FATAL ACCIDENT INVESTIGATION REPORT

Isomerization Unit Explosion
Final Report

Texas City, Texas, USA

Date of Incident: March 23, 2005
Date of Report: December 9th 2005

Approved for release by J. Mogford, Investigation team leader

Executive Summary

On March 23rd 2005, 15 people were killed and over 170 harmed as the result of a fire and explosion on the Isomerization plant (ISOM) at the BP Products North America owned and operated refinery in Texas City, Texas, USA.

On May 17th an interim report was released to quickly spread initial learnings from the incident and to accelerate implementation of corrective actions. The interim report identified critical factors. To achieve early publication, the interim report did not address the underlying root causes leading to the incident.

This final report seeks to deepen understanding of the causes of the incident, and recommends additional corrective actions to prevent recurrence of a similar incident and to improve safety performance at the site.

The team's opinion is that there were four critical factors, as listed in the interim report, without which the incident would not have happened or would have been of significantly lower impact.

- **LOSS OF CONTAINMENT**
- **RAFFINATE SPLITTER STARTUP PROCEDURES AND APPLICATION OF KNOWLEDGE AND SKILLS**
- **CONTROL OF WORK AND TRAILER SITING**
- **DESIGN AND ENGINEERING OF THE BLOWDOWN STACK**

The incident was an explosion caused by heavier–than-air hydrocarbon vapors combusting after coming into contact with an ignition source, probably a running vehicle engine. The hydrocarbons originated from liquid overflow from the F-20 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. Many of those injured could have been warned and left the area safely had warning been provided by those who were aware of events. It is not clear why those aware of the process upset failed to sound a warning. 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.

The team found no evidence of anyone consciously or intentionally taking actions or decisions that put others at risk.

While the site management had introduced improvement programs, such as the 1000-day program, had completed a site-wide Major Accident Risk assessment exercise (MAR) and, following previous incidents, had begun to introduce many improvements in the areas of training, audit, and culture, the team found many areas where procedures, policies, and expected behaviors were not met.

In the course of this investigation, the team found many areas, although not critical factors in the incident, where practices should be improved and have included recommendations to achieve this.

The investigation used the BP root cause methodology supplemented by the CCPS (Center for Chemical Process Safety) guidance. Documentary or instrumentation records were given credence and where evidence was purely drawn from interviews corroboration has been sought from at least two parties. Where confirmation could not be gained it has been noted in the report.

These underlying causes are identified as follows:

- 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 behaviors this meant that rules were not consistently followed, rigor was lacking and individuals felt disempowered from suggesting or initiating improvements.
- Process safety, operations performance and systematic risk reduction priorities had not been set and consistently reinforced by management.
- 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.
- A poor level of hazard awareness and understanding of process safety on the site resulted in people accepting levels of risk that are considerably higher than comparable installations. One consequence was that temporary office trailers were placed within 150 feet of a blowdown stack which vented heavier than air hydrocarbons to the atmosphere without questioning the established industry practice.
- 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 underlying reasons for the behaviors and actions displayed during the incident are complex, and the team has spent much time trying to understand them.

It is evident that they had been many years in the making and will require concerted and committed actions to address.

The interim report made recommendations in the areas of

- People and Procedures
- Control of Work and Trailer Siting
- Design and Engineering

This report augments those recommendations with additional recommendations in these three areas and new ones in the areas of leadership and underlying systems.

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1. INTRODUCTION

During startup of the Isomerization Unit (ISOM) on Wednesday, March 23, 2005, following a temporary outage, an explosion and fire occurred which killed fifteen and harmed over 170 persons in the BP Products North America owned and operated Texas City Refinery. The site was secured and a Fatality 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. Terms of Reference for the investigation are detailed in Appendix 1.

Evidence gathering started immediately following the emergency response by the Texas City Site Incident Management Team (IMT). A joint team of BP and contractor (Jacobs Engineering (parent company of JE Merit), GE, and Fluor-Daniel) staff was assembled and officially took over the evidence gathering responsibility from the IMT on Saturday, March 26, 2005.

At the request of BP Products North America Inc., a BP group executive was assigned to lead the investigation and three individuals from outside the Refining Business Segment were assigned to the team. Six Texas City employees, three union and three salaried, completed the team.

A preliminary investigation was performed over 5 weeks at the BP Texas City site. It included visiting the incident site, interviewing witnesses, and collecting documents and records. Photographs were taken to assist in the investigation. The hard drive from the process control system was secured. Samples were collected for chemical analysis and third party specialist companies were retained to document the explosion debris and effects, and to model the nature and extent of the explosion.

An interim report was issued on May 17, 2005. This interim report presented an analysis of the events leading up to the incident, identified a number of provisional critical factors for the incident, and made a number of early recommendations to prevent a recurrence until a root cause analysis could be completed. Although it was recognized that the evidence and analysis was not complete at that time, it was felt beneficial to issue the interim report to ensure that the organization and the industry gained the early benefit in terms of learnings and prevention of recurrence.

Since the publication of the interim report, the BP Investigation Team has continued to gather, research and analyze additional evidence. The Team has also completed analysis of the process stream samples and modeling of the process and explosion. Additionally, the process instrumentation and equipment, such as level indicators and relief valves, has been tested, and an internal inspection of the Raffinate Splitter (Splitter) made. All evidence gathered has been shared with the US Chemical Safety Board (CSB) and the Occupational Safety and Health Administration (OSHA).

This final report presents an analysis of the events leading up to the incident, identifies a number of system (or root) causes for the incident, and makes recommendations for corrective actions to prevent a recurrence or a similar incident in the future.

Changes from the Interim Report

Since the Interim report, further research has confirmed the Team's view of the critical factors presented in the Interim Report. One inaccuracy was discovered when analyzing further information.

A number of trailers were located in the vicinity of the ISOM unit for the turnaround of the adjacent Ultracracker. Nine trailers were located north of Avenue F on the south side of the Ultracracker. A further eight trailers were located west of the ISOM unit to the north of the catalyst warehouse. One of these trailers was the double-wide J.E. Merit trailer. The other seven trailers included storage trailers and wooden buildings. A Management of Change (MOC) for the siting of nine trailers was approved for commission (i.e., occupancy) on February 15, 2005, and was mistakenly believed by the team to apply to the trailers involved in the incident Based upon further review, the BP Investigation Team now understands that this MOC applies to the nine trailers on the north side of Avenue F, and not the trailers west of the ISOM unit as stated in the interim report. Other than the J.E. Merit trailer, the trailers west of the ISOM unit did not have a MOC to cover their siting, as required by site procedures.

2. Background

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 ISOM and involved the Raffinate 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, Ultrafiner Desulfurizer, Penex Reactor, Vapor Recovery/Liquid Recycle plus the Raffinate Splitter, which takes a non-aromatics stream from the Aromatics Recovery Unit (ARU) and fractionates it into light and heavy components.

Many of those injured or killed were congregated in or around temporary trailers used for supporting turnaround work taking place on the nearby Ultracracker unit.

Raffinate Splitter

The Raffinate Splitter (the Splitter) was commissioned in 1976 as the Heavy Ultraformate (HUF) Fractionator, as part of Ultraformer No.1, built to recover xylene from Ultraformer product streams. In 1985, the Ultraformer was converted to a naphtha isomerization unit to provide additional octane needed for the government's lead phase-out program, and the HUF Fractionator was converted to its current use. In 1987, the ISOM was again modified, and the Splitter underwent minor changes to improve its ability to split light and heavy raffinate.

The resulting Splitter is a single fractionating column, 164 ft tall with 70 distillation trays (at 2-ft spacing, numbered from the top), 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 C_5 / C_6 light raffinate and is used as feed stock for the ISOM. The remaining heavy raffinate is used as chemicals feedstock for olefins cracking and for regular unleaded gasoline blending. The Splitter may be run in conjunction with the ISOM or independently to build inventory when the ISOM is shut down.

Figure 2-1

Raffinate Splitter

Blowdown System

The purpose of the blowdown system is to receive, quench, and dispose of hot hydrocarbon vapors and minor associated liquids from the ISOM relief, vent, and pump-out systems during upsets or shutdowns. The blowdown system consists of relief pipework headers, (two from other parts of the ISOM plus one from the Splitter), the Blowdown Drum & Stack (F-20), and Pump-Out Pump. Vapors 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 diameter with a 113-ft-high stack, and has an approximate volume of 390 bbls.

Simplified process flow diagrams (PFDs) of the Splitter and Blowdown System can be found in Appendices 2 & 3.

Figure 2-2

Blowdown Drum and ISOM Unit, After the Incident

Temporary Offices

Trailers are primarily used as temporary offices at the Texas City Refinery and many other refineries, supporting, for example, contract workers involved in project work and turnarounds. In this case they were required for a turnaround on the Ultracracker Unit across the road to the north of the ISOM. At Texas City, procedures call for them to be sited under a Management of Change (MOC) control process. When a trailer is to be sited within 350 feet of a process unit there is a specific requirement for a Facility Siting Analysis. The closest trailer, a double-wide J.E. Merit trailer, was located within 150 ft of the base of F-20, and is where most of the fatalities occurred at the time of the explosion.

Several trailers involved in the incident were located between two operating units, the ISOM and the Naphtha Desulfurization Unit (NDU). A normally unoccupied building for storing catalyst is also in this area. The plot plan of the ISOM and surrounding areas is depicted in Appendix 4.

When the site completed a comprehensive study of occupied buildings in 1995/7, and again in 2002 during a revalidation, no concerns were raised regarding this location for siting trailers. Trailers have been sited in the same area on several occasions previously.

3. Description of the Incident

3.1 Sequence of Events Leading up to the Incident

A double-wide trailer for J.E. Merit was installed west of the ISOM on September 1, 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 October 6. 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, including trailers for Fluor, Contech (January 10, 2005), Timec (February 4), and Hahn & Clay (February 14). No MOC was initiated for these trailers.

On February 21, 2005 the Splitter was shut down for a planned temporary outage, because of work on another part of the ISOM and Aromatics Recovery Unit (ARU) TAR. The Splitter was steamed out to remove hydrocarbons from February 26 to 28. Some minor maintenance tasks were carried out during the outage, and all planned work, except repair of the corroded line from F-20 to the sewer, was completed prior to startup. Condensate was drained from low point drains on March 14 in preparation for restarting the unit. Following pressuring with nitrogen at 22.5 psig for tightness testing, the Splitter was depressured on March 21.

The manpower on shift on the ISOM, NDU and AU2 units was doubled up for the period of the temporary outage from February 21, 2005, through March 23, 2005. On March 22/23, the crews had the following makeup:

Table 3-1
AU2/ISOM/NDU Operations Crews

Shift	Duty	Qualifications	Referred to in This Report as:
Night	Shift Supervisor	Shift Supervisor	Night Shift Supervisor
Night	Board Operator – AU2/ISOM/NDU units	Board Operator	Night Shift Board Operator
Night	Operator receiving step-up pay for outage duties	Board Operator	Operator A
Night	2 Outside Operators	Process Tech	N/A
Night	4 Outside Operators	Outside Operator	N/A
Day	Shift Supervisor	Shift Supervisor	Day Shift Supervisor
Day	Board Operator – AU2/ISOM/NDU units	Board Operator	Day Shift Board Operator
Day	Operator receiving step-up pay for outage duties	Board Operator	Operator B
Day	Outside Operator - ISOM	Outside Operator	Operator C
Day	Outside Operator - ISOM	Outside Operator on Hydrogen Unit	Operator D
Day	Trainee Outside Operator - ISOM	None	Operator E
Day	Trainee Outside Operator - ISOM	None	Operator F
Day	3 Outside Operators – AU2/NDU	Outside Operator	N/A

Note: Operator qualifications are discussed in detail in Section 5.11.3

Operators A and B were receiving step-up pay, but the reasons for their temporary assignments and precise duties for the temporary outage are unclear.

On March 22, the Texas City Refinery Production Planning Department requested the Shift Supervisor to start up the Raffinate Splitter. Instrument and Electrical (I&E) 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 startup. The 3 psig vent system control valve (H-5002) was stroked on March 22, 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 March 22/23, the Night Shift Supervisor told Operator A to commence starting up the Splitter. Operator A 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 (F-1101) and Tower (E-1101), and to pack the Reboiler (B-1101) circulation loop. Prior to startup, the instrumentation on the tower was not checked as per the procedure. He commenced charging feed to the tower at approximately 15,000 barrels per day (bpd) at 02:13 hrs March 23. By 02:38 hrs the Splitter base level sensor (LT-5100) started to indicate a gradually increasing level. At 02:44 hrs he opened the Reboiler flow control valve (FCV-5005) 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 in. height above tangent). Thereafter, the Splitter base level gradually rose again until the level indicator’s high level alarm (LT-5100) activated at 72% at 03:05 hrs (approximately 5 ft 5 in. height above tangent) as the tower was filled. Operator A acknowledged the alarm, and at 03:08 hrs, after calling the ARU Supervisor to cut feed, 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 (LAH-5102), 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. Operator A closed the feed to the Splitter and the reboiler circulation to leave the remainder of the startup to the day shift.

Operator A left the site at 04:59 hrs after making shift relief with the NDU/AU2 Shift Supervisor (not the Day Shift Supervisor). Although Operator A packed the Splitter from the satellite control board, he left before the Day Shift Board Operator arrived. A handover did occur between the Night Shift Board Operator and the Day Shift Board Operator while the 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. height above tangent in the 164-ft-tall tower). The night shift did not report the faulty hard-wired high level alarm (LAH-5102) 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 March 23, the day shift operators made their normal rounds and checked the unit lineup. The Day Shift Supervisor entered the site at 07:13 hrs. No pre-job safety review was conducted, nor a walkthrough of procedures performed as detailed in the operating procedure. At 09:21 hrs the outside operators briefly opened the 8-inch 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, probably due to the vapor pressure of the cold hydrocarbon in the base of the Splitter. A natural gas connection at the Reflux Drum (F-1102) is set to a nominal 5 psig, but was not lined up and could not have been a source of pressure.

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 (LCV-5100) to verify the lineup to tankage, the Day Shift Board Operator closed this control valve in manual. (The startup procedure specifies 50% set point in automatic mode, see section 5.10 below). 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. During the early stages of starting up the unit, the heavy raffinate rundown is the only way to maintain/control the liquid level in the Splitter as it takes time (typically around three to four hours) to heat up the liquid sufficiently to begin generating an overhead product.

At approximately 10:00 hrs, two main burners were lit in the Reboiler fired heater (B-1101) prior to establishing heavy raffinate rundown, contrary to the startup procedure. Shortly afterwards, the Day Shift Supervisor for the ISOM left the site due to a personal family matter without ensuring that procedures were being followed before leaving. 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 startup procedure. The exact number of main burners eventually lit is unknown as it is not recorded in the control system records 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.

In the main control room a possible distraction occurred when someone made outgoing telephone calls from the Control Board extension to Galveston, Texas, from 11:00 – 11:13 hrs, and 11:15 – 11:50 hrs.

Concerned at the continued absence of any indicated liquid level in the Reflux Drum (F-1102) by sometime late morning, the Outside Operators checked the bottom tap of the Reflux Drum level gauge and only vapor emerged. The Reflux Drum level transmitter (LT-5006) continued to show 0% until 13:20 hrs. Due to the lack of heavy raffinate rundown (and the resultant heat addition it would have provided to the feed stream) and the continued feed of cold liquid into the Splitter, the time required to produce light raffinate overhead was significantly longer than a normal startup.

The acting Superintendent and NDU/AU2 Shift Supervisor left the site to get lunch and returned by 12:03 hrs. The acting Superintendent stated that he spent 75% of his workday on

March 23 assisting the ARU turnaround. At 11:47 hrs Operator B and trainee Operator E left the site to go and get lunch for the crew, and returned at 12:05 hrs.

By 12:20 hrs the Splitter base had reached the target temperature of 275˚F stipulated in the startup procedure, with the feed temperature to the Splitter still only 120˚F. (The normal feed temperature is 205˚F). The absence of heat exchange between the Heavy Raffinate rundown and feed at the Feed/Bottoms Exchangers (C-1104A/B) at this time confirms the lack of any Heavy Raffinate rundown flow to tankage. The slow rise in feed temperature from less than 100˚F (i.e., under range) before 11:00 hrs to 120˚F was due to heating in the convection section of the Reboiler fired heater (B-1101) and none from the Feed/Bottoms Exchangers. The lack of feed preheat also delayed the generation of light raffinate overhead product from the Splitter. 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 below the top of the tower. Trainee Operator E 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 C and E opened the 8-inch chain-operated vent valve for the second time in order to reduce the elevated pressure. Operator E reported seeing vapors that “looked like steam” venting from the top of the stack, but Operator C 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 this time (12:40 hrs), the Splitter base temperature had reached 302˚F (normal operating temperature is about 275˚F). At this temperature, modeling predicts some vaporization in the bottom of the Splitter, despite the head of colder liquid above. The feed to the Splitter continued at 20,000 bpd with no outflow, and the calculated level in the tower reached over 130 ft.

A safety meeting was held in the Control Room for the ISOM/NDU/AU2 units, around the control board for the ISOM, from approximately 12:45-13:00 hrs, and was attended by the Area Superintendents, Shift Supervisors and up to 20 other operations and maintenance personnel. None of these attendees was alerted or aware of any difficulties with controlling the Splitter startup.

After reviewing the unit status on the Satellite control board, Operator B 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 (LCV-5100). The Heavy Raffinate rundown flow did not indicate a flow until approximately 13:00 hrs, which is additionally confirmed by a delay in heat exchange between the hot tower bottoms and the relatively cold tower feed. It is not clear why this flow was delayed, but it is possible that a block valve was closed on the heavy raffinate rundown. The Heavy Raffinate flow matched the 20,000 bpd feed rate for the first time by 13:03 hrs, and by 13:09 hrs had stabilized at 31,000 bpd (any zero error is likely to be negligible at this flow rate, see Appendix 5). The feed to the Splitter continued at 20,000 bpd and the calculated level peaked at 137 ft in the tower (based on a simplified calculation ignoring the effect of liquid vaporization in the base of the tower, the actual liquid level in the Splitter was therefore higher than this).

As explained, this Heavy Raffinate rundown stream exchanges heat with the incoming feed to the tower in the Feed/Bottoms Exchangers (C-1104A/B). At 13:01 hrs the feed preheat was 126˚F, and rose to 260˚F by 13:10 hrs. This abnormally rapid increase in temperature led to the rapid onset of vaporization of the feed at the inlet point to the tower, causing a rapid rise of the Splitter contents above the feed tray. The temperature at tray 33 in the Column, a few feet below the feed tray 31, started to increase rapidly at 13:00 hrs, indicating that the hot feed was beginning to impact conditions in the Splitter.

At 13:02 hrs the off-site Day Shift Supervisor telephoned the ISOM Satellite Control Room from outside the Refinery, and spoke to Operator B, who indicated he was busy and would call back. At 13:09 hrs Operator B telephoned the Day Shift Supervisor at home, who, upon hearing of the pressure trend, suggested opening the 1½ inch 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 inlet feed rate to the column remained at approximately 20,000 bpd throughout this period.

Another possible distraction occurred when an outgoing telephone call was made from the Control Board extension to Evansville, Indiana, from 12:52 – 12:53 hrs, with a call received from the same number from 13:10 – 13:12 hrs.

Raffinate Splitter Level

As stated earlier, the night shift on March 22/23 packed the Splitter with feed, and left the column base level at 100% (of the level transmitter range) and in DCS high level alarm mode. The Day Shift Board Operator recommenced feed at 09:52 hrs at a rate of 20,000 bpd. The Heavy Raffinate rundown control valve (LCV-5100) was not opened until 12:41 hrs, and a Heavy Raffinate outflow registered at approximately 13:00 hrs. 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, and while the startup procedure specified the tower level control should be set at 50% (in automatic mode), it was in manual. Up to 13:00 hrs approximately 2,500 barrels had been added to the column since 09:52 hrs. By 13:09 hrs the Heavy Raffinate outflow at 31,000 bpd exceeded the incoming feed rate, but in this short period this would only have reduced the volume in the column by a small amount. From 13:09 hrs onwards, a simple calculation shows that the difference in outflow vs. feed rate would have reduced the liquid level in the tower by about 4 inches per minute, but the liquid level in the tower may not have fallen due to the effect of increasing vaporization of the feed and tower base.

With a higher level (100%) in the Splitter column to begin with than specified in the procedure, and operating out of the control range, an additional 3 hours of feed at 20,000 bpd (i.e., 2,500 barrels) was added to the column with no outflow. The liquid level within the column reached tray 13 level (137 ft high vs. normal operating level in range of 6-7 ft) at approximately 12:45 hrs. At this level, 57 of the 70 trays within the column were flooded, and the feed inlet at tray 31 was submerged. Under these circumstances the Splitter could not perform as a conventional distillation column. The high bottoms temperature of the Splitter caused vaporization of hydrocarbons in the bottom of the tower, lifting 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 vapors and prevented them from distilling overhead.

Temperature indications at several trays within the column confirm a very high level. At 11:30 hrs the temperature profiles of the Splitter feed and at tray 33 were the same, suggesting that the liquid level had reached tray 33. At 12:00 hrs, the temperature profiles suggest that the liquid level had reached tray 27.

By 13:10 hrs the feed preheat had risen rapidly to 260˚F, leading to vaporization of the feed introduced at the feed tray 31. 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 overhead line.

The detailed timeline of the incident is shown in Appendix 6, while graphs depicting the key process parameters are shown in Appendices 7 and 8.

3.2 The Incident

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

Heavy Raffinate rundown from the Splitter had commenced by 13:00 hrs. At 13:13 hrs the pressure at the inlet to the Overhead Condenser was 20.5 psig, but starting 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 overhead line above the pressure transmitter and relief valves, located about 150 ft below the top of the tower. As the head of liquid built up in the overhead line, the indicated pressure at the overhead condenser rose rapidly.

Around this time Operator B telephoned the Day Shift Board Operator and asked him to reduce firing on the Reboiler Heater due to the high temperature of 304˚F on the Splitter base. The Board Operator trimmed the Fuel Gas control valve (FCV-5008 in cascade with T-5025) output from 18% to 15% at 13:14 hrs to reduce the Reboiler Heater outlet temperature.

Another possible distraction occurred when an incoming telephone call was received at the Shift Supervisor's extension in the ISOM/NDU/AU2 Control Room from a local wireless number from 13:10 – 13:16 hrs. There was also an outgoing telephone call from the Control Board extension to the PX1 Control Board extension at 13:15 hrs, lasting 12 seconds.

By 13:15 hrs the pressure at the inlet to the Overhead Condenser peaked at 63 psig, and Operators C and E confirmed that the column 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 header. The temperatures at trays 27 and 33 in the Column, either side of the feed tray 31, started to increase rapidly at 13:15 hrs. The temperature at tray 13 and the temperature of the Overhead were quite cold at less than 115˚F and started to increase rapidly as hotter fluids were lifted up the tower by vaporization at the feed tray.

At this point the fuel gas firing to the heater was stopped, Operators C and E blocked in the main burners, and at 13:19 hrs shut the Fuel Gas control valve at both the main and satellite control boards. At 13:16 hrs the Reflux Drum low-low level alarm (LALL-5010) cleared, indicating liquid in the vessel for the first time, and the Outside Operators D and F started the Reflux Pump (J-1102A) at 13:17 hrs. The indicated reflux flow rate went off scale in excess of 35,700 bpd. The Reflux Drum low level alarm (LAL-5004) 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 (J-1102) was also started at 13:19 hrs, although none of the Outside Operators remembered doing so when interviewed after the incident.

At about this time there were radio messages from at least two witnesses, who saw vapors and liquid emerging approximately 20 ft above the top of the stack "like a geyser" and running down and pooling around the base of the Blowdown Drum & Stack (F-20). Vapors were seen evaporating from the liquid pool. The F-20 high level alarm (LAH-5020) 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 vapors 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 modeling suggests that there was only one explosion. The explosion severely damaged the J.E. Merit, Fluor and other trailers on the west side of the ISOM, and resulted in 15 fatalities (11 in the J.E. Merit trailer, 3 in the Fluor trailer, and one nearby) and over 170 individuals harmed. The exact number of injuries is difficult to ascertain as some contractors and members of the public sought medical attention directly without involving site first aiders. The blast resulted in damage to the ISOM, causing a number of secondary hydrocarbon releases and fires. Aerial views of the damage are found in Appendix 9.

