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CSB Investigation of the Explosions and Fire at the BP Texas City Refinery on March 23, 2005

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At approximately 1:20 p.m. on Wednesday, March 23, 2005 a series of explosions and fire occurred at the BP Texas City oil refinery during the start-up of an isomerization (ISOM) process unit. Fifteen workers were killed and about 170 other people were injured. Many of those killed were working in or around office trailers located near a blowdown drum and stack open to the atmosphere. The U.S. Chemical Safety and Hazard Investigation Board (CSB) found that because of problems that began during the ISOM process unit start-up, a sudden, geyser-like release of flammable hydrocarbon liquid and vapor discharged from the atmospheric vent stack. This release created a flammable vapor cloud, which ignited, causing as many as five explosions and fire in and around the ISOM unit. CSB identified multiple possible ignition sources in and around the blowdown drum area, including idling vehicles; however, the exact ignition source remains unknown.

CSB deployed a team of investigators to BP Texas City to conduct a root-cause investigation immediately after the incident. This team examined blast patterns to determine the explosion origin; reviewed the design of the isomerization unit equipment; and examined plant safety and operating procedures, past accidents, maintenance procedures, and oversight and inspection. Investigators also reviewed the adequacy of applicable regulations and industry standards for the placement of temporary structures such as trailers in refineries. This article presents the preliminary findings from the CSB investigative team regarding the technical and underlying causes of the incident and discusses three urgent recommendations issued by the CSB stemming from the BP incident.

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1. INTRODUCTION

The March 23, 2005 incident at the BP Texas City refinery involved a sudden release of flammable hydrocarbon liquid and vapor from an atmospheric vent stack in the refinery's isomerization (ISOM) unit. Temporary work trailers were positioned 100 to 150 feet away from the vent stack. Their purpose was to provide office and storage space for contractors performing maintenance work during turnaround at an adjacent unit. The fifteen fatalities were contractors who were in and around these trailers at the time of the explosions and fire [1].

2. TEXAS CITY REFINERY BACKGROUND

The BP Texas City refinery is the third largest in the United States. Amoco Corporation built and oper-

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ated the refinery until January 1999 when Amoco Corporation merged with BP. The Texas City refinery can produce about 11 million gallons of gasoline a day. The refinery has 30 process units spread over a 1200-acre site. In addition to gasoline, the refinery produces jet fuels, diesel fuels, and chemical feed stocks. The Texas City refinery also employs about 1800 staff and hundreds of contractors.

3. PROCESS DESCRIPTION

The incident occurred in the raffinate section of the ISOM unit. The ISOM unit converts the feed hydrocarbons pentane and hexane into the products isopentane and isohexane to boost the octane rating of gasoline. The unit works by heating the pentane and hexane in the presence of a catalyst. The raffinate section is composed of a splitter tower and associated process equipment, which are used to prepare the hydrocarbon feed for the isomerization reactor.

4. INCIDENT DESCRIPTION

On the morning of March 23, the raffinate splitter was being restarted after a maintenance outage. During the start-up, liquid hydrocarbons were pumped into the splitter tower for 3 hours without any liquid removed and transferred to storage. As a result, the 164-foot tall distillation column was overfilled and eventually overflowed hydrocarbons into the vertical piping on the top of the tower. In addition, unknown to operators controlling the process, critical alarms and control instrumentation were malfunctioning, providing the operators with erroneous process control information.

The hydrocarbon level in the vertical piping built up and exerted pressure on the emergency relief valves 150 feet below. Over a period of several minutes, the pressure, as measured at the bottom of the overhead piping, rose from about 20 pounds per square inch (psi) to about 60 psi. This pressure activated three pressure relief valves used to vent high pressure in the column; the relief valves were set to open at 40, 41, and 42 psi. The relief valves remained open for 6 minutes, according to computerized records. During this period, hydrocarbon liquid and vapor were discharged to the blowdown drum. The blowdown drum overfilled with hydrocarbon liquid, leading to a geyser-like release from the stack. The flammable hydrocarbons pooled on the ground, releasing vapors that ignited, resulting in multiple explosions and fires. This blowdown system was of an antiquated design; it was originally installed in the 1950s and it had never been connected to a flare system to safely combust flammable vapors released from the process.

