U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

INVESTIGATION REPORT

CHLORINE RELEASE

(66 Sought Medical Evaluation)

DPC ENTERPRISES, L.P.

FESTUS, MISSOURI

AUGUST 14, 2002

KEY ISSUES:

- MECHANICAL INTEGRITY
- EMERGENCY MANAGEMENT
- CHLORINE TRANSFER HOSE SUPPLY

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Acronyms and Abbreviations

AMS	American Society for Metals
API	American Petroleum Institute
ATSDR	Agency for Toxic Substances and Disease Registry
CCPS	Center for Chemical Process Safety
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
CTH	Chlorine transfer hose
DOT	U.S. Department of Transportation
EEI	Engineering Evaluations Inspections, Inc.
EMA	Emergency Management Agency (Jefferson County)
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
ESD	Emergency shutdown
ºF	Degrees Fahrenheit
FEMA	Federal Emergency Management Agency
FRA	Federal Railroad Administration
HAZCOM	Hazard Communication Standard (OSHA)
HAZMAT	Hazardous materials
HAZWOPER	Hazardous Waste Operations and Emergency Response Standard (OSHA)
HDPE	High density polyethylene
IDLH	Immediately dangerous to life or health
lb/hr	Pounds per hour

Acronyms and Abbreviations (cont'd)

LEPC	Local emergency planning committee
LTA	Less than adequate
MDNR	Missouri Department of Natural Resources
mg/L	Milligrams per liter
MI	Mechanical integrity
mph	Miles per hour
MSDS	Material safety data sheet
NACD	National Association of Chemical Distributors
NAHAD	National Association of Hose and Accessories Distributor
NIOSH	National Institute for Occupational Safety and Health
NRT	National Response Team
OSHA	Occupational Safety and Health Administration
PMI	Positive materials identification
PPE	Personal protective equipment
ppm	Parts per million
psig	Pound per square inch gage
PSM	Process Safety Management Standard (OSHA)
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluorid
QA	Quality assurance
RCRA	Resource Conservation and Recovery Act
RDP	Responsible Distribution Process (NACD)

Acronyms and Abbreviations (cont'd)

RMP	Risk Management Program (EPA)
SARA	Superfund Amendments and Reauthorization Act
SCBA	Self-contained breathing apparatus
SPCC	Spill Prevention, Control, and Countermeasures (Oil Pollution Act)
XRF	X-ray fluorescence

Executive Summary

On the morning of August 14, 2002, 48,000 pounds of chlorine was released over a 3-hour period during a railroad tank car unloading operation at DPC Enterprises, L.P., near Festus, Missouri. 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.

Chlorine is a toxic chemical. Concentrations as low as 10 parts per million are classified as “immediately dangerous to life or health” (NIOSH, 2003). Although the wind direction on the day of the release carried the majority of the chlorine plume away from neighboring residential areas, some areas were evacuated. Sixty-three people from the surrounding community sought medical evaluation at the local hospital for respiratory distress, and three were admitted for overnight observation. The release affected hundreds of other nearby residents and employees, and the community was advised to shelter-in-place for 4 hours. Traffic was halted on Interstate 55 for 1.5 hours. Three DPC workers received minor skin exposure to chlorine during cleanup activities.

This incident began with the failure of a chlorine transfer hose (CTH) connecting a tank car to the facility repackaging process. The U.S. 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 (CSB, 2002). The CSB investigation determined the following root causes:

- The DPC quality assurance (QA) management system did not have adequate provisions to ensure that chlorine transfer hoses met required specifications prior to installation and use.

- Branham Corporation, the CTH fabricator/distributor, did not have a QA management system to ensure that fabricated hose complied with customer specifications or that its own certification of materials specifications were correct.

- The DPC testing and inspection program did not include procedures to ensure that the process emergency shutdown system would operate as designed.

In addition, the following factors were contributing causes:

- The hose identification system of CTH manufacturers is inadequate to provide continuous positive identification of similar-looking structural braiding materials of construction, such as Hastelloy C and stainless steel.

- The DPC mechanical integrity 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:
    - The community notification system was inefficient, which resulted in additional exposure to neighboring residents and businesses.
    - DPC emergency preparedness planning was deficient.
    - Jefferson County community emergency preparedness planning was inadequate for an incident of this magnitude.

CSB makes recommendations to DPC Enterprises, Festus; DX Distribution Group (DPC corporate); Branham Corporation; Jefferson County Emergency Management Agency; Missouri State Emergency Response Commission; Missouri Department of Natural Resources; Agency for Toxic Substances and Disease Registry; The Chlorine Institute, Inc.; National Association of Hose and Accessories Distributors; and National Association of Chemical Distributors.

1.0 Introduction

1.1 Background

Around 9:20 am on Wednesday, August 14, 2002, a 1-inch chlorine transfer hose (CTH) used in a railroad tank car unloading operation at the DPC Enterprises, L.P., facility, near Festus, Missouri, catastrophically ruptured (Figures 1 and 2). The facility is located in an unincorporated area of Jefferson County. The hose rupture initiated a sequence of events that led to the release of 48,000 pounds of chlorine. The release continued unabated for nearly 3 hours.

Figure 1. Railroad tank car unloading station #3.

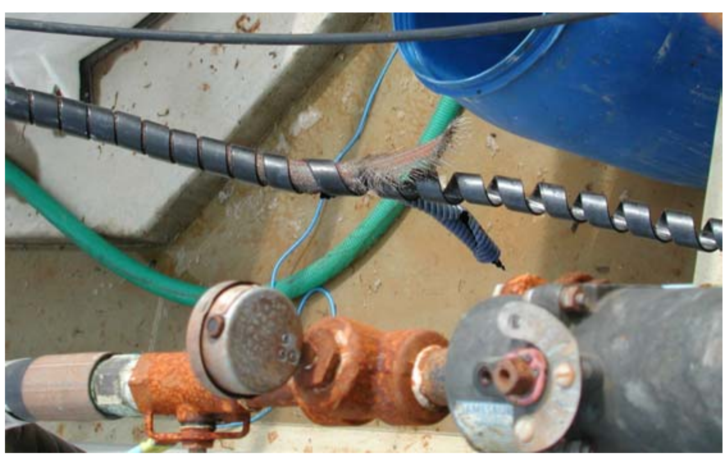

Figure 2. Failed stainless-steel transfer hose.

Chlorine is a toxic chemical. When inhaled in high concentrations, chlorine gas causes suffocation, constriction of the chest, tightness in the throat, and edema of the lungs. At around 1,000 parts per million (ppm),[1] it is likely to be fatal after a few deep breaths. According to the National Institute for Occupational Safety and Health (NIOSH, 2003), chlorine gas concentrations of 10 ppm are classified as "immediately dangerous to life or health" (IDLH). Depending on a number of factors—such as release volume, terrain, temperature, humidity, atmospheric stability, and wind direction and speed—a chlorine gas plume can travel several miles in a short time at concentrations well above IDLH.

DPC Festus is located 35 miles south of downtown St. Louis and 3 miles south of both the Festus and Crystal City town centers. Festus and Crystal City have a combined population of 14,000. CSB estimates that 1,500 people live and work within a 1-mile radius of DPC. Although about 200 people live adjacent to DPC in the Blue Fountain mobile home park, the release occurred primarily downwind of the park, with the majority of the plume traveling east-to-southeast.

The majority of residents of the mobile home park were at work on the morning of August 14. Nevertheless, 63 people from the surrounding community sought medical evaluation at the local hospital; three persons were admitted and released the following day. Three workers also received minor skin exposure to chlorine during cleanup activities after the release.

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

- The large quantity of release and prolonged duration, with potential catastrophic offsite consequences to the public.

[1] 1,000 parts of chlorine per million parts of air.

- The wide use of chlorine within the United States and the potential for similar incidents at other facilities.

1.2 Investigative Process

CSB investigators arrived at the facility on the morning of August 15. CSB conducted interviews with DPC employees and members of the community, reviewed relevant company documents and scientific literature, and examined physical evidence. CSB also arranged for testing of the ruptured hose and critical elements of the process emergency shutdown (ESD) system (EEI Inc., 2003) and for dispersion modeling of the chlorine plume (Trinity Consultants, 2003).

To obtain information on the CTH manufacturing and supply process, CSB investigators visited Branham Corporation and Crane-Resistoflex. In addition, CSB visited another chlorine repackaging facility (DXI Industries, Inc.), in Houston, Texas, to evaluate chlorine handling procedures. CSB also contacted other chlorine repackagers and reviewed recommended practices of The Chlorine Institute, Inc.

Other investigative organizations onsite included the Occupational Safety and Health Administration (OSHA), U.S. Environmental Protection Agency (EPA), and U.S. Department of Transportation–Federal Railroad Administration (DOT–FRA).

Under a Memorandum of Understanding, the Agency for Toxic Substances and Disease Registry (ATSDR) assisted CSB in investigating emergency and medical response to the incident.

1.3 Characteristics, Use, and Hazards of Chlorine

1.3.1 Characteristics

In 2002, 12.7 million tons of chlorine was manufactured in the United States. Chlorine is produced by passing an electrical current through a salt solution or melted salt, which splits the salt molecules.

Chlorine gas can be liquefied by the application of pressure at reduced temperatures to form a clear, amber-colored liquid. Liquid chlorine (a liquefied compressed gas) is more economical to ship and store.

Other than at large production facilities, liquid chlorine is typically stored and shipped in 150-pound cylinders, 1-ton containers, or 55- and 90-ton tank cars. One volume of liquid chlorine, when vaporized, yields about 460 volumes of gas. The release and vaporization of liquid chlorine from its pressurized containment often condenses the moisture in air, creating a highly visible fog. Chlorine gas is 2.5 times heavier than air and tends to float near the ground.

Chlorine is referred to as either dry or wet, depending on its moisture (water vapor in air) content. DPC Festus repackaged dry liquid chlorine (Appendix A). Below 250 degrees Fahrenheit (ºF), common metals such as carbon steel, copper, lead, nickel, and brass are resistant to dry chlorine from a corrosion standpoint. However, in the presence of water/moisture, dry chlorine is very corrosive to most common metals.

1.3.2 Products and Safe Handling

Chlorine has a variety of uses—ranging from household bleach, water disinfectants, and the manufacture of pesticides to medicines, bullet-resistant vests, plastic piping, silicon chips, automotive parts, and many other products.

Because of chlorine's characteristics and widespread use, safety has long been a focus of producers, packagers, distributors, and users. Chlorine handlers look to The Chlorine Institute to provide leadership and continuous improvements in chlorine safety. DPC is a member of The Chlorine Institute.

1.3.3 Health Hazards

At room temperature, chlorine is a greenish-yellow gas. Its very pungent and irritating bleach-like odor provides warning of high concentrations. Chlorine gas can be detected by smell at concentrations well below 1 ppm.

Chlorine exposure occurs through inhalation or through skin or eye contact. Inhalation of larger amounts irritates the mucous membranes of the eyes, nose, throat, and lungs. Prolonged exposure or exposure to high concentrations may be fatal, as outlined below (Ellenhorn and Barceloux, 1988):

- 1-3 ppm: mild mucous membrane irritation
- 5-15 ppm: moderate irritation of upper respiratory tract
- 30 ppm: immediate chest pain, vomiting, dyspnea, and cough
- 40-60 ppm: toxic pneumonitis and pulmonary edema.
- 430 ppm: lethal over 30 minutes
- 1,000 ppm: death within a few minutes.

Although inhalation is the primary mode of exposure, direct skin contact with gaseous or liquid chlorine may result in chemical burns as the chlorine reacts with moisture on the skin. In addition, the extremely cold temperatures associated with liquid chlorine and vaporized gas escaping from pressurized containment can cause frostbite.

OSHA and EPA regulate the manufacture, storage, and use of chlorine. The OSHA Process Safety Management (PSM) standard requires compliance with a variety of provisions designed to protect workers at facilities that handle chlorine in amounts greater than 1,500 pounds (29 CFR 1910.119,

Appendix A). Similarly, one of the objectives of the EPA Risk Management Program (RMP) rule is to protect the public from facilities that handle more than 2,500 pounds of chlorine (40 CFR 68.130).

1.4 DPC Enterprises Festus Facility

AG Kit Chemical Company initially developed the Festus site in 1960. Jones Chemical Company acquired it in 1972 and constructed the chlorine repackaging facility (Figure 5). In August 1998, DPC Enterprises bought the facility from Jones Chemical; it upgraded the chlorine repackaging process design to include area chlorine detectors and an ESD system (Appendix B).

DPC Enterprises owns and operates the Festus repackaging facility, five other similar facilities, and two warehouses. It is part of the DX Distribution Group network of 18 repackaging and distribution companies. Technical expertise is provided to the various sites through DX Distribution Group headquarters.

DPC Festus is located on an 8-acre site in the Plattin Creek Valley of Jefferson County, at 1785 Highway 61. The facility receives bulk dry liquid chlorine in 90-ton tank cars and repackages it into 150-pound cylinders and 1-ton containers for commercial, light industrial, and municipal use (Figure 3 and 4). DPC Festus employs 12 full-time personnel—four packaging operators (packagers), four truck drivers, two administrative staff, a sales representative, and an operations manager.

The chlorine repackaging process is a one-shift operation, typically running from 6:00 am to 4:00 pm, Monday through Friday. At the end of the day, a packager climbs the ladder to the top of the tank car and closes all car valves manually. Residual chlorine in the piping system is directed to the bleach production process. A vacuum is pulled and the system is left under negative pressure. As a final step, the ESD button is pressed to close all ESD valves (see Section 2.4). The chlorine transfer hoses remain connected to the tank car overnight. Leak testing (by spraying small amounts of ammonia solution around possible leak points) is performed prior to startup the next day.

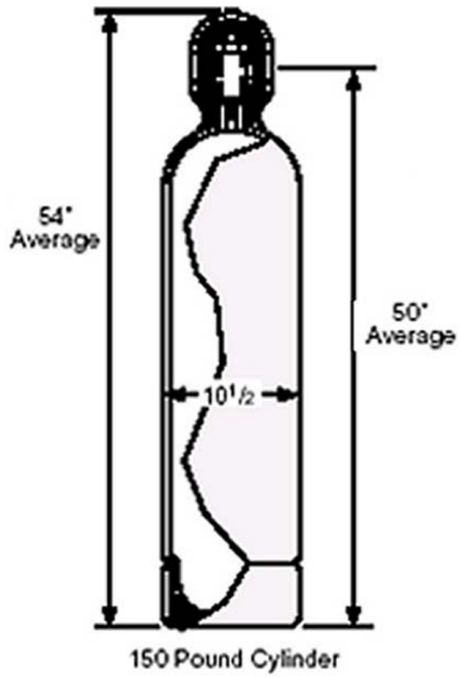

Figure 3. Schematic of 150-pound cylinder.

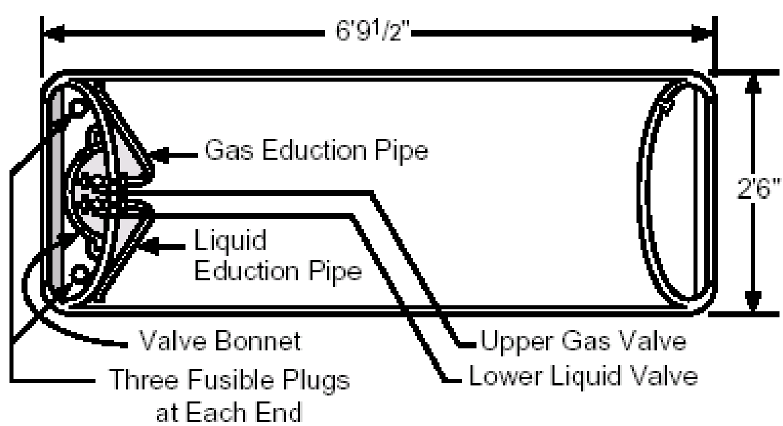

Figure 4. Schematic of 1-ton container.

