Dow Learnings and Actions from the Deepwater Horizon Accident

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The Deepwater Horizon drilling rig explosion on April 20, 2010, killed 11 workers, injured 16 others, and resulted in an offshore oil spill in the Gulf of Mexico that is considered the largest accidental marine oil spill in the history of the petroleum industry. As with all major incidents in industry, there are lessons to learn from systemic failures that resulted in the tragic loss of life, insult to the environment, and the equipment loss. Many companies, including The Dow Chemical Company, followed the subsequent investigation closely to determine which lessons could be leveraged to strengthen internal programs.

Risk identification and management systems in Dow's Process and Occupational Safety programs are robust. Dow management systems are intended to meet or exceed Industry Standards with respect to design, operation, and layers of protection. The prevention of large scale accidents like Deepwater Horizon depends on an acute awareness of worst-case scenarios and an unfailing vigilance to ensure that essential protection layers are not compromised. Dow management system reviews in 2011 on the same management systems involved in this incident identified opportunities for improvement and/or action plans in several areas. This article will focus on three programs that resulted from those management system reviews. The three programs are:

1. *a targeted High-Consequence Emergency Response Drill program,*
2. *a High Potential Process Safety Near Miss Program, and*
3. *technology-specific Process Safety Cardinal Rules.*

For each of the three programs, a description of the content of the program and how it was implemented at the company level is provided. Specific examples of how these programs were implemented at a facility level are included. Each of these programs play a key role in preventing a catastrophic event and have been a part of Dow's continuing process safety performance improvement over the last several years. © 2015 American Institute of Chemical Engineers Process Saf Prog 34: 335–344, 2015

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INTRODUCTION

The Deepwater Horizon drilling rig explosion on April 20, 2010, killed 11 workers, injured 16 others, and resulted in an offshore oil spill in the Gulf of Mexico that is considered the largest accidental marine oil spill in the history of the petroleum industry. As with all major incidents in industry, there are lessons to learn from systemic failures that resulted in the tragic loss of life, insult to the environment, and the equipment loss. Many companies, including The Dow Chemical Company, followed the subsequent investigation closely to determine which lessons could be leveraged to strengthen internal programs.

In January 2011, the National Commission on the BP Deepwater Horizon Oil Spill and Off-Shore Drilling issued its Report to the President on the disaster. This 398 page report describes in detail the circumstances that led to the explosion and subsequent spill, as well as the commission's investigation results and recommendations. In February 2011, The Dow Chemical Company formed a multifunctional team to review the report and determine what response should be taken to ensure Dow's management systems were as robust as possible to prevent a disaster of a similar magnitude, as well as lesser events.

CORPORATE TEAM STRUCTURE AND STRATEGY

The team formed to evaluate the commission's investigative report consisted of representatives from Environment, Health, and Safety (EH&S), Process Safety, Regulatory Affairs, Emergency Services and Security (ES&S), and Legal. Additionally, since land-based drilling operations performed by the Mining, Storage, and Pipelines (MSP) business within Dow utilized similar technologies to those used on the Deepwater Horizon drilling rig, representatives from MSP were also included on the team. This broad multidisciplined team was tasked with reviewing the incident causes and management system failures as outlined in the commission's report and exploring the relation to Dow's management systems. Finally, the team was to determine where any opportunities for improvement existed and recommend necessary actions for follow-up.

The team did not define any root causes related to the Deepwater Horizon Gulf Oil disaster independent from the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling. Instead, the team relied strictly on the issued report findings. The value from this exercise is not dependent on the accuracy of the findings of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, which Dow assumed are completely accurate in this exercise.

The commission's report was carefully reviewed and every management system failure or other incident cause was assessed to determine if it was applicable to Dow as a whole or to one or more particular businesses within Dow. For any applicable failures or causes, the relevant management system(s) in place was reviewed to determine if opportunities for improvement relevant to the failure existed. If opportunities existed, solutions were proposed. Potential solutions were then grouped into process steps [1] as follows:

- People: Anyone involved with the process
- Methods: How the process is performed and the specific requirements for doing it, such as policies, procedures, rules, regulations, and laws
- Environment: The conditions, such as location, time, temperature, and culture in which the process operates

Each potential solution was then rated using the following criteria:

- Success at reducing Dow's risk (independent of gap size)
- Size of the gap
- Resource impact (money, people, time)
- Multiple impacts (e.g., process safety, reliability, ES&S, etc.)
- Effort to sustain change

A vote of 1, 3, or 9 was recorded for each criterion. Higher numbers reflected a positive evaluation for the criterion in question. For example, if a potential solution could be very successful at reducing Dow's risk, a score of 9 would be recorded for that criterion. Similarly, if the resource impact was large, that is, would require a large number of people and time to implement the score for that criterion would be 1. After all criteria for each potential solution was scored, the scores were summed for each solution. The solutions were then prioritized based on the relative score. Higher scoring potential solutions became actions which were proposed for implementation. Several actions were proposed by the team, three of which are detailed in this article.

HIGH-CONSEQUENCE EMERGENCY RESPONSE DRILL PROGRAM

Deepwater Horizon Incident—From the Commission Report. . .

These conclusions from the report provided a focus on emergency preparedness and response.

