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Case study

Chlorine transfer hose failure

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Abstract

On the morning of 14 August 2002, a 1 in. transfer hose used in a rail tank car unloading operation at DPC Enterprises, near Festus, Missouri, catastrophically ruptured and initiated a sequence of events that led to the release of 48,000 pounds of chlorine —a toxic gas—into neighboring areas. The facility repackages bulk dry liquid chlorine into 1 ton containers and 150 pound cylinders for commercial, industrial, and municipal use in the St. Louis metropolitan area. Fortunately, the wind direction on the day of the release limited the effects of the chlorine plume on the surrounding community. However, 63 people sought hospital treatment due to exposure, and hundreds of others were affected by the release (the community was advised to shelter-in-place for 4 h, and traffic was halted on Interstate 55 for 1.5 h).

The US Chemical Safety and Hazard Investigation Board (CSB) investigated this incident for the following reasons:

- Potential catastrophic off-site consequences to the public.
- Large quantity of chlorine released.
- Prolonged release duration.
- Wide use of chlorine within the US and potential for similar incidents at other facilities.

This paper presents the lesson-learned from this incident to help prevent similar occurrences.

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1. Introduction

Around 9:20 a.m. on Wednesday, 14 August 2002, a 1 in. chlorine transfer hose (CTH) used in a railroad tank car unloading operation at the DPC Enterprises, L.P., facility, in Jefferson County, Missouri, catastrophically ruptured. The facility repackages bulk dry liquid chlorine into 1 ton containers and 150 pound cylinders for commercial, industrial, and municipal use in the St. Louis metropolitan area. The hose rupture initiated a sequence of events including emergency shutdown (ESD) system valve failure, inaccessible emergency response equipment, and deficiencies in facility and community emergency response that led to the release of 48,000 pounds of chlorine. The release continued unabated for nearly 3 h.

Chlorine is a toxic chemical. Concentrations as low as 10 parts per million are classified as "immediately dangerous to life or health" [1]. The wind direction on the day of the release sent the majority of the chlorine plume away from neighboring residential areas. Nevertheless, 63 people from the surrounding community sought medical evaluation at the local hospital for respiratory distress, and three were admitted for overnight observation. Hundreds of others were affected by the release; the community was advised to shelter-in-place for 4 h, and traffic was halted on Interstate 55 for

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1.5 h. Three workers received minor skin exposure to chlorine during cleanup activities.

The US Chemical Safety and Hazard Investigation Board (CSB) determined that the ruptured hose was constructed of stainless-steel braid rather than Hastelloy C, a metal alloy [2,3]. The CSB investigation determined the following root causes:

- The company's quality assurance (QA) management system did not have adequate provisions to ensure that chlorine transfer hoses met required specifications prior to installation and use.
- The company's testing and inspection program did not include procedures to ensure that the process emergency shutdown system would operate as designed.
- The hose fabricator/distributor, failed to ensure—through a QA management system—that chlorine transfer hoses met all customer specifications.

In addition, the following factors were contributing causes:

- The hose identification system of CTH manufacturers was inadequate to visually distinguish similar-looking structural braiding materials of construction, such as Hastelloy C and stainless-steel.
- The company's mechanical integrity (MI) program failed to detect corrosion in the chlorine transfer and pad air systems before it caused operational and safety problems.
- The overall emergency response and planning system had serious deficiencies:
  - o The community notification system was inefficient, which resulted in additional exposure to neighboring residents and businesses.
  - o The company's emergency preparedness planning was deficient.
  - o The community emergency preparedness planning was inadequate for an incident of this magnitude.

This paper will discuss three key issues; mechanical integrity, emergency management, and chlorine transfer hose supply, which link the root and contributing causes from the investigation.

2. Hose supply chain

Since April 2000, Branham Corporation has been the sole supplier of chlorine transfer hose to DPC Festus. As a hose distributor, Branham purchases long rolls of raw hose and components (e.g., end-fittings and HDPE spiral guards) and fabricates the hose according to customer requirements. Crane-Resistoflex is Branham's only supplier of bulk quantity chlorine transfer hose.[1] Other manufacturers, including Crane-Resistoflex, provide Branham with bulk raw hose (e.g., rubber, stainless-steel) for use in transferring other chemicals.