5. KEY ISSUES

At this point in its investigation, The U.S. Chemical Safety and Hazard Investigation Board (CSB) identified six key issues:

1. Occupied trailers were sited in an unsafe location, too close to a process unit handling highly hazardous materials. All 15 fatalities occurred in or around the two trailers positioned closest to the blowdown drum and atmospheric vent stack.
2. The ISOM unit should not have been started up with existing malfunctions of the tower level indicator, level alarm, and control valve. Known problems with instrumentation and equipment were not repaired before start-up.
3. The raffinate splitter tower had a history of abnormal start-ups. It became the norm to fill the splitter tower with liquid above the range of the indicator for long periods of time throughout the start-up process; therefore, it was impossible for operators to discern the actual level of liquid in the tower.
4. On the day of the incident, an unsafe blowdown drum and stack vented highly flammable material to the atmosphere. The drum was never connected to a flare since its construction in the 1950s. The first rule of oil refinery safety is to keep the flammable hazardous materials inside the piping and equipment. A properly designed flare system would safely contain the liquids and combust flammable vapors, preventing an unsafe release to the atmosphere.
5. Between 1995 and March 23, 2005, there were at least four other serious releases of flammable material from the ISOM blowdown drum and stack. Even though these serious near misses revealed the hazard of the blowdown design, no effective investigations were conducted or changes made.
6. The refinery missed a number of opportunities to replace the hazardous blowdown drums. In 1992, OSHA cited a similar blowdown drum and stack at the refinery as unsafe, but the citation was dropped and the drum was not connected to a flare. In 1997, the ISOM blowdown drum and stack corroded and were replaced with like equipment, even though corporate safety standards required replacing blowdown drums with flares when major modifications were made to existing equipment. In 2002, the refinery evaluated connecting the ISOM blowdown system to a flare as part of an environmental initiative, but did not pursue this option.

6. PRELIMINARY FINDINGS

The following are some important facts that relate to the causes of the hydrocarbon release, the subsequent fire and explosions, and the reasons for the injuries and the fatalities. Because the investigation is not complete, CSB will refer to these items as preliminary findings.

6.1. Trailer Siting

The first preliminary finding concerns the siting of the occupied trailers too close to hazardous process areas. All of the fatalities, and many of the critically injured, were in or around the nine contractor trailers that were positioned near process units and as close as 121 feet from the ISOM blowdown drum and stack. The ISOM unit contained large quantities of flammable hydrocarbons and had a history of releases, fires, and other safety incidents over the previous two decades.

At the Texas City refinery, trailers have been periodically sited in and around process units handling highly hazardous materials for reasons of convenience, such as ready access to work areas. BP had sited trailers for contractors in the same location near the ISOM unit for a number of years. Trailers such as these did not need to be sited as close as they were to process areas for the contractors to perform their job duties.

Under BP's siting policy, trailers used for short periods of time, such as turnaround trailers, were considered as posing little or no danger to occupants. This approach conforms to the safety guidance published in Recommended Practice 752, by the American Petroleum Institute (API) [2].

The American Petroleum Institute is the primary safety standard setting trade association for the oil industry. API 752 states that each company may define its own risk and occupancy criteria. There are no defined minimum protections. API 752 provides no safe minimum distances from process areas for the location of trailers used in refineries and other chemical facilities.

Over 40 trailers were damaged in this incident. Workers in adjacent units were injured in trailers 480 feet from the ISOM blowdown drum. A number of trailers, some as far as 600 feet from the blowdown drum, were heavily damaged. Trailers can be easily relocated to less hazardous areas.

Trailers are not generally designed to protect occupants from fire and explosion hazards. In contrast, occupied buildings such as control rooms and operator shelters located within a process unit are typically permanent and constructed to be blast and fire resistant. For these reasons, CSB issued an urgent recommendation to API to advise their members to remove trailers away from hazardous areas in process plants.

