



U.S. Chemical Safety and Hazard Investigation Board

Safety Bulletin

Key Lessons from the ExxonMobil Baton Rouge Refinery Isobutane Release and Fire

SUMMARY OF KEY LESSONS:

Companies should:

- Evaluate human factors associated with equipment design and apply the hierarchy of controls to mitigate identified hazards.
- Establish detailed and accurate written procedures and provide training to ensure workers can perform all anticipated job tasks safely.

Incident Date: November 22, 2016

4 Workers Injured

No. 2016-02-I-LA



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Initialisms

API	American Petroleum Institute
CCPS	Center for Chemical Process Safety
CSB	U.S. Chemical Safety Board
OSHA	Occupational Safety and Health Administration
PHA	Process Hazard Analysis
PSM	Process Safety Management

1. Introduction

On November 22, 2016, an isobutane release and fire seriously injured four workers in the sulfuric acid alkylation unit at the ExxonMobil Refinery in Baton Rouge, Louisiana (“Baton Rouge refinery”). During removal of an inoperable gearbox¹ on a plug valve,² the operator performing this activity removed critical bolts securing the pressure-retaining component of the valve known as the top-cap.³ When the operator then attempted to open the plug valve with a pipe wrench,⁴ the valve came apart and released isobutane into the unit, forming a flammable vapor cloud. The isobutane reached an ignition source within 30 seconds of the release, causing a fire and severely burning four workers who were unable to exit the vapor cloud before it ignited.

The CSB learned that there were long-standing reliability issues with gearboxes used to operate plug valves in the refinery’s alkylation unit. In addition, when alkylation unit operators encountered a malfunctioning gearbox on a plug valve, it was an accepted practice for the operator to remove the gearbox to open or close the valve with a pipe wrench. Baton Rouge refinery management did not, however, provide alkylation unit workers performing this operations activity with a written procedure or training on safe gearbox removal from plug valves and its associated hazards. While some operators felt comfortable performing this type of work, others did not and referred this work to maintenance personnel, who they felt were more qualified to remove the gearbox.⁵

The CSB also learned that 15 (approximately three percent) of the roughly 500 plug valves with manually operated gearboxes in the refinery’s alkylation unit were an older design that required attaching the gearbox support bracket (Figure 2) to pressure-retaining valve components. This design created the potential for incorrect removal of the gearbox, which can have catastrophic consequences, as seen in this incident. The improved valve design involves attaching the gearbox support bracket without connecting to pressure-retaining parts of the valve, allowing for safer gearbox removal.

The following safety bulletin highlights the details of the incident and its causes, provides key safety lessons, and communicates industry safety guidance with the goal of preventing a similar incident. The CSB urges companies to review the key safety lessons and safety guidance contained in this document for application at their facilities and to evaluate their existing process safety management practices and equipment design for potential improvements.

¹ A gearbox is a mechanical device attached to a valve that uses gears to make it easier to turn the handwheel connected to the gearbox. This type of gearbox is also known as a gear operator. See [Tekval gear operator](#) (Tekval, 2001).

² See [animation of plug valve design and operation](#) (GM Engineers Pvt. Ltd, n.d.). A plug valve is used primarily for establishing flow when open or isolating flow when closed, and some throttling services. It controls flow by means of a cylindrical or tapered plug with a hole in the center that lines up with the flow path of the valve to permit flow. Plug valves are generally operated in either the open or closed position and are commonly used in the Baton Rouge refinery to isolate equipment.

³ [Durco plug valve parts and component names](#) (Flowserve, 2014) at page 3. Durco, the brand of the valve involved in the incident is among a number of Flowserve products. See [Flowserve product brands](#) (Flowserve, 2017).

⁴ The handwheel attached to the gearbox would not turn the stem of the valve when operated.

⁵ At the Baton Rouge refinery, maintenance personnel who would work on valves are referred to as “mechanical.”

2. Incident Description

On the afternoon of November 22, 2016, two Baton Rouge refinery alkylation unit operators were preparing isobutane equipment for maintenance.⁶ As part of this preparation, the operators needed to adjust valves to put a spare isobutane pump into service. (Figure 1). To switch the pumps, the operators needed to open the inlet (suction) plug valve to the spare pump. The refinery used a type of valve known as a quarter-turn plug valve for many applications in the alkylation unit, including the inlet valves to these isobutane pumps.⁷

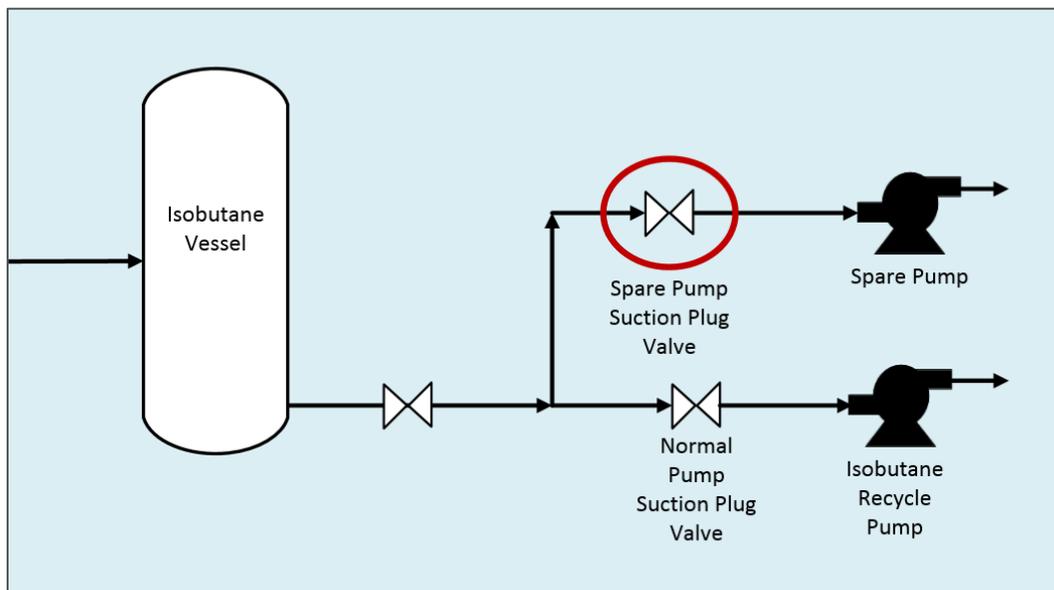


Figure 1. Simplified diagram of the alkylation unit equipment where the release occurred.

Infrequently used plug valves like this one are often operated manually. An operator turns a handwheel connected to a gearbox to open or close the valve.⁸ (Figure 2). The handwheel rotates gears to turn the valve stem into the open or closed position, and a support bracket attaches the gearbox to the valve body using bolts. On the afternoon of the incident, one of the operators attempted to open the plug valve to the spare pump using the handwheel attached to the valve. But the gearbox was not operating properly, and although the handwheel turned, the valve did not open.⁹

⁶ The alkylation unit converts isobutane and olefins into gasoline through a reaction catalyzed by sulfuric acid.

⁷ The “quarter-turn” refers to how the valve is operated – requiring a 90-degree turn of the valve stem to move the plug from closed to open and vice-versa.

⁸ See [animation of gearbox with handwheel](#) (2L Engineers, 2015).

⁹ ExxonMobil operators described the handwheel as “free spinning,” meaning the gearbox was inoperable - the handwheel freely turned but did not turn the stem of the plug valve. At times, some plug valve gearboxes broke down and required replacement.

