0260-9576/06/$17.63 + 0.00

IChemE

Lessons from Texas City A Case History

Michael P. Broadribb, C.Eng.
Senior Consultant, Process Safety, BP America Production Company, Houston, Texas

Summary

A major incident occurred in March 2005 on the Isomerization Unit at the BP refinery in Texas City, Texas, one of the largest refineries in the USA.

An explosion occurred when heavier than air hydrocarbon vapours combusted after coming into contact with an ignition source, probably a running vehicle engine. The hydrocarbons originated from liquid overflow from a blowdown stack following the operation of the Raffinate Splitter overpressure protection system caused by overfilling and overheating of the tower contents. The severity of the incident was increased by the presence of many people congregated in and around temporary trailers, which were sited close to the process unit.

This paper will explain how and why the incident occurred, the general lessons learned, the actions taken to prevent recurrence, and highlight some wider messages for the industry.

Introduction

The Texas City Refinery is BP's largest and most complex oil refinery, with a rated capacity of 460,000 barrels per day (bpd) and production of up to 11 million gallons of gasoline a day. It also produces jet fuels, diesel fuels and chemical feed stocks. The refinery has 30 process units spread over a 1,200-acre site and employs about 1,800 permanent BP staff. It was owned and operated by Amoco prior to the merger of BP and Amoco in 1999 and largely uses Amoco safety management systems pre-dating the merger. At the time of the incident approximately 800 additional contractor staff were on site for significant turnaround work.

The incident occurred on the Isomerization Unit (ISOM) and involved the Raffinate Splitter (the Splitter), and Blowdown Drum & Stack. The ISOM converts low octane blending feeds into higher octane components for blending to unleaded regular gasoline. The unit has four sections, one of which is the Splitter, which takes a non-aromatics stream from the Aromatics Recovery Unit (ARU) and fractionates it into light and heavy components. The Splitter may be run in conjunction with the ISOM or independently to build inventory when the ISOM is shut down.

The Splitter was originally commissioned in 1976, but has been modified several times. It is a single fractionating column, 164 ft (50 m) tall with 70 distillation trays, feed surge drum, fired heater reboiler, fin fan overhead condenser, and reflux drum. It has an approximate volume of 3,700 barrels, and processes up to 45,000 bpd of raffinate from the ARU. About 40% of the total raffinate fed to the unit is recovered overhead as C5/C6 light raffinate. The remaining bottoms product consists of C7/C8 heavy raffinate.

Hot hydrocarbon vapours and minor associated liquids from the ISOM relief, vent, and pump-out systems during upsets or shutdowns are disposed of to a blowdown system. The blowdown system consists of relief pipework headers (one of which is from the Splitter), the Blowdown Drum & Stack (F-20), and a pump-out pump. Vapours disperse from the top of the stack and liquids flow out of the drum through a gooseneck into the site's closed sewer system. F-20 was commissioned in the 1950s and has been modified several times over the years. It is a vertical drum of 10-ft (3 m) diameter with a 113-ft-high (34 m) stack.

During start-up of the ISOM on Wednesday, 23 March, 2005, following a temporary outage, an explosion and fire occurred which killed fifteen and harmed over 170 persons. Many of those injured or killed were congregated in or around temporary trailers used for supporting contract workers involved in a turnaround taking place on the nearby Ultracracker unit. Several trailers were located between two operating units, the ISOM and the Naphtha Desulfurization Unit (NDU). The closest trailer, a double-wide trailer, was located within 150 ft (45 m) of the base of F-20, and is where most of the fatalities occurred at the time of the

As presented at the American Institute of Chemical Engineers 40th Annual Loss Prevention Symposium and Center for Chemical Process Safety 21st Annual International Conference, Orlando, Florida, April 2006

FIGURE 1: RAFFINATE SPLITTER

explosion. Trailers had been sited in the same area on several occasions previously, as no concerns were raised regarding this location from prior siting studies.

The site was secured and an Investigation Team established the following day to investigate the circumstances surrounding the incident, determine the root causes, make recommendations to prevent a recurrence, and identify lessons learned.

The investigation was performed over eight months, and included site inspections, witness interviews, document and record reviews, and chemical analysis of process samples. The computer hard drive from the process control system was secured and the data downloaded. Third party specialist companies were retained to document the explosion debris and effects, and to model the process and nature of the explosion. Process instrumentation and equipment, such as level indicators and relief valves, were tested, and an internal inspection of the Splitter was conducted.

Description of the incident

A double-wide trailer was installed west of the ISOM on 1 September, 2004. The MOC for the siting of this trailer was approved to proceed (i.e., develop MOC for final approval) and a hazard review was conducted on 6 October. The trailer was not approved for occupancy prior to the incident, but was occupied from late October/early November 2004. Subsequently, several other trailers were installed west of the ISOM for the Ultracracker turnaround. No MOC was initiated for these trailers.