> *The crew should have diverted the flow overboard when mud started spewing from the rig floor. Considering the circumstances, the crew also should have activated the blind shear ram to close in the well. There are a few possible explanations for why the crew did neither:*
>
> - *First, they may not have recognized the severity of the situation, though that seems unlikely given the amount of mud that spewed from the rig floor.*
> - *Second, they did not have much time to act. The explosion occurred roughly 6–8 min after mud first emerged onto the rig floor.*
> - *Finally, and perhaps most significantly, the rig crew had not been trained adequately how to respond to such an emergency situation. In the future, well-control training should include simulations and drills for such emergencies—including the momentous decision to engage the blind shear rams or trigger the Emergency Disconnect Switch* [2].

Dow Self-Assessment and Identified Improvement Opportunity

Dow requires that all emergency and crisis plans are tested at least annually. Each plan should identify the process and requirements for drills and exercises. Dow also requires that personnel with roles responding to emergencies or crises have training to demonstrate proficiency in the handling of these events. Drills and exercises are a key part of the training process. Corporate Emergency Services has a guidance document for drill/exercise planning and has a library of sample drills.

Dow also requires that all plants implement the Dow standard Immediate Response work process. Each plant is required to conduct immediate response drills at a minimum of one per quarter per shift team. Drill scenarios are identified and planned by the organization based on Immediate Response criteria. There is a corporate guidance document for design and conduct of Immediate Response drills.

Evidence indicates that these Dow work processes are effective in preparing the organization to respond to typical and predicted scenarios. However, the Deepwater Horizon response team recognized an opportunity to augment the existing drilling process with defined "High Consequence" scenario expectations. The intent is to build organizational and individual capabilities to make decisions and manage these low frequency, but higher consequence unplanned events.

A global subteam was formed that developed the framework to roll out a formal program for all Dow manufacturing facilities to implement drills on high consequence scenarios. In late 2012, the program was pushed out globally with expectations established for defining the scenarios and executing at least one drill in 2013 with full implementation by year-end 2014.

So, what constitutes a high consequence scenario? First and foremost are scenarios with significant offsite toxic impact or onsite toxic/flammable impact. These scenarios typically come from the technology/facility list of worst-case scenarios and/or facility risk assessments. However, candidate scenarios could also be ones that result in significant environmental impact, or even adverse publicity and litigation from something like a nuisance odor. See Table 1 for more details.

Note that many Dow manufacturing facilities already had drilling on these types of scenarios in place, but the intentions of the program developed by the global subteam was the following:

1. **To formalize the program**—ensuring that all manufacturing facilities have these types of scenarios incorporated into their routine drilling plans at the appropriate frequency.
2. **To drive consistency in implementation**—ensuring that all facilities are using the same criteria for defining what the high consequence scenarios are.
3. **To drive engagement and oversight by the business technology expertise groups (Business Technology Centers, see Figure 1)**—ensuring that the Business Technology Centers, in conjunction with the manufacturing facilities, lead the identification and development of the high consequence scenarios and define the appropriate response that should be taken. The expectation is that each facility's emergency response plan include the identified scenarios and align with the defined response

Table 1. Example high consequence scenarios.

High Impact, Low-Probability Events		
Category	Potential Impact	Examples
Toxic releases	Off-site severe injuries/fatalities	Catastrophic tank failure of a volatile material that impacts neighbors
Large fires/Explosions	Multiple on-site severe injuries/fatalities	Large release of a volatile hydrocarbon through a vent stack with subsequent ignition
Large spills impacting the environment	High impact on the environment (determined on a site-by-site basis)	Pipeline failure of an environmentally impactful material to the storm sewers, resulting in a fish kill and needed remediation
Other off-site scenarios included in active QRAs	Multiple on-site or off-site severe injuries\fatalities	Large loss of containment from cross-country hydrocarbon pipeline near populated area

Dow first created Business Technology Centers in 1965. These centers were created around common technologies within Dow. They were tasked with ensuring consistent application of the safest and most effective technology practices. Although the focus of the technology centers has expanded over the years to include responsibilities such as technology specific training and documentation of best operating and design practices, the core focus still remains strongly aligned with process safety.

Figure 1. Business Technology Centers at Dow.

plans, as documented by the Business Technology Center. See Figure 1 for a description of Business Technology Centers.

Once the corporate guidance was issued, each of the businesses developed a strategy to implement and then executed that strategy over the next 2 years. The following section describes how one site implemented the drilling plans once the scenarios were developed by the Technology Centers.

Case Study on Implementation of a High Consequence Emergency Response Drilling Program at a Large Integrated Manufacturing Site

Once the scenarios were developed by the Business Technology Centers partnering with the manufacturing facilities, the planning for executing those drill scenarios could begin. Each facility was expected to incorporate the scenarios into their normal Immediate Response drilling activities. Oversight was provided at the site and Technology Center level to ensure that this took place. The remaining discussion will surround the drill planning activities at Dow's Houston Operations sites.

Dow's Houston Operations is divided into 11 discrete manufacturing entities for which drills are planned. Each of the 11 facilities is required to participate in a live action site level drill once every other year. These drills involve activation of Dow's Emergency Operations Center (EOC), response by onsite Emergency Response Team, as well as response from the manufacturing personnel. All activities that would occur in a real scenario are simulated during the drill. For example, during a recent ammonia spill scenario, fire monitors were actually operated to simulate the vapor suppression that would occur in a real situation.

