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Elements of Process Safety Management: Case Studies

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Abstract
Process Safety Management can provide immense benefits by reducing operational risks in the production and handling of hazardous chemicals. By proactively identifying hazards, assessing and characterizing risks, and taking actions to reduce those risks, organizations can prevent accidents and reduce the potential for death, injury, property damage, and environmental impacts. U.S. Occupational Safety and Health Administration regulations detailed in the Process Safety Management Standard include 14 key elements. This paper provides a brief description of each key element, followed by case studies that illustrate the importance of proper implementation of these elements. These case studies provide lessons learned that can be used to improve process safety efforts.

Introduction

Process Safety Management generally refers to the application of management principles and systems to the identification, understanding, and control of process hazards to protect the workplace. Process Safety Management is focused on prevention of, preparedness for, mitigation of, response to, and restoration from catastrophic releases of chemicals or energy from a process associated with a facility. In Process Safety Management, a process is defined as any use, storage, manufacturing, handling, or on-site movement of highly hazardous chemicals, or combination of these activities.

Process Safety Management is regulated by the U.S. Occupational Safety and Health Administration (OSHA) through the Process Safety Management (PSM) Standard, 29 CFR 1910.119, titled *Process Safety Management of Highly Hazardous Chemicals*. The PSM Standard was implemented following a number of disasters, including accidents in Bhopal, India in 1984 and Pasadena, Texas in 1989 (ref. 1). The objective of the PSM Standard is to prevent an unwanted release of hazardous chemicals. This becomes especially important when the workplace could be subject to catastrophic consequences of such a release. The PSM Standard emphasizes a systematic approach to identification, prevention, and mitigation of risks associated with hazardous chemicals. These regulations establish a comprehensive safety program that integrates technologies, procedures, and management practices.

The PSM Standard applies to companies that process toxic and reactive chemicals specified by OSHA. The regulations primarily apply to manufacturing industries such as those producing or handling paints, pharmaceuticals, adhesives, industrial organic and inorganic chemicals, petrochemicals, and sealants. However, other sectors such as farm products, food processing, and sanitary services are also covered.

The PSM standard does not apply to the following:

- Retail facilities.
- Oil or gas well drilling or servicing operations.
- Normally unoccupied remote facilities.
- Hydrocarbon fuels used solely for workplace consumption as a fuel (e.g. propane used for comfort heating, gasoline for vehicle refueling), if such fuels are not a part of a process containing another highly hazardous chemical covered by this standard.
- Flammable liquid stored in or transferred to atmospheric tanks, which are kept below their normal boiling point without benefit of chilling or refrigerating and are not connected to a process.

The PSM Standard contains 14 elements.

1. Employee participation
2. Process safety information
3. Process hazard analysis
4. Operating procedures
5. Training
6. Contractors' obligations
7. Pre-startup safety review
8. Mechanical integrity
9. Hot work permit
10. Management of change
11. Incident investigation
12. Emergency planning and response
13. Compliance audits
14. Trade secrets

This paper will briefly describe each element of the PSM Standard. The importance of each element of the PSM Standard will be illustrated using accident reports from various industries. These case studies will show how a failure to address any one of these elements could result in an unwanted chemical release or other accident. The lessons learned from these incidents can help organizations learn and improve their own PSM efforts.

Elements of Process Safety Management

The case studies presented show how focus on a particular PSM element may have helped prevent the accident or could have reduced the impact of the undesirable event. In discussing these accidents, the intent is not to oversimplify the events and conditions that led to the accidents or blame any individual or organization. There is rarely a single identifiable cause leading to an accident. Accidents are usually the result of complex factors that include hardware, software, human interactions, procedures, and environments. The accidents and incidents are used to illustrate where the safety engineering and management processes failed in some way. Readers are encouraged to review the full accident and mishap investigation reports to understand the often complex conditions and chain of events that led to each incident discussed here.

Employee Participation

Organizations should plan the PSM effort, and plans should include the scope of the effort, roles and responsibilities, reporting requirements, hazard analysis approaches, document control processes, and hazard control strategies. As part of the PSM effort, employers must consult with employees and their representatives to ensure that all parties understand the hazards and risks in the process. In particular, employees must have access to the process hazard analysis and information used to support that analysis. Without participation of employees risks may not be fully understood or appropriately communicated.

