorough, and some significant problems have slipped through the system.
Possible Solution:	Administer these reviews as you would a PHA. Depending upon the potential significance of the change, a team-based review may be required to get the right mix of expertise. The rules used to ensure the effectiveness of PHAs should apply here as well.
Comments:	Simple, standardized changes may be evaluated by a single person using a checklist approach.

FIGURE 24

CCPS book *Guidelines for the Management of Change for Process Safety* suggests a team-based review can benefit MOC processes by more effectively identifying and controlling important health and safety impacts.

Following the incident, Williams Geismar identified methods to communicate the types of changes that require an MOC. Also, Williams personnel informed the CSB that workers have an increased focus in ensuring MOCs are complete before fieldwork begins. Williams began facilitating this verification by sending around a plant-wide email to communicate MOC approval. If implemented effectively, these cultural and procedural changes can strengthen process safety management at the Williams Geismar facility. The CSB recommends to Williams several processes to ensure that these positive changes continue (Sections 9.0 and 12.0).

8.3 Improved PHA Action Item Implementation Process

Before the incident, the Williams Geismar PHA procedure did not specify a method to follow when the leadership team decided to reject a PHA recommendation or deviate from the proposed recommendation language. Identifying this gap after the incident, Williams Geismar updated the Geismar PHA procedure accordingly (Figure 25), requiring a more robust process when deviating from the proposed PHA recommendation.

Williams

If a PHA recommendation is rejected, or must be implemented differently than originally written, the Geismar Leadership Team must communicate this to the PHA Team, and expeditiously resolve any subsequent recommendations of the PHA Team. Williams can justifiably decline to adopt a recommendation where they can document, in writing and based upon adequate evidence, that one or more of the following conditions is true:

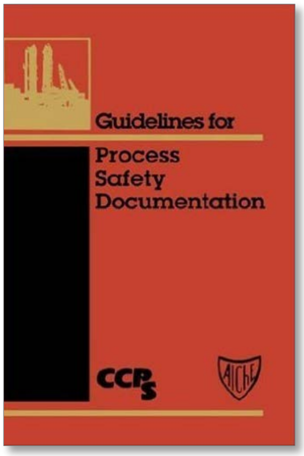
1. The analysis upon which the recommendation is based contains material factual errors;
2. The recommendation is not necessary to protect the health and safety of the employer's own employees, or the employees of contractors;
3. An alternative measure would provide a sufficient level of protection; or
4. The recommendation is infeasible.

If a recommendation is rejected, the PSM Coordinator will document the PHA files with the decision and reason the recommendation was rejected.

FIGURE 25

The Williams Geismar revised, post-incident PHA procedure now specifies a method the leadership team must follow to implement PHA recommendations differently than originally worded.

The post-incident procedure change highlighted in Figure 25 reflects good practice guidance presented in the CCPS book *Guidelines for Process Safety Documentation*:



Resolution [of PHA recommendations] is not synonymous with adoption; not all recommendations will eventually be implemented as originally proposed. Circumstances change, some recommendations may ultimately be seen to be inappropriate, or a better means of achieving the same results may become known. […] In any event, the method of final resolution of recommendations should be documented, either in the summary report, in an addendum to the report, or in a separate follow-up report. The rationale for not implementing the recommendation as originally proposed, as well as any alternative course of action intended to achieve the objective, should be clearly documented.[68]

This new procedure can aid management when implementing action items differently than originally recommended by the PHA team.

Williams has also increased emphasis on verifying proper completion of PHA action items. Before the incident, simply communicating to the PSM Coordinator, who tracks action items, was sufficient to close an action. This practice led to the ineffective implementation of an action item to install car seals on both propylene fractionator reboilers, and it prevented Williams Geismar from identifying that an MOC was not conducted for the change. Now, more enhanced closure verification requirements associated with PHA action items—for example the MOC and PSSR documentation—link to the PHA action item tracking system. This approach can more effectively verify PSM element completion.

Williams also developed a new field verification requirement to ensure accuracy of all P&IDs associated with each PHA before conducting the PHA.[69] If effectively implemented, this practice can help to ensure accurate process safety information prior to conducting the PHA.

8.4 New Definitions for "Standby" and "Out-Of-Service" Equipment

Before the incident, the differences in definitions and pressure relief requirements for "standby" and "out-of-service" equipment likely were not fully understood by all Williams personnel. When Williams implemented the 2006 PHA action item to car seal open the reboiler shell-side valves, only the active reboiler outlet valve was car sealed open. Prior to the incident, some Williams personnel may have believed that standby equipment, such as the standby propylene fractionator reboiler, did not require overpressure protection because they perceived it as "out-of-service." To clarify these definitions and prevent future misunderstandings, after the incident Williams Geismar developed definitions for the two categories. The company now emphasizes these definitions in training and in operating procedures to ensure standby equipment has adequate overpressure protection:

[68] Center for Chemical Process Safety. *Guidelines for Process Safety Documentation;* American Institute of Chemical Engineers: New York, New York, 1995; pp 102-103.

[69] Williams has not developed a procedure for this practice.

> **Standby Equipment** is a term used to describe equipment available for active service with a minimum of interaction and under the control of the operations group [through] normal operating procedures. Pressure relief protection is required and is available without further interaction by operators.
>
> **Out-of-Service Equipment** is a term used for positive isolation of a piece of equipment from active service. This is accomplished when isolation is complete and the process fluids have been emptied. At this point relief protection is not needed.

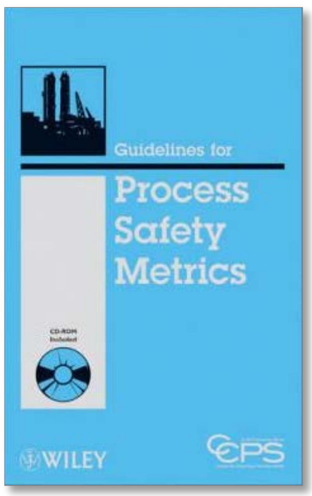
Williams more clearly specified pressure relief requirements for "Standby" and "Out-of-Service" equipment internally; however, the CSB found little industry guidance on the definitions and pressure relief requirements for the two categories of inactive equipment. API Standard 521, *Pressure-relieving and Depressuring Systems* is the applicable industry standard to provide guidance on pressure relief requirements for standby versus out-of-service equipment. The CSB found that this industry standard defined neither standby equipment nor out-of-service equipment. In addition, pressure relief requirements for these classifications of equipment are not explicitly stated. API can improve the clarity of overpressure protection requirements by defining these terms and stating whether overpressure protection is required for each classification.

8.5 Improved Troubleshooting Support

Since the incident, Williams Geismar improved information provided to operators during an event that may require troubleshooting, such as when a process alarm activates. Now, when board operators get an alarm on the distributed control system (DCS), they can right-click on the alarm and display troubleshooting guidance. The guidance includes directions on what to check in the field, what the field operators should look for, and the consequences of improper field actions. This information is also in the standard operating procedures, and operators receive training on this information. A Williams Geismar technical employee informed the CSB, "Although troubleshooting is still kind of beyond the standard operating procedure, I think [this new practice] gives us a more disciplined set of guidelines, and it gives the operators [better] access to that guidance."

