Next Generation Root Cause Investigation and Analysis

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Keywords: Root Cause Investigation; Management System; Incidents; Process Safety

Abstract

As with all industrial process safety incidents, there are lessons to learn from systemic failures that have the potential to end in the tragic loss of life, insult to the environment, and/or equipment loss.

Dow has had a long and successful history of reducing process safety incidents. This started with the establishment of formal generational goals in 1995 to reduce incidents by 90% over 10 years. These goals and progress metrics were and are externally published on www.Dow.com.

In 2005 another 10 year goal was established to further reduce process safety incidents and their severity by 75% and 90% respectively.

By 2008 it was clear that our performance had plateaued and we were not continuing to make progress towards meeting our 2015 goal for reducing incidents. As process safety incidents were analyzed, the data showed a lot of repetition. While an incident may not be on the same equipment or in the same plant, it was clear that the same failure mode(s) and management system(s) were involved.

Analysis of the data also showed an opportunity to ensure every required protection layer failure and its associated management system failure were identified and fixed and to improve how the investigation results were leveraged across the company.

By 2009 we were back on track and actually surpassed our 2015 goal in 2011. Of the many factors supporting this performance, this paper will focus on 4 factors:

1. Effective root cause investigations (RCI),
2. Senior manufacturing and process safety RCI Effectiveness reviews for process safety incidents which includes a repetitive incident analysis,
3. Leveraging incident investigation learnings through actions at the appropriate level consistent with the level of management system failure, and
4. Broadly communicating incident investigation learnings in formal Learning Experience Reports (LERs) across the company.

The paper also contains examples demonstrating RCI and follow-up techniques.

Introduction

Many factors are involved in improving process safety performance, with leadership and culture being at the top. The intent of this paper is to articulate improvements in Root Cause Investigation (RCI) and follow-up process that engage leadership and change the culture to prevent repetitive incidents. This paper focuses on 4 factors:

1. Corporate RCI Standard and work process
2. RCI effectiveness reviews and repetitive incident analysis
3. Leveraging corrective actions
4. Learning Experience Reports (LERs) that reinforce the proper execution of management systems

Each of these four factors will be explored with real life examples given to support the intended focus and results.

Background

As with all industrial process safety incidents, there are lessons to learn from systemic failures that have the potential to end in the tragic loss of life, insult to the environment, or equipment loss.