Case Study: Fire in Texas

On February 16, 2007, a fire occurred at a refinery near Sunray, Texas. The fire caused extensive damage to the facility and led to the facility being shut down for months. Four people were injured by the accident. The cause of the accident was a cracked pipe that leaked liquid propane. The pipe that cracked was in a section of piping that had not been used in 15 years. The piping was not properly isolated (an isolation valve leaked). The U.S. Chemical Safety and Hazard Investigation Board (CSB) noted in its accident investigation report that water had accumulated in the low portion of the pipe and froze during cold weather cracking the pipe. When the outside temperatures warmed the propane expanded and vented out of the crack, ultimately igniting. The fire was likely made worse by the inability of the operator to shut off flow of propane to the pipe – remotely operated valves had not been installed. 3

The CSB faulted the refinery's freeze protection processes and its hazard analysis process. The CSB identified several aspects of the hazard analysis that led to the failure to identify conditions leading to the accident. The CSB stated that the hazard analysis failed to identify the potential for a "dead leg" that could be subject to freezing, and did not identify the need for remotely operated valves. In addition, the CSB stated that the hazard analysis was performed by a contractor and did not involve the operators of the facility. This failure to involve the personnel running the facility may have led to the failure to uncover these hazards. The CSB also noted that no hazard tracking process existed to follow up on recommendations made as part of the hazard analysis process (ref. 2).

Process Safety Information

Under the PSM Standard, employers must assemble written process safety information prior to conducting a hazard analysis. The purpose of this information is to assist in identifying the hazards and risks associated with the process. Information on the chemicals used or produced, technology, and equipment should be included. Specifically, information related to toxicity, permissible exposure limits, physical data, reactivity, corrosivity, chemical stability, thermal stability, and hazards associated with inadvertent mixing should be included. Block flow diagrams, piping and instrument diagrams (P&IDs), material and energy balances, and Material Safety Data Sheets (MSDS) should be produced. Critical parameters such as maximum upper and lower limits and maximum inventory should also be addressed. Other information on the equipment might include materials of construction, relief systems, safety systems, cooling systems, ventilation systems, and codes and standards used in the design.

<u>Case Study: Explosion in Pennsylvania</u>

On February 19, 1999, a vessel containing several hundred pounds of hydroxylamine exploded at a manufacturing facility near Allentown, Pennsylvania. Four employees and a manager from a nearby business were killed. Four other people in nearby facilities were injured, and 10 buildings were damaged in the explosion. Employees were starting up a new process for the first time at a new production facility when the accident occurred. The employees were distilling an aqueous solution of hydroxylamine and potassium sulfate. The CSB stated that the hydroxylamine in the process tank and associated piping explosively decomposed after the distillation process was shut down. A high chemical concentration and high temperature likely led to the resulting explosion. The CSB concluded that the safety management systems at the company were insufficient to properly address the hazards inherent in the manufacture of hydroxylamine. The CSB emphasized that the company did not collect and analyze safety information properly prior to starting up the new process. The CSB also faulted the design review and corrective action processes at the company and its decisions to perform such operations in a light industrial park. As stated by the CSB, "[This incident] demonstrates the need for effective process safety management and engineering throughout the development, design, construction, and startup of a hazardous chemical production process." (ref. 3)

Process Hazard Analysis

A process hazard analysis is defined by OSHA as a thorough, orderly, systematic approach for identifying, evaluating, and controlling the hazards of processes involving highly hazardous chemicals. The process hazard analysis is key to the safety effort because it provides information to help management and operators improve safety and make better decisions to reduce risk. OSHA recommends one of the following methods (or their equivalent) for conducting the analysis:

- Checklist
- What-if/checklist
- Hazard and Operability Study (HAZOP)
- Failure Modes and Effects Analysis (FMEA)
- Fault Tree Analysis

OSHA emphasizes that the process hazard analysis effort should be performed using a team knowledgeable in both the process and the hazard analysis techniques. In addition, a process must be established to address the findings and 4 recommendations from the hazard analysis effort. This process must include a schedule on when actions must be completed. The regulations require that the hazard analysis be updated at least every five years.