8.6 IMPROVED FOCUS ON LEADING AND LAGGING INDICATORS

In recent years, both industry and the CSB have published guidance and conducted forums emphasizing the importance of collecting and analyzing leading[70] and lagging[71] indicators (metrics) to help prevent process safety incidents.[72] The CSB conducted a 2012 public hearing and issued a recommendation to API to develop a consensus standard defining performance indicators for process safety for use in the refining and petrochemical industry. (In response, API developed API RP 754, *Process Safety Performance Indicators for the Refining and Petrochemical Industries.*) The CCPS book *Guidelines for Process Safety Metrics* describes the purpose of process safety metrics succinctly:



> *Process safety metrics are critical indicators for evaluating a process safety management system's performance. More than one metric and more than one type of metric are needed to monitor performance of a process safety management system. A comprehensive process safety management system should contain a variety of metrics that monitor different dimensions of the system and the performance of all critical elements […]. Good process safety metrics will reinforce a process safety culture promoting a belief that process safety incidents are preventable, that improvement is continuous, and that policies and procedures are necessary and will be followed. Continuous improvement is necessary and any improvement program must be based on measureable elements. Therefore, to continuously improve performance, organizations must develop, implement, and review effective process safety metrics.*[73]

KEY LESSON

"Good process safety metrics will reinforce a process safety culture promoting a belief that process safety incidents are preventable, that improvement is continuous, and that policies and procedures are necessary and will be followed."[i] By measuring and analyzing process safety metrics, weaknesses in a company's process safety management program can be identified. Finding these weaknesses and taking proactive steps to improve upon them can help to strengthen safety culture and prevent process safety incidents.

i. Center for Chemical Process Safety (CCPS). *Guidelines for Process Safety Metrics;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p 30.

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[70] Leading Indicators can help to predict future performance. API RP 754 provides leading indicator examples, including process hazard evaluations completion, process safety action item closure, training completed on schedule, procedures current and accurate, and MOC and PSSR compliance. See API Recommended Practice 754, 2nd ed. *Process Safety Performance Indicators for the Refining and Petrochemical Industries*, April 2016, Section 8.3.

[71] Lagging Indicators are retrospective, based on incidents that have occurred. API RP 754 provides lagging indicator examples, including number of recordable injuries, loss of containment incidents, and pressure relief device discharge events. See API Recommended Practice 754, 2nd ed. *Process Safety Performance Indicators for the Refining and Petrochemical Industries*, April 2016, Section 5.2.2 and Section 6.2.2.

[72] Publications and events include (1) CSB Public Hearing: Safety Performance Indicators, July 23-24, 2012, Houston, Texas, http://www.csb.gov/events/csb-public-hearing-safety-performance-indicators/ (accessed August 17, 2016); (2) U.S. Chemical Safety and Hazard Investigation Board, Refinery Explosion and Fire, BP Texas City, REPORT NO. 2005-04-I-TX, (March 2007); (3) API Recommended Practice 754, 1st ed., *Process Safety Performance Indicators for the Refining and Petrochemical Industries*, April 2010; (4) International Association of Oil & Gas Producers Recommended Practice, *Process Safety - Recommended Practice on Key Performance Indicators, Report No. 456*, November 2011; (5) Center for Chemical Process Safety (CCPS). *Guidelines for Process Safety Metrics;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; among others.

[73] Center for Chemical Process Safety (CCPS). *Guidelines for Process Safety Metrics;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p 30.

Williams Geismar did not effectively measure leading and lagging process safety indicators before the incident. Such a system could have identified the excessive time it was taking to implement PHA action items. For example, it took three and a half years to close the 2006 PHA action item to car seal open the propylene fractionator reboiler valves. Since the incident, Williams worked to develop a leading and lagging process safety metrics system. For example, Williams Geismar increased its focus on incident and near miss[74] reporting, and these events are now valued as learning opportunities. Williams distributes incident and near miss reports to all facility leads, supervisors, engineers, and managers. In addition, the company now investigates high potential near miss incidents using a root cause methodology. Williams began performing statistical analyses on the incidents reported, and the trends and findings are distributed each month to Williams employees and senior managers (Figure 26). Williams also implemented electronic tools and databases to track PHA action items and preventive maintenance items—with the ability to report overdue items or upcoming due dates for action items to management.

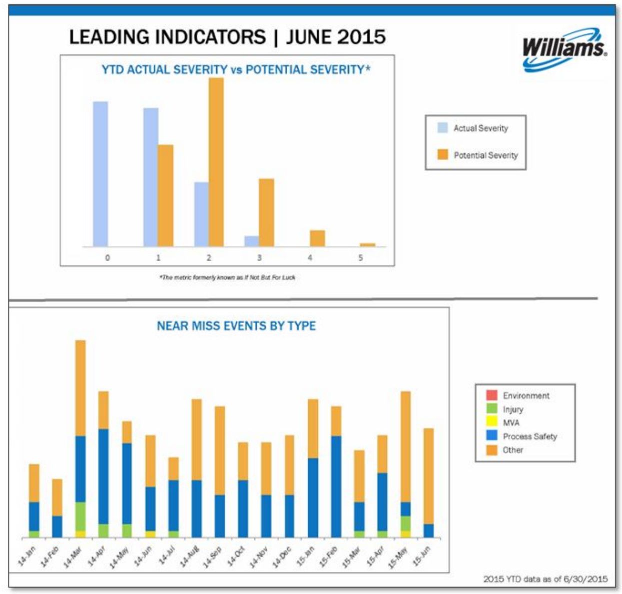


FIGURE 26

Sample indicators report circulated to Williams Geismar management.

These efforts are just the beginning in the development of a robust leading and lagging process safety indicators program. CCPS developed example leading and lagging indicators that facilities can use in all areas of process safety management. Figure 27 shows an example list of indicators for Management of Change published by CCPS.[75] Williams Geismar should expand its existing indicators program to ensure all facets of its process safety management systems, including MOC, PSSR, PHAs, and operating procedures, are effective.

[74] CCPS defines a near miss incident as "The description of less severe incidents (i.e., below the threshold for inclusion in a lagging metric), or unsafe conditions that activated one or more layers of protection. Although these events are actual events (i.e., a "lagging" metric), they are generally considered to be a good indicator of conditions that could ultimately lead to a severe incident." Center for Chemical Process Safety (CCPS). *Guidelines for Process Safety Metrics;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p xvii.

[75] Table from Center for Chemical Process Safety (CCPS). *Guidelines for Process Safety Metrics;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p 152.

MANAGEMENT OF CHANGE	Identify Potential Change Situations	Evaluate Possible Impacts	Decide Whether to Allow the Change	Complete Follow-up Activities	Maintain a Dependable Practice
Number of incidents with management of change (MOC) as a root cause					X
Percentage of work orders/requests that were misclassified as replacement-in-kind (RIK) (or were not classified) and were really changes	X				
Percentage of temporary MOCs for which the temporary conditions were not corrected/restored to the original state at the deadline				X	
Percentage of MOCs reviewed that were in full compliance with the site's MOC procedure					X
Number of "emergency MOCs" or the ratio of 'emergency MOCs" to total MOCs					X
Percentage of MOCs for which the drawings or procedures were not updated				X	
Percentage of changes that were reviewed within the MOC system but were reviewed incorrectly		X			
Percentage of MOCs reviewed that were not documented properly				X	
Number of MOCs performed each month					X
Percentage of MOCs reviewed that did not have adequate hazard/risk analysis completed					X
Percentage of MOCs for which the workers were not informed or trained				X	
Percentage or variation in the number of changes processed on an emergency basis					X

FIGURE 27

Example MOC indicators published in the CCPS book *Guidelines for Process Safety Metrics*

8.7 Process Safety Management Program Assessments

Conducting in-depth assessments of a facility's process safety management program is another way to proactively identify weaknesses in process safety programs including MOC, PSSR, PHA, and operating procedure programs. These assessments go beyond the requirements of the OSHA PSM Compliance Audit—which only requires basic compliance with the OSHA PSM regulation—to evaluate the *quality* of each process safety management program and the *quality* of implementation of those programs. Such an evaluation requires detailed analyses of historical process safety management documentation, including MOC and PSSR forms, PHA recommendations, PHA action item tracking systems, and written operating procedures. Process safety management program assessments that analyze a high percentage of historical process safety documentation can be used to identify systemic safety management program failures.

The CSB found that process safety management program deficiencies spanning the 12 years leading to the incident were causal to the June 13, 2013 Williams Geismar reboiler rupture and fire. A robust process safety management program assessment—that analyzes years of historical process safety documentation—should be instituted by Williams to identify past safety management deficiencies that could cause future process safety incidents. To drive continual improvement, the CSB recommends to Williams Geismar to conduct such process safety program assessments at least once every three years.

