CSB Safety Bulletin

U.S. Chemical Safety and Hazard Investigation Board

Key Lessons for Preventing Incidents When Preparing Process Equipment for Maintenance

Flash Fire at the Delaware City Refinery

Delaware City, DE
Incident Date: November 29, 2015
1 Employee Injured
No. 2015-01-I-DE

KEY LESSONS

- Operational tasks that involve preparing equipment for maintenance can be uncommon and non-routine; therefore, ensure procedures include steps for preparing all process equipment for maintenance.
- For all equipment preparation activities, develop a process that requires pre-planning and hazard identification prior to initiating the work, which includes assessing hazards that may be introduced and steps for mitigating those hazards.
- When isolating equipment for de-inventorying or decontaminating activities prior to maintenance work, avoid relying on single block valves, even when the valves are newly installed, to control the release of hazardous energy.
- When an equipment preparation task or isolation plan needs to be modified or expanded due to leaking valves or changing conditions, initiate a process to evaluate hazards that may be introduced by the change.
- Avoid draining materials containing, or potentially containing, hydrocarbon or flammables into the sewer or other systems not specifically designed for such services, especially when ignition sources are present.

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1.0 INTRODUCTION

On Sunday, November 29, 2015, an operator at the Delaware City Refining Company's (DCRC) sulfuric acid alkylation unit suffered second-degree burns to the face and neck and third-degree burns to the wrist from a flash fire.[1] The incident occurred when operations personnel were preparing equipment for maintenance work by de-inventorying and draining vessels located between two isolation points. A single block valve isolated the vessels being decontaminated from a pressurized and inventoried depropanizer column containing hydrocarbons; unknown to operations personnel, the valve leaked in the closed position, resulting in backflow of flammable material from the depropanizer. When an operator opened the vessel drain valve to empty what he assumed was condensate water from the vessel to the oil water sewer, the hydrocarbons from the depropanizer also released to the sewer and ignited, resulting in a flash fire.

Prior to maintenance work, operations personnel commonly prepare equipment by depressurizing, de-inventorying, washing, and draining. These activities often involve opening process equipment and piping and can result in a release of hazardous energy. Though equipment preparation activities can occur rather frequently in process plants, the tasks involved may vary among pieces of equipment and piping and combinations of equipment and, thus, may be non-routine and not be included in an existing procedure. Because of the non-routine nature of equipment preparation activities, process plants should develop a system to ensure that equipment preparation activities are carefully planned, which includes selecting proper isolation methods and identifying hazards through a risk assessment.

Of incidents the CSB has investigated, 37 percent occurred in chemical and manufacturing facilities prior to, during, or immediately following maintenance activities and resulted in 86 fatalities and 410 injuries. Some of these are current investigations in which the CSB is examining issues with non-routine operations and maintenance.[2] This Safety Bulletin identifies the immediate causes of the flash fire at DCRC and summarizes key lessons to prevent similar incidents.

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2.0 DESCRIPTION OF THE ALKYLATION UNIT PROCESS

Alkylation is a refinery unit operation in which lighter hydrocarbons react with isobutane in the presence of an acid catalyst (sulfuric or hydrofluoric acid) to produce larger branch-chain hydrocarbon molecules with a high octane rating. The alkylation unit at DCRC receives butylenes from the fluid coker unit[3] and the fluid catalytic cracker (FCC) unit.[4] The alkylation unit contains two alkylation reactor sections, each comprised of two reactors that run in parallel.[5] When operated at lower temperatures, the reaction produces a higher quality alkylate. Propane and excess isobutane cycle through the reactors to cool the reaction and are then condensed and sent back to the alkylation reactors. A small amount of the propane and excess isobutane recycle stream is purged to the depropanizer column. The depropanizer column maintains

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[1] This incident followed two others at the DCRC facility on August 21, 2015, and August 28, 2015. The CSB deployed a four-person investigative team to DCRC on December 3, 2015, to assess conditions at the refinery in the wake of the most recent incident.

[2] See Appendix A for a list of CSB investigations involving maintenance.

[3] In the fluid coker unit, the heaviest residual oils are heated and decompose into petroleum coke and lighter hydrocarbon products.

[4] The FCC unit breaks down heavy oils into lighter gasoline components in the presence of heat and a catalyst.

[5] The DCRC alkylation unit contains two separate sulfuric acid (H_2SO_4) process designs licensed by M.W. Kellogg Co. (acquired by Exxon) and STRATCO, Inc. (acquired by DuPont).

optimal propane concentration in the unit by removing excess propane. Prior to entering the depropanizer column, the alkylation reactor purge streams travel through a caustic wash system to mitigate the risk of corrosion by removing trace amounts of sulfur dioxide.

The November 2015 incident occurred in the caustic wash section of the alkylation unit. Caustic sodium hydroxide is used to scrub trace amounts of sulfur dioxide from the purge streams in a caustic settler (Figure 1). The solution is then fed to a coalescer or "carry over" vessel to ensure the caustic and water mixture is removed from the hydrocarbon stream prior to entering the depropanizer column. Caustic in the stream is removed in the caustic settler through the drain valve and recirculated into the process. Occasionally, spent caustic is extracted from the caustic settler and routed to a quench drum[6] prior to venting to the refinery flare system.

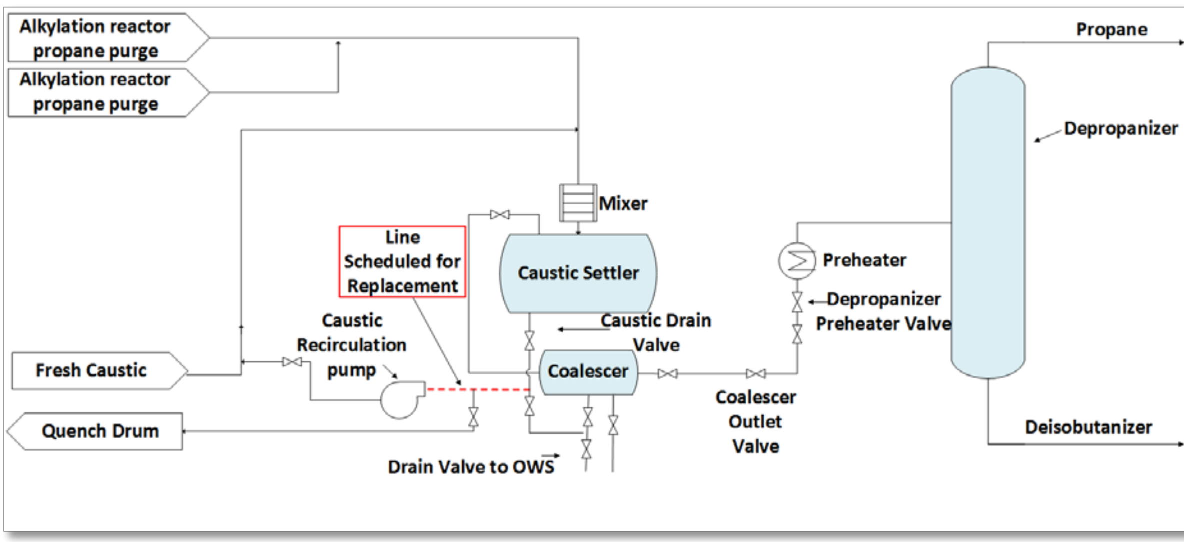

FIGURE 1. Simplified process flow diagram of depropanizer caustic wash system (Source: CSB).