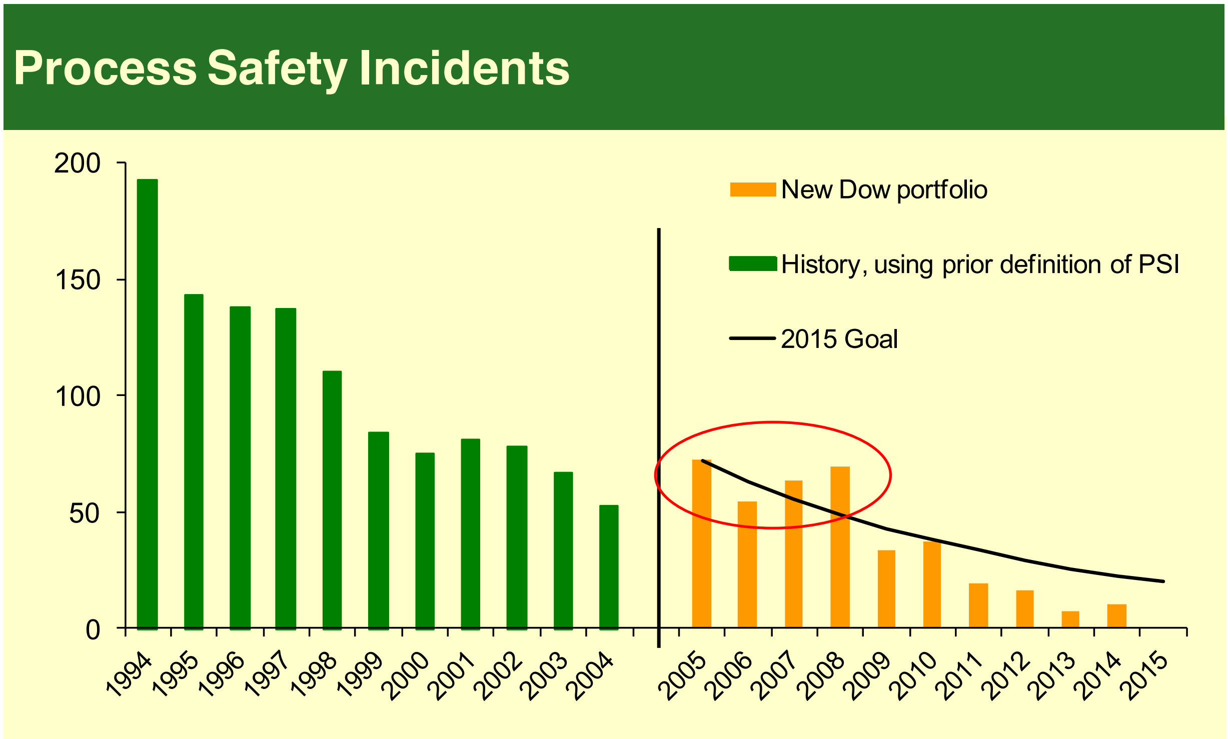
Dow has had a long and successful history of reducing Process Safety Incidents (PSIs). This started with senior executives establishing formal generational goals in 1995 to reduce incidents by 90% over 10 years. These goals and progress metrics were and are externally published on www.Dow.com. In 2005 another 10 year goal was established to further reduce PSIs and their severity by 75% and 90% respectively. The senior executives also established a corporate incident reduction team to help drive improvement across the company.

As illustrated in Figure 1, by 2008 it was clear that our performance had plateaued and we were not making progress in reducing incidents. As process safety incidents were analyzed, the data showed a lot of repetition. While an incident may not be on the same equipment or in the same plant, it was clear that the same failure mode(s) and management system(s) were involved.

Analysis of the data also showed an opportunity to ensure every required protection layer failure and its associated management system failure were identified and fixed and to improve how the investigation results were leveraged across the company.

By 2009, we were back on track and actually surpassed our 2015 goal in 2011.

Figure 1, The Dow Chemical Company Process Safety Incidents by Year



Corporate RCI Standard and Work Process

One key focus regarded the Corporate RCI Standard and associated work process. Chemical facility unit operations and equipment containing hazardous chemicals typically have multiple layers of protection to prevent specific process safety related scenarios. In Dow, some of these are defined by standards (e.g., Mechanical Integrity, Safety Instrumented Systems, Management of Change, Procedures and Reactive Chemicals) or identified by a risk assessment such as Layers of Protection Analysis or in some cases a Quantitative Risk Assessment. Once established as a required protection layer and implemented, these protection layers need to be operated within their established operating constraints and maintained. Protection layers are typically governed by a management system to ensure this happens.

When there is a process safety incident in a Plant with established protection layers in place to prevent the incident, by definition, each preventive protection layer and its associated management system failed.

Dow's investigation process now includes the following basic tenets of an effective RCI:

1. Identify the immediate cause for every required protection layer failure, including both:
   a. Dow standard required protection layers and
   b. Risk assessment validated protection layers

2. Identify the Root cause for every protection layer's management system failure
3. Involve the function responsible for the local implementation of each management system failure
4. Establish corrective actions for each protection layer and management system failure
5. Include the appropriate level of functional ownership for management system corrective actions

The rational for identifying each management system failure is that a management system may cover hundreds if not thousands of protection layers. If an incident occurs and the management system is not fixed, repetition is likely.