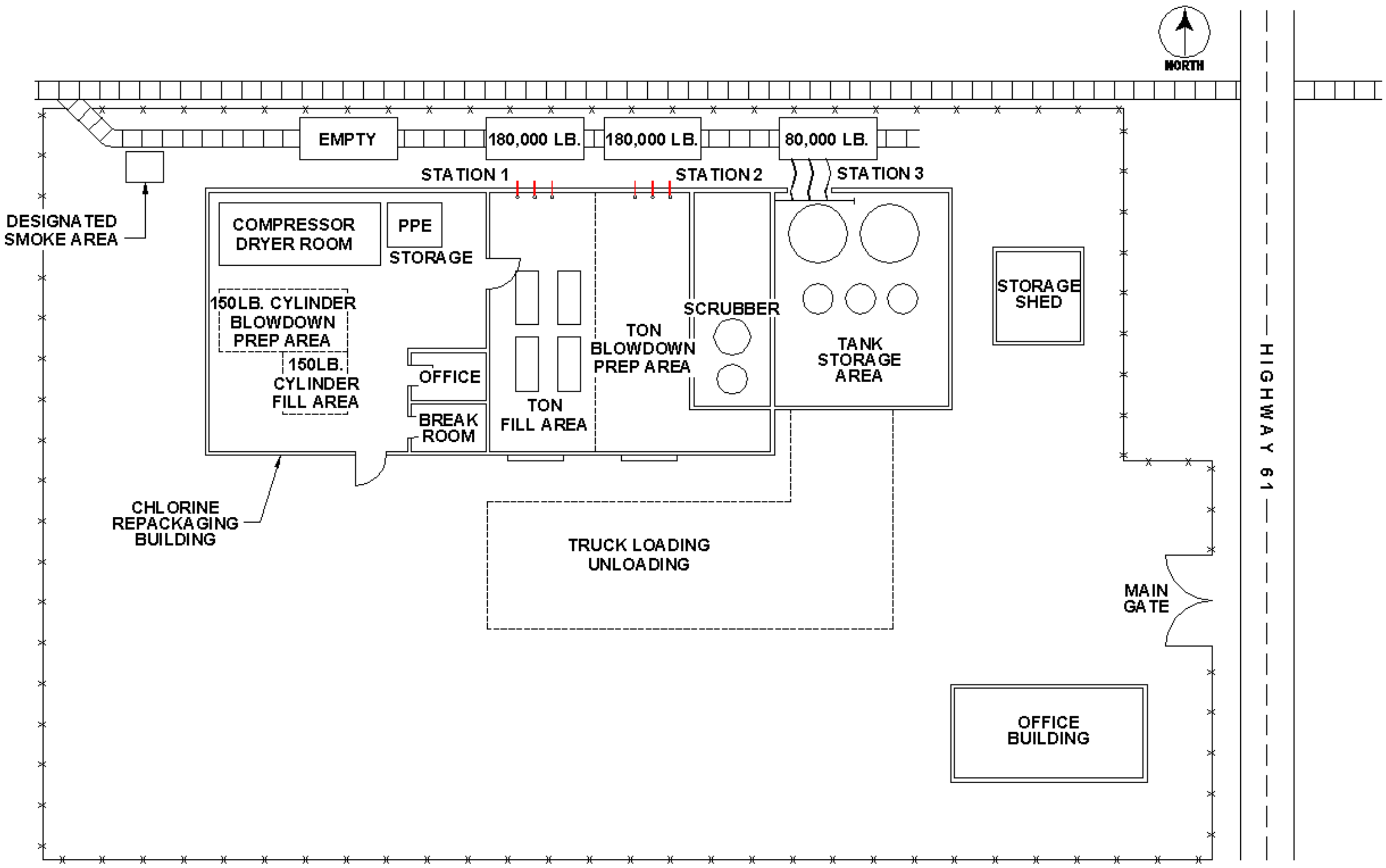

Figure 5. DPC Festus facility layout.

1.5 Surrounding Community

Various businesses and residential areas surround the DPC Festus facility (Figure 6):

- Blue Fountain residential mobile home park, consisting of about 100 homes, is directly adjacent to the southwest.

- Goodwin Brothers Construction and Intermodal Tire Retreading are located about 100 feet to the east, separated from DPC by Highway 61. Each business has about 18 full-time employees.

- A farm is located just to the north, separated from the site by railroad tracks.

- Several other residential areas and businesses—as well as the Jefferson Memorial Hospital system, including a hospital, assisted-living facility, child care center, cancer treatment center, and medical offices; St. Pius High School; and Festus–Crystal City Airport—are located within a 1-mile radius of the facility.

Plattin Creek, which flows into the Mississippi River 5 miles to the east, is located about 500 feet to the south. Interstate 55 is located less than 0.5 mile to the east.

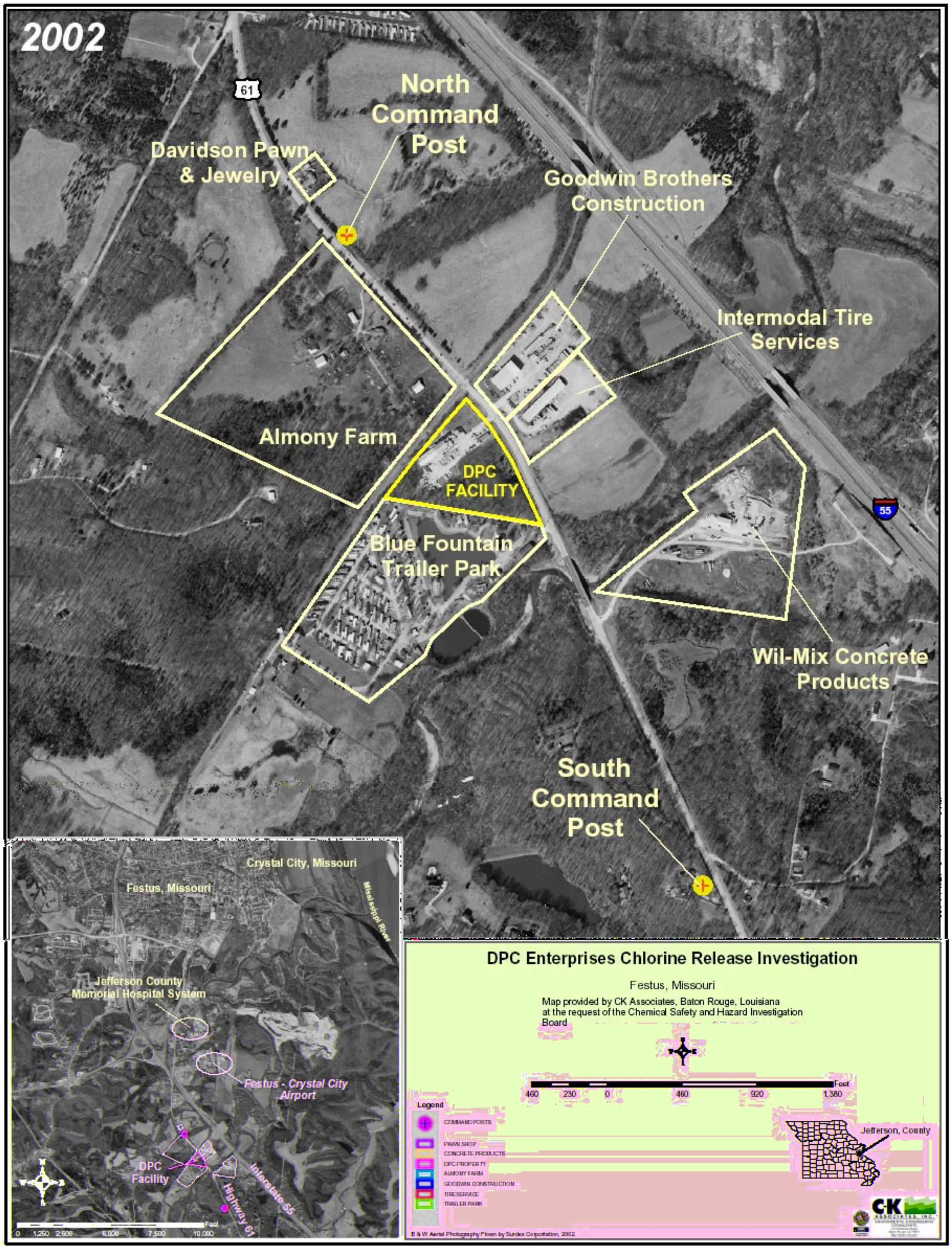

Figure 6. Aerial view of DPC Festus facility and surrounding area.

2.0 Chlorine Repackaging Process

2.1 Process Overview

The chlorine repackaging process operation involves the following:

- Connecting a 90-ton (180,000 pounds) chlorine tank car to one of three unloading stations.
- Transferring liquid chlorine from the tank car through the process piping system to filling stations.
- Loading the filled 150-pound cylinders and 1-ton containers onto trucks for distribution.
- Cleaning and preparing empty cylinders and containers for reuse.

In addition to repackaging chlorine, the Festus facility also runs a continuous bleach manufacturing process.

2.2 Chlorine Tank Cars

A chlorine tank car has four manually operated angle valves and a spring-loaded pressure relief device mounted within a protective dome (Figure 7). Valves A and C on the longitudinal centerline of the tank car are used for liquid chlorine discharge; valves B and D on the transverse centerline are connected to the vapor space (Figure 7). At DPC Festus, valve D supplied air (also referred to as "pad air") to pressurize the tank car during chlorine unloading; valve B was not in use. The valve openings on a chlorine tank car have a 1-inch inside diameter.

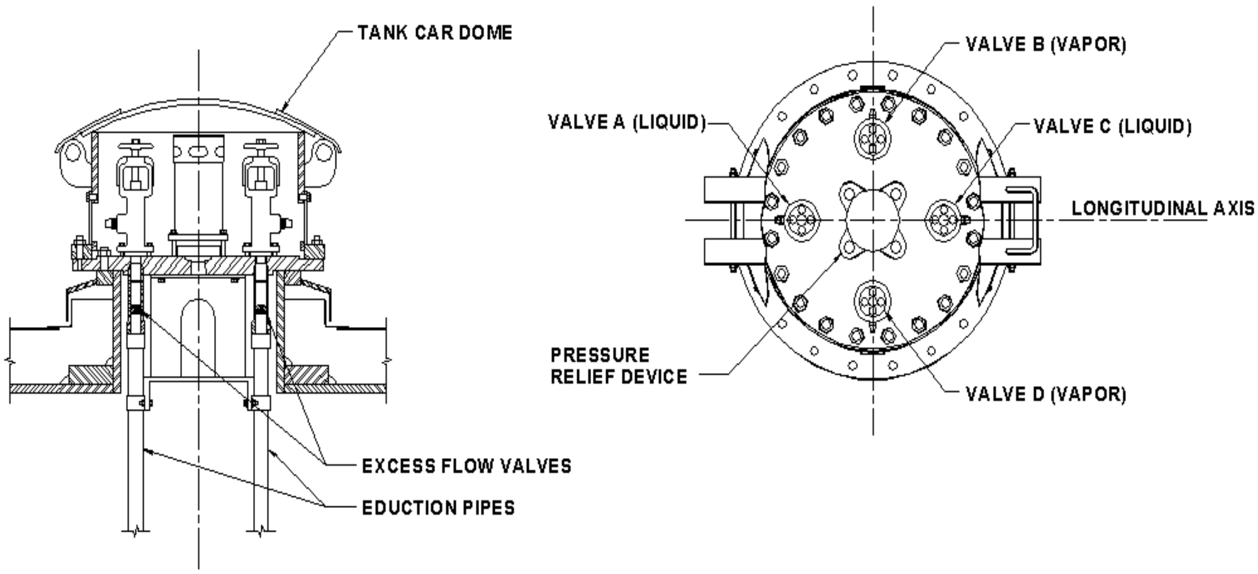

Figure 7. Schematic of tank car protective dome, angle valves, and pressure relief device.

An excess flow valve,[2] which consists of a rising ball that closes when the rate of flow exceeds 15,000 pounds per hour (lb/hr), is located beneath each liquid valve (Figure 8). Liquid chlorine is withdrawn from inside the tank car through eduction pipes[3] attached to the excess flow valves.

Appendix B describes the tank car chlorine unloading procedures and assemblies, and the pad air and instrument air systems used in the repackaging process.

[2] An excess flow valve is designed to stop the flow of material when the flow rate exceeds a preset limit. This device is used to prevent large releases during material transport. During normal operation, the excess flow valve remains open.
[3] An eduction pipe is used to unload liquid material. It is a long steel pipe attached to the liquid valve and extends to the bottom of the tank car.

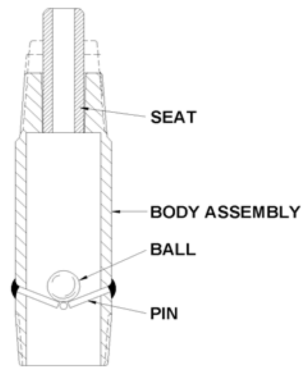

Figure 8. Schematic of excess flow valve.

2.3 Chlorine Transfer Hose

Although the DPC Festus facility has three chlorine tank car unloading stations, only one tank car is unloaded at a time. Each unloading station is equipped with three chlorine transfer hoses, each approximately 11 feet in length and 1 inch in diameter (Figure 9). DPC specifications call for each hose assembly to be constructed of a Teflon inner liner (plastic), a Hastelloy C-276 structural reinforcement braid layer (metal) for pressure containment, and a high-density polyethylene (HDPE) spiral guard for abrasion protection (Figure 10). DPC uses no other transfer hose assemblies with similar dimensions for chlorine tank car unloading or for any other operation within the repackaging process.

2.4 Emergency Shutdown System

The DPC Festus ESD system is designed to shut off accidental releases of chlorine from the repackaging system. Chlorine detectors and automatic air-actuated ball valves (ESD valves) at the unloading stations are critical components of the ESD system (Figure 11), which is activated either automatically or

Figure 9. Typical fully assembled chlorine transfer hose.