3.0 PRE-INCIDENT ACTIVITIES

On the day of the incident, alkylation unit operators were preparing equipment for turnover to the maintenance department, scheduled for the following day. The unit remained under the operations staff control throughout the equipment preparation activity, up to and including when the incident occurred. The maintenance activity involved replacing a 20-foot section of thinning piping located between the caustic settler drain line and the caustic recirculation pump (Figure 1) that was identified during a routine inspection process a month prior (Figure 2).

[6] A quench drum cools and condenses hot vented gas streams before they enter a refinery vent header system.

FIGURE 2. 20-foot replacement piping (Source: CSB).

For the maintenance department to replace the piping, operators had to first drain and isolate it. Earlier in the week, operators planned to isolate the caustic settler from the pumps by closing the caustic drain valve (Figure 3), which is immediately downstream of the caustic settler and upstream of the line that needed replacement. Four days prior to the incident, however, operators learned that the caustic drain valve was leaking and therefore would not seal properly, which would result in material passing through the valve when in the closed position.

Because the valve would not seal, operations could not isolate the section of piping that needed replacement and therefore had to expand the isolation to another block valve downstream of the coalescer and settler. As a result, the caustic settler and the coalescer needed to be included in the isolation. The equipment preparation activity for the expanded isolation was scheduled for Sunday, November 29, 2015. In the alkylation unit weekend instructions, the unit superintendent noted the leaking isolation valve and directed operators to take the caustic settler out of service on Sunday to isolate the piping that was scheduled for replacement on Monday, November 30. In addition to the caustic settler, the expanded isolation plan required removing the contents of the coalescer to ensure the line to be replaced was free of hydrocarbons (Figure 4). An operator looked for a procedure or job aid for the task of taking those vessels out of service; however, no job aid or procedure existed, so the dayshift operator and board operator developed informal instructions for isolating and de-inventorying that equipment.

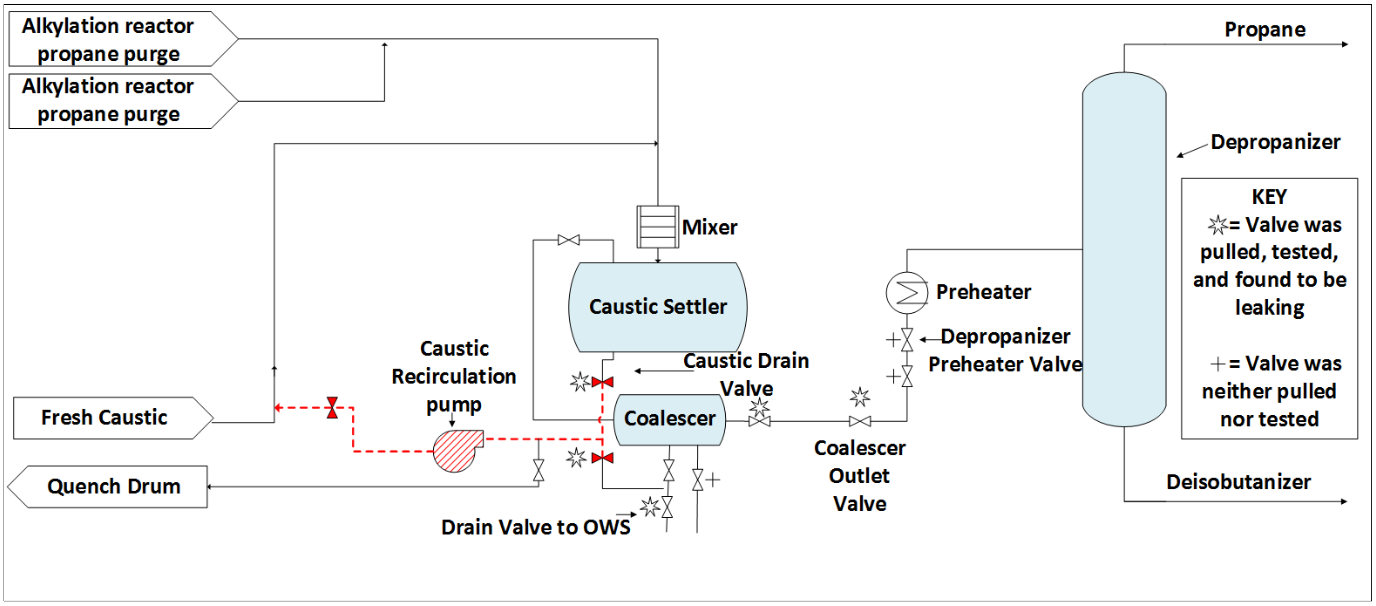

FIGURE 3. Original isolation plan shown in red (Source: CSB).

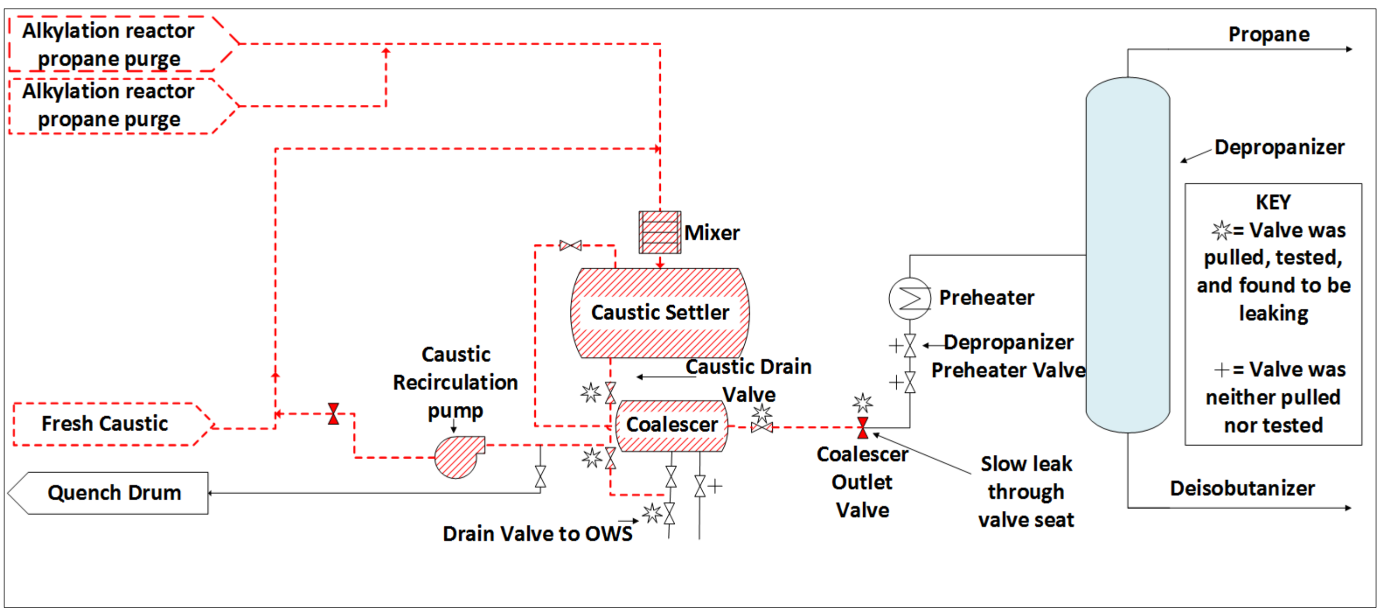

FIGURE 4. Expanded isolation plan shown in red (Source: CSB).