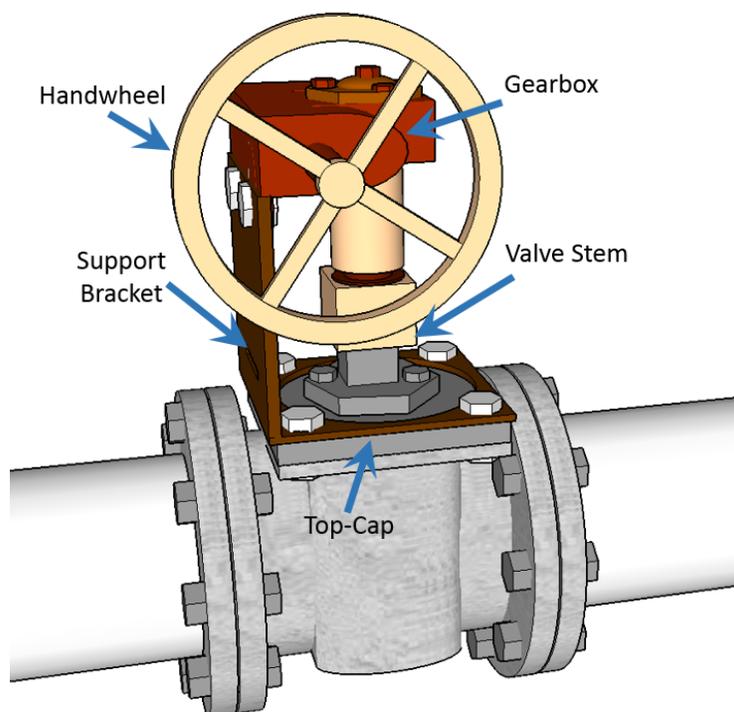


Figure 2. Illustration showing an alkyl unit plug valve with gearbox, valve stem, top-cap, support bracket, and handwheel similar to the one involved in the incident.

One of the operators removed the gearbox assembly so he could turn the valve stem with a pipe wrench to open the valve.¹⁰ Removing a malfunctioning gearbox from a plug valve is an accepted practice for alkylation unit operators.¹¹ To remove the gearbox, the operator removed the four vertical bolts that connected the gearbox support bracket to the valve body.¹² These four bolts, however, also secured the top-cap – a pressure-retaining component – to the valve body.¹³ The two horizontal bolts that could safely remove the gearbox from the support bracket remained in place. (Figure 3).

One of the operators then opened the valve by rotating the valve stem with a pipe wrench, while the other operator observed. With the four bolts removed from the top-cap, critical valve components were no longer held together. When the operator turned the valve stem, the plug valve loosened and came apart. Pressurized isobutane¹⁴ escaped from the valve body, forming a flammable white vapor cloud.

¹⁰ The Baton Rouge refinery replaces and does not repair inoperable gearboxes.

¹¹ While some might view this as an operator-performed maintenance activity, ExxonMobil and OSHA both consider removing the gearbox in order to operate the valve to be an operations activity. Operator-performed maintenance occurs when appropriately trained operators perform simple maintenance operations, especially those that are required frequently. See [Operator Performed Maintenance](#) (McGroarty, 2012).

¹² Vertical and horizontal orientation as used in this report applies to a valve installed parallel to the ground. For a valve installed perpendicular to the ground, these orientation descriptions should be reversed.

¹³ See [FLOWSERVE plug valve information](#) (Flowserve, 2014) at page 3.

¹⁴ The isobutane supply pressure to the valve was approximately 20 pounds-per-square-inch-gauge (psig) and its temperature was about 45 degrees Fahrenheit.

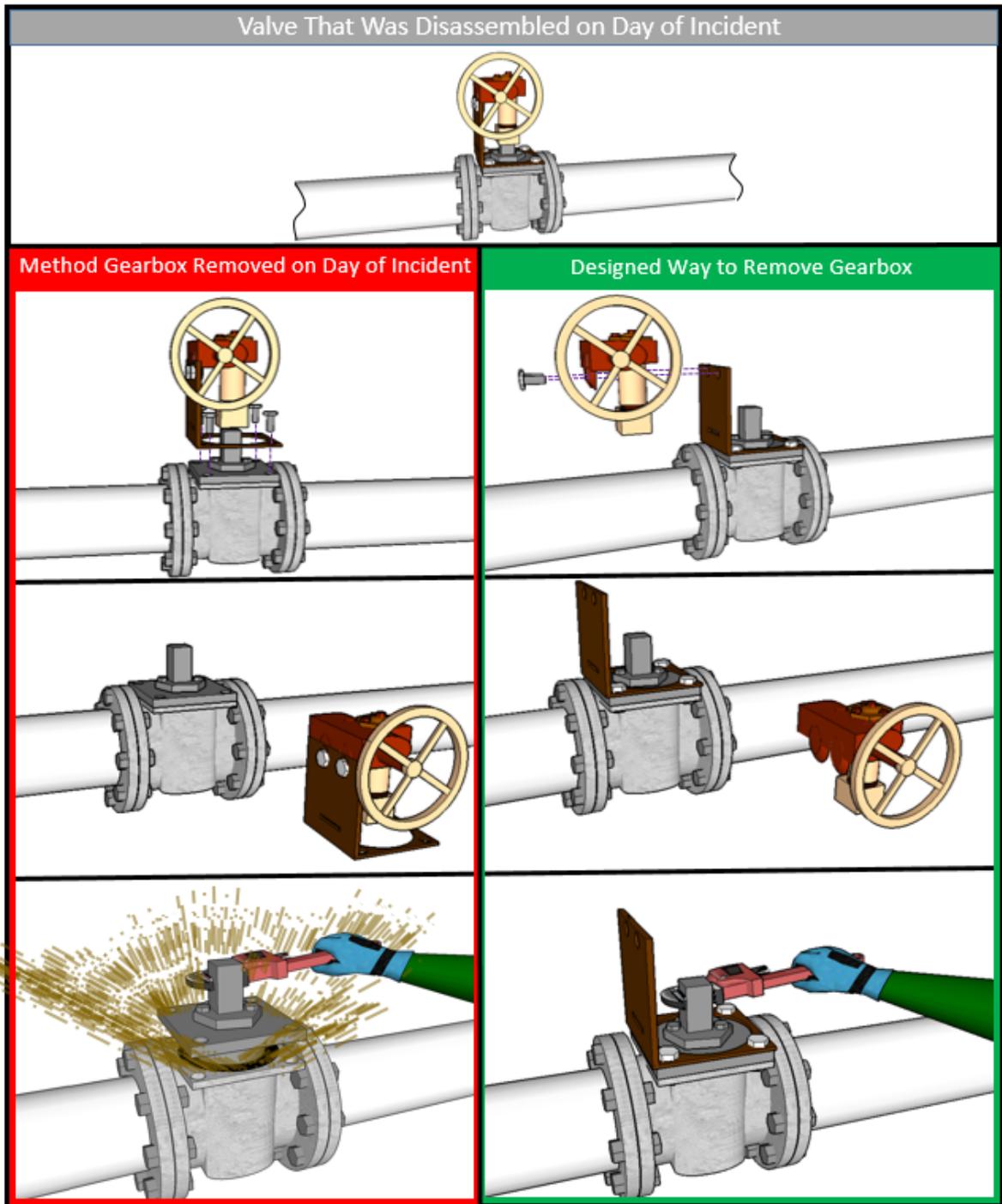


Figure 3. Gearbox removal. The left column illustrates how operators removed the plug valve gearbox on the day of the incident. It shows operators removed the entire support bracket. By design, removing the gearbox did not require removing the four vertical bolts that secured the pressure-retaining top-cap. The right column illustrates how the plug valve gearbox should be disassembled. The gearbox and handwheel could be disconnected from the support bracket by removing the two horizontal bolts on the side of the support bracket.

Following the release, the operators shouted to others in the area, including workers on the scaffolding above, warning them of the immediate danger and ordering them to evacuate. One of the operators alerted the board operator of the emergency by radio and told him to shut down the unit.

ExxonMobil estimated that 2,000 pounds of isobutane released into the atmosphere. Based on surveillance video, an energized welding machine located roughly 70 feet away likely ignited the vapor cloud. (Figure 4 and Figure 5). The resulting fire seriously injured one ExxonMobil employee and three contractors working in the vicinity of the release.¹⁵ Emergency responders isolated the release and extinguished the fire about 25 minutes after the initial ignition.