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 2 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.

The detailed timeline of the Emergency Response phase of the incident is shown in Appendix 10.

4. EVIDENCE

Evidence gathering started immediately following the emergency response by the IMT.

Photographs were taken within minutes of the incident and continued throughout the emergency response. The hard drive containing the process control information was powered down immediately following the emergency response and secured on March 24. The board operator log book and shift supervisor log books were secured the evening of March 24 by the Investigation Team. The hard copy of the startup procedure in use on the ISOM at the time of the incident was not secured until April 2.

All evidence gathered has been shared by the BP Investigation Team with the Occupational Safety and Health Administration (OSHA) and the US Chemical Safety Board (CSB).

4.1 Site Inspections

Access to the ISOM was controlled by OSHA and further restricted due to the court imposed restraining order. On April 1, 2005, a member of the Investigation Team was granted access to areas of the ISOM by OSHA. However, there was no access to the area between the ISOM and the Naphtha Desulphurization Unit (NDU) where the trailers were located. Key observations were:

- The valve on the middle line of 3 lines feeding the Tower (E-1101) appeared to be in the open position. The valve on the top feed line was subsequently confirmed as one quarter open, while the valve on the bottom line was closed.
- The 3-psig vent line was blocked in downstream of the control valve.
- The position of the 8-inch chain-operated vent valve to F-20 was closed.
- The explosion damage on the ISOM was mainly on the west side of the unit.
- The block valve on the reflux drum 1½-inch vent to F-20 was closed.

On April 6, 2005 the balance of the Investigation Team was granted access to the incident scene. Key observations were:

- Detailed fire and explosion damage on the ISOM.
- Fire damage around F-20, including spalling of reinforced concrete construction and concrete pad.
- Valve positions on 14-inch relief line from the Splitter to F-20 and the 6-inch F-20 outlet line were open.
- Damage to the satellite control room.
- Damage to the catalyst warehouse.

- Confirmed earlier observation that the 3-psig vent line was blocked in downstream of the control valve.
- Confirmed earlier observation that the 8-inch chain-operated vent valve was in the closed position.
- Confirmed earlier observation of the valve positions on feed lines to the Splitter.
- Damaged trailers in the area between the ISOM and the NDU.
- Corroded liquid flow line from F-20 to the sewer system.

Subsequently, members of the Investigation Team made multiple visits to the site to observe sampling of process vessels and lines, and testing of process instrumentation and control equipment, as well as to observe the damage to the process sewer. Third party companies were retained to document and catalog the explosion debris and effects of the blast, model the nature and extent of the explosion, and have been given wide access to the site.

4.2 Witnesses

Initial witness interviews were organized by the IMT and commenced on Thursday, March 24, 2005. The interview portion of the evidence-gathering phase of the interim investigation was concluded on Thursday, April 28, 2005. Additional interviews were held in August, September and November 2005. Additional interviews were also conducted in an attempt to resolve inconsistencies in initial testimonies.

During the course of the investigation, the team has conducted 106 interviews with 73 persons (68 BP employees and 5 contractors), and received 27 written witness statements. Most of the interviews were conducted in the presence of a court reporter.

4.3 Samples

Samples were taken on April 12 and April 19 from various process streams in the presence of regulatory agency personnel for analysis by an independent certified laboratory, BSI Inspectorate. Environmental Standards, Inc. (ESI) provided quality assurance oversight of these analyses on behalf of the BP Investigation Team. The samples were split into two sets, one of which BSI Inspectorate analyzed and BP analyzed the other set.

The following process stream samples were taken:

- Raffinate Splitter hydrocarbon liquid feed collected from the suction of the Feed Pump (J-1101)
- Raffinate Splitter hydrocarbon liquid bottoms collected from the outlet of the Heavy Raffinate Product Coolers (C-1106)
- Raffinate Splitter hydrocarbon liquid reflux collected from the suction of the Reflux Pump (J-1102)

- Raffinate Splitter overhead product from the outlet of the Light Raffinate Product Coolers (C-1107)
- Blowdown Drum and stack hydrocarbon liquid collected from the suction of the Pump-out Pump (J-14A)
- Raffinate Splitter hydrocarbon liquid feed collected from the Feed Surge Drum (F-1101)
- Raffinate Splitter hydrocarbon liquid reflux collected from the discharge of Flow Valve (FV-5007)
- Raffinate Splitter overhead product from the flow control valve line (FCV-5106)
- Raffinate Splitter overhead water knockout drum (F-452) pump (J-454A)

Detailed analytical results are attached in Appendix 11.

Several locations around the ISOM Unit were sampled to check for the presence of water. These checks were inconclusive as conflicting reports were received on the presence of a clear liquid that may have been water or hydrocarbon, at the following locations:

• Reflux Control Valve (F-5007)	60% clear liquid in first sample can.
• Reflux pump (J-1102)	Initially 2-3 cups of clear liquid**.**
• Raffinate Splitter (E-1101)	Clear liquid was observed dripping from a ¾-inch bleeder plug in the pumpout line.

4.4 Equipment Testing

Items of instrumentation and process control equipment were tested *in situ* and/or removed under custody control to a workshop. All testing was performed to protocols developed in line with the equipment manufacturer's maintenance procedures, and agreed by all relevant parties to the investigation (BP, CSB, OSHA, and plaintiff experts).

Equipment was tested *in situ* in the "as-found" condition to evaluate functionality, and in some cases to check signal output from instruments. The equipment tested included:

- Control valves
- Level transmitters
- Level switches
- Flow transmitters

The ISOM unit was without DCS and utilities during the tests, and each device was tested locally with hand held meters and bottled compressed air where needed. A third party instrumentation company, Industrial I&E, was engaged for specialist support to handle all instrument connections, measure instrument output, and provide control valve input signals. Interested parties observed and documented the tests conducted between 21 June 2005 and 18 July 2005.

Items removed for testing were sent to independent specialist engineering organizations.

Relief Valves
The following relief valves (RVs) were removed and sent to a specialist third party testing facility, Groquip, for testing and internal inspection:

- Raffinate Splitter overhead line (RV-1001A/B/C)
- Reflux Drum (RV-1002G)
- Light Raffinate product rundown (RV-1199G)

Control Valves
The following control valves were tested *in situ* by Industrial I & E:

- Raffinate Splitter Tower (LCV-5100)
- Light Raffinate Jumpover to Heavy Raffinate (PCV-5012)
- Feed to Raffinate Splitter Tower (FCV-5000)
- ARU Raffinate Feed (FCV-5003)
- Total Raffinate Feed (LCV-5006)
- Raffinate Splitter Reflux Drum to 3-psig Vent System (PCV-5002)
- Reflux Flow to Raffinate Splitter (FCV-5007)
- Reflux Drum (PCV-1002)
- Heavy Raffinate to Reboiler Furnace (FCV-5005)

The following control valves were removed, shop tested and inspected by a specialist third party facility, Stress Engineering Services:

- Raffinate Feed to Tower (FCV-5000)
- Reflux Drum vent to 3# System (PCV-5002)
- Raffinate Tower Heavy Raffinate Rundown (LCV-5100)

Instrumentation
Key instruments were identified and tested *in situ* by Industrial I & E to verify the accuracy of the PI/DCS records.

- Level Sensors
    - Feed Surge Drum (LT-5007)
    - Raffinate Splitter Tower (LT-5100)

    - Reflux Drum (LT-5008)

- Flow Sensors
    - Fuel Gas (FT-5008)
    - Heavy Raffinate to Reboiler (FT-5005)
    - Heavy Raffinate rundown (FT-5015)
    - Light Raffinate rundown (FT-5106)
    - Feed from ARU (FT-5001)
    - ARU Raffinate (North Feed) (FT-5003)
    - Raffinate Splitter Flow from Feed Drum (FT-5000)
    - Reflux flow to Raffinate Splitter (FT-5007)

- Pressure Sensor
    - Raffinate Splitter (at inlet to Overhead Condenser) (PT-5002)

- Alarms
    - Raffinate Splitter Tower level switches (LAH-5102, LAL-5104)
    - Raffinate Splitter Tower level indicator alarm (LT-5100)
    - Feed Surge Drum level switch (LAH-5006)
    - Reflux Drum level switches (LAL-5004, LALL-5010)
    - Blowdown Drum level switch (LAH-5020)

The following level transmitter and switches were also removed, shop tested and inspected by a specialist third party facility, Stress Engineering Services:

- Raffinate Splitter Tower (LT-5100)
- Raffinate Splitter Tower level switches (LSH-5102, LSL-5104)
- Blowdown Drum high level switch (LSH-5020)

Vessel
An internal inspection of the Raffinate Splitter tower (E-1101) was conducted after the vessel was deinventoried and gas freed.

4.5 Documentation

Documents, procedures, records and engineering drawings were reviewed, including the following:

- Operations log books (Shift Supervisor log, Board Operator log)
- PI records for the past 5 years and DCS records for 15 days prior to the accident
- Startup Procedure (for March 23, 2005)
- Trailer Siting MOC/Facility Siting Plan
- Witness statements and transcripts
- Training records
- Maintenance records
- MOC records
- Hazard analysis records
- HSE policies and procedures
- Staffing studies
- Other general site documentation

Immediately following the incident, the hard copy startup procedure in use at the time of the incident was believed by the team to be in the heavily damaged satellite control room. On April 2, ten days after the incident, the procedure was handed to the investigation team by the Day Shift Supervisor assigned to the ISOM on the day of the incident. The procedure had been signed off by trainee Operator E, who was not present for all the activities undertaken, under instruction of the Day Shift Supervisor.

A list of documentation reviewed is included in Appendix 12. A chronology of additional evidence is found in Appendix 13.

A chronology of the events leading up to the incident was compiled, based upon review of the PI and Honeywell DCS records, and the Operations log books (see Appendix 6). Interviews of the night and day shift operators and supervision provided clarification.

A separate chronology of the emergency response has been prepared, based upon the Emergency Response Team (ERT) log (Appendix 10). This was supplemented by interviews of the first responders, who provided information on the location of casualties, and the circumstances surrounding the secondary fires.

5. EVIDENCE ANALYSIS

5.1 Introduction to Evidence Analysis

The BP Investigation Team has examined the evidence collected, and commissioned a number of specialist studies, to understand the series of events that occurred on March 23, 2005. The Team has also been assisted by specialist consultants.

Major areas for this analysis have included:

- Detailed examination of the DCS instrumentation data
- Modeling of the process, hydrocarbon release and the explosion
- Comparison of the startup to the specified operating procedures and previous unit history

This section describes the evidence analysis, commencing with the provisional scenarios from the Interim Report, followed by details of the process modeling, explosion modeling, and the elements of the process safety management system.

The BP Investigation Team has placed primary credence upon the physical and documentary evidence collected, and the use of the witness testimonies has been carefully considered. In line with investigation guidance (ref. 4, CCPS Guidelines), the verbal testimony of an individual has been given less importance unless it has been possible to corroborate that evidence through other means, such as testimony from another witness or physical evidence. The Investigation Team has conducted followup interviews and/or looked for additional evidence in order to resolve inconsistencies in the initial verbal testimonies. Given that early witness interviews are likely to be more reliable than later testimony, these have been valued more highly. Witnesses may have discussed the incident with others or recast events, which can influence their perceptions and recollections later.

The following hierarchy represents the weighting put upon the evidence gathered:

- DCS / PI data
- Paper / electronic documents
- Multiple witness statements (where consistent)
- Visual inspection (possibly disturbed by emergency response)
- Process sample analysis (possibly changed by delay in sampling)
- Process equipment testing (possibly damaged/changed by incident)
- Single uncorroborated witness statement

5.2 Loss of Containment - Potential Scenarios

The explosions were the result of ignition of hydrocarbon vapors released from the Blowdown Drum & Stack. These hydrocarbons were discharged when the Raffinate Splitter overhead relief valves (RV-1001A/B/C) opened due to a rapidly increasing pressure which at 13:13 hrs, exceeded their set pressures. At the time of the interim report, four potential causes of this excess pressure were postulated:

(a) Vapor pressure of hydrocarbons due to excessive thermal energy coupled with high liquid level in the column

(b) Steam generation from the presence of water at high temperature

(c) Non-condensables (nitrogen) remaining from the tightness testing

(d) Improper feed to the unit or introduction of "foreign material" in the feed

(e) Any combination of the above

A second possibility that hydrocarbon vapors were spread through the sewer system and became the source of the initial ignition could not be discounted at the time of the interim report. F-20 has a drain connection to the sewers, and liquid hydrocarbons could have passed from an Oily Water Separator into a Dry Weather Sump, and into stormwater sewers near the trailers.

The Investigation Team analyzed each of these possible energy sources, to verify or discount each scenario, after considering the possibility of other scenarios. A third party assessment of potential scenarios was commissioned (Appendix 14). This detailed analysis is discussed below:

5.2.1(a) Vapor Pressure/Liquid Carryover

As the Investigation Team's understanding of the circumstances of the incident developed, this scenario was modified. It was originally postulated that the high pressure in the Raffinate Splitter may have been due to the vapor pressure of the column contents at high temperature. Immediately prior to the rapid increase in pressure, the column base temperature was stable at 302˚F (27˚F above the temperature specified in the startup procedure). The high liquid level in the Splitter and relatively cold feed at only 126˚F could have allowed a high base temperature to be masked by colder hydrocarbon above.

As the Team's understanding developed, this scenario changed to a combination of vapor pressure and head of liquid in the overhead line. (Note that the pressure transmitter is located at the inlet to the overhead condenser 150 ft below the top of the tower.) Dynamic process modeling of the Splitter has concluded that the late intervention of starting Heavy Raffinate rundown flow exacerbated the incident. The rapid heat exchange between the tower bottoms and incoming feed resulted in vapor generation around the submerged feed inlet to the tower. When the 8-inch vent valve was opened to reduce the Splitter pressure, the high temperature at the reboiler furnace outlet and in the bottom of the tower caused significant vaporization. The combination of vapor in the feed and bottom of the tower eventually caused liquid carryover into the tower overhead line. The hydrocarbon vapor pressure coupled with the hydrostatic pressure of the liquid carried over into the overhead pipework system accounts for the high pressure experienced at the inlet to the overhead condensers and relief valves (See Section 5.3 and Appendix 15).

5.2.1(b) Steam Generation

The presence of water during the startup of the Raffinate Splitter could have liberated steam, as temperatures increased, resulting in the rapid pressure increase. The Splitter was steamed out in February 2005 to gas-free the unit, and, although water was drained from a number of low points prior to restarting the unit, it was hypothesized that some condensed water could have remained in the unit. An early flow of Heavy Raffinate to tankage would be expected to remove any water, but on this occasion Heavy Raffinate rundown to tankage was not established until approximately 13:00 hrs.

Samples of the feed to Raffinate Splitter were taken from low points and indicated traces of sulfolane, indicating the presence of limited water from the ARU feed (See Section 5.6 and Appendix 11). Small quantities of a clear liquid were drained from one or two sample points prior to taking representative samples of the process stream, but it is unclear whether this clear liquid was water or hydrocarbon.

The configuration of the base of the Raffinate Splitter indicated that water could not have collected in the tower base while the reboiler circulation was in commission. Contrary to internal engineering drawings, a vortex breaker, and not a standpipe, is in the base of the Raffinate Splitter. Water present would not collect in the tower, and would be emulsified in the bottoms circulation and progressively removed once the Heavy Raffinate rundown flow commenced.

Limited quantities of water could accumulate in seal pans in the tower, especially at the upper feed tray, where the transition from two-pass to single-pass trays occurs. However the volumes are too small to make a substantive impact.

The absence of any internal damage to the fractionating tower trays suggests that the incident occurred gradually. If water had been present in significant quantities, the transition to steam would have occurred suddenly and would likely have resulted in distortion to trays, especially where tray sections adjoin and/or seal with the tower wall.

5.2.1(c) Nitrogen

The Raffinate Splitter was pressure tested for tightness with nitrogen at approximately 22.5 psig. Some residual nitrogen would have remained after depressuring, and may have become concentrated in the column overhead reflux system due to the high liquid level in the Splitter. As temperatures were raised to distill vapors overhead, it was postulated that the presence of nitrogen could have inhibited the vapors from reaching the cold surface area of the Overhead Condensers (C-1101), and prevented condensing to provide reflux. Without condensing capacity, the column pressure would rise. Any nitrogen present could also exert its partial pressure, adding to the column total pressure.

There is also a natural gas connection to the reflux drum, nominally set at 5 psig. This connection was not lined up and was found to be isolated after the incident. If it had been open during the startup, when the Raffinate Splitter was depressured from 4 psig to zero at 09:21 hrs, then natural gas could have been introduced when the pressure slowly increased over the next hour and impacted the condensing capacity.

Dynamic process modeling of the Splitter has indicated that, although non-condensables may have contributed to a small extent, they did not account for the high pressure (See Section 5.3 and Appendix 15). Nitrogen and natural gas were eliminated because a lack of reflux and overhead product was not considered the problem.

5.2.1(d) Improper Feed

The high pressure experienced in the Raffinate Splitter was hypothesized to have been caused by an unusually light hydrocarbon feed to the unit, or contamination of the feed stream with foreign materials. Sampling of the feed streams confirmed that the feed to the Raffinate Splitter was within the normal specification range (See Section 5.6 and Appendix 11).

5.2.2 Sewers

There were many indications that hydrocarbon liquids were discharged to the refinery sewer system during the incident. Several high hydrocarbon level alarms occurred in the Diversion Box and Dry Weather Sump west of the ISOM after the Overhead RVs lifted at approximately 13:14 hrs. Spreading hydrocarbons to adjacent areas via the sewer system and a corroded pipework connection were postulated to have created another possible source of flammable vapors near the trailers.

The BP Investigation Team was restricted from entering the site, making it unable to sample fluids in the sewer system, or document its post-accident condition before it was disturbed.

Mass balance and dynamic modeling confirms that large volumes did indeed enter the sewers and may have contributed to secondary fires.

5.2.3 Scenario Conclusion

Third party specialists were retained to model the process and the explosion. Together with analytical results of process samples and internal vessel inspections, these models have been used to determine which scenario occurred.

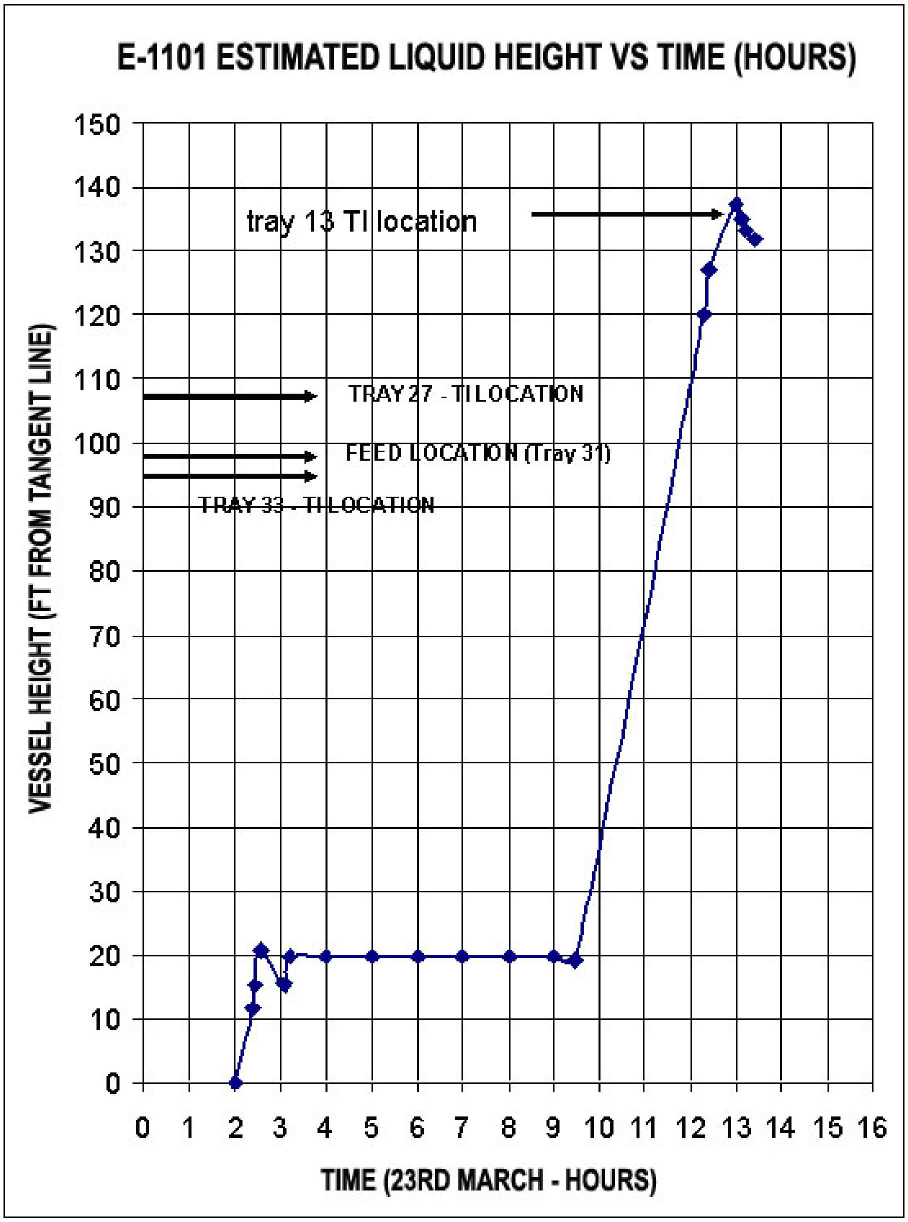
The Investigation Team has determined that the "vapor pressure/liquid carryover" scenario (5.1.1(a)) is the most probable scenario, possibly exacerbated by limited quantities of nitrogen and water.

5.3 Process Modeling

Analysis of the DCS/PI process data leading up to the incident was conducted using a dynamic model of the Raffinate Splitter (by Process Systems Enterprise (see Appendix 15)) and the flow rate through the Raffinate Splitter relief valves (as calculated by Packer Engineering (see Appendix 16)). The dynamic simulation was limited to the Raffinate Splitter column only, although Packer Engineering also estimated hydrocarbon flow rates to the Blowdown Drum and emission from the stack. The main findings from this work are:

5.3.1 Inventory of Liquid in the Raffinate Splitter

A mass balance based upon DCS data performed by integrating the Splitter flow meters into and out of the column over the startup period indicates that the vessel was substantially overfilled. During the night shift, the column was initially overfilled to greater than 100 % of the base level range. When the main startup recommenced at 09:52 hrs, the feed rate was increased to approximately 20 MBPD and was held at this rate for a period of almost 4 hours. There was no bottoms offtake from the column until 13:00 hrs, (possibly due to a closed block valve). A summary of the accumulation of liquid in the vessel, shown in Figure 5-1 below, indicates that the calculated liquid level peaked at tray 13. This makes no allowance for vaporization and expansion of the liquid within the vessel, as the contents partly vaporize in the base of the tower. These are discussed in more detail in the dynamic modeling section below. The estimated liquid level was confirmed when the Splitter was deinventoried.



Note: this excludes the effect of vaporization in the feed and bottom of the Splitter tower.