On 21 February, 2005 the Splitter was shut down for a planned temporary outage, because of work on another part of the ISOM and ARU turnaround. The Splitter was steamed out to remove hydrocarbons and some maintenance tasks were carried out during the outage. Condensate was drained from low point drains on 14 March in preparation for restarting the unit. Following pressuring with nitrogen at 22.5 psig for tightness testing, the Splitter was depressured on 21 March.

The manpower on shift on the ISOM, NDU and AU2 units was doubled up for the period of the temporary

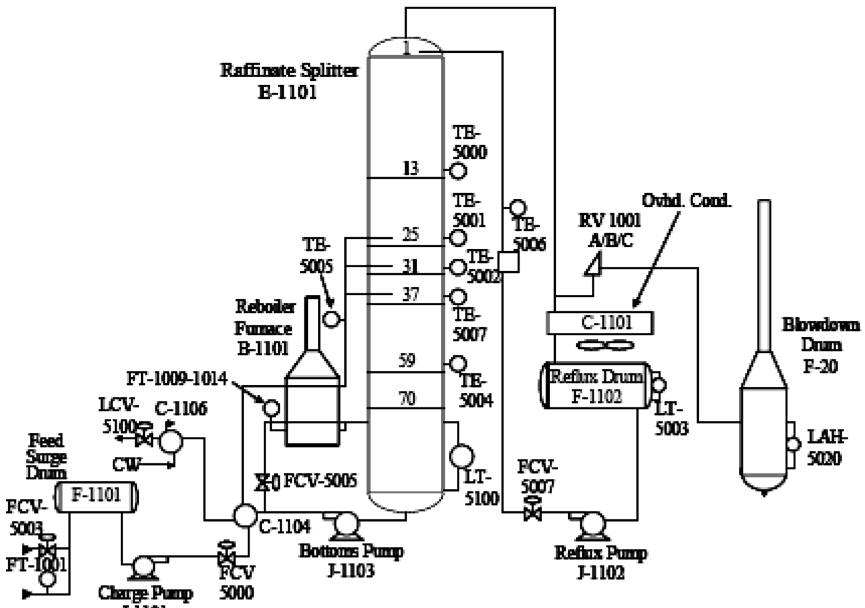

FIGURE 2: FLOW DIAGRAM OF RAFFINATE SPLITTER

FIGURE 3: BLOWDOWN DRUM AND ISOM UNIT, AFTER THE INCIDENT

outage from 21 February, 2005, through 23 March, 2005. On 22 March, the Production Planning Department requested the Shift Supervisor to start up the Raffinate Splitter. Technicians were checking instrumentation on the Splitter when they were informed the unit would be starting up. It appears from interviews that they may not have completed all the checks prior to start-up. The 3 psig vent system control valve (used to purge nitrogen from the Splitter) was stroked on 22 March, although it is not clear from witness statements whether it functioned properly. There was no entry in the log book or work order raised for repair.

On night shift 22/23 March, the Night Shift Supervisor told an operator to commence starting up the Splitter. The operator took control of the packing (establishing liquid levels) from the on-shift board operator and elected to pack the tower from the satellite control room. He brought in cold feed to the Splitter to establish levels in the Feed Drum and Tower, and to pack the Reboiler circulation loop. Prior to start-up, the instrumentation on the tower was not checked as per the procedure. He commenced charging feed to the tower at approximately 15,000 bpd at 02:13 hrs on 23 March. By 02:38 hrs the Splitter base level sensor started to indicate a gradually increasing level. At 02:44 hrs he opened the Reboiler flow control valve to establish reboiler circulation and charge liquid to the reboiler circuit, causing the indicated level to fall back to 3% by 02:55 hrs (3% is equivalent to approximately 2 ft 9 (0.8 m) in height above tangent). Thereafter, the Splitter base level gradually rose again until the level indicator's high level alarm activated at 72% at 03:05 hrs (approximately 5 ft 5 in. (1.6 m) height above tangent) as the tower was filled. The operator acknowledged the alarm, and at 03:08 hrs reduced the feed rate to the Splitter to approximately 10,000 bpd. The alarm remained on and acknowledged until after the incident, 11 hours later. The redundant hard-wired high level alarm, set at 78%, did not operate during this packing of the Splitter. The indicated Splitter base level continued to rise to 100% by 03:16 hrs, and at 03:20 hrs the ARU feed was routed to tankage. The operator closed the feed to the Splitter and the reboiler circulation to leave the remainder of the start-up to the day shift.