To begin the task, the dayshift operator first shut down the propane flow from the alkylation reactors by turning off the propane purge pumps that supply the caustic settler and double blocked the control valve stations on the pump discharge lines. The dayshift operator then filled the caustic settler with process condensate water[7] to displace the contents of the settler and coalescer in the direction of the depropanizer column; this condensate water carried over into the downstream coalescer. Operators monitored the temperature of the piping downstream of the coalescer, as an increase in temperature would indicate that the process condensate fill had reached the preheater valve and displaced the contents of the settler and coalescer. The dayshift operator also connected a nitrogen hose to the caustic settler to aid in displacing the hydrocarbons and other contents of the vessels. Once the dayshift operator confirmed that the settler and coalescer were filled with process water and the contents of the vessels were displaced to the depropanizer column, the dayshift operator removed the depropanizer from service by closing the column's inlet and outlet valves.[8] As part of the modified isolation plan, the depropanizer column remained inventoried and pressurized. The closed coalescer outlet valve was intended to isolate both the coalescer and the caustic settler from the pressurized and inventoried depropanizer column throughout operation's preparation for the maintenance task.

After isolating the coalescer and caustic settler from the depropanizer column, the dayshift operator drained some of the condensate water that filled the coalescer and caustic settler to a quench drum to vent any remaining hydrocarbons to the refinery flare system. Then the dayshift operator drained the rest of the vessel contents to the oil water sewer (OWS) directly under the caustic settler [9] and began the second and final condensate water filling until shift change.

4.0 INCIDENT DESCRIPTION

Shortly after arriving for his shift on November 29, 2015, the nightshift operator spoke to the dayshift operator about the maintenance preparation task and reviewed the dayshift operator's handwritten list of steps, while also identifying which equipment had been isolated. The nightshift operator, who was working alone on the equipment preparation assignment, proceeded with the next step in the process: draining the vessels from the second condensate wash. At about 6:00 pm the nightshift operator continued to de-inventory the vessels by opening the drain valve to the OWS to drain the carry-over condensate water into the OWS system. Shortly after opening the 3-inch drain valve to the OWS (Figure 3), he recalled hearing a pop and suddenly seeing a wall of fire advancing toward him; he suffered second-degree burns to the face and neck and third-degree burns to the wrist from the flash fire. He left the area and turned on stationary fire monitors. After turning on two of the monitors, a fellow operator advised him to seek medical attention due to the severity of his burns. The injured operator was transported by ambulance to the hospital and released December 3, 2015, three days after the incident.

During the incident, fires were observed at multiple 4-inch OWS drains located at most of the pump stations between the OWS drain under the caustic settler and a furnace. The furnace was operating about 120 feet east of the caustic settler. Another operator was making rounds in the alkylation unit and responded to the fire along with

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[7] Condensate from the 40 pounds-per-square-inch (psi) steam system is used for flushing equipment and vessels in the units. The condensate typically is registered at about 200ºF.

[8] DCRC reported to CSB investigators that the depropanizer column was not critical to the alkylation process and could be shut down while the unit was in operation.

[9] OWS is a pipeline that traverses from the alkylation unit to a monitoring box on the outer perimeter of the unit. The facility has two sewer systems: an OWS system and a storm water sewer. The OWS runs through a monitor box to the wastewater treatment plant.

other operators stationed in the control room. The fire burned for approximately one hour before onsite refinery emergency response teams extinguished the fire by isolating the fuel source.

An alkylation unit operator, who was also a fire brigade member, was called to assist. He recalled that the main source of flames came from the 3-inch drain pipe beneath the caustic settler near the drain to the OWS. He isolated the burning hydrocarbon streams by closing the drain valve to the OWS and extinguished a smaller fire at a half-inch drain pipe coming off the caustic settler by closing the associated valve (Figure 5). The operator/fire brigade member closed the depropanizer pre-heater valve upstream of the depropanizer column to cut off the supply of hydrocarbons that appeared to be coming from the depropanizer column.

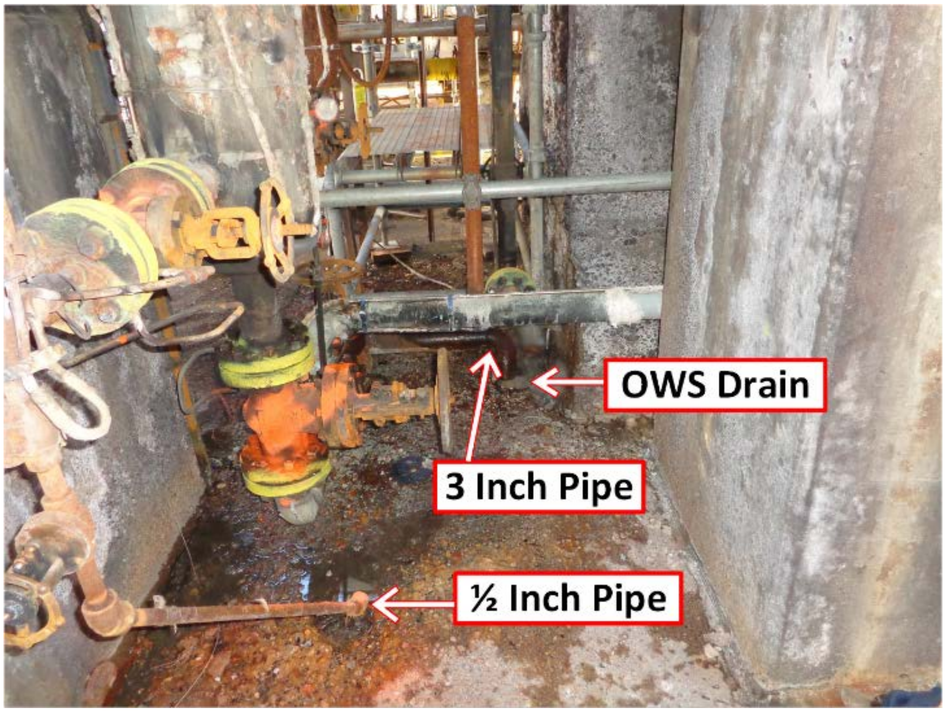

FIGURE 5. Drain pipes associated with the November 29 incident (Source: CSB).

5.0 INCIDENT ANALYSIS

5.1 ORIGIN OF THE FLASH FIRE

The CSB concluded that hydrocarbons in the depropanizer column likely backflowed through the leaking 4-inch coalescer outlet valve into the coalescer and caustic settler during the maintenance preparation activity. A furnace, located about 120 feet east of the caustic settler, most likely ignited the hydrocarbons when the nightshift operator began draining the contents of the vessels into the OWS (Figure 6).[10] When the alkylation

[10] The investigation team concluded that the furnace, operating on an adjacent process unit downwind of the maintenance preparation activity, was the most likely source of ignition. The injured operator recalled the fire advancing toward him from the direction of the furnace. Isobutane vapors are known to travel to the source of ignition and flash back. The atmospheric conditions on the day of the incident would have allowed for the isobutane vapors to travel in the direction of the furnace.

unit operators expanded the isolation to include the coalescer and caustic settler that morning, they closed only one valve between the depropanizer column and the equipment they were attempting to isolate.

The four-inch coalescer outlet gate valve was later determined to have a slow leak through the valve seat,[11] and likely allowed hydrocarbons in the depropanizer column to backflow into the caustic settler and coalescer during the equipment preparation activity. Post-incident analysis of the control system data verified depropanizer backflow and review of the process data revealed that the caustic settler level indicator recorded a slight increase in volume before the dayshift operator began filling the coalescer and caustic settler for the second condensate wash.

The slight increase in volume indicated that the contents of the depropanizer were passing through the leaking valve. In addition, control system data show a drop in the depropanizer pressure and level indicators starting immediately before the second condensate fill, indicating that the column was depressurizing vapor back to the coalescer and settler.