Figure 5-1
Raffinate Splitter Estimated Liquid Height vs. Time

Inside the column, there are temperature indicators (TIs), just below trays 13, tray 27, tray 33, tray 48 and tray 59 (located in the downcomers) with readings visible to the board operator and recorded on the DCS. These further confirm that the column was substantially overfilled with liquid during the startup period between 9:52 hrs and the rapid pressure increase at 13:13 hrs. The feed temperature into the column (T-5005) gradually warmed up from a temperature of 80˚F at 10:00 hrs to 126˚F at 13:00 hrs. When one compares the feed temperature (red line) with these column TIs, the point at which these temperatures cross (or diverge) indicates the level in the column at that particular time, as illustrated in Figure 5-2:

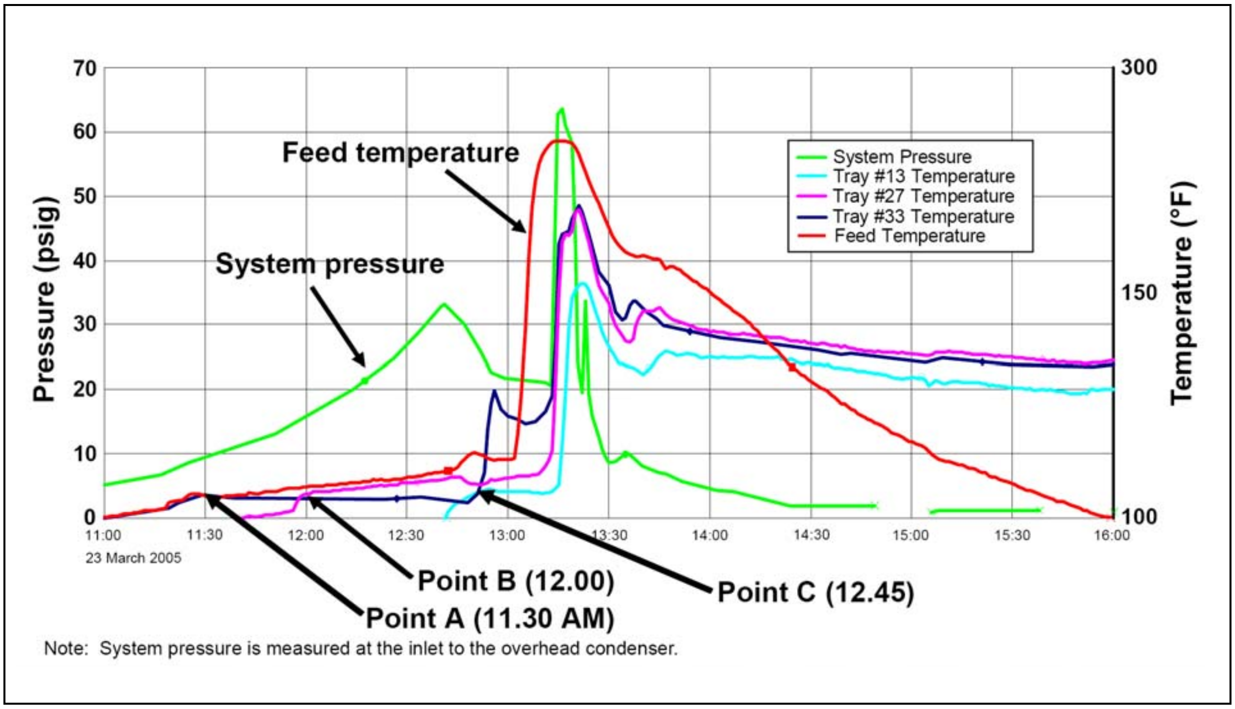


Figure 5-2
Raffinate Splitter Tower Temperatures as Level Rises

The feed tray location was at tray 31 (tray 1 is the top tray).

At Point A (at around 11:30 hrs) tray 33 temperature and the feed temperature diverge. After this, tray 33 temperature remains constant, while the feed inlet temperature continues to increase. This suggests that the level in the column has reached and exceeds tray 33.

At Point B (at around 12:00 hrs) tray 27 temperature starts to warm up and approach the feed temperature. This suggests that level in the column is approaching tray 27 at this time.

At Point C (at around 12:45 hrs) tray 13 temperature starts to warm up and approach the feed temperature. This suggests that the level is close to tray 13 at this time.

The temperature crosses at these times are broadly as predicted by the simple volume balance over the column which indicates that the liquid accumulation in the vessel reached tray 13 at around 12:45 hrs. Around 13:00 hrs, the heavy raffinate bottoms flow is opened and there is a net outflow from the column—so one would then expect the level in the column to start falling. However, as previously stated, this simple analysis makes no allowance for vaporization and expansion of the liquid in the base of the tower. This is an important factor, and is discussed in detail in the dynamic modeling report. From the period 10:00 hrs to the time of the incident, there is a steady heat input from the fired reboiler, and this is likely to have caused vaporization in the base of the column.

When the heavy raffinate rundown was opened, there was a rapid increase in the feed temperature from 126˚F to 260˚F in less than 10 minutes. This abnormal heat addition at feed tray 31 caused a rapid onset of vaporization to occur, which led to the liquid above the feed tray being lifted to the top of the tower and into the overhead line. Given the pressure at the feed tray (including liquid head above it), the feed would have started to vaporize at about 255˚F.

5.3.2 Feed Charge into Raffinate Splitter

Analysis of the characteristics of the feed charge flow meter (F-5000) shows that the feed rate into the unit varies depending upon the Splitter static pressure. The feed pump is a centrifugal pump with a typical flow vs. head curve. The feed flow control valve (FCV-5000) was on manual up to 13:01 hrs, and as the pump backpressure increases, so the inlet flow rate falls. This is shown in Figure 5-3:

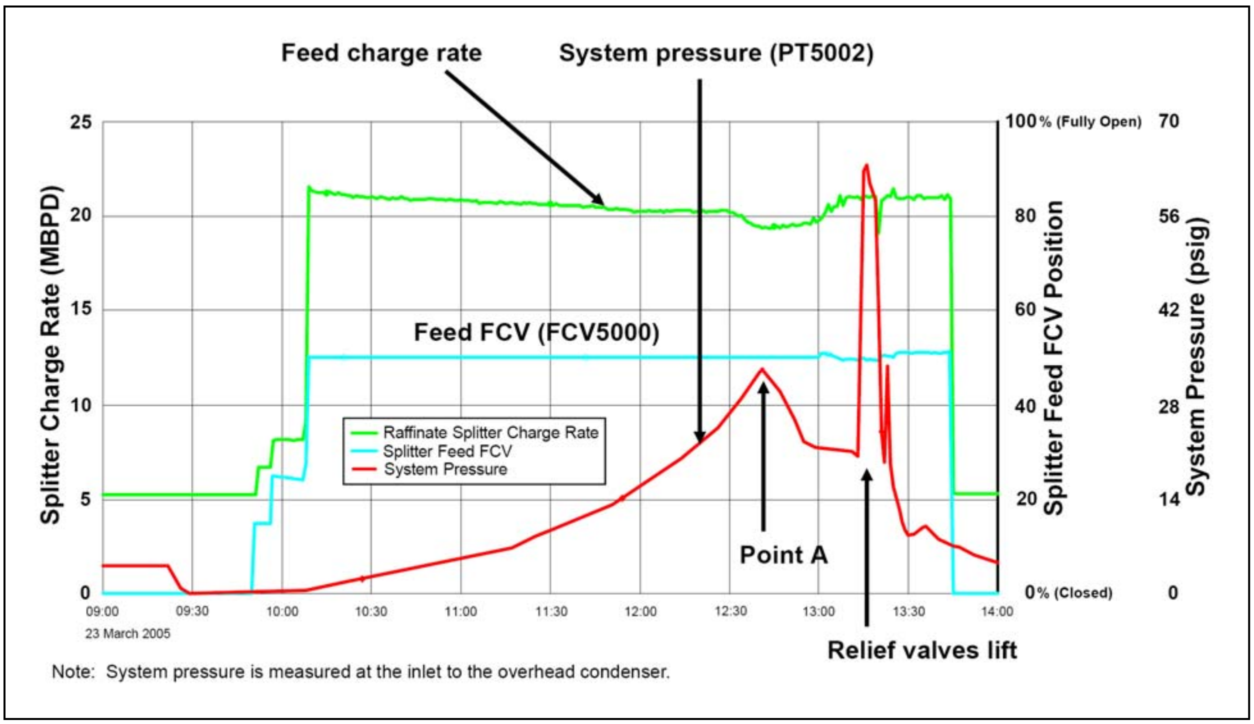


Figure 5-3
Decline in Feed Flow Rate as Splitter Pressure Rises

These data show that the feed inlet rate generally responds to the column backpressure. As the column pressure builds (as the column is overfilled) so the feed inlet rate falls gradually. As the column is manually depressurized (point A), the feed rate then increases.

The feed flow control valve (FCV-5000) was put in automatic mode at 13:01 hrs and the pressure in the Feed Surge Drum rose during the incident, but, taking this into account, it is still evident that the feed pump did not see the rapid increase in pressure seen at the relief valves, as there was no significant change to the valve output when the system pressure spiked very rapidly to 63 psig at the time of the incident.

The column pressure transmitter (PT-5002) and relief valves are located adjacent to the overhead condenser fin-fan inlets approximately 150 ft below the top of the column.

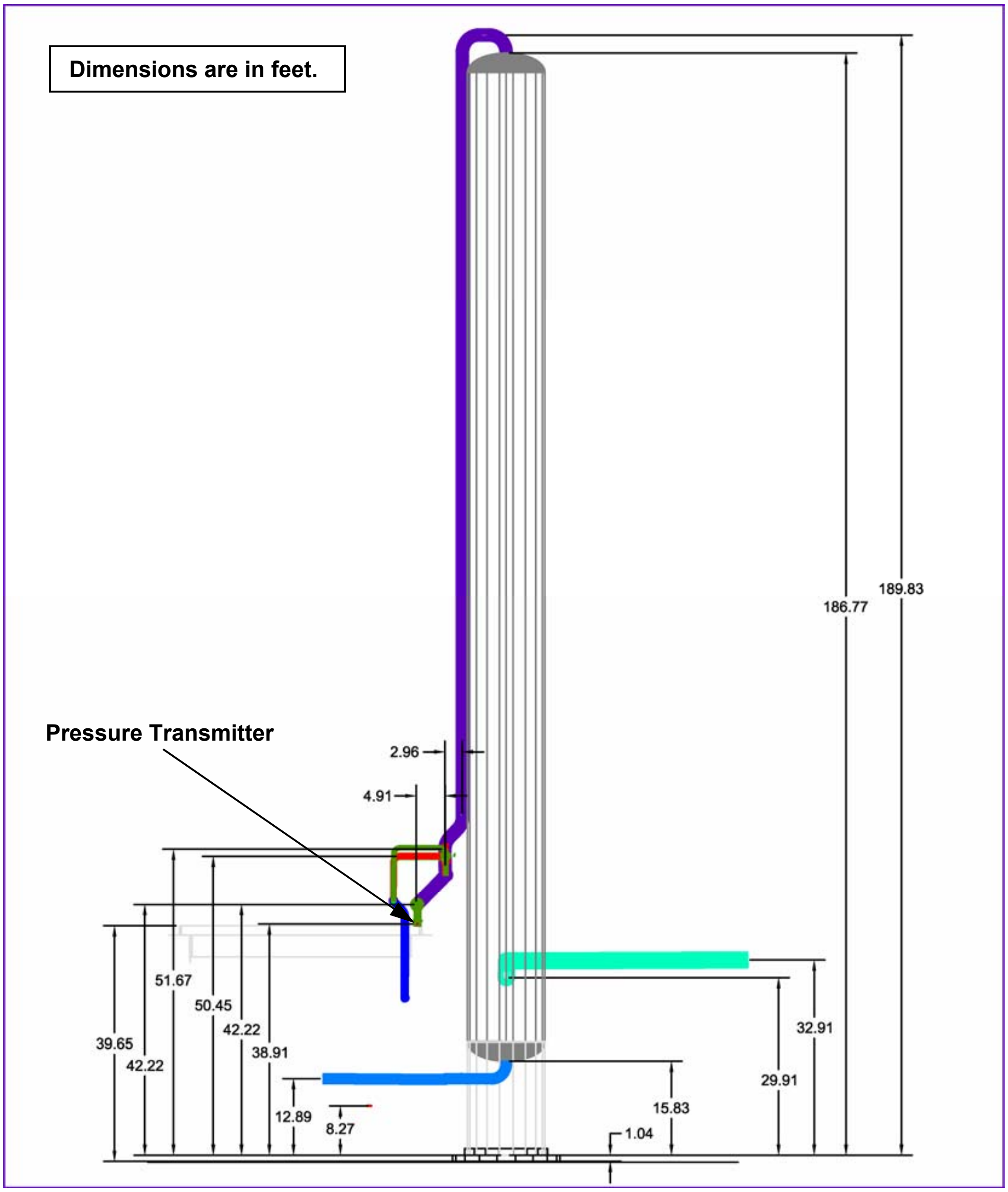


Figure 5-4
Raffinate Splitter Tower Elevation

The only way that the pressure transmitter would indicate a higher pressure than the column pressure (as inferred from the feed pump) is due to the hydrostatic head in the overhead line—up to 150 ft of liquid. The fluid density is approximately 41.4 lbs/cu ft, so this head creates a pressure of up to 42.4 psi. The column pressure just before the rapid increase in system pressure was 21 psig. When these two figures are added (63.4 psig), this closely agrees with the maximum pressure observed from the PI data (for PT-5002).

This suggests that the overhead 24-inch vapor line to the condenser was filled with liquid, which had been lifted up and over into the overhead line by vaporization of the feed and the reboiler return/tower bottoms lifting the extremely high liquid level in the tower. The sample analysis of the liquid in the reflux drum (see Appendix 11) confirms that feedstock had been carried overhead. The relatively high hydrostatic head coupled with a static column pressure of 21 psig was easily sufficient to lift the relief valves (also located at a similar elevation to the fin fans). Since the pressure spike is due to a high hydrostatic liquid head, then the pressure relief valves pass largely 100% of sub-cooled liquid (see section 5.3.3 below).

5.3.3 Feed Composition to Raffinate Splitter

Analysis of the feed composition to the unit (Appendix 11) was compared with historical data. There were no significant abnormalities regarding the feed composition to the unit on the day of the incident. The corresponding bubble point pressure predictions for the unit feed are shown below compared with a historical data set in Figure 5-5.

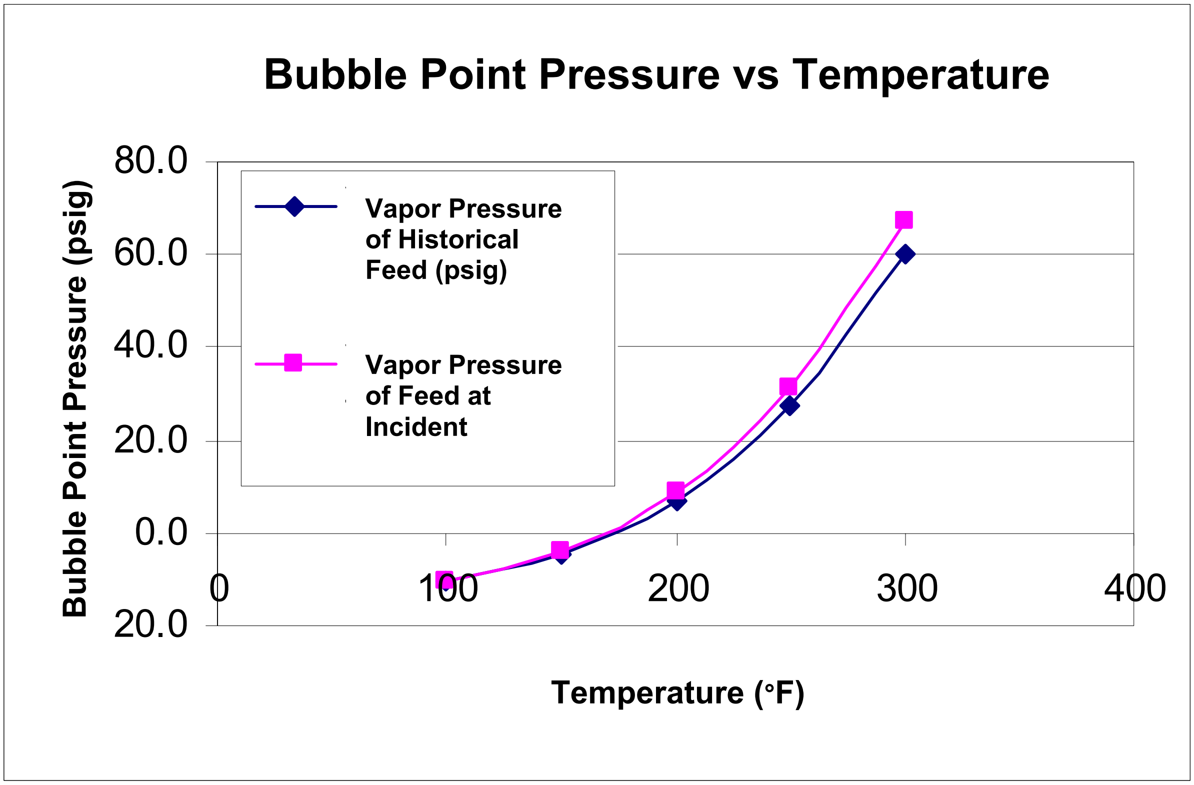


Figure 5-5
Bubble Point Pressure vs. Temperature

These vapor pressure calculations confirm that the historical feed analyses and the analyses of March 23 are quite similar.

The column overhead temperature (TI-5506) during the period when the column relief valves were lifting (13:14 – 13:20 hrs) was approximately 90˚F, rising latterly to 180˚F. The bubble point temperature at atmospheric pressure is approximately 170˚F, suggesting that for the vast majority of the relieving period, the liquid relief was subcooled liquid (with no flashing). There is a very brief period of a few seconds near the time the relief valves are presumed to have closed when the bubble point pressure exceeds atmospheric pressure (indicating limited isenthalpic flashing may have occurred in the blowdown system).

5.3.4 Heat Input to the Splitter

There are 3 sources of heat input to the raffinate splitter:

- the column reboiler (fired)
- feed effluent preheat exchangers
- feed preheat from convection coils in the fired reboiler heater

The Raffinate Splitter reboiler is a recirculating fired heater. The circulation rate during the startup was approximately 100 MBPD, and the differential temperature between the reboiler outlet and the column outlet was around 10˚F. A summary of the reboiler fuel gas flows (green line) during the startup are shown below in Figure 5-6:

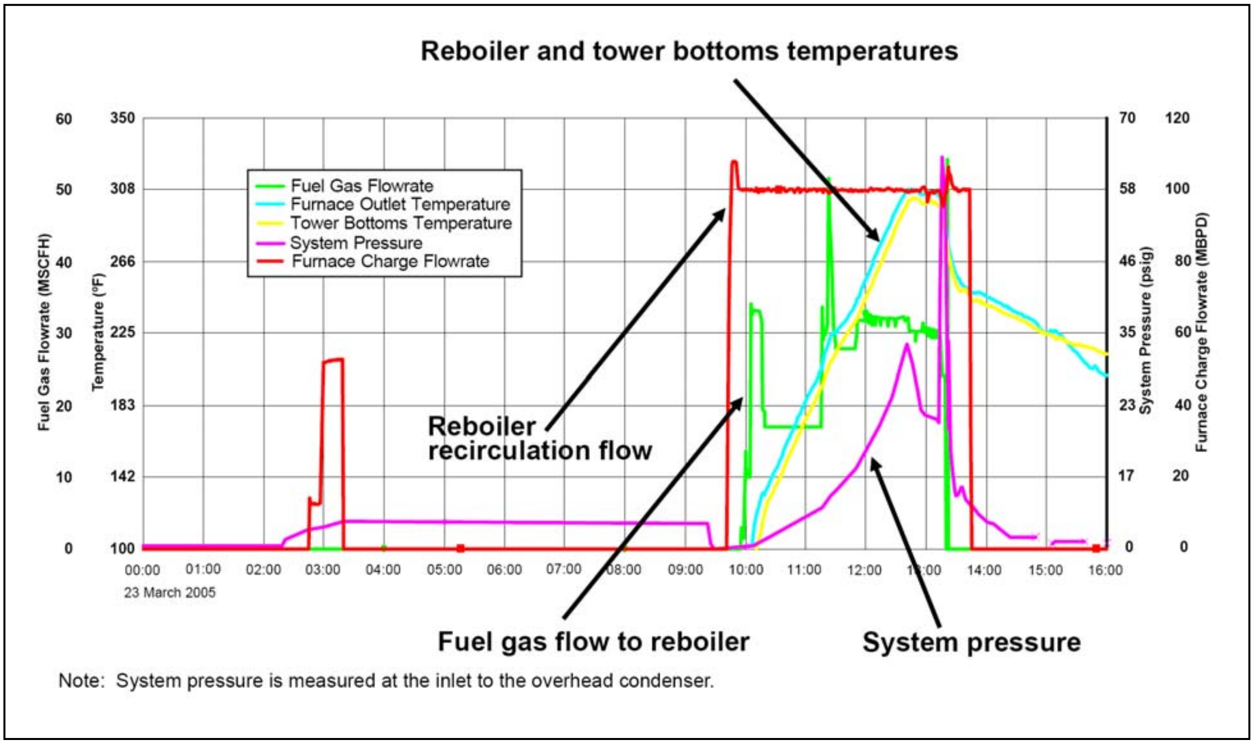


Figure 5-6
Reboiler Fuel Gas Flow Rate During Incident

The fuel gas analysis indicates a calorific value (Cv) of 857 btu/cu ft. Based on the fuel gas flows and Cv, with an assumed heater efficiency of 80%, the heat energy transferred to the process from the reboiler was calculated as follows (Table 5-1):

Table 5-1
Heat Input to Raffinate Splitter

	Minutes	Fuel Gas (Kscfh)	Heat Input (mmBTU/hr)
10.00 – 10.05	5	10	6.86
10.05 – 10.17	12	33	22.62
10.17 – 11.17	60	17	11.66
11.17 – 11.21	4	30.5	20.91
11.21 – 11.30	9	35	24
11.30 – 11.49	19	27.9	19.13
11.49 – 11.52	3	30.3	20.77
11.52 – 12.43	51	31.8	21.80
12.43 – 13.15	32	30.2	20.71
13.15 – 13.19	4	24.08	16.51
13.19 – 13.20	1	12	8.23
13.20 onwards	0	0	0
	200		
Average Calorific Value (BTU/ft^3)		857	
Assumed Heater Efficiency		80%	
Average Heat Input (mmBTU/hr) (assumed 80% efficiency)		17.90	

Feed preheat is via the feed/effluent exchangers (C-1104A/B). Heat transfer has been estimated from the process data and checked by comparing shell and tube side temperature differentials.