Case Study: Explosion in Mississippi

On October 31, 2002, an explosion occurred at a chemical facility in Pascagoula, Mississippi. Three workers were injured, and a number of buildings were damaged in the explosion. The explosion occurred as a result of the rupture of a mononitrotoluene distillation column. This distillation column was in standby mode, and was thought to be isolated by the use of a manual valve. Mononitrotoluene is a chemical used in the production of dyes, rubber chemicals, and agricultural chemicals. The distillation column is used to separate chemical compounds for final use. The CSB determined in its accident investigation that, on the day of the accident, the distillation column was inadvertently heated because of a leak in steam isolation valves. These valves likely leaked because of corrosion and possible contamination that prevented the valves from seating properly. The CSB stated that had the temperature of the column been monitored, the heating may have been discovered. The heating caused some material to be vaporized, and this material was carried up the column and accumulated on the chimney tray at the top. Eventually, the pressure increase from the vaporized material reached a level high enough to cause the explosion. The CSB stated that the company had failed to conduct a formal hazard analysis for mononitrotoluene, specifically to determine instabilities in the process. Because the hazard analysis was not performed, the hazards were not known and controls for an unstable process were not instituted. The CSB also stated that the company did not have proper controls such as alarms to warn of thermal instabilities, interlocks to shut down the heat source, or overpressure protection on the distillation column. The CSB also faulted the work practices and operating procedures used by the company when isolating equipment (ref. 4).

Operating Procedures

Operating procedures describe the tasks that must be performed, data to be recorded, and operating conditions to be maintained. The procedures also identify the safety and health precautions. Operating procedures must be clear, concise, accurate, and consistent with the process safety information derived from the process hazard analysis. The procedures should be formally reviewed and updated as necessary to assure that they are consistent with existing processes. Training must accompany these operating procedures, with an emphasis on what employees should do in case of emergency.

<u>Case Study: Explosions in Nevada</u>

On January 7, 1998, an explosives manufacturing plant near Reno, Nevada was destroyed by two explosions. Four workers died in the accident, and six others were injured. This plant produced small explosive devices used in the mining industry. The CSB determined that the probable cause of the accident was a chain of events that began the day before the accident. A worker had left 50 to 100 pounds of explosive material, pentaerythritol tetranitrate (PETN), in one of the mixing bowls the day prior to the accident. PETN is normally transported wet because of its inherent instability when dried. The material in the mixing bowl dried and solidified overnight. It is theorized that on the day of the accident a worker turned on the mixing motor with the solidified PETN and the contact of the blades with the dried explosive set off the initial explosion. The shock wave from the initial blast detonated several thousand pounds of explosive in a nearby storage facility, according to the CSB. In its investigation the CSB found that no workers had been involved in the process hazard analysis, and therefore did not understand the hazards in the mixing process. According to the CSB, management did not understand the hazard, and in fact believed that the explosives could only detonate with a blasting cap. Therefore, workers were allowed to regularly use metal tools such as hammers to break up rejected explosive materials despite the hazard of accidental detonation. The CSB stated that the building location contributed to the accident. The buildings were not located at safe distances, leading to the second explosion. The CSB also faulted the company for a lack of procedures and an informal training program, stating, “Without written procedures, training was conducted in an informal, on-the-job manner, relying upon physical demonstration and word of mouth.” According to the report, none of the operators had seen any written procedures at the plant, and the procedures used varied by operator. Management had developed a generic operating procedure, but it did not address all phases of operation and did not include emergency procedures (ref. 5).

Training

Training is a critical element of the PSM Standard. Training provides employees with the knowledge and tools to fully understand the risks in working with hazardous chemicals. All employees, including contractor employees and maintenance personnel, must be trained to understand the MSDS, as well as safe work practices and operating procedures. Of particular importance is training in emergency response, including conditions for evacuation and shelter-in-place and the use of personal protective equipment. The employer must identify who is to be trained, the goals of the training, and what the training will cover. This training should be tailored for the organization and operations. The training should include a mix of classroom and hands-on training to increase its effectiveness. The training should be periodically evaluated and updated as conditions and operations changes.