This operator left the site at 04:59 hrs after making shift relief with the NDU/AU2 Shift Supervisor (not the Day Shift Supervisor). A handover did occur between the Night Shift Board Operator and the Day Shift Board Operator while the start-up procedure remained in the satellite control room. At shift relief the tower had 4 psig pressure and a 100% base level indication (equivalent to 10 ft 3 in. (3.1 m) height above tangent). The night shift did not report the faulty hard-wired high level alarm to the oncoming day shift either verbally or in the shift log. A work order was not initiated for repair of the alarm.

On arrival at around 06:00 hrs 23 March, the day shift operators made their normal rounds and checked the unit line-up. The Day Shift Supervisor entered the site at 07:13 hrs. No pre-job safety review or procedure review was conducted. At 09:21 hrs the outside operators briefly opened the 8-inch (0.2 m) chain-operated vent valve, around the tower overhead relief valves that vented residual nitrogen from the Splitter tower and dropped the pressure from 4 psig to nominally atmospheric pressure. This pressure gradually rose back to 0.5 psig by 10:08 hrs.

The Day Shift Board Operator started the reboiler circulation at 09:41 hrs, and at 09:52 hrs reintroduced the feed to the Splitter at a rate of 20,000 bpd. After stroking the Heavy Raffinate rundown control valve to verify the lineup to tankage, the Day Shift Board Operator closed this control valve in manual. (The start-up procedure specifies 50% set point in automatic mode). The flow meter indicated a Heavy Raffinate flow of 3,000 to 4,700 bpd. This is believed to be a zero error on the meter, as the control valve was closed, and there was no heat exchange between the Heavy Raffinate and feed.

At approximately 10:00 hrs, two main burners were lit in the Reboiler fired heater. Shortly afterwards, the Day Shift Supervisor for the ISOM left the site due to a personal family matter. He later stated that he passed command to the NDU/AU2 Shift Supervisor, but this could not be confirmed. Two additional main burners were lit in the heater at 11:17 hrs, and the Splitter bottoms temperature continued to rise at approximately 75°F per hour compared to the 50°F per hour specified by the start-up procedure. The exact number of main burners eventually lit is unknown as it is not recorded and operators interviewed variously described four, five, or six burners. Throughout this period, feed into the Splitter continued at about 20,000 bpd and the heavy raffinate rundown remained closed. No liquids were taken out of the Splitter despite the continuous feed input.

Several possible distractions occurred in the Main Control Room during the start-up, when someone made several external telephone calls from the Control Board extension, and a safety meeting was held in the Control Room, around the control board for the ISOM.

Concerned at the continued absence of any indicated liquid level in the Reflux Drum by sometime late morning, the outside operators checked the bottom tap of the Reflux Drum level gauge and only vapour emerged. The Reflux Drum level transmitter continued to show 0% until 13:20 hrs.

The acting Superintendent, NDU/AU2 Shift Supervisor, an outside operator and a trainee operator left the site to get lunch and returned by 12:05 hrs. The acting Superintendent stated that he spent 75% of his workday on 23 March assisting the ARU turnaround.

By 12:20 hrs the Splitter base had reached the target temperature of 275°F (135°C) stipulated in the start-up procedure, with the feed temperature to the Splitter still only 120°F (49°C). (The normal feed temperature is 205°F (96°C)). The absence of heat exchange between the Heavy Raffinate rundown and feed at the Feed/Bottoms Exchangers at this time confirms the lack of any Heavy Raffinate rundown flow to tankage. The feed rate remained unchanged at 20,000 bpd.

By 12:40 hrs, the Splitter pressure had steadily climbed to 33 psig (normal operating pressure is about 20 psig) at the inlet to the overhead condenser, approximately 150 ft (45 m) below the top of the tower. A trainee operator noticed the high pressure on the satellite building control board screen display, and brought it to the attention of the other operators. At this point the outside operators opened the 8-inch (0.2 m) chain-operated vent valve for the second time in order to reduce the elevated pressure. The trainee reported seeing vapours that 'looked like steam' venting from the top of the stack, but another operator told him not to worry as it was nothing unusual. After approximately 10 to 15 minutes the chain-operated valve was closed, and by 12:55 hrs the pressure had fallen to 22.6 psig.

By 12:40 hrs, the Splitter base temperature had reached 302°F (150°C) (normal operating temperature is about 275°F (135°C)). The feed to the Splitter continued at 20,000 bpd with no outflow, and the calculated level in the tower reached over 130 ft (40 m) . At this temperature, modelling predicts some vaporization in the bottom of the Splitter, despite the head of colder liquid above. This would have lifted the liquid level higher than tray 13, but lower than the overhead line at the top of the tower. The cold liquid higher up the tower quenched these vapours and prevented them from distilling overhead.