Involving the function responsible for the local implementation of the management system that fails, ensures:

- Identification of the correct management system failure, and
- Proper ownership of the corrective action.

The function can establish the appropriate level of correction for a management system and drive the improvement. In some cases a management system needs to be corrected at a single facility, in other cases a management systems needs to be corrected across a site, a business or for the entire company. It is important to note that even if an alternate protection layer is found for an incident on one piece of equipment, if the management system is not also corrected, there is no protection against repetition on other equipment under the same management system.

The following case study illustrates an incident involving failures of multiple management systems that, if not corrected, could potentially repeat.

What Happened – Case Study 1 – Multiple Layers of Protection and Management System Failures

There was an uncontrolled reaction inside a reactor's raw material preparation tank. At the time, this tank was being filled with compatible raw materials which should not react. The temperature of the tank's contents rapidly increased by 100° C within 10 minutes. The accompanying rapid increase in pressure blew the rupture disk.

There was a known and confirmed contamination reactive chemical scenario that could have these consequences. The RCI confirmed that this contamination scenario had taken place and that all preventive protection layers failed. The contamination was due to close proximity of other raw materials and common charging tools.

Root Cause – Ineffective management systems to prevent contamination

- **MOC/Risk Assessment Management Systems (review of changes to the tank purpose)**
  - **Improper location of alternate raw material charging system**
  - **Ineffective identification and managing pre-weigh areas and containers**
- **Procedure Implementation / Validation Management Systems**
  - **Ineffective batch operating procedure, allowing simultaneous charging of raw materials**
  - **Ineffective implementation of charging tools cleaning practices**

RCI Effectiveness and Repetitive Incident Analysis Reviews

An additional review with senior manufacturing and process safety leadership was established for all process safety incidents to:

1. Perform an RCI effectiveness review to ensure all protection layers and management system failures were identified and corrected.
2. Review a repetitive incident analysis to help determine whether the appropriate leveraging of management system opportunities is initiated.

The RCI effectiveness review has senior leaders evaluate whether the basic tenets of the Corporate RCI Standard and work process (detailed in previous section) were carried out.

The repetitive incident analysis is carried out by the RCI team and includes reviewing past incidents in a facility, site or business to determine where we have repetitive incidents. Key questions posed during a repetitive incident analysis include:

1. Was this a repetitive incident within the plant by equipment type and protection layer failure type?
2. Was this a repetitive incident within the plant by protection layer failure type or management system failure on a different equipment type?
3. Was this incident type a historical, significant event that is reviewed as part of the plant process hazard assessment or a scenario in LOPA? Or is this new to the plant?
4. The same questions are assessed for a site and business.

This process is greatly aided by a searchable database of incidents.

This repetitive incident analysis is also reviewed with senior leaders to help determine:

1. If the appropriate actions were being taken across a facility, site or business, consistent with the level of management system failure;
2. If corporate corrective actions are warranted; or
3. Whether the incident should be communicated for learning value to reinforce basic protection layer and management system implementation, operation and maintenance.

A review template is given to the RCI team prior to the RCI with expectations set for this review.

The RCI effectiveness review process is also being leveraged to Loss of Primary Containment (LOPC) incidents of lesser significance and High Potential Process Safety Near Misses (HP-PSNM) to drive improvements from these more frequent but less severe incidents.

Leveraging Learnings through Formal Action

As indicated in the previous section, one aspect of the manufacturing and process safety leadership review is to ensure that learnings are leveraged by actions at the appropriate level consistent with the level of management system failure.

Following are three examples of actual incidents where three different strategies were employed to leverage the learnings of the incidents through formally tracked action items. One was a corporate wide initiative, one was a business wide initiative, and the other was for a geographic region. A fourth example is given on a non-Dow incident where leadership determined value in taking actions from the learning of the reports on the Deep Water Horizon accident.