Improving Process Safety Culture – Management's Obligations

Improving an organization's process safety culture starts with management. Managers can help to set a high bar for the organization's commitment to implement effective safety management programs and company expectations (i.e., operational discipline) by:

- Requiring the collection of key performance indicators for process safety and regularly reviewing them;
- Setting process safety performance expectations and providing the resources to achieve them;
- Looking for management system failures as root causes for incidents;
- Consistently identifying and correcting substandard actions or conditions during field walkthroughs;
- Completing management reviews and approvals related to work activities in a timely manner;
- Holding everyone (including themselves) accountable for commitments and ensuring that issues are resolved in a timely manner;
- Ensuring adequate staffing to operate units safely; and
- Ensuring adequate funding to maintain equipment and safety systems in good condition.

These are examples from the CCPS book *Conduct of Operations and Operational Discipline—For Improving Process Safety in Industry*, 2011, p 5.

9.0 Strategies For Improving Safety Culture

A sequence of process safety management deficiencies resulting in unmitigated hazards often precedes serious process safety incidents such as the June 13, 2013 Williams Geismar incident. Additionally, incidents often initiate when existing system gaps coincide with actions at the front line, where workers may not recognize the underlying hazards. To prevent process incidents, organizations must develop a culture that promotes effective process safety management systems.

In recent years, the chemical process industry has increasingly focused on process safety culture ("safety culture"). An organization's safety culture is determined by the quality of its written safety management programs (e.g., process safety management procedures, including PHA, MOC, PSSR, operating procedures; written corporate policies) and the quality of implementing those programs by individuals in the organization, ranging from the CEO to the field operator. The Center for Chemical Process Safety has labeled these two facets as "Conduct of Operations" and "Operational Discipline," respectively.[76]

In the years leading up to the incident, Williams Geismar exhibited characteristics of a weak process safety culture. The weaknesses below contributed to the June 13, 2013 incident, reflecting both deficiencies in and poor implementation of the existing process safety management system:

(1) Williams did not perform the 2001 MOC until after the plant was operating with the valves installed, and the associated PSSR was incomplete. These actions did not comply with facility (and regulatory) safety management system requirements; however, Williams management accepted both of these practices;

(2) Car seals are low-level, administrative controls, but they were the favored safeguard in the 2006 PHA recommendation to prevent overpressure events. Williams Geismar did not have a policy requiring the effectiveness of safeguards to be analyzed;

(3) Williams Geismar did not follow OSHA PSM regulatory requirements that operations activities have an associated procedure to safely conduct the work. For example, Williams did not create a procedure specifically for switching the propylene fractionator reboilers Such a procedure should have alerted the operations personnel of the overpressure hazard;

[76] Center for Chemical Process Safety (CCPS). *Conduct of Operations and Operational Discipline—For Improving Process Safety in Industry*; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2011, pp 6-7.

KEY LESSON

It is essential to maintain a high level of vigilance when implementing process safety management programs. Only partially or ineffectively conducting elements of PSM programs such as MOCs, PSSRs, PHAs, safeguard evaluations, and procedure development programs can cause significant hazards to be overlooked, and this can lead to catastrophic incidents, sometimes years later.

(4) The Williams PHA policy did not require effective action item resolution and verification, resulting in incorrect action item implementation in the field;

(5) The Williams PHA policy did not require PHA teams to effectively evaluate and control risk; and

(6) Operations personnel had informal authorization to manipulate field equipment as part of assessing process deviations without first conducting a hazard evaluation and developing a procedure.

Lessons from the Williams Geismar incident have broad application to other organizations. The deficiencies listed above highlight that both a strong written safety management system and effective implementation of that system are required to have good process safety performance. Lessons to consider include:

(1) Ensure company standards always meet or exceed regulations, industry codes and standards, and best practices;

(2) Verify the facility complies with company standards and procedures through activities such as performing audits and tracking indicators; and

(3) Assess and strengthen the organizational safety culture including the organization's commitment to process safety.[77]

Item (3) above can be the most challenging to measure and to identify action items to improve performance. Areas to consider include:

(1) Leaders create culture by what they pay attention to. Is management, from the top down, engaged in process safety? Do leaders require proof of safety rather than proof of danger?

(2) Does the organization have a reporting culture? Is reporting of incidents, near misses, and unsafe conditions encouraged? Can personnel report such occurrences without fear of retaliation? Does the company / site proactively investigate worker safety concerns and implement timely and effective corrective actions?

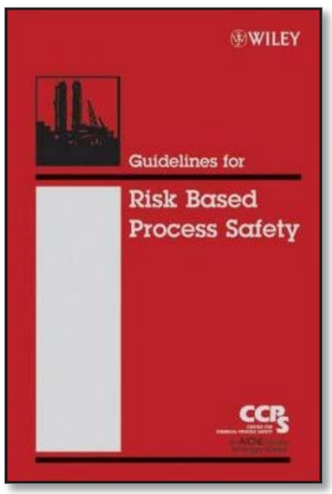
(3) Does the organization encourage a learning culture? Does it examine incidents outside of the organization? Does it apply relevant lessons broadly across the organization?

(4) Are employees effectively involved in process safety decisions? Before making decisions, is there an open and collaborative process to evaluate problem areas?

[77] "Process safety" refers to strategies to prevent chemical releases, fires, and explosions through process design and process safety management programs.

(5) Are members of the organization overconfident, or do they maintain a healthy sense of vulnerability regarding safety? Are employees susceptible to normalization of deviance?[78]

In its book *Guidelines for Risk Based Process Safety*, the Center for Chemical Process Safety provides example methods a facility can employ to improve its process safety culture. These include:



(1) Establish process safety as a core value;

(2) Provide strong leadership [for process safety];

(3) Establish and enforce high standards of [process safety] performance;

(4) Maintain a sense of vulnerability;

(5) Empower individuals to successfully fulfill their process safety responsibilities;

(6) Defer to expertise;

(7) Ensure open and effective communications;

(8) Establish a questioning / learning environment;

(9) Foster mutual trust;

(10) Provide timely response to process safety issues and concerns; and

(11) Provide continuous monitoring of [process safety] performance.[79]

Another tool to evaluate a facility's safety culture is the use of anonymous safety culture assessments of staff. These assessments have historically been conducted by surveying a site's employees through multiple-choice questionnaires. Facilities may also use qualitative assessment practices that go beyond simple employee questionnaire surveys. Such safety culture assessments include personnel interviews, focus group discussions, and detailed document analyses. With qualitative assessments, workers interact with auditors, "using their own terms and concepts to express their point of view…. [I]ntensive and in-depth information can be obtained using the [workers'] own language." [80]

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[78] Normalization of deviance is the acceptance of events that are not supposed to happen. Objective outside observers view the given situation as abnormal or deviant, whereas those individuals on the inside become accustomed to it and view it as normal and acceptable. See Vaughan, Diane. Interview with ConsultingNewsLine, May 2008, http://www.consultingnewsline.com/Info/Vie%20du%20Conseil/Le%20Consultant%20du%20mois/Diane%20Vaughan%20%28English%29.html (accessed August 17, 2016).

[79] Center for Chemical Process Safety (CCPS). *Guidelines for Risk Based Process Safety;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2007; pp 39-66.

[80] Wiegmann, Douglas A.; Zhang, Hui; von Thaden, Terry L.; Sharma, Gunjan; Gibbons, Alyssa Mitchell. Safety Culture: An Integrative Review. *The International Journal of Aviation Psychology*, 2004, Vol 14, No 2, pp 117-134.

Guidance published in recent years describes how to conduct safety culture assessments of chemical process facilities. In 2011, Contra Costa County in California published a guidance document on conducting safety culture assessments.[81] Also in 2011, CCPS released the second edition of its book *Guidelines for Auditing Process Safety Management Systems*. Chapter four of this book provides detailed guidance for auditors evaluating an organization's safety culture.[82] Such safety culture assessments are an additional tool for understanding the overall commitment to process safety at a facility, and facilities can use findings from the assessment to develop action items to continually improve the facility's approach to safety. The CSB recommends that Williams begin implementing a process safety culture continual improvement program—using safety culture assessments—as another tool to improve overall safety at its Geismar facility.