Figure 4. Welding machine that was the likely ignition source of the isobutane vapor cloud.

¹⁵ All four workers received third degree burn injuries. Each worker was wearing refinery-required personal protective equipment including [flame-resistant clothing](#). See (Bulwark FR, 2015).

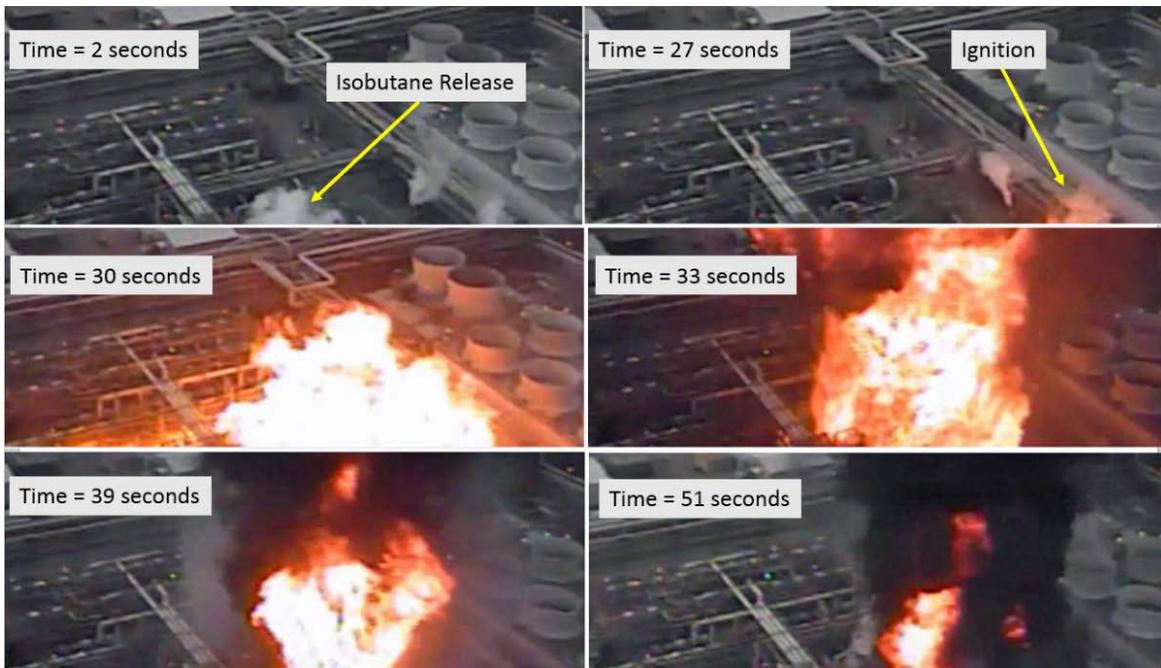


Figure 5. Sequence of events. Baton Rouge refinery security video clips showing the isobutane release and subsequent fire. This sequence does not show time zero – the first indication of the isobutane vapor cloud.

3. Incident Analysis

A number of Baton Rouge refinery safety management system deficiencies led to the removal of the plug valve gearbox and the inadvertent disassembly of its pressure-retaining top-cap, resulting in an isobutane release and fire. These deficiencies included:

- Failure to identify and address the older model plug valve design and gearbox reliability issues;
- Lack of a human factors¹⁶ evaluation to identify the older model plug valves' design and reliability issues as well as the potential hazards associated with operating and maintaining these valves;
- No written procedures detailing the steps needed to remove different models of gearboxes from plug valves to manually open or close the valve safely;
- Not training workers to safely remove the various plug valve gearbox models in the alkylation unit and the hazards associated with this type of work; and
- An organizational culture that accepted operators removing malfunctioning plug valve gearboxes despite the lack of detailed procedures and training for safe removal.

¹⁶ In Volume 3 of the Macondo investigation report, the CSB explained human factors as a discipline concerned with understanding interactions between people and other elements of complex systems. Human factors applies scientific knowledge and principles as well as lessons learned from previous incidents and operational experience to optimize human wellbeing, overall system performance, and reliability. The discipline contributes to the design and evaluation of organizations, tasks, jobs and equipment, environments, products and systems. See [Macondo Investigation Report: Volume 3](#) (USCSB, 2016) at page 23.

3.1. Plug Valve Gearbox Reliability

Plug valves, such as those used in the Baton Rouge refinery alkylation unit, can be difficult to operate, and refinery records indicate that the handwheel and gearbox assembly are “for convenience in operating a valve.” Even in low-pressure applications, the operating torque of a plug valve is high.¹⁷ In fact, some Baton Rouge refinery operators told the CSB that they previously encountered numerous difficulties while trying to operate gearboxes in the refinery’s alkylation unit, such as a free spinning or stuck handwheel. One worker described the free spinning gearbox handwheel as a “chronic” issue.

In discussing the reliability issues with the plug valve gearboxes, an alkylation unit operator explained:

So you have problems just with the gearbox sometimes. You’ll go to turn it and it won’t move. Sometimes the little shear pins that ... that the hand wheel mount to the steering with, they’ll break, they’ll shear off. And you can replace those pins. We’ve had them ... we’ve had them just free spin. Like gears or something break inside of them and they free spin.

Another operator clarified that the plug valve itself works well, but the gearboxes have reliability issues. The operator stated, “The valve itself usually works well. It holds. It’s a good style of valve to have to work behind, but ... you will have issues with the gear operator and/or the handwheel.” The operator described stripped or broken gears as typical reliability issues with the plug valve gearboxes. In describing the frequency of gearbox reliability issues, the operator stated that these problems happen often enough that workers are not surprised when a plug valve gearbox does not work.

3.2. Equipment Design and Human Factors Analysis

3.2.1. Plug Valve Design

Gearbox support brackets (see example in Figure 2) on 15 plug valves located in the Baton Rouge refinery’s alkylation unit were attached using the same four vertical bolts that secure the pressure-retaining top-cap to the valve body. This gearbox (a 30-plus year-old design), however, could be removed by taking off the two horizontal bolts without disturbing the critical top-cap bolts.

According to American Petroleum Institute (API) Standard 599, *Metal Plug Valves – Flanged, Threaded, and Welding Ends*,

Valves supplied with the capability of mounting actuators or gear operators shall be capable of doing so without removal of any [pressure-retaining] parts (e.g. body bolts, bonnet bolts, flange bolts, packing gland bolts, packing retaining stem nut, etc.).¹⁸

¹⁷ [Valve and Actuator Technology](#) (Ulanski, 1991) at page 148.

¹⁸ [API Standard 599 – Metal Plug Valves – Flanged, Threaded, and Welding Ends](#), (American Petroleum Institute (API), 2013) at Section 5.7.8.

The gearbox involved in the incident conformed to this part of the standard because it *could* be removed without removing any pressure-retaining parts. The operator could have removed the two horizontal bolts that connect the support bracket directly to the gearbox, rather than the four vertical bolts that secure the support bracket to the pressure-retaining top-cap (as shown on the right side of Figure 3 and in Figure 6). But the operator did not remove these two horizontal bolts; instead, he removed the four vertical bolts, which he believed to be the correct bolts to remove.



Figure 6. Gearbox support bracket for the valve involved in the incident. The two horizontal bolts (yellow arrows) can be removed to take the gearbox off the support bracket and the valve without disturbing the top-cap bolts. By removing the gearbox in this manner, the pressure-retaining valve components are not disturbed.

The CSB learned that the plug valve manufacturer (Durco) updated the plug valve design in 1984 so that the gearbox support bracket could be attached to the valve using different bolt connections than those that secure the pressure-retaining top-cap to the valve body. Approximately 97 percent of the plug valves located in the Baton Rouge refinery's alkylation unit are the more recent Durco plug valve design, which secures the gearbox assembly to the valve body flanges. (Figure 7 and Figure 8). With this improved design, the gearbox support bracket is unlikely to connect to the pressure-retaining top-cap, which can help prevent future incidents.