When the nightshift operator began draining the condensate water from the vessels, he expected the vessels' contents to empty completely. Instead, hydrocarbon liquid and vapor backflowing from the depropanizer, and condensate water flowed into the OWS drain. The hydrocarbon vapor, made up of mostly highly flammable isobutane[12] and propane, found an ignition source at the furnace (Figure 7) and the flash fire traveled back toward the nightshift operator's location. Flames overcame the nightshift operator at the base of the coalescer and caustic settler.

Six-inch collection drains at a number of pump stations (Figure 8) are located en route to the OWS collection drum and the pathway for the OWS is located in an orientation that brings it in close proximity to the operating furnace, with the closest drain about 25 feet from a furnace (Figure 9).

[11] The valve seat is a stationary part of a valve. When the valve seat is in contact with the movable portion, it stops the flow

[12] Isobutane is a highly flammable liquefied petroleum gas used in sulfuric acid alkylation. Vapor from isobutane can travel significant distances to ignition sources and flash back. Isobutane is also heavier than air (vapor density = 2) and can accumulate in drains and sewers where ignition can occur.
Isobutane; MSDS. [Online]; ConocoPhillips: Houston, TX, April 2, 2012. http://www.conocophillips.com/sustainable-development/Documents/SMID_213_%20Isobutane.pdf, (accessed March 21, 2017).

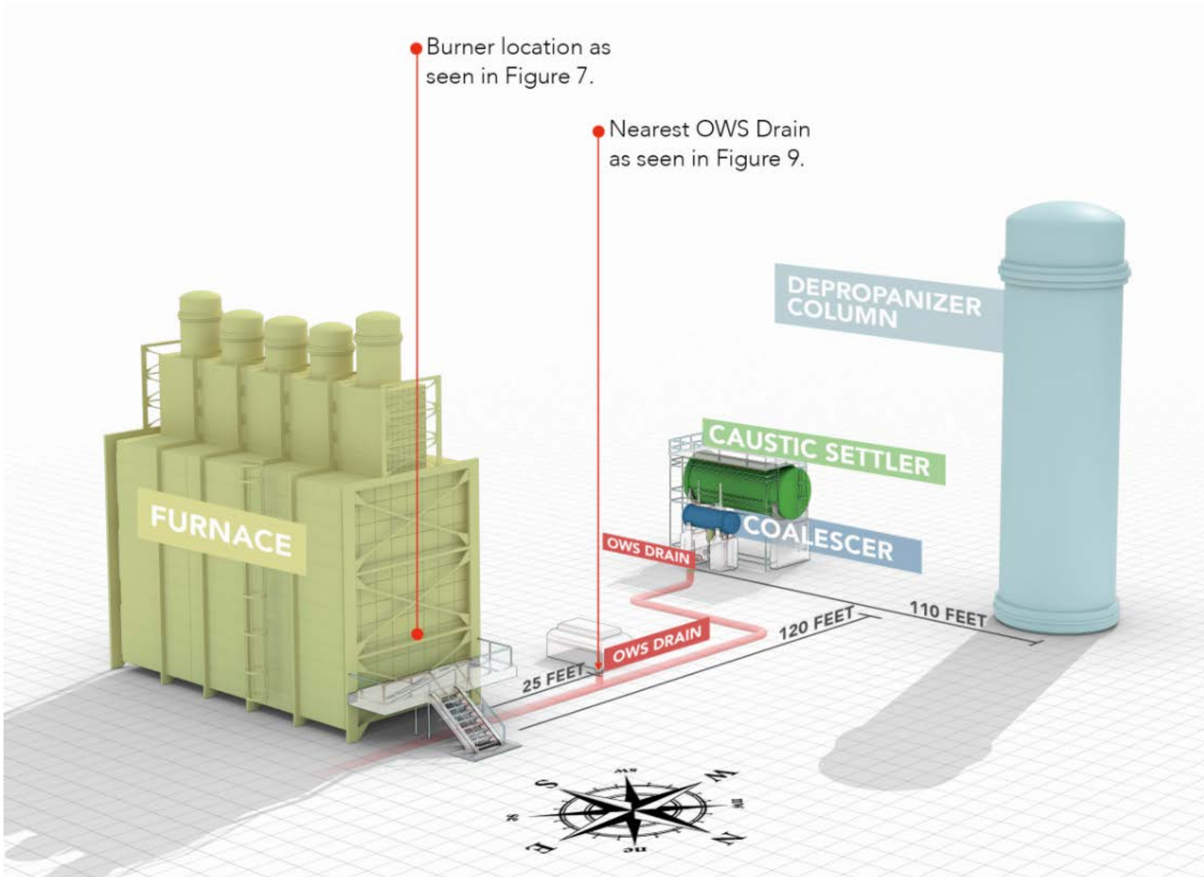

FIGURE 6. Diagram (not to scale) of depropanizer caustic wash system and associated equipment (Source: CSB).

FIGURE 7. Burner on furnace (Source: CSB).

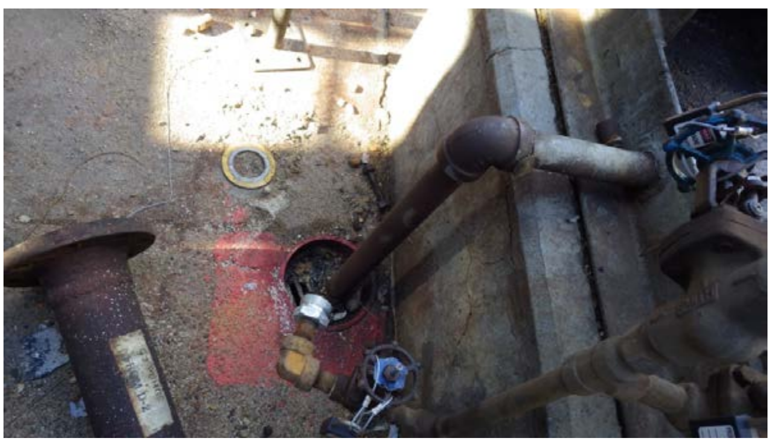

FIGURE 8. Typical pump drain to OWS (Source: CSB).

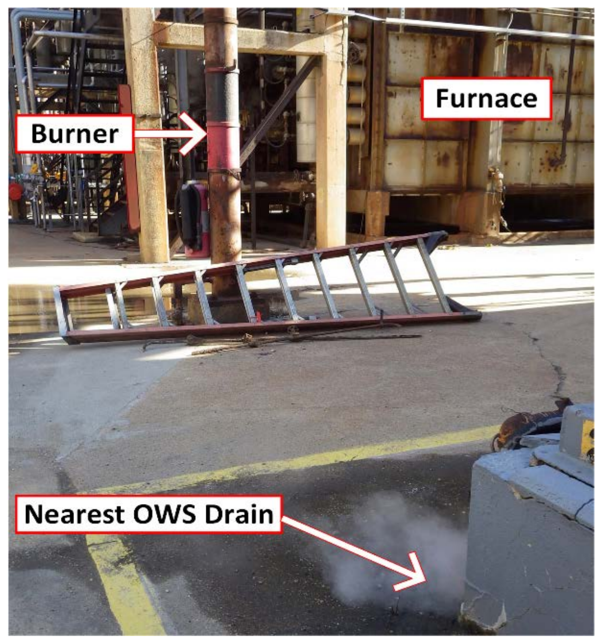

FIGURE 9. Proximity of furnace to OWS drain (Source: CSB).