"Achieving and sustaining a positive [safety] culture is not a discreet event, but a journey. Organisations should never let their guard down. Healthy safety cultures result in high reliability organisations which are characterized by their "chronic sense of unease". Organisations must ensure that senior management are committed to a journey of continuous improvement." International Association of Oil & Gas Producers, A Guide to Selecting Appropriate Tools to Improve HSE Culture, 2010.

[81] Contra Costa Health Services. *Industrial Safety Ordinance Guidance Document, Section F-Safety Culture Assessments;* June 15, 2011. http://cchealth.org/hazmat/iso/guidance.php (accessed August 17, 2016).

[82] Center for Chemical Process Safety (CCPS). *Guidelines for Auditing Process Safety Management Systems;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2011; pp 181-211.

10.0 Key Lessons

1. Overpressure protection is an essential safeguard for all pressure vessels. PHA teams must ensure that all pressure vessels have effective overpressure protection. At a minimum, a pressure relief device is a necessary safeguard to protect process equipment from overpressure scenarios where internal vessel pressure can exceed design code limits.

2. Closed gate (block) valves leak, and they are susceptible to inadvertent opening. Both scenarios can introduce process fluids to offline equipment. More robust isolation methods, such as inserting a blind, can better protect offline equipment from accumulation of process fluid.

3. It is important to ensure that the final implementation of PHA action items addresses the original safety concerns identified by the PHA team. Companies should ensure that action items have been effectively implemented and field verified before closing them out.

4. Robust Management of Change (MOC) practices are needed to ensure the review analyzes hazards in the entire process *affected* by the change. Similar to PHAs, conducting MOC reviews as a multidisciplinary group—composed of individuals with different experiences and different areas of expertise—can assist in identifying hazards introduced by a process change. Companies must conduct MOCs *before* implementing a change in the field, and should not treat them as a paperwork or check-the-box exercise.

5. Pre-Startup Safety Reviews (PSSRs) are key opportunities to verify effective implementation of design intent, accuracy of process safety information, and proper installation and configuration of field equipment. Companies should conduct thorough and effective PSSRs before placing equipment in service.

6. Operating procedures need sufficient detail to ensure effective performance of critical steps, including performing steps in the correct order. Affected employees such as operators must receive training on the procedures. Management must establish expectations to maintain and follow accurate procedures.

7. PHA and MOC teams should effectively use the hierarchy of controls to the greatest extent feasible when evaluating safeguards. Pressure relief devices are typically more robust safeguards than car seals. Pressure relief devices (active safeguards) are higher on the hierarchy of controls than car seals (administrative controls).

8. "Good process safety metrics will reinforce a process safety culture promoting a belief that process safety incidents are preventable, that improvement is continuous, and that policies and procedures are necessary and will be followed."[83] By measuring and analyzing process safety metrics, weaknesses in a company's process safety management program can be identified. Finding these weaknesses and taking proactive steps to improve upon them can help to strengthen safety culture and prevent process safety incidents.

9. It is essential to maintain a high level of vigilance when implementing process safety management programs. Only partially or ineffectively conducting elements of PSM programs such as MOCs, PSSRs, PHAs, safeguard evaluations, and procedure development programs can cause significant hazards to be overlooked, and this can lead to catastrophic incidents, sometimes years later.

[83] Center for Chemical Process Safety (CCPS). *Guidelines for Process Safety Metrics;* John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p 30.

11.0 Conclusions

In the years leading up to the June 13, 2013 incident, significant weaknesses in the Williams Geismar process safety culture were evident in a series of deficiencies in implementing the site's process safety management programs and in weaknesses in the written programs themselves. These deficiencies include a poorly conducted MOC and PSSR, ineffective safeguard selections and insufficient safeguard evaluation requirements, poor implementation of PHA action items, inadequate focus on developing and maintaining operating procedures, and allowing uncontrolled field equipment manipulations without first assessing the hazards and developing a procedure. Those deficiencies ultimately contributed to the reboiler rupture and the deaths of two employees. This incident highlights that maintaining process safety excellence at a facility requires consistent and organized effort by a company and its employees. Former CSB Chairperson John Bresland called on companies to strive for process safety excellence when he stated, "Operating hazard[ous] chemical plants need to have the highest level of chemical process safety possible to make sure they operate safely day in and day out. It requires constant diligence and constant attention to process safety management."[84]

While Williams made safety improvements following the incident, the CSB has identified additional good practices Williams Geismar should implement for further improvement. These strategies, including conducting safety culture assessments, developing a robust indicators tracking program, and conducting detailed process safety program assessments, can aid in maintaining a consistent focus on process safety.

The CSB also identified gaps in industry guidance provided by the American Petroleum Institute (API). Post-incident, API now requires relief devices for scenarios that generate pressure greater than what is allowed by the equipment design code; however, the CSB found the API guidance remains inconsistent, as API still specifies in some guidance that reliance on administrative controls is sufficient to prevent equipment from overpressuring. In addition, the CSB found limited guidance from API on definitions and pressure relief requirements for standby and out-of-service equipment. Further enhancing guidance in API publications can enable broader learning of the lessons from the Williams incident. Applying these lessons industry-wide can prevent future catastrophic incidents.

[84] Walter, Laura; CSB Issues Urgent Safety Recommendations Following CITGO Refinery Accident. *EHS Today* [Online] 2009. http://ehstoday.com/safety/news/csb-issues-urgent-safety-recommendations-citgo-refinery-accident-1411 (accessed August 17, 2016).

12.0 Recommendations

12.1 Williams Geismar Olefins Facility

2013-03-I-LA-R1

Implement a continual improvement program to improve the process safety culture at the Williams Geismar Olefins Plant. Ensure oversight of this program by a committee of Williams personnel ("committee") that, at a minimum, includes safety and health representative(s), Williams management representative(s), and operations and maintenance workforce representative(s). Ensure the continual improvement program contains the following elements:

a. *Process Safety Culture Assessments.* Engage a process safety culture subject-matter expert, who is selected by the committee and is independent of the Geismar site, to administer a periodic process safety culture assessment that includes surveys of personnel, interviews with personnel, and document analysis. Consider the process safety culture audit guidance provided in Chapter 4 of the CCPS book *Guidelines for Auditing Process Safety Management Systems* as a starting point. Communicate the results of the Process Safety Culture Assessment in a report; and

b. *Workforce Involvement.* Engage the committee to (1) review and comment on the expert report developed from the Process Safety Culture Assessments, and (2) oversee the development and effective implementation of action items to address process safety culture issues identified in the Process Safety Culture Assessment report.

As a component of the process safety culture continual improvement program, include a focus on the facility's ability to comply with its internal process safety management program requirements. Make the periodic process safety culture report available to the plant workforce. Conduct the process safety culture assessments at least once every five years.

2013-03-I-LA-R2

Develop and implement a permanent process safety metrics program that tracks leading and lagging process safety indicators. Consider available industry guidance, such as the guidance presented in the Center for Chemical Process Safety (CCPS) book *Guidelines for Process Safety Metrics* and the example metrics provided in the book's accompanying CD. Design this metrics program to measure the effectiveness of the Williams Geismar Olefins Facility's process safety management programs. Include the following components in this program:

a. Measure the effectiveness of the Williams Geismar Management of Change (MOC) program, including evaluating whether MOCs were performed for all applicable changes, the quality of MOC review, and the completeness of the MOC review;
b. Measure the effectiveness of the Williams Geismar Pre-Startup Safety Review (PSSR) program, including the quality of the PSSR review and the completeness of the PSSR review;

c. Measure the effectiveness of the Williams Geismar methods to effectively and timely complete action items developed as a result of Process Hazard Analyses (PHAs), Management of Change (MOC), incident investigations, audits, and safety culture assessments; and
d. Measure the effectiveness of the Williams Geismar development and implementation of operating procedures.

Develop a system to drive continual process safety performance improvements based upon the data identified and analysis developed as a result of implementing the permanent process safety metrics program.