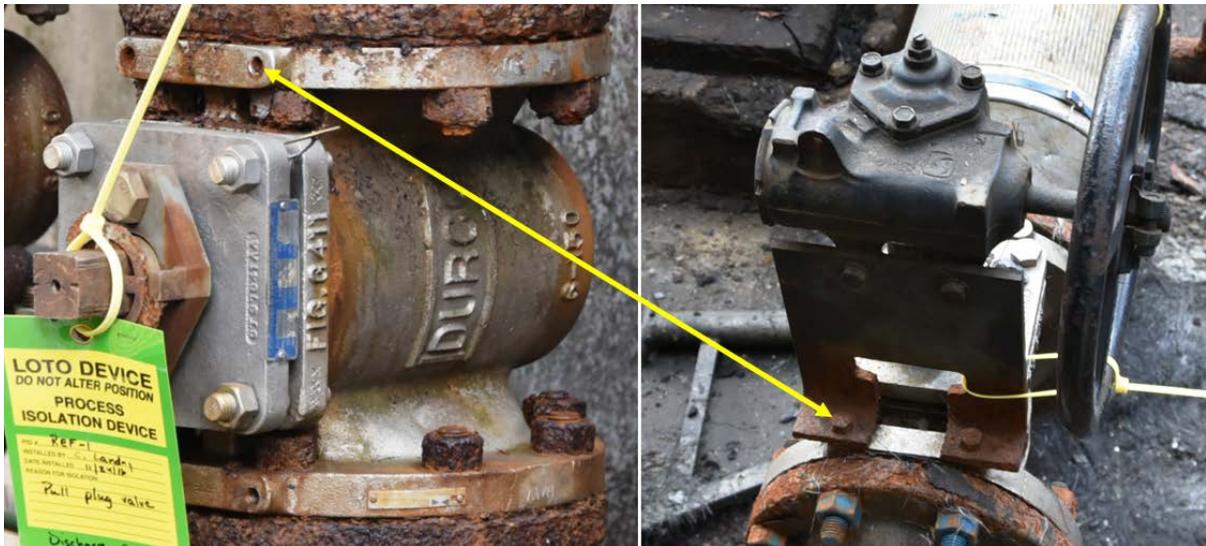


Figure 7. The improved plug valve design includes an additional four gearbox support bracket holes separate from the pressure-retaining top-cap (located on the valve body flanges) as seen at the yellow arrows. The photo on the right shows a gearbox support bracket attached to the valve body flange for a valve that was not involved in the incident. The photo on the left shows a different plug valve in the alkylation unit with its gearbox removed.



Figure 8. Two of several designs of gearbox support brackets (yellow circles) used at the Baton Rouge refinery. These specific brackets attach to the valve body flange – they are not among the approximately three percent of valves in the alkylation unit that attach the gearbox support bracket using the same four vertical bolts that secure the pressure-retaining top-cap.

The effective implementation of the hierarchy of controls¹⁹ is key to reducing risks and preventing major accidents. The hierarchy of controls is a method of evaluating safeguards to provide effective risk

¹⁹ The hierarchy of controls is a concept that refers to the ranking of the safety potential of various strategies for hazard management from most to least effective. Even if a greater risk-reduction action, such as minimizing hazardous chemicals, is used, it is still important to maintain other, lower level, administrative controls, such as wearing adequate personal protective equipment (PPE). This way even if one risk reduction system fails others are in place to prevent or minimize the incident's consequence. Prevention and mitigation strategies represent the safeguards designed to eliminate, prevent, reduce, or mitigate a scenario; they are also referred to as barriers, layers of protection, lines of defense, or control measures. See [CSB Investigation](#)

reduction.²⁰ Despite the fact that the Baton Rouge refinery satisfies API Standard 599 requirements with this older valve design, upgrading these valves to the improved design is high on the hierarchy of controls and would have likely prevented the incident. This design neglects an important adage API provides in safety guidance for improving human performance, “making it easy for people to do things right and hard for them to do things wrong.”²¹ Nevertheless, adoption of other controls such as written procedures and worker training, while lower on the hierarchy of controls, is also important to help prevent future incidents.

3.2.2. Equipment Design Good Practice

As an important equipment design text, Dr. Don Norman’s *The Design of Everyday Things* has been referenced in several books published by the Center for Chemical Process Safety (CCPS), which provide the chemical industry with important safety guidance, including:

- *Guidelines for Preventing Human Error in Process Safety*;
- *Guidelines for Investigating Chemical Process Incidents*; and
- *Plant Guidelines for Technical Management of Chemical Process Safety*.²²

In his book *The Design of Everyday Things*, usability engineering and cognitive scientist Dr. Norman analyzed the Three Mile Island nuclear power plant accident.²³ Norman described how misdiagnosis of a simple mechanical failure led to destruction of the reactor and a halt to the U.S. nuclear power industry.²⁴ He also described how, as can often be the case, blame focused on the operators, but that his committee found design to be at fault, stating:

The operators were blamed for these failures: “human error” was the immediate analysis. But the committee I was on discovered that the plant’s control rooms were so poorly designed that error was inevitable: design was at fault, not the operators. The moral was simple: we were designing things for people, so we needed to understand both technology and people.²⁵

In *The Design of Everyday Things*, Norman described why problems and undesired outcomes can occur when people interface with equipment. He stated that, “Design is concerned with how things work, how they are controlled, and the nature of the interaction between people and technology.”²⁶ The text

[Report. Catastrophic Rupture of Heat Exchanger. Tesoro Anacortes Refinery](#) (USCSB, 2014) at pages 34-35. Also see [OSHA graphic showing the hierarchy of controls](#) (USDOL).

²⁰ CCPS Book, [Inherently Safer Chemical Processes – A Life Cycle Approach](#) (Center for Chemical Process Safety (CCPS), 2009), Section 2.1.

²¹ [Human Factors Tool for Existing Operations](#) (American Petroleum Institute (API), 2006) at page 1.

²² [Guidelines for Preventing Human Error in Process Safety](#) (Center for Chemical Process Safety (CCPS), 1994), [Guidelines for Investigating Chemical Process Incidents](#) (Center for Chemical Process Safety, 2003), and [Plant Guidelines for Technical Management of Chemical Process Safety](#) (Center for Chemical Process Safety (CCPS), 1995).

²³ [The Design of Everyday Things](#) (Norman D. , 2013) at page 7.

²⁴ *Id.* at page 7.

²⁵ *Id.*

²⁶ *Id.* at page 5.

explained that there are a number of reasons for deficiencies in human-machine interactions, including an insufficient understanding of human behavior by equipment designers.²⁷

Norman also specifically warned of potential problems and dangers that develop when equipment design does not fully consider how the equipment gets used: “With everyday objects, the result is frustration. With ... industrial processes, the resulting difficulties can lead to accidents, injuries, and even deaths.”²⁸

Norman attributed equipment design incidents (like what occurred at the Baton Rouge refinery) to the design being “focus[ed] upon the requirements of the system ... and not upon the requirements of people.”²⁹ He stated in *The Design of Everyday Things* that it is common to attribute human error to problems stemming from poor equipment design.³⁰

In its book *Human Factors Methods for Improving Performance in the Process Industries*, CCPS encouraged incident investigation teams to avoid blaming individuals, but to strive to gain an understanding for the underlying reasons the actions occurred, which are typically rooted in design, including:

- Design of equipment;
- Design of the task; or
- Design of the work environment.³¹

In his autobiography *By Accident ... A Life Preventing Them In Industry*, Trevor Kletz stated, “To say accidents are due to human failing is true but is as helpful as saying that falls are due to gravity.”³² Kletz also expanded on this in his book, *An Engineer’s View of Human Error*, where he stated:

To say that accidents are due to human failing is not so much untrue as unhelpful. It does not lead to constructive action. All we can do is tell someone to be more careful. In contrast if we say that an accident can be prevented by better design ... we can take action that may prevent a recurrence.³³

In *The Field Guide to Understanding Human Error*, Sidney Dekker confronted the idea that human error is a cause of accidents. Dekker stated:

I keep writing books about human error, even though I don’t believe that “human error” actually exists—other than as a convenient but misleading explanatory construct; as an intervention in history that helps us structure

²⁷ *Id.* at page 6.