After reviewing the unit status on the satellite control board, an operator telephoned the Day Shift Board Operator and told him that he needed to take a heavy raffinate rundown flow out of the tower. At 12:41 hrs the Day Shift Board Operator opened the Heavy Raffinate rundown control valve. The Heavy Raffinate rundown flow did not indicate a flow until approximately 13:00 hrs, and by 13:09 hrs had stabilized at 31,000 bpd. The feed to the Splitter continued at 20,000 bpd, and from 09:52 to 13:00 hrs approximately 2,500 barrels had been added to the tower. The calculated level peaked at 137 ft (42 m) in the tower (based on a simplified calculation ignoring the effect of vaporization in the base of the tower). At this level, 57 of the 70 trays within the column were flooded, and the feed inlet at tray 31 was submerged.

During these operations, the level transmitter (designed to operate with a liquid gas interface) was fully submerged and displayed a signal on the DCS screen slowly drifting downwards to 80% before any liquid was removed from the Splitter. The DCS high level alarm remained in alarm mode throughout.

An Ultracracker turnaround meeting had been called in the doublewide trailer, and attendees had started arriving at around 13:00 hrs.

At 13:02 hrs the off-site Day Shift Supervisor telephoned the satellite control room from outside the Refinery, and spoke to an operator, who indicated he was busy and would call back. At 13:09 hrs the operator telephoned the Day Shift Supervisor at home, who, upon hearing of the pressure trend, suggested opening the 11/2 inch (38 mm) vent valve around the Reflux Drum relief valve to vent nitrogen. This vent valve was opened and by 13:13 hrs the pressure at the inlet to the Overhead Condenser had fallen from 22.6 to 20.5 psig.

The Heavy Raffinate rundown stream exchanges heat with the incoming feed to the tower in the Feed/Bottoms Exchangers. At 13:01 hrs the feed preheat was 126°F (52°C), and rose to 260°F (126°C) by 13:10 hrs. This abnormally rapid increase in temperature led to the rapid onset of vaporization of the feed at the inlet point (tray 31) to the tower. This would have lifted the liquid above the feed tray even higher, such that it quickly reached the top of the Splitter and flowed over into the 24-inch (0.6 m) overhead line.

At 13:13 hrs the pressure at the inlet to the Overhead Condenser was 20.5 psig, but started to increase rapidly. This rapid pressure increase likely resulted from the rapid increase in feed preheat exchanged from the heavy raffinate rundown, which vaporized feed at the tower inlet, in conjunction with vaporization in the bottom of the tower, and lifted the excessively high liquid level over the top of the tower and into the overhead line. The liquid filled the 24-inch (0.6 m) overhead line above the pressure transmitter and relief valves, located about 150 ft (45 m) below the top of the tower.

Around this time an operator telephoned the Day Shift Board Operator and asked him to reduce firing on the Reboiler furnace due to the high temperature of 304°F (151°C)on the Splitter base. The Board Operator trimmed the Fuel Gas control valve output at 13:14 hrs to reduce the Reboiler outlet temperature.

By 13:15 hrs the pressure at the inlet to the Overhead Condenser peaked at 63 psig, and two outside operators confirmed that the tower overhead relief valves (with set points of 40, 41 and 42 psig) had opened to relieve directly into the Blowdown Drum & Stack (F-20) through a 14-inch (0.35 m)header.

At this point the fuel gas firing to the heater was stopped, and the outside operators blocked in the main burners. At 13:16 hrs the Reflux Drum low-low level alarm cleared, indicating liquid in the vessel for the first time, and the outside operators started a reflux pump at 13:17 hrs. The indicated reflux flow rate went off scale in excess of 35,700 bpd. The Reflux Drum low level alarm cleared at 13:19 hrs, indicating that the vessel was full of liquid (the drum normally runs in a flooded state). The DCS system shows that the second reflux pump was also started at 13:19 hrs, although none of the operators remembered doing so when interviewed after the incident.

At about this time there were radio messages from at least two witnesses, who saw vapours and liquid emerging approximately 20 ft (6 m) above the top of the stack 'like a geyser' and running down and pooling around the base of the Blowdown Drum & Stack. Vapours were seen evaporating from the liquid pool. The F-20 high level alarm alarmed for the first time at 13:20 hrs.

Alerted by the radio messages and the shouting of at least one eyewitness, several personnel in the area of the ISOM left the immediate vicinity before the vapours ignited. The evacuation alarm was not sounded. At least one witness saw a pickup truck parked just north of the Blowdown Drum & Stack with its engine racing and exhaust glowing, but it is not known if this was the source of ignition. Several witnesses described two or more explosions; the first minor explosion(s) followed rapidly by a louder, more powerful blast at approximately 13:20 hrs, although subsequent modelling suggests that there was only one explosion. The explosion severely damaged the doublewide and other trailers on the west side of the ISOM, and resulted in 15 fatalities and over 170 individuals harmed. The blast resulted in damage to the ISOM, causing a number of secondary hydrocarbon releases and fires.