6.2. Unit Start-up and Mechanical Integrity Issues

The next preliminary finding addresses unit start-up and mechanical integrity issues. The raffinate splitter tower was started up despite malfunctioning key process instrumentation and equipment on the day of the incident, including the tower level indicator and sight glass, tower hard-wire level alarm, blowdown drum high-level alarm, and the tower 3-lb pressure valve. Both the tower level indicator and a hard-wired high-level alarm were malfunctioning during the events that led to the incident. The hard-wired high-level alarm and the level indicator were documented by work orders as malfunctioning, but were not repaired before start-up. The sight glass on the raffinate splitter tower, which gives a visual check of tower liquid level and can help verify the accuracy of the level indicator, was reported before the start-up to be dirty and nonfunctional. In addition, the high-level alarm for the blowdown drum did not sound before the incident.

Before unit start-up, operators informed management that the tower 3-lb pressure valve (that is, a valve used to remove noncondensables and excess pressure) was not operating. Still, the valve was not repaired before start-up. This led operators to use alternative methods to remove nitrogen and reduce tower pressure, such as opening an 8-in. chain bypass valve to the blowdown drum and stack.

Post-incident testing confirmed that the 3-lb valve was not working properly. The proper working order of key process instrumentation was not checked as required by the start-up procedure. This was an additional opportunity to verify that the instrumentation was working properly. However, operations personnel starting up the unit did not know of problems with the tower level indicator and high-level alarm because checks to determine operability of these instruments were not performed. Verification of instrument operability is required in the procedures and is a critical step in the start-up process. However, unit operations management turned away instrument technicians and signed off on the checks as if they had been completed. The raffinate unit should not have been started up when important instrumentation and equipment were known to be malfunctioning.

Operations personnel did not open the tower level control valve at the time specified in the start-up procedure. They did not balance the hydrocarbon flows in and out of the tower. The tower filled up because liquid was being added for nearly 3 hours without being removed. CSB is further investigating possible underlying causes such as workload, fatigue, communications, and management oversight concerning this issue.

During the hours of 10:00 a.m. to 1:00 p.m., the liquid level was rising rapidly to the top of the 164 foot tower. However, the indicator that operators were using to determine the level in the tower showed the level to be significantly less, within the bottom 10 feet of the tower and declining further, during this same time period. The tower level indicator only spans the bottom 10 feet. A false level indication showing the tower level declining was a factor in the delay in removing liquid from the tower. Operators relied on this level indication and they took no action as they observed the level drifting back toward the normal operating range below the 10 foot indicator. Start-up procedures did not address the importance of maintaining a balance of liquid flow in and out of the tower or the consequences of deviation. The tower was not equipped with additional instrumentation indicating tower level, such as a tower bottom pressure indicator, that could have provided the operators with additional information concerning the tower level.

The tower had a history of abnormal unit start-ups. In 16 start-ups of the raffinate splitter tower from April 2000 to March 23, 2005, eight of these start-ups of the raffinate splitter experienced at least two times the normal pressure, greater than 40 vs. 20 psi, the normal operating pressure.

In 13 of the 16 start-ups, the pressure exceeded 30 psi, the alarm set point for high tower pressure. In February 2003, the set points of the emergency relief valves were lowered from 70 to 40 psi as a result of corrosion in the tower.

Since 2003, two splitter tower start-ups had pressure excursions of over 40 psi that likely resulted in the emergency relief valves venting to the blowdown drum. Thirteen of the start-ups of the raffinate splitter had liquid levels above the range of the level indicator, that is, greater than 10 feet, some lasting as long as 4 hours.

Also, in two thirds of the start-ups, liquid feed circulation to the raffinate splitter was started when the tower was already above the range of the level indicator. Filling above the level indicator makes it difficult to know how much liquid is within the tower, thus making it much easier to overfill. However, most of the previous start-ups established liquid flow out of the tower much sooner, between 3 and 45 minutes after flow was introduced, rather than the 3 hours it took in this incident. Moreover, preliminary analysis indicates that none of the previous start-ups experienced a high level into the upper section of the tower, as occurred in the March 23 incident.