²⁸ *Id.*

²⁹ *Id.* at page 168.

³⁰ *Id.* at page 6.

³¹ [Human Factors Methods for Improving Performance in the Process Industries](#) (Center for Chemical Process Safety (CCPS), 2007) at page 203.

³² [By Accident ... A Life Preventing Them In Industry](#) (Kletz, *By Accident ... A Life Preventing Them In Industry*, 2000) at page 138.

³³ [An Engineer’s View of Human Error](#) (Kletz, *An Engineer’s View of Human Error*, 1992) at page 2.

and make sense of the past. Initially, such a construct may make our own life easier. But it quickly troubles our ability to really understand sources of safety and risk in our own organizations and elsewhere.³⁴

More recently, in a video discussing why things go wrong and accidents occur, Dekker stated:

So, why do things go wrong? We used to believe that things go wrong because somebody makes an error or something breaks. Today, however, we believe ... that things go wrong because lots of things ... inside the organization are wrong [or] have been wrong for a long time. These are things related to:

- Procedures;
- Culture;
- Design of equipment;
- Supervision; [and]
- Work practices.

And all these things can combine to create the potential for an accident. ... This has been an extraordinarily empowering idea. It has shifted the focus upstream – to the system surrounding the work that people do.³⁵

Like Dekker, Norman similarly challenged the stereotype that human error is a common cause of industrial accidents and Norman also further emphasized the importance of good design to prevent accidents, stating: “Most industrial accidents are caused by human error: estimates range between 75 and 95 percent. How is it that so many people are so incompetent? Answer: They aren’t. It’s a design problem.”³⁶ Norman also observed:

[I]n my experience, human error usually is a result of poor design: it should be called system error. Humans err continually; it is an intrinsic part of our nature. System design should take this into account. Pinning the blame on the person may be a comfortable way to proceed, but why was the system ever designed so that a single act by a single person could cause calamity?^{37, 38}

³⁴ [The Field Guide to Understanding Human Error](#) (Dekker, 2006), at ix (Acknowledgements).

³⁵ [Professor Sidney Dekker on Why Things Go Wrong](#) (Ranpara, 2012).

³⁶ [The Design of Everyday Things](#) (Norman D. , 2013) at page 162.

³⁷ *Id.* at page 66.

³⁸ In addition to Kletz, Dekker, and Norman, other experts such as Erik Hollnagel also prefer not using the term “human error,” but he recognized it is likely to remain for years to come. Hollnagel explained that using the term “human error” provides for “clear and simple explanations” that are comfortable to some people and may satisfy a psychological desire to avoid anxiety. (Reason, 2013) at pages xi through xiii. On the contrary, James Reason is among the human factors experts who prefer to retain the “error” terminology. Reason states “errors are not intrinsically bad” and nearly all human actions contain three basic elements – plans, actions, and consequences. Reason used these elements to construct an error definition and to classify errors. (Reason, 2013) at pages 7 and 8. Among other error classifications, Reason described skill-based slips, rule-based mistakes, and knowledge-based mistakes. (Reason, 2013) at page 15.

To illustrate equipment design problems, Norman used, among other things, common everyday doors.³⁹ Norman described pushing doors meant to be pulled open and pulling doors that need to be pushed open.⁴⁰ Although doors are simple devices, their designs are often confusing to people, and a common example capable of causing momentary frustration that most people likely experienced throughout their lives.⁴¹ Norman stated, “The design of a door should indicate how to work it without any need for signs, certainly without the need for trial and error.”⁴² He described a door built for appearance – a stylish, attractive door without visible lines, pillars, or hinges that his friend could not figure out how to open until observing how a person familiar with the door opened it.⁴³ Norman used this everyday example to explain two important characteristics of good design – discoverability and understanding.⁴⁴

Discoverability: [Can a person] even figure out what actions are possible and where and how to perform them?⁴⁵

Understanding: What does it all mean? How is the [device] supposed to be used?⁴⁶

Similar to Dr. Norman’s example of the attractive door, the older model plug valve involved in this incident lacked good design characteristics. The support bracket appeared to be part of the gearbox, and it was not sufficiently obvious to the operator that the gearbox removal did not require removing the support bracket.

The design of the Baton Rouge refinery’s pre-1984 plug valves lacked dedicated connection points to attach the gearbox. The valve designers only provided the top-cap connections and these were used to attach the gearbox support bracket. As shown by this incident, however, removal of the support bracket can result in an undesired and uncontrolled release of a highly hazardous chemical.

To address inadvertent disassembly, it appears the valve designers took a logical design approach – they secured the support bracket to the top-cap and then they provided additional connection points within the support bracket to attach the gearbox. To the valve designers this likely appeared to be a perfectly acceptable design, but to an operator who needs to remove an inoperable gearbox to open the valve, the support bracket could appear to be part of the gearbox itself. Complicated by other issues, such as a small number of valves with this design installed in the alkylation unit and a lack of training and written

³⁹ See [Norman Doors: Don't Know Whether to Push or Pull? Blame Design](#). (99% Invisible, 2016). See also [It's not you. Bad doors are everywhere](#). (Posner, 2016).

⁴⁰ [The Design of Everyday Things](#) (Norman D. , 2013) at page 1.

⁴¹ *Id.*

⁴² *Id.* at page 2. In a another design context, according to Dr. Prabhiot Singh, Director of Systems Design at the Earth Institute, “We spend a lot time designing the bridge, but not enough time thinking about the people who are crossing it.” (Parater, 2015). The seeds for the incident at Baton Rouge were sown in a design room decades ago during valve development. Designers did not fully anticipate the danger associated with gearbox removal during operation by the end users who would be working on the valve in a highly hazardous chemical operation.

⁴³ *Id.*

⁴⁴ *Id.* at page 3.

⁴⁵ *Id.*

⁴⁶ *Id.*

procedures to guide employees responsible for removing failed gearboxes, the risk of an incident grows even further.

The newer plug valve more broadly used in the alkylation unit is a better design. The redesign addressed the potential to have a chemical release when removing the gearbox assembly. The valve designers provided four additional connection points to secure the gearbox support brackets and these attachment locations are not pressure-retaining components. (Figure 9). With the newer and improved valve design, if a worker completely removes the gearbox and its support bracket(s), a chemical release cannot occur.

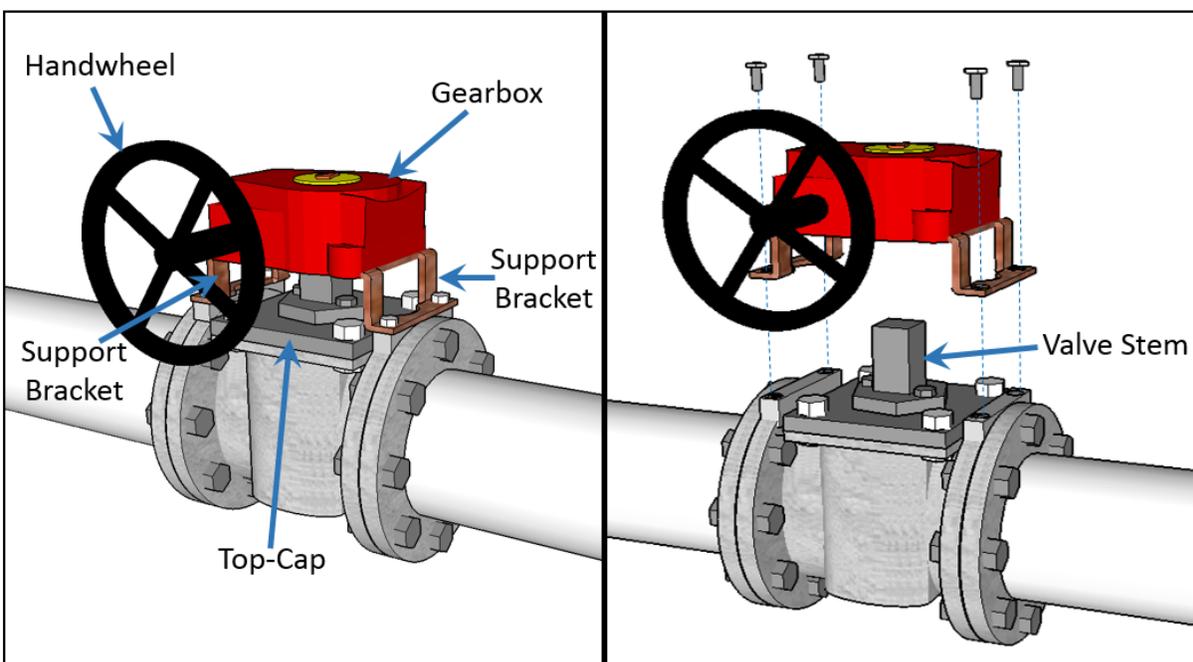


Figure 9. The post-1984 plug valve design, showing how one type of gearbox connects to all four dedicated attachment points on the valve flanges that are not pressure-retaining parts.