Case Study: Chlorine Release in Arizona

On November 17, 2003, chlorine gas was inadvertently released during transfer operations at a manufacturing facility in Glendale, Arizona. This chlorine release led to the evacuation of large portions of Glendale and Phoenix. In addition, five residents and a number of police officers received medical attention for chlorine exposure. The facility transferred and repackaged chlorine from larger railcars into smaller containers. During transfer operations excess chlorine gas was captured using a scrubber; this scrubber used sodium hydroxide to convert chlorine gas into bleach. On the day of the accident the sodium hydroxide had become depleted, making the scrubber ineffective and allowing the release of toxic chlorine compounds into the atmosphere. The CSB noted that the safeguards were not appropriate for the operational risks. Operators had to detect when there was a problem, such as depletion of the sodium hydroxide, and shut down the operation based on their knowledge of the problem. The CSB stated that, "[The company's] corporate standards relied solely on procedural safeguards against scrubber overchlorination." The CSB also stated that the hazard analysis did not account for a failure to follow the standard operating procedure. An Oxygen Reduction Potential (ORP) meter was used to measure the effectiveness of sodium hydroxide, but the CSB noted that the procedures failed to indicate what the operators were supposed to do when a reading indicated depletion, and the procedures did not indicate the consequences of such a reading. In particular, the CSB faulted the operator training, stating that "Operator training, based on the operating procedure, did not address the sensitivity of the scrubber to over-chlorination or the safety and environmental consequences of over-chlorination." The CSB also faulted the company for deficiencies in its auditing program in detecting problems with procedures, training, and hazard assessment (ref. 6).

Contractors' Obligations

Many tasks at a job site are performed by contractors hired by the employer. It is the responsibility of the employer to assure that the contractors who work in and around hazardous chemicals have the appropriate skills and knowledge to perform those tasks without compromising safety. The employer must obtain appropriate certifications from that contractor, and should screen the contractor to assure that they can perform the tasks safely. The employer must manage the contractor to maintain control over the safety of the work.

Case Study: Fire in Colorado

On October 2, 2007, five workers were killed and three others were injured in a chemical fire at the Cabin Creek Hydroelectric Plant near Georgetown, Colorado. Contractors were working in a confined space, recoating the penstock tunnel with an epoxy coating material, when the fire occurred. The CSB report stated that the flammable solvent used to clean the epoxy likely ignited, and the fire grew as additional buckets of epoxy material and solvent also ignited. The workers had only one way to exit the tunnel, and that exit was blocked by the flames. The report stated that the workers communicated with other personnel for 45 minutes before losing their lives to smoke inhalation. The CSB report stated that the company and its contractor failed to plan and coordinate the recoating project, and therefore did not analyze or prepare for the confined space hazards. The CSB report stated that, "the serious safety hazards of using a flammable solvent inside the confined space were not identified or addressed." Because of a failure to perform such safety analyses, controls such as substituting a non-flammable solvent, monitoring the work area, providing adequate ventilation, eliminating ignition sources, and providing confined space rescue teams were not considered. The report also stated that contractor personnel had expressed concerns about the single exit point prior to the accident, but the company and contractor management failed to address those 6 concerns. The report also identified concerns with the poor safety record of the contractor and the inadequate training of its personnel. According to the report, “The majority of [contractor] employees working at Cabin Creek had not received comprehensive formal safety training; effective training on company policies; or site-specific instruction addressing confined space safety, the safe handling of flammable liquids, the hazard of static discharge, emergency response and rescue, and fire prevention.” The report also stated that, although the work created the potential for life threatening exposure to a flammable atmosphere with a need for immediate emergency response, the only emergency plan was to call 9-1-1 emergency dispatch. No emergency responders were on site on the day of the accident, and the response time for trained personnel was over an hour. The workers died before trained emergency response crews could arrive (ref. 7).

Pre-Startup Safety Review

Many accidents occur in the transition between operational phases, rather than when the system is up and running in “steady state” mode. Accidents can occur during startup, especially in new or untried processes, from a combination of factors not expected in normal operation. Starting up a new process or upgrading an existing system can be especially hazardous because changes to design or operations may be made in real time to meet schedule pressures, potentially introducing new hazards. A pre-startup review is a valuable tool to assure that operating procedures are in place, hazards are understood, P&IDs have been completed, and emergency shutdown procedures have been communicated.