BP did not investigate these previous raffinate splitter tower start-ups with high pressures and high levels as required by BP policy. The occurrence of high pressures and high liquid levels during the tower start-ups had become part of the operating norm. It is important to investigate these near-miss incidents, even those without serious consequences, because catastrophic incidents can follow if problems go uncorrected. Investigation of these incidents could have resulted in improvements to tower design, instrumentation, procedures, controls, and training.

6.3. Management Oversight and Accountability

BP management did not ensure that an experienced supervisor was in the unit to provide oversight during start-up. BP policy requires experienced supervisory personnel to be assigned to process units during start-up to assist in making important decisions. At 10:00 a.m., the supervisor in charge left the unit for a family emergency but no substitute with ISOM operating experience was assigned. The departing supervisor had many years of operating experience in the unit. The relief supervisor was not involved in the start-up and had no ISOM operating experience. He could not provide the necessary level of guidance during the critical start-up period. No other experienced supervisors were assigned to this start-up.

6.4. Process Design

The blowdown drum was not properly sized to handle the flammable material coming from the raffinate tower. The drum was attached to a 67 foot tall vent stack open to the atmosphere. The blowdown drum and stack design is outdated and unsafe because this system releases flammable hydrocarbons to the atmosphere. In fact, BP policies recommended phasing out such blowdown systems when major modifications were made. Modern emergency relief systems send hydrocarbons to a flare system that includes an adequately sized knock-out drum to capture liquids and a flare to safely combust the flammable vapors.

Amoco safety standards, last revised in 1994, state that blowdown drums should be connected to a flare when major modifications are made. In 1997, Amoco replaced the blowdown drum and stack with identical equipment rather than connecting the drum to a safer location such as a flare system. This replacement, the result of corrosion, was a major modification under Amoco's procedures. Amoco was the owner of the refinery in 1997. Consequently, at that time, the blowdown drum and stack should have been converted to a flare system. After the merger in 1999, BP adopted the Amoco safety standard for blowdown drums at the refinery. In 2002, BP evaluated connecting the ISOM blowdown system to a flare as part of an environmental initiative, but did not pursue this option.

Since the March 23, 2005 incident, BP has stated they plan to discontinue the use of blowdown drums open to the atmosphere at the facility. At the time of the incident, the raffinate splitter tower did not have an effective pressure control system to reduce high pressure and remove hydrocarbons to a closed system. This led, in part, to the dependency on a blowdown drum and stack to reduce high pressures that may build up within the tower. The tower should have had an additional layer of protection such as a pressure control valve to a closed system to remove hydrocarbons and reduce built-up excess pressures, thus lessening the dependency on the blowdown drum and stack relieving the atmosphere. The use of a closed system could have prevented or reduced the severity of the incident.

In 1992, OSHA cited and fined Amoco on the hazardous design of a similar blowdown drum and stack that handled flammable hydrocarbons at the Texas City refinery. The blowdown referred to was located in another unit, but was of similar design to the ISOM blowdown system. In the original citation and notification of penalty, OSHA suggested that the appropriate abatement method was to reconfigure the blowdown to a closed system with a flare. In a settlement agreement, OSHA withdrew the citation and fine and the refinery continued to use blowdown drums without flares. This early opportunity to remove hazardous blowdown drums was not acted on.

6.5. Previous Incidents

Since 1995, at least four releases from the blowdown drum sent hydrocarbons to the stack and sewer, generating flammable vapor clouds at ground level. During these releases, vapors formed ground-level flammable clouds. The drain valve off the bottom of the blowdown drum was chained open at the time of the incident and had been in this position for a number of years to allow for liquid hydrocarbons to flow into the process sewers. Because the hydrocarbon vapors coming out of the stack were heavier than air, material released descended toward the ground and also formed flammable clouds. Fortuitously, these previous releases did not find a source of ignition. CSB found that the four previous blowdown incidents were not properly investigated, nor were needed corrective actions implemented.