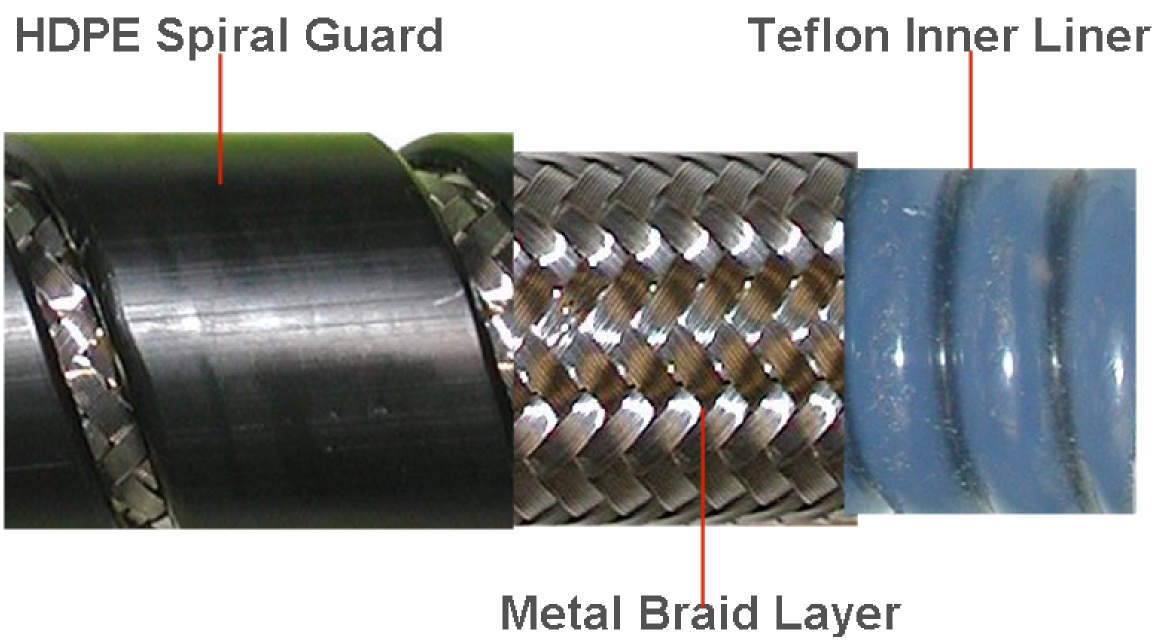

Figure 10. Typical chlorine transfer hose layers.

manually by pressing one of several ESD buttons located throughout the facility.[4] At concentrations of 5 ppm, the chlorine detectors trigger flashing lights and sound an audio alarm. At concentrations of 10 ppm, the ESD valves are automatically activated along with a second higher decibel audio alarm.

Figure 11. ESD valve and actuator.

Tank car station #3 is equipped with a chlorine detector. Each tank car station is also equipped with five ESD valves—three on the tank car side as part of the air supply and chlorine unloading assemblies, and two on the plant side piping (Figure 12). Air-operated actuators mounted on top of the valves open and close the valves. Indicators on the actuators show the positioning of the valves (Figure 13). When high-levels of chlorine are detected or the ESD system is manually activated, the solenoids[5] controlling the actuators are deenergized—which causes the ESD valves to close, shutting down the chlorine flow.

[4]The air actuators used at DPC contain a piston in a housing. A spring holds the piston in one position, while air pressure on the other side of the chamber pushes the piston against the spring, which in turn moves the valve stem through a series of gears. If air pressure is suddenly lost, the spring pushes against the piston to push the valve to the close position. All the valves are controlled off the same central system.
[5]At the instant the external force (electricity) is removed, the magnetic field vanishes and shuts off air to the actuators.

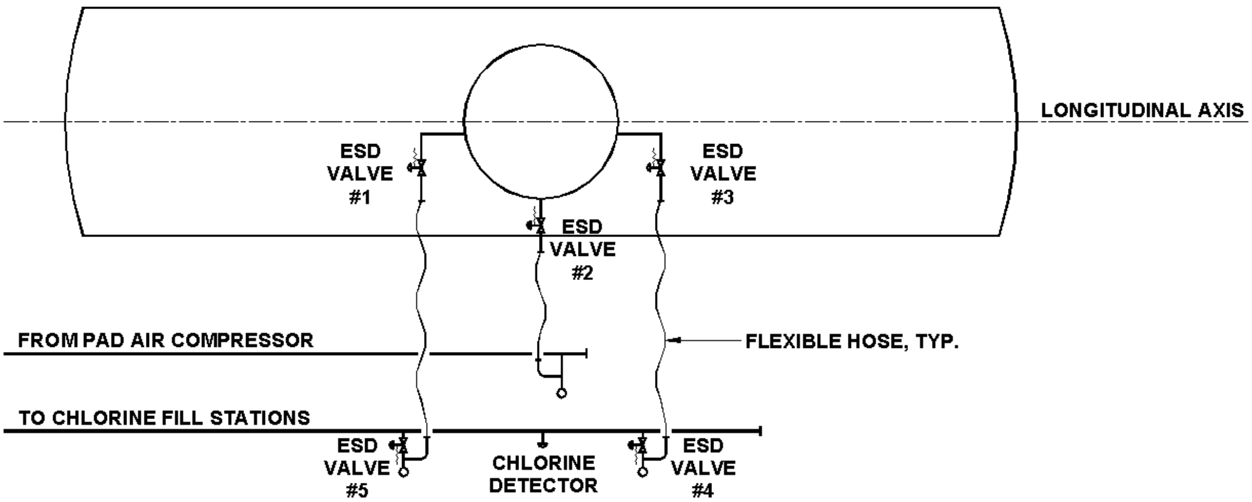

Figure 12. Schematic of ESD valve arrangement at unloading station.

Figure 13. Actuator indicator showing position of valves.

The ESD system is manually activated at the end of each day as part of normal shutdown procedures. However, DPC standard operating procedures do not require packagers to verify that the indicators show actual closure of the ESD valves.

3.0 Description of Incident

3.1 Pre-Incident Events

3.1.1 Operations at Tank Car Station #3

On August 12, 2002, a tank car containing 180,000 pounds[6] of chlorine was connected to station #3, which served all chlorine filling operations until the time of the release on August 14. The facility repackaging production records indicate that the car contained 80,000 pounds of chlorine at the time of the incident. It was later determined that 48,000 pounds of chlorine had been released.[7]

3.1.2 Repackaging System Standby and Shutdown Modes

The chlorine repackaging system is on standby during morning and afternoon breaks, lunch, and cylinder changeouts. When all cylinder filling operations are complete for the day, the system is shut down (Table 1). In both standby and shutdown modes, the chlorine transfer hoses remain connected to the tank car. Appendix B describes DPC procedures for standby and shutdown modes.

3.2 The Incident

3.2.1 The Release

At about 6:30 am on August 14, four DPC packagers, a truck driver, and the operations manager[8] started up chlorine filling and container preparation operations for the day. Around 9:00 am, these employees placed the repackaging system on standby mode and took their morning break. Two of the packagers and the truck driver went to the designated smoking area outside the repackaging building; the others

[6] The DOT load limit for the chlorine tank car is 180,000 pounds (90 tons).
[7] Weight of tank car prior to release minus weight of car after the release (80,000 –32,000 = 48,000).
[8] The operations manager had various responsibilities, including assisting packagers with cylinder filling operations.

remained in the breakroom. At approximately 9:20 am, the three men outside heard a loud pop and observed a continuous release of chlorine at tank car station #3 (Figure 14). They immediately evacuated the area.

Table 1

Repackaging System Components in Standby and Shutdown Modes

Repackaging System Components	Standby Mode	Shutdown Mode
150-lb and 1-ton fill station valves	Closed	Closed
ESD valves	Open	Closed
Tank car manual valves	Open	Closed
System piping	Contains chlorine	No chlorine

KTVI-TV, St. Louis, Missouri

Figure 14. Chlorine release at tank car station #3.

The leak activated an area chlorine detection monitor audio alarm. Upon hearing the alarm, the employees in the breakroom tried to identify the source of the leak. They found chlorine entering the repackaging building through an open access door near tank car station #3. Because of the apparent magnitude and intensity of the release, the employees evacuated the building. The operations manager pushed the ESD button (Figure 15) as he exited in an attempt to manually shut off the chlorine release.

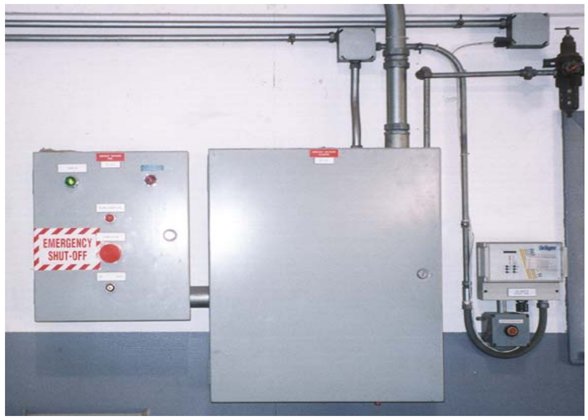

Figure 15. ESD panel with emergency shutdown button.

3.2.2 ESD Valve Failure

The chlorine repackaging system ESD valves are intended to close either automatically based on chlorine detection levels or through hand-operated ESD buttons. Although both methods were activated during the incident, several critical ESD valves failed to close, which allowed the release to continue unabated. The ESD system was not designed to provide a signal of actual valve closure.

3.2.3 Tank Car Excess Flow Valve

According to *The Chlorine Manual*, an excess flow valve:

> . . . Is designed to close automatically against the flow of liquid chlorine if the angle valve is broken off in transit. It may close if a catastrophic leak involving a broken connection occurs but it is not designed to act as an emergency shut-off device during transfer (Chlorine Institute, 1997; p. 14).

The tank car excess flow valves were designed to close only if the flow rate exceeds their set point (15,000 lb/hr). These valves remained open during the release.

3.2.4 Access to Emergency Response Equipment

DPC had four self-contained breathing apparatus (SCBA) units in addition to other emergency response equipment. The packagers (who also served on the facility emergency response team) were trained on use of the SCBA and on how to respond to a chlorine release. However, because the equipment was not adequately maintained or organized inside the repackaging building, the men were unable to gather it as they exited the building.

3.2.5 Facility Evacuation

The nine DPC personnel working on August 14, including two administrative staff and one salesperson, evacuated the facility through the front entrance around 9:30 am. All but two of the employees drove north on Highway 61 to an assembly point 1 mile away, as predetermined in the emergency plan. The operations manager established radio contact with the two employees who drove south on Highway 61.

3.2.6 Community Notification

DPC Festus had no community sirens or other community-wide alert systems to notify neighboring residents and businesses of a release.

Wind speed was generally 3 to 5 miles per hour (mph) on the morning of August 14. The chlorine plume (Figure 16) moved primarily east-to-southeast in the direction of Goodwin Brothers Construction and Intermodal Tire, though it is likely that it migrated into the adjacent Blue Fountain mobile home park when there was no wind. As indicated by dispersion modeling,[9] chlorine concentrations of 3 ppm could have extended to approximately 3.7 miles from the point of release (Trinity Consultants, 2003).

KTVI–TV, St. Louis, Missouri

Figure 16. Movement of chlorine plume offsite.

The owner of Goodwin Brothers and an employee at Intermodal Tire saw the approaching chlorine plume. These two businesses share a parking lot that accesses Highway 61. By the time all employees were notified, the plume had migrated across the highway and was moving over the parking lot, close to the ground. Several employees drove through the plume and had to seek medical evaluation. Neither of the businesses had an alternative escape route.

Hundreds of residents—including occupants of an assisted living facility and a learning center, both part of the Jefferson Memorial Hospital system; and students at a local school—were sheltered-in-place for up to 4 hours. Interstate 55 traffic was shut down for 1.5 hours, from 9:45 to 11:15 am. A total of 63 people in the surrounding community sought medical evaluation because of inhalation exposure to chlorine.

[9] Dispersion modeling represents the ***possible*** behavior of the plume; results may vary depending on the model.

Eight persons were administered oxygen. Three persons were kept overnight at Jefferson Memorial Hospital for observation of possible chlorine-induced pneumonia and were released the next day.

In addition, the chlorine caused tree leaves and other vegetation around the facility and in the plume path to turn brown. The release did not appear to affect water quality in Plattin Creek (MDNR, 2002). The chlorine plume continued generally eastward along Plattin Creek Valley before dissipating.

3.2.7 Emergency Response

At 9:27 am—approximately 7 minutes after the release began—the DPC operations manager called 9-1-1 to report the chlorine release. The Jefferson County R-7 volunteer fire department arrived on scene within 10 minutes. The R-7 fire chief immediately requested 9-1-1 dispatch to notify mutual aid response fire departments and the Jefferson County hazardous materials (HAZMAT) unit. A reconnaissance team of R-7 fire-fighters was sent to Goodwin Brothers, Intermodal Tire, and DPC to search for victims; all employees had evacuated the area. The R-7 fire department also initiated evacuation of residents from the Blue Fountain mobile home park.

Highway 61 was shut down in both directions. Two separate command posts were set up on the highway (one by municipal authorities and the other by county responders). Emergency response personnel from the north post notified the Jefferson Memorial assisted living facility and the learning center and St. Pius High School to shelter-in-place. The Jefferson County R-7 fire department, Jefferson County sheriff's department, Missouri State Highway Patrol, Joaquin Plattin Ambulance Service, and several mutual aid fire departments staged at the south post.

A drive-through "bull horn" notification, followed by door-to-door evacuation, was conducted at Blue Fountain mobile home park and the Howe Crossing residential area. It took emergency response personnel over 1 hour to evacuate the areas. The sheriff's department and the highway patrol shut down Interstate 55. The ambulance service transported six people from neighboring areas with symptoms of chlorine exposure to Jefferson Memorial. The majority of people seeking medical evaluation drove to the hospital, which is located 1 mile north of the DPC facility. The release continued unabated for nearly 3 hours until HAZMAT personnel closed the tank car valves.

The Jefferson County HAZMAT unit is made up of all volunteers, who live and work in various parts of the 660-square-mile county. The team duty officer received notification of the DPC release from 9-1-1 dispatch at 9:45 am, and the team was paged within 15 minutes. Although the south post was designated as the HAZMAT staging area, the response truck and several team members initially went to the north post. Decontamination setup began at 11:00 am. Most of the team had arrived on scene by 11:15 am.

It took 45 minutes to complete medical monitoring; entry team selection; and site safety planning, including entry and exit; and to don personal protective equipment (PPE). HAZMAT responders measured chlorine concentrations of greater than 1,000 ppm at the release site, which is life threatening without proper respiratory equipment.

Three HAZMAT personnel and one DPC employee (who had specialized HAZMAT training) entered the release area around noon, where a yellowish-green fog about 4 feet high covered the area surrounding the tank car. Visibility was very poor. Two HAZMAT personnel climbed the tank car ladder to access the top of the car (Figure 17). They closed the liquid valve that supplied the ruptured hose (valve A), but the release did not stop. They then closed the other liquid valve (valve C) and vapor valve D halfway; then they completely closed both valves. The release stopped when valve C was closed.

The HAZMAT team surveyed the area surrounding the tank car and the repackaging building for other release sources. None were located. They identified a 4- by 4-foot formation of chlorine hydrate[10] next to the tank car (underneath the ruptured hose), but it was determined to pose no imminent danger.

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[10] Chlorine ice or chlorine hydrate (Cl_2–$8H_2O$) may crystallize below 49º F at atmospheric pressure and at higher temperatures at increased pressure.

KTVI–TV, St. Louis, Missouri

Figure 17. HAZMAT personnel accessing the top of tank car to close valves.

A majority of the emergency responders left the scene after the release was stopped. However, Highway 61 remained closed, and the evacuation order stayed in effect due to high levels of chlorine. Over the next several hours, the State of Missouri Department of Natural Resources conducted monitoring throughout the facility as well as the neighboring community (MDNR, 2002). Around 5:00 pm, the Jefferson County R-7 fire department lifted the evacuation order and reopened Highway 61.

3.2.8 Cleanup Activities

DPC began cleanup activities immediately after the R-7 fire department released the scene. Figure 18 shows the area of cleanup. Alarms were turned off, the chlorine piping system was evacuated and depressurized, and all fill stations were isolated.

Figure 18. Cleanup area around tank car station #3.

In consultation with DPC corporate personnel, the operations manager decided to remediate the chlorine hydrate formation. No remediation plan was developed to formally review potential hazards. Three of the DPC packagers, wearing chlorine-resistant suits and carrying escape respirators, placed lime (calcium carbonate) on top of and around the ice formation. However, the material was not fully neutralized when the packagers attempted to place it into drums. The trapped liquefied chlorine was exposed to warm air and released as a gas.