<u>Case Study: Explosion in Delaware</u>
On July 17, 2001, an explosion at a refinery in Delaware City, Delaware led to the death of one maintenance worker and injuries to eight others. According to the CSB, the workers were repairing a catwalk that had deteriorated due to acid vapors in the atmosphere around sulfuric acid storage tanks. A spark from the maintenance work welding operations likely ignited flammable vapors near one tank, Tank 393, that had been leaking, resulting in the explosion. The explosion led to the release of sulfuric acid from other tanks; acid flowed into the Delaware River, resulting in significant environmental damage. Tank 393 was originally designed to store fresh sulfuric acid, but had been converted to store spent acid. This tank had a history of leaks, and the CSB reported that the company had failed to conduct inspections that may have identified the presence of these leaks. The spent acid in the tank contained impurities such as hydrocarbons which were flammable and could vaporize. The company was aware of the hazards of vaporized hydrocarbons, so it installed a carbon dioxide inerting system with ventilation. However, this inerting system was undersized and implemented improperly and therefore did not prevent formation of a flammable atmosphere above the tank prior to the explosion. The CSB noted that the company did not use its management of change (MOC) system to analyze the conversion of the tank from fresh to spent acid storage. In addition, the company failed to perform proper pre-startup safety reviews prior to completing the conversion. A pre-startup safety review is required after a change is made but before the equipment is put into use as part of a proper MOC effort. As stated in the report, “Such a safety review would likely have identified the temporary hose inserted into a hole on top of tank 393 as an unacceptable means of delivering inerting gas. With a more comprehensive application of its MOC system prior to initiating the tank 393 conversion – including a review by a multidisciplinary team of refinery personnel – [the company] would likely have identified the inadequacy of the proposed inerting system, the lack of emergency pressure relief capability, and the need for engineering.” (ref. 8)

Mechanical Integrity

It is not enough that equipment be built and operated. That equipment must be maintained to ensure that it will continue to operate correctly. The PSM Standard requires that an organization establish and implement written procedures for maintaining equipment such as the following:

- Pressure vessels and storage tanks
- Piping systems (including piping components such as valves)
- Relief and vent systems and devices
- Emergency shutdown systems

 Controls (including monitoring devices and sensors, alarms, and interlocks)

 Pumps

Inspection and testing of equipment is an important part of maintaining mechanical integrity. Further, an effective quality assurance program must be implemented to assure conformance to standards and codes, identify and record deficiencies, and confirm that deficiencies have been corrected.

<u>Case Study: Chlorine Release in Missouri</u>
On August 14, 2002, approximately 48,000 gallons of chlorine was released from a railroad tank car at a company near Festus, Missouri during a repackaging operation. The company received bulk liquid chlorine in 90-ton tank cars and repackaged it into 150-pound cylinders and 1-ton containers for commercial and municipal use. According to the CSB, 63 people from the surrounding community sought medical attention for symptoms related to the release, and three workers received minor skin exposure. Hundreds of residents in the community were required to shelter-in-place for 4 hours. The CSB found that the release was the result of a hose that had ruptured; the CSB stated that poor quality assurance practices and ineffective testing and inspection procedures led to the hose failure. The hose that failed was made of materials inappropriate for the chlorine unloading operation, according to the CSB, and therefore it corroded and eventually failed. The report stated that this hose was similar in appearance to one that should have been used, but there was no mechanism at the company to identify and differential similar looking hoses. The CSB report went on to say that, while a mechanical integrity program existed, inspections, tests, and maintenance activities “were not performed to the level necessary to identify or prevent corrosion.” The CSB found a number of deficiencies in the mechanical integrity program: inadequate oversight of inspection and test personnel, insufficient training of packagers, inadequate auditing of operating procedures, and inadequate detail in inspection procedures (ref. 9).

Hot Work Permit

Nonroutine work, specifically hot work such as welding operations, introduce the potential for increased risks from explosions and fires. The organization must establish a hot work permit system to assure that the hazards have been properly analyzed, the risks have been mitigated, and the personnel performing the work understand the hazards. Procedures should be established, including what is needed to inform others that the work is complete.