What Happened: Case 2 – Corporate Wide Actions

Ethylene piping failure due to Corrosion Under Insulation (CUI) – Picture 1

Note that CUI is particularly aggressive where operating temperatures cause frequent or continuous condensation and re-evaporation of atmospheric moisture.

Management System Failure

Corporate Mechanical Integrity (MI) Standard and Work Process was not specific on performing CUI inspections

Corporate Corrective Actions

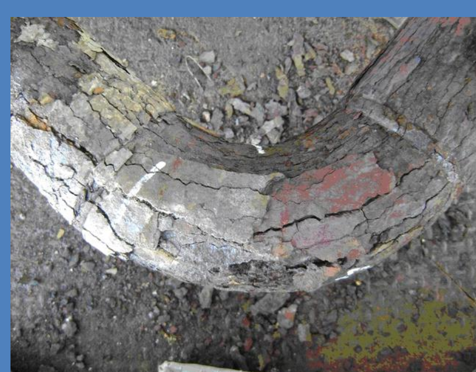
1. **Update MI Standard and Work Process to clearly articulate CUI Requirements**
2. **Train Maintenance and Production Leadership**
3. **Technology Centers define and prioritize susceptible areas for CUI**
4. **Facilities to carry out CUI Inspections within a defined time frame and report back findings**

Results

Additional finding of severe CUI, prevention of repeat incidents –Picture 2

Picture 1

Picture 2

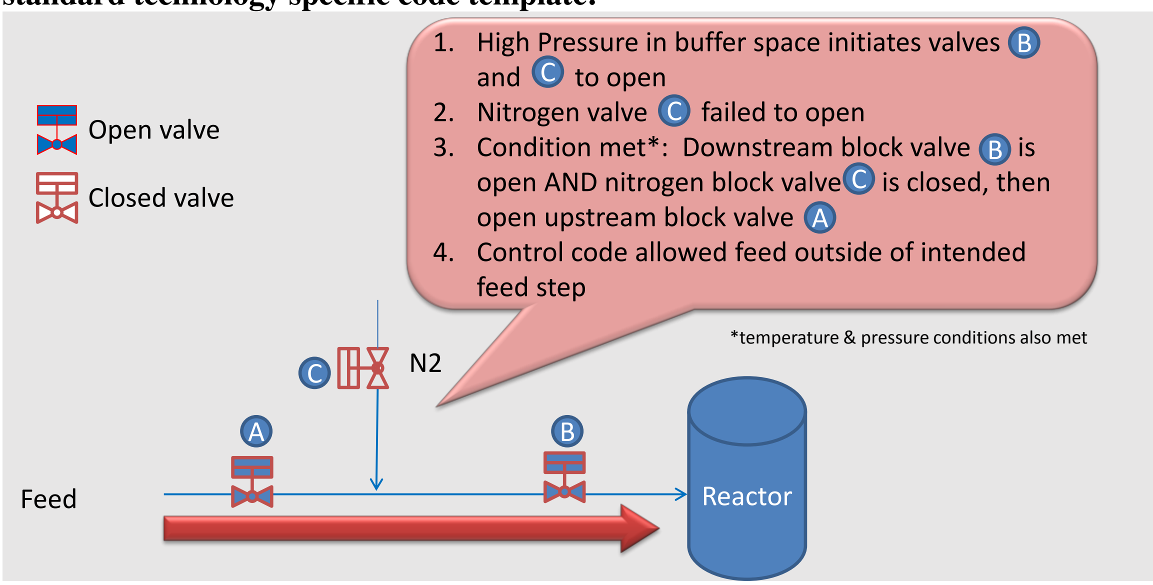


__What Happened: Case 3 – Business Actions__

The investigation of a product quality issue uncovered that additional raw material had been added inadvertently (and automatically) five hours after the termination of the feed step. Further investigation uncovered issues with the code for the reactors' double-block-and-buffers that led to the event. This case was classified as a HP PSNM due to the high learning value and the potential to have a PSI under slightly different circumstances.