The drill planning usually takes several months, and goes through the following steps:

1. **Identification of facility representative—**This person is process knowledgeable and typically experienced in the operations of the plant.
2. **Selection of scenario and date—**The facility representative works with site Emergency Services leadership to select one of the high consequence scenarios to drill on. The scenario selection is based on factors such as how long since the last drill on that scenario and what the learning objectives are that we want to accomplish with the drill. A date will also be selected based on the facility availability. Important note: Only the planners and the facility leader know when the drill will occur. Only the people planning the drill know what the scenario will be, but the leader does not know the scenario. So, the drill is effectively unannounced, which provides for a better simulation of the responders' preparedness, rather than allowing them time to preplan their response any more than if the actual event were to occur.
3. **Preparation of detailed timeline—**The Technology Center package provides the basic structure of the scenario and the expected response. However, the detailed logistics of executing the drill has to be planned on a case-by-case basis. And, contingencies should be planned for anticipated responses that are different than the desired response. For example, during one of our toxic chemical release scenarios, we had a contingency to inform personnel that they were overcome by the cloud if they chose to respond without donning breathing air packs. To the responders' credit, they did indeed put their breathing air packs on, so the contingency was not needed.
4. **Executing the drill—**The drill is typically initiated by the proctor handing someone a cue card, announcing that this is a drill and that something specific is happening, such as a gas detector going off or a high temperature alarm. See an example cue card in Figure 3. This should trigger a response that leads them naturally through the timeline, usually taking actions such as sending first responders and activating the EOC. Cue cards are handed out as defined by the timeline. The drill is considered concluded when all objectives have been met.
5. **Critique—**This is one of the most critical steps of the drilling process, because the whole purpose of a drill is to learn from it and continue to improve the management systems. Immediately after the conclusion of the drill, key learnings and observations are captured by the EOC, the Emergency Responders, and the facility personnel while

Figure 2. Live drill with HAZMAT team members installing a chlorine cylinder patch kit. Live drills provide the most realistic simulation of a real situation. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**.]

the drill is fresh in everyone's minds. At a later date, these critiques are consolidated and follow up action items are created to address identified opportunities.

These types of planning activities are not anything new or novel. However, the corporate initiative provided a catalyst to drive a more formalized drill planning and execution process for Houston Operations. Drills on higher impact scenarios are being conducted more frequently, and a wider variety of the systems that could be called upon for use in a real situation are tested. At the time of writing, Houston Operations has held six drills under the corporate initiative. Some of the systems tested during these drills include:

1. Planning out the logistics of executing a large-scale evacuation during a slow-building reactive chemicals event.
2. Improving our interface with the community alerting systems.
3. Simulating the interface with key external entities, such as law enforcement agencies, the news media, and the US Coast Guard.
4. Interacting with the Local Emergency Planning Committee to initiate a widespread community shelter-in-place, and then dealing with the effects of that.

So what has been learned from these drills?

1. **Immediate response has worked well.** Although there have been some minor tweaks made to emergency plans and training after the drills were completed, the first responders have all responded with the correct actions. As important, observations have been that they have taken the drills seriously. This reinforces that leadership expectations around emergency preparedness have been established and followed in these facilities.
2. **Communication is a critical aspect of emergency response that must be frequently trained on and practiced.** In a few of the earlier drills, the EOC was not communicating well with the Incident Commander, resulting in incorrect actions being taken by the EOC. The importance of establishing linkage between the EOC and the Incident Commander early has been reemphasized in training to both parties and communication is steadily improving in more recent drills.
3. **Scenario-specific items can be learned each time.** For example, in one unit, the field operators had been relocated from one building to another. Self-Contained Breathing Apparatus (SCBAs) are located at strategic spots throughout the plant, however, the new building did not have SCBAs. If the wind had been directed toward the new building, the operators would have been trapped in the building unable to respond. The corrective action was captured to place SCBAs in the new building. Each drill has had at least one discovery of this nature that has led to an improved capability to respond in the future.

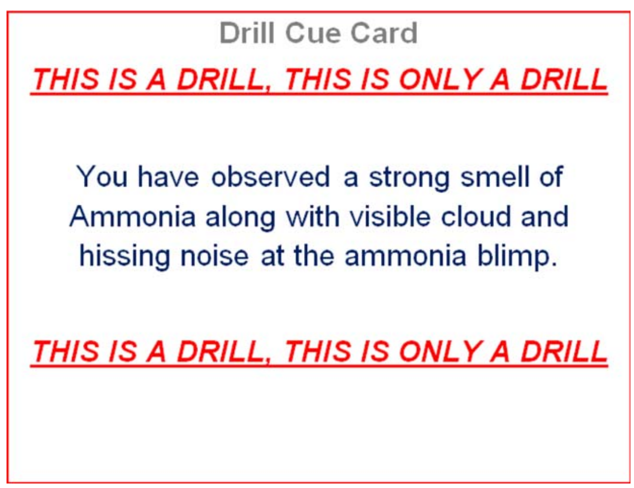


Figure 3. Example cue card to initiate drill. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**.]

Drills have been a regular part of the Houston Operations Emergency Preparedness program for years. However, the corporate initiative on High Consequence Drill Scenarios has catalyzed us to increase the scale and effectiveness of the drills we perform. Furthermore, making these drills unannounced and building in dynamic contingencies has increased the level of realism that allows us to better test our emergency response systems. Although nobody is ever comfortable in the midst of a serious event, by continuing to drill and practice for the worst we can imagine, we are in a better position to respond effectively and correctly in a real situation, should it ever occur.

HIGH-POTENTIAL PROCESS SAFETY NEAR MISS PROGRAM

Deepwater Horizon Incident—From the Commission Report. . .

These conclusions from the report provided a focus on the need to quickly and widely distribute the learnings from incidents across the organization to prevent a similar occurrence.