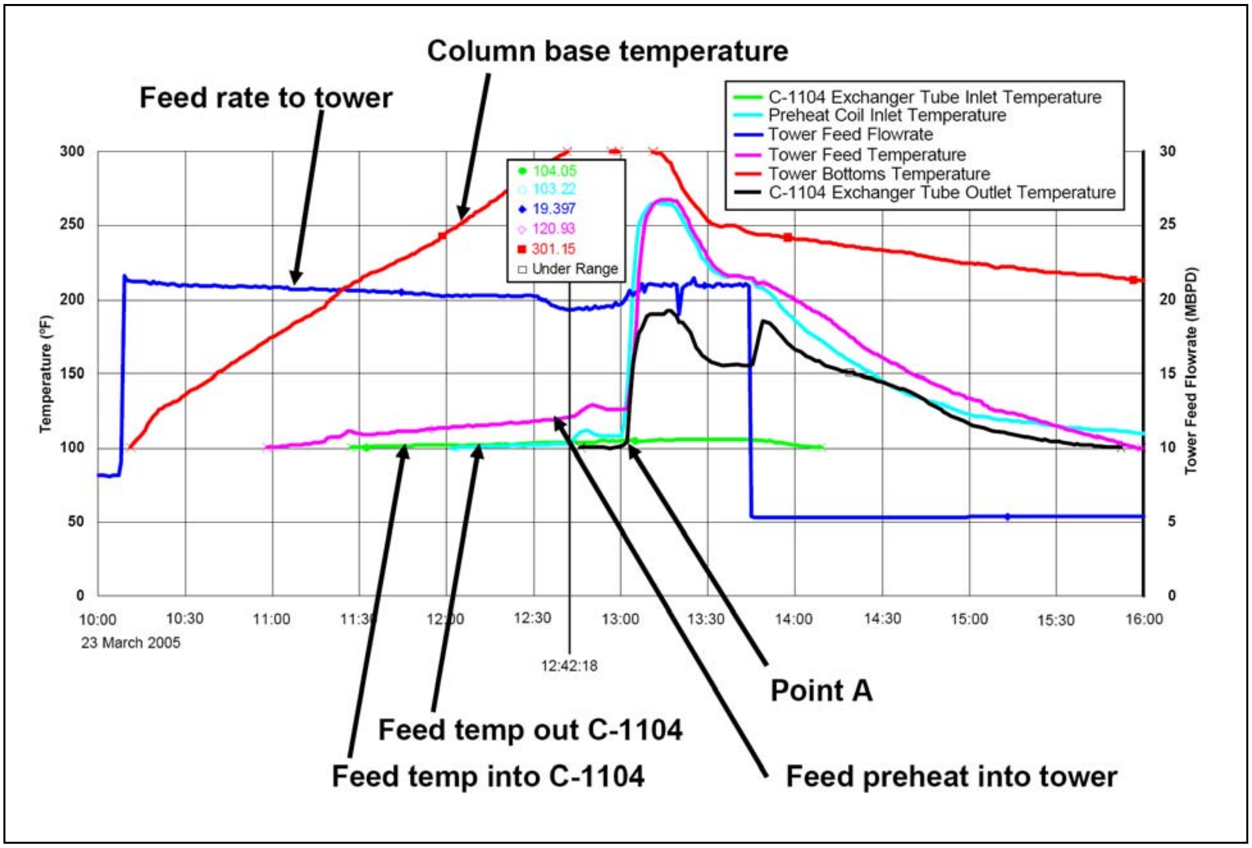


Figure 5-7
Feed/Effluent Heat Exchange

The heat balance across the feed/effluent exchangers (C-1104A/B) indicates that up until the time at Point A (at 13:00 hrs), there is no differential temperature across the tube side (feed). For the shell side (heavy raffinate), the shell effluent temperature is under range (less than 100˚F). This is not surprising since the heavy raffinate level control valve (LCV-5100) was in the closed position (i.e., no flow through the shell side). At Point A, the heavy raffinate LCV is open, and the heavy raffinate flow increases rapidly to approximately 31 MBPD. This has a dramatic effect on the feed preheat increasing across the feed/effluent exchangers from 126˚F to 267˚F between 13:00 to 13:10 hrs. This is equivalent to a preheat energy transfer of about 18.6 mmBTU/hr (assuming no phase change). The corresponding transfer from the heavy raffinate shell side is around 17 mmBTU/hr (based on a differential temperature of 302˚F to 191˚F and a flow average of 24 MBPD).

There is a relatively small heat transfer picked up from the feed preheat through the fired reboiler heater coils (convection section) of around 15 – 18˚F when the feed is relatively cold (less than 126˚F) and before the heavy raffinate flow commences. This transfer rate is around 1.7 mmBTU/hr.

5.3.5 Feed Preheat and Feed Vaporization to the Splitter

As noted previously, the feed preheat to the Splitter increased dramatically once the Heavy Raffinate bottoms flow was opened. Between the period 13:00 to 13:10 hrs, the feed preheat increased from 126˚F to 267˚F (Figure 5-8).

The estimated pressure at the feed location (tray 31) is the column operating pressure plus the hydrostatic head of liquid at that point. From discussion above, the liquid level at this time is believed to have been at tray 13—approximately 41 ft above the feed location. The column pressure (from PT-5002) at this time was 21.5 psig, so the feed pressure is calculated as 33.1 psig. Based on the feed composition, it is estimated that the feed quality at 33.1 psig and 267˚F is approximately 14.9 mole % (14.1 wt %) vapor.

Despite some vapor being quenched by the relatively cold hydrocarbon liquid above, the quantity was sufficient to lift the liquid up and over into the overhead line. The absence of any tray damage, when the tower was inspected after the incident, indicates that this sequence of events was a gradual steady effect sustained for six minutes and not a sudden one.

It has proven very difficult to model the exact circumstances of the incident, and the accuracy of the process modeling, based upon a 1/5 scale (15 trays vs. 70 trays in the actual tower), is not as precise as other aspects of the analysis, such as, for example, the flow through the relief valves. The dynamic modeling indicates that the effect of the feed preheat accelerated the event by about 2 minutes, and that vaporization in the reboiler outlet and bottom of the tower would have eventually caused liquid carryover into the overhead line.

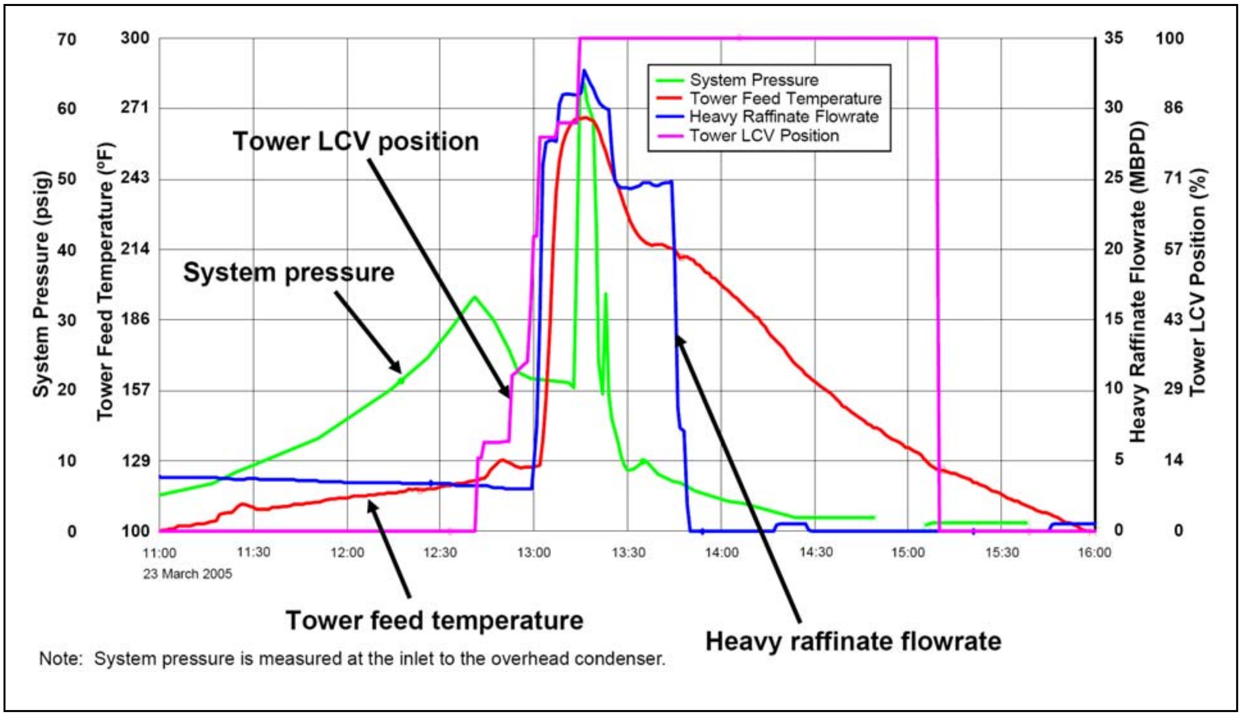


Figure 5-8
Feed Preheat to Raffinate Splitter Tower

5.3.6 Volume of Hydrocarbon Relieved to Blowdown Drum

After the incident, the feed and heavy raffinate rundown continued for one hour 25 minutes until the power failed at 14:45 hrs. On power failure, control valves went to their fail-safe position and maintained the liquid levels in the vessels. Two calibrated pressure gauges were installed after the incident to determine the level of liquid remaining in the tower. The residual liquid level (measured by pressure differential) was approximately 69.2 ft (above the tower tangent line), (assuming a fluid specific gravity of 41.2 lb/cu ft).

An analysis of the flow rate from the Splitter relief valves (RV-1001A/B/C) into the F-20 blowdown system has been completed by Packer Engineering (Appendix 16). This included an analysis of the liquid accumulation in the Blowdown Drum and Stack, and the resultant hydrocarbon flow rate to the sewer system.

Two cases were considered by Packer Engineering:

1. Hydrocarbon liquid relief only (this is thought to be the most likely relief scenario)
2. An additional relief case with hydrocarbon liquid and nitrogen vent gas

The calculated volumes of hydrocarbon released to F-20 (through the relief valves) are shown below in Table 5-2:

Table 5-2
Hydrocarbon Discharge Through Relief Valves

Case	Total Volume (US gal)
All liquid	45,900
Reflux Drum N2	46,600

Based on this modeling (for 100% liquid relief), the total estimated volume of hydrocarbons released to the Blowdown Drum (F-20) is 45,900 US gallons (6,100 cu ft or 1,100 bbls). Simpler calculations based on the RV characteristics showed a similar volume (about 7,600 cu ft) to that dynamically modeled.

Using an overall volume balance to corroborate shows:

- Estimated liquid inventory in the Splitter at end of incident (balance of flow meters) (corresponds to liquid height of 131.8 ft—close to tray 13) = 16,200 cu ft
- Estimated liquid flow to relief system (from Packer Eng) = 6,100 cu ft
- Estimated liquid accumulation in reflux drum = 400 cu ft
- Estimated volume remaining in the Splitter = 16200-(6100+400) = 9700 cu ft

This volume is equivalent to a liquid height of 78 ft above the tangent line (simpler modeling predicts 70ft of liquid remaining).

The residual liquid level (measured by pressure differential) was approximately 69.2 ft (above the tower tangent line), assuming a fluid specific gravity of 41.2 lb/cu ft.

All three figures are in reasonable agreement.

5.3.7 Volume of Hydrocarbon Released to Sewer

The hydrocarbon liquid discharged through the relief valves overwhelmed the 6-inch drain line from the blowdown drum to the sewer. As the liquid level accumulated in the blowdown drum and filled the stack, the hydrostatic head of the liquid above the drain line increased, increasing the flow through the drain line. The liquid remaining in the blowdown drum and stack when the relief valves reseated after six minutes would have subsequently drained into the sewer.

The quantities of hydrocarbon released to the sewer were calculated by Packer Engineering (Appendix 16), as follows (Table 5-3). Flow calculations are approximate, due to the complex design of the sewer system, and assume that the main restriction to flow was the 6-inch outlet line through the gooseneck to the sewer. Any additional restriction would reduce flow to the sewer and increase discharge from the top of the blowdown stack. The 6-inch line was corroded at ground level, and may have leaked some hydrocarbon at the base of the blowdown drum.

Table 5-3
Maximum Liquid Flows into the Sewer System

Case	Height of Liquid (ft)	Static Pressure (psig)	Pressure (psia)	Maximum Liquid Flow (gpm)
Bottom Empty	0	0	14.7	1,800
Bottom full	27	7.5	22.2	2,900
Bottom & Cone full	37	10.3	25	3,200
Bottom, Cone and Stack full	113.5	31.5	46.2	5,000

Based upon these flow rates, the total volume of hydrocarbon that flowed through the gooseneck to the sewer was 44,000 US gal (5,900 cu ft or 1,050 bbls). This includes flow while the relief valves are open plus drainage from the blowdown stack and relief header after the relief valves close. This quantity represents an upper bound, for the reasons detailed above.

5.3.8 Volume of Hydrocarbon Released to Atmosphere

The difference between the total discharge through the relief valves and the flow to the sewer is the quantity of hydrocarbon liquid that was ejected from the top the stack. Therefore:

Total release to Blowdown Drum (F-20)	= 45,900 US gal
Flow through gooseneck to the Sewer	= <u>44,000 US gal</u>
Liquid release to Atmosphere	= 1,900 US gal

A slightly higher estimated quantity released to atmosphere is obtained if the presence of some nitrogen in the relief is assumed. Overall, the volume of hydrocarbon liquid ejected from the stack is estimated at approximately 2000 US gal (250 cu ft or 48 bbls). This quantity represents a lower bound, and any additional restriction to flow into the sewer and/or leakage from the corroded gooseneck line would increase this figure.

5.3.9 Dynamic Modeling

A dynamic model (Appendix 15) of the raffinate splitter column was developed by Process Systems Enterprise (PSE) to better understand the liquid level in the raffinate splitter column over time. Based on a simple single phase volume balance, it seems that the liquid level should only have reached tray 13 (top tray =1). However, the actual level will be much more complex to predict because of vaporization in the vicinity of the reboiler and at the feed location (once the feed preheat increases).

The dynamic model of the Splitter included a detailed representation of the internal trays (active area and downcomers). The heat input into the unit was included to allow a full tray-by-tray vapor liquid equilibrium (VLE) calculation over the column and throughout the startup. The full report is attached as Appendix 15. The main results are, as follows:

- The hydrocarbon liquid does fully reach the overhead line at the top of the column.
- There is a lot of vaporization in the bottom trays (from reboiler input) and this lifts liquid up the column.
- Some vaporization at the feed tray accelerated the overflow of liquid into the overhead line.
- The model matched the peak pressures observed, but predicts the system pressure spike a few minutes ahead of the actual spike. This difference is likely due to small errors in the feed flow meter or possibly simplifications associated with aggregating some of the feed components in the model.
- In order to match the general buildup of pressure over time (before the pressure spike), the model needs a small vent to be open in the system. This suggests that the 1½ inch vent was possibly open.
- There is no suggestion that water played a significant effect in the incident. PSE were able to match the system pressure profile without assuming any free water was present.

5.3.10 Conclusions of the Technical Analysis

The main conclusions from the technical analyses of the incident are as follows:

- The high peak pressures observed (63 psig) were caused by liquid filling up the 24-inch overhead line off the Splitter column. This is supported by the dynamic modeling results and supported by the flow response from the feed pump during the pressure release. As the RVs were located close to the bottom of the overhead line, the high hydrostatic pressure from a filled overhead line was sufficient to exceed the RV set pressure.
- Virtually all of the release was subcooled liquid.
- The liquid reached the overhead line by a combination of grossly overfilling the main column with the liquid charge, and vaporization and expansion of the tower base and feed charge.

Based on Packer Eng. estimates, the total release to the F-20 Blowdown Drum was 45,900 US gallons (6,100 cu ft or 1,100 bbls). This is fairly consistent with the volume balance and is corroborated by other modeling performed.

5.4 Release Modeling

5.4.1 Dispersion of Vapors From Blowdown Drum

The raffinate that was ejected from the top of the blowdown stack was modeled to determine if the dispersion of vapors matched the observed blast damage. A Computational Fluid Dynamics (CFD) model of the dispersion of the vapor cloud that originated from the liquid hydrocarbon ejected from the blowdown stack was developed (Appendix 17).

The modeling was performed with a large eddy simulation (LES) CFD model. It shows the movement of the vapor cloud throughout the ISOM unit and the surrounding areas and the effects that the wind and obstructions played in the dispersal and concentration of the vapor cloud. The modeling was performed over the 6-minute period of the relief valve discharge, beginning at 13:14 and culminating at the time of the explosion (approximately 13:20). Supporting calculations and methodology for the release source terms (shown in Appendix 16) show that the hydrocarbon release took place during approximately the one to one-and-a-half minutes prior to the time of the explosion.

Weather data were obtained from on-site and off-site weather stations. The on-site weather stations were located on the roof of the North Office Building (NOB) and in the Alkylation (Alky) 3 process unit. The NOB weather station is taken as the most representative, since the anemometer is located above the roof of the NOB building, clear of any plant congestion, whereas the Alky 3 weather station is located within the unit and is shielded by process equipment.

Table 5-4
Flows from Top of Blowdown Stack for Different Scenarios

Scenario	Vapor Mass Flow (lb/s)	Liquid Mass Flow (lb/s)	Total Mass Flow (lb/s)
All Liquid	0.00	425	425
N_2 Reflux Drum	14	412	426

Modeling was performed for a total of four different scenarios:

1. A liquid release from the blowdown stack occurring one minute prior to the explosion (13:19 hrs).

2. A two-phase release from the blowdown stack occurring one minute prior to the explosion (13:19 hrs), caused by nitrogen present in the Reflux Drum mixture.
3. A liquid release from the blowdown stack occurring 1½ minutes prior to the explosion (13:18:30 hrs).
4. A two-phase release from the blowdown stack occurring 1½ minutes prior to the explosion (13:18:30 hrs) and caused by nitrogen present in the Reflux Drum mixture.

The dispersion modeling results indicate that a flammable vapor cloud formed in the area surrounding the ISOM unit. The wind and obstructions in the area generate a flow field such that the majority of the vapor cloud within the flammability limits is contained within the area surrounding the contractor trailers, the piperack west of the ISOM, the area surrounding the base of the blowdown stack, and the area known as the "ballpark," south of the ISOM.

The predicted vapor cloud location is in reasonable agreement with the explosion modeling (see section 5.5 below) that estimated the locations of the congested zones involved in the explosion. The dispersion results demonstrate that the release scenario from the blowdown stack was capable of creating a flammable cloud of sufficient flammable mass and location to match the observed damage.

The modeling results and additional calculations indicate that the fireball created by the ignition of the vapor cloud had a diameter of up to 236 ft and lasted approximately 6 seconds in duration.

5.5 Explosion Modeling

Baker Engineering and Risk Consultants, Inc. (BakerRisk), was retained to evaluate the possible scenarios for the explosion. Six potential causes were evaluated: five types of explosions and natural disasters. The damage patterns, explosion energy, and observations of the condition of specific pieces of equipment were the primary basis for the evaluation of explosion types. All explosion scenarios were based on observed damage patterns within the ISOM unit.

The explosion scenarios considered were a fired heater explosion, vapor cloud explosion (VCE), bursting pressure vessel, boiling liquid expanding vapor explosion (BLEVE), and bombing. A natural disaster that could have caused any of the first four explosion types was also considered. It was concluded that the explosion was a VCE and all other scenarios were eliminated for the following reasons (Appendix 18).

- Fired Heater Explosion
  - Heater damage inconsistent with internal heater explosion; no outward deformation
  - Inconsistent with plant damage pattern; damage was not centered on the fired heaters or greatest at the heaters
  - Insufficient explosion energy
  - ELIMINATED

- VCE
  - Discharge of fuel from the F-20 blowdown stack and vapors from the pooled liquid were observed
  - Sufficient explosion energy
  - Consistent with damage pattern
  - Consistent with sequence of events
  - PROVEN

- Bursting Pressure Vessel
  - No burst vessel
  - Inconsistent with damage patterns; no localized damage from a burst vessel
  - Inconsistent with sequence of events; discharge from F-20 stack preceded the explosion by about 6 minutes
  - ELIMINATED

- BLEVE
  - No burst vessel
  - Inconsistent with damage patterns; no localized damage from a BLEVE
  - Inconsistent with sequence of events; no fire or other condition to cause a BLEVE before the explosion
  - ELIMINATED

- Bombing
  - Inconsistent with sequence of events; discharge from F-20 stack preceded the explosion by about 6 minutes
  - Inconsistent with plant damage pattern—no zone of intense damage
  - ELIMINATED

- Natural Disaster (causing loss of containment)
  - Earthquake—no reports in any nearby facilities or communities
  - Lightning—no storms or reports of lightning; weather was mild and winds were low
  - ELIMINATED

The VCE scenario was studied by considering possible ignition sources, oxidizers, and fuels. It was confirmed that the release occurred from the F-20 blowdown stack, and the vapor cloud formed from vaporization of falling liquid droplets and pooled liquid.

The location of the vapor cloud was determined from a combination of observed damage patterns, dispersion modeling, eyewitness accounts, and the final energy calculation. From an examination of the structural damage, a number of items (damage indicators) were selected for analysis. The structural indicators were used to provide the target values of pressure and impulse at known distances from the blast source. Areas of congestion and confinement within the ISOM were taken into consideration. The vapor cloud explosion energy was iterated until a best fit was obtained between predicted blast loads and the damage indicator target values.

Consideration of directional vectors indicates that the vapor cloud extended into parts of the ISOM, the pipe rack to the west of ISOM, and the area of the trailers and vehicles immediately west of the pipe rack. The audible report was likely to have two or more peaks in sound pressure level, and witnesses would have experienced reflections or echoes delayed long enough to sound like multiple explosions. Given the physical geometry and damage patterns, it is unlikely that there were multiple explosions.

It is estimated that the energy in the vapor cloud in the zones that contributed to the blast pressure is 2.8×10^{11} in. lb (3.2×10^{10} J), equivalent to the energy in 1,600 lbs (730 kg) (6 bbls) of raffinate feed stock. This represents approximately two seconds of the estimated flow through the relief valves and up to one eighth of the discharge from the F-20 stack.

It should be noted that the energy estimate only accounts for the energy inside the congested zones. The flammable cloud extended to open (uncongested) areas and the amount of discharged fuel was, therefore, larger than these estimates would indicate. The fuel outside congested zones did not contribute to the blast loads, but was consumed in a fireball. Some of the discharged fuel mixed with air below the lower flammability limit (LFL) and dispersed harmlessly. Additionally, some of the fuel was in a liquid pool at the time of ignition and vapors above the pool would have been too rich to burn. Combining these factors, actual fuel discharge would have been significantly greater than the amount shown from the explosion energy calculation.

The footprint of the flammable cloud, shown in Appendix 18, Figure 6, is in reasonable agreement with the CFD dispersion modeling (Appendix 17), and the locations of congested zones that were involved in the explosion. The dispersion results indicate that the release scenario from the F-20 Blowdown Stack was capable of creating a flammable cloud of sufficient flammable mass and location to match the observed damage. It also indicates that additional hydrocarbon spread through the sewer system was not required to supplement the vapor cloud to create the main explosion damage observed.

The energy distribution was used to produce side-on (unreflected) pressure and impulse contours. These contours have been overlaid on the plot plan of the facility. The pressure contours are shown in Appendix 18, Figure 7, and the impulse contours are shown in Appendix 18, Figure 8.

The side-on pressure at the J.E. Merit trailer, and the immediately adjacent Fluor trailer, is calculated to be 2½ psig, with an impulse of 430 psi.ms. This impulse is large and primarily due to the trailers being within the vapor cloud. Vapors were likely to have entered under the trailers. Of the 22 persons known to be in the J.E. Merit trailer at the time of the explosion, there were 11 fatalities and 11 injured (5 BP and 6 contractor). The location of one other fatality is not known precisely, other than being in or around the J.E. Merit trailer at the time of the explosion. This corresponds to 50-52% vulnerability for the J.E. Merit trailer. There were two fatalities in the Fluor trailer and no injuries. A third person, who was fatally injured, was last seen walking towards the Fluor trailer, and is presumed to have been inside at the time of the explosion. This corresponds to 100% vulnerability for the Fluor trailer. Injuries, but no fatalities, were sustained by individuals in other trailers at distances of 350 to 480 ft from the blowdown drum.

The CCPS/API and Amoco facility siting methodologies (see section 5.12) are based upon simplified screening processes that are intended to be conservative, i.e., err on the side of caution by over-predicting casualties. The vulnerability correlations (see section 5.12.8.1) for wood frame trailers within these methodologies do not appear to be as conservative as originally thought. The Amoco correlation predicts 10% vulnerability at 2½ psig side-on (5 psig reflected) pressure, and CCPS/API predicts 50% vulnerability at the same pressure. Clearly the CCPS/API vulnerability correlation is closest to the actual experience, but under-predicted for the Fluor trailer at this specific location.

The quantity of hydrocarbon involved in the VCE was relatively small, at 6 bbls of raffinate. The vapor cloud drifted towards the south into the ISOM unit, which is not as congested as some refinery process units. As the degree of congestion (number of obstacles due to process equipment and pipework) and confinement (extent of enclosure in three dimensions) of a vapor cloud increases, the magnitude of the resulting VCE also increases in the event of ignition. The Ultracracker just north of the Blowdown Drum & Stack is one of the more congested process units on the refinery. If a similar size of vapor cloud (with same energy) had collected within the congested zones of the Ultracracker, the resulting VCE would have created a higher blast overpressure at a given distance from the center of the explosion. Table 5-5 below illustrates the effect.

Table 5-5
Effect of Congestion on Explosion Overpressure

Overpressure (psi)	Pressure Contour Radius (ft) Average Radius (max-min radius)	
	March 23 Incident	Higher Congestion, Equivalent Energy Case
1.0	310 (265-356)*	500 (472-519)*
0.75	385	640
0.50	535	900
0.25	970	1630
0.10	2170	3610

*The closest contours followed the shape of the confined/congested zones that comprised the explosion sources, and were not easily approximated as circular contours; as a result, the maximum and minimum "radius" is also provided.