The Site Emergency Response Team responded immediately and mounted a search and rescue operation. Mutual Aid and Lifeflight resources were requested and mobilized by 13:45 hrs. The feed to the Raffinate Splitter was not shut down, and stopped when electrical power went down at 14:45 hrs. The fires were brought under control after two hours, and injured personnel had been treated and/or transported to local hospitals, allowing ambulances and Lifeflight resources to stand down by 16:44 hrs. The final body was found at approximately 23:00 hrs, having been buried under debris.

Causal analysis

Immediate and system causes were analysed using the evidence compiled. The evidence was broken down into discrete building blocks of events or conditions from which the Critical (Causal) Factors were identified. Critical factors are those events or conditions that, if removed, might eliminate or reduce the possibility of the event occurring, or reduce the severity of it. For each critical factor, possible Immediate Causes and possible Management System Causes (Root Causes) were identified using BP's Comprehensive List of Causes (CLC) methodology.

The CLC is a 'pre-defined tree' technique for root cause analysis, which provides a systematic method of considering possible root causes associated with an incident. The investigator does not have to build the tree, but rather apply the critical causal factors to each branch in turn, and discard those branches that are not relevant to the specific incident. Further information on pre-defined trees is contained within the CCPS *Guidelines for Investigating Chemical Process Incidents.*

A number of underlying cultural issues were then distilled from the management system causes by using a '5 Whys' type of analysis.

Critical factors

The following critical causal factors were identified without which the incident would not have happened or would have been of significantly lower impact:

Loss of containment

Actions taken or not taken led to overfilling of the Raffinate Splitter and subsequent overpressurization and pressure relief. Hydrocarbon flow to the Blowdown Drum and Stack resulted in liquids overflowing the stack, causing a vapour cloud, which was ignited by an unknown source.

Raffinate Splitter start-up procedures and application of knowledge and skills

Failure to follow the start-up procedure contributed to the loss of process control. Key individuals (management and operators) did not apply their level of skills and knowledge, and there was a lack of supervisory presence and oversight during this start-up.

Control of work and trailer siting

Numerous personnel working elsewhere in the refinery were too close to the hazard at the Blowdown Drum and

Stack during the start-up operation. They were congregated in and around temporary trailers and were neither evacuated nor alerted.

Design and engineering of Blowdown Drum and Stack

The use of Blowdown Drum and Stack as part of the relief and venting system for the Raffinate Splitter, after several design and operational changes over time, close to uncontrolled areas.

Possible management system causes (Root Causes)

The following possible management system causes were determined for each critical causal factor. The bulleted items represent the title of the closest CLC branch:

Loss of containment

- poor judgment;
- inadequate training effort;
- inadequate leadership;
- inadequate adjustment/repair/maintenance;
- inadequate enforcement of policies/standards/procedures.

Raffinate Splitter start-up procedures and application of knowledge and skills

- fatigue;
- poor judgment;
- low mechanical aptitude;
- preoccupation with problems;
- improper supervisory example;
- inadequate training effort;
- conflicting roles/responsibilities;
- inadequate leadership;
- inadequate or lack of safety meetings;
- inadequate reference materials or publications;
- inadequate audit/inspection/monitoring;
- inadequate enforcement of policies/standards/procedures;
- inadequate vertical communication between supervisor and person;
- inadequate communication between work groups.

Control of Work and trailer siting

- inadequate leadership;
- inadequate correction of worksite/job hazards;
- inadequate identification of worksite/job hazards;
- inadequate evaluation and/or documentation of change;
- inadequate implementation of policies/standards/procedures due to deficiences;
- inadequate communication between different work groups.

Design and engineering of Blowdown Drum and Stack

- inadequate leadership;
- inadequate correction of worksite/job hazards;
- inadequate performance measurement and assessment;
- inadequate design;
- inadequate evaluation and/or documentation of change;
- inadequate work planning;
- inadequate audit/inspection/monitoring;
- inadequate communication of safety and health data, regulations or guidelines.

More information on the reasoning behind these possible management system causes is provided in the final investigation report.

Lessons learned

The significant number of possible management system causes identified above indicated many linked issues requiring further evaluation. In order to understand which recommendations would prevent reoccurrence it was decided to go deeper to the underlying cultural issues. The following issues were distilled from the system causes and illustrate a number of lessons learned, some of which will be applicable to a wider cross-section of the industry.