On 18 March 2002, the DPC corporate headquarters ordered three 1 in. chlorine transfer hoses for tank car unloading operations at Festus. Branham completed the DPC order on 4 April and shipped the hose directly to the Festus facility. Two of the hoses were put into service on 15 June at tank car station #3, and the third hose was put into service at station #1 on 26 July.[2] The hose at station #3 that initiated the chlorine release failed after 59 days in service.[3]

CSB concludes that the 316L stainless-steel structural braid layer material of construction of the ruptured hose was inappropriate for the chlorine unloading operation at the Festus site. Once the hose was put into service at tank car station #3, atmospheric moisture—in combination with permeating chlorine molecules from the Teflon inner liner—caused the stainless-steel braid layer to corrode, lose structural integrity, and eventually fail.

2.1. Identification

Hastelloy C-276 and 316L stainless-steel structural braiding appear to be identical (see Fig. 1). CSB investigators believe that the inability to visually distinguish these two structural braid layer alloys facilitated installation of the incorrect hose at DPC Festus. In fact, throughout the hose supply chain, there was no adequate mechanism (e.g., color-coding, stenciling, or stamping) to help identify similar looking hoses.

2.2. Opportunities for error in supply chain

CSB investigators examined DPC hose practices, and also visited both Branham Corporation and Crane-Resistoflex to observe quality assurance and the manufacturing process for various types of hoses. CSB ruled out the possibility of a mixup at DPC Festus because the facility did not use any other hose assemblies with dimensions similar to the chlorine transfer hose (1 in., 11 ft).

From the site visits and review of documentation, CSB investigators identified the following opportunities for error because of the inability to visually differentiate the two braid materials:

- The paper tag labeling system used in the supply chain is not sufficient to prevent human error in positively identifying braid materials at receiving, fabricating, and shipping. If the tag of a hose within the Hastelloy bin is missing, mislabeled, or illegible, the hose could be assumed to be of Hastelloy braid construction.
- Shipping areas in the supply chain contain various orders. Hastelloy C-276 and 316L stainless-steel braided hose

[1] Several other companies in the United States manufacture Teflon-lined chlorine transfer hose with Hastelloy C braid.

[2] Visual inspection and X-ray fluorescence (XRF) testing confirmed that the two intact hoses from the 18 March order were constructed of Hastelloy C.

[3] DPC typically keeps chlorine transfer hoses in service for 24 months from date of fabrication.

Fig. 1. Identical appearance of Hastelloy C-276 and 316L stainless-steel structural braiding.

could potentially be interchanged during packaging and the wrong material shipped to the customer.

- Neither Crane-Resistoflex nor Branham conducts positive materials identification (PMI) testing of *CTH shipments*. (The North Carolina headquarters of Crane-Resistoflex performs PMI on bulk chlorine transfer hose as rolls are accepted into stock. However, no PMI is performed on chlorine transfer hose at the time of shipment to external fabricators or other customers.)

Furthermore, CSB investigators found that Branham shipping documents indicated that the ruptured hose was constructed of Hastelloy braid when it was actually constructed of stainless-steel. Investigators also determined that Branham relied on visual verification and had no QA testing mechanisms prior to shipment to ensure that it supplied the correct hose to the customer. These findings lead CSB to conclude that Branham sent the incorrect hose to DPC Festus.

Crane-Resistoflex—which has several QA processes to aid in proper hose identification—is one of the manufacturers that supplies 316L stainless-steel structural braid hose to Branham. Although CSB investigators were unable to determine exactly where in the supply chain the hose mixup occurred, they believe that it is unlikely that the error occurred at Crane-Resistoflex.

2.3. Positive materials identification

Positive materials identification is a chemical analysis that verifies the percentage of metals (e.g., iron, nickel) in various alloys, such as stainless-steel and Hastelloy. It is particularly useful in differentiating metallic parts of process components. Although PMI may not be a viable option on all types of chlorine transfer hose because of varying outer materials of construction, it is appropriate for the type of hose used at DPC Festus for chlorine transfer. A PMI program can be used to verify critical part components as a final check prior to shipping and receiving, and may prevent errors from material mixups throughout the supply chain.