This system is a batch process. The raw material fed into the reactor has a Double Block & Buffer (DB&B) used to isolate the reactor from the raw material source when the addition is completed. There is potential to trap liquid raw material between the DB&B. The process code includes steps to relieve any liquid trapped in the buffer space to prevent damage/LOPC from thermal expansion by using the nitrogen to push the raw material into the reactor.

There was also a control logic condition: with the reactor at correct temperature & below high pressure limits, if the downstream block valve is open AND nitrogen block valve is closed, then open upstream block valve, allowing raw materials into the reactor, regardless of the process step. The software was assembled using a standard technology specific code template.



__Management System Failure__

Inadequate checkout of the process control code conditions for allowing raw material feed upstream valve opening outside of raw material feed step.

__Business Corrective Actions__

1. **Review all plants utilizing standard software code**
2. **Upgrade software code validation protocols**

__Results__

Found same programming at several other plants, immediate action was taken, potentially averting a repeat incident. A LER was generated for review across the company.

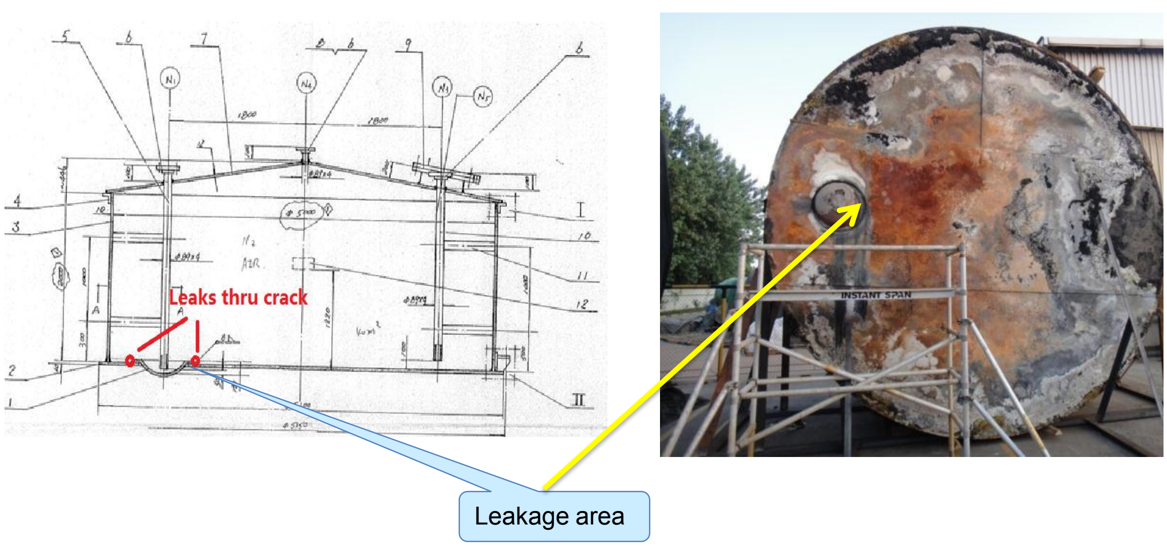
What happened: Case 4 – Regional Corrective Actions

Process Safety Incident: Loss of Primary Containment of Chlorosulfonic Acid from a crack in a storage tank floor weld. This incident was from a recently acquired facility. The causes of the incident were due to poor welding quality and an inadequate foundation design.

Management System Failures

1. **Vendor had not been pre-qualified with a check of their fabrication protocols**
2. **No welding standard was specified for use in tank bottom fabrication and construction**
3. **No validation inspections occurred after fabrication of the tank**
4. **No foundation inspection or quality check was performed prior to setting tank**
5. **Risk Based Inspection plan did not include an evaluation of the tank floor failure modes**

The leakage was from the welding area on the bottom sump



Region Corrective Actions

1. **Verify that Dow engineering and maintenance protocols implemented in the region address the management system failures.**
2. **Inventory tanks fabricated by the same company in the region and evaluate appropriate course of action**

Results

Several additional tanks fabricated by the same company were found with poor weld quality and were repaired.