Business context

There was a lack of clearly defined and broadly understood context and business priorities for the Texas City site. A clear view of the key process safety priorities for the site or a sense of a vision or future for the long term could not be identified.

- focused on environment and personal safety, not process safety;
- there was little ownership of PSM through the line organization;
- the development of people was a low priority, with inadequate training;
- in staff's minds this created no future.

Over the years, the working environment had eroded to one characterized by resistance to change, and lacking of trust, motivation, and a sense of purpose. Coupled with unclear expectations around supervisory and management behaviours this meant that rules were not consistently followed, rigour was lacking and individuals felt disempowered from suggesting or initiating improvements.

- created a poorly motivated workforce who behaved in a disempowered way;
- lack of enforcement of following procedures, etc.;

- lack of role models at supervisor and superintendent levels;
- little expectation of behaviours and performance;
- no consequences of good or bad performance;
- reward structure leads to unintended circumstances;
- inward looking at plant and site level;
- lack of completion or follow-through;
- no verification of actions;
- fear to challenge and say 'no';
- lack of teamwork evidenced by many behaviours and attitudes

Examples of this environment include:

- Failure to follow procedures was identified as a causal factor in several previous investigations, but there were not any consequences for this behaviour at either supervisory/management or operator level.
- An explicit description of the desired behaviours for supervisory/management personnel was not readily available and evidenced by the absence of supervisors during key events such as critical shift handovers during a start-up procedure.
- Supervisors did not reinforce the importance of following procedures.
- At its last inspection, appreciable corrosion and internal damage was discovered in F-20, an item of safety critical equipment, but it was neither repaired nor a work order submitted for later repair.
- A reward system that encouraged supervisors and operators to work for extended periods of time with no clear consideration of fatigue.
- Many examples were given where individuals felt that making suggestions for improvements had little value and, over the years, had moved into a mode where they would follow instructions in an incomplete and routine way without thinking.

The 'check the box' approach to processes, such as MOC, was indicative of the poor motivation and reluctance to go beyond minimum compliance, and sometimes even the minimum was ignored. The inward-looking, closed environment resulted in corporate initiatives receiving limited attention as a 'not invented here' culture was tolerated. The learnings from external incidents were largely ignored at the site.

'Safety' as a priority

Process safety, operations performance and systematic risk reduction priorities had not been set and consistently reinforced by management.

Good safety is delivered through good line operations, underpinned by the right safety culture and values. The quality of basic operations had declined to the level where real safety interventions were necessary to ensure the right actions were being taken. Evidence of this was that shift changovers were inadequate, procedures were not followed, and line managers were unaware of operations that were underway.

There was no evidence of comprehensive and consistent business plans to reduce site risks. Existing plans focused on projects for reducing personal injuries and enhancing environmental compliance, but contained no plans for the systematic reduction of process risks or improving basic operations. For example, there were no plans to reduce or eliminate the use of blowdown stacks which vent to the atmosphere. A project considered an option to modify F-20 to tie into a flare system, but this was not progressed as the focus was on environmental compliance issues.

A number of interviewees noted that safety did not seem to be a priority, particularly as compared to cost management, for example. Although leadership stated 'safety first', this was not evidenced or believed by many of the workforce. Lack of leadership visibility and poor communication through the complex, siloed organization did not assist in delivering the right messages. Examples to support this included the absence of reporting (in some cases) and investigation (in most cases) around loss of containment incidents and process upsets.

No clear plans were found for enhancing organizational capacity or capability for the site. The required training for compliance was generally being provided, but training and development for first-level supervisors and superintendents was incomplete. This was most evident in the case of step-up supervisors, where the training and development program for these individuals in their step-up roles was poor or nonexistent. The low investment in developing supervisory levels appears to have harmed the communication with, and behaviours of, the workforce.

In general, the further down the organizational structure, the less clear the picture was with regard to safety priorities and the future vision for the refinery. As a result, many employees felt as though it was not useful to raise safety concerns or think of future actions, ultimately reducing morale and pride in the site.

Organizational complexity and capability

Many changes in a complex organization had led to the lack of clear accountabilities and poor communication, which together resulted in confusion in the workforce over roles and responsibilities.

The Texas City facility is a large complex site, which had multiple levels within the organization, apparently to address the span of control across such a large site. This organization had many interfaces requiring clear accountabilities and good communication both horizontally and vertically throughout the organization. In reality, examples were found of a lack of accountability, unclear roles and responsibilities, and poor communication with employees tending to work within silos. This, in turn, created confusion around some of the many interfaces. As a result, the working environment was cluttered with many processes, committees, etc., such that it was relatively easy to lose sight of the basic fundamental requirements for safe efficient operation.