CSB obtained samples of Teflon-lined hose with both Hastelloy C and stainless-steel braidings and contracted with a third party to analyze the samples via XRF nondestructive testing, a commonly used PMI test method. The analysis demonstrated that PMI testing would have differentiated Hastelloy C-276 braid from 316L stainless-steel.

DPC Festus relied on visual inspection and shipping documentation[4] to confirm that the chlorine transfer hose met its specifications. The documentation received from Branham with the order containing the incorrect hose indicated that all three hoses were Teflon-lined with structural braiding of Hastelloy C-276. PMI (or some other QA mechanism) could have been performed on CTH shipments upon receipt from Branham or prior to installation.

Thus, CSB concludes that DPC Festus had no procedure in place to verify that the chlorine transfer hose was constructed of the correct material prior to placing it into hazardous materials service.

3. Mechanical integrity

The mechanical integrity program for the Festus facility was based on dry chlorine service requirements. The

[4] Documentation includes the hose pressure test certification, work order with bill of materials, invoice, and shipping certification.

materials of construction were appropriate for dry chlorine and were expected to provide years of service if the repackaging piping system was kept free of moisture.

CSB reviewed the MI program at DPC Festus for inspection, testing, and maintenance frequencies specific to several critical components of the chlorine repackaging system. The company did routinely inspect, test, and maintain critical components of the chlorine repackaging system. However, these tasks were not performed to the level necessary to identify or prevent corrosion. CSB investigators identified the following deficiencies in the MI program:

- Inadequate supervision (management oversight) of inspection and test personnel.
- Insufficient training of employees on the catastrophic potential of corrosion-induced system failure. Such training could have emphasized the importance of keeping the system free of moisture.
- Inadequate auditing of operating procedures to ensure positive verification of ESD valve closures.
- Insufficient detail in procedures to ensure adequate inspection.

Although the company provided training on elements of the MI program—such as inspection, testing, and maintenance—it focused on "how to and when to," not on the consequences of a less-than-adequate inspection or warning signals of equipment failure. The MI program at the company did not provide sufficient training on the causes and effects of moisture-induced corrosion in the chlorine repackaging system—training that could have heightened employee awareness to deteriorating equipment conditions.

3.1. Source of corrosion

DPC Festus employees were not fully aware of the importance of keeping the system free of moisture or the consequences of failing to do so. This lack of awareness played a critical role in events leading up to the incident on 14 August. In dry chlorine service, even very small amounts of moisture entering the chlorine piping system, such as humidity, can create significant corrosion problems within carbon steel piping [4].

CSB concludes that the emergency shut down valves did not close because of the buildup of corrosion products around valve balls. Inspection of the repackaging system revealed evidence of corrosion within the pad air supply and tank car unloading assemblies, as well as in parts of the facility liquid and pad air carbon steel piping (Fig. 2).[5] These corrosion products readily migrated to the valves.

CSB identified three possible sources of the corrosion-producing moisture:

Fig. 2. Corrosion buildup in chlorine repackaging piping system.

- Pad air used to provide pressure for the transfer of liquid chlorine from the tank car.
- Ambient moisture intrusion into the piping.
- Wet chlorine in the tank car.

4. Emergency management

Emergency management is the process of preparing for, mitigating, responding to, and recovering from an emergency [5]. Facilities that handle chemicals—and the communities in which they are located—are required by Federal law to address all aspects of emergency management through the development of emergency response plans.

4.1. DPC Festus emergency response plan

In reviewing the DPC emergency response plan, CSB investigators identified the following deficiencies:

- Lack of clear guidelines and mechanisms for community notification (e.g., community sirens, alert network).
- Inadequate designation of responsibilities of facility emergency response personnel.
- Lack of clear guidelines to determine if an incident requires facility response or offsite community responders (emergency response assessment).
- Inadequate procedures for training and drills.
- Inaccessible location of emergency response equipment.
- Lack of clear guidelines for post-incident remediation (i.e., planning, handling, and disposing of hazardous materials).