> *Transocean failed to adequately communicate to its crew lessons learned from an eerily similar near miss on one of its rigs in the North Sea 4 months prior to the Macondo blowout. The incident cost Transocean 11.2 days of additional work and more than 5 million British pounds in expenses. Transocean eventually sent out an "operations advisory" to some of its fleet (in the North Sea) on April 14, 2010, reiterating many of the lessons learned and warnings from the presentation. It set out "mandatory" actions to take, acknowledging a "Lack of Well Control preparedness during completion phase," requiring that "[s]tandard well control practices must be maintained through the life span of the well" and stating that "[w]ell programs must specify operations where a single mechanical barrier . . . is in effect and a warning must be included to raise awareness. . . ." Moreover, according to Transocean, neither the PowerPoint nor this advisory ever made it to the Deepwater Horizon crew [*[2]*].*

Dow Self-Assessment and Identified Improvement Opportunity

Dow's EH&S and Process Safety organizations currently have a Learning Experience Reporting (LER) process which is designed to incorporate the learning from an event into the Management Systems where there is documented value. For the significant internal EH&S or Process Safety events, key learnings and required actions (if any) are documented in the LER and distributed globally. Similarly, LERs are also created for significant external incidents when there is learning value and/or required actions. Follow-up to actions included in LERs are formally recorded and tracked through completion.

Additionally, in 2009, Process Safety Near Miss (PSNM) Reporting was implemented and is intended to be a sensitive indicator which presents an opportunity to learn valuable information that may prevent more serious future incidents. To further strengthen the PSNM Reporting program, the opportunity identified by the Deepwater Horizon response team was to elevate the learnings from the highest potential PSNM events. Identification, investigation, and corporate leveraging of the events with the highest potential for major impact within the corporation can only further strengthen and drive continuous Process Safety performance improvement.

A High Potential Process Safety Near Miss (HP PSNM) is defined as a PSNM event that results in the highest *potential* for a fatality, numerous Day Away from Work Cases or most significant community impact if the circumstances had been slightly different. The HP PSNM should provide significant learning value to the corporation or the reinforcement of critical protection layers. The elements of the HP PSNM reporting process include:

1. Immediate reporting of event to Business and Technology Leaders;
2. Formal Root Cause Analysis conducted, including key roles from Process Safety and the Technology Center;
3. Process Safety develops a LER for distribution across the technologies and sites.
4. Positive recognition for the team identifying and reporting a HP PSNM.

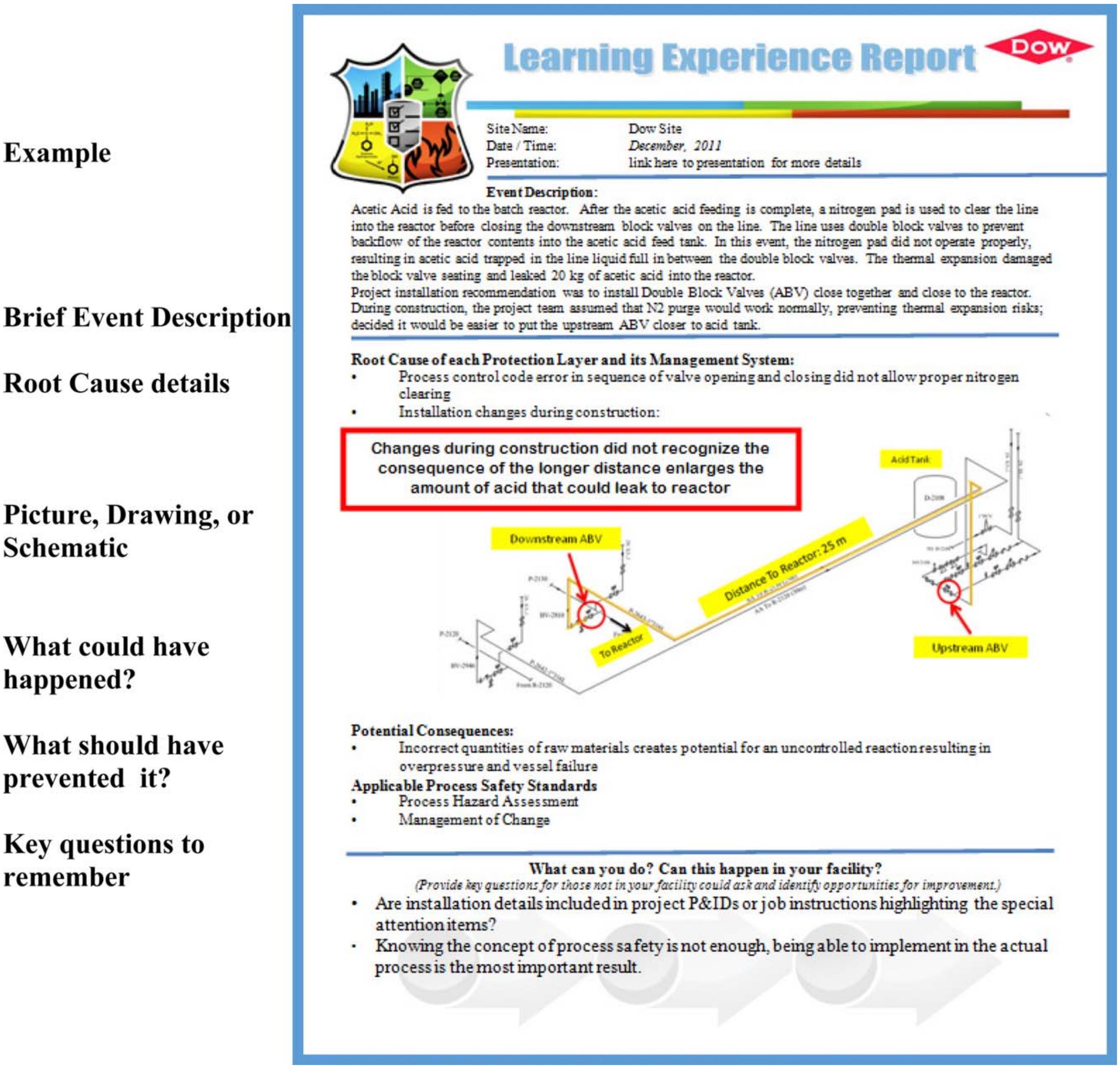
Case Study on Implementation of HP PSNM Reporting