6.0 Preparing Equipment for Maintenance

Typical day-to-day duties of refinery and chemical plant operators include controlling chemical process conditions and monitoring equipment to ensure it is working as designed and recognizing when adjustments or repairs are needed.[13] When process equipment needs repair or replacement, operators are usually involved in initiating work orders for the maintenance department and preparing equipment so it is ready for maintenance work.[14] Preparation can include depressurizing equipment, purging, draining or displacing tank contents, and isolating other process equipment or energized sources.[15] Once operations personnel prepare equipment for maintenance, maintenance personnel take over to perform repair or replacement.

6.1 Non-routine Work

Maintenance, which can be non-routine, is a major source of incidents, due mostly to preparing the equipment for the maintenance, rather than the maintenance itself.[16] Generally, preparing equipment for maintenance is a common task for operations personnel; however, the tasks involved can vary among different types of equipment and, in some cases, occur much less frequently than typical daily operational duties. Therefore, these tasks can be uncommon or non-routine and thus may not be included in existing procedures.

Preparing equipment for maintenance can involve uncommon or non-routine tasks such as draining, displacing, and/or isolating hazardous materials or energy sources.

In refineries, routine operations can include daily operator activities such as making slight adjustments to process equipment and retrieving product samples to ensure product quality. Non-routine operations entail work that may be done infrequently and, as such, warrant particular attention because they often involve more risk.[17] Examples of non-routine work can include tasks related to planned and unplanned maintenance, turnarounds, and equipment modifications.[18]

Operators and refinery personnel at DCRC reported to CSB investigators that preparing equipment for maintenance is routine for operations personnel; however, the CSB concluded that the specific task of isolating and de-inventorying the coalescer and caustic settler was uncommon. An operator reported to CSB investigators that the original isolation plan was routine because the task is similar to the procedure for removing spent caustic

[13] Center for Chemical Process Safety of the American Institute of Chemical Engineers. *Guidelines for safe process operations and maintenance* [Online]; New York, 1995; pp. 203-224. http://app.knovel.com/hotlink/pdf/id:kt003VFW31/guidelines-safe-process/maintenance (accessed March 22, 2017).

[14] Center for Chemical Process Safety of the American Institute of Chemical Engineers. *Guidelines for safe process operations and maintenance* [Online]; New York, 1995; pp. 203-224. http://app.knovel.com/hotlink/pdf/id:kt003VFW31/guidelines-safe-process/maintenance (accessed March 22, 2017).

[15] Sanders, R. E. *Chemical process safety: learning from case histories*, 4th ed. [Online]; Elsevier: New York, 2015; pp. 149-164. http://app.knovel.com/hotlink/pdf/id:kt010QITX1/chemical-process-safety/preparation-maintenance. (accessed March 23, 2017).

[16] Sanders, R. E. *Chemical process safety: learning from case histories*, 4th ed. [Online]; Elsevier: New York, 2015; pp. 149-164. http://app.knovel.com/hotlink/pdf/id:kt010QITX1/chemical-process-safety/preparation-maintenance. (accessed March 23, 2017).

[17] Center for Chemical Process Safety. Guidelines for Risk Based Process Safety - 10.2.2 Identify What Operating Procedures are Needed. Center for Chemical Process Safety/AIChE. [Online], 2007, http://app.knovel.com/hotlink/pdf/id:kt004MHNG1/guidelines-risk-based/identify-what-operating. 2007.

[18] Lutchman, C.E.; Douglas, M.; Rohanie, S.R. *Process Safety Management – Leveraging Networks and Communities of Practice for Continuous Improvement* [Online]; Taylor & Francis: Boca Raton, FL, 2014; p. 19. http://app.knovel.com/hotlink/pdf/id:kt00TSLGX2/process-safety-management/process-sa-safety-management (accessed March 23, 2017).

from the caustic settler. The expanded isolation plan, however, was non-routine, and the dayshift operator did not recall ever taking the coalescer and settler out of service prior to the day of the incident.

After a review of applicable DCRC procedures and job aids for the work being performed on the day of the incident, the CSB concludes that the refinery lacked specific procedures for removing the caustic settler and coalescer from service. DCRC also lacked any general procedures to ensure that preparing equipment for maintenance, prior to lockout-tagout (LOTO), was done safely.

6.1.1 Removal of Specific Equipment From Service

Although DCRC has some procedures for taking specific equipment out of service, at the time of the incident no procedure for taking the coalescer and caustic settler out of service existed. There is a job aid that lists steps for removing spent caustic from the coalescer, but the task is limited to removing contents from that vessel into the quench drum only. The task performed on the day of the incident was much more complex and involved purging and displacing the contents of both vessels.

Without specific procedures for taking equipment out of service, operators have no way to positively identify all associated valves to properly isolate equipment from the unit when performing non-routine or unfamiliar work. The absence of a step-by-step procedure or job aid may also create the opportunity for operator error as preparation activities may be inconsistent or misunderstood between shifts.

6.1.2 Preparation of equipment for Maintenance

At the time of the incident, DCRC also lacked general procedures for preparing equipment for maintenance and processes for identifying and addressing potential hazards associated with those tasks. While procedures for taking specific equipment out of service are needed, capturing every possible operational task or maintenance preparation activity can be difficult for refineries and chemical plants given the number of complex processes involved. Therefore, more general procedures should be applied in these situations to ensure that hazards are identified and addressed. Preparing equipment for maintenance, referred to as "safing equipment" at DCRC, involves non-routine tasks such as isolating energy, depressurizing, purging, and draining, as well as other activities. If these activities are not done safely, they can increase the possibility of exposure to flammable or toxic materials, hazardous energy sources, steam, or asphyxiant gases.

Had the incident not occurred, the nightshift operator would have completed the safing activity as planned and then placed tags and locks on valves in accordance with the DCRC energy isolation (LOTO) procedure. DCRC's energy isolation procedure states that operators must complete an equipment isolation log to identify which equipment will be worked on, isolate equipment energy sources, and prepare equipment to ensure a state of "zero energy." Thorough isolation is accomplished by de-pressuring, draining, steaming, washing, de-energizing, and evacuating the equipment. After which operations affix an isolation lock and a "do not operate" tag on each energy isolation device, such as block valves, and create a record in the energy isolation log in the control room. Once the isolation is verified, operations personnel turn the equipment over to the maintenance department to perform maintenance work.

Though the energy isolation procedure includes steps for performing safing activities on equipment and ensuring "zero energy," the procedure is not referred to until equipment preparation activities are completed and LOTO activities are initiated. As a result, at the time of the incident, DCRC had no formalized process, general procedure, or job aid for ensuring equipment was properly isolated, de-inventoried, or decontaminated prior to maintenance work.

6.2 Isolating Equipment

Maintenance preparation activities, such as draining equipment, often involve isolating the equipment being taken out of service from energized and inventoried equipment and piping. Pipes and vessels can be isolated from a process by closing valves, blocking and bleeding the valve system, inserting a blind (or blank), and physically disconnecting the energy source.[19] Closing valves is the least effective because valves can leak, allowing for the passage of hazardous energy sources. In a double block and bleed, a bleed line is located between two closed block valves that vents any material that passes through the first closed valve. A more protective isolation measure is the insertion of a blind or solid metal plate that blocks flow in the line. The most protective measure is to disconnect the hazardous energy source.

DCRC relied on an isolation method that used a single closed isolation valve, which was later determined to have a slow leak, to act as a barrier between the hydrocarbons in the depropanizer and the vessels they were draining. DCRC reported that the valve was only three months old at the time of the incident. Even though the valve was relatively new, the single closed isolation valve method did not adequately isolate the depropanizer column from the coalescer and caustic settler to prevent hydrocarbons in the column from backflowing into the vessels and providing a flammable atmosphere when the nightshift operator began draining the vessels into the OWS system.