These deficiencies resulted in the company's inadequate preparation for a large uncontrolled release. CSB does not question the company decision to evacuate the facility and request community emergency response assistance. The focus of the CSB review of the emergency response plan was on evaluating the company emergency management to identify

[5] The unloading assembly in use at tank car station #3 at the time of the incident and a second set of assemblies not in use were inspected; both exhibited corrosion.

areas of improvement in terms of preventing exposures and reducing the mitigation time of future releases.

4.2. Community notification

The DPC emergency response plan did not contain adequate guidelines or mechanisms to ensure prompt community notification of an incident. Although local authorities have the primary responsibility for notifying the public of an emergency, the company shares responsibility for notifying and educating neighboring residents and businesses in advance on how to respond to an emergency. The plan did not clearly designate an employee or establish a system (e.g., sirens, alert network) to notify neighboring businesses and residents.

4.3. Designation of responsibilities

The DPC emergency response plan did not clearly specify the responsibilities of response team members during a release. The Chlorine Institute [6] recommends that any emergency response plan include the following:

- Types of emergencies to which the team will respond.
- Role of each response team member during an emergency (e.g., gathering response equipment, release assessment, release control, communications, first aid).
- Chain of command.
- Community notification procedures.

An emergency response plan that clearly designated responsibilities would have ensured that the company was better prepared for managing a large uncontrolled release.

4.4. Emergency response assessment

Although the DPC Festus facility evacuation procedures contained instructions for employee action during a release, they did not provide clear guidance on when facility emergency response personnel respond to a release or when off-site community HAZMAT response is required. This lack of guidance explains the indecision among facility personnel responsible for assessing emergency response options. For example, the company emergency response plan states: "... for large releases, the company emergency response team, or an off-site HAZMAT team would be contacted for assistance. A large release is defined as an uncontrolled release."

The plan goes on to define both an "uncontrolled" and a "controlled or incidental" release, but it does not provide any guidance on conditions (e.g., weather, quantity of release, availability of response team members) under which an uncontrolled release requires offsite community response. More definitive emergency response plan guidelines would have helped the company personnel better assess response capabilities.

"One of the most important issues in an emergency response plan is deciding which response actions will be assigned to employees and which will be handled by offsite personnel" (USEPA, 2000a). The DPC emergency response plan contained no guidance to help personnel assess the situation and respond appropriately.

4.5. Training, audits, and drills

The DPC emergency response plan did not contain timetables or schedules for either initial or annual employee refresher training in accordance with HAZWOPER requirements. The plan had no built-in audit procedures. Furthermore, it made no provisions for drilling emergency response personnel on various levels of response. Interviews with facility personnel reiterated that the company did not conduct training, audits, or drills on a regular basis.

4.6. Emergency response equipment

The DPC emergency response plan did not have clear guidelines on emergency equipment testing and inspection. Also omitted were guidelines for proper storage and accessibility of response equipment. The absence of these plan elements contributed to the company being unprepared for a large uncontrolled release.

Emergency response equipment was not readily accessible during the release. The company emergency response plan states: "Designated exiting employees shall collect and take SCBA and other appropriate emergency response equipment to the staging area." This equipment was stored in the repackaging building, which was an appropriate location for responding to a minor release. However, because the equipment was not adequately maintained or organized, the employees (who also served on the facility emergency response team) were unable to gather it upon exiting the building and the facility. The building rapidly filled with chlorine gas because of its proximity to the release. One alternative could have been to store additional equipment at another location, possibly offsite.

The EPA RMP guidance document specifies that an emergency response plan should include the following written guidelines on equipment testing and inspection (USEPA, 2000b):

- How and when to properly use the equipment.
- How and when to conduct routine equipment maintenance.
- How and when to inspect and test equipment for readiness.

The company emergency response plan contained no documentation, schedules, or procedures to indicate that these regulatory requirements were fulfilled.