To differentiate between a PSNM and a HP PSNM, the operating units must first have a well established PSNM program. This includes the staff and operators being aware of what is a PSNM, a culture of positive recognition for reporting PSNM, and using the PSNM reporting to identify Management System Opportunities for improvement. The next step to identify an event as a HP PSNM requires awareness of the potential consequences had circumstances been slightly different. This should be reviewed at the time of a PSNM event with subject matter experts and leadership from the facility, the Technology Center, and Process Safety agreeing on the final conclusion. In many cases, the classification of a HP PSNM is obvious. Once agreed that an event has met the criteria of a HP PSNM, a notification should be communicated to the appropriate business and geographic leadership for their awareness and support of necessary resources for the Root Cause Analysis and corrective actions.

A formal Root Cause Analysis of the HP PSNM event includes the correct participation from the facility personnel, Technology Center, and Process Safety. Additionally, subject matter experts from the anticipated management systems failures are represented. For example, a fired equipment expert would be involved if the event involved fired equipment. Evidence is gathered prior to the schedule review. Using the collected evidence of process conditions, sequence of events, and operator testimonial, a cause and effect diagram is derived until the root cause is identified. This includes the sharp end root cause(s), such as a failed instrument, and the system root cause(s), such as ineffective maintenance for the instrument. Corrective actions can then be developed to address all of the identified root causes. The management system root causes and corrective actions are typically what are most leverageable globally.

With the Root Cause Analysis complete, the HP PSNM Learning Experience Report can be developed. Typically, a learning experience report issued from a root cause investigation will include the event description, the root causes, and corrective actions. The impact of the lessons learned depends on the quality and effectiveness of the communication through which it is shared. Summarizing the key lessons learned from a HP PSNM event into a single page learning experience report provides direct and concise information that can be easily communicated throughout an organization, beyond the facility that had the event.

An example of a HP PSNM LER is provided in Figure 4. While it is tempting to include all of the technical details of what occurred during the event, the importance of a learning experience report is to provide enough information on the



Learning Experience Report DOW

Site Name: Dow Site
Date / Time: *December, 2011*
Presentation: link here to presentation for more details

Event Description:
Acetic Acid is fed to the batch reactor. After the acetic acid feeding is complete, a nitrogen pad is used to clear the line into the reactor before closing the downstream block valves on the line. The line uses double block valves to prevent backflow of the reactor contents into the acetic acid feed tank. In this event, the nitrogen pad did not operate properly, resulting in acetic acid trapped in the line liquid full in between the double block valves. The thermal expansion damaged the block valve seating and leaked 20 kg of acetic acid into the reactor.
Project installation recommendation was to install Double Block Valves (ABV) close together and close to the reactor. During construction, the project team assumed that N2 purge would work normally, preventing thermal expansion risks; decided it would be easier to put the upstream ABV closer to acid tank.

Root Cause of each Protection Layer and its Management System:
- Process control code error in sequence of valve opening and closing did not allow proper nitrogen clearing
- Installation changes during construction:

Potential Consequences:
- Incorrect quantities of raw materials creates potential for an uncontrolled reaction resulting in overpressure and vessel failure

Applicable Process Safety Standards
- Process Hazard Assessment
- Management of Change

What can you do? Can this happen in your facility?
(Provide key questions for those not in your facility could ask and identify opportunities for improvement.)
- Are installation details included in project P&IDs or job instructions highlighting the special attention items?
- Knowing the concept of process safety is not enough, being able to implement in the actual process is the most important result.

Figure 4. HP PSNM learning experience report example. [Color figure can be viewed in the online issue, which is available at **wileyonlinelibrary.com**.]

significant learning value or the reinforcement of critical protection layers. Setting a boundary to a one page learning experience report provides a format that is simple, direct, and easily transferable to a range of disciplines. The key content includes a brief description, root cause(s), consequence(s), what should have prevented the event, and most importantly, key questions to ask of the recipients of the report. The brief description of the event should provide enough information of what occurred without the full technical details. The intended audience of the report must be considered before including full technical details of the event. If more details are needed, a separate document or presentation can be linked within the one page report.

As with any event, the identified root causes are an important lesson. A picture or schematic of key elements of the process related to the event can provide a visual effect that contributes to an improved understanding of the incident. For a HP PSNM, the LER should include the potential consequences of the event. This could be the potential chemical released, personnel injured, or cost of equipment damaged. The corporate standards or industry best practices that could have influenced or prevented the event if effectively in place are highlighted. Finally, challenging questions that someone reading the report could ask of themselves are provided, which allows the reader to internalize the event to their specific situation. The opportunity is to leverage the lesson learned beyond the boundaries of that single event. One or two questions can generate discussion or serve as a reminder when a similar topic arises.