The protective suits worn by the packagers provided only minimal protection because they were not fully encapsulating. The three men received minor skin exposure, and experienced numbness, itching, and irritation of affected skin. Direct contact with liquefied chlorine gas is known to cause such effects because of mild-to-severe frostbite. All three men received medical evaluation.

The hydrate formation continued to give off minor amounts of chlorine gas for the next 2 days until an environmental remediation company completed the cleanup.

4.0 Reconstructive Analysis

The catastrophic rupture of a 1-inch transfer hose attached at tank car station #3 initiated the chlorine release (Figure 19). Reconstructive analysis determined why the chlorine transfer hose ruptured and why the ESD valves failed to close. The excess flow valves were dismantled and inspected to determine if they should have closed.

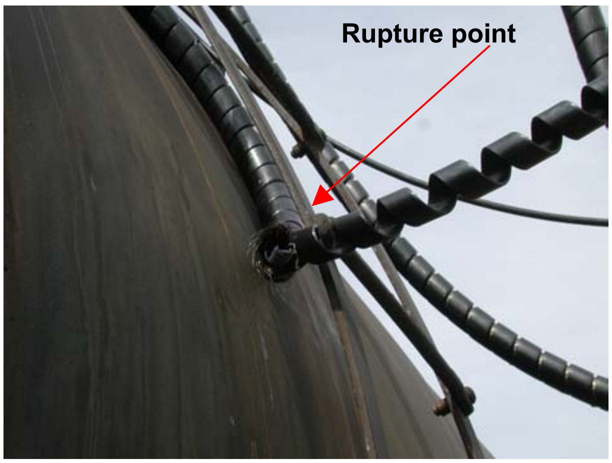

Figure 19. Ruptured chlorine transfer hose at tank car station #3.

4.1 Hose Construction

The CTH assembly used at DPC Festus was specified to be constructed of a Teflon inner liner, a Hastelloy C-276 structural reinforcement braid layer for pressure containment, and an HDPE spiral guard for external protection,[11] as discussed in Section 2.3. Although hoses with nonmetallic[12] cores, such as Teflon, are more tolerant of moisture, they are subject to permeation by chlorine molecules. To ensure

[11] The design specifications of the CTH assembly met recommended practice guidelines of The Chlorine Institute.
[12] Most plastics react chemically with chlorine because of their hydrocarbon structural makeup. This reactivity is avoided with some plastics in which fluorine atoms are substituted into the hydrocarbon molecule (e.g., Teflon).

structural integrity, The Chlorine Institute (1998) recommends that hoses with such inner lining “have a structural layer braid of polyvinylidene fluoride (PVDF) monofilament material or a structural braid of Hastelloy C-276” [13] (Figure 20).

Figure 20. Structural braid layer pulled back to expose Teflon inner liner.

4.2 Hose Rupture

The rupture occurred in the chlorine transfer hose attached to tank car valve A, about 3.5 feet from its connection to the tank car (Figure 21). CSB investigators found a 2.5-inch-long segment of the hose inner liner and several pieces of the structural braiding scattered throughout the immediate area. The external spiral guard kept the ruptured hose attached to both the tank car and the plant piping.

The ruptured hose and the other two intact hoses at tank car station # 3 were removed from service and sent to a St. Louis laboratory for inspection and testing.

[13] PVDF and Hastelloy C-276 can resist corrosion from exposure to both dry chlorine in the presence of moisture and wet chlorine.

Figure 21. Ruptured hose and piece of Teflon inner liner.

4.3 Metallurgical Examination

The HDPE spiral guards around each of the three hoses were cut off, and each hose was visually inspected. The structural braid layer of the intact hoses showed no signs of deterioration or discoloration; however, the structural braiding of the ruptured hose was significantly corroded, as evidenced by brown discoloration and granular flakes. The inner liner of the ruptured hose showed no sign of deterioration.

Materials testing of the structural braiding of both the ruptured hose and one of the intact hoses revealed that the ruptured hose braid layer was constructed of 316L stainless steel and the braid layer of the intact hose was constructed of Hastelloy C-276. As discussed in Section 4.1, nonmetallic inner liners (e.g., Teflon) must be reinforced with chlorine-resistant outer layers.

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 316L stainless-steel braid layer to corrode. Thus, CSB concludes that the hose ruptured because its stainless-steel structural braiding was inappropriate for chlorine transfer.

During chlorine unloading operations, the transfer hose is subjected to maximum operating pressures of about 175 pounds per square inch gage (psig). The hose also encounters bending forces during each connection/disconnection to the tank car. CSB concludes that corrosion of the 316L braid layer weakened the structural integrity of the hose. Normal operating pressure, in combination with repetitive bending forces, caused the hose to rupture and release chlorine. (See fault tree analysis of hose rupture in Appendix E.)

4.4 ESD Valve Positioning

Section 2.4 describes the DPC Festus ESD system. CSB investigators checked the indicators on all five ESD valves at tank car station #3 after the incident.[14] Although both the automatic and manual ESD mechanisms were employed, four of the five valves failed to completely close and isolate the release (see Figure 22):

- ESD valve #2, connected to the pad air supply, was fully open.
- ESD valve #3, connected to the intact liquid line chlorine transfer hose, was 60 percent open.
- Both ESD valves (#4 and 5) on the plant side piping were fully open.

The one valve that did close was ESD valve #1, connected to the ruptured chlorine transfer hose.

Determining the actual positioning of the five ESD valves at tank car station #3 led CSB investigators to conclude that the chlorine flowed through the partially opened ESD valve #3, to the attached intact liquid CTH line, into the plant side piping, and back through the ruptured hose (see Figure 22). Closing tank car

[14] Valves #1 and #3 were later dismantled to verify the actuator indicator readings and to determine valve positioning.

valve A did not stop the release because valve C continued to supply chlorine through the intact liquid CTH line.

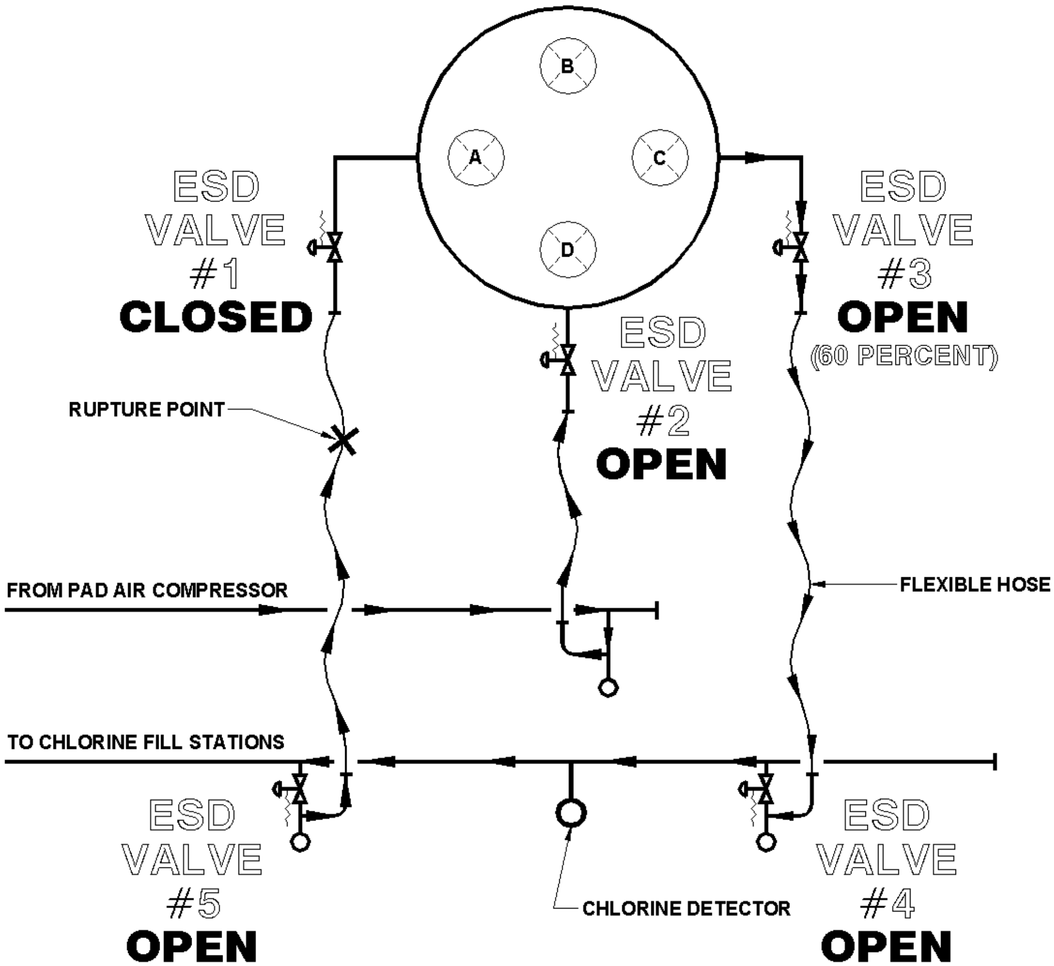

Figure 22. Positioning of ESD valves at time of release.

The failure of ESD valve #2 to close and isolate the pad airflow supplied pressure to push chlorine out of the tank car during the release. DPC Festus had no other automatic mechanism to shut down the pad air system in an emergency. Such a mechanism may have slightly reduced the flow of chlorine from the tank car; however, in any case, the vapor pressure of chlorine and the air pressure already in the tank car would have continued to provide sufficient force to push the chlorine out of the car.

4.5 ESD System Testing

The ESD system was tested to determine why ESD valves #2, 3, 4, and 5 failed to close. The chlorine detector at tank car station #3 and the system's electrical circuitry were also examined, as well as the hand-operated ESD buttons. All solenoids controlling the ESD valve actuators were found to be deenergized prior to testing. Testing results are as follows:

- The solenoids energized and deenergized properly.
- Each ESD button functioned properly.
- The instrument air hoses providing plant air to the actuators were found to be free of mechanical damage.

CSB investigators thus eliminated the control system as a cause of the ESD valve failures.

Testing of ESD valves # 3 and 4 revealed that the torque necessary to close the valves—in excess of 40 foot-pounds—far exceeded the 5 foot-pounds available from the actuators. Visual inspection of both valves revealed corrosion product buildup around the valve balls (Figure 23); these deposits were found to be ferric chloride. CSB investigators recognized that some corrosion within the repackaging system, including the unloading piping assemblies, occurred after the release. Therefore, a second set of piping assemblies—not in use at the time of the incident—was inspected and tested; these assemblies were also found to have corrosion, and they did not close properly when activated. It was concluded that corrosion products impeded motion of the ESD valves.

The valve balls were constructed of Monel, which is resistant to moisture-induced corrosion in chlorine service. The corrosion products were determined to have migrated to the valves from the pad air supply and tank car assemblies, as well as from parts of the plant liquid and pad air carbon steel piping.

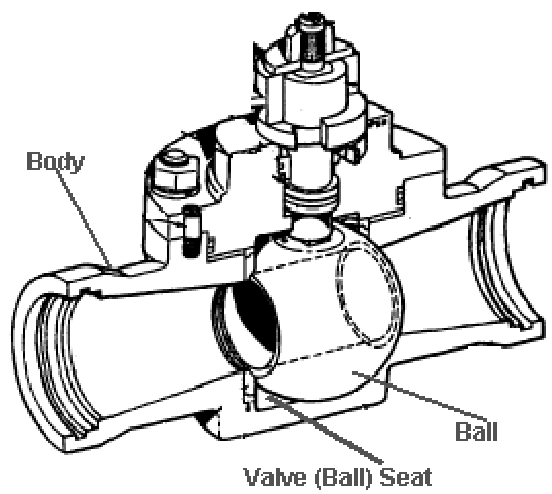

Figure 23. Schematic of ESD valve.

4.6 Excess Flow Valve

The tank car excess flow valves were dismantled and examined for mechanical defects and corrosion; nothing was found that would have prevented the valves from closing.

The rate of chlorine flow through the ruptured transfer hose was estimated to be 16,000 lb/hr,[15] above the set point of 15,000 lb/hr. At this rate, the excess flow valves should have closed and stopped the release. (However, the intended use of excess flow valves on chlorine tank cars is to prevent releases during transport; they should not be relied upon to stop releases during unloading operations.)

[15] Assuming 48,000 pounds of chlorine over 3 hours.

Facility production records may have overestimated the amount of chlorine in the tank car. For example, if the tank car contained only 76,500 pounds of chlorine (instead of the 80,000 pounds), the estimated flow rate (44,500 lb/3 hr ≈ 14,800 lb/hr) would have been below the excess flow valve set point of 15,000 lb/hr. The flow may have been reduced because:

- ESD valve # 3 was only 60 percent open, which may have changed flow characteristics or created a drop in pressure.
- The attachment of transfer assemblies and hoses can cause a decline in pressure, which would alter product release rates and flow characteristics.

5.0 Analysis of Incident

5.1 Hose Failure

5.1.1 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.[16] Other manufacturers, including Crane-Resistoflex, provide Branham with bulk raw hose (e.g., rubber, stainless steel) for use in transferring other materials.

On March 18, 2002, DPC corporate headquarters ordered three 1-inch chlorine transfer hoses for tank car unloading operations at Festus. Appendix B further discusses the DPC hose order arrangement. Branham completed the DPC order on April 4 and shipped the hose directly to the Festus facility. Two of the hoses were put into service on June 15 at tank car station #3, and the third hose was put into service at station #1 on July 26.[17] The hose at station #3 that initiated the chlorine release failed after 59 days in service.[18]

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 DPC Festus (see Section 4.3). Once the hose was put into service at tank car station #3, atmospheric moisture—in combination with permeating

[16] Several other companies in the United States manufacture Teflon-lined chlorine transfer hose with Hastelloy C braid.
[17] Visual inspection and X-ray fluorescence (XRF) testing confirmed that the two intact hoses from the March 18 order were constructed of Hastelloy C (see Section 5.1.4).
[18] DPC typically keeps chlorine transfer hoses in service for 24 months from date of fabrication.

chlorine molecules from the Teflon inner liner—caused the stainless-steel braid layer to corrode, lose structural integrity, and eventually fail.

5.1.2 Hose Identification

Hastelloy C-276 and 316L stainless-steel structural braiding appear to be identical (see Figure 24). 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.

Figure 24. Identical appearance of HastelloyC-276 and 316L stainless-steel structural braiding.

5.1.3 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 (QA) 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 inch, 11 feet).

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 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.

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.

5.1.4 Positive Materials Identification

PMI 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 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 relied on visual inspection and shipping documentation[19] 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 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.

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

5.2 Mechanical Integrity

A mechanical integrity (MI) program should ensure that critical process equipment and components are designed, fabricated, installed, inspected, tested, and maintained in a manner that preserves the originally intended integrity of the equipment. Furthermore, management should provide adequate oversight to ensure that only trained and qualified personnel carry out these activities. DPC is required to have an MI program because it stores and handles chlorine above the OSHA PSM and EPA RMP threshold quantities (as discussed in Section 1.3).

The MI program for the Festus facility was based on dry chlorine service requirements. The 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 for inspection, testing, and maintenance frequencies specific to several critical components of the chlorine repackaging system. Appendix C presents these frequency data.

DPC Festus 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 packagers 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.

The MI program at DPC 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. As described below, CSB investigators reviewed whether routine schedules for inspection and testing of critical components, such as the system piping and dryers, were sufficient to identify corrosion-related problems.