The location of the bolts on the newer valve design may have also contributed to the operator removing pressure-retaining bolts. On the newer design, the bolts connecting the support bracket to the valve are vertical, and are usually removed in order to remove the gearbox and handwheel. In describing how to remove a gearbox from this type of plug valve, an alkylation unit operator explained, “I would only have to pull those [vertical] bolts right there and the whole thing would come off.” Although another operator recognized that there were two different ways to remove the plug valve gearbox, there was not a preferred method. While looking at a photo of a plug valve to explain how to remove the gearbox, the operator said either the horizontal or the vertical bolts could be removed.

For the less common, older valve design, the vertical bolts were the pressure-retaining bolts and should not be removed; instead, the horizontal bolts should be removed to disassemble the gearbox and handwheel safely. (Figure 9 and Figure 10). It could appear as though these critical vertical bolts had to be removed to take the inoperable gearbox off the valve. Although other bolts allowed for gearbox removal without touching the critical pressure-retaining bolts, this design can lead to potentially

catastrophic consequences. The CSB concludes that poor equipment design was a significant factor that led to this incident.

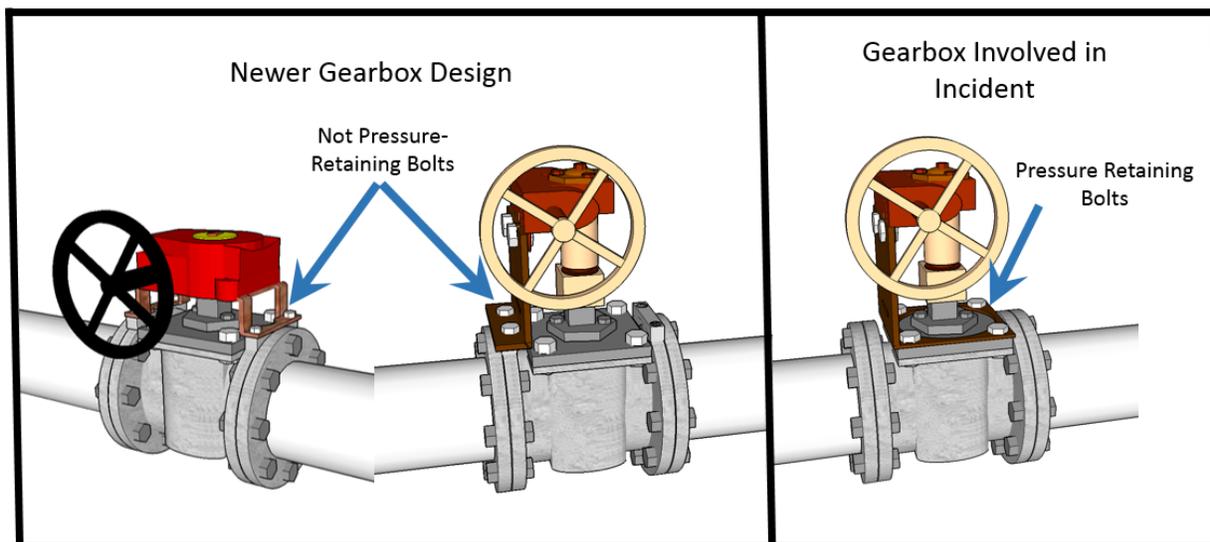


Figure 10. Comparison of newer gearbox attachment designs, which are among the approximately 97 percent of the gearboxes in the alkylation unit, and the gearbox involved in the incident. Importantly, the improved valve design connects the gearbox support bracket to dedicated connection points on the valve flange as shown in the left illustration.

3.2.3. Human Factors

The Occupational Safety and Health Administration (OSHA) Process Safety Management (PSM) Standard requires companies to perform a detailed process hazard analysis (PHA) under 29 C.F.R. § 1910.119(e)(1) on covered processes that identifies, evaluates, and controls the hazards involved in the process. This analysis includes evaluating human factors.⁴⁷

API published a human factors tool intended, among other things, to improve how hazard analyses (including PHA revalidations) address human factors.⁴⁸ The scope of the API human factors tool “includes existing operations and human tasks,” such as the periodic removal of an inoperable plug valve gearbox.⁴⁹ API states that the tool “is intended for use without specific training on human factors.”⁵⁰ The tool provides several questions that could have prompted discussion of the reliability issues with plug valve gearboxes at the Baton Rouge refinery including the lack of procedures or training to remove a gearbox. Some of the relevant human factors questions provided by API include:

- Is there any equipment that often does not work as designed?
- How could human error cause an incident or unsafe condition?

⁴⁷ 29 C.F.R. § 1910.119(e)(3)(vi).

⁴⁸ [Human Factors Tool for Existing Operations](#) (American Petroleum Institute (API), 2006) at page 2.

⁴⁹ *Id.*

⁵⁰ *Id.*

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- Are routine duties well-defined?
 - Are the job aids adequate (including training)?⁵¹

In its most recent alkylation unit PHA, the Baton Rouge refinery did not document any consideration of human factors related to valve operational issues. Had the PHA human factors analysis prompted workers to discuss the removal of these gearboxes, the company could have identified the potential hazard of inadvertently taking the valve apart during gearbox removal. As a result, valves with this potential hazard could have been recommended either for replacement or an appropriate modification through a PHA corrective action, thus avoiding the incident.

Baton Rouge refinery operators acknowledged to the CSB that they frequently encountered situations where the handwheel did not turn the valve. Demonstrating the frequency of gearbox removal, during a review of one photograph of the alkylation unit with CSB investigators, one of the operators identified three other plug valves whose gearboxes had all been removed. Given the history of issues with these alkylation unit gearboxes, the Baton Rouge refinery should have evaluated these operational difficulties, recognizing that this older valve design could result in unintentional disassembly of pressure-retaining components, which, as seen, can have catastrophic consequences.

3.3. Written Procedures

As part of this evaluation, the Baton Rouge refinery should examine the lack of a written procedure for plug valve gearbox removal. When companies expect workers to perform tasks that do not have dedicated procedures, it can increase the likelihood of an undesired event. The CSB has addressed procedural deficiencies in a few past investigations. For example, the CSB noted in its investigation of the June 2013 Williams Olefins Plant Explosion and Fire that when a process condition requires operator activity in the field, such as opening or closing valves, these actions can present hazards to workers.⁵² Before starting such field operations, a company's process safety management system must ensure a procedure is developed and a thorough hazard evaluation is performed to identify and control hazards.⁵³

As the CSB's investigation noted, detailed written procedures can help ensure that operations activities are safe and hazards are effectively controlled. In its book *Guidelines for Writing Effective Operating and Maintenance Procedures*, 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

⁵¹ *Id.* at pages 3, 4, and 5.

⁵² [CSB Investigation Report: Williams Geismar Olefins Plant: Reboiler Rupture and Fire: Geismar, Louisiana](#) (USCSB, 2013) at page 36.