- complex and unclear accountabilities;
- functional silos exist;
- communication within the plant is generally poor.

There were numerous examples of unclear accountabilities between groups; for example, with regard to who was actually accountable for the area between the ISOM unit and the NDU unit, where the damaged trailers were located. Similarly, when asked who was accountable for siting the trailers in this area, a mixture of answers was received.

There was no evidence of communication of the Splitter start-up to the adjacent work sites. One individual stated that contractors working inside the battery limits (ISBL) of the ISOM had been notified and warned to keep out of the area but, in the immediately adjacent catalyst warehouse area, no effort was made to notify or evacuate the people present in the trailers. The organization appeared to operate in walled silos.

The relationship between operations and engineering appeared inconsistent and fractured; evidence of this was the fact that engineering was not called during the start-up problems; nor were engineering rounds being routinely conducted. In addition, the 'independent' functions, such as training and PSM, had become under-resourced and lacked the influence to ensure that standards were met.

The Shift Director's meeting should be a key cross-unit communication vehicle, but attendance was not mandatory and discussion for the entire site was compressed into about 15 minutes, which was not adequate for genuine communication. Communication worked better within immediate work groups but not well outwards or upwards.

The low investment in developing supervisory levels contributed to this lack of clarity and poor communication due to the low leadership skill levels of those involved. This was exacerbated by a lack of reward or recognition for those who stepped across boundaries and stood in personal leadership.

This complexity created an organization which required behaviours across boundaries, between different groups and companies, but the clear divisions seen ensured that people were unlikely to communicate with or influence across these boundaries. Because of this, natural teams were often incomplete or incoherent.

Inability to see risk

A poor level of hazard awareness and understanding of process safety on the site resulted in people accepting levels of risk that were considerably higher than comparable installations.

Although some effort had been expended to raise awareness and understanding of process safety in the early 1990s, when OSHA promulgated the PSM rule, this basic training had not been effectively refreshed over the intervening years. There was no ongoing training program in process hazards risk awareness and identification for either operators or supervisors/managers.

- no risk reduction plan;
- passed down by experience, which was sometimes bad;
- gradually increasing risks and no process for systemic review;
- accepting incrementally lower standards throughout operations.

There were not effective holistic plans to systematically reduce risks in the refinery. Examples of this included no plan in place regarding the ultimate replacement/reconfiguration of the blowdown stacks in the site. The most recent Major Accident Risk assessment for the site failed to address the risks associated with blowdown stacks. The ISOM unit and its associated blowdown stack did not feature in the list of the top 80 risks at the site. Similarly, the MOC risk review for the doublewide trailer placement did not include any consideration of the risks associated with the blowdown stack, located within 150 feet (45 m).

One consequence was that temporary office trailers were placed within 150 feet (45 m) of a blowdown stack which vented heavier than air hydrocarbons to the atmosphere without questioning the normal industry practice.

Many examples of a high level of risk were observed within the site. At the most basic level was the significant number of vehicles allowed on the site, in close proximity to hydrocarbon processing units, and the extensive use of trailers for housing people in close proximity to hydrocarbon processing units. To visitors, this appeared unnecessary but had grown by custom and practice.

During the course of the investigation there were a number of (minor) fires within the site, in addition to a serious incident on the RHU. The general reaction of the workforce to these fires appeared to be not to worry, as fires were a fact of life in the refinery. Indeed, this was supported by the lack of investigation around previous fires. There were references to fires in Emergency Response Team logs without any documented investigation reports.

Other examples of high risk tolerance concerned the failure to conduct a review of the Splitter start-up procedure with the crew, as required by the procedure; the absence of supervision during the start-up, when it is common knowledge that start-up is a higher risk activity; and the lack of reporting of significant process upsets, such as relief valves lifting during previous start-ups.

All of these observations point to both a high level of risk having become accepted and an inability to see key process risks.

Lack of early warning

Given the poor vertical communication and performance management process, there was neither adequate early warning system of problems, nor any independent means of understanding the deteriorating standards in the plant.

The fifth and final cultural issue was the lack of a holistic early warning system for process safety exposures. The site had numerous measures for tracking various types of operational, environmental and safety performance, but no clear focus on the leading indicators for potential catastrophic or major incidents. Numerous audits had been conducted at the site in line with regulatory and corporate requirements, but had generally failed to identify the systemic problems with work practices uncovered by the investigation.

- vertical communication was poor;
- many Key Performance Indicators, but not transparent or useful for loss of containment, showing recordable injury frequency improvement;
- audit was process focused and did not gain verification of action.