2013-03-I-LA-R3

Develop and implement a program that demands robust and comprehensive assessments of the process safety programs at the Williams Geismar facility, at a minimum including Management of Change, Pre-Startup Safety Review, Process Hazard Analyses, and Operating Procedures. Ensure that the assessments thoroughly evaluate the effectiveness of these important safety programs. To drive continual improvement of process safety programs to meet good practice guidance, ensure these assessments result in the development and implementation of robust action items that address identified weaknesses. Engage an expert independent of the Geismar site to lead these assessments at least once every three years.

12.2 AMERICAN PETROLEUM INSTITUTE

2013-03-I-LA-R4

To help prevent future major incidents such as a rupture of a pressure vessel in a special operating status, strengthen API Standard 521, *Pressure-relieving and Depressuring Systems*, by defining the various types of equipment operating statuses. Include definitions for "standby" and "out-of-service." Specify pressure relief requirements for each type of equipment operating status.

2013-03-I-LA-R5

To help prevent future major incidents such as pressure vessel rupture from ineffective or failed administrative controls, clarify API Standard 521, *Pressure-relieving and Depressuring Systems*, to require a pressure relief device for overpressure scenarios where internal vessel pressure can exceed what is allowed by the design code. Although some portions of API Standard 521 already require a pressure relief device for these scenarios, other areas, such as Section 4.4.12 *Hydraulic Expansion*, are not as protective. Section 4.4.12 *Hydraulic Expansion* (the failure mode that caused the Williams overpressure incident) permits omitting a pressure relief device and allows the exclusive use of administrative controls.

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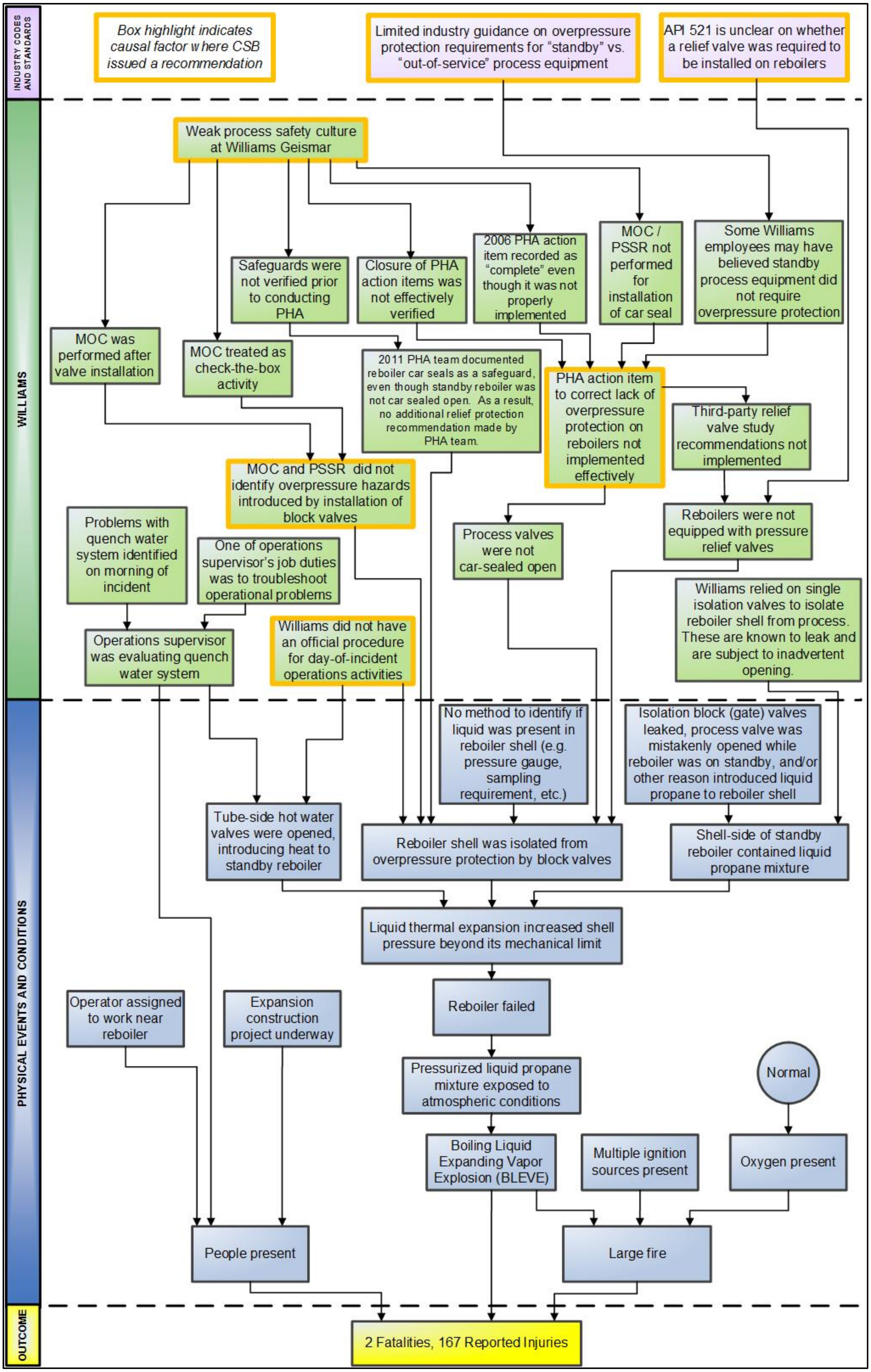
INDUSTRY CODES AND STANDARDS
WILLIAMS
PHYSICAL EVENTS AND CONDITIONS
OUTCOME
Box highlight indicates causal factor where CSB issued a recommendation
Limited industry guidance on overpressure protection requirements for "standby" vs. "out-of-service" process equipment
API 521 is unclear on whether a relief valve was required to be installed on reboilers
Weak process safety culture at Williams Geismar
Safeguards were not verified prior to conducting PHA
Closure of PHA action items was not effectively verified
2006 PHA action item recorded as "complete" even though it was not properly implemented
MOC / PSSR not performed for installation of car seal
Some Williams employees may have believed standby process equipment did not require overpressure protection
MOC was performed after valve installation
MOC treated as check-the-box activity
2011 PHA team documented reboiler car seals as a safeguard, even though standby reboiler was not car sealed open. As a result, no additional relief protection recommendation made by PHA team.
PHA action item to correct lack of overpressure protection on reboilers not implemented effectively
Third-party relief valve study recommendations not implemented
MOC and PSSR did not identify overpressure hazards introduced by installation of block valves
Problems with quench water system identified on morning of incident
One of operations supervisor's job duties was to troubleshoot operational problems
Process valves were not car-sealed open
Reboilers were not equipped with pressure relief valves
Williams relied on single isolation valves to isolate reboiler shell from process. These are known to leak and are subject to inadvertent opening.
Operations supervisor was evaluating quench water system
Williams did not have an official procedure for day-of-incident operations activities
No method to identify if liquid was present in reboiler shell (e.g. pressure gauge, sampling requirement, etc.)
Isolation block (gate) valves leaked, process valve was mistakenly opened while reboiler was on standby, and/or other reason introduced liquid propane to reboiler shell
Tube-side hot water valves were opened, introducing heat to standby reboiler
Reboiler shell was isolated from overpressure protection by block valves
Shell-side of standby reboiler contained liquid propane mixture
Liquid thermal expansion increased shell pressure beyond its mechanical limit
Operator assigned to work near reboiler
Expansion construction project underway
Reboiler failed
Pressurized liquid propane mixture exposed to atmospheric conditions
Normal
Boiling Liquid Expanding Vapor Explosion (BLEVE)
Multiple ignition sources present
Oxygen present
People present
Large fire
2 Fatalities, 167 Reported Injuries

CSB Analysis of Likely Reboiler Failure Scenario

Williams Geismar, LA Investigation
Incident Date: June 13, 2013

Table of Contents

1.0 SUMMARY

On June 13, 2013, a propylene fractionator reboiler (Reboiler B) catastrophically ruptured, resulting in the fatalities of two Williams employees. The reboiler had been offline, isolated from the propylene fractionator by a single valve on the inlet piping and a single valve on the outlet piping, when hot water was introduced to the tube side of the exchanger while the shell-side valves were still closed. Approximately three minutes after the tube-side hot water valves were opened, the reboiler ruptured. Post-incident analysis indicates the reboiler shell likely failed at an internal pressure estimated to be between 674 and 1,212 psig.[85] The CSB determined that a pressure of this magnitude was likely generated by liquid thermal expansion in the liquid-filled, Reboiler B shell. The process liquid within the shell, which contained mostly propane with smaller amounts of propylene and C4 hydrocarbons, such as butane, likely entered the offline Reboiler B shell during the 16 months it was isolated from the process by at least one of the following: (1) a leaking process valve; (2) a mistakenly opened process valve; or, (3) another reason not identified. This report details the possible failure scenarios for the reboiler shell, which the CSB evaluated.