Identifying and implementing a HP PSNM reporting provides stratification in a dataset of events. The dataset of events that almost occurred is the PSNM. The value of any near miss is opportunity to correct and prevent a significant event. The additional focus on the HP PSNM events can

Example Monomer Handling Process Safety Cardinal Rules (Not all-inclusive)

1. **Never** thaw frozen acrylic acid or methacrylic acid with steam
2. **Never** remove liquid from a partially thawed container of acrylic acid or methacrylic acid
3. **Never** contaminate a monomer with a foreign material
4. **Never** sparge nitrogen through aerobic inhibited monomer
5. **Never** store aerobic inhibited monomer beyond the shelf life
6. **Always** know the inhibitor concentration of a monomer

Figure 5. Example Cardinal Rules for Acrylic Monomers.

leverage that opportunity to prevent future events beyond the impacted facility where the near miss originated. Effectively leveraging the Management System Opportunities across technologies and across sites within a global corporation has a significant impact to eliminating Process Safety Incidents and protecting the community, personnel, property, and the environment.

PROCESS SAFETY CARDINAL RULES

Deepwater Horizon Incident—From the Commission Report. . .

These conclusions from the Commission Report indicate the need to emphasize the most critical safety standards and what can go wrong if they are not followed.

> *The Culture on the Rig*
>
> *BP was operator of the Macondo well and in that capacity had both the overall responsibility for everything that went on and was in the best position to promote a culture of safety on the rig, including in the actions of its two significant contractors, Halliburton and Transocean whatever the specific contractual relationships, operating safely in this environment clearly demands a safety culture that encompasses every element of the extended drilling services, and operating industry.*
>
> *Survey Responses from the Transocean Crew*
>
> *According to the final survey report, Transocean's crews "don't always know what they don't know. [F]ront line crews are potentially working with a mindset that they believe they are fully aware of all the hazards when it's highly likely that they are not."*
>
> *Communication Issues*
>
> *The management systems of the involved companies (BP, Transocean, and Halliburton) were marked by poor communication among the BP, Transocean, and Halliburton employees regarding the risks associated with decisions being made (page 223). The decision making process on the rig was excessively compartmentalized, so individuals on the rig frequently made critical decisions without fully appreciating just how essential the decisions were to well safety—singly and in combination. As a result, officials made a series of decisions that saved BP, Transocean, and Halliburton time and money—but without full appreciation of the associated risks* [2].

Dow Self-Assessment and Identified Improvement Opportunity

Dow Process Safety risk identification and management systems are incorporated throughout Dow's internal standards and requirements. Self-assessments and audits indicate that these management systems are implemented. Continuous improvement in Injuries, LOPCs and PSIs indicate that these systems' effectiveness is also improving. Although Dow Management systems are very robust they can sometimes be complex and take significant time to understand. The prevention of large scale accidents like the Deepwater Horizon that have a low frequency of occurring, but a high impact if they do occur, depends on an acute awareness of worst-case scenarios and the assurance that the protection layers cannot be compromised. Cardinal Rules used within Dow are intended to help prevent major process safety hazards like these. A management system review around the use of the Cardinal Rules has led to updates to enhance the business specific process safety training in these higher risk areas.

While Dow has robust systems to manage process safety in addition to individual worker occupational safety, efforts are under way to firmly differentiate both those process safety and occupational safety risks that are "Life" or "Company" Critical and of which Dow expects no compromise on the execution of our management systems. In addition, this is especially challenging for temporary contract workers who migrate on our sites for relatively short durations of time. Although all people entering our sites will not necessarily understand all our safety rules, there is an absolute need that they clearly understand the most important safety rules.

The systems that Dow has established in order to differentiate the most important safety rules, both process and occupational are the following:

1. Life Critical Occupational Safety Standards, for example, Isolation of Energy
2. Company Critical Process Safety Management Systems:
   a. Operation and Maintenance Procedures and Procedure Use Requirements
   b. Mechanical Integrity Standard
   c. Maintenance of Interlocks and Alarms
   d. Management of Change, including staffing or startup changes
   e. Process Risk Management Standard, which includes PHA and LOPA
3. Company Critical Process Safety Technology Cardinal Rules

These systems are differentiated to personnel through periodic training, emphasizing the importance of these rules and what can happen if these rules are not followed.

Case Study on Implementation of Technology Process Safety Cardinal Rules

Technology Process Safety Cardinal Rules have been in existence in some technologies within Dow for many years. In the last few years, an increased emphasis has been placed on ensuring that all technologies have Cardinal Rules developed and disseminated all the way to the shop floor. The

Table 2. Details behind an example Cardinal Rule.

Cardinal Rule	What Could Happen?	Where Does the Hazard Exist?	Minimum Safeguards
Never thaw frozen acrylic acid or methacrylic acid with steam	The use of steam can initiate a thermal, uncontrolled polymerization of the monomer, resulting in potential equipment rupture. Note that a tank truck exploded in 1976 due to this	Freezing can occur in pumps, pipe systems, and storage vessels that are uninsulated, poorly insulated, have inadequate heat tracing, or inadequate temperature control of heating systems	1. Well maintained insulation and heat tracing systems to prevent freezing. 2. Procedures and training on the safe methods that can be used for thawing are critical. 3. Never increase the temperature of the heat tracing system above the maximum allowable temperature. 4. The use of a hot water mixing station requires automatic shutoff capability for high temperature.

case study in this section will be focused on the Acrylics Monomers technology within Dow.