<u>What happened: Case 5 - Corporate actions from an external event</u>
Dow put together a multi-functional team to review the learnings from reports on the Deep Water Horizon Incident. This review led to actions to upgrade Dow's management systems in the following three areas:

1. **High Consequence Emergency Drills**
2. **High Potential Process Safety Near Misses**
3. **Technology Specific Process Safety Requirements (Cardinal Rules)**

These Management System Opportunities are the subject of another paper at this conference.*

*** Champion, John et al. "Dow Learnings & Actions from the Deepwater Horizon Accident" 2015 AIChE Global Congress on Process Safety Conference Proceedings.**

<u>Learning Event Reports</u>

To foster effective leveraging of learnings and raise awareness of the more significant events in the company, Dow publishes one page summaries, "Learning Event Reports" (LERs), on all process safety incidents as well as HP-PSNM.

These LERs are one-page summaries that are broadly communicated across the company to reinforce the importance of:

- the proper definition, design, and implementation of protection layers
- operating within the constraints and maintaining all protection layers

The goal is to prevent repetitive failures which accounts for the majority of our incidents by providing learning in a simplified manner that reinforces the appropriate behaviors in all functions of the company.

Dow encourages all leaders to review the learnings and determine if they are applicable to any of their facilities, sites, or businesses. In addition Dow expects that leadership teams seeing similar management system opportunities to determine their own preventative actions if deemed appropriate. This is an optional initiative to drive improvements and is self-directed.

Based on independent assessments and interviews with personnel who perform the work in the field, single page short summaries posted in control rooms, on bulletin boards, and discussed in safety meetings have been proven to be an effective way to communicate learnings.

Two LERs of actual incidents are included in the appendix. While these LERs are from actual incidents, specific details around the actual chemicals, technology and location have been removed. The LERs are intended as examples for demonstrating the concept.

Conclusions

As with any effort, tracking performance and making necessary adjustments when the desired results are not being reached is critical to success. The process safety incident performance plateau observed in 2008 indicated that a change was needed in order to reach the 2015 process safety performance goals. As outlined in this paper, the change in approach involved many aspects crucial to solid process safety performance. Conducting effective RCIs, correcting all protection layer failures and their associated management systems and appropriately leveraging the corrective actions and learnings are foundational to building a strong culture. Engaging leadership by requiring manufacturing and process safety reviews for PSIs also contributed to a culture that recognized the importance of process safety.

This has not been a simple stage in the journey to having no PSI. Much time and effort was required to make this change. But it was well worth the change in process safety performance and further efforts to continue this journey will also be well worth the unknown future efforts.

Appendix

1. Example 1: One-Page LER HP-PSNM
2. Example 2: One-Page LER HP-PSNM

References

Dow Chemical Work Processes

Learning experience from unplanned events

DOW

LER HP PSNM – *Location, Plant*
Site Name: AAAA, BB
Date: XX-YY-ZZZ
Action Tool#: ZZZZ-XX
Presentation Shortcut: <Detailed Presentation of Event>

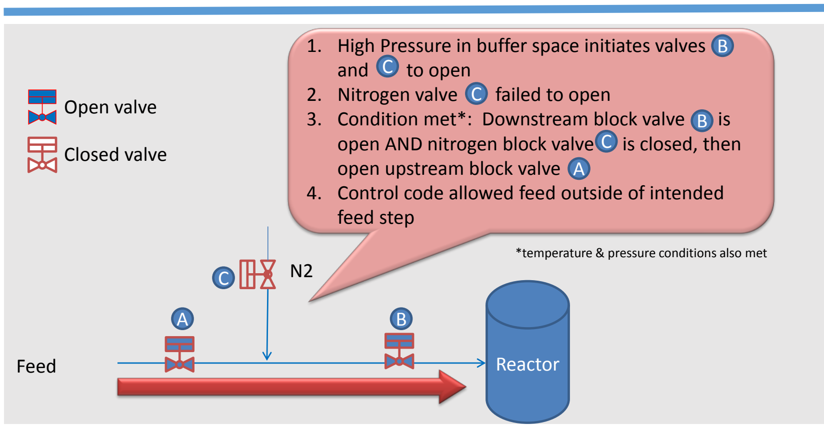
Event Description:

The high viscosity results on a product batch from the reactor led to a product quality investigation. The investigation uncovered that additional raw material had been added inadvertently (and automatically) five hours after the raw material feed step terminated. Further investigation uncovered issues with the code for the reactors' double-block-and-buffers that led to the event.

This system is a batch process. The raw material fed into the reactor has a Double Block & Buffer (DB&B) used to isolate the reactor from the raw material source when the feed is completed. There is potential to trap liquid raw material between the DB&B. The process code includes steps to relieve any liquid trapped in the buffer space to prevent damage/LOPC from thermal expansion by using the nitrogen to push the raw material into the reactor.

There was also a control logic condition: with the reactor at correct temperature & below high pressure limits, if the downstream block valve is open AND nitrogen block valve is closed, then open upstream block valve, allowing raw material into the reactor, regardless of the process step.

The **software** was assembled using a technology specific software code template to protect against raw material backflow.



Management System Failure

Inadequate checkout of the process control code conditions for allowing raw material feed upstream valve opening outside of raw material feed step.

Business Corrective Actions

1. Review all plants utilizing standard software code
2. Upgrade software code validation protocols

Found same programming at several other plants, immediate action was taken to correct, potentially averting a repeat incident.

Learning experience: What can you do? Can this happen in your facility?

- Does your facility utilize double block and buffer valving for liquid feeds?
  - How is thermal expansion in the buffer space prevented?
  - Could that prevention cause an unintended consequence?
- How well is your software code validated prior to upload?

Learning experience from unplanned events

LER HP PSNM – *Location, Plant*
Site Name: AAAA, BB
Date: XX-YY-ZZZ
Action Tool#: ZZZZ-XX
Presentation Shortcut: <Detailed Presentation of Event>

Event Description:

There was an uncontrolled reaction inside a reactor‘s raw material preparation tank. At the time this tank was being filled with compatible raw materials which should not have reacted. The temperature of the tank‘s contents rapidly increased by 100° C within 10 minutes. The accompanying rapid increase in pressure blew the rupture disk.

An emergency response plan was immediately activated and operators were evacuated to the assembling point. Cooling water was applied through the tank's internal coils, to bring the temperature down to 32° C. No further sign of reaction was observed. No personal injuries occurred. There was no environmental impact, and no impact on surrounding plants and communities.

There was a known and confirmed contamination reactive chemical scenario that could have resulted in these consequences. The RCI confirmed that this contamination scenario was the unintended reaction that had taken place and that all preventive protection layers had failed. The contamination was due to close proximity of other raw materials not intended to be placed in this tank and the use of common charging tools for different raw materials.

Root Causes:

Management System Failures – Ineffective management systems to prevent contamination

- MOC/Risk Assessment Management Systems (review of changes to the tank purpose)
  - Improper location of alternate raw material charging system
  - Ineffective identification and managing pre-weigh areas and containers
- Procedure Implementation / Validation Management Systems
  - Ineffective batch operating procedure, allowing charging of several raw materials at the same time
  - Ineffective implementation of charging tools cleaning practices

Learning experience:

- Good and effective emergency response planning and actions can minimize the adverse consequences of an event.
- Thorough MOC review must be applied to all changes in processing and equipment use.
- A distinguishing label system and/or separation is critical to prevent charging of the wrong materials.