Avoid using single block valves to isolate hazardous energy sources. Valves can still leak, even when newly installed.

DCRC tested five block valves associated with the isolated equipment post-incident, and all were found to leak when in closed positions. Three drain valves downstream of the caustic settler had both slow and heavy leakage. Also tested was the 4-inch drain valve directly downstream of the caustic settler that was intended to be closed during the original isolation phase, but would not hold. The leak test concluded that the valve seat on the caustic settler drain valve was broken or missing and that the new 4-inch coalescer outlet valve had a slow leak through both seats under 120 psi air pressure. When isolation was expanded to include the coalescer and the depropanizer, DCRC relied on the outlet valve of the coalescer to prevent hydrocarbon backflow from the depropanizer. An adjacent coalescer outlet valve that remained open during the maintenance preparation activity was also tested post-incident and was found to have a heavy leak.

Proper equipment isolation and decontamination begin with effective preplanning and hazard identification, and companies must ensure that equipment is free from hazardous energy during maintenance preparation activities.[20] This de-energized state can be achieved by selecting proper isolation points and verifying that the system is free from hazardous materials or energy sources that can injure workers. Though it may be common to close valves when isolating equipment prior to de-inventorying vessels and piping, companies should avoid using a single block valve and consider more protective methods of isolation when preparing equipment for maintenance.

[19] Mannan, S. *Lees' Loss Prevention in the Process Industries*, 4th Ed. [Online]; Elsevier: New York, 2012; Vol. 2, pp.1840-1843. http://app.knovel.com/hotlink/pdf/id:kt00BFG451/lees-loss-prevention/equipment-maintenance (accessed March 23, 2017).

[20] Wallace, S.; Merritt, C. Know When to Say 'When:' A Review of Safety Incidents Involving Maintenance Issues. *Process Saf. Prog.* **2003,** 212-19.

Prior to the incident, DCRC had no procedure or process to ensure that isolation points were holding prior to starting equipment preparation activities. Nor was there a process or procedure to require the use of more protective forms of isolation for equipment preparation activities when possible. When isolating the depropanizer, the operator closed a single block valve between the depropanizer and to the coalescer. Because this valve had a slow leak when closed, hydrocarbons from the depropanizer backflowed into the vessels during equipment preparation and fueled the flash fire. The CSB identified three other valves between the coalescer and the depropanizer that remained open for the maintenance preparation activity in addition to the closed and leaking coalescer outlet valve (Figure 3).[21] A closed isolation valve should be used only to isolate low-hazard fluids, not lines containing pressurized hydrocarbons.[22] In addition, a line containing isobutanes within close proximity to a furnace warrants a more secure method of isolation.

Proper equipment isolation and decontamination begins with effective preplanning and hazard identification.

6.2.1 EXPANSION OF THE ISOLATION PLAN

When alkylation unit operators and the unit superintendent learned that the valve immediately downstream of the caustic settler leaked, they decided to expand the isolation to include additional equipment. Because DCRC lacked a general procedure or job aid for preparing equipment for maintenance and for taking those specific pieces of equipment out of service, the alkylation unit operations personnel, relying on their knowledge and expertise of the equipment and process, developed an informal plan. The expanded isolation plan was much more complex than the original, as it involved isolating more equipment and de-inventorying vessels (Figure 4). A complex isolation can be defined as any situation in which equipment requires special control methods due to the nature of the hazards and variables influencing effective isolation.[23] When the need for a more complex isolation is recognized, particular attention should be paid as to how the situation differs from the traditional or conventional method, in addition to hazards that may be introduced.

[21] A coalescer outlet valve and two depropanizer pre-heater valves remained open during the isolation. The coalescer outlet valve directly downstream of the coalescer was found to have heavy leakage. The two depropanizer preheater valves were not tested after the incident, so it is unknown if closing the preheater valves in the isolation plan would have blocked the flow of hydrocarbons from the depropanizer.

[22] Mannan, S. *Lees' Loss Prevention in the Process Industries*, 4th Ed. [Online]; Elsevier: New York, 2012; Vol. 2, pp.1840-1843. http://app.knovel.com/hotlink/pdf/id:kt00BFG451/lees-loss-prevention/equipment-maintenance (accessed March 23, 2017).

[23] Grund, E. V. Lockout Tagout: *The process of controlling hazardous energy*: The National Safety Council: Chicago, Illinois. 1995.

6.3 DCRC Equipment Preparation Guidelines

The CSB found that the November 2015 incident at DCRC could have been prevented by applying more protective energy isolation techniques and identifying potential hazards introduced by expanding the isolation scheme. This could have been accomplished through preplanning that identified hazards prior to equipment preparation activities or a Management of Change (MOC) review to address risks imposed by changes to work methods. Since the incident, DCRC has developed and implemented a standing instruction for operations personnel when preparing process equipment for maintenance. The instruction provides a structured approach to identify hazards through a risk assessment and steps to mitigate hazards that may be introduced during equipment preparation and decontamination. For all equipment preparation activities that are non-routine, an equipment preparation plan must be developed to document all aspects of de-inventorying and decontamination prior to maintenance work.[24] The plan requires operations to conduct a simple, qualitative risk assessment that includes identifying hazards and developing mitigation steps to reduce hazards and listing the steps for preparing the equipment. The plan also requires management and other departments to review and authorize the plan depending on the complexity of the proposed work.

When modifying or expanding an isolation plan, establish a process to identify new hazards that may be introduced to the process and ensure secure isolation.

For all routine and non-routine equipment preparation activities that involve opening process equipment, the new standing instruction also requires operations personnel to follow general guidelines for all types of equipment. These general guidelines require consideration for isolating energy for decontamination activities, draining equipment to closed systems, and referencing existing safety procedures that also apply during these activities.

6.4 Management of Change (MOC)

MOC is a process for evaluating and controlling hazards that may be introduced during modifications to facility equipment, operation, personnel, or activities; MOCs can also be used to identify, evaluate, and control unintended hazards introduced by modifying procedures or when developing a new plan or procedure. The MOC process, intended to occur prior to the change, requires evaluations and approvals, and safeguards the facility and workers by preventing unintended consequences. MOC is a required element for all OSHA Process Safety Management-(PSM) covered facilities.[25] An MOC process is used for changes to facility design, equipment, processes, plans, procedures, maintenance tasks, and the organization. Typically, once the need for a change is identified, an MOC proposal is developed to describe the details of the change and its impact on health and safety. Qualified facility personnel evaluate the MOC and assess the hazards via a systematic hazard assessment methodology (e.g., hazard and operability study[26]) prior to approval. Once approved, the process requires communication and training to ensure all changes are well understood.

DCRC has an MOC procedure that covers all temporary and permanent alterations to process equipment,

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[24] A DCRC equipment preparation plan must be developed for "non-standard" jobs: those that do not have specific procedures, preparation activities involving multiple units, or jobs that can result in potential exposure to certain listed hazards, among other criteria.

[25] OSHA. Process Safety Management of Highly Hazardous Chemicals. 29 CFR 1910.119(l). https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9760 (November 3, 2016).

[26] A hazard and operability study (HAZOP) is a method of identifying hazards through a systematic and structured examination of operations and processes.

procedures, or information. DCRC performed an MOC for the planned piping replacement scheduled for the day after the incident because the replacement piping segment material was different from that of the previous pipe. DCRC's MOC process also addresses procedural changes when there are "revisions to steps, additions to warnings or notes, new procedures, or when removing invalid/obsolete procedures." DCRC's MOC reviews are subject to process hazard analysis (PHA) requirements, depending on the complexity of the change. This can range from an evaluation question review for minor and well-understood changes to a full PHA for complex changes. DCRC stated that an MOC did not apply to the maintenance preparation activity or the expansion of the isolation scheme because there was no standing procedure, job aid, or instruction from which to deviate.