<u>Case Study: Explosion and Fire in Florida</u>

On January 11, 2006, an explosion and fire occurred at the Bethune Point Wastewater Treatment Plant in the City of Daytona Beach, Florida. Two employees of the treatment plant were killed and a third was severely burned. The CSB investigated the accident and found that maintenance workers were using a cutting torch to repair a roof above a methanol storage tank at the time of the accident. Methanol is used as part of the wastewater treatment process. The cutting torch ignited vapors from the storage tank and the flame propagated back into the tank, starting an explosion. The CSB found that workers at the plant had not received any training in the hazards of methanol in the last ten years. In addition, the City of Daytona Beach did not require reviews of work plans for safety considerations. The CSB found that critical piping and valves were constructed of PVC, not metal, in violation of OSHA regulations. The PVC piping failed mechanically during the explosion, resulting in the spraying of methanol on the maintenance personnel. As stated in the report, “Had the methanol piping and valves been constructed of steel, the system would most likely have remained intact. The mechanic in the crane would likely not have been killed, and the other two workers may have been less severely injured.” The CSB also stated that a faulty flame arrester contributed to the severity of the accident. A flame arrester is a device that acts as a hazard control to ameliorate the effects of fire in piping systems. The arrester can stop a flame while allowing gases and vapors to flow freely; transfer of heat to metal plates helps to extinguish the flames. The CSB found that the arrester used was made of aluminum. However, methanol corrodes aluminum, and this flame arrester showed signs of severe corrosion. Flame arresters require frequent inspections to assure proper operation. However, treatment plant personnel were unaware of the need for inspection, and this unit had not been inspected since its installation 12 years prior to the accident. The CSB reported that due to the corrosion, the flame arrester failed to do its job in preventing fire outside the tank from igniting the tank contents, thereby contributing to the explosion. The root 8 causes of this accident were determined to be a failure to implement adequate controls for hot work at the plant and an ineffective hazard communication program (ref. 10).

Management of Change

Engineering by its very nature is an activity that involves change. As systems are used in operation, the design and procedures often change, and the associated risks may increase. Changes could include modifications to equipment, procedures, raw materials, and processing conditions. Therefore, changes must be thoroughly evaluated to assure that safety is maintained. The change analysis must include all of the following:

- Technical basis for the proposed change
- Impact of the change on employee safety and health
- Modifications to operating procedures
- Necessary time period for the change
- Authorization requirements for the proposed change

Organizations should not assume that “minor” changes have no impact on safety. Many accidents have resulted from small changes that did not appear to have an effect on safety prior to the incident.

<u>Case Study: Fire in Washington</u>

On November 25, 1998, a fire at an oil refinery in Anacortes, Washington led to six fatalities. The fire occurred in the delayed coker unit; a delayed coker is a vessel used to convert heavy, tar-like oil into lighter petroleum products such as gasoline and fuel oil. On the day prior to the accident a severe storm caused loss of electrical power in the refinery. Loss of power interrupted the process that filled the coker. Power was restored within two hours, but the refinery could not produce steam until ten hours later. During this delay, material hardened in the lines and in the coker drum. Refinery workers tried to clear the hardened material with little success. They then removed the drum bottom to extract the material, thinking that the material had cooled. Sensors were not available inside the drum to accurately gauge the temperature of the coke. The workers had expected to find congealed residue when they removed the drum bottom, but instead hot liquid fuel poured out and ignited. The CSB investigated the accident and found that the workers did not understand the hazards and that no procedures existed for handling this abnormal situation. As stated by the CSB, “Chemical processing enterprises should establish policies to manage deviations from normal operations.” The work permit system was found to be flawed in that it falsely determined that the drum parameters were adequate for removing the drum bottom when in fact the employees had no way of knowing the temperature of the material. The change in procedures initiated by the employees should have triggered a review of those procedures through the company’s management of change policy, but no review was conducted. The CSB report also stated that had the company performed a formal hazard analysis it would likely have determined the limitations of the temperature readings and that it was unsafe to open the drum (ref. 11).

Incident Investigation

Known problems should not be allowed to persist. A failure to investigate and fix the root cause allows the opportunity for the problem to reappear, or for that problem to lead to an accident. Organizations should focus on preventing accidents, not just reporting problems, and this requires root cause analysis. Organizations must have an active, aggressive incident evaluation program to identify the underlying causes of these incidents and break the sequence of events that can lead to an accident. Such incidents include those that could be called a “near miss,” an event that could have resulted in catastrophic consequences if the conditions had been different. Lessons from the incident or problem investigation should be factored back into the hazard analysis.

