National Aeronautics and Space Administration

SYSTEM FAILURE CASE STUDY

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Fire From Ice

February 16, 2007: Propane gas leaked from the McKee Refinery's Propane Deasphalting Unit in Sunray, Texas. As winds carried the vapor cloud, a spark ignited the propane and the entire cloud burst into flames. The fire spread quickly, forcing an evacuation of the refinery as firefighters battled the blaze. Three workers suffered serious burns and the refinery was shut down for two months. Gas prices increased 9 cents per gallon in the west.

Figure 1: The Refinery Fire

BACKGROUND

Industrial Overview

Shamrock Oil and Gas built the McKee Refinery outside Sunray, Texas in 1933. The refinery underwent major modifications in the 1950s and 1990s. Valero acquired the refinery in 2001 and further upgraded it in 2004. By 2005, Valero was the largest refiner in North America, with eighteen refineries producing 3.3 million barrels per day. The McKee Refinery contributed about 170,000 barrels per day to Valero's overall production.

PROPANE DEASPHALTING (PDA) UNIT

One part of the refinery is the Propane Deasphalting (PDA) Unit, where high-pressure propane serves as a solvent to recover fuel and asphalt from crude oil residues. In 1992, the refinery shut down a control station in the PDA unit. Rather than remove the idle subsection, or isolate it with slip blinds[1], the refinery simply closed the six-inch valves around this section. This configuration created a "dead-leg" of pipes that had nothing flowing through them. Normally, these pipes would be empty. However, a foreign object blocked one of the valve seats, preventing it from sealing completely. Over the fifteen years that the control station was out of service, water entrained in the propane passed through the jammed valve and settled in the low point of the supposedly empty dead-leg. Unlike piping that was in use, the dead-leg was not insulated or heat-traced to prevent freezing, leaving it vulnerable to low temperatures.

[1] Slip blinds are solid pieces of metal inserted between flanges to positively isolate piping or equipment.

WHAT HAPPENED?

In February 2007, a four-day cold front froze the water in the dead-leg pipe, causing it to expand, and crack the pipe. Ice blocked the crack and prevented any propane from exiting.

February 16, 2007: Freezing water cracked an idle section of pipe causing a propane gas release. The propane ignited and set off a severe fire at the McKee Refinery.

Proximate Cause:

- Water in an idle section of pipe froze and expanded, cracking the pipe. As the ice thawed, propane escaped and ignited.

Underlying Issues:

- Lack of planning for idle pipes.
- Lack of fire-proofing.
- Remotely Operable shutoff valves were not installed.

When the ice thawed, propane could escape through the crack (Figure 2). On February 16, the cold front passed and the ice began to melt. As the ice melted, propane began spewing from the cracked pipe at approximately 4,500 pounds per minute.

Workers reported hearing a pop and noticed a vapor cloud spewing from the PDA unit. They initially thought a steam line had ruptured but soon realized the potential for significant danger. Wind carried the propane cloud toward a boiler house, where it likely found the spark that ignited the entire cloud. Immediately, flames shot back to the source of the propane leak in the PDA unit. The fire alarm sounded as flames attacked nearby piping and, as the pipes carrying liquid propane failed, the fire ferociously consumed their contents. A high-pressure jet of flaming propane launched itself at a steel column supporting a pipe rack filled with petroleum products. This steel column did not have fireproofing and it collapsed under the flames within minutes. The pipes broke and the fire intensified as it fed on more propane.

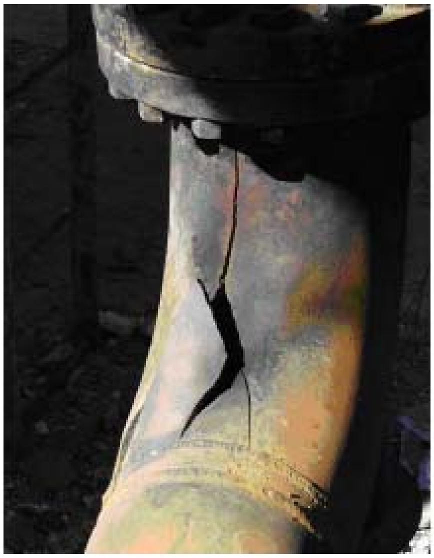

Figure 2: Crack in the 10" diameter propane mix control station "dead-leg" inlet elbow