4.7. Post-incident remediation

Three DPC employees were exposed to chlorine as they attempted to remediate an accumulation of chlorine hydrate that had formed next to the tank car, underneath the ruptured hose. The company emergency response plan included no guidelines for planning post-incident cleanup of hazardous materials.

The employees attempted to neutralize the chlorine with calcium carbonate (limestone). However, the employees wore level C PPE, which was inadequate for the job; and they were exposed to the chlorine.

The OSHA HAZWOPER regulation requires proper planning to address the following elements prior to beginning post-incident remediation:

- Evaluation of hazards.
- Selection of proper PPE.
- Understanding of potential outcomes.
- Requirements for additional resources.

4.8. Community emergency response plan

CSB investigators identified the following deficiencies in the Jefferson County emergency response plan:

- The plan had not been updated since 1996.
- Its hazardous materials incident component was too general. It should have included, for example, specific procedures for high public consequence HAZMAT events—such as a large chlorine release—that may require community notification, community evacuation, or shelter-in-place.
- It did not include methods and schedules for testing with all participating local authorities (e.g., Jefferson County EMA; LEPC; Festus, Crystal City, and Jefferson County police and fire departments; HAZMAT unit; Jefferson Memorial Hospital; ambulance services).
- It had not been tested for such potential responses as public evacuation or shelter-in-place.

Response to the 14 August incident highlighted the need for evaluation and revision of the community emergency response plan—which may include review of actual responses and incorporation of lessons learned, simulation drills/exercises, and regular collection of new data. Drills and exercises could have revealed or clarified planning and training weaknesses, resource needs, roles and responsibilities, and coordination among all responsible local authorities (e.g., 9-1-1 dispatch, police, fire, and HAZMAT), thus improving the overall performance of all parties. Effective emergency preparedness requires periodic review and evaluation of the community emergency response plan at the community level (National Response Team [NRT], [7]).

4.9. Community emergency preparedness

The 14 August release at DPC Festus continued for nearly 3 h. Better preparedness among local emergency planning and response authorities could have reduced the overall response and mitigation time; however, it is no substitute for prevention of the release itself through preventive maintenance, testing, and inspection to ensure that the emergency shutdown system effectively shuts off all releases. NRT [8] recommends that the emergency response plan identify all local agencies that make up the community's existing response preparedness network. It states:

> . . . each (agency's) function (e.g., direction and control, communications, evacuation, release shut off) should be clearly marked with a tab so that it can be located quickly. . . each response function usually includes several response activities. Some communities prepare a matrix that lists all response agencies down the left side of the page and all response activities across the top of the page. Planners can then easily determine which response activities need interagency coordination and which, if any, activities are not adequately provided for in the plan.

As noted below, CSB investigators determined that the overall response and release mitigation time could have been improved:

- It took 15 min for the HAZMAT duty officer to page the full team to respond to the incident. HAZMAT team procedures require the duty officer, once notified, to first contact the incident commander to assess if a full team response is necessary. Alternatively, for large chemical releases (as determined by the incident commander), 9-1-1 could inform the duty officer that a full team mobilization is necessary rather than having him or her take additional time to contact the incident commander.
- The HAZMAT duty officer and several other team members had to request permission to leave their jobs to respond to the incident, which caused some delay in response. Procedures could be developed to facilitate immediate release of volunteer HAZMAT team members upon notification of an emergency.
- The HAZMAT duty officer was delayed in traffic for 15 min en route to the incident. He said during an interview that he was not authorized to place markings, lights, or sirens on his personal vehicle when responding to an emergency; without such, he was unable to use an open shoulder lane to bypass highway construction.
- The HAZMAT truck was redirected from the north command post to the south post, where State, County, and local authorities were coordinating their response. Having two command posts increased the potential for breakdowns in communication.

These specific deficiencies indicate less-than-adequate community planning, training, and drills. Better coordination among all planning and response authorities would improve emergency communication, allocation of resources, and response and mitigation time. Regular updates of the community emergency response plan—to incorporate lessons-learned from training, drills, and actual incidents—are also critical to effective emergency response.

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