6.6. Vehicle Traffic

The final preliminary finding we will discuss concerns BP's vehicle traffic policy. CSB found that vehicles played an important role in the incident. BP's vehicle policy allowed vehicles unrestricted access near process units. BP's policy does not establish safe distances from process unit boundaries for vehicles. Nearly 55 vehicles were located in the vicinity of the blowdown drum and stack at the time of the incident. Two running vehicles may have provided sources of ignition for the incident. One was within 25 feet of the blowdown drum and stack.

7. URGENT RECOMMENDATIONS

In light of these findings, CSB issued three urgent recommendations that the agency believed needed immediate action such that it could not wait until completion of the full root cause investigation. The first urgent recommendation called on the BP Global Executive Board of Directors to commission an independent panel that would review a range of safety management and culture issues. It is the first safety recommendation in CSB's 8-year history that has been designated as "urgent" and issued in advance of a completed investigation. In voting to adopt the recommendation, the Board said that identified safety management lapses pose an issue that "is considered to be an imminent hazard and has the potential to cause serious harm unless rectified in a short time frame."

Citing a series of serious safety incidents at the Texas City facility over the past two years, including two that occurred after the March 23rd incident, the Board recommended that BP establish and fund a diverse panel of experts, including employee representatives. The panel would review corporate safety oversight, safe management of refineries obtained through mergers and acquisitions, corporate safety culture, and management systems such as near-miss reporting and mechanical integrity programs.

The Board directed the other two urgent recommendations to two leading national trade organizations, the American Petroleum Institute (API) and the National Petrochemical & Refiners Association (NPRA), which represent most major domestic oil and petrochemical producers. API develops recommended safety practices that influence operations at thousands of petrochemical facilities around the country.

The first recommendation calls on API to develop new industry guidance "to ensure the safe placement of occupied trailers and similar temporary structures away from hazardous areas of process plants." The Board noted that the existing safety guidance, API Recommended Practice 752, does not prohibit the placement of trailers in close proximity to hazardous process units. The guidance, entitled "Management of Hazards Associated with Location of Process Plant Buildings," is widely used by U.S. oil and chemical companies to assess siting hazards, a regulatory requirement under OSHA's Process Safety Management standard.

As currently written, API 752 allows individual companies to define their own risk and occupancy criteria for trailers. Before March 23, BP had defined trailers used for short periods of time as posing little or no danger to occupants and allowed the placement of the trailers near the ISOM unit.

According to findings accompanying the Board's urgent recommendation, the explosions in Texas City injured workers in trailers as far as 480 feet from the source of the release, and trailers as far as 600 feet away were heavily damaged. Subsequent to the incident, BP announced it would relocate trailers at least 500 feet away from potential hazards and move nonessential workers into office space outside the refinery.

In many cases, trailers are positioned for convenience during maintenance and are not essential for facility operations. These trailers can be easily relocated to safe distances. Permanent buildings in refineries and chemical plants are often heavily reinforced to resist blast and fire damage, whereas most trailers and temporary structures provide little protection for occupants.

A separate urgent recommendation, directed jointly to API and NPRA, called on the organizations to immediately contact their members urging "prompt action to ensure the safe placement of occupied trailers away from hazardous areas of process plants," before the new API safety guidance is completed.

8. ONGOING INVESTIGATION ACTIVITIES

CSB's investigation into the BP incident continues. The root and contributing causes to catastrophic events, such as what happened on March 23, 2005, are often complex and interrelated. For this reason, incident investigations require detailed and thorough analysis to uncover the underlying safety issues that may exist at the facility and within the industry in general. CSB is dedicated to that task. Once completed, the report will be available at www.csb.gov.

LITERATURE CITED

1. 40th Annual Loss Prevention Symposium, 2006, AIChE Spring National Meeting, Orlando, FL, April 24–26, 2006.
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