5.2.1 Management Oversight

Routine inspection, testing, and maintenance checks at DPC Festus were inadequate and poorly supervised. For example, one of the requirements in the chlorine system startup checklist (used daily) is to visually inspect the external surface of the chlorine transfer hose. DPC packagers should have inspected the subject hose on the day of the incident, prior to startup, and looked for visual or physical clues as to any potential problems. With appropriate training and supervision, they should have been able to identify external corrosion of the hose braid layer and to then follow a set procedure for reporting such observations.

In July 2001, the DPC Festus operations manager resigned. Over the next 6 months, various DPC corporate personnel managed the site. During this transition, there were periods with no management supervision of day-to-day operations, including inspections.

Although a new manager was hired and assigned day-to-day supervision responsibility in January 2002, he was inexperienced in chlorine repackaging operations. DPC provided some training on chlorine repackaging, but it was inadequate for his safety responsibilities and did not sufficiently cover the importance of preventive maintenance and inspection. The new manager assumed that the packagers were performing their tasks properly because of their combined chlorine repackaging experience.

5.2.2 Operator Training

Although DPC 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. For example, CSB investigators believe that neither the supervisor nor the packagers fully understood the need to keep the repackaging system free of moisture or the potential impacts of not identifying and preventing corrosion. Corrosion problems within the pad air and unloading assemblies and other parts of the system (created by moisture-intrusion) were not addressed in a timely manner, which allowed the ESD valves to become clogged.

The MI program at DPC 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.

5.2.3 Auditing of Inspection Procedures

The review and update of MI program standard operating procedures is critical to ensure the optimal and safe performance of process equipment. DPC did not adequately audit its standard operating procedures. For example, though DPC tested operation of the ESD system daily by activating manual buttons, the testing procedures offered no assurance that the valves actually closed during shutdown at the end of the day or in an emergency because personnel did not verify the position indicators on the ESD valves (Figure 13). A thorough audit of standard operating procedures could have identified that additional steps were needed to positively verify closure of the ESD valves.

5.2.4 Auditing of Schedules

DPC bought the Festus facility in August 1998. The chlorine repackaging system piping was replaced in June 1999 as part of the process upgrade. Since that time, however, the piping had not been measured for wall thickness, nor internally inspected. The DPC inspection and testing frequency for this piping is every 5 years; the next testing was scheduled for 2004.

The Chlorine Institute (1998) provides recommendations and guidance for the regular inspection, testing, and maintenance of chlorine piping systems. The definition of "regular" is left up to the facility to determine based on individual site conditions.

In dry chlorine service, corrosion should be anticipated because of the difficulty in isolating the system from moisture. Historical information and operating experience are good measures for selecting inspection and testing frequencies. MI program schedules should be routinely audited to ensure that their intervals are of adequate duration to identify and prevent process safety problems, such as corrosion, before there is a risk of system failure. The internal inspection of the piping system and valves at DPC Festus was not sufficient to identify corrosion problems.

The ESD valves were not visually inspected or tested for ease of closure prior to the incident. The Chlorine Institute (1997) provides minimum guidelines for design and installation of ESD valves: ". . . such emergency systems must be regularly inspected for mechanical integrity." The Center for Chemical Process Safety (CCPS, 1997) discusses emergency isolation of releases, design and operation of emergency ESD valves, and the need for routine inspection and testing. CCPS states: "Testing of isolation devices needs to be a complete functional check, which includes switch operation through actuation of the final control element (valve, pump, etc.) . . ."

It is vital that critical process piping and equipment and safety systems, such as the ESD system, be included in a documented and audited MI program. Routine testing of the ESD valves to verify that they are, in fact, closed after actuating the system—combined with periodic internal inspections—could have ensured that the valves would close on demand, and greatly lessened the quantity and duration of the chlorine release.

5.2.5 Source of Corrosion

DPC Festus packagers 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 August 14. 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 (Roberge, 2000).

As discussed in Section 4.5, CSB concludes that the valves did not close because of the buildup of corrosion products around ESD 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 (Figure 25).[20] These corrosion products readily migrated to the valves.

CSB identified three possible sources of the corrosion-producing moisture (see Appendix A for details):

- 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.

[20] 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.

Figure 25. Corrosion buildup in chlorine repackaging piping system.

The DPC Festus MI program was not successful in preventing corrosion within the chlorine repackaging system because it did not adequately address related supervision, procedures, and inspection.

5.3 Emergency Management

Emergency management is the process of preparing for, mitigating, responding to, and recovering from an emergency (FEMA, 2003). 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.

5.3.1 Facility Requirements

Facility emergency response plans primarily address requirements of the following Federal laws and regulations:[21]

- Emergency Planning and Community Right-To-Know Act (EPCRA; Title III of the Superfund Amendments and Reauthorization Act [SARA] of 1986).
- EPA Risk Management Program (RMP).
- OSHA Process Safety Management (PSM) Standard.[22]

The basic requirements of these laws and regulations are similar. Because DPC stores and handles chlorine at quantities that exceed threshold values set by EPCRA, RMP, and PSM, it is required to comply with the emergency planning and response elements of these regulations. Appendix D provides information on procedures for community notification and emergency response, employee training and drills, and coordination of activities.

5.3.2 DPC 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.

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[21] Various other laws and regulations have emergency management requirements, such as The Oil Pollution Act Spill Prevention, Control and Countermeasures (SPCC), the EPA Oil Pollution Prevention Regulation, the OSHA Emergency Action Plan Regulation and Hazardous Waste Operations and Emergency Response (HAZWOPER), and the Resource Conservation and Recovery Act (RCRA) Contingency Planning Requirements.
[22]The PSM Standard references the OSHA Emergency Action Plan (1910.38) and HAZWOPER (1910.120) with regard to emergency response plans.

- 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 DPC's inadequate preparation for a large uncontrolled release. CSB does not question the DPC decision to evacuate the facility and request community emergency response assistance. The focus of the CSB review of the emergency response plan is on evaluating DPC emergency management to identify areas of improvement in terms of preventing exposures and reducing the mitigation time of future releases.

5.3.2.1 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.

One of the critical elements of the EPA RMP is to ensure that a facility's emergency response plan includes procedures for informing the ***public*** and ***local authorities*** of a release. "This must include the groups and individuals that will be contacted and why, the means by which they will be contacted, the time frame for notification, and the information that will be provided" (USEPA, 2000a).

Although DPC had procedures and effectively notified local agencies and emergency response personnel of the release, it did not adequately inform the public. The emergency response plan contained contact numbers for the local emergency planning committee (LEPC), nearby businesses, and neighbors—including the construction and tire retreading company, the mobile home park, and the owner of an adjacent farm—but it did not assign responsibility for notification to any specific personnel. Emergency responders went door-to-door at the Blue Fountain mobile home park and in other nearby residential areas to notify residents of the release; this took over an hour. No procedures for evacuation or shelter-in-place had been given in advance to residents or businesses.

Another incident at DPC Festus, in January 1999, demonstrated the need for improved community notification. In that incident, a 1-ton container of chlorine was dropped as it was being loaded onto a truck (Figure 26). The fall damaged the container valves and released 1,500 pounds of chlorine. Twenty-two residents and two DPC employees sought medical evaluation due to exposure; one person was admitted and released the following day. Several residents and community officials interviewed by CSB in the course of the 2002 investigation indicated that DPC had committed to update its community notification procedures and implement a notification system as result of the 1999 incident. However, DPC did not follow through on this commitment.

Figure 26. Truck loading station at DPC Festus.

In both incidents, the lack of an adequate community notification system and clear guidelines for its implementation contributed to impact or injury to the public. The Chlorine Institute (2000a) states that "internal and external communications are critical during an emergency." The Institute recommends the use of siren systems, automatic telephone alert systems, and radio and TV media. To facilitate implementation, it further recommends that local authorities be involved in developing community notification procedures. (Section 5.3.4.1 discusses community requirements regarding notification.)

Once a community notification system is in place, it must be tested and updated on a regular basis, and the public should be educated on how to properly respond to an emergency. However, community notification is no substitute for prevention of the release in the first place.

5.3.2.2 Designation of Responsibilities

The DPC emergency response plan did not clearly specify the responsibilities of response team members during a release. The Chlorine Institute (2000a) 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 DPC was better prepared for managing a large uncontrolled release.

5.3.2.3 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 offsite community HAZMAT response is required. This lack of guidance explains the indecision among facility personnel responsible for assessing emergency response options. For example, the DPC Festus 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 DPC 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.

5.3.2.4 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 DPC did not conduct training, audits, or drills on a regular basis.

The Chlorine Institute (2000a) recommends that emergency response plan training include the following elements:

- Timetables or schedules for training, including start date, number of sessions held, and target completion date.
- Yearly refresher training.
- Documentation, including a list of personnel trained and date training was completed.

Audits and drills are effective in determining the adequacy of emergency response plan training. Audits provide a thorough assessment of employee knowledge of responsibilities, communication needs, and equipment. Drills test the actual mechanics of the plan, and employee reactions and effectiveness in implementing the plan (Chlorine Institute, 2000a). Tabletop drills provide a low-stress opportunity to discuss emergency response issues; functional drills simulate an actual emergency; and full-scale drills test the response of the entire community.

DPC Festus was not prepared for a major uncontrolled release because of inadequate auditing of emergency response team capabilities and the lack of periodic, scheduled drills. Essential equipment was inaccessible. The DPC emergency response plan should have contained guidelines on auditing and drilling for releases/emergencies with varying degrees of response, and incorporated lessons learned from audits and drills. It should be reviewed annually, whenever the facility is modified, and whenever there are personnel or organizational changes.

5.3.2.5 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 DPC being unprepared for a large uncontrolled release.

As discussed in Section 3.2.4, emergency response equipment was not readily accessible during the release. The DPC 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 packagers (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 Chlorine Institute (2001) states: " All personnel required to wear respiratory protection equipment (such as SCBAs) should be trained and tested annually on its proper use." The Institute recommends that respiratory protection equipment be inspected monthly and after each use. Furthermore, the OSHA Respiratory Protection Standard (1910.134) requires monthly inspections and annual refresher fit testing of respirators used for emergency response.

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

5.3.2.6 Post-Incident Remediation

Section 3.2.8 describes cleanup activities after the release was shut off. 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 DPC emergency response plan included no guidelines for planning post-incident cleanup of hazardous materials.

DPC operators attempted to neutralize the chlorine with calcium carbonate (limestone). However, the operators 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.

5.3.2.7 Other Issues

Under EPCRA, RMP, and PSM, facilities are not required to submit emergency plans to local authorities. However, EPCRA and RMP do require the facility to coordinate with and provide information to local authorities so that the community is prepared to handle accidental hazardous chemical releases. An emergency coordinator must be designated to work with local authorities on chemical emergency preparedness. The EPA RMP guidance document recommends that the facility also coordinate emergency response training and drills with local planning authorities, and offer them a copy of the plan.

Coordination between local emergency planning and response entities and DPC was insufficient to ensure that the emergency plan would provide for timely community notification and mitigation of the release.

5.3.3 Community Emergency Response Requirements

In 1986, Congress passed the Superfund Amendments and Reauthorization Act (SARA). It was designed to establish a national baseline for planning, response, management, and training for chemical emergencies. Title III of this legislation, EPCRA, requires the establishment of both state and local LEPC groups.

The community right-to-know aspect of SARA created new rights for members of the public and local governments to increase their knowledge and access to information on hazardous chemicals from neighboring facilities. The LEPC is responsible for developing an emergency response plan that includes:

- Local facilities and transportation routes where hazardous materials are present.
- Procedures for immediate response in case of an accident, including a community-wide evacuation plan.
- Procedures for community notification.
- Names of response coordinators at local facilities.
- Procedures for testing emergency response.

The plan is reviewed by the state and publicized throughout the community. The LEPC is required to review, test, and update the plan each year.

The Jefferson County LEPC works with the County Emergency Management Agency (EMA) in planning for emergencies The EMA develops the community emergency response plan. The LEPC, which includes various local authorities (e.g., fire, police, HAZMAT) and facilities, is scheduled to meet six times a year. The DPC operations manager is a member of the LEPC.

5.3.4 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 August 14 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 (see Appendix D). Effective emergency preparedness requires periodic review and evaluation of the community emergency response plan at the community level (National Response Team [NRT], 2001).

5.3.4.1 Community Notification

Local authorities have the primary responsibility to notify the public of an emergency. In this incident, the community notification system was inadequate. Both local authorities and DPC should have worked together during development of the community emergency response plan to establish a warning system. As discussed in Section 3.2.6, emergency personnel drove through neighborhoods and went door-to-door to notify people to evacuate, which extended the period of public exposure.

The community emergency response plan calls for evacuation and shelter-in-place information to be disseminated via radio and television. However, community sirens or alert networks that immediately notify the exposed public are a better alternative. Radio and television can be used to provide followup information.

The NRT *Hazardous Materials Emergency Planning Guide* recommends that the community plan contain precise information on how sirens or other signals will be used to alert the public. This should include information on what the different signals mean, how to coordinate the use of sirens, and the geographic area covered by each siren. If possible, a backup procedure should be identified. Further, the guide states that, though “a siren alerts those who hear it, an emergency broadcast is necessary to provide detailed information about the emergency and what people should do” (NRT, 2001).

5.3.4.2 Community Emergency Preparedness

The August 14 release at DPC continued for nearly 3 hours. 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 ESD system effectively shuts off all releases.

NRT (2001) 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 minutes 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 minutes 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.

ATSDR and the Federal Emergency Management Agency (FEMA) offer additional guidance specifically designed to assist communities develop evidence-based assumptions in preparing for hazardous materials emergencies and disasters.

5.4 The Chlorine Institute Recommended Practices

DPC Enterprises is a member of The Chlorine Institute, Inc., which is the chief source of industry best practices for chlorine repackagers. The specific Chlorine Institute publications that pertain to this incident are:

- Pamphlet 6, Piping Systems for Dry Chlorine (1998)
    - Contains the majority of recommended practices dealing with the metallurgy of piping and hoses in chlorine transfer operations. Although this guidance provides details for piping in ***dry chlorine*** service, as well as specifications for transfer hoses, it does not discuss the pathways for moisture intrusion, consequences of moisture-induced corrosion, or specifications for piping systems that are susceptible to such corrosion.

- Pamphlet 57, Emergency Shut-Off Systems for Bulk Transfer of Chlorine (1997)
  - Addresses the design and installation of emergency shutoff systems. However, it does not provide guidance on the procedures for testing and inspection to ensure continued operation of the shutoff valves, especially with regard to potential moisture-induced corrosion.
- Pamphlet 64, Emergency Response Plans for Chlorine Facilities (2000a)
  - Addresses the full range of releases, from minor to catastrophic. The Institute refers to these releases as "major emergencies, outside the overall facility—requiring outside help." Although this guidance calls for the involvement of outside responders for emergency control, it does not discuss communication between a facility and the local responders and emergency planning authorities to ensure that adequate resources are in place for major emergencies.

5.5 NACD Responsible Distribution Process

DPC Enterprises is part of DX Distribution Group, a network of distribution and storage companies. The DX Group is a member of NACD. As a condition of membership, companies commit to the NACD Responsible Distribution Process (RDP), which requires continuous improvement in protecting health, safety, and the environment, and includes the Code of Management Practice. The code covers 12 elements, including risk management, carrier selection, handling and storage, and continuous improvement. Article IV, Handling and Storage, specifies that the company have a program to promote facility integrity and provisions for control of processes during emergencies.