The safety measures focused primarily on occupational safety measures, such as recordable and lost time injuries. This focus on personal safety had led to the sense that safety was improving at the site. There was no clear focus or visibility on measures around process safety, such as lagging indicators on loss of containment, hydrocarbon fires, and process upsets. Examples seen of this included that site leadership was not focused on trend analysis of measures that were likely to deliver an accurate sense of process safety at the site. Loss of containment incidents and process incidents did not get the attention they warranted. Many were not even formally reported or investigated, and thus corrective actions were not identified and addressed.

A large number of audit reports were reviewed by the investigation team, demonstrating that audits were being routinely conducted. The reports indicated that, for the most part, these audits were focused primarily upon review of processes and documentation. With the exception of the 'Big 4' safe work practice audit, none of the audits reviewed focused on verification and assessed, for example, whether or not procedures were being followed, and whether work practices were actually consistent with the procedures.

Follow-up actions

The Investigation Report identified a large number of recommendations specific to the Texas City refinery, and the ISOM unit in particular. The site leadership team has developed prioritized plans to address all the recommendations. However the following are some of the high priority actions already underway:

Developing people, skills and behaviour

- Appointed a new refinery manager and created a new leadership position to ensure prioritization and tracking of key site initiatives.
- Simplified the Texas City organization, so that everyone involved in maintenance and operations knows what they are accountable for and to whom.
- Clarified and reinforced roles, responsibilities and expectations around start-up, operating, maintenance and evacuation procedures.
- Initiated specific education and communication actions to ensure personnel are following procedures across the site.
- Started a program to design and deliver enhanced operator training and frontline leader education.
- Retained a consulting firm to assist with leadership development and design of an improved workplace environment.
- Co-located leadership in a common office location for improved communication.
- Created the role of Group Vice President for Health, Safety, Environment and Technology in the Refining and Marketing segment.
- Appointed a Group Vice President Safety and Operations to lead improvements in Safety, Health and Environmental Management.

Ensure safe, reliable equipment operation

- Began a top-to-bottom, continuous inspection and evaluation of the refinery.
- Removed the four high pressure units (above 1000 psi) from service and have underway a complete root and branch analysis from design through to current configuration. The units will not be run until that process is complete, and they are determined to be safe.

- Heightened oversight by requiring supervisors be present for all start-ups, shutdowns and for other critical operations including requiring written shift handovers with supervisor present.
- Strengthened control of work verification process to ensure work is stopped when deviations occur.
- Leased a 100,000 square foot (9000 m^2) building in Texas City to provide offices for employees whose work does not require their presence on the refinery site.
- Undertaking a complete relief valve revalidation study for all process units and a relief and flare system review.
- Begun the process to replace blow down stacks with flares.
- Initiated a process to identify and stop nonessential work.
- Engaged an outside firm to help assess and improve current maintenance work processes.
- Conducting a review of span of control and focus of operations leadership roles.

Refine and implement HSSE policies

- Removed temporary office trailers from within the site.
- Drastically reduced the number of vehicles allowed within the refinery.
- Instituted leadership audits to verify proper use of start-up, shutdown and safe procedures.
- Engaged a consultant to assist with management information around process safety.
- Have underway training for employees regarding enhanced communications on non-routine operations and expectations for sounding alarms.

Conclusions

The incident was an explosion caused by heavier-than-air hydrocarbon vapours combusting after coming into contact with an ignition source, probably a running vehicle engine. The hydrocarbons originated from liquid overflow from the Blowdown Stack following the operation of the Raffinate Splitter overpressure protection system caused by overfilling and overheating of the tower contents.

The failure to institute liquid rundown from the tower, and the failure to take effective emergency action, resulted in the loss of containment that preceded the explosion. These were indicative of the failure to follow many established policies and procedures. Supervisors assigned to the unit were not present to ensure conformance with established procedures, which had become custom and practice on what was viewed as a routine operation.

The severity of the incident was increased by the presence of many people congregated in and around temporary trailers which were inappropriately sited too close to the source of relief. The likelihood of this incident could have been reduced by discontinuing the use of the Blowdown Stack for light end hydrocarbon service and installing inherently safer options when they were available.

While the site management had introduced improvement programs, had completed a site-wide Major Accident Risk assessment and, following previous incidents, had begun to introduce many improvements in the areas of training, audit, and culture, the investigation found many areas where procedures, policies, and expected behaviours were not met. The underlying reasons for the behaviours and actions displayed during the incident were complex. It is evident that they had been many years in the making and will require concerted and committed actions to address.

The author would like to thank BP for permission to publish this paper.

References

1. Fatal Accident Investigation Report, Isomerization Unit Explosion, Texas City, 23rd March, 2005: BP America, Inc., December 9, 2005
2. Guidelines for Investigating Chemical Process Incidents, 2nd Ed., New York: American Institute of Chemical Engineers, Center for Chemical Process Safety, 2003