2.0 FAILURE SCENARIOS EVALUATED

The following sections detail the CSB's analysis of possible propylene fractionator reboiler (Reboiler B) failure scenarios. These include overpressurization due to an increase in the equilibrium vapor pressure as the reboiler temperature increased, detonation due to an accumulation of methyl acetylene and propadiene (MAPD), and vessel rupture due to liquid thermal expansion.

[85] See Metallurgical Evaluation of Williams Olefins Ruptured Reboiler EA-425B in Appendix C.

2.1 Overpressurization Due to Equilibrium Vapor Pressure at Quench Water Feed Temperature

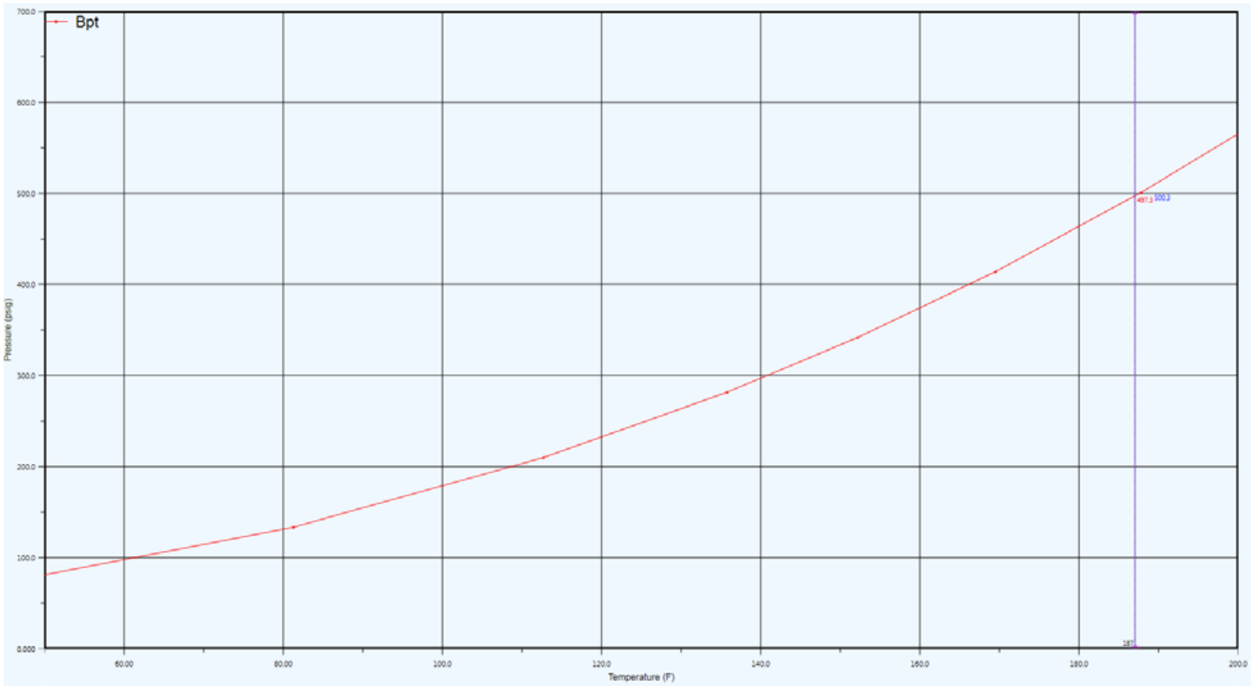

FIGURE B-1

Boiling Point Curve of Williams reboiler process fluid. Graph indicates process fluid could generate a vapor pressure of 496 psig at equilibrium conditions.

The tube-side quench water was at a temperature of 187 °F. At equilibrium conditions at 187 °F, the shell-side propane mixture generates a vapor pressure of approximately 496 psig (Figure B-1). This pressure is not high enough to have ruptured the reboiler, which Finite Element Analysis predicts ruptured between 674 and 1,212 psig.[86] The CSB concludes that the overpressurization of the Williams reboiler was likely not caused by an increase in vapor-liquid equilibrium pressure when heat was introduced to the closed shell side of the reboiler.

[86] See Metallurgical Evaluation of Williams Olefins Ruptured Reboiler EA-425B in Appendix C.

2.2 Explosion Due to High Concentrations of Methyl Acetylene and Propadiene

Mixtures of methyl acetylene and propadiene (MAPD) can decompose and ignite without the presence of oxygen, resulting in an explosion inside of equipment that can violently rupture process vessels. Heat input to the mixture could be sufficient to initiate the ignition of the materials.[87] Experimental studies have found that hydrocarbon mixtures containing approximately 60 mol% MAPD can sufficiently decompose and propagate a flame.[88]

The CSB analyzed whether the decomposition and ignition of MAPD in the reboiler shell caused this incident. Williams regularly sampled the MAPD composition exiting the propadiene converter, which was immediately upstream of the propylene fractionator (Figure B-2). The propadiene converter was installed into the process specifically to prevent accumulation of MAPD in the process. Plant data indicates the propadiene converter was functioning normally between a February 2012 maintenance activity and the day of the incident. Between the time Reboiler B was last opened for maintenance (February 2012) and the incident, available composition data indicates that the process fluid entering the propylene fractionator did not exceed approximately 1.4 mol% MAPD. This concentration likely was not enough to accumulate a high percentage of MAPD in the standby reboiler, which was isolated from the propylene fractionator by closed valves.

In a 2013 presentation by Dow at the AIChE Ethylene Producers' Conference, two scenarios were identified that could result in accumulation of MAPD in a propylene fractionator: operating on total reflux or operating with a loss of bottoms flow.[89] The propylene fractionator was not operated under either condition between February 2012 and the incident. The CSB concludes that this incident was likely not caused by the accumulation and detonation of MAPD in the offline Reboiler B.