In response to the November 2015 incident, DCRC established a process that requires a risk assessment prior to selecting isolation points and de-inventorying and de-energizing equipment. An MOC review should also be considered to manage hazards during non-routine equipment preparation activities, particularly in the absence of an existing procedure or when a change to the planned isolation arrangement is necessary.

The risk of an incident increases significantly when changes to hazardous processes are not reviewed.[27] The effective use of an MOC program for identifying and mitigating risks associated with a change is limited to the ability to recognize which changes should initiate the MOC. In the absence of a robust MOC program, operating decisions are based solely on experience without the benefit of a hazard analysis.[28] Though DCRC created a handwritten list of steps for performing the maintenance preparation activity and did not deviate from an existing procedure when expanding the isolation, the CSB concludes that the new plan should have been considered a change.

Changes that appear to be minor can introduce hazards;[29] therefore, MOC systems should include non-traditional changes that do not fit into common MOC categories. Anything that "feels" like a change should initiate an MOC,[30] including additions or deletions to a process or its supporting systems.[31] Had an MOC review been initiated, a hazard evaluation could have identified the potential for backflow and recognized the need for a more protective method of isolation between the coalescer and the depropanizer column.

MOC systems should include non-traditional changes that do not fit into common MOC categories.

[27] Center for Chemical Process Safety of the American Institute of Chemical Engineers. Maintenance. *Recognizing Catastrophic Incident Warning Signs in the Process Industries* [Online]; John Wiley & Sons: Hoboken, NJ, 2012; p. 128. http://app.knovel.com/hotlink/pdf/id:kt00AOZ6A1/recognizing-catastrophic/failure-recognize-operational (accessed March 22, 2017).
[28] *Ibid.*
[29] Mannan, S. *Lees' Loss Prevention in the Process Industries*, 4th Ed. [Online]; Elsevier,:New York, 2012; Vol. 2, pp.1834-1888. http://app.knovel.com/hotlink/pdf/id:kt00BFG451/lees-loss-prevention/equipment-maintenance (accessed March 23, 2017).
[30] Center for Chemical Process Safety of the American Institute of Chemical Engineers. Maintenance. *Guidelines for safe process operations and maintenance;* New York, 2008.
[31] *Ibid.*

7.0 Key Lessons

1. Operational tasks that involve preparing equipment for maintenance can be uncommon and non-routine. Ensure standard operating procedures include steps for preparing all process equipment for maintenance, either in procedures for specific pieces of equipment or general procedures for equipment preparation that cover all types of equipment. These procedures should cover tasks such as de-inventorying, decontaminating, washing, steaming, purging, and draining equipment and vessels.

2. For all equipment preparation activities, develop a process that requires pre-planning and hazard identification prior to initiating the work. This should include the proper selection of isolation points and an assessment of hazards that may be introduced during the equipment preparation activity and steps for mitigating those hazards.

3. When isolating equipment for de-inventorying or decontaminating activities prior to maintenance work, avoid reliance on single block valves, even when the valves are newly installed, to control the release of hazardous energy such as toxic, flammable or pressurized materials. Valves may fail, leak or be inadvertently closed or open. Always consider more protective measures for isolation, including double blocks, the insertion of blinds, or the complete disconnection of hazardous energy sources.

4. When an equipment preparation task or isolation plan needs to be modified or expanded due to leaking valves or changing conditions, initiate a process to evaluate hazards that may be introduced by the change. This process can include a risk assessment initiated by an MOC or another work process to ensure effective isolation and removal of hazardous energy sources.

5. Use closed systems such as tanks, drums, flares, or scrubbers to control the dissipation, draining, or relieving of hazardous energy in preparation to isolate equipment for maintenance. Avoid draining materials containing or potentially containing volatile hydrocarbons or flammable materials into oily water sewer systems not designed for such services, especially when ignition sources are present.

8.0 Conclusion

Maintenance preparation activities can be non-routine and, as such, warrant additional consideration to ensure hazards are properly identified and addressed, particularly when the maintenance preparation activity lacks procedures or requires modifications due to changing conditions. Based on the immediate causes of the DCRC incident, this Safety Bulletin highlights issues that can arise when equipment is not securely isolated and emphasizes the need for general and equipment-specific procedures when taking equipment out of service. It also calls for careful evaluation when isolation plans need to be expanded or modified.

Non-routine operations and maintenance can account for a significant number of incidents in the process industries. As a result, key lessons from this DCRC Safety Bulletin can be used to remind operations personnel, maintenance staff, and plant management to have maintenance preparation procedures and processes that ensure hazards are evaluated prior to non-routine maintenance preparation activities. This is especially important if refineries and chemical plants have increased cross-functional work between operations and maintenance, in which operations personnel engage in more non-routine preparation work prior to handing equipment over to the maintenance department.

Appendix A: CSB Incident Investigations involving Maintenance and Non-Routine Operations

Preparing equipment for maintenance is a major cause of serious incidents in plants of all types.[32] In the chemical industry, 30 percent of incidents are maintenance-related, with half involving the release of a harmful substance.[33] A more recent study of incidents in the refining industry concludes that 50 percent of process safety incidents occur during transient or non-routine operations or planned operations that infrequently occur.[34]

CSB has investigated or is currently investigating several incidents that occurred prior to or during a maintenance or non-routine work activity. Of the 96 completed CSB investigations[35] and 7 incidents currently under investigation, 39 (37 percent) occurred prior to, during, or immediately following maintenance work. These maintenance-related incidents resulted in a total of 86 fatalities and 410 injuries to employees and members of the public.

	Incident/Date	Maintenance Activity	Maintenance Phase	Consequences
1	Union Carbide, March 1998	Workers were performing a black light inspection and cleaning of flanges on a 48-inch pipe with a temporary enclosure while part of the piping was being purged with nitrogen.	Shutdown	1 fatality 1 injury
2	Tosco Avon Refinery, February 1999	Workers cut into a line after several unsuccessful attempts to isolate naphtha due to a leaking valve. The naphtha ignited and exploded.	Online maintenance[36]	4 fatalities 1 injury
3	Bethlehem Steel Corp., February 2001	Accumulated coke oven gas condensate in an unused section of pipe ignited when workers were attempting to remove a slip-blind for replacement.	Shutdown	2 fatalities 4 injuries
4	BP Amoco Polymers, March 2001	An unbolted cover blew off a vessel, expelling hot plastic and ignited when workers were troubleshooting issues after an aborted startup.	Shutdown	3 fatalities
5	Motiva Enterprises LLC, July 2001	Contractors were performing hot-work to repair grating on a sulfuric acid tank catwalk when sparks ignited flammable vapor in a storage tank.	Online maintenance	1 fatality 8 injuries
6	First Chemical Corp., October 2002	A runaway reaction in a distillation column resulted in an explosion upon start-up after maintenance work.	Startup	3 injuries

[32] Grossel, S. S.; Crowl, D.A. *Handbook of Highly Toxic Materials Handling and Management,* Marcel Dekker: New York, 1995.

[33] Grossel, S. S.; Crowl, D.A. *Handbook of Highly Toxic Materials Handling and Management,* Marcel Dekker: New York, 1995.

[34] Ostrowski, S.W.; Keim, K. K. Tame Your Transient Operations: Use a special method to identify and address potential hazards. [Online]. July 23, 2010 http://www.chemicalprocessing.com/articles/2010/123/.