First the definition of Technology Process Safety Cardinal Rules must be understood. In the Process Safety world, the Cardinal Rules could be compared to the biblical Ten Commandments. They are short statements that are expressed in absolute terms like "never" and "always." These rules are portrayed to personnel as something that cannot be violated, because to do so could lead to something bad. And, there are a limited number of these rules for a given technology, to help emphasize their importance. A maximum of 10–15 Cardinal Rules is considered effective; any more than that can dilute the emphasis.

The Acrylic Monomers technology owners developed their list of Cardinal Rules in 2010, based on the internal and external storage and handling standards that had been in existence for many years prior to that. The storage and handling standards are comprised of many pages of detailed rules and guidelines for the safe handling of Acrylic monomers. Many of the rules and guidelines are based on not only best practices, but learnings from past events, both big and small, internal and external. The key benefit of taking a standard as extensive as that and developing a list of Cardinal Rules is to distill things down into short sound bites that can be more easily hard-wired into people's way of working. Several examples of these rules are shown in Figure 5.

Behind each of the short statements is the detail to reinforce the importance of the rule. Each rule includes a description of what could happen or has happened if the rule is violated, where in the plant the hazard exists, and what are the minimum safeguards that shall be in place in the plant. Table 2 shows an example for one of the rules from Figure 5.

Once the development of the Cardinal Rules was finalized, they were incorporated into the training program of all personnel who interact with the plant. Operators, Engineers, Leaders, and others were all trained initially on these rules in live interactive training sessions with the technology experts. Periodic formal recurring training is built into the program to ensure retention by those trained initially. Furthermore, they are built into the daily work practices to keep them fresh in everyone's minds. For example, each of the operating plant control rooms has a copy of the rules prominently displayed, as do some of the staff buildings. The rules are frequent topics of safety meetings and even informal discussions.

Finally, any violation of a Technology Process Safety Cardinal Rule that does not result in a Process Safety Incident is recorded as a PSNM and investigated. The learnings from the investigation are leveraged across the technology to help prevent reoccurrence.

The concepts contained in the Technology Process Safety Cardinal Rules have been around for decades and have been a part of Operator and Engineer training as well. However, putting them in this format has provided a new emphasis and additional detail to help the people who need this information the most remember the importance of these rules.

CONCLUSIONS

Dow expends considerable effort investigating and learning from internal incidents and near misses, and a process has been developed and fully implemented for sharing those learnings broadly throughout the company. It is a natural extension to also learn from the most significant external incidents, and develop internal action plans for strengthening our own management systems. The process for doing this successfully is complex and difficult to succeed at without leadership support and a solid implementation plan.

1. The external incident itself must be dissected and internalized.
2. The internal reflections must result in the identification of key management system opportunities at a global level.
3. The management system opportunities have to be turned into solid action plans for improvement.
4. Finally, the action plans have to be executed in a sustainable manner.

Getting these activities to be executed in all global geographies and in the highly varied business groups is a huge undertaking. And to sustain those activities going forward will require great fortitude and continued oversight. Dow is currently in the late stages of implementation, and only time will tell if these actions can be sustained.

However, there are two key reasons why sustainability is achievable. First, corporate manufacturing leadership is 100% supportive of the effort. Without that, the effort would surely fail. Second, each of these three programs "feels" right, which is why they were already implemented to varying degrees within different business units and geographies. The corporate programs established best practices and consistent guidelines for implementation across the company. And, Dow is already seeing benefit from the increased traffic in LERs, from the increased drilling occurring on worst-case scenarios, and the increased focus on the fundamental process safety issues contained in the Cardinal Rules.

Table 3. Timeline for drill.

Time	Action
8:50 AM	Maintenance staff in the South shop notice strong ammonia smell and see a small white plume near the metering skid. Hissing noise is coming from the leak location. "Initial Report Cue Card"
8:55 AM	Control room is notified by phone of the situation and sends the field operator to immediately investigate. The field operator arrives and notes that the leak rate is too high to approach safely and informs the panel operator to close all remote shutoff valves from the control room and to initiate Emergency Response. "Outside Operator Initial Response Cue Card"
9:00 AM	Dispatcher notices ammonia odor in building and initiates shelter-in-place and notifies Site Emergency Manager to establish alternate EOC. "Dispatch Initial Odor at Dispatch Cue Card"
9:00 AM	Plant shutdown is in progress. Site shelter-in-place protocols are initiated. South plant occupied buildings South-Southwest of the leak location are immediately impacted. This includes the normal EOC which must dispatch to the alternate location
9:05 AM	Receive a call from pipeline supplier reporting detectors at the ammonia metering station have all gone off scale. "Pipeline Supplier Initial Call Cue Card"
9:10 AM	Deer Park LEPC calls Safety Dispatch and requests Dow Rep at Deer Park EOC. "Dispatch LEPC Request for Dow Rep in DP EOC"
9:15 AM	ER crews arrive with SCBA and apply water spray from upwind of the release. ER crews note that closure of the shutoff valves did not stop the leak—leak point is upstream of the metering skid valve and downstream of the pig station valve. Community impacts are expected, communications are made for offsite impacts. "Outside Operator Second Response Cue Card" then "IRL Initial Response Cue Card"
9:25 AM	ER crews continue water spray with aqueous ammonia runoff to the nearby surface sewer. Aqueous ammonia travels by surface sewer throughout the South plant.
9:35 AM	A call from Deer Park LEPC with a report of a motorist on public road complains of ammonia odor. "Dispatch LEPC Odor Complaint on Tidal Cue Card"
9:40 AM	ER crews continue water spray as leak is slowing. Impacts on the surface are recognized and measures are taken to contain the aqueous ammonia.
9:55 AM	Leak stopped. Spill response/cleanup efforts begin.