Based upon the CCPS/API methodology, the 1.0 psi contour for wooden trailers corresponds to isolated buildings overturning and the collapse of roofs and walls. The methodology predicts 10% vulnerability of the occupants at this overpressure. As discussed above, this may not be as conservative as previously believed. At these conditions it can be seen that the 1.0 psi overpressure extends to about 500 ft under the higher congestion case vs. 300 ft for the ISOM incident. This suggests that, depending upon the location of the explosion, many locations within the site boundary could potentially experience this level of overpressure in the event of an explosion in a more congested area. This should be addressed when determining safe locations for buildings in future.

In the event of an explosion in a more congested area, lower overpressures than 1.0 psi extend to greater distances that cover the whole site. Lower overpressures can result in a sudden vibration to buildings with potential to cause window breakage, and dislodge light fittings and items stored against external walls. This should be addressed when considering the adequacy of existing or new buildings.

5.6 Sewers

A post-incident inspection of the sewer system around the ISOM unit was conducted (see plot plans in Appendix 19). Several areas Inside Battery Limits (ISBL) had standing water (firewater and/or rainwater) and showed no signs of draining.

West of the ISOM unit, the Oily Water Separator and Diversion Box #2 were damaged by fire. The Oily Water Separator sump pump was in good condition. The inspection hatch on the Dry Weather Sump #17 was open, and had a temporary diesel pump with automatic start from a floating mercury switch in the sump. The diesel pump was severely damaged. The carbon canister in the Dry Weather Sump was also severely damaged as if it had been squeezed.

It was impossible to identify the indicators on the conservation vents to the west of the Flash Drum (F-200), north of the Isomerization Reactor (D-300). The conservation vents located in the pipe alley between the ISOM unit and the warehouse had been damaged, and the indicators blown off. Concrete around the fire trap lid was broken. The fire trap prevents the ignition of flammable vapors in the sewer.

There were no sewer connections or P-traps in the catalyst warehouse or the immediate vicinity of the trailers west of the ISOM that could have spread hydrocarbons during the incident.

From inspection and the explosion modeling, it was determined that the sewers were not the route for the formation of the hydrocarbon vapor cloud that subsequently exploded. The damage observed to the sewer system was assessed to be the result of secondary fires caused by the main explosion.

5.7 Sample Analysis

Samples were taken on April 12 and April 19 from different process streams in the presence of regulatory agency personnel for analysis by an independent certified laboratory, BSI Inspectorate. An independent report addressing the custody transfer, analysis methodologies and detailed results is attached in Appendix 11. The samples were split and analyzed separately by BSI Inspectorate and BP.

The samples taken from the Raffinate Splitter feed surge drum, tower and reflux drum systems were analyzed for hydrocarbon species, and reported by carbon number (Appendix 11, Attachment 5).

Sample results showed that:

- The Splitter feed was typical and contained around 53% C7 and heavier components.
- Liquid in the reflux drum and reflux pump suction contained slightly more light ends concentrations than the feed drum.
- The bottoms sample showed slightly less light ends concentrations than the feed drum.

The reflux samples contained substantial quantities, around 45%, of heavier hydrocarbons (C7 and C8). During normal operation, the overhead product contains only 1% to 6% C7 and heavier components, averaging around 3.5%. This indicates essentially no fractionation of the feed occurred during the Raffinate Splitter startup and during the 22 minutes after the explosion, when feed, bottoms product, and reflux were still in operation.

These results further support the conclusion that liquid above the tower feed location was pushed overhead and into the reflux drum by vaporization of the overheated feed and tower base. Some of the lighter components from the bottom liquid appear to have moved above the feed tray when the bottoms were heated to 300˚F and the feed to 260˚F. Some lighter components flashed up the tower when the liquid above the feed tray was pushed overhead, but very little distillation occurred.

Samples were taken from several low points with the potential for water, including the Splitter overhead water knockout system, Light Raffinate product, the Splitter reflux line to the tower, and at the blowdown drum (F-20). The label on one of the samples was illegible, and was referred to in the report (Appendix 11) as “P-4107B Pump.” This sample was a low point drain on the Light Raffinate at the outlet of the Light Raffinate Product Cooler (C-1107B).

These low point samples were analyzed for sulfolane (See Appendix 11, Attachment 4). Sulfolane is a water soluble compound used in the ARU to extract aromatics (benzene, toluene and xylene) to produce raffinate for Splitter feed. Its presence is indicative of the presence of water.

Water from the Raffinate Splitter samples contained a few hundred ppm of sulfolane from the water wash tower of the ARU. Raffinate from the ARU is expected to be wet and the Splitter is designed to handle small quantities of water during normal operation. These quantities of water in the feed from the ARU were insufficient to cause the pressure spike when the relief valves opened at 13:14 hrs.

The traces of sulfolane present do not allow any conclusions to be drawn about how much condensate might have been in the Raffinate Splitter system before the startup. The tower was steamed in preparation for the temporary outage. Condensate would have collected at low points and in the seal pans within the tower. Prior to the startup, when the tower was pressurized with nitrogen for tightness testing, the low point drains were opened to drain any condensate present. A small quantity of water could have remained within the seal pans in the tower, but insufficient to cause the pressure spike when the relief valves opened at 13:14 hrs. The absence of any tray damage when the tower internals were inspected supports the conclusion that steam generation was not responsible for the pressure spike.

5.8 Operations

5.8.1 Control Board Indications

The Day Shift Board Operator had a variety of instrumentation, controls and alarms for monitoring and controlling the Raffinate Splitter levels, temperatures, pressures and flows. Two instruments did not indicate accurate data, while many other instruments verified that conditions were deviating from those prescribed in the startup procedure.

The Day Shift Board Operator had attended Basic Operator Training (BOT) and process troubleshooting training. These classes emphasized the importance of paying attention to all parameters (flow, pressure, temperature, level and indirect measures, such as material and heat balances) to ensure understanding of actual process conditions and to be able to discern if any instrument is providing misleading indications due to process conditions.

The Day Shift Board Operator made shift relief with the night shift board operator, who was not involved in bringing in feed and packing the Splitter. Operator A, who packed the Splitter and would have been aware of the failure of LAH-5102 to alarm, left the site before the Day Shift Board Operator arrived. No mention of an alarm malfunction was found in the log book, and the operating procedure was still in the satellite control room. The Day Shift Board Operator stated that prior to the startup he was unaware of any instrumentation problems with the Raffinate Splitter.

A discussion of the instrumentation, controls and alarms for monitoring and controlling the Raffinate Splitter is presented below. An independent analysis is appended (see Appendix 20).

5.8.1.1 Raffinate Tower Level Indicator

The Raffinate Splitter level indicator (LT-5100) is a displacer type device and worked as designed, providing accurate readings of liquid levels in the tower until it was filled over the design control range. Figure 5-9 shows the level indication on the control board screen.

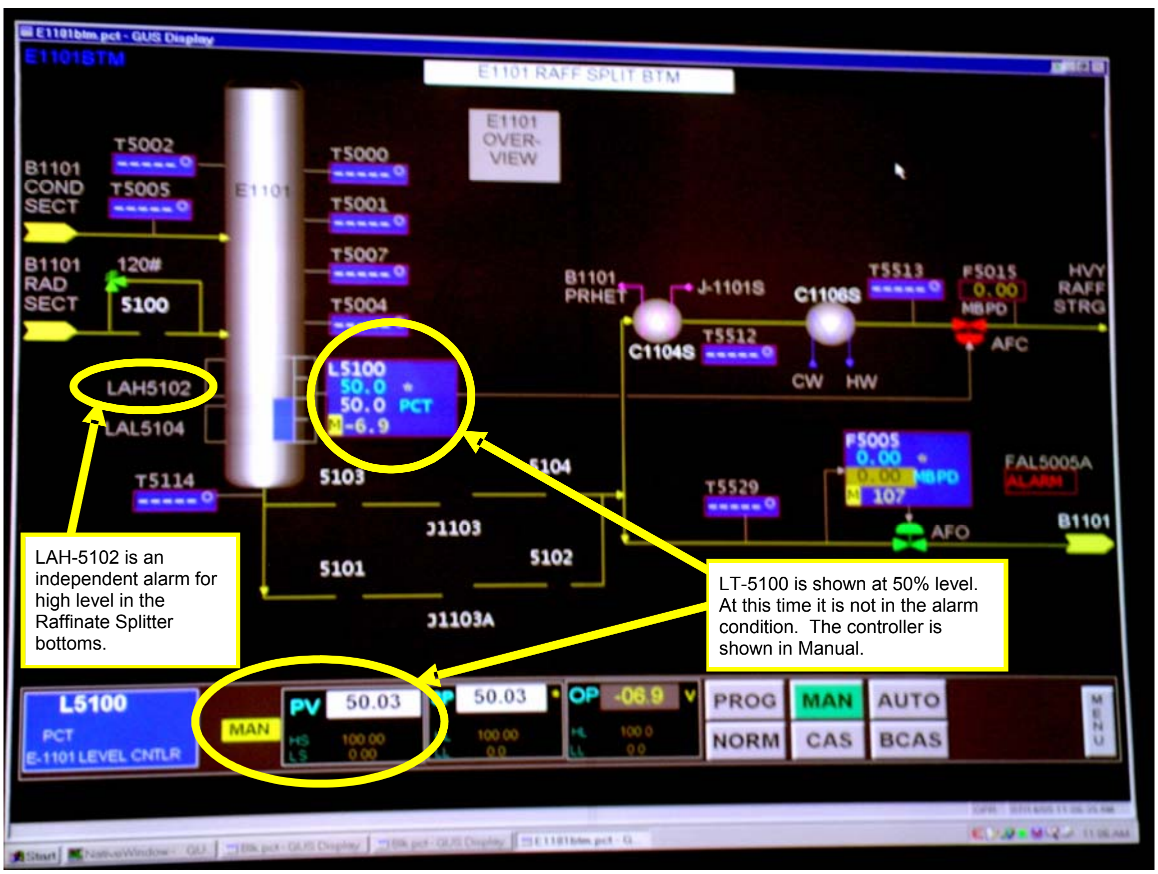


Figure 5-9

DCS Screen Showing Raffinate Splitter Level Not in Alarm at 50% Level

If both impulse lines to the level indicator are submerged, once the liquid density in the base of the column falls below the reference density for the level instrument, then the indicated level will start to fall (see Appendix 21).

The level transmitter indicated accurate trends, such as falling and rising again when the reboiler circuit was packed. When the level indicator reached 100%, Operator A stopped loading the tower and stopped circulating raffinate through the reboiler. The level indicator was showing 100% when the day shift started, and 97% at 09:30 hrs, when the Day Shift Board Operator resumed startup of the Raffinate Splitter. Although the startup procedure calls for a 50% level, the Day Shift Board Operator resumed filling the tower at a rate of 20,000 BPD and took no action to remove any liquid from the tower until 12:41 hrs. The startup procedure requires the tower bottoms level control valve (LCV-5100) to be set in automatic mode at 50% early in the startup.

The level indicator is not designed to show levels greater than 100%. Instrument readings are generated by a float that exerts force as liquid is added or taken out of the tower. No additional force is exerted after the tower is filled to the maximum recommended liquid level, i.e., 100% (about 10 feet).

After liquid had been pumped into the tower for 90 minutes with the runoff closed, the indicator showed a level of 92%. After two more hours of pumping raffinate into the tower with the pressure rising, operators opened the runoff. The indicator showed a level of 80% when the flow of raffinate to tankage was established. Sections 5.8.2 and 5.8.3 explain the effect of decreasing liquid density, caused by heating of the liquid, on the indicated level. If the Heavy Raffinate rundown had been established prior to adding heat, as prescribed in the startup procedure, the risk of a fully submerged level float indicating a level slowly trending down would have been eliminated. The level indicator functioned correctly when the tower was deinventoried some 3 months after the incident. The board operator had received some training in level indicators in his basic operator training.

The tower level transmitter, LT-5100, had a local display giving an indication of level on a 0-100% scale for the outside operators. The Day Shift Board Operator does not appear to have requested the outside operators to check the tower level during the startup.

The Investigation Team could not find an updated instrument data sheet for the level indicator (LT-5100) since its original installation that shows a higher gravity than Heavy Raffinate. The original specific gravity used for calibration was 0.652, which equates to 40.67 lbs/cu ft. The density for heavy raffinate at 275/280˚F, which is the normal operating conditions for the bottom of the tower, is 37.5 lbs/cu ft. This 8% difference equates to less than 5 inches difference between indicated and actual level under normal operation. At the top of its range, i.e., 100% level or higher than the upper tap of the float pot, the indicated level would be 92%.

5.8.1.2 High Level Alarms

The high level alarm from the distributed control system (DCS) level controller (LT-5100), which was set to sound when the level reached 72%, worked as designed. The alarm sounded and was acknowledged at approximately 03:00 hrs March 23. The alarm indication remained on throughout the subsequent startup and only cleared during deinventorying of the tower. Figure 5-10 shows the control board screen with the level transmitter in alarm.

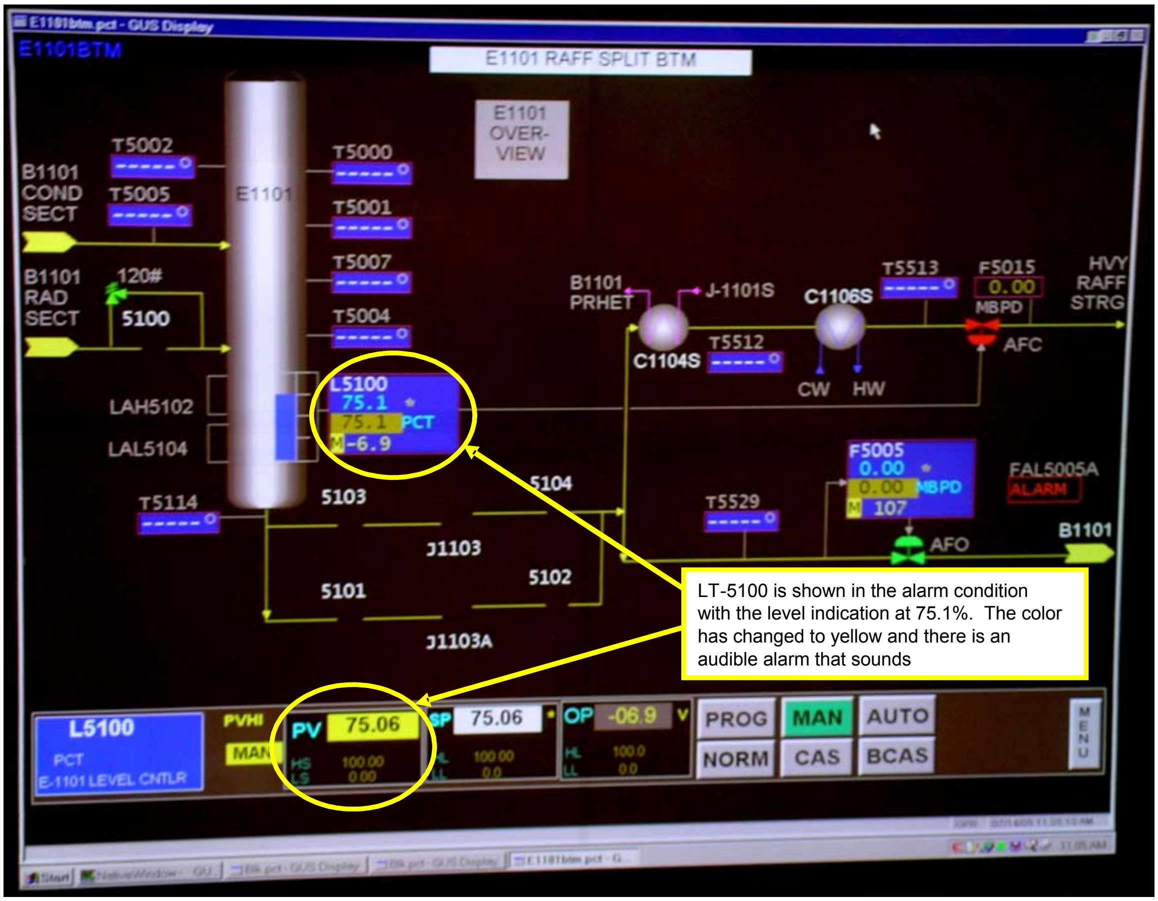


Figure 5-10

DCS Screen Showing Raffinate Splitter Level in Alarm at 75% Level

A redundant high level alarm (LAH-5102), set to sound at 78%, failed to operate. This was not reported or passed on to the day shift. If it had worked, it too would have sounded just after 03:00 hrs March 23. This alarm also indicates on the DCS screen, not a separate alarm panel, and has a similar visibility as the 72% alarm. It was not classified as a critical alarm.

Both of these alarms automatically reset when the level drops below the thresholds at which they are programmed to alarm. Once the liquid level in the tower exceeded these thresholds after packing the reboiler circuit at 03:00 hrs, the indicator never dropped below them. Even though data seen from the level indicator trended below 100%, the level indicator continued to communicate that the liquid level in the tower exceeded the level prescribed in the startup procedure, and functioned as designed. The Day Shift Board Operator had not been informed of the faulty redundant high level alarm at the beginning of the shift. At this time the level indicator showed 100%.

A list of instrumentation on the Raffinate Splitter and summary of alarms are found in Appendices 22 and 23, respectively.

5.8.1.3 Hydrocarbon Removal from the Tower

The feed to the Raffinate Splitter Charge Drum from the ARU is controlled by the ARU and cannot be adjusted by the Board Operator for the Raffinate Splitter. Communication clearly occurred on March 23, when the feed was started. The feed rate from the ARU varied from 15,000 to 20,000 bpd. The Splitter Board Operator controls the feed rate from the Charge Drum to the tower.

There are two pathways to remove hydrocarbon from the tower; the Heavy Raffinate bottoms product, and the Light Raffinate overhead product. Under normal operation both are utilized with a 55/45 split between bottoms and overhead. During startup, it takes time to gradually heat the feed enough to generate overhead flow, so initially the only outflow from the Splitter is through the bottom Heavy Raffinate rundown.

The Day Shift Board Operator closed the bottoms level control valve (LCV-5100), blocking one pathway, from 09:46 to 12:41 hrs. The closed status of this valve was indicated on the control board screen, and the low flow alarm on the Heavy Raffinate flow transmitter (F-5015) remained in alarm until 13:00 hrs. The startup procedure calls for the level controller to be set at 50% set point in automatic control to ensure the liquid levels in the Raffinate Splitter tower are at the recommended level of 50%. In previous startups this was done as soon as, or before, introducing feed for the majority reviewed (see Appendix 24).

The startup procedure also includes a note after Step G.16 to the effect that:

> *"Flow is now established in the reboiler section of the B-1101 Raffinate Furnace and heavy raffinate is running down to tankage."*

This note precedes the next section of the procedure titled: "H. Heat the B-1101 Raffinate Furnace and Rundown Light Raffinate."

The Day Shift Board Operator failed to activate the automatic level control system until Operator B, an experienced board operator, reviewed the status of the startup from the control screen in the satellite control room. Upon realizing the tower was overfilled, he telephoned the Day Shift Board Operator around 12:40 hrs and told him that he needed to take a bottoms flow out of the tower. The Day Shift Board Operator attempted to start the rundown and opened the level control at 12:41 hrs (although a block valve may have been closed), and then placed it back in manual at 13:00 hrs and began opening the valve manually. The heatup commenced three hours earlier at around 10:00 hrs.

The second pathway for removing liquid from the tower is the overhead product from the Reflux Drum. A startup typically takes 3 to 4 hours to heat up the tower (at the specified 50˚F per hour) before fractionating an overhead product. During this, the only means of controlling the tower level up to then is to ensure that there is sufficient Heavy Raffinate product rundown flow to balance the incoming feed rate.

Although the heatup rate was faster (75˚F vs 50˚F per hour), control room instrumentation for the reflux drum showed no indication of liquid in the reflux drum until 13:16 hrs, four minutes before the explosion. Outside operators physically checked the reflux drum level at the request of the Day Shift Board Operator between 11:30 and 11:45 hrs and confirmed no liquid level. The control board screen also indicated zero reflux flow and zero Light Raffinate flow to tankage. The continued input of cold feed up until 13:00 hrs slowed the normal overhead vaporization process despite the high bottoms temperature.

The bottoms flow transmitter indicated a flow of 3-4 MBPD (thought to be a zero error) (see Appendix 5), significantly lower than the 20 MBPD entering the tower. A material balance across the tower would have shown that more feed was entering the Raffinate Splitter than was being removed, even if the Day Shift Board Operator believed the zero error to be an actual flow. The control valve was indicated closed and should have confirmed that it was an error. A mass balance calculation would have provided clear indication of the overall process picture, i.e., that the Splitter had an abnormally high internal liquid level.

5.8.1.4 Preheat to the Raffinate Splitter Feed

The temperature of the raffinate feed to the Splitter tower should be progressively increased over time during a normal startup. The inlet feed temperature remained low until after the Splitter bottoms level control valve (LCV-5100) (and possibly a closed block valve) was opened at 13:00 hrs. At this time the tower feed temperature increased rapidly from 126˚F to 260˚F in the space of 9 minutes due to the heat transfer at the Raffinate Splitter Feed / Bottoms Exchangers (C-1104 A/B).

The control board screen correctly indicated a feed temperature of only 100˚F to 126˚F until 12:41 hrs compared with a normal Raffinate Splitter feed temperature of 205˚F. Up to 13:00 hrs, there was no differential temperature across the tube side (feed), and less than 100˚F (well under range) for the shell side. As the Heavy Raffinate LCV was in the closed position until 12:41 hrs, and a block valve on the rundown line may have been closed until 13:00 hrs, there was no flow through the shell side explaining these temperatures. The absence of any feed/bottoms heat exchange should have been apparent to the Board Operator, given further evidence of no Heavy Raffinate product flow to tankage (i.e., the Heavy Raffinate LCV was in the closed position and the indicated 3-4 MBPD was a zero error).

The Splitter tower feed temperature provided a clear indication that conditions were deviating from a normal startup. A more detailed heat balance would have verified that no heat exchange was occurring across the Raffinate Splitter Feed / Bottoms Exchangers (C-1104 A/B), due to the absence of any heavy raffinate rundown.

5.8.1.5 High Bottoms Temperature

The startup procedure mandates a maximum Raffinate Splitter bottom temperature of 275˚F, and a maximum heatup rate of 50˚F per hour. Control room instrumentation shows that the temperature reached 275˚F by 12:22 hrs, and peaked at 306˚F. The actual heatup rate was 75˚F per hour. Although small reductions in reboiler fuel gas were made, firing continued to heat the tower bottoms until minutes before the explosion. In fact, firing was not reduced until Operator B, another board operator, noticed the high bottoms temperature on the satellite control screen and telephoned the Day Shift Board Operator to tell him to reduce temperatures.

The control board screen continued to indicate correctly that the reflux drum was empty until 13:16 hrs, even with the excessive bottoms temperature. This was confirmed by the Outside Operators around 11:45 hrs, when some light ends would have been expected to have started fractionating, given the bottoms temperature. The Investigation Team concludes that any vapors generated in the bottom of the tower were being compressed and quenched due to the high level of cold feed above the hot bottoms. This caused the delay in vapors passing overhead to be condensed in the reflux drum.

5.8.2 Intervention

As stated previously, the redundant high level alarm (LAH-5102) did not operate when the night shift packed the tower. Operator A continued to pack the tower to just over 100% of the level sensor range. The correct behavior when key instrumentation does not work is to stop the startup and discuss with supervision whether it is possible to repair or mitigate the failure in an acceptable manner. The investigation team could not find any record of the alarm failure being communicated or a maintenance work order being submitted.

The Day Shift Board Operator stated that he was not aware that the 8-inch chain-operated vent valve was opened (at 12:40 hrs) to drop the tower pressure. Given the importance of this action, it appears that communication between the Outside Operators with the Day Shift Board Operator was not complete or effective.