[35] Includes CSB investigations that resulted in products such as safety bulletins, case studies investigation reports, and hazard investigation studies. See http://www.csb.gov/investigations/ for a complete listing of investigations.

[36] The term "online maintenance" refers to maintenance activities performed on equipment containing hazardous energy sources (e.g., an empty tank interconnected to other tanks containing flammable vapors) or maintenance work on equipment isolated from operating processing equipment.

7	Hayes Lemmerz International, Inc., October 2003	A combustible metal dust explosion occurred after the shutdown of a system due to a smoldering fire near the furnace. Shortly after restarting the system, maintenance workers were troubleshooting issues when a fireball erupted.	Startup	1 fatality 6 injuries
8	Huntsman Petrochemical Corp., January 2004	Thermally reactive material remained in a low section of piping after operators purged the line with nitrogen. During a high-pressure steam purge, the material violently decomposed and ruptured the pipe.	Preparing equipment	2 injuries
9	Giant Industries, April 2004	Maintenance workers began working on a pump that they believed had been previously isolated from the process when high pressure alkylate released from the pump case flange and ignited.	Online maintenance	6 injuries
10	Sterigenics, August 2004	After running a series of tests to troubleshoot the sterilization chamber, mechanics and operators abbreviated a calibration cycle to get the system started up. Ethylene Oxide leaked from the chamber and ignited.	Startup	4 injuries
11	Valero Delaware City, November 2005	A contractor attempted to retrieve a roll of tape from a tank under a nitrogen purge and became unconscious. Another employee also became unconscious while trying to assist the worker. Both workers died of nitrogen asphyxiation.	Shutdown	2 fatalities
12	Bethune Point, November 2006	Mechanics were welding on a methanol storage tank when vapor ignited.	Online maintenance	2 fatalities 1 injury
13	BP America, March 2005	The incident occurred during the startup of an isomerization unit when a raffinate splitter tower was overfilled and contents ignited.	Startup	15 fatalities 180 injuries
14	Partridge-Raleigh, June 2006	Contractors were welding on production tanks when flammable vapor inside one of the tanks ignited.	Shutdown	3 fatalities 1 injury
15	Xcel Energy, October 2007	Workers were in a confined space flushing an epoxy sprayer with MEK when flammable vapor ignited.	Shutdown	5 fatalities 3 injuries
16	Packaging Corporation of America Tomahawk, July 2008	Workers were welding on a temporary metal clamp to stabilize a damaged flange connection. The flange was located on top of an 80-foot tall storage tank that contained recycled water and fiber waste. The welding ignited tank vapor.	Online maintenance	3 fatalities
17	Bayer CropScience, August 2008	Operators were restarting a pesticide production unit when a vessel exploded.	Startup	2 fatalities 8 injuries
18	Goodyear, June 2008	A heat exchanger ruptured after an isolation valve was left closed during a prior maintenance activity.	Online maintenance	1 fatality 6 injuries
19	MAR Oil, October 2008	Contractors were welding on a series of interconnected crude oil storage tanks when flammable vapor ignited.	Online maintenance	2 fatalities

20	EMC Used Oil Corp. December, 2008	A contractor was welding transfer piping on a two-compartment oil tanker when residual hydrocarbon vapor ignited.	Online maintenance	1 fatality 1 injury
21	ConAgra Boardman, February 2009	A welder was performing hot work inside a tank containing waste water from a potato washing process. The liquid contained organic matter that likely produced flammable gas ignited by the welding activity.	Online maintenance	1 fatality
22	A.V. Thomas Produce, March 2009	Employees were using a torch to refurbish an old fuel tank when residual hydrocarbon inside the tank exploded.	Online maintenance	2 injuries
23	TEPPCO Partners, LP, May 2009	Contractors were performing hot work on top of an internal floating roof storage tank when flammable vapor in the tank exploded.	Online maintenance	3 fatalities
24	ConAgra Garner, June 2009	A worker was attempting to purge a new gas line by venting natural gas indoors when an explosion occurred.	Online maintenance	3 fatalities 67 injuries
25	Kleen Energy, Feb 2010	Workers were conducting a "gas blow" to force natural gas through power plant fuel gas piping to remove debris prior to start up. The natural gas was released to the atmosphere and ignited.	Startup	6 fatalities 50 injuries
26	Tesoro Anacortes, April 2010	Workers were in the final stages of start-up after maintenance on heat exchangers when another in-service heat exchanger catastrophically ruptured.	Startup	7 fatalities
27	DuPont Yerkes, November 2010	A contract welder and foreman were repairing the agitator support atop an atmospheric storage tank containing flammable vinyl fluoride.	Online maintenance	1 fatality 1 injury
28	Hoeganaes, January 2011	A maintenance mechanic and electrician were troubleshooting a suspected off-track bucket elevator. Upon restart of the elevator, vibrations from the equipment dispersed iron dust into the air and shortly after, the dust ignited.	Startup	2 fatalities
29	Hoeganaes, March 2011	When replacing igniters on a band furnace, an engineer lofted large amounts of iron dust when using a hammer. The iron dust ignited resulting in a flash fire.	Online maintenance	1 injury
30	Hoeganaes, May 2011	After shutting the plant down because of a previous incident that led to two fatalities, the plant was in start-up mode, when a hydrogen flash/metal dust fire occurred.	Startup	3 fatalities 3 injuries
31	Chevron, August 2012	Workers were trying to determine how to best fix a leaking pipe when the piping system broke loose and light gas oil ignited.	Online maintenance	26 injuries[37]
32	Williams Olefins, June 2013	Incident occurred during troubleshooting of poor performance of unit. An operator went out without developing a plan or procedure and	Online maintenance	2 fatalities

[37] Six Chevron employees suffered minor injuries as a result of the incident. 15,000 area residents sought medical attention following the incident and 20 were admitted for inpatient treatment.

		began to turn valves. He inadvertently added heat to a blocked-in heat exchanger causing an explosion.		
33	Tesoro Martinez, February 2014	Incident occurred when operators opened a block valve to return an acid sampling system back to service. Very shortly after this block valve had been fully opened, the tubing directly downstream of the valve came apart, spraying two operators with acid.	Startup	2 injuries
34	DuPont La Porte, November 2014*	Incident occurred after a series of events during troubleshooting a clogged feed line. During troubleshooting, valves were opened and toxic gas entered the process building, killing four workers.	Online maintenance	4 fatalities
35	Exxon Mobil Torrance, February 2015†	Incident occurred during troubleshooting to bring a piece of equipment back in service. This was a normal activity and had happened many times before.	Online maintenance	2 injuries
36	Delaware City Refining Co, November 2015	When preparing equipment for maintenance operators were in the process of emptying process vessels when hydrocarbon backflowed from a downstream depropanizer through a leaking block valve.	Preparing equipment	1 injury
37	Sunoco Logistics, August 2016*	Contractors were performing hot work on a pipeline when flammable crude oil vapor in that section of the piping ignited.	Online maintenance	7 injuries
38	Exxon Mobil Baton Rouge, November 2016*	Flammable vapor were released during unplanned maintenance on a pump. Although there was no explosion, the release ignited and caused a large fire.	Online maintenance	6 injuries
39	Packaging Corporation of America DeRidder February 2017*	Contractors were performing welding near a tank that contained flammable material. The welding ignited vapor inside the tank.	Shutdown	3 fatalities 7 injuries

*Ongoing CSB investigations

†In September 2015, PBF Energy, which owns and operates DCRC, announced the acquisition of the Exxon Mobil Torrance, CA, Refinery.

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