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While this will not generate an incident-free future, it does help enable Dow to continue the drive to an incident free workplace.

APPENDIX: EXAMPLE HIGH CONSEQUENCE DRILL PLANNING PACKAGE

Large NH_3 Pipeline Leak: Emergency Response Drill Scenario

Potential Initiating Events

1. Hydraulic hammer or pressure surge, resulting from sudden open/closure of automated valves. This is different than "water hammer" where a sudden change in velocity can cause pressure shock waves in water pipes. Hammer in ammonia pipes is caused by the sudden collapse of small gas bubbles in a liquid pipe usually due to a sharp increase in pressure. As the bubble collapses, the liquid in the pipe "hammers" against itself. The impact can be sufficient to fracture pipes or valves and can cause big leaks. The liquid is incompressible so the hammering is transferred to the wall of the pipe.
2. Piping segments are blocked in with ambient temperature heat-up resulting in pipe rupture due to thermal expansion. Thermal relief protection is provided but could be ineffective for multiple reasons.
3. Cold temperature embrittlement of carbon steel piping resulting in pipe rupture. During startup operation (line filling), the initial pressure is 0 psig and flashing NH_3 to this pressure can result in temperatures as low as −34°C. A flange leak to atmosphere can result in external icing (moist air) and localized embrittlement of piping components.

Consequence

NH_3 is toxic and corrosive. NH_3 releases can have far reaching impacts. For the case of a full bore, line size pipe rupture, the release rate and impact distances are estimated as follows:

- Total release rate: 472,200 lb/h
- Airborne rate: 222,300 lb/h
- Distance to ERPG-2 Conc.: 4,715 ft
- Distance to ERPG-3 Conc.: 1,980 ft

The design has strategically placed excess flow valves around the NH_3 storage tank to prevent significant losses from the tank if connecting piping were to rupture. Remote shutoff valves are available at both ends of the line. During an incident involving a pipe rupture, NH_3 losses would be limited to the piping volume between shutoff valves. This is estimated as

- Total release quantity: 48,300 lb
- Total airborne quantity: 30,000 lb

ERPG-3 concentrations cover the South side of the site with direct impacts on occupied buildings. Occupants need to shelter-in-place. EOC should use an alternate location since the primary EOC will be impacted by this event. ERPG-3 concentrations also reach beyond site fence line impacting public roads and industrial neighbors. The public road should be closed to traffic.

ERPG-2 concentrations cover the entire DPO site, neighboring plants, and Hwy. 225. Additional shelter-in-place protocols should be initiated for the Whitehouse, Lubrizol, and/or ITC depending on wind direction. Hwy. 225 should be closed to traffic.

Design, Procedures, and Mitigation

NH_3 leaks are toxic with large impact potential to the site and community. Emergency Response is impacted by the leak size/location, release cloud and weather conditions. Remote shutoff capability improves the effectiveness of response and minimizes release impacts. Leak prevention is a function of design, operation, and mechanical integrity. Engineering design sets design temperature and pressure marginally above the max operating conditions and envisions operating scenarios that could lead to unsafe conditions. For example, slow opening/closing automated valves are specified to prevent hydraulic hammer and thermal relief is provided in sections of piping that can be blocked in. Operating discipline ensures that system components are operated consistent with the engineering design basis. For example, procedures are used to ensure systems are commissioned and operated properly—system leak tested, correct lineups made, PSVs in service, operating parameters are healthy, etc. Mechanical integrity programs ensure that system components remain at design service condition. This requires periodic defined inspections from trained maintenance staff to determine if service conditions have deteriorated from design and to take corrective action.

During an emergency situation, the following mitigating actions should be taken immediately.

- Close all remote shutoff valves from the control room.
- Initiate ER and shelter-in-place protocols to minimize impact to site personnel and the community.
- Activate deluge or water spray to knock down NH_3 vapors if it can be done safely. Do not put water directly on anhydrous NH_3.
- ER approach leak location if safe to do so with appropriate PPE. Responders should also be aware of frostbite hazards in addition to toxic and corrosive hazards.

Drawings

The drawings in the links below are provided to help the Emergency response to a NH_3 leak event in the South plant with potential community impacts.

- Release Impact Zones
  - Leak at pigging station
  - Leak at metering skid/storage tanks

- P&ID—NH_3 Pigging Station
- P&ID—NH_3 Metering Skid
- P&ID—NH_3 Storage Tanks
- P&ID—NH_3 Vaporizer

NH_3 Property and Handling Information

- NH_3 MSDS
- OSHA Guideline for NH_3
- Thermodynamic Properties of NH_3

Drill Objectives

1. Determine if Unit Personnel and Immediate Response Leader report as a Level 3 event
2. See how well the team does in the alternate EOC
3. Shelter in place downwind
4. Test mechanisms that lead to closing Highway 225 and adjacent roadways.
5. Test process of Industrial Neighbors notification
6. Observe run off and test notification of Waste Water Treatment Plant
7. Notification to Deer Park Emergency Manager.

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