⁵³ It is important to note that OSHA's PSM standard requires companies to develop written operating procedures that cover steps for each operating phase, including normal operations (under 29 C.F.R. § 1910.119(f)(1)(i)(B)) and temporary operations (under § 1910.119(f)(1)(i)(B)); safety and health considerations (under § 1910.119(f)(1)(iii)) such as precautions necessary to prevent exposure, including engineering controls, administrative controls, and personal protective equipment (under § 1910.119(f)(1)(iii)(B)); and any special or unique hazards (under § 1910.119 (f)(1)(iii)(E)). 29 C.F.R. § 1910.119(f)(4) requires companies to develop and implement safe work practices to provide for the control of hazards during operations including opening process equipment or piping.

important resource in developing procedures. Using this information ensures that the known hazards are addressed properly.⁵⁴

The CSB found in its investigation of the Williams Olefins incident that an operations supervisor conducted field troubleshooting operations to determine the cause of decreased quench water flow through a reboiler. This type of operational troubleshooting was an accepted practice at the Geismar facility and could be performed without conducting a hazard analysis or developing a procedure for the activity. Among other things, this led to a catastrophic rupture that killed an operator and the operations supervisor.

The CSB noted in the Williams Case Study that:

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.⁵⁵

Both incidents illuminate important safety lessons, culminating in the fact that process safety management program deficiencies can lead to catastrophic events.

The CSB also recently completed an investigation report on the ExxonMobil Torrance, California, refinery⁵⁶ explosion that occurred on February 18, 2015, in the refinery's Electrostatic Precipitator, a pollution control device in the fluid catalytic cracking unit that removes catalyst particles using charged plates that produce sparks during normal operation. The incident occurred when ExxonMobil was attempting to isolate equipment for maintenance while the unit was in an idled mode of operation; preparations for the maintenance activity caused a pressure deviation that allowed hydrocarbons to backflow through the process and ignite in the precipitator.

The CSB found that a lack of procedures contributed to the incident. The company had not developed a procedure that would provide guidance to operators on how to run the unit safely for foreseeable modes of operation. The lack of a procedure meant that there was no guidance on what constituted an unsafe condition and operators had no instruction on how to handle process deviations. As a result, operators were not aware that the process was in an unsafe condition and made decisions that ultimately contributed to an explosion.

As demonstrated by these incidents, it can be hazardous to conduct activities in the field without first establishing procedures. As such, the Baton Rouge refinery should have developed written procedures detailing the appropriate steps for safely removing its various types of plug valve gearboxes.

⁵⁴ [Guidelines for Writing Effective Operating and Maintenance Procedures](#) (Center for Chemical Process Safety (CCPS), 1996) at page 18.

⁵⁵ [CSB Investigation Report: Williams Geismar Olefins Plant: Reboiler Rupture and Fire: Geismar, Louisiana](#) (USCSB, 2013).

⁵⁶ PBF acquired the Torrance refinery from ExxonMobil on July 1, 2016, and Torrance Refining Company LLC (TORC), a fully-owned subsidiary of PBF, currently operates the refinery. See [PBF News Release](#) (PBF Energy, 2016).

3.4. Training

OSHA requires under 29 C.F.R. § 1910.119(g)(1)(i) that each employee involved in operating a process be trained in an overview of the process and in operating procedures. The training should include emphasis on the specific safety and health hazards, emergency operations including shutdown, and safe work practices applicable to the employee's job tasks.⁵⁷

In addition, an agreement between ExxonMobil and the United Steelworkers union states that, as part of their duties and responsibilities, operators will perform mechanical tasks on their assigned operating equipment. The agreement provides a commitment to training these workers, stating, "As the need exists, [operators] will be given on-the-job mechanical training including classroom instruction."

The Baton Rouge refinery provided the CSB with numerous training records that the company asserts it gave to its operators. None of these documents, however, addressed how to remove an inoperable gearbox from a plug valve. The CSB also conducted multiple worker interviews, in part, to gain an understanding of the effectiveness of the Baton Rouge refinery's training program.

In its plug valve literature, Flowserve warns users not to remove the pressure-retaining top-cap bolts, stating:

WARNING: Do not loosen or remove top cap fasteners [bolts] ... when removing a[] [gearbox] or accessory. Remove the operator [gearbox] by unfastening it from the bracket.⁵⁸

This warning, however, was not communicated to Baton Rouge refinery workers. In addition, Baton Rouge refinery operator training material lacked information about the potential consequences of attempting to remove an inoperable plug valve gearbox.⁵⁹

One refinery operator training course called "*Manual Valve Basics*" contained more than 150 slides and reviewed nine different types of manual valves, including plug valves. One slide describes the top-cap (bonnet) as a pressure boundary and identifies its bolts as pressure-retaining parts (Figure 11).

⁵⁷ See also [OSHA Publication 2254: Training Requirements in OSHA Standards](#) (USDOL, 2015) at page 13.

⁵⁸ [FLOWSERVE plug valve information](#) (Flowserve, 2014) at page 4.

⁵⁹ *Id.* According to Flowserve Corporation, valves must be relieved of process fluid and pressure prior to disassembly. This is a recommended precautionary measure. The force applied to the top of the valve, coupled with the removal of the pressure retaining bolts, allowed the isobutane in the line to release to the atmosphere. A properly trained operator performing this activity should be aware that a valve would need to be isolated, emptied, and depressured prior to opening.

VALVE COMPONENTS

Valve Bonnet (Continued)

- **Bonnet is connected to the body by a threaded, bolted, or welded joint**
- **In all cases, the attachment of the bonnet to the body is considered a pressure boundary**
- **The weld joint or bolts that connect the bonnet to the body are pressure-retaining parts**
- **Valve bonnets, although a necessity for most valves, represent a cause for concern. Bonnets can:**
 - Complicate the manufacture of valves
 - Increase valve size/weight
 - Be a source for potential leakage

Figure 11. Slide from ExxonMobil *Manual Valve Basics* training course. The third bullet point in this slide, which is slide 24 of 153, indicates that the bolts connecting the bonnet to the body are pressure-retaining parts.

Despite recurring plug valve gearbox reliability issues, operators consistently stated they had not received formal training on how to remove a gearbox from a plug valve. Consequently, operator responses as to how they would address an inoperable plug valve gearbox were inconsistent. Some operators stated that there was a known history of removing gearboxes to open or close the valve manually with a pipe wrench, and that they had done so before with no adverse consequences. Other, more experienced operators stated that they would not attempt to fix the issue themselves, and would instead notify maintenance personnel to repair the issue, which, depending on urgency, could happen right away or might be delayed for several days. In addition, although Baton Rouge refinery maintenance workers may be more experienced with gearboxes in general, the CSB did not identify any evidence (including interviews and document review) that maintenance workers had a procedure or received training on how to remove these plug valve gearboxes safely.

While the gearbox could have been detached without removing the four vertical bolts that secure the pressure-retaining top-cap to the valve body, it was not clear to all workers that there was an alternate way of performing the disassembly. As shown in Figure 6 the gearbox could have been removed by unscrewing two horizontal bolts between the gearbox and the support bracket. On the day of the incident, however, the operator did not identify the hazard of removing the four vertical bolts that connected the support bracket directly to the pressure-retaining top-cap of the plug valve. In addition, for the majority of the alkylation unit plug valves, it would not matter which gearbox support bracket bolts were removed as none were connected to pressure-retaining components. Furthermore, the operator's coworker observed the removal of the gearbox and did not identify the hazard with removing the bolts.

Despite the fact that there is a history of operators performing this type of activity, there appears to be a lack of hazard awareness, as the operator disassembled more of the valve than necessary to remove the inoperable gearbox. The CSB concluded after interviewing operators and reviewing training material that

ExxonMobil did not adequately prepare alkylation unit operators at the refinery to remove a gearbox attached to the top-cap of a plug valve safely.