> **2007 McKee Refinery Fire Timeline**
>
> **Before the fire:**
> - [Circa 1992] PDA unit "dead-leg" created.
> - [March 1996] Process Hazard Analysis recommends installing Remotely Operable Shutoff Valves (ROSOVs) in PDA.
> - [January 2002] Valero takes ownership of refinery.
> - [February 12, 2007] Sub-freezing temperatures in Sunray, Texas.
>
> **February 16, 2007:**
> - [9:05 am] Temperature rises above 32° F.
> - [2:09-2:10 pm] First signs of propane release on security camera.
> - [2:10 pm] Ignition of propane cloud; three personnel injured.
> - [2:26 pm] Total evacuation of refinery.
>
> **1:00 pm February 17, 2007: Fire extinguished.**

Firefighters tried to combat the fire from the South, but the wind blew and shifted, forcing the firefighters to find another attack position. The fire blocked access to manual valves that could help isolate flames, and operators could not isolate propane flow remotely because prescribed remotely operated shut-off valves (ROSOV's) had not been installed. Emergency managers ordered a total refinery evacuation 15 minutes after the fire ignited. Too many pressurized pipes had ruptured, and responders actually worked near vessels containing liquid propane that were engulfed in flames and at risk of failing. They sounded the evacuation alarm and shut down the refinery as responders isolated the main feeds and gas supplies.

Later, emergency response teams reentered the refinery to isolate fuel sources and gradually control the fire. Valero planned to reenter and extinguish the fire the next day, but chlorine and sulfuric acid leaks prevented them and it was not until February 17, a day later, that Valero personnel finally extinguished the fire.

Proximate Cause

Freezing water cracked a pipe that had been unused for fifteen years. Propane gas leaked through the crack, forming a vapor cloud. A single spark, probably from the boiler room, ignited the gas and the fire flashed back through the propane cloud.

Underlying Issues

Dead-Leg Not Discovered

There was no record that the refinery conducted a formal management of change review when the control station was taken out of service. The change consisted of shutting the valves surrounding the control station. Operators did not remove the idle portion or isolate it with slip blinds. When Valero acquired the refinery in 2001, the dead-leg had been in place for almost ten years. Without a formal written program to identify, review and freeze-protect dead-legs and other infrequently used piping, Valero personnel did not recognize the presence of a dead-leg in the control station and never addressed the freezing hazard. The pipes remained unused, without freeze protection, and imperfectly isolated from the functioning unit.

Process Hazard Analysis (PHA) Finding erroneously closed before completion

Refinery operators could not cut off the fuel for the fire because remotely operable shutoff valves (ROSOVs) had not been installed. The fire prevented them from reaching the shutoff valves in the unit itself. A 1996 Process Hazard Analysis (PHA) by the previous owner identified the need for ROSOVs in the PDA. Although the valves were never installed, the action item was checked complete. The 2006 Valero PHA revalidation did not revisit earlier findings or apply Valero's ROSOV standard, so the revalidation did not uncover the missing valves.

The refinery did not violate any official standards, but the missing valves violated Valero's requirements. While the American Petroleum Institute (API) does not offer specific guidance for ROSOV design or location, Valero's corporate policy requires ROSOVs for installations such as the PDA.

Inadequate Fire Protection Standards

Valero covered steel supports within thirty feet of potential fire sources with fire-resistant insulation to keep the steel cool and delay structural failure. The columns within a thirty foot radius of the PDA unit that had been fireproofed remained standing after the fire, but an unprotected pipe bridge 77 feet away collapsed (Figure 3).

Even though the pipe bridge was outside the radius for required fireproofing, a loss-prevention report listed the rack as a "top priority" for the fireproofing program. Unfortunately, the rack had not been fireproofed by February 2007.

Fireproofing would have given firefighters more time to respond before the fire grew out of control. The McKee Refinery fireproofed beyond both the American Petroleum Institute's recommendations and Valero's corporate policies, but the fire's size exceeded industry expectations. The mishap investigation found that neither API's recommendations nor Valero's fireproofing standards specified sufficient protective distances.

Aftermath

Three workers at the refinery suffered serious burns; one member of the fire brigade suffered minor burns. Ten people were treated for minor injuries. The refinery was shut down for approximately two months and operated at reduced capacity for one year. The losses were greater than fifty million dollars and Valero received three OSHA citations.