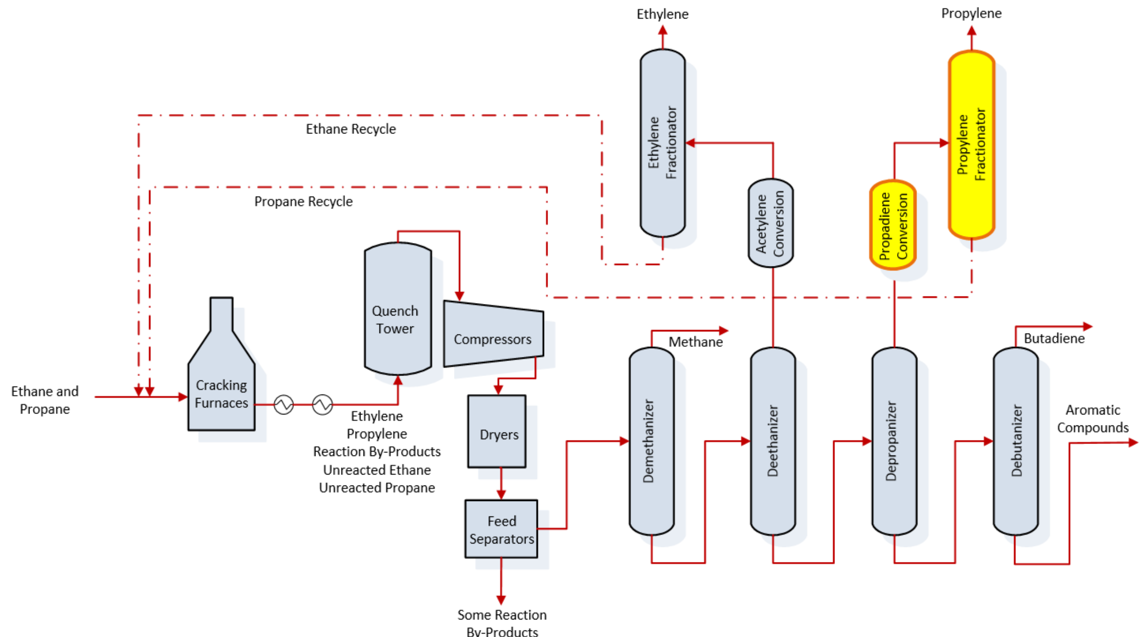

FIGURE B-2

Simplified flow diagram of the olefins process. The propadiene converter and the propylene fractionator are highlighted in yellow.

[87] Kuchta, J.M.; Spolan, I.; Zabetakis, M.G. Flammability Characteristics of Methylacetylene, Propadiene (Allene), and Propylene Mixtures. *Journal of Chemical and Engineering Data*, **1964**, *Vol. 9, No. 3*, 467-472.

[88] Yoshimine, M.; Kern, W.G.; Belfit, R.W. Stabilization of Methylacetylene and Propadiene Mixtures. *Journal of Chemical and Engineering Data*, **1967**, *Vol. 12, No. 3*, 399-405.

[89] Feld, Peter; *MAPD Stability and Management in Ethylene Plants*, 2013 AIChE Spring National Meeting; San Antonio, Texas; May 1, 2013; AIChE Paper Number 111b.

2.3 Overpressurization Due to Liquid Thermal Expansion

Liquid expands as it is heated and has the ability to generate high pressures when the liquid is confined within a closed vessel. Based on equipment dimensions and the physical properties of the design composition of the propylene fractionator bottoms product, the CSB calculated the minimum quantity of process liquid required at ambient temperature (approx. 77 °F) to completely fill the propylene fractionator Reboiler B at the quench water temperature (187 °F). The following calculations were performed to determine the approximate quantity of liquid process fluid required on the shell side of the Williams reboiler and in connected piping to result in a liquid overpressurization of the reboiler shell.

Total Volume Available Between Closed Valves

$V_{total} = 289.93\ ft^3$

Volume of Process Fluid Required to Fill Exchanger Shell at Quench Water Feed Temperature

Williams Propylene Fractionator Bottoms Design Case:

Component	Flow Rate (lbmol/hr)
Propylene	8.327
Propane	235.921
C_4's	2.831

The density of this liquid was evaluated at two conditions using Aspen HYSYS, SRK equation of state:

(1) Ambient temperature (77°F): $\rho_{l,77°F} = 30.89\ \frac{lb_m}{ft^3}$

(2) Quench water inlet temperature (187°F): $\rho_{l,187°F} = 20.22\ \frac{lb_m}{ft^3}$

<u>*Mass of liquid required to fill shell side volume at 187°F:*</u>

$$m_l = (V_{total})(\rho_{l,187°F}) = (289.93\ ft^3)\left(20.22\ \frac{lb_m}{ft^3}\right) = 5{,}862.38\ lb_m$$

<u>*Volume this mass occupies at 77°F:*</u>

$$V_{l,77°F} = \frac{m_l}{\rho_{l,77°F}} = \frac{5{,}862.38\ lb_m}{30.89\ \frac{lb_m}{ft^3}} = 189.78\ ft^3$$

<u>*Percentage total volume occupied at 77°F:*</u>

$$\frac{189.78\ ft^3}{289.93\ ft^3}\ x\ 100 = 65.5\ vol\%$$

The piping and exchanger shell between the two closed reboiler process valves had to be *at least* 65.5 vol% full of the liquid propane mixture prior to the introduction of hot quench water to the tube side of the reboiler for liquid expansion to result in overpressurization of the exchanger shell and piping. A liquid inventory of at least this minimum quantity of liquid is reasonable because (1) it would have resulted in a level in the reboiler below the liquid level in the propylene fractionator, and (2) this quantity of liquid would have had enough contact with the reboiler tubes to sufficiently heat and expand (Figure B-3). Reboiler B was likely between 65.5 vol% and 100 vol% full of the liquid propane mixture prior to the introduction of the 187 °F quench water.

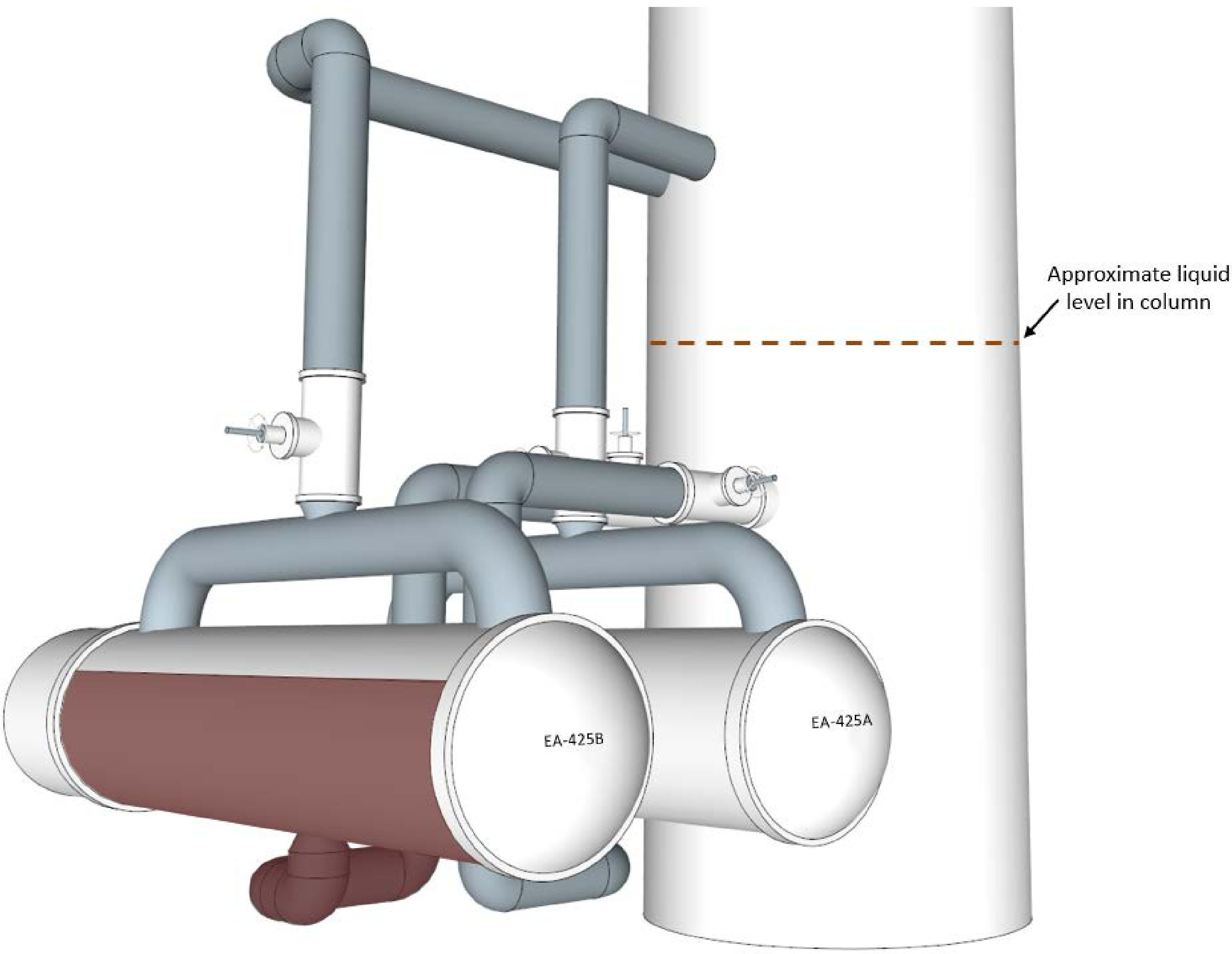

FIGURE B-3

Depiction of minimum required liquid level in reboiler EA-425B (Reboiler B) to result in possible liquid overpressurization of reboiler shell.