<u>Case Study: Explosion in Texas</u>

On June 22, 1997, an explosion occurred at a chemical plant in Deer Park, Texas. The facility produced a number of petroleum intermediates by processing crude petroleum feed stocks. Although no one was killed in the explosion, 9 several workers received minor injuries and the facility and nearby residences were extensively damaged. The accident was jointly investigated by the Environmental Protection Agency (EPA) and OSHA. The EPA/OSHA team found that the cause of the accident was the failure of a check valve located on a high-pressure light hydrocarbon gas line. The check valve failure started a large flammable gas leak; the escaping gas then formed a vapor cloud which ignited. The report stated that the check valves had not been properly designed and manufactured for heavy duty service, and were susceptible to failure during normal use. There were check valve failures prior to this accident, but the EPA/OSHA report stated that lessons from the prior failures had not been properly shared and implemented. These prior incidents were treated as maintenance actions and therefore no formal investigations were conducted to determine root cause. A processes hazard analysis had been performed, but this analysis did not include failure of a check valve, and therefore mitigations were not implemented for such failures. Procedures were also found to be inadequate, and did not instruct operators to verify the valve positions prior to restarting the process (ref. 12).

Emergency Planning and Response

Process Safety Management is an effort first and foremost to prevent accidents and incidents. But no matter how hard organizations try to build their systems safely, designs will be flawed, people will make mistakes, components will fail, software will do the unexpected, and environmental conditions will exist that are beyond the company's control. Therefore, organizations must plan for an emergency and be prepared to respond. At a minimum, employers must develop an emergency action plan that includes evacuation and shelter-in-place instructions and training in the use of personal protective equipment. Employees must be trained to this plan for it to be effective, and alarm systems should be implemented to warn employees that emergency conditions exist.

Case Study: Fire in Illinois

On July 14, 2006, a fire erupted during a mixing operation at a chemical facility in Bellwood, Illinois. One person was killed and two were injured in the fire. At the time of the incident an operator was mixing heptanes and mineral spirits, a flammable combination of chemicals, to create a product to cure concrete surfaces. During mixing the operator noticed a dense fog forming on the floor below. This dense fog was in fact vapors from the process. In reconstructing the accident the CSB found that a temperature controller had malfunctioned, allowing a steam valve to remain open and heat the mixture beyond its boiling point, thereby creating the vapor cloud. In addition, the CSB found that the ventilation system failed to remove the vapor cloud, in part because it was not designed to remove such high volumes of vapor and because the exhaust fan belts were broken prior to the incident. The vapor cloud spread into various parts of the facility where it eventually was ignited by one of many ignition sources. The CSB faulted the company for designing and constructing a flammable liquid heating and mixing operation using an open top tank without proper safety controls in place. The CSB also highlighted failures in the company's emergency planning. The company had no emergency response plan, employees had not received emergency response training, no drills had been conducted, and no alarms were available to alert employees of an emergency. In fact, the person who was killed was a delivery driver who had come onto the facility during the emergency and was unaware of the hazard. The CSB stated that had there been better emergency planning it is possible that all personnel may have escaped injury (ref. 13).

Compliance Audits

Compliance audits provide a means for assuring that the procedures and practices in the PSM Standard are being followed and are adequate. Under the PSM Standard, compliance audits must be conducted at least every three years. The audit must be conducted by a trained individual or team, and the auditing effort should be planned to ensure success.