A key requirement of RDP and a condition of membership in NACD is third-party verification of member RDP policies and procedures. Although DPC Enterprises is a part of the DX Distribution Group network, NACD did not considered the Festus facility to be a member and it did not have to meet RDP membership requirements. Based on membership information provided by NACD, only one DX Distribution Group company (DXI Distributors, Inc.) was an NACD member.

6.0 Root and Contributing Causes

6.1 Root Causes

1. **The DPC quality assurance (QA) management system did not have adequate provisions to ensure that chlorine transfer hoses (CTH) met required specifications prior to installation and use.**

   Hastelloy C-276 and 316L stainless-steel structural braiding are identical in appearance. The inability to visually distinguish the two materials offers an explanation for installation of the inappropriate hose at DPC Festus. DPC relied on information from the supplier to verify that the chlorine transfer hose met required specifications; the lack of an internal QA management system, including verification of braid material, allowed the incorrect hose to be installed and left in operation until it failed.

2. **Branham Corporation, the CTH fabricator/distributor, did not have a QA management system to ensure that fabricated hose actually complied with customer specifications or that its own certification of materials specifications were correct.**

   Branham did not have a system to ensure that it fabricated and shipped the exact hose specified by the customer (DPC Festus) because of the absence of PMI testing and the inability to validate its own certification and shipping documents.

3. **The DPC testing and inspection program did not include procedures to ensure that the process emergency shutdown (ESD) system would operate as designed.**

   DPC procedures for daily testing of the ESD system were not specific. For example, it was not explicitly stated that the system must be tested from the activating device (button or detector) through to verification that the valves actually closed. Inadequate testing and inspection of the ESD system probably led to undetected failures of the system valves at tank car station #3 prior to the August 14, 2002, failure.

6.2 Contributing Causes

1. **The hose identification system of CTH manufacturers is inadequate to provide continuous positive identification of similar-looking structural braiding materials of construction, such as Hastelloy C and stainless steel.**

2. **The DPC mechanical integrity (MI) program failed to detect corrosion in the chlorine transfer and pad air systems before it caused operational and safety problems.**

Wet chlorine caused excessive corrosion of the chlorine unloading piping and pad air piping systems, which prevented the ESD valves from closing properly. Potential sources of water include:

- Atmospheric moisture from inadequate capping of hoses and tank car piping assemblies.
- Moisture from the pad air supply system.

3. **The community notification system was inefficient, which resulted in additional exposure to neighboring residents and businesses.**

Because of the catastrophic nature of the chlorine release, personnel evacuated the facility immediately without simultaneously notifying neighboring businesses and residents.

4. DPC emergency preparedness planning was deficient.

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 response; inadequate training and drills; inaccessible location of emergency response equipment; and lack of clear guidelines for post-incident remediation resulted in DPC's inadequate preparedness for a large uncontrolled release.

5. Jefferson County community emergency preparedness planning was inadequate for an incident of this magnitude.

Better planning that involved all local emergency response and planning authorities could have improved the overall response and mitigation time on August 14. For example, members of the all-volunteer Jefferson County HAZMAT response team arrived on-scene over a 0.5- to 1.25-hour period, and the setup of two separate command posts along the highway caused confusion.

7.0 Recommendations

DPC Enterprises L.P., Festus Site

1. Revise the mechanical integrity program:

   - Develop and implement a quality assurance management system, such as positive materials identification, to confirm that chlorine transfer hoses (CTH) are of the appropriate materials of construction. (2002-04-I-MO-R1)

   - Implement procedures and practices to ensure the emergency shutdown (ESD) system operates properly. Include procedures to verify that the ESD valves will close to shut down the flow of chlorine. (2002-04-I-MO-R2)

   - Revise the preventive maintenance and inspection program for the chlorine transfer system to address moisture-related corrosion. Evaluate and correct any problems associated with corrosion that could potentially lead to chlorine transfer and safety system failure. (2002-04-I-MO-R3)

   - Require periodic inspection of the above critical safety systems by the operations or facility manager. (2002-04-I-MO-R4)

2. Revise the Emergency Response Plan:

   - Develop procedures to clearly designate the roles and responsibilities of facility emergency response personnel, including post-incident remediation. (2002-04-I-MO-R5)

   - Develop and implement a timetable for drills to test emergency response personnel on various levels of response, including a large uncontrolled release that could affect the public. Coordinate these drills with local emergency response authorities. Provide a copy of the revised Emergency Response Plan to the local emergency planning committee, and review the plan with the committee and the local fire department. Work with these authorities to implement an improved community emergency notification system. (2002-04-I-MO-R6)

- Improve accessibility of equipment required for emergency response, considering likely response scenarios. (2002-04-I-MO-R7)

DX Distribution Group (corporate owner of DPC Enterprises, L.P.)

1. In light of the findings of this report, conduct periodic audits of the safety management systems involved in this incident, such as mechanical integrity, emergency response, and material quality assurance. Ensure that the audit recommendations are tracked and implemented. Share findings and recommendations with the work force at your repackaging facilities. (2002-04-I-MO-R8)

2. To improve supervision of day-to-day operations, revise your corporate safety management-training program on chlorine repackaging operations. Emphasize safety critical systems, including verification of safety system performance. (2002-04-I-MO-R9)

3. Communicate the findings and recommendations of this report to all DPC facilities. (2002-04-I-MO-R10)

Branham Corporation

Implement a materials verification procedure to improve quality assurance during chlorine transfer hose fabrication and shipment, such that hoses shipped to customers are readily identifiable and meet required specifications. (2002-04-I-MO-R11)

Jefferson County Emergency Management Agency (EMA)

1. Work with DPC to implement a community notification system that will immediately alert neighboring residents and businesses of a chemical release. (2002-04-I-MO-R12)

2. Work with DPC, local emergency planning and response authorities in Jefferson and adjacent counties, the City of Festus, and Crystal City to improve overall response and mitigation time. (2002-04-I-MO-R13)

3. Communicate the findings and recommendations of this report to your membership. (2002-04-I-MO-R14)

Missouri State Emergency Response Commission

Communicate the findings and recommendations of this report to local emergency planning committees (LEPC), emergency management agencies (EMA), and local fire departments. (2002-04-I-MO-R15)

Missouri Department of Natural Resources (MDNR)

In collaboration with appropriate agencies, hold a community meeting in Festus, Missouri, to hear concerns raised by local citizens affected by the DPC incident and to respond to issues raised by the community. (2002-04-I-MO-R16)

Agency for Toxic Substances and Disease Registry (ATSDR)

Work with State and local agencies to address concerns about the long-term health effects of the chlorine release in Festus, Missouri, and communicate your findings to the community. (2002-04-I-MO-R17)

The Chlorine Institute, Inc.

1. Work with the Association of Hose and Accessories Distributors (NAHAD) and chlorine hose manufacturers, such as Crane-Resistoflex, to develop and implement a recommended practice requiring continuous positive identification (e.g., coding, stenciling, stamping) throughout the supply chain, from manufacturing to the end user of the product. (2002-04-I-MO-R18)

2. Develop recommended practices to address moisture in dry chlorine piping systems. Include information on suggested material specifications, prevention and corrective measures, and adverse consequences (particularly for emergency shutdown [ESD] systems). (2002-04-I-MO-R19)

3. Develop recommended practices for testing, inspection, and preventative maintenance of ESD systems for bulk transfer of chlorine. (2002-04-I-MO-R20)

4. Communicate the findings and recommendations of this report to your membership. (2002-04-I-MO-R21)

National Association of Hose and Accessories Distributors (NAHAD)

1. Work with The Chlorine Institute and chlorine hose manufacturers, such as Crane-Resistoflex, to develop and implement a recommended practice requiring continuous positive identification (e.g., coding, stenciling, stamping) throughout the supply chain, from manufacturing to the end user of the product. (2002-04-1-MO-R22)

2. Communicate the findings and recommendations of this report to your membership. (2002-04-1-MO-R23)

National Association of Chemical Distributors (NACD)

Communicate the findings and recommendations of this report to your membership. (2002-04-I-MO-R24)

By the

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APPENDIX A: Dry Chlorine Corrosion

A.1 Definition

The Chlorine Institute (2000b) defines dry chlorine as "liquid or gaseous chlorine with its water content dissolved in solution." It is important to understand that even dry chlorine contains some very low levels of water. When not all the water is dissolved in solution because of system conditions (e.g., temperature or pressure)[1] or contamination (e.g., atmospheric moisture intrusion), the excess water forms a second aqueous phase. It is this water-rich phase that creates corrosion problems within a system in dry chlorine service. At ambient temperature, dry chlorine contains less than 50 ppm water.

A.2 Corrosion Mechanism

In dry chlorine service, carbon steel is the most commonly used material of construction for system piping. The iron in carbon steel is reactive with dry chlorine:

$$2\ Fe + 3\ Cl_2 \rightarrow 2\ FeCl_3 \qquad \text{[Eq A-1]}$$

The reaction product, ferric chloride ($FeCl_3$), forms a passive layer on the steel surface, which protects the underlying iron from further attack by chlorine.[2] Carbon steel is corrosion resistant to chlorine as long as high water concentrations or temperatures do not deliquesce the protective layer (Chlorine Institute, 2002).[3]

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[1] The water content at which chlorine is dry varies with temperature (e.g., chlorine with a water content of 30 parts per million (ppm) at a temperature of 50 degrees Fahrenheit (º F) is dry; the same chlorine (30 ppm) at a temperature of -4º F is wet.

[2] Ferric chloride is a very hygroscopic salt; it absorbs moisture/water very quickly when exposed to the atmosphere, which accelerates the overall corrosion rate and buildup of products in the system.

[3] Deliquesce: to dissolve and become liquid by absorbing moisture from the air.

The corrosion mechanism for chlorine attack on steel is a water-rich phase or an increase in temperature. In either case, ferric chloride forms; this solution is an electrolyte, a very strong oxidizer, and a strong acid.

The water-rich phase not only dissolves the protective layer of ferric chloride, but also forms an acid medium by reaction of chlorine with water (Updyke, 1982). The chlorine-water reaction forms hypochlorous acid (HOCl) and hydrochloric acid (HCl):

$$Cl_2 + H_2O \rightarrow HOCl + HCl \qquad \text{[Eq A-2]}$$

The acids and the dissolved ferric chloride form a concentrated solution that is corrosive to steel.

A.3 Sources of Corrosion

A.3.1 Dryer System

The compressed air used to “pad” the tank car is a potential source of moisture. Pad air at approximately 175 pounds per square inch gage (psig) is piped to the vapor space of the tank car to push liquid chlorine into the DPC system. The compressor is equipped with a moisture analyzer and an automatic regenerating dessicant dryer that uses a moisture-absorbing material, such as aluminum silicate. (One dryer is in service while the other is heated to drive off moisture.)

The moisture analyzer had provided the same exact readings for several months, which may have indicated a malfunction. Maintenance did not include a check of the dew point indicator. The last dryer system maintenance inspection was conducted in July 2002.

As further evidence of inadequately dried air, inspection of one of the emergency shutdown (ESD) valve actuators revealed liquid moisture trapped within the actuator mechanism. This moisture is likely to have originated in the air used to power the actuator. The plant air dryer was upgraded prior to the chlorine release because of excessive moisture clogging the plant sandblasting equipment.

Moisture in the plant air system was a key indicator of the potential for similar problems with the pad air dryer. If employees had been trained on the criticality of the dryer system, they would have known to conduct preventive maintenance.

A.3.2 Atmospheric Moisture

Whenever chlorine piping is disconnected from a system or tank car, trace amounts of chlorine may remain in the hose or piping, or may evolve from the Teflon liner. Combined with ambient moisture, this chlorine can produce a thin film of corrosion products that is washed downstream the next time the piping is used.

The practice at DPC is to cap hoses, pad air supply and unloading assemblies, and system piping immediately upon disconnection or when not in use. There was a potential for moisture intrusion if the packagers did not immediately cap all assemblies.

At DPC Festus, the piping system is also evacuated, held under vacuum each night, and evacuated again in the morning prior to being tested for leaks with chlorine vapor. When the system is under vacuum, there is a slight potential for moist ambient air to intrude via minor joint and fitting leaks.

A.3.3 Tank Car

Chlorine producers employ safeguards to ensure that the chlorine loaded into tank cars is shipped with no free moisture. Tank cars are visually inspected, pressure tested, and dried with compressed air. The air exiting the tank cars is analyzed, and airflow continues until the dew point of the exiting air is at or below –40°F, which corresponds to a moisture content of 0.1 milligram per liter (mg/L) or 125 ppm. The cars are loaded with liquid chlorine that is dried to the same standard. In the case of the August 14 release, this information—along with the certificate of analysis for the shipment—provides the basis for the CSB assertion that the tank car is unlikely to have been the source of corrosion.

APPENDIX B: Additional Details on DPC Festus Facility

B.1 Facility Layout

The DPC Festus site is triangular in shape, with a fenced perimeter and a gated main entrance off Highway 61. It includes a chlorine repackaging building, a storage tank area, and an office building.

The repackaging building houses the cleaning, preparation, and fill areas for the cylinders and containers; the air compressor and compressed air dryer room; a breakroom; and the sodium hypochlorite (bleach) production area.

Tank cars are brought into the facility through a rail spur along the northwest corner of the site. A storage area located on the eastern side of the repackaging building contains several bulk storage tanks of sodium hydroxide (caustic soda), bleach, and wastewater. The three chlorine tank car unloading stations are located along the northern side of the repackaging building. Each station is equipped with three flexible transfer hoses to connect plant piping to the tank car.

B.2 Chlorine Repackaging Process

B.2.1 Tank Car Unloading

The railroad company moves a tank car to the assigned unloading station. Only one tank car is unloaded at a time.

Because there are no working platforms at the unloading stations, a DPC packager uses the car ladder to climb to the top of the tank car. The packager then opens the cover of the protective dome and tests for leaks using a spray bottle of ammonia solution.[4] If no leak is detected, the packager removes the plug in the vapor valve (valve D) opening[5] and threads in the "pad" air supply assembly. Pad air is used to help push the liquid chlorine out of the tank car into the plant piping (Figure B-1). The plugs from the two liquid valves (valves A and C) are then removed, and two chlorine unloading assemblies are threaded in. Each of the three assemblies is attached to a chlorine transfer hose, which connects the tank car to process piping. The packager then uses the ammonia solution to test the connections for leaks.