The response to the startup upset of initiating Heavy Raffinate rundown almost three hours after the feed was reintroduced to the tower exacerbated the upset by rapidly increasing the preheat via the already overheated tower bottoms. This appears to have been the trigger event for lifting liquid over the top of the tower into the overhead line, due to the combination of rapid vaporization at the feed inlet to the tower, coupled with vaporization of the tower base. With the exception of the trainees, all the board and outside operators had received training in process troubleshooting in 2000 but have since had no refresher training.

5.8.3 Indicated vs. True Level in Raffinate Splitter Bottoms

The lowest indicated level at the time of the relief valves lifting was 78%, well above the specified automatic level control set point, and the DCS high level alarm remained in alarm mode throughout.

BakerRisk were consulted regarding the effect of the Raffinate Splitter tower density change on the operation of the level sensor and automatic level control. Their response is attached as Appendix 25.

The conclusion is that the level would have remained within range of the tower level sensor; and as a result, automatic level control set on 50% would have functioned. The level indicated at the highest temperature detected would have been about 64% of level range compared with the level control valve (LCV) set point of 50%, because of the density reduction at higher temperature. Until the actual level in the tower surpasses the elevation of the top nozzle for the level bridle, the level sensor will continue to detect level changes and provide a feedback signal to the LCV.

5.8.4 Density Errors for Level Measurement

When using displacer type level measurements for level indication, the measurement error will be directly proportional to any density (specific gravity) error from the calibrated or reference specific gravity used. For differential pressure applications, the calibrated range of the transmitter in inches of water column is determined by taking the distance between the lower tap and the upper tap, or to the desired upper level, multiplied times the specific gravity of the process fluid at the operating temperature and pressure of the vessel. Since the distance used for the span is a constant, any changes in the density due to vapor or temperature changes cause a direct correlation to the error in the level measurement (i.e., a 10% change in density will cause a 10% error in level measurement). As a displacer level tube works off a change in force due to the buoyancy of a fixed displacer, it has the same direct correlation in density error to level error. The change in force of the displacer is directly proportional to the difference in density of the fixed displacer and the reference fluid. The level sensor is calibrated against the difference of force with no liquid covering the displacer versus the displacer being fully submerged by the process fluid. Since the density of the displacer is constant, any change in the density of the fluid causes a direct change in the measured force from the displacer.

For both differential pressure and displacer applications, once the level rises above the upper reference tap, the transmitter sees maximum differential pressure or minimum force respectively, and will not be affected by any additional increase in level. For displacer level devices, once the displacer is fully submerged, there is no addition net change in force beyond the upper range of the displacer. See also Appendix 21.

In the case of the Splitter displacer type level indicator (LT-5100), calibration records were difficult to find, and the reference density for the instrument does not appear to have been changed when the tower was modified for its current Raffinate Splitter duty. The reference density for the instrument appears to be 8% higher than the density at normal process conditions for the heavy raffinate, i.e., 40.67 vs. 37.5 lbs/cu ft. As a result, if the density is less than 40.67 lbs/cu ft in the base of the column with the impulse lines fully submerged, the instrument will indicate a level of less than 100%. The following table (5-6) estimates the liquid density in the base of the column (assuming feed qualities) at various temperatures.

TABLE 5-6
Raffinate Feed Density vs. Temperature

Temperature ˚F	Fluid Density lbs/cu ft
100	42.27
120	41.66
140	41.03
160	40.39
180	39.73
200	39.05
220	38.36
240	37.64
260	36.89
280	36.11
300	35.29

Once the base temperature exceeds 151˚F (density of reference of 40.67 lbs/cu ft), then the indicated level drifts downwards. However, the actual process data (figure 5-11) show that the drift occurs at a lower base temperature (around 135˚F base temperature). This could be due to:

- Raffinate feed composition in the bottom of the Splitter due to lack of fractionation
- Calibration error or slightly different reference density
- Vaporization from the heater affecting base density (unlikely at the process temperatures)
- Dissolution of light-ends (nitrogen and methane from the feed drum) lowering the bulk density

The dissolution of light-ends could also explain that the level drift in the period of 07:00 to 09:00 hrs (when the column is isolated) could be due to a slow warming up of the vessel due to increasing ambient temperature.

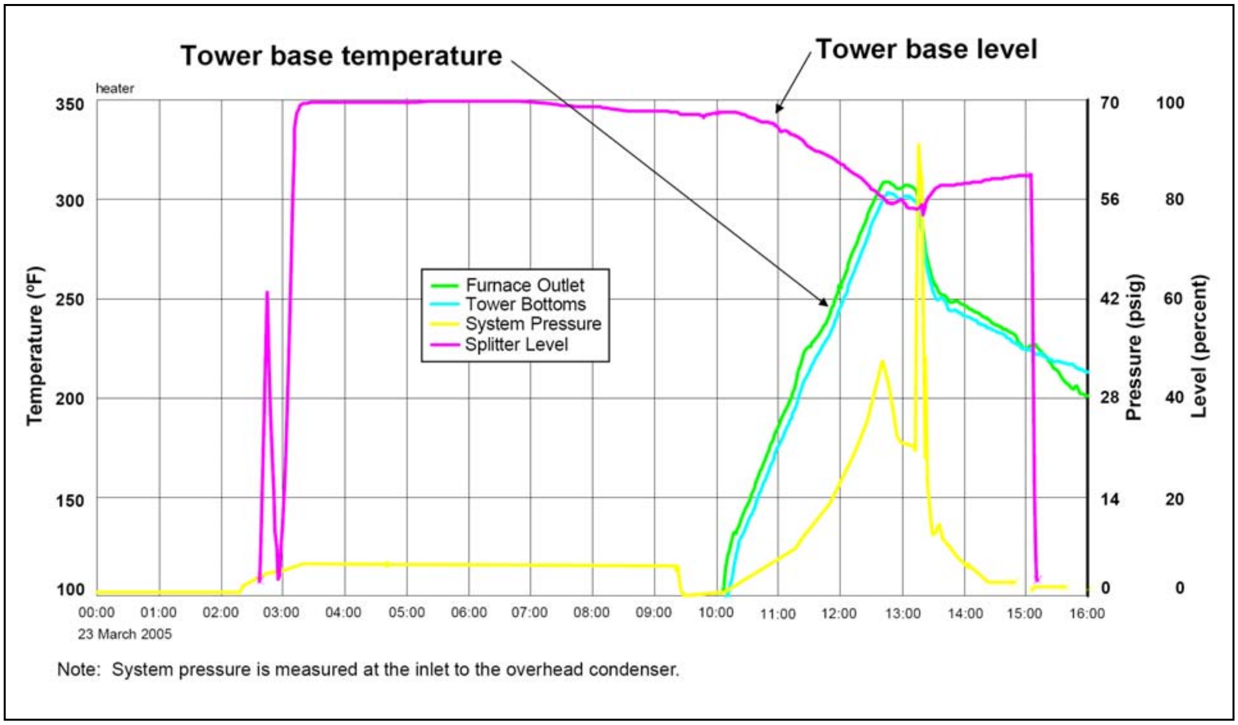


Figure 5-11
Indicated Tower Base Level as Temperature Increases

5.8.5 Raffinate Splitter Pressure Control

During normal operation the reflux rate is used for pressure control of the Raffinate Splitter. The control scheme uses the pressure controller output to control the reflux control valve. The condenser/reflux drum mode of operation is with the drum flooded, with condensing indirectly controlled by the exposed condenser surface area. The light Raffinate rundown from the reflux drum is used to control the light Raffinate composition, as follows:

- Rising Splitter pressure increases reflux, lowering the level in the condenser and exposing more tubes for condensing, thus lowering the Splitter pressure.
- Falling Splitter pressure decreases reflux covering the condenser surface area, resulting in a rise in the Splitter pressure.

By contrast, during startup there are no liquid hydrocarbons in the reflux drum until the hydrocarbons in the tower are sufficiently heated to distill overhead and condensed. Therefore, pressure control has to be by other means.

There are two key actions to control pressure during startup. Firstly, any non-condensables must be purged from the system, preferably from the vent to the 3 psig system off the reflux drum. Condensing is inhibited if hot hydrocarbon vapors distill overhead to the condenser when non-condensables remain in the system, leading to overpressure. Venting to the 3 psig system from the start of heatup will safely remove the non-condensables, if the heatup rate specified in the startup procedure is followed. The quantity of nitrogen in the Raffinate Splitter is well within the capacity of the 3 psig vent system to handle.

Secondly, the heatup rate, measured at the reboiler outlet, must be limited to 50˚F/hr, and the maximum reboiler outlet temperature must not exceed 275˚F. This allows the non-condensables to be purged and prevents hot hydrocarbon vapors from overwhelming the condenser. These three requirements are stipulated in the startup procedure:

- Purging non-condensables to the 3# system
- Heating up at 50˚F per hour
- Staying below 275˚F on the reboiler outlet

Meeting these requirements allows the hydrocarbons to distill overhead gradually without a significant pressure spike.

Once condensing starts, venting to the 3# system should be stopped and reflux can be started. Initially, reflux is controlled in manual and gradually increased, while stable operation of the Splitter is being achieved. Once a normal reflux rate is achieved, the pressure control can be placed in automatic mode, controlling the reflux as described above for normal operation.

Capacity of the 3# Vent Valve for Startup

There appeared to be widespread misconceptions amongst the supervisors and operators around the use of the 3# vent system, stemming from concerns that the system was not able to handle nitrogen and/or had limited capacity. The design capacity of the Splitter Reflux Drum 3# vent control valve (H-5002) is large enough to safely purge non-condensables from the Splitter during startup, providing the procedure is followed. The basis for this design is:

- The Splitter is depressured to 3 psig prior to startup. If the startup is after a turnaround (TAR) and the system contains nitrogen, the nitrogen should be vented to atmosphere at a safe location.
- Venting to 3 psig leaves 30,000 SCF of non-condensables in the system.
- A 3# system pressure of 15 psig at the ISOM battery limit was used for the design calculations. It normally runs between 12 and 15 psig at the battery limits.
- H-5002 is opened 100% before heatup, and the check valve prevents significant backflow from the 3# system to the Splitter.
- H-5002 (with closed bypass valve) passes 16,500 SCFH at 22 psig tower pressure.
- H-5002 (with closed bypass valve) passes 60,000 SCFH at 30 psig tower pressure.
- At 50˚F/hr heatup rate, heat up takes 3½ hrs from a cold start to the maximum 275˚F reboiler outlet temperature.
- By the time hot hydrocarbon vapors distill over the top of the Splitter between 3 and 3½ hrs after start of heat up, essentially all of the non-condensables will have been purged. This allows the vapors to condense and establish a liquid level in the reflux drum without

a pressure spike above 30 psig. Once the level in the reflux drum reaches 50%, H-5002 should be closed to prevent sending liquids to the 3# system.

5.8.6 Conclusion

Through most of the startup, alarms, mass balance and process instrumentation showed the liquid level in the tower was too high and that no liquid was being removed from the tower through the two pathways available. As a normal startup requires 3-4 hours to generate overheads at the recommended heatup rate, a critical operational step is to ensure that the Heavy Raffinate rundown rate is equal to the feed rate as soon as feed is introduced to the tower. As soon as a level reaches 50% in the Splitter tower and the reboiler circulation is established, the startup procedure (Step G.16) requires that:

> *"On the Honeywell computer, put L5100 in the automatic mode and enter a set point of 50%."*

This step matches the Heavy Raffinate rundown to tankage with the incoming feed rate, until such time as the subsequent heatup starts to distill vapors overhead to make a Light Raffinate product.

A review of 18 previous startups since 2000 indicated that the typical lag time between start of feed and start of rundown ranged from 10 minutes before feed is reintroduced to 46 minutes after, with an average of typically within 15 minutes. On March 23 there was a three-hours-eight-minutes delay in initiating the heavy raffinate rundown. In none of these other startups did the tower experience an abnormally high internal liquid level.

The delay in generation of overheads in the reflux drum was another indicator of abnormal conditions (very high liquid level). The intervention made of a late rundown (at 13:00 hrs) of heavy raffinate accelerated overflowing liquid into the overhead line. The appropriate intervention step would have been to shut off the feed, which was never done.

The Board Operator has continual indications of feed rate, product rundown flow rates, tower tray temperatures, and preheat exchange temperatures. He also sets/controls the feed rate to the tower, sets/controls the rundown valve position (level set point), and sets/controls the automatic mode for level control. The combination of the available information should have caused the Board Operator to question, investigate, and then interpret inconsistent data from the raffinate splitter level indicator, which, despite working as designed, wrongly signaled that liquid levels were slowly drifting down in the hours prior to the explosion. If the auto control had been set at 50% per the startup procedure, heavy raffinate rundown would have initiated and the abnormal overfilling of the tower would never have occurred, even with the level indicator initially flooded by overfilling.

5.8.7 High Level Alarm in the Blowdown Drum

The high level alarm (LAH-5020) on the Blowdown Drum (F-20) sounded at the time of the explosion. If it had functioned properly, it would have sounded when the Blowdown Drum had partially filled after the relief valves on the Raffinate Splitter had opened. When the relief valves lift, it takes about 30 seconds to fill the relief line and the blowdown drum to the level of the gooseneck. It takes a further 2 minutes for liquid to reach the top of the blowdown stack. The alarm, set just below the gooseneck level, would have sounded approximately 2 minutes before liquid was released from the stack.

The distributed control system (DCS) had already alerted the control room that the relief valves had opened via the high high pressure alarm (P-5002). Outside Operator C heard the relief valves lift and was running to the Blowdown Drum when the explosion occurred. There were also radio reports of liquids being discharged from the blowdown stack. The loss of containment and the subsequent explosion and fire would not have been prevented if this alarm had been functioning properly at the time of the incident. However, it may have been seen as another indicator that they had lost control of the process, and prompted the operators to sound the emergency alarm.

5.8.8 Satellite Control Room

There is a second DCS control board in the Satellite Control Room, located immediately adjacent to the Raffinate Splitter. This control board is not normally used for controlling the Splitter, but offers the outside operators the opportunity to monitor unit conditions. The control board displays are identical to those in the main control room. The Satellite Control Room also serves as a shelter for the outside operators. The 3-ring binder with the startup procedure was kept in the satellite control room, and steps in the procedure were signed off by a trainee operator under instruction from the Day Shift Supervisor.

On March 23, Operator A decided to establish levels in the Splitter, and pack the reboiler circulation from the satellite control board. He appears to have chosen this approach because of the location close to the Splitter. The Night Shift Board Operator in the main control room was not involved in these tasks.

On the day shift, the main startup control actions were made from the main control room. Operator B and other outside operators periodically monitored the Splitter startup from the satellite control board. Trainee Operator E noticed the Splitter pressure had risen to 33 psig at 12:40 hrs, and alerted the other operators. Operators C and E opened the 8-inch chain-operated vent valve to drop the pressure, which fell to 22.6 psig.

At about this same time, Operator B telephoned the Day Shift Board Operator in the Main Control Room and told him that he needed to take a heavy raffinate rundown flow from the Splitter. The Day Shift Board Operator opened the Heavy Raffinate rundown control valve at 12:41 hrs, although it is possible that a block valve on the rundown line was closed until about 13:00 hrs, as no flow commenced.

The Day Shift Supervisor, who had left the site, telephoned the Satellite Control Room at 13:02 hrs, and briefly spoke to Operator B, who was busy. He called the Day Shift Supervisor back at 13:09 hrs to discuss the pressure in the tower. The Day Shift Supervisor suggested opening the 1½-inch vent valve around the Reflux Drum relief valve in case any nitrogen remaining was causing the pressure to rise. Operators C and E opened the 1½-inch vent valve by 13:13 hrs, dropping the pressure to 20.5 psig.

Operator B called the Day Shift Board Operator a second time from the Satellite Control Room, and asked him to reduce firing on the Reboiler Furnace due to the high temperature (304˚F) of the tower bottoms. The Day Shift Board Operator responded by trimming the fuel gas control valve at 13:14 hrs, at about the same time as the pressure at the overhead condenser spiked rapidly upwards.

5.8.9 Outside Operators

As noted previously, the Outside Operators used the satellite control room as a shelter and could monitor the unit status on the control board. As well as the various outside actions detailed above, the outside operators also performed the following activities:

Shift relief between the outgoing night shift and oncoming day shift outside operators on March 23 did not occur on the ISOM unit and appears to have been brief and inadequate. The only other part of the ISOM unit in operation on March 23 was the Desulfurizer, which was stable in circulation with the Hydrogen Compressor running. The day shift operators conducted their routines and checked the unit lineup prior to depressuring the Splitter at 09:21 hrs to purge nitrogen by opening the 8-inch chain-operated vent valve for the first time.

After reintroducing feed to the Splitter at 09:52 hrs, Operators C and D lit pilots and main burners in the Reboiler Furnace from about 10:00 hrs through 11:17 hrs when the last burners were lit. When no level had been indicated in the Reflux Drum by late morning, the outside operators checked the lower tap on the level gauge and confirmed the presence of vapors only, it is unclear who this was communicated with.

Operators B and E left the site at 11:47 hrs to collect lunch for the crew and returned at 12:05 hrs. After lunch Operator E noticed the Splitter pressure had risen to 33 psig by 12:40 hrs, and alerted the rest of the crew, operators C and E then opened the 8-inch chain-operated vent valve to drop the pressure, which fell to 22.6 psig. Operator E saw heavy vapors discharging from the blowdown stack, but was told not to be concerned by the more experienced Operator C.

5.8.10 Extended Working

Many of the supervisors and operators had been working for extended periods of time in support of the temporary outage on the Raffinate Splitter and other duties associated with catalyst replacement on another part of the ISOM unit. Since the Splitter was shut down on February 21, 2005, some employees had worked up to 30 days of consecutive 12-hour shifts. The reward system (staff remuneration and union contract) within the site encouraged this extended working period without consideration of fatigue. There were no clear limitations on the maximum allowable work periods without time off.

It has not been possible for the Investigation Team to directly attribute actions or inactions of the operators and supervisors to fatigue. However, this extended working period clearly has the potential to contribute to a lack of attentiveness, and slowness to identify and respond to process upsets.

5.8.11 Conclusion

Although the level alarm on the blowdown drum did not function, the DCS high high pressure alarm had already indicated to the control room that the relief valves had opened. Outside Operator C also heard the relief valves lift, and the actions taken by the crew indicate that they were aware of hydrocarbons heading to the blowdown stack.

5.9 Hazard Studies

Many hazard analysis studies have been performed on the Raffinate Splitter over the last twelve years. These include PHAs performed in compliance with the OSHA PSM rule (base Hazop and five-year revalidations), a site-wide QRA (termed a Major Accident Risk (MAR) assessment), Facility Siting Studies, and hazard reviews of MOCs.

5.9.1 Hazop and Revalidations

Hazop was chosen as the most appropriate Process Hazards Analysis (PHA) methodology for Texas City refinery unit studies. A full Hazop of the ISOM Unit was conducted in 1993, and five-year revalidations were performed in 1998 and 2003.

5.9.1.1 1993 Hazop

The 1993 Hazop raised concerns about the capacity of the unit relief valve system. The Hazop report stated:

> *"Capacity of the unit relief valves. The unit was originally designed as an Ultraformer with a capacity of 21,200 BPSD and was converted to an Isomerization unit in 1985, then in 1986 was converted to a Penex unit with a capacity of 27,000 BPSD and an Ultrafiner capacity of 27,500 BPSD, or 125% of ISOM conversion design. The index in the data books for the Penex conversion listed a section for relief valve design, but this section could not be located. The Penex process also recovers and recycles untreated product. This could put additional loads on the relief system. A relief study done for the ISOM conversion in 1984 stated the Ultrafiner header was very close to its maximum capacity and any additional increase may require additional relief capacity. The unit relief valve system may need to be checked to ensure adequate capacity."*

An action item (no. 33) was created to verify proper sizing of the relief valves, although it appears that the study was focused on the ISOM conversion to a Penex process, rather than on the Raffinate Splitter. Amoco Worldwide Engineering & Construction was assigned this action for resolution. They concluded:

> *"As part of the Isomerization unit's conversion to the Penex process, a full and thorough relief system evaluation was performed by Litwin Engineering. No particular problems were noted in the Ultrafiner section of the unit, and each piece of equipment was evaluated from a ground zero design basis.*
>
> *An abbreviated pressure relief system survey was performed as a part of the Hazop resolution, focusing on worst case scenarios for the three independent vent headers.*
>
> *The results of the Hazop study and the Litwin relief valve documentation indicate that the existing pressure relief system is adequate, and no modifications are required to the header system."*

The resolution noted a need to change one relief valve on the F-5 drum, since the drum's service had changed. The resolution further stated:

> *"In addition, the F-20 blow down drum was evaluated and was found to be adequate. No changes are required for the Isomerization Unit's pressure relief header system or the F-20 blow down drum."*

The Hazop also raised concerns about the blast resistance capability of the ISOM Unit control room. The Hazop team could not determine the degree of blast resistance incorporated into the construction of the building when it was built. An action item (no. 65) was created to review the need to upgrade the control room to be more blast resistant. This action was resolved in 1995 with the following justification:

> *"The ISOM control room was included in the Facility Siting study completed in the second quarter of 1995. The ISOM control room fell into Zone 2 (acceptable risk) on both a population and an individual risk basis relative to its susceptibility to a vapor cloud explosion."*

5.9.1.2 1998 Hazop

The 1998 Hazop revalidation considered the incident on May 8, 1995, when the 8-inch vent valve around the Raffinate Splitter relief valves was left open during startup. Node no. 63 identified an undesired consequence of major hydrocarbon release to the blowdown drum and an environmental release. The action was to:

> *"Identify any previous incidents that did or could have resulted in a catastrophic release of hazardous material and verify that adequate modifications have been made to prevent the incident from reoccurring."*

The safeguards listed in the Hazop to prevent this type of incident were:

1. Trained operators.
2. Installed a sign at valve chain operator (for the 8-inch bypass) to help indicate valve position.
3. Modified startup procedure to slow down warm-up of the tower so that this (the 8-inch) valve will not be needed.

It is not clear from the Hazop documentation whether other previous process upsets that resulted, for example, in high pressures during startup, were considered, as most of these were not recognized or reported.

The Hazop also identified a high level in F-20 as a consequence of concern. An action item was created to:

> *"Consider locking open the valve in the F-20 Blowdown Stack goose-neck overflow line. This would help prevent the valve from being closed which could cause high liquid level in the Blowdown Stack."*

This action item was closed on June 26, 1998, when a chain and lock were applied to the F-20 goose-neck block valve.

5.9.1.3 2003 Hazop

The most recent Hazop revalidation of the ISOM unit was conducted from February 17 through February 25, 2003.

An action item was created to complete a full unit relief valve study for the ISOM to verify all relief valves are adequately sized for the service they were in. Although selected relief valves have been studied through the years, the last full ISOM Unit relief valve study was completed in 1986. This action item had a target closure date of March 31, 2005, but was still open, and had not been started, as of March 23, 2005.

The MOC for de-rating of the Raffinate Splitter tower (# MOC-ISOM-2003-005) was not reviewed during the 2003 HAZOP revalidation, despite the relief valve set points being changed in January 2003. This MOC was not authorized for commissioning until March 3, 2004, over a year after the Hazop revalidation. The Splitter operated throughout this period with the reset relief valves.

It is not clear from the Hazop revalidation documentation whether previous process upsets that resulted, for example, in elevated pressures during startup, were considered.

5.9.1.4 MOC Hazard Reviews

In line with good practice, PHAs are required on all changes subject to MOC at the Texas City site. A Process Safety Institute course is used to train the MOC PHA leaders on the HAZOP and "What-If"/Checklist techniques.

Section 2 of the training manual indicates that the "… MOC PHA should include:

- Hazards of the process
- Previous incidents
- Engineering and administrative controls and their inter-relationships
- Consequences of failure of these controls
- Facility siting
- Human factors
- A qualitative evaluation of a range of the possible safety and health effects on all employees in the workplace

The training manual provides a detailed checklist for "What If" analysis, and advises that "A PHA must address all hazards during all modes of operation, including startup, shutdown, maintenance turnarounds, power failures, control failures, bypasses, and, of course, normal operations."