Pressure Rise Due to Liquid Thermal Expansion

The following equation was used to calculate the theoretical pressure that could be reached inside the Reboiler B shell due to liquid thermal expansion of the propane mixture. The calculation assumed that the reboiler was initially full of the liquid propane mixture.

Assuming negligible leakage across the shell-side valves during the three minutes between the introduction of hot quench water and vessel failure:[90]

$$P_2 = P_1 + \frac{(T_2 - T_1)(\alpha_v - 3\alpha_l)}{\chi + \left(\frac{d}{2E\delta_w}\right)(2.5 - 2\mu)}$$

Where

P_2 is the final gauge pressure of blocked-in, liquid-full equipment, expressed in psig;

P_1 is the initial gauge pressure of blocked-in, liquid-full equipment, expressed in psig;

T_2 is the final temperature of blocked-in, liquid-full equipment, expressed in °F;

T_1 is the initial temperature of blocked-in, liquid-full equipment, expressed in °F;

α_v is the cubic expansion coefficient of the liquid, expressed in 1/°F;

α_l is the linear expansion coefficient of metal wall, expressed in 1/°F;

χ is the isothermal compressibility coefficient of the liquid, express in 1/psi;

d is the internal pipe diameter, expressed in inches;

E is the modulus of elasticity for the metal wall at T_2, expressed in psi;

δ_w is the metal wall thickness, expressed in inches;

μ is Poisson's ratio, typically 0.3.

This calculation finds that the pressure inside of the Reboiler B shell could reach approximately 5,000 psig due to liquid thermal expansion of the propane mixture within the confined shell. Finite element analysis predicted the reboiler failed at an internal pressure between 674 and 1,212 psig.[91] The pressure generated by liquid thermal expansion would be sufficient to achieve this failure pressure. The CSB concludes that liquid thermal expansion of the liquid-filled Reboiler B shell was the likely failure scenario that initiated the mechanical failure sequence resulting in the boiling liquid expanding vapor explosion (BLEVE).

[90] Equation from API Standard 521, 6th ed. *Pressure-relieving and Depressuring Systems*, January 2014, section 4.4.12.4.1.
[91] See Metallurgical Evaluation of Williams Olefins Ruptured Reboiler EA-425B in Appendix C.

3.0 Boiling Liquid Expanding Vapor Explosion (BLEVE)

When the reboiler shell failed locally (cracked) due to liquid thermal expansion of the shell contents, the shell contents began to flash near the failure opening and a two-phase (liquid and vapor) jet release would have accelerated out of the failure opening. The two-phase flow would have choked in the failure opening, maintaining the pressure in the vessel for a short period of time. The pressure loading on the open edges of the failure caused the crack to continue to grow along the vessel length and the failure opening rapidly increased in size. As this opening increased in size, the two-phase jet would have grown rapidly. At some point, the full opening of the vessel would have resulted in an explosive release of the remaining vessel contents. This explosive release is called a boiling liquid expanding vapor explosion (BLEVE).[92] The pressure forces during this process usually flatten the vessel cylinder on the ground (Figure B-4). The escaping propane mixture then found an ignition source and ignited.

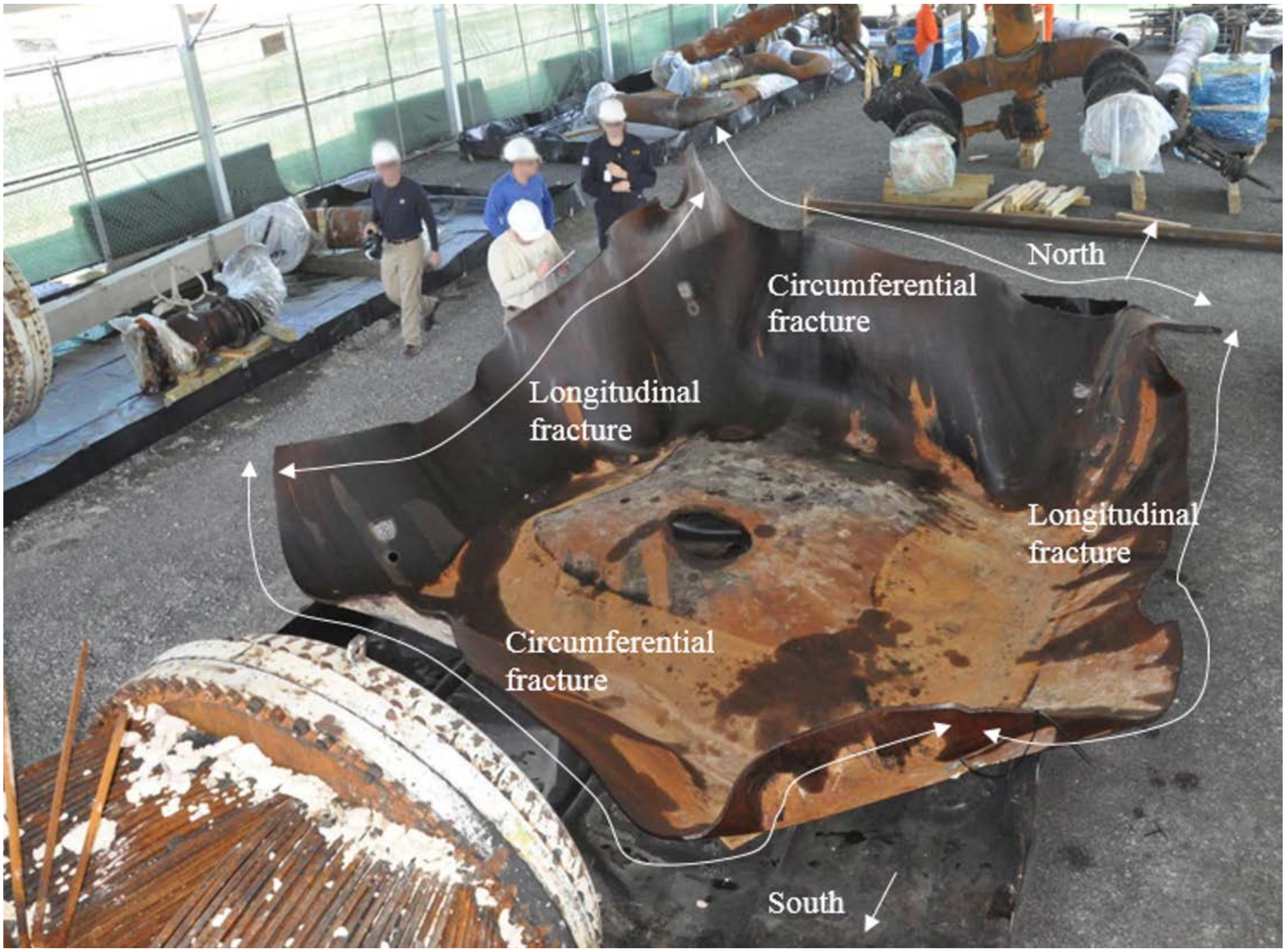

FIGURE B-4

Post-incident photo of Reboiler B shell. The originally cylindrical shell was flattened during the event.

[92] Center for Chemical Process Safety (CCPS). *Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards*, 2nd ed.; John Wiley & Sons, Inc.: Hoboken, New Jersey, 2010; p 311.

Appendix C – Metallurgical Analysis Report

The Metallurgical Analysis Report is on the CSB website on the *Williams Olefins Plant Explosion and Fire* investigation page.

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