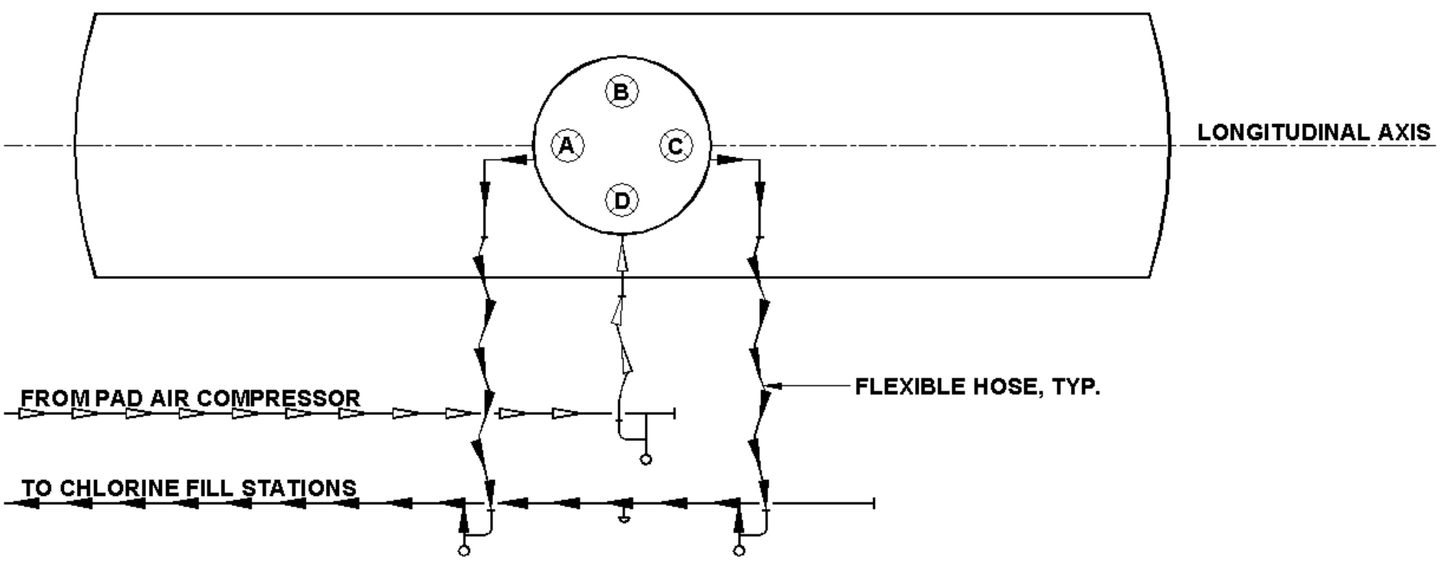

Figure B-1. Pad air supply assembly.

At all three unloading stations, the liquid chlorine system piping ties into a common header located in the repackaging building. The header feeds a main supply line, which branches off and supplies chlorine to the fill stations.

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4 Ammonia reacts with chlorine to form a visible white aerosol cloud (ammonium chloride).
5 A plug is threaded into the valve opening to prevent the inadvertent release of material.

The tank car remains connected to plant piping via the chlorine transfer hoses until all chlorine is unloaded. The hoses are then disconnected from the car, capped, and left hanging from the process piping. The pad air supply and chlorine unloading assemblies are also disconnected from the tank car and capped on both ends.

The DPC Standard Operating Procedures Manual describes the sequence of actions necessary to connect plant piping to the chlorine tank car. It specifies that both the chlorine transfer hoses and the unloading and pad air supply assemblies need to be immediately capped.

B.2.2 Pad Air Supply and Chlorine Unloading Assemblies

Two assemblies are needed for chlorine tank car unloading at DPC Festus because both of the car's liquid valves are used. The air-actuated valves are a critical part of the ESD system (Figure B-2).

- The first component of the air supply assembly is a threaded 1-foot-long, 1-inch-diameter carbon steel pipe. This end of the assembly is passed through an access hole on the side of the tank car dome and threaded onto vapor valve D. A two-bolt flange is threaded onto the other end of the steel pipe. A screwed-end ball valve plus actuator, a pressure gauge, a gate valve, and several lengths of 1-inch pipe are then attached to this flange.

- The first component of the chlorine unloading assembly is a threaded 2-foot-long, 1-inch-diameter carbon steel pipe that attaches to the tank car in a similar manner as the air supply assembly (valves A and C). A 90-degree elbow is threaded onto the unattached end, and a two-bolt flange is added for attachment to the air-actuated valve (Figure B-2).

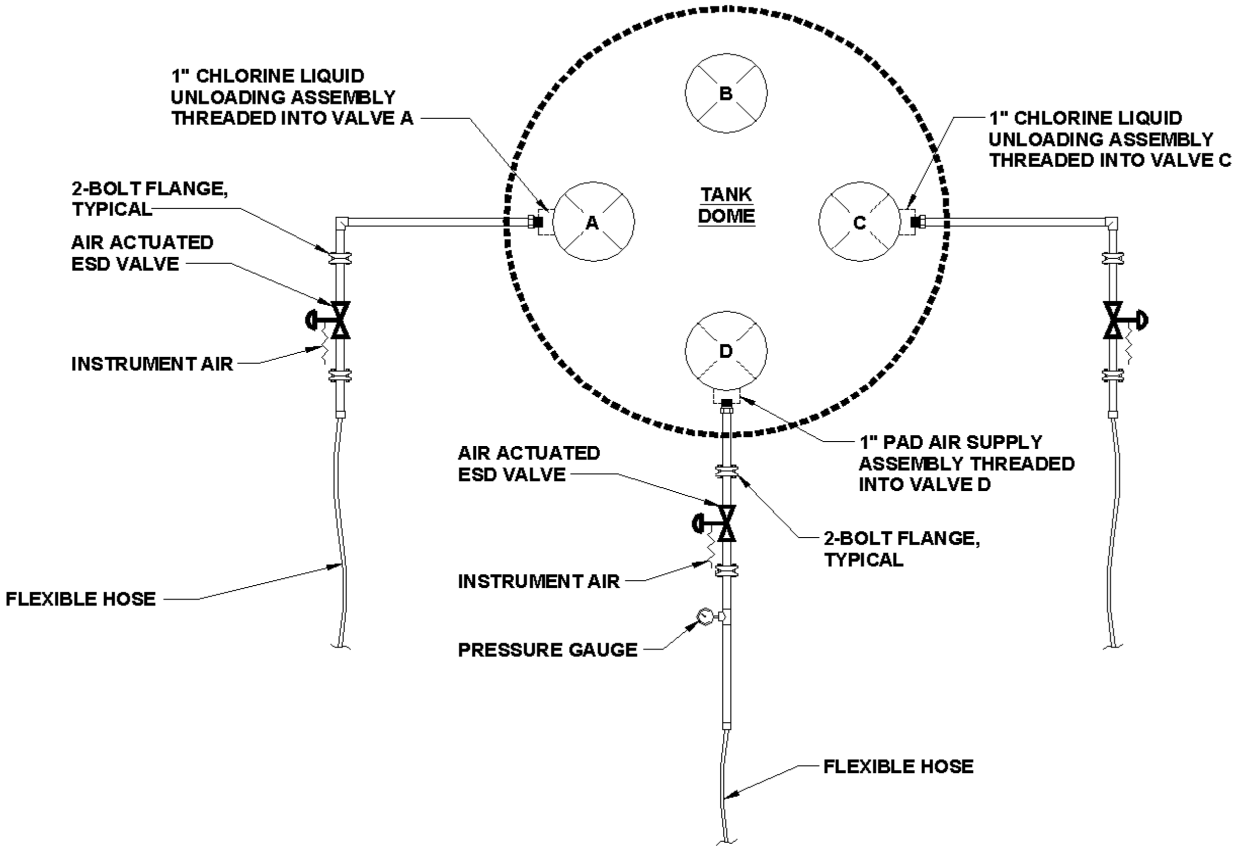

Figure B-2. Piping assembles for tank car unloading.

B.2.3 Pad Air and Plant Air Supply

The pad air supply system provides air pressure to facilitate transfer of chlorine from the tank car to the fill stations. This system has a dedicated compressor, air drier, and piping. A malfunction of the pad air system drier could potentially introduce wet air into the tank car, which would contaminate the chlorine and create corrosion problems in the transfer piping.

The plant air supply system—which provides air pressure to air-operated instrumentation throughout the facility, including the ESD actuators and valves—also has its own compressor, air drier, and piping.

During normal operation, plant air supplies the force to overcome the actuator spring pressure, thus keeping the ESD valves open.[6] When solenoids controlling the ESD valve actuators are deenergized, the plant air port closes and the atmospheric port opens to relieve air pressure and allow the actuator spring to close the valve.

B.3 Tank Car Specification

The tank car was a U.S. Department of Transportation (DOT) 105J500W specification car manufactured in 1981, with a carbon steel pressure tank and insulation covered by a steel jacket. Its water capacity was 17,300 gallons.

PLM Tank Car Management Services Canada Ltd. owned the tank car. The car received a maintenance inspection and service in May 2000.[7] It was leased to Westlake CA&O Corporation, a Calvert City, Kentucky, manufacturer of chlorine, which shipped a full load of chlorine to DPC Festus on July 12, 2002. A quality analysis performed by Westlake prior to shipment found the material to be 99.944 percent chlorine. This purity was well within DPC purchase specifications.

B.4 Repackaging System Standby and Shutdown Modes

Although all filling stations are isolated in standby mode, the plant piping system contains chlorine and is not isolated from the tank car. The tank car liquid valves A and C and the pad air vapor valve D are open. The ESD valves within the process piping system and on the tank car air supply and unloading assemblies are also open.

[6] Typical instrument air hoses are used to provide airflow to the actuators.
[7] During this inspection, various safety systems were verified, including the pressure relief valve and excess flow valves. DOT requires chlorine tank car pressure relief valves to be inspected every 5 years and an overall tank inspection every 10 years.

In shutdown mode, the process piping is evacuated of chlorine and put under vacuum conditions. The piping system is isolated from the tank car by manually closing all car valves and pressing the ESD button to activate (close) all air-actuated ESD valves.

In both standby and shutdown modes, the chlorine transfer hoses remain connected to the tank car.

B.5 DPC Hose Order Arrangement

Prior to April 2000,[8] DPC used chlorine transfer hoses with a Monel inner lining[9] rather than Teflon. DPC switched to the Crane-Resistoflex Teflon-lined CTH design for future replacements because it offered a greater degree of flexibility.

DX Distribution Group made arrangements with Branham Corporation to fabricate the Crane-Resistoflex chlorine transfer hose. The company placed its first order (for the Festus facility) with Branham for the Crane-Resistoflex CTH design[10] on July 24, 2000. The hose description used in this purchase order was of the old Monel-lined design (see Figure B-3). Branham corrected the error because its arrangement with DPC was to fabricate Teflon-lined hoses. On July 25th, Branham shipped to Festus the newly fabricated hose.

All DPC hose descriptions on purchase orders to Branham placed after July 24, 2000—including the March 18, 2002, order—stated "Monel-lined." On all orders prior to March 18, Branham had supplied DPC with the correct Teflon-lined CTH design despite the incorrect hose description on purchase orders. Furthermore, two of the three hoses supplied to DPC Festus as part of the March 18 order were correct,

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[8] In May 1999, all nine Monel-lined hoses at the three tank car unloading stations at DPC Festus were replaced. These chlorine transfer hoses had Monel inner lining rather than Teflon.
[9] Crane-Resistoflex does not manufacture Monel-lined chlorine transfer hoses.
[10] Tank car unloading hose specifications: 1-inch, 11-foot-long hose with Schedule 80 Monel 400 end fittings, a high density polyethylene (HDPE) spiral guard, and shrink-wrapped paper hose identification tags.

which suggests that the hose mixup may be explained by an error in the supply chain rather than an error in the purchase order.

FLEX HOSE:
Chlorine Railcar and Truck Unloading

Flex Hose Description: Monel MPT each end, Monel annular lining, double braid wire, s/s interlocked armor cover.

Date: 07/24/00 Purchase Order # 171031

Description	Minimum Requirements	Comments
Vendor:		Branaham Corp.
Manufacturer:		Resistoflex
Date of Manufacturer:		
Hose Installation Date:		
Hose Replacement Date:		
Location:		
Diameter and Length:	1" x 11'	
End Types:	1" Monel MPT	
Test Types and Pressure:	Gas 750 lbs. psig	
Maximum Working Pressure:	375 psig	
Design Bursting Pressure:	1,875 psig	
Vacuum Rating:	25"	
Maximum Service Temperature:	-40 F to 120 F	
Minimum Bend Radius:	6"	
Serial Number	DPC Issued Number	

* Manufacturer Tag Information needed on each hose.
** *Tag to be supplied by Manufacturer,* information to be filled out by district

DPC Issued Serial Numbers:

2300CL0700868

Figure B-3. DPC purchase order, flex hose for chlorine railcar and truck unloading.

APPENDIX C: Inspection, Schedule for Chlorine Repackaging System

Table C-1 lists the inspection/testing schedule followed by DPC Festus for each of the chlorine repackaging system components.

Table C-1

Chlorine Repackaging System Inspection Schedule

System Components	Inspection/Testing Frequency
System piping	Inspect and thickness test every 5 years
Other system components (valves, rupture discs, limit switches, etc.)	Repair/replace as necessary
Air-actuators	Repair/replace as necessary
Emergency shutdown system (alarms, lights, buttons, etc.)	Quarterly test
ESD valves	Repair/replace as necessary
Chlorine detection system	Calibrate/inspect annually
Chlorine unloading assembly	Clean and inspect after each car unloading; replace as necessary
Pad air supply assembly	Clean and inspect after each car unloading; replace as necessary
Pad air dryer	Annual inspection
Plant air dryer	Annual inspection
Pad air compressor	Semiannual inspection
Plant air compressor	Semiannual inspection
Chlorine transfer hose	Daily external inspection; clean and inspect after each car unloading; replace 2 years from date of fabrication

APPENDIX D: Critical Elements of Emergency Response Plan

An emergency response plan should include all of the following elements:

- Procedures for responding to an emergency based on type of event and potential effects.
  - Employee-managed response
  - Employee evacuation to a preplanned safe zone area
  - Local community emergency response.
- Procedures for informing the public and emergency response agencies.
- Delegation of responsible authorities (i.e., incident command system) for making decisions, monitoring response actions, and recovering back-to-normal operations.
- Specific instructions for shutting down equipment and processes.
- Facility evacuation procedures, including a designated meeting site outside the facility and a process to account for all employees after an evacuation.
- Emergency response equipment requirements and procedures for use, inspection, testing, and maintenance.
- Training requirements for employees who are responsible for rescue operations, medical duties, hazardous response, and firefighting.
- Procedures for update, review, and redistribution of the emergency response plan.

- Procedures for coordination of related activities with local emergency response and planning officials.