The "What If" Analysis Checklist and Vessel/Exchanger Maximum Allowable Working Pressure (MAWP) Rerate Checklist used are not as comprehensive as the checklists provided in the training. They did not specifically include the following aspects:

- Previous incidents
- Engineering and administrative controls and their interrelationships
- Consequences of failure of controls
- Facility siting
- Human factors
- A qualitative evaluation of a range of the possible safety and health effects on all employees in the workplace
- Modes of operation, including startup, shutdown, maintenance turnarounds, power failures, control failures, bypasses, and normal operations

It is difficult to verify closure of any PHA actions, as there is no requirement to document the detail of physical completion of the actions detailed in Section III, "Requirements for Change," of the MOC.

A Pre-Startup Safety Review (PSSR) is required prior to commissioning a change subject to MOC. For major capital projects, a formal PSSR is led and documented by a trained PSSR leader. The priority of actions identified during the PSSR is categorized as either "will delay startup" or "will not delay startup." The original PSSR must be sent to the MOC Administrator, who files these materials and enters any action items into an electronic database. Details on PSSR requirements are covered in a local policy (SH-PSM-7.0).

For more typical limited-scope changes, the Operations Superintendent completes the PSSR by signing Section IV, "Authorization to Commission," of the MOC form. By signing, the Operations Superintendent confirms that

- All required items are complete
- Construction and equipment satisfy design specifications
- Safety, operating, maintenance, and emergency procedures are in place and are adequate

The MOC (# MOC R-ISOM-98-09) for converting the Raffinate Splitter to operate with a flooded drum generated action items for instrumentation. Completion of Section III "Requirements for Change" was deemed sufficient for the PSSR requirement.

The MOC (# MOC ISOM-2003-005) for de-rating the Raffinate Splitter in 2003 generated action items for updating instrument alarm set points and changing the set points of the relief valves. The 2003 turnaround should have prompted a formal PSSR, i.e., beyond completion of Section III "Requirements for Change," but this could not be found. Local policy (SH-PSM-7.0) required a formal PSSR prior to startup following a turnaround.

None of the hazard analysis/checklist reviews for these MOCs appeared to consider startup conditions, such as actual process data or the history of pressure excursions during startup.

See Appendix 26 for a summary of MOCs related to the ISOM incident.

5.9.2 Major Accident Risk (MAR)

As a voluntary extension to regulatory requirements, BP has adopted a group-wide process dealing with major accident risk. These Major Accident Risk (MAR) assessments assess societal risk by determining the risk of multiple fatalities (greater than 3 fatalities) from all potential scenarios at a particular site. The technique does not entail a particularly detailed Quantitative Risk Analysis (QRA), but it does consider potential catastrophic and major incidents, such as fires and explosions, on a high level. It is designed to provide a measure of overall risk compared to a management reporting line, based upon typical industry criteria, to highlight if a risk reduction program should be a priority. The MAR methodology is described in a BP Engineering Technical Practice (ETP GP 48-50).

Key features of the MAR process include:

- Focus on hypothetical major accident hazards.

- Develop scenarios for each major hazard on all the process facilities.
- Base likelihoods for each scenario on historic accident data.
- Calculate consequences using the BP CIRRUS consequence package to establish fire, explosion and toxic consequences to people (measured as potential fatalities) .
- Summate risks for all events to obtain a cumulative risk picture for a site or business (the societal risk “FN curve”).
- Estimate environmental risks based on public reaction and local impact.
- Sites must demonstrate continuous risk reduction for risks identified by the process.
- The results of the MAR characterization and the plan to manage the risks should be reported to the BP Business Segment. Where the combination of the frequency of potential events identified and their potential consequences are of a certain magnitude, the plan designed to manage the MAR is also reported at Group level.

A MAR assessment was conducted for the Texas City site in March/April 2003. The MAR addressed the top 80 risks on the site, but did not recognize or include any risks due to blowdown drums or the ISOM unit. The possibility of liquid overflow and relief was not considered. It was determined that the ISOM unit did not pose a major accident risk relative to the rest of the Texas City site. The MAR also did not address the risk to personnel in temporary trailers or those involved in periodic turnarounds. The MAR did not use actual Texas City site experience for the frequency of fires and explosions, but used generic industry data instead.

The MAR indicated that the predicted risks for the BP Texas City site were below the Group Reporting Line for onsite risks (i.e., on-site workers, contractors, and staff on surrounding industrial facilities) and well below the Group Reporting Line for offsite risks to the general public. A number of potential risk mitigation measures were identified for consideration as part of the site’s policy for continuous risk reduction. None of these measures involved the ISOM unit or blowdown drum.

5.9.3 Action Tracking

The progress of actions from PHAs, including major Hazops and MOCs, are tracked in TRACKS (an Access database). Another database, Traction, is used primarily for corporate reporting purposes, while TRACKS reports are regularly distributed to site management. E-mail notices are sent to responsible individuals to inform them of their action item assignments, and reminders are sent when items are overdue. The databases are also used to record other actions from audits, incident investigations and PSC generated items.

Monthly status reports on PHA, audit and investigation actions are generated for management review by the Operations Superintendent and above. These reports identify percentage completion, but are not prioritized and do not focus on overdue actions. Equipment inspections, including overdue items, and MOC and other PSM actions are addressed through quarterly status reports, which also present percent completion without prioritization.

A MOC is complete when all safety and environmental action items have been resolved and documented. An action item is considered resolved when either the recommendation has been adopted as written or the recommendation has been justifiably rejected. A recommendation may be justifiably rejected when, based upon adequate evidence, one of the following is true:

1. The analysis upon which the recommendation is based contains material factual errors.
2. The recommendation is not necessary to protect the health and safety of employees or contractor employees.
3. An alternative measure would provide a sufficient level of protection.
4. The recommendation is technologically and/or economically infeasible.
5. The equipment is out of service.

When a recommendation is justifiably rejected, this action must be communicated to the PHA, investigation, or audit team and any subsequent recommendations of the team resolved.

An action item is marked complete when the action item has been fully implemented or justifiably rejected and documentation has been recorded in the site PSM Action Item Tracking System. The documentation need not be detailed, but must be a positive statement of action (e.g., Completed as recommended-date, Training completed-date, Rejected-solution infeasible-substantiation-date, etc.). If the supporting documentation is lengthy (e.g., an RV study, complex engineering calculations, etc.), a synopsis must be entered into the tracking system and a complete copy sent to the site PSM group.

The PSM Action Item Tracking System has an additional check. When the individual assigned a safety or environmental action item responds to the action item with the resolution and justification for closure, the response is reviewed by both the unit Superintendent and the PSM group for concurrence. In the event of rejection by either, the action item is returned to the responder for reconsideration and appropriate response.

As of March 23, 2005, the ISOM unit had seven safety action items that were past due from the 2003 HAZOP revalidation. None of these action items were directly related to the Raffinate Splitter or Blowdown Drum.

5.9.4 Conclusions

The "What If" Analysis technique is not robust enough to consider all modes of operation or process upset scenarios. Nor are any reviews adequate if real incident and historical data is not considered. The ability to identify the major risks present on the site is highly dependent upon the level of risk awareness of the individuals involved in the process. The lack of reporting of process excursions/incidents also hinders all types of hazard analyses.

5.10 Operating Procedures

5.10.1 Startup Procedures

There are two Standard Operating Procedures (SOPs) for startup of the Raffinate Splitter:

1. "Raffinate Unit Startup Following a TAR" (SOP 201.0)
2. "Normal Raffinate Startup Procedure Following a Temporary Outage" (SOP 201.1)

As the Raffinate Splitter was pressure tested for tightness with nitrogen, the correct procedure for the startup on March 23, 2005, was SOP 201.0 (Startup following a TAR).

SOP 201.0 was last updated on October 1, 2003, and the Operations Superintendent, on the advice of the Training Coordinator, confirmed in the last annual certification (early March 2005) that all ISOM unit operating procedures were current and accurate. However, previous to this on January 25, 2003, the Overhead RVs (RV-1001A/B/C) were de-rated from 70 psig to 40/41/42 psig respectively and this change was not reflected in the copy of SOP 201.0 in use on March 23, 2005. Most of the operators did though indicate that they were aware of the change. This de-rating also affects the pressure at which nitrogen tightness testing can take place, which is stated as 50 psig in SOP 201.0, i.e., above the new set pressure for the RVs. The nitrogen tightness testing was conducted at 22.5 psig on March 21, 2005, in line with the new set points.

The MOC (ISOM-2003-005) to de-rate the Raffinate Splitter from 75 psig to 40 psig included an action to train operating personnel. There was no indication found that this training had occurred. The training guide (#14 Raffinate Splitter Tower Overhead System) was not updated to reflect changes in operating pressure and relief valve settings. Another training guide (#13 Raffinate Splitter Overview and Charge System) does not reference the pressure rating of the tower or the set points of the relief valves.

Another item requiring updating in the startup procedure was the designation of the controller for the 3# vent system. Prior to the modifications in 1998 to operate with a flooded reflux drum and control Splitter pressure by the furnace reboiler firing rate, P-5002 controlled the valve to the 3# vent system. Following the MOC (# R-ISOM-98-09) to convert the Splitter to a flooded reflux drum, the startup procedure was not updated to show that H-5002 now controls the valve to the 3# vent system.

Post-incident interviews indicated that MOCs were typically communicated in unit meetings or bulletins with a sign-off sheet. No records of these communications could be found. No records were found in the site PSM Department's files to indicate what action had been taken to close out the procedure and training requirements. Although documentation stated that the actions were closed, detailed interrogation revealed that these changes to startup procedures had not been made.

SOP 201.0 addresses the hazards inherent in the first three potential scenarios for the incident (see Section 5.1 of this report), i.e., excessive thermal energy, presence of water, and presence of non-condensables (nitrogen and/or natural gas). Most of these references are contained in individual steps or notes within the procedure, but without sufficient emphasis on these hazards or inclusion of troubleshooting guidance if problems arise. There is no reference to the hazards associated with overfilling the tower.

Excessive Thermal Energy
The procedure includes the following caution (in bold text with shading) on the hazard of heating up too quickly, as part of section H, "Heat the B-1101 Raffinate Furnace and Rundown Light Raffinate":

> *"Caution: Bring the system temperature up slowly to avoid over pressuring the E-1101 Raffinate Tower. The E-1101 Raffinate Tower RV setting is 70 psi."*

Presence of Water
The "General" section at the beginning of the startup procedure includes the following guidance on the hazard of water:

> *"Water is removed to prevent surges caused by unplanned mixing of water and hot oil. Water removal is accomplished by draining at all low point bleeders in lines and vessels. Plugs or blind flanges should be installed in all drains after water has been removed from the systems."*

The procedure also includes step #C.b.72 for the tower, as part of the section on "Unit Purging and Tightness Testing":

> *"Depressure the system through all low point drains and pumpouts to remove all free water from the system left by steaming or hydro testing."*

Similar steps with identical wording address other sections of the Raffinate Splitter, such as the Charge Drum, Raffinate Furnace, and Natural Gas system.

Presence of Non-Condensables
The procedure includes the following guidance prior to the section on "Isolation Blind Removal":

> *"Prior to introducing gas and/or hydrocarbons into systems, lower each system to a minimum pressure. This will help reduce the amount of nitrogen to the 3# system and help minimize pressure problems during the unit startup."*

The procedure also includes the step #F.2 as part of the section on "Unit Alignment":

> *"Ensure that all system pressures have been lowered to a minimum of ~1-2 psi. This will help to prevent over pressuring during startup by removing most of the nitrogen used as the purging medium."*

Finally, the startup procedure includes one further piece of guidance prior to the "Start Raffinate Circulation" section:

> *"The Raffinate system is now lined up and ready for charge from the ARU. It is essential that the system pressure be at a minimum prior to startup. This will help prevent over pressuring the system."*

The aim of these cautions and guidelines is to avoid overpressuring the Raffinate Splitter. The design intent was for vapor only (no liquid) relief through the relief valves.

A review of eighteen previous Raffinate Splitter startups (see Section 5.10.6 of this report) indicates that the tower pressure exceeded the relief valve set pressure (40 psig) on two occasions, marginally at 41 psig on one of these startups. The tower pressure was close to the RV set point on two other occasions. Most startups had pressure excursions, but only two resulted in the RVs lifting, as the pressure was controlled effectively. High pressures were avoided when the tower was well-drained, well-purged and heated slowly.

The author of the startup procedure appears to have made a reasonable effort in capturing these aspects of previous experience within the procedure, although the process safety implications could be better drawn out by specific references to the process safety booklets available as guidance to the operators. Despite the startup procedure not being fully up to date, the procedure is generally of high quality, with safety cautions and an appropriate level of detail addressing all the key process control steps.

The key difference between the March 23 startup and previous startups is that previous startups did not fill the tower for more than 3 hours without starting the Heavy Raffinate rundown, leading to an extraordinary high liquid level in the tower. The startup procedure specifically requires that the Splitter tower level controller is set at 50% in automatic mode, as soon as the level reaches 50% in the tower and the reboiler circulation is established. This step ensures that the Heavy Raffinate rundown rate is equal to the feed rate as soon the operating level is achieved.

5.10.2 Use of Startup Procedure

The startup procedure for the Raffinate Splitter includes provision for the operators to sign off each step together with the date and time performed. The Day Shift Supervisor printed the latest version of SOP 201.0 (Startup Following a TAR) on March 21, 2005 and gave it to the Outside Operators to record completed steps in the procedure as the startup progressed. Trainee Operator E was instructed by the Day Shift Supervisor to sign off the individual steps in SOP 201.0, although he was not a qualified operator on the ISOM and he did not personally witness all of the steps. The Day Shift Supervisor signed off a few steps. Although the first part of the operation was completed by the night shift, they did not appear to sign off any of the steps. Operator E stated that at one stage he was at least 24 hours behind in signing off the completed steps, although he stated that no steps were signed off after the explosion.

Operator A packed the Raffinate Splitter and Charge Drum with feed in the early hours of March 23 from the satellite control board, and had access to a copy of the startup procedure. However, he did not sign off those steps, and shut down the feed to await the day shift, who would continue the startup. The Night Shift Board Operator played no part in charging the feed.

Following shift relief on the morning of March 23, the Day Shift Board Operator stated that he printed off a copy of the wrong startup procedure, SOP 201.1 (Startup after Temporary Outage), but left the document on the printer. When the Board Operator eventually collected the procedure, he stated that he made little or no reference to the document.

5.10.3 Startup Procedure Steps Signed Off

In general, Operator E initialed and dated the steps but did not indicate the time of the actions. Several steps were annotated to the effect that the item was out of service, had remained in service or was not applicable. Other steps (B.5-7) covering I&E activities, such as checking instrumentation, were signed off by the Day Shift Supervisor, although this work was not completed before the Splitter startup. However, the only critical alarm (F-20 high level, LSH-5020) was tested during the outage on February 28, 2005.

A few steps were left blank, as follows:

Step B.12 *Conduct a pre-startup review of the procedure with all crewmembers.*

Step E.5 *Open the natural gas block valve at the north manifold and pressure the natural gas header (1381) (2"-NG-1000).*

Step F.18 *On the Honeywell computer, put P5002 in the manual and open the valve 100%. (This will help remove non-condensable gases during startup),* (Note that H5002 controls the valve to the 3# vent system, not P5002).

Step H.9 *As the level rises in the F-1102 Reflux Drum, pack the J-1102 and J-1102A pumps (2622-1).*

No other steps after H.9 were signed off, probably because the incident occurred within a few minutes of this step having been completed.

5.10.4 Normal Startup

The key steps (in sequence) in the startup procedure (SOP 201.0) for a normal well-performed startup after maintenance activity are:

Preparatory Activities

- Review startup procedure with crew
- Check instrumentation, alarms, trips
- Commission utilities (steam, electric power, cooling water) if necessary
- Ensure tightness using nitrogen pressure
- Remove air using the nitrogen purge
- Remove water by opening low point drains
- Remove isolation blinds

Startup

- Check unit lineup
- Depressure to 1 – 2 psig to remove nitrogen
- Line up 3# vent system with pressure control valve open on Manual
- Establish feed to Charge Drum
- Pack the Tower feed pumps
- Establish 50% level in Charge Drum
- Establish feed to Tower
- Pack the Reboiler circulation pumps
- Establish 50% level in Tower
- Establish Reboiler circulation to pack Reboiler circuit
- Establish Heavy Raffinate rundown flow to tankage
- Set Tower level control to Auto with 50% set point
- Light Reboiler Furnace pilots
- Light Reboiler Furnace main burners
- Set Reboiler Furnace temperature control to Auto
- Heat up to 275˚F at 50˚F per hour
- Establish level in Reflux Drum
- Pack reflux pumps
- Establish reflux flow when level reaches 50%
- Close 3# vent system pressure control valve when Reflux Drum low level alarm clears
- Establish Light Raffinate rundown to tankage at 40% of feed rate
- Adjust flows/temps/etc. based on sample/analyzer results

While many steps were not correctly followed, including checking instrumentation and a pre-startup review, the key contributor to the overfilling of the tower on the March 23 startup was that the heavy raffinate rundown should have been started early in the startup sequence, **before** heating up the tower.

With the exception of the preparatory activities, the startup steps can be completed during one 12-hour shift, minimizing any risk due to handover between shifts. The startup on March 23 was performed over two shifts; night shift packed the tower to a high level and shut down, and day shift reintroduced the feed and heated up prior to initiating the heavy raffinate rundown to tankage. This was out of step with the above sequence of tasks for a normal startup. Communication at the shift relief on March 23 appears to have been brief and inadequate.

5.10.5 Departures From the Startup Procedure

The startup on March 23 deviated from the above normal startup procedure in a number of areas. Although many of the preparatory steps in the startup procedure (SOP 201.0) were followed during the lineup of the Raffinate Splitter, several important steps were omitted or a different action taken, as follows:

Preparatory Activities

- All alarms were not tested prior to startup (Step B.5).
- All trips were not tested prior to startup (Step B.6).
- All control valves were not tested prior to startup (Step B.7).
- The HSE Department was not notified 14 days prior to startup (Step B.10).
- Review of procedure with all crew members not done (Step B.12) (see Section 5.10.7 below).
- The unit emergency horn was apparently not checked prior to startup, and at the beginning of each shift during the startup (Step B.15), although this step was signed off but not dated in the startup procedure.
- It was not verified that all instrumentation was in service and that functional checks were complete (numerous steps in Section C of SOP 201.0). Some instrument checks were conducted but not completed.
- The Nitrogen tightness test was conducted at 22.5 psig vs. 50 psig in procedure (numerous steps in Section C of SOP 201.0) in line with the new rerated RV settings.

Several important steps were also omitted, or a different action taken, during the actual startup, as follows:

Startup

- Line up 3# Vent System with pressure control valve open on manual was not done (Steps F.17/18). This helps remove non-condensable gases (nitrogen) during startup. The block valves on the 3# vent system were opened, and the control valve (H-5002) was stroked on March 22. However, the block valves were closed again, isolating the vent system prior to the startup. Although the 3# vent system was used in the four previous startups, there appeared to be widespread misconceptions amongst the operators and supervisors around the use of the system. These misconceptions stemmed from concerns that the system was not able to handle nitrogen and/or had limited capacity. Neither concern is valid. This was addressed earlier (see section 5.8.5).
- Night shift put in excess of 100% level in the Splitter tower vs. 50% required in the procedure (Step G.11/16). The night shift did not proceed to establish the Heavy Raffinate rundown. This would have packed the rundown pipework and heat exchangers. Operator A stated that, from experience, he was anticipating a fall in the tower level when the pipework and heat exchangers were subsequently packed.
- Day shift filled the Splitter tower above 100% level vs. 50% required in the procedure (Step G.11/16). Although the DCS indicated a high level and high level alarm when the startup recommenced on day shift, the board operator started the feed at 20,000 bpd and continued to supply feed to the tower without any Heavy Raffinate rundown.
- Day shift did not establish Heavy Raffinate rundown to tankage (Steps G.15/16) until just before the incident. The Day Shift Board Operator did not attempt to start the Heavy Raffinate rundown until 12:41 hrs when prompted by another operator, but flow did not commence until 13:00 hrs, possibly due to a closed block valve. The time delay in starting the Heavy Raffinate rundown meant that 20,000 bpd of feed was added to the tower for approximately three hours without any outflow. The rundown did not equal or exceed the feed rate until 13:03 hrs.
- Day shift did not set the Splitter tower level control to Auto with 50% set point (Step G.16) until just before the incident. The procedure requires that the level control be set to automatically control at 50% level, i.e., if the level is above 50%, the control valve will open automatically to increase the rundown flow rate. This step of the procedure should immediately follow starting the rundown flow to tankage and precede lighting reboiler furnace burners to heat up. The board operator did not attempt to start the Heavy Raffinate rundown until 12:41 hrs. At this time the level control was set to Auto, a delay of approximately three hours, but a block valve may have been closed on the rundown line. At 13:00 hrs, when the Heavy Raffinate rundown flow was first established, the board operator put the control back in manual, and opened the valve manually.
- Day shift started adding heat to the Splitter at 10:00 hrs without first establishing the rundown to tankage (Steps H.4/8). The startup procedure clearly specifies that the Splitter temperatures are raised after the flow is established in the reboiler section of the furnace **and** heavy raffinate is running down to tankage. Instead of following these steps, the heatup preceded the heavy raffinate rundown by three hours.

- Splitter temperatures were raised at approximately 75˚F/hr vs. 50˚F/hr specified in the procedure (Step H.6). The startup procedure includes a bolded caution that the system temperature should be brought up slowly to avoid overpressuring the tower. The board operator took control of the heatup immediately after the main burners were lit and raised temperatures at 150% of the specified rate. The Splitter tower pressure reached 33 psig at 12:40 hrs. The normal operating pressure is 10 – 20 psig. After manually venting vapor to the Blowdown Drum, the tower pressure held steady in the range 20 – 25 psig. Several small cutbacks in furnace fuel gas were made, but not until Operator B prompted the Day Shift Board Operator because of the high furnace outlet temperature.
- Reboiler Furnace outlet temperature was raised to 307˚F vs. 275˚F maximum required in the procedure (Step H.6). The board operator took control of the heatup immediately after the main burners were lit and raised temperatures to 32˚F in excess of the required limit. Several small cutbacks in furnace fuel gas were made, but no major reduction was made until around 13:13 hrs when Operator B prompted the Day Shift Board Operator because of the high furnace outlet temperature (in excess of 300˚F). The high furnace outlet temperature contributed to the rapid heat exchange between the Heavy Raffinate rundown with the incoming feed to the tower. This rapid heat exchange led to significant vaporization of the feed, sufficient to lift the already excessively high liquid level in the tower up and over into the overhead line. The head of liquid in the overhead line coupled with the tower pressure caused the rapid rise in pressure at the inlet to the overhead condenser at 13:13 hrs, which in turn caused the relief valves to unseat and discharge liquid hydrocarbons to the blowdown drum.
- The 8-inch vent valve around the Overhead RVs was opened to control pressure. The outside operators opened the 8-inch chain-operated vent valve when the pressure rose to 33 psig at 12:40 hrs. The use of this valve is not part of the startup procedure, but appears to have become local custom and practice to use whenever a pressure spike occurred during a startup. The startup procedure specifically cautions that the system temperature should be brought up slowly to avoid overpressuring the tower. Since the Splitter was modified to operate with a flooded reflux drum, the primary pressure control during startup has been the reboiler furnace firing rate. A reduced heatup rate of 50˚F per hour was recognized in the 1998 Hazop in order to minimize any requirement for additional venting. The 3# vent system is only used during startup to purge any remaining non-condensables (nitrogen) from the system.
- The 1½-inch Vent valve around Reflux Drum RV was opened to purge nitrogen instead of using the 3# Vent System required in the procedure (Steps F.18). The outside operators opened the 1½-inch vent valve around 13:09 hrs, when the off-site Day Shift Supervisor suggested by telephone that the pressure problems being experienced might be due to the presence of nitrogen. The use of this valve is not part of the startup procedure. The startup procedure specifically requires the control valve on the 3# vent system to be opened to 100% on manual to help purge any remaining non-condensables (nitrogen) from the system.

While many departures to the startup procedure occurred, the key step that was instrumental in leading to the incident on March 23 was:

- Failure to establish Heavy Raffinate rundown to tankage, while continuing to feed and heat the tower.