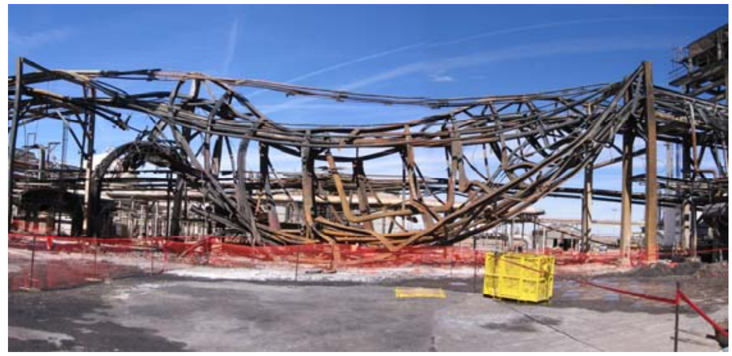

Figure 3: Collapsed pipe bridge. Fireproofed supports remain standing, but columns that were not fireproofed (center) collapsed.

Near Miss – Chlorine Release and Butane Sphere Failure

The Valero Refinery fire could have been much more damaging to personnel and the surrounding community. Three one-ton containers of highly toxic liquid chlorine located approximately 100 feet from the PDA unit were exposed to radiant heating. The containers had fusible plugs designed to melt and allow the container to vent under excessive heat. The plugs melted, but one container ruptured and the other two vented entirely, releasing more than two and a half tons of chlorine. Fortunately, responders pulled back before the bulk of the 2.5-ton chlorine release, and no one suffered symptoms associated with chlorine exposure.

Like the chlorine containers, a sphere containing liquid butane was also exposed to the raging fire. In 1956, another severe fire at the McKee refinery that involved a butane sphere killed nineteen individuals and wounded many more. Fortunately, in 2007 the wind prevented the fire from reaching the sphere, and the flames did nothing more than blister the paint on the sphere's protective coating. Valero substituted sodium hypochlorite (bleach) for chlorine during reconstruction.

Applicability to NASA

Among the many lessons that can be learned from the Valero Refinery fire, two stand out as particularly relevant to NASA's work. First, develop controls that detect and correct the latest conditions in unused equipment or facilities. As far as investigators could tell, the PDA dead-leg remained attached to the unit for at least a decade before the pipe finally burst and released the propane that fueled a fire for more than two days.

Remember that discontinued components attached to a system still pose a safety risk. Just because you aren't using a piece of equipment does not mean that it cannot or will not cause problems. Conduct and verify hazard analyses to determine where safety hazards might arise. Review the decision to discontinue a system and, whenever possible, completely remove the idle section. If removing the idle portion is not possible, follow best practices to mitigate problems.

"What you don't have can't leak."

-Trevor Kletz, quoted by the CSB

Another lesson from the Valero fire is to plan for the actual energy releases possible within a system – be realistic when estimating safety margins. As Dr. Richard Feynman noted during the Challenger inquiry, "Nature cannot be fooled." If Valero had fireproofed the pipe bridge that collapsed during the fire, firefighters might have had time to control the fire. This sort of preventative measure is difficult to value because it is impossible to tell how much damage or injury preventive safety measures avert.

Other lessons to remember from the Valero fire include the impact of environmental changes on a process, especially when environmental changes are intermittent rather than consistent. Consider how changing weather conditions might affect your systems. While the weather cannot be controlled, we can control how prepared we are.

Finally, the extent of damages at the Valero refinery would have been significantly lessened had first responders been able to close manual and remotely operable shut-off valves. This failure in one area caused other areas to fail in a matter of minutes. At NASA, isolate systems and processes whenever possible to ensure that initial failures do not cause a chain reaction that leads to catastrophic failures. Build safeguards and ensure that safety measures and equipment will be accessible, even under the worst conditions, to limit potential damages.

Questions for Discussion

- Is your project accepting a PHA for a legacy system without verifying the analysis?
- What systems do you have in place to ensure work is actually completed before it is marked complete?
- What is the greatest energy release possible in your system(s)? What is your margin of safety?
- What change management practices do you employ when modifying a facility?

Figure 4: Surveillance video view of the fire approximately 60 seconds after ignition.

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