The emergency response plan also needs to consider whether:

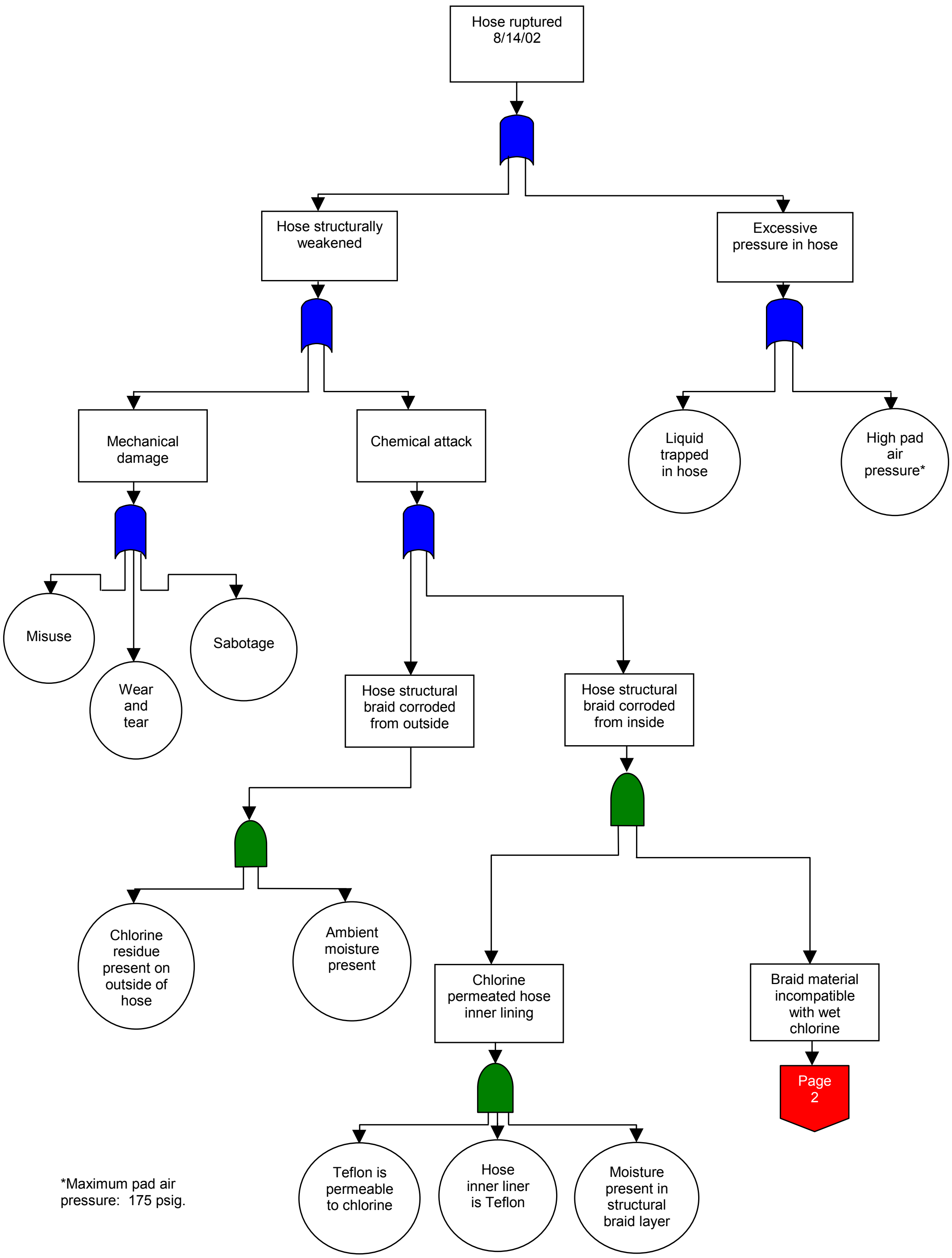
- Other nearby facilities may pose a hazard in the event of an emergency.

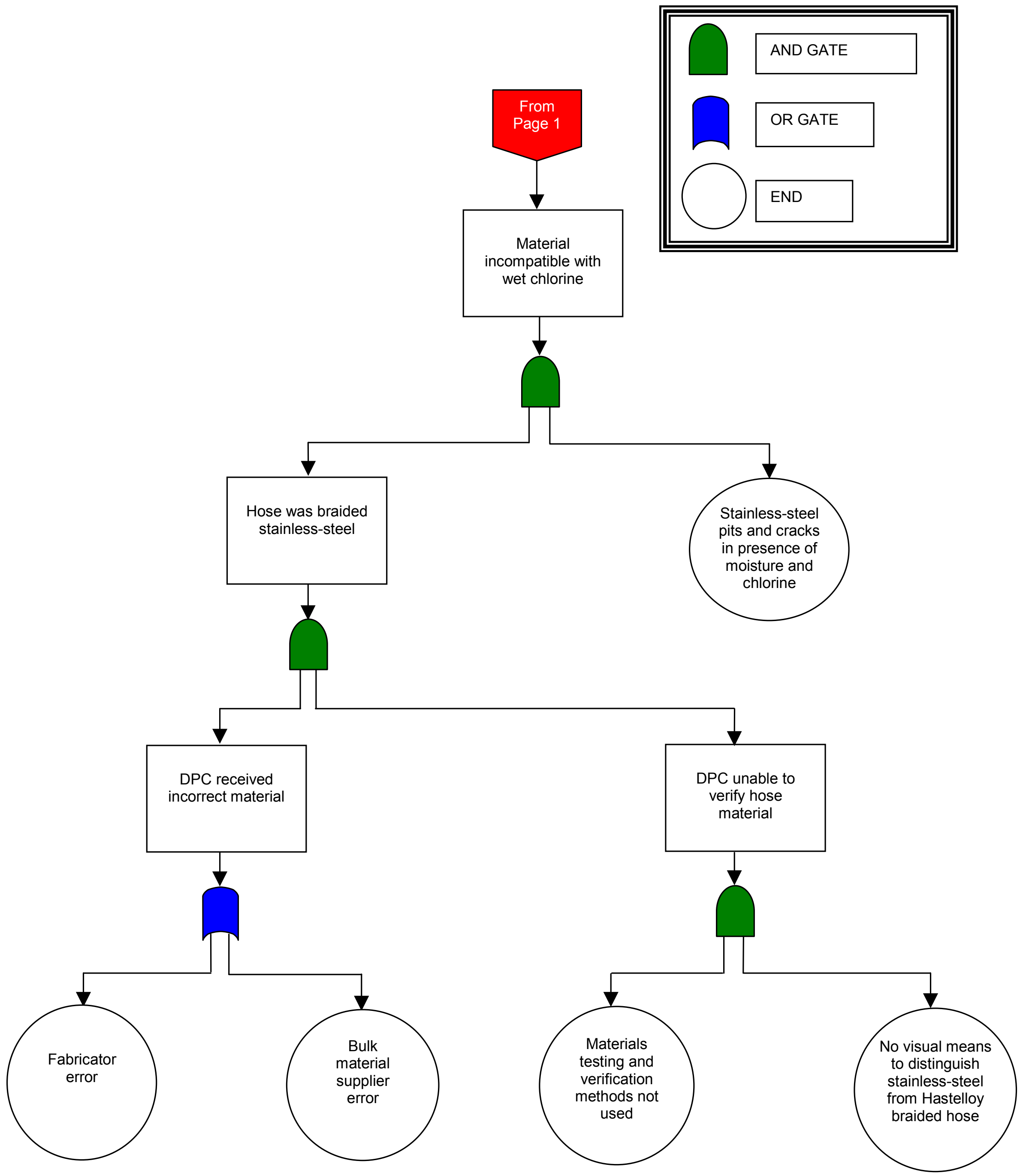
- Toxic materials themselves may cause unsafe conditions.

The chemical manufacturer or supplier of toxic materials provides material safety data sheets (MSDSs), which describe potential hazards; list precautions for handling, storing, or using the substances; and outline emergency and first-aid procedures. This information should be easily accessible to employees and the community.

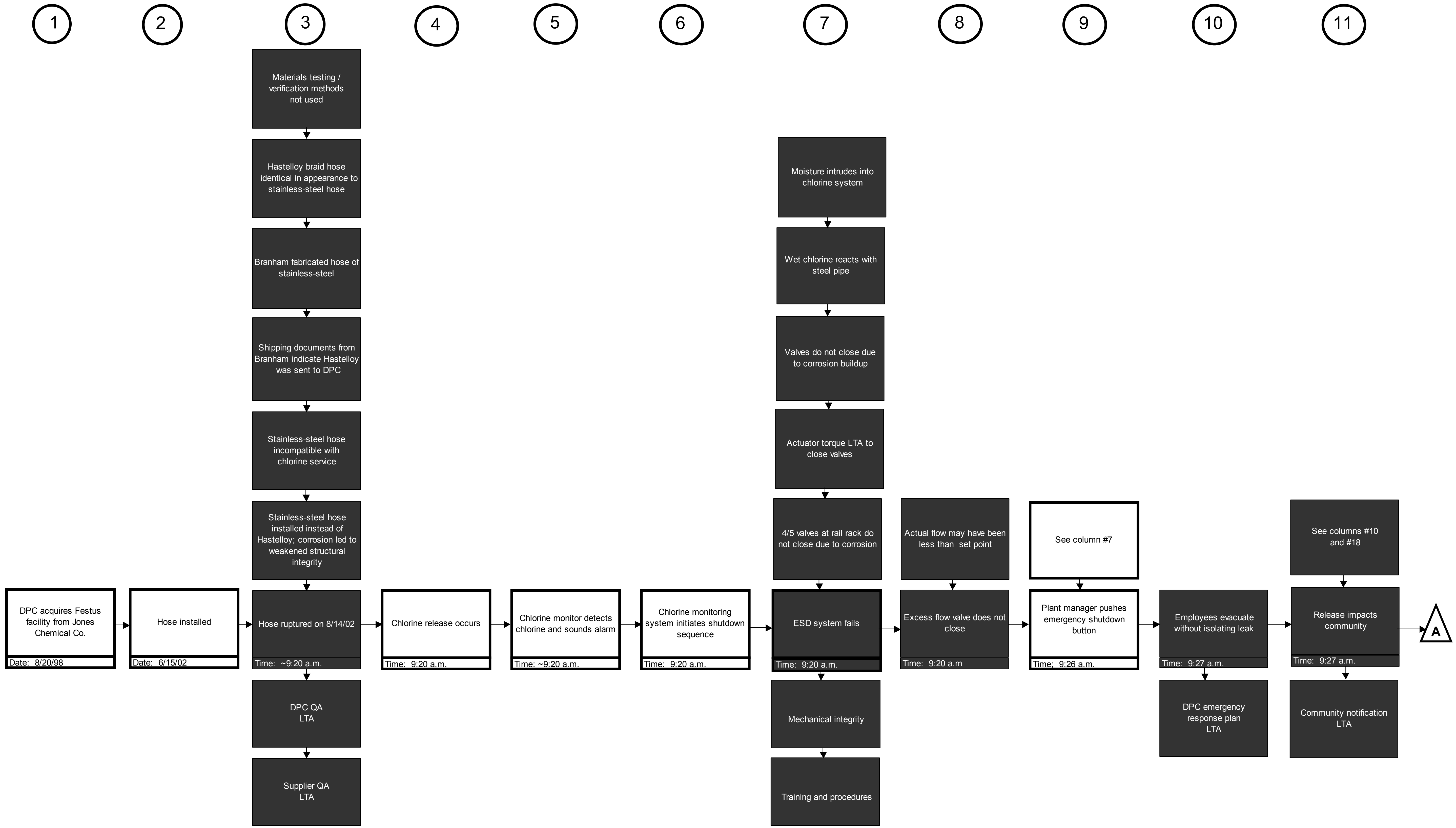
All employees must be trained on how to respond to potential emergencies. The emergency response plan should be reviewed with all employees when it is initially developed, when employee responsibilities change, and whenever the plan itself is revised. It should be kept in a location that is easily accessible to all employees.

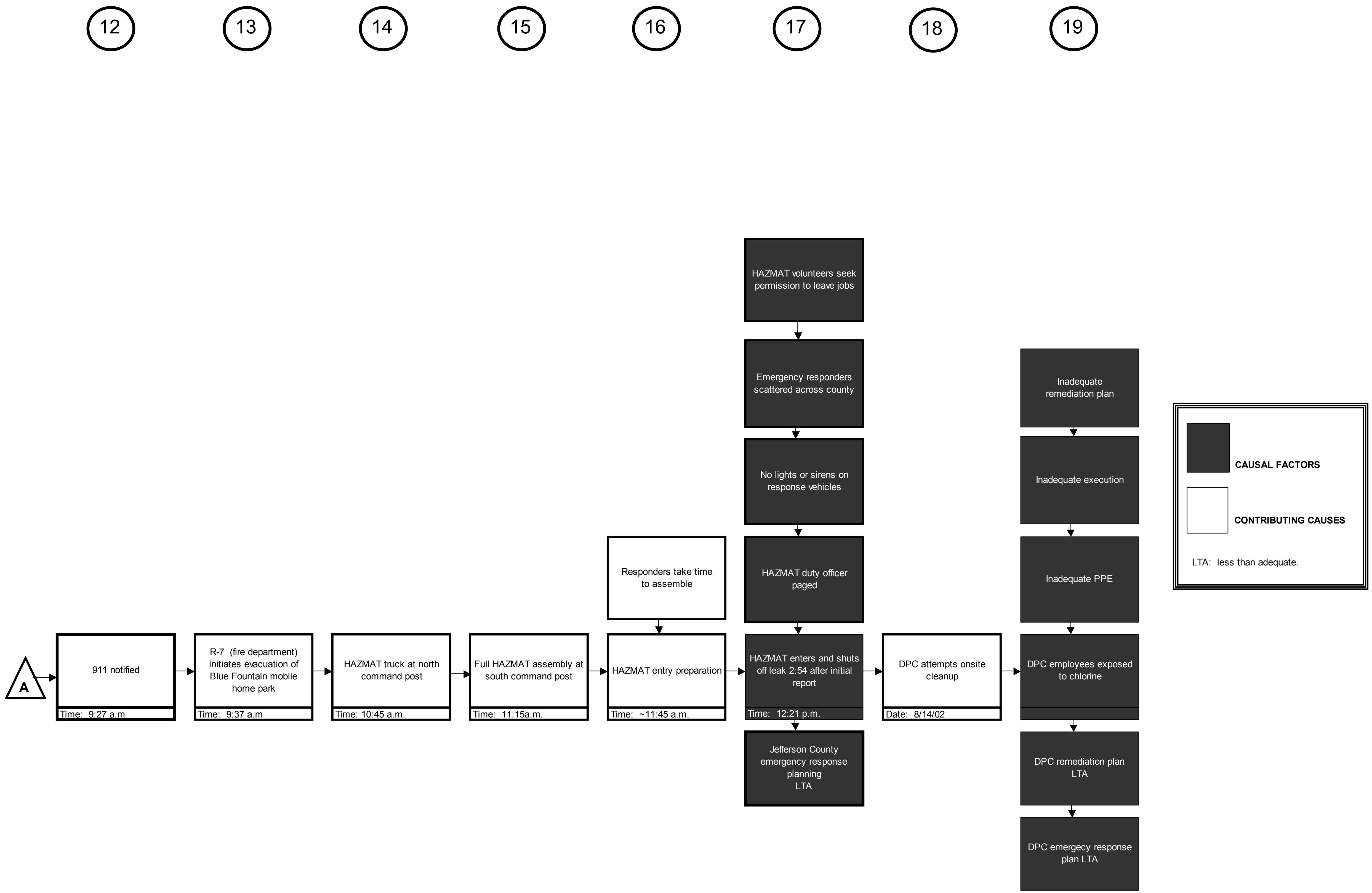
APPENDIX E: Fault Tree Analysis, Hose Failure




AND GATE
OR GATE
END
From Page 1
Material incompatible with wet chlorine
Hose was braided stainless-steel
Stainless-steel pits and cracks in presence of moisture and chlorine
DPC received incorrect material
DPC unable to verify hose material
Fabricator error
Bulk material supplier error
Materials testing and verification methods not used
No visual means to distinguish stainless-steel from Hastelloy braided hose

APPENDIX F: Causal Factors Diagram, Chlorine Release




12
13
14
15
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18
19
A
911 notified
Time: 9:27 a.m
R-7 (fire department) initiates evacuation of Blue Fountain moblie home park
Time: 9:37 a.m
HAZMAT truck at north command post
Time: 10:45 a.m.
Full HAZMAT assembly at south command post
Time: 11:15a.m.
Responders take time to assemble
HAZMAT entry preparation
Time: ~11:45 a.m.
HAZMAT volunteers seek permission to leave jobs
Emergency responders scattered across county
No lights or sirens on response vehicles
HAZMAT duty officer paged
HAZMAT enters and shuts off leak 2:54 after initial report
Time: 12:21 p.m.
Jefferson County emergency response planning LTA
DPC attempts onsite cleanup
Date: 8/14/02
Inadequate remediation plan
Inadequate execution
Inadequate PPE
DPC employees exposed to chlorine
DPC remediation plan LTA
DPC emergency response plan LTA
CAUSAL FACTORS
CONTRIBUTING CAUSES
LTA: less than adequate.