Case Study: Explosions in Ohio

On May 4, 2009, two employees were seriously injured and two others sustained minor injuries from an explosion at a company in West Carollton, Ohio. The initial explosion was followed by multiple secondary explosions that damaged every structure on the company site. In addition, residences and businesses in the surrounding area were 10 damaged by the explosions. The company provided hazardous waste services for industrial and municipal customers. This facility received waste products, both hazardous and non-hazardous, which were typically spent solvents from industrial generators. After distilling the waste products, the clean solvent could be sold to other industrial users. Immediately prior to the explosion the operating crew had shut down a tetrahydrofuran (THF) solvent recovery process per procedure. After completing this process the pipes required cleaning. The crew performed this cleaning function by back-blowing nitrogen gas through the piping into the dirty tank. The CSB accident investigation report stated that employees heard a loud vapor release just before the explosion, and they detected strong THF odors. The CSB found that the tanks were equipped with relief devices to protect the tank from overpressure. However, the relief devices vented directly to the atmosphere. This uncontrolled venting allowed highly flammable THF vapors to accumulate to explosive concentrations outside the process equipment. The THF should not have vented during normal cleaning operations, but the CSB stated that it was possible that the dirty tank was not manifolded properly, allowing overpressurization of the tank. Another possibility was that accumulated THF residue became active when exposed to oxygen. Two natural gas-fired boilers in a nearby lab/operations building likely served as the ignition source. The CSB found no record of a process hazard analysis to evaluate the siting of a lab/operating building so close to the operating units. OSHA issued citations for numerous violations following this accident, alleging that the company had failed to conduct compliance audits every three years to ensure policies and procedures were being following for hazardous chemicals. The CSB recommended that the company conduct a process hazard analysis on all OSHA Process Safety Management covered processes to ensure all buildings and structures at the West Carrollton facility are located and designed in accordance with electrical classification and spacing as defined in appropriate standards (ref. 14).

Trade Secrets

Organizations must make critical safety information available to all personnel developing the hazard analysis, creating operating procedures, providing emergency planning and response, performing audits, and participating in incident investigation. They must make this information available even if trade secrets are included. However, the organization may use confidentiality agreements to assure that the information is not disclosed.

<u>Case Study: Toxic Chemical Release in Georgia</u>

On April 12, 2004, a runaway chemical reaction at a facility in Dalton, Georgia resulted in the release of toxic chemicals into the local community. One employee sustained serious injuries, and 154 people were treated for chemical exposure. The CSB found in its investigation that the accident occurred when the company was attempting to manufacture a new product, triallyl cyanurate (TAC), in a 4,000-gallon reactor. The runaway chemical reaction over-pressurized the reactor, activating the emergency vent, which then released toxic vapors (allyl alcohol and allyl chloride) into the atmosphere. The CSB stated in its report that personnel did not conduct an adequate evaluation of the reactive chemistry hazards associated with manufacturing TAC prior to producing the first batch. As such, the operators were unaware of the potential for a runaway reaction when they added the entire quantity of each chemical and a catalyst all at once to make TAC. The CSB stated that the company did not conduct process hazard analyses or pre-startup reviews prior to manufacturing the first batch of TAC. Such analyses may have highlighted the need for a liquid/vapor containment system on the emergency vent to prevent a toxic chemical release. A hazard analysis may also have uncovered the need for personal protective equipment such as respirators in case of a spill and air-monitoring equipment to detect such a spill. The CSB did state that the company had conducted small-scale testing of the process on a 30-gallon reactor, but those tests were different from the final process in that the small scale tests did not use catalyst. These tests misled company employees on the amount of cooling required for the 4,000-gallon tank, and hence the tank was not sufficiently cooled to control the reaction. The company had performed an analysis to design the cooling system, but that analysis failed to consider key aspects of the reaction chemistry.

The report noted that the company had agreed to produce TAC in a tolling agreement with a client company. Toll manufacturing is an arrangement whereby a first firm with specialized equipment processes raw materials or semi-finished goods for a second firm. In this arrangement, the client issued a purchase order to the company for the manufacturer of TAC. The client had performed its own laboratory-scale tests of this process, and had identified manufacturing safety considerations, including that the process liberated significant heat. Both the company and the client discussed issues associated with the process. However, the report stated that the client did not ensure that the company specifically addressed the hazards of production-scale manufacturing of TAC. In addition, the report stated 11 that the company did not share all process information with the client, in part because some of the information was proprietary and contained company trade secrets (ref. 15).

Summary

Process Safety Management (PSM) is a proactive management and engineering approach to protect employees, contractors, and other personnel from the risks associated with hazardous chemicals. These hazardous chemicals have the potential for catastrophic consequences if not properly controlled. Companies that use chemicals in quantities specified by OSHA must comply with the regulations in the PSM Standard. The PSM Standard contains 14 key elements - all these elements are critical to safety in hazardous chemical processing. The lessons provided here, in the form of accidents and incidents, should be used as a reminder of the importance of these elements.

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