3.5. Organizational Culture

The organizational culture at the Baton Rouge refinery accepted operators removing malfunctioning plug valve gearboxes in the alkylation unit despite the lack of detailed procedures and training. ExxonMobil even acknowledged that it was “accepted practice” at the refinery alkylation unit for operators to remove malfunctioning gearboxes from plug valves and manually rotate the valve stem with a pipe wrench. The operator working on the valve at the time of the incident told the CSB that they had conducted similar work in the past without adverse consequence, and described this type of work as a “learned habit” from watching more experienced operators remove gearboxes from plug valves when they encountered a similar gearbox problem.

The cultural issues identified in this report that led to the November 22, 2016 incident include:

- The long-standing gearbox reliability issues were never investigated or corrected;
- Operators sometimes encountered inoperable gearboxes on alkylation unit plug valves and removed the gearbox to open or close the valve despite the lack of detailed written procedures and training to perform this activity safely; and
- The refinery’s human factors analysis did not identify and control this hazard before the incident.

The CSB also addressed organizational culture in its investigation of the explosion in the fluid catalytic cracking unit at the ExxonMobil Torrance refinery. Due to the frequency of process safety incidents at the Torrance refinery, the CSB encouraged refinery management to consider the implementation of a process safety continual improvement program at the Torrance refinery to help prevent process safety incidents. The Baton Rouge refinery incident may suggest a similar need to strengthen the process safety focus of that refinery’s organizational culture.

4. Key Lessons

The CSB provides the following key lessons for companies with chemical manufacturing facilities, including refineries:

1. Evaluate human factors associated with operational difficulties that exist in your machinery and other equipment, especially when the equipment is part of a process covered by the PSM standard. Apply the hierarchy of controls to mitigate the identified hazards. In this case, the Baton Rouge refinery should have evaluated the fact that approximately three percent of the plug valves in the alkylation unit used a gearbox attachment design that could result in inadvertent disassembly of pressure-retaining components. Once identified, the refinery should have applied the hierarchy of controls to establish a mitigation strategy for susceptible plug valves.
2. Establish detailed and accurate procedures for workers performing potentially hazardous work, including job tasks such as removing an inoperable gearbox. In this case, establish procedures specific to removing malfunctioning gearboxes from plug valves. It is especially important when different types of equipment or configurations exist which could cause confusion.
3. Provide training to ensure workers can perform all anticipated job tasks safely. This training should include a focus on processes and equipment to improve hazard awareness and help prevent chemical accidents.

5. Safety Guidance

Based on the findings of this investigation, the CSB provides the following guidance to companies with chemical manufacturing facilities, including refineries, which use manual gear-operated plug valves.

Such companies should:

- Survey valves to identify gear-operated plug valves with gearbox support brackets attached to pressure-retaining components (“susceptible valves”);
- Perform a hazard analysis and risk assessment on susceptible valves using the hierarchy of controls to establish a mitigation strategy;
- Consider upgrading to a newer plug valve design and attach the gearbox support bracket to the valve flanges (see Figure 9) or otherwise address the potential hazard;
- For susceptible valves identified for future upgrades, develop an interim hazard mitigation plan to control hazards and protect workers;
- Provide written procedures and training to ensure workers can safely remove the gearbox from the plug valve; and
- Consider expanding this guidance beyond manual gear operators to evaluate other devices such as motors or actuators that may attach to pressure-retaining valve components.

6. ExxonMobil Post-Incident Actions

Post-incident, ExxonMobil informed the CSB that they made the following changes regarding its susceptible plug valves in the Baton Rouge refinery alkylation unit:

- Refinery personnel surveyed the alkylation unit to identify susceptible plug valves. The survey identified 15 plug valves in the alkylation unit with gearbox support brackets attached to pressure-retaining components.
- To address the potential hazard, refinery personnel established a mitigation strategy to either:
 - replace the older plug valve design with the newer design; or
 - eliminate the support bracket and install manual levers on the valve stem for plug valve operation.

The Baton Rouge refinery implemented the strategy to address all the identified susceptible valves in the alkylation unit.

- Prior to plug valve modifications, refinery personnel installed warning signs on the susceptible valves to alert workers that bolts were used to secure the support brackets to pressure-retaining components.
- ExxonMobil communicated incident learnings to its other sites and made a presentation on the incident to the petroleum refining industry at an API conference in May 2017.
- Other ExxonMobil refineries were required to conduct surveys of their plug valves to identify both:
 - gear-operated plug valves with gearbox support brackets attached to pressure-retaining components; and
 - components other than gear operator support brackets that may be mounted to pressure-retaining components.

7. Causal Analysis

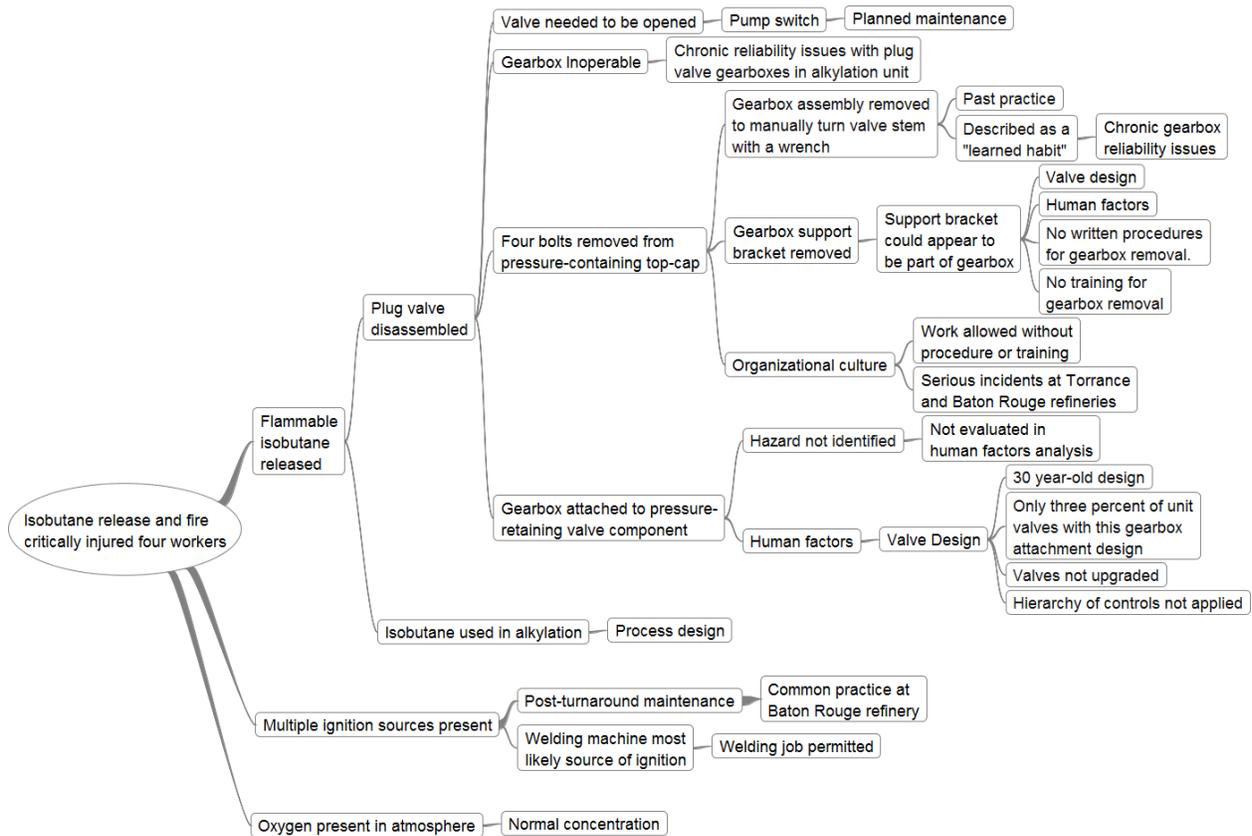


Figure 12. Simplified causal analysis of the November 22, 2016 incident at the Baton Rouge refinery.

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