If a Heavy Raffinate rundown flow had been started as soon as the feed was re-established, the incident would not have occurred. The absence of supervisory presence on the unit probably contributed to the failure to establish rundown. The startup procedure has a bulleted note emphasizing the importance of establishing flow in the reboiler section and running down heavy raffinate to tankage that precedes the procedure steps for heating the tower.

By the time the Heavy Raffinate flow was eventually started, the Splitter bottoms temperature was so high, and the liquid level in the tower so high, that this intervention made matters worse by introducing significant additional heat to the feed. At that stage the correct intervention would have been to shut down the reboiler furnace and close the feed valve.

According to the procedure this should have been done by:

- Setting the Splitter tower level control to Auto with 50% set point, but several alternative interventions could have prevented the incident even until just prior to the relief.

When the feed was re-established at 09:52 hrs, the indicated tower level was 97% (although the actual level at this time was probably just above 100% of the instrument range, i.e., approximately 10 feet in the tower). The top tap of the instrument had been flooded at about 03:00 hrs, and was no longer providing an accurate level indication. It was, however, correctly indicating a higher level than required by the startup procedure.

If the Heavy Raffinate rundown had been started at this time and the level controller set to 50% on auto, as required by the startup procedure, the control valve would have opened to increase the rundown flow rate and lower the level in the tower, and the liquid level would have quickly come into range. With the liquid level within range, the level transmitter would have provided an accurate level indication.

5.10.6 Departures From the Startup Procedure During Previous Startups

Eighteen previous startups of the Raffinate Splitter were analyzed for comparison with the startup on March 23. These startups happened over the five years since 2000. Data related to these startups are tabulated in Appendix 24.

The major difference between these startups and that of March 23, 2005, was that the Heavy Raffinate rundown flow was started before or shortly after the feed was introduced to the tower. The longest delay in starting the rundown was 46 minutes, compared to 3 hours 8 minutes on March 23. On March 23 this delay resulted in a liquid height of 137 ft in the Splitter, corresponding to a level at tray 13, close to the top of the 70 tray tower. This liquid height is estimated based upon clear liquid and does not take into consideration any vapor volume contributed by the reboiler or hot feed.

When the Raffinate Splitter is shut down, the liquid on the 70 distillation trays drains down into the tower base. It is therefore not unreasonable to have a high level indicated on the tower level transmitter (LT-5100) prior to starting the unit again (a "warm" startup). A level indication of 100% is below the bottom tray and is equivalent to approximately 10 ft 3 in. above the tangent line of the tower.

During previous startups it was common for the tower level indication to exceed 100% at some time. Three startups commenced with liquid levels within the level transmitter range, i.e., 9 to 10 ft of liquid. However, most of the startups occurred following a short shutdown ("warm" startup) when the liquid from the trays drained into the bottom of the tower and the level exceeded 100% Estimated levels ranged from 11 to 35 ft above tangent. The highest (35 ft) covered the bottom 9 trays but was well below the feed inlet at tray 31. None of these startups resulted in a significant incident.

In many of these startups the Heavy Raffinate rundown flow rate went off range at maximum flow but, for estimating the liquid level, a flow rate corresponding to the range maximum has been taken. This means that the actual liquid levels will be somewhat lower than estimated in Appendix 24.

There is a correlation between heatup rate and splitter tower pressure for all startups prior to March 23. Every startup had a pressure spike upon the initial temperature ramp-up. The board operator cut the heat to the reboiler to stop the pressure spike and then restart the heatup. Generally, the height of the pressure spike was related to the heatup rate and duration of the heatup before heat was reduced on the reboiler. Another variable is the amount of non-condensables in the system when the pressure spike occurred, but, because the degree of venting is indeterminable, it is impossible to estimate the amount of non-condensables in the system. The PI data suggests that the 8-inch chain-wheel valve, in parallel to the overhead relief valves, was opened temporarily during some startups to control these pressure spikes, but DCS data is not available to give precise details. The 3# system appears to have been used during the last four startups to purge non-condensables.

The Raffinate Splitter was derated from 70 psig to 40 psig in January, 2003, and the overhead relief valves reset. Since then, there have been two occurrences when the pressure exceeded the overhead relief valves set points for short periods. The relief valves lifted February 21, 2003, and possibly on October 29, 2003, when the indicated pressure just reached 41 psig. The relief valves relieved pressure to the blowdown drum and stack, and the vapors dispersed without further incident.

Three recent startups since the tower derating more closely adhered to the specified heatup rate (50˚F per hour) and maximum reboiler outlet temperature (<275˚F) specified in the startup procedure. Under these circumstances, the maximum pressures were controlled in the range 28.8 to 32.5 psig, well below the relief valves set point of 40 psig. The 3# vent system appears to have been used during the last four startups to purge non-condensables from the reflux drum.

In general, previous startups indicate that the characteristics of a good startup, where the maximum pressure is controlled well within the relief valves set point, are:

- Start Heavy Raffinate rundown before/as soon as feed started
- 3# vent system is open to purge non-condensables
- Slow heatup rate (not exceeding 50˚F per hour)
- Low reboiler outlet temperature (not exceeding 275˚F)

By contrast, the characteristics of startups where the maximum pressure gets close to or exceeds the relief valves set point is the reverse, i.e., delay in starting rundown, fast heatup rate, and high reboiler outlet temperature.

5.10.7 Pre-Startup Review

The startup procedure requires a review, commonly referred to as a "pre-startup review," of the procedure before the procedure is used (Step B.12).

> *"Conduct a pre-startup review of the procedure with all crewmembers"*

This review is similar to the Pre-Startup Safety Review (PSSR) requirement before commissioning a modification subject to a MOC, but simpler. A PSSR after a MOC requires a check of equipment design specifications, adequacy of procedures, PHA action resolution and completion of employee training, but a startup review is merely a check that the procedure is still adequate for the task and that the crew members understand the procedure.

This review was not performed prior to the startup on March 23, and there appears to have been no supervisory oversight to ensure that it was performed. The AU2/ISOM/NDU/ARU Superintendent was unaware that this, and other procedural steps, had not been followed.

Local site policy required a formal PSSR following a TAR. The shutdown of the Raffinate Splitter in February/March, 2005, was termed a "temporary outage," which did not require a PSSR. A PSSR was not conducted.

5.10.8 Troubleshooting and Intervention

The OSHA PSM rule (ref. 1) requires written operating procedures that provide clear instructions which address:

> *"Operating limits: (A) Consequences of deviation; and*
> *(B) Steps required to correct or avoid deviation."*

These procedures are required to be consistent with the process safety information (PSI), which further requires information concerning the technology of the process to include:

"Safe upper and lower limits for such items as temperatures, pressures, flows or compositions; and,

An evaluation of the consequences of deviations, including those affecting the safety and health of employees."

The startup procedure for the Raffinate Splitter does emphasize warnings about hazards such as high pressure, but does not include any information about troubleshooting or intervening if operating parameters deviate from intended ranges. For example, there is no guidance on what to do in the event of high pressure and no specific warning about the hazard of a high level in the tower or guidance on intervention if a high level occurs. It relies on operator knowledge and training. The operating envelope is available electronically on a site server in a document called "ISOM Operating Envelope" revision no.4, dated February 26, 2004.

A separate training class on process troubleshooting is periodically offered at the site to improve an operator's ability to monitor, evaluate, troubleshoot and control typical refinery processes (see Section 5.11.7). The Day Shift Board Operator and Operators B, C and D attended this class in June/July 2000. The training was not ISOM unit specific.

Additional general information on process troubleshooting is provided in the series of Process Safety booklets (referenced in the SOP).

5.10.9 Safe Work Practices

Task risk assessment is the simplest form of hazard/risk analysis and is known by many names, including Job Safety Analysis (JSA) and Job Hazard Analysis (JHA). Tools such as JSA are widely used within the industry to help identify hazards and orientate workers before commencing each new task, whether that task involves operations, maintenance or construction activities. No task risk assessment or review of the startup procedure took place on the ISOM unit prior to starting up the Raffinate Splitter. This could have provided an opportunity to reinforce procedures, and identify and alert nonessential personnel in the vicinity of the startup.

Hazardous Area Classification (HAC) drawings are used in some other sites as an indication of areas where nonelectrical ignition sources, such as vehicles, diesel-engined air compressors, etc. require an Authorization to Work (ATW, hot work permit). This is not the practice at Texas City refinery. The site Hot Work policy (PR-2) states:

> *"OSBL roadways are considered free burn areas for vehicles or mobile equipment in motion. Stationary vehicles or mobile equipment and other stationary sources of hot work located on or adjacent to the roadways or ISBL areas for greater than one hour while operating must be permitted. The group commissioning the work will issue the permit………An Authorization to Work and a hot work permit are not required for the entry/exit of vehicles and mobile equipment into an operating unit. However, a person qualified in gas testing must test the space ahead of the advancing mobile equipment and*

remain with the mobile equipment until it arrives at a job location with a current hot work permit or exits the unit."

The site Traffic Safety policy (ME-1) states:

> *"For TAR's and large capital projects, a traffic control plan must be developed. ………No vehicle must be left unattended with the motor operating. 'Unattended' is defined as no operator physically in the driver's seat of the vehicle in a position to control it. The provision does not apply to a vehicle providing a power source necessary for mechanical operation other than propulsion, passenger compartment heating or air conditioning; emergency response vehicles are considered power sources."*

On March 23, there did not appear to be a traffic control plan for the Ultracracker TAR, and numerous vehicles were parked in the vicinity of the trailers between the NDU and ISOM units. Despite the proximity to operating units, there were no controls over vehicular access, as the HAC for this area was classified "non-hazardous." The delineation of ISBL areas was not clear.

Several vehicles were parked on the shoulder of the roadway north of, and adjacent to, the ISOM unit and Blowdown Drum. At least one truck was attended with the engine running, and was a possible ignition source for the explosion. An unattended vehicle was inside the ISBL on the south side of the ISOM, and the engine appears to have been running, as the air bag deployed in the explosion. The Investigation Team could not find any record of gas testing or ATW for the entry of this vehicle into the ISOM unit.

5.10.10 Shift Handover

The startup procedure includes the following note on the importance of good communication for safety:

> *"Through all phases of a startup, maximum attention must be paid to safety, details and communications. This must be shared between involved units, shifts and individual crewmembers. Good planning, scheduling, judgment and communication make safe and efficient startups."*

The Day Shift Supervisor for the ISOM outage arrived late for his shift on March 23 and did not receive any handover from Operator A, who had packed the tower, or from the night shift supervisor. The passdown between the respective Outside Operators occurred off of the unit at the refinery gate, and its duration and quality appears less than adequate.

The Day Shift Board Operator received a handover with the Night Shift Board Operator, who was not involved in packing the Splitter. The Splitter had been packed by Operator A, who had left the site at 04:59 hrs, an hour before shift change. The startup procedure used by Operator A was in the satellite control room and not in the main control room.

It is not clear why the startup was conducted across two shifts. Previous startups, including preliminary packing to establish liquid levels, have been easily completed within a single shift. By spanning two shifts, an additional risk was created, which could only be managed by ensuring good communication between the two shifts.

5.10.11 Operations Upset/Problem Reporting

Process upsets, including lifting relief valves, were not routinely reported and investigated at the ISOM unit. While systems exist and could be used for this purpose, there appeared to be little diligence in reporting. Operations log books for the ISOM unit seldom reported pressure excursions on startups, including when relief valves lifted and vented vapors to the blowdown drum.

There also appears to have been little feedback to Operations management and Engineering, concerning equipment problems and departures from the formal operating procedures.

5.10.12 Conclusions

Despite the startup procedure not being fully updated, the procedure is generally of high quality, addressing all the safety warnings and key process control steps in detail. Many steps in the procedure were not followed, and the fact that the procedures were not updated indicates that they were not seen as important documents. Supervisors and Superintendents did not verify that the procedures were available and correct or being followed. Poor handover procedures meant that risks were not discussed and the correct procedures were not available to the board operator.

In general, employees were unaware of the risks of operating without the procedures, considering this to be a routine operation needing little evaluation or thought. As a result of this, the Control of Work process broke down.

5.11 Training (Knowledge & Skills)

5.11.1 Training Program

A local site policy, SH-PSM-5 "Training for Process Safety," outlines the requirements for training of operators and supervisors. The content of the training depends upon the employee or contractor's duties and responsibilities relative to the covered process.

The policy requires:

> *"Employees involved in operating or directing the operation of a covered process must be trained in an overview of the process and in the operating procedures. The training must include an emphasis on specific safety and health hazards, emergency operations and safe work practices, policies and regulations applicable to the employee's job tasks or work environment. Employees or contractors involved in maintaining or inspecting a covered process must be trained in an overview of the process and in the safe work practices applicable to the maintenance or inspection task."*

The policy requires each unit to certify every 3 years their employees covered by the scope of the OSHA PSM and EPA RMP rules. The requirement further states that:

> *"Prior to having the document signed, the Training Coordinator should verify that the required training has been completed."*

5.11.1.1 Basic Operator Training (BOT) Course

Prior to 2002, the training required by SH-PSM-5 was delivered through a five-week Basic Operator Training (BOT) class, covering a process safety overview, operating procedures, safe work practices, site policies, process safety booklets, process safety standards, and recommended good practices.

The class was delivered in four phases for all new employees, and transfers into the Texas City site:

- Phase 1: New employee orientation and training
  - Operator Specific Responsibilities
    - Operator Roles and Responsibilities
    - Environmental Control and Responsibility
    - Hydrocarbon Loss
    - Energy/Steam Utilization
    - PRIDE training
- Phase 2: Unit introduction, process safety overview, process hazards and safeguards
- Phase 3: Job qualification training, including comprehensive review of process equipment and operating parameters
- Phase 4: Periodic refresher training

The course included:

- Refinery chemistry and physics
- Refinery operations, flow diagram and layout
- Refinery process equipment
  - Steam traps
  - Heat exchangers
  - Surface condensers
  - Distillation, Absorption and Stripping
  - Fractionation
  - Cooling Towers

  - Rotating Equipment
  - Motors
  - Furnaces
  - Analyzers
- Instrumentation
- Safety Training
- Safe work practices
- Hydrogen Sulfide
- Normal Operating Procedures
- Role of the Refinery Operator
- Sampling Procedures
- Startup Procedures
- Shutdown Procedures
- Emergency Procedures

Currently the site's objective is to only hire individuals with an associate degree in process technology or 3 year's experience in the petrochemical process industry. The framework continues to use a 4-phased approach, but has been shortened in recognition of the prerequisite education/experience requirements. Details of the current program are included in Appendix 27.

The qualified Outside Operators and Board Operators involved in the March 23 incident attended the 5-week BOT course. The two trainees, Operators E and F, were hired as interns from the College of the Mainland, and received on-the-job training.

5.11.1.2 Training Budget

Over the past five years, the budget for the Texas City Refinery Learning & Development (L&D) Department has risen, while the department's headcount has been reduced through the period. Spending level and headcount peaked in 1998 after the site implemented the HiPRO organizational model.

The L&D training budget and headcount (expressed in full-time equivalents (FTEs)) for the past 8 years was:

Table 5-7
Learning and Development Department Training Budget

Year	**Actual Spending** $000	**Resource Allocation** FTEs
1997	1,728.40	30
1998	2,847.90	28
1999	1,114.47	21
2000	1,413.51	~17.5
2001	1,250.75	~11.5
2002	1,111.76	10
2003	1,220.30	9
2004	1,429.70	8
2005	1,700.00*	9

* Budgeted amount

According to ISOM Unit supervision, most training costs are captured in the fixed cost budget. There is not a separate line item or cost center for capturing the unit-specific costs associated with training. Unit personnel were not able to furnish the BP Investigation Team with data for training budget or spending.

5.11.2 Training Records

There are two primary sources of training records for employees on the ISOM Unit, (1) a computer-based database, Virtual Training Administrator (VTA), and (2) hardcopy records maintained in process unit files.

Operator training records consist of:

- Records of training completion in the Virtual Training Assistant (VTA) database
- Demonstration Evaluation Forms
- PSM Certification documentation

The Training Coordinator is responsible for assigning employees to a training program via VTA. The employee then receives an e-mail from VTA indicating the course and expected date of completion. The employee then accesses the course in VTA and completes the appropriate lessons. In the case of ISOM training, the employee prints out a Certification Evaluation form from VTA and manually completes the evaluation activities with their immediate Supervisor or an Evaluator. Upon successful completion of the Certification Evaluation, the form is signed off by the Employee and the Supervisor (or Evaluator) and sent to the Training Coordinator. The Training Coordinator is responsible for accessing the employee's record in VTA and marking the course record as complete. The completed Certification Evaluation form and VTA record form the basis for the PSM Certification.

Examples of employee training records are presented in Appendix 28.

5.11.3 ISOM Operators

The Outside Operators and Board Operators involved in the March 23 incident attended the BOT course. However, a review of VTA records revealed incomplete records for some ISOM operators.

The most significant gap involved Operator D, for whom no evidence was found in VTA or in hard copy records to show that he was ever assigned ISOM Operator training. The Day Shift Supervisor issued an e-mail stating that he was a qualified ISOM operator. When interviewed, Operator D asserted that he is a trained and qualified outside operator for the ISOM. Based upon the supervisor's e-mail, Operator D was eligible for overtime working on the ISOM from October 25, 2004. Operator D was certified as a Hydrogen Unit operator, and transferred from the Hydrogen unit to the ISOM unit during 2004.

Three minor exceptions were also identified, as follows:

The Training Coordinator did not mark the VTA records for Operator B and Operator C that their Certification Evaluation was complete.

The Training Coordinator incorrectly cited the 1992 grandfathering paragraph of the PSM standard on the PSM Qualified certification letters, instead of the 3-year refresher training paragraph he should have cited. (This administrative error is repeated on each PSM certification letter for employees on the ISOM.)

- The Training Coordinator signed his own PSM Qualified certification letter.

Comparison of training records for ISOM Unit personnel against the site process safety training requirements (SH-PSM-5) reveals a number of gaps in training delivery and topics covered, including:

- Normal Start-Up Procedures (post TAR)*
- Normal Shutdown Procedures (pre-TAR)*
- Critical Corrective Actions
- PSM Policies
- Process Safety Booklets
- Process Safety Standards and Guidelines
- Recommended Good Practices

* This training is required prior to performing the task.

While the Investigation Team did identify deficiencies in training records, the ISOM was generally staffed by operators who had the necessary knowledge and skills to run the unit safely. However, post-incident interviews of the Day Shift Board Operator led the Investigation Team to conclude that he did not adequately understand the process or the potential consequences of his actions or inactions on March 23. Operator B, another board operator, prompted the Day Shift Board Operator several times to make corrective moves, such as starting heavy raffinate rundown to avoid overfilling the tower. The Day Shift Board Operator stated that he was performing a mental mass balance every few minutes, but the actions taken are inconsistent with this.

5.11.4 ISOM Supervisors (Including Step-Ups)

The training of ISOM Supervisors comprises two main categories: technical training, and management/supervisory training.

Technical training is covered in a local policy (SH-PSM-5). With a few exceptions, this training is generally equal to what is required for an Outside Operator, as follows:

- Safe-Off/Emergency Procedures
- Critical Corrective Action Procedures
- Temporary Operating Procedures
- Outside Specific Operations
- General Unit Operations
- Process Safety Overview
- Process Safety Booklets
- Process Safety Standards and Guidelines
- Recommended Good Practices

The exceptions are:

- Board-Specific Operations—additional knowledge
- Normal Startup Procedures (post-TAR)—awareness only
- Normal Shutdown Procedures (pre-TAR)—awareness only

The policy requires a step-up to have the same training as required for the position that they are filling temporarily. If a newly appointed first line supervisor or step-up is a trained and certified Board Operator, then they are automatically qualified to be a Supervisor per the technical training requirements of SH-PSM-5.

The Day Shift Supervisor's technical training records were up to date.

The Investigation Team was unable to identify any specific management/supervisory training requirements for first line supervision or step-ups. However, VTA records indicate a number of management/supervisory training courses. Some courses were taken by only a few individuals, but most, if not all, of the ISOM supervision had completed the following courses:

- Preventing Workplace Harassment
- Diversity and Inclusion review
- Are you ethical?
- Records Retention
- Capital Value Process
- HR Policies/Procedures/Labor Relations

Training requirements were to be covered on an individual basis in each supervisor's professional development plans, but audits by L&D revealed this was not being done for the ISOM.

5.11.5 Gun Drills

A 2001 MOC (# MOC-NDU-2001-002) was initiated to combine Board Operator responsibilities for the NDU with the AU2/ISOM. The MOC identified an action item to conduct gun drills.

> *"Develop a simulator for the AU2/ISOM/NDU control board operator position, or in the alternative developing effective gun drills."*

The action item resolution was reported as "Gun Drill Program has been developed as required." There is no evidence in unit training records to verify that the gun drills occurred.

An incident investigation (# INV-ISOM-2002-001) involving a runaway thermal excursion of D-301 had also recommended implementation of gun drill exercises. The action item was resolved by development of a gun drill for the situation. A review of the ISOM Unit training records identified hardcopy documents for two drill scenarios addressed on each shift. One drill was for loss of the J-203 pump and the other for loss of Perc Pumps to the Penex Reactors. These records were not dated as to when they were performed. Neither scenario involved the Raffinate Splitter.

The Investigation Team concluded that the ISOM unit did not meet the intent of either of these recommendations, and they should not have been closed out as complete. At the time of the March 23 incident, the ISOM unit had contracted a consultant to develop a comprehensive gun drill program for the ISOM Unit in 2004 in response to the identified corrective actions. The program includes planning tools, scenarios and critiques, but had yet to be implemented.

5.11.6 Lack of Simulator

In the past there has been limited use of simulators for operator training at the Texas City site. In the early 1990s two generic simulators were used, Foxborough software and Dexter distillation, to provide operators with a general understanding of process equipment and parameters. Their use was discontinued.

While it is very difficult to quantify "incidents that won't occur" and "improved operator performance" the team believes that the advantages to the site from the use of simulator training would be significant. In order to leverage the use of simulators to their best value, a clear simulator strategy is needed, outlining most-likely-to-be-realized benefits, and critical success factors. This needs to be backed by resources to develop meaningful ongoing training and optimization programs.

5.11.7 Training in Troubleshooting

In conjunction with the BOT training, a 2-day course on process troubleshooting is offered periodically. K&S Associates designed and developed the course to improve an operator's ability to monitor, evaluate, troubleshoot and control the processes encountered in refinery and chemical operations. The methods taught improve the operators' ability to organize their thought process into a logical sequence of steps.

The method is divided into two procedures. The first is the troubleshooting procedure, which the operator uses to identify the process control factor and the root cause of a problem. The second is the corrective action procedure, to help the operator develop a plan to safely counteract the problem or shut down the process, and evaluate the long-term effects the problem has on efficient and safe operation of the unit.

Course participants become familiar with the troubleshooting procedure and corrective action in a universal unit that contains reaction, separation, distillation, absorption, and stripping processes. When a unit enters an abnormal condition, the operators stabilize, troubleshoot the unit, and develop and implement a corrective action plan.

Competent operators have the knowledge, skills, authority, and confidence to interact with the process and, during normal operations, to monitor, collect data, evaluate and determine whether changes to the process are normal or abnormal. They maintain a constant vigil over the process.

During abnormal operations, competent operators examine effects, determine cause and initiate corrective action. They know safe upper and lower limits for key parameters and how to mitigate the immediate consequences of a deviation. They take immediate action to stabilize the process, ensure safety, and stop any environmentally damaging emissions.

Flow, temperature, pressure, and level are the parameters most often indicated to the operator. The indicated value of a parameter means little unless it is referenced to the internal characteristics of a process. A competent operator can interpret and adjust flow, temperature, pressure, and level. Operators can validate an indication because they know how the four parameters interrelate. The training did not specifically address the risk of overfilling a tower to the point of liquid overflow, and the appropriate mitigating actions required.

ISOM supervision, board operators and outside operators attended these process troubleshooting classes in 2000/2001, including the Training Coordinator (August 31, 2000), Day Shift Supervisor (August 17, 2000), Day Shift Board Operator (June 15, 2000), Operator A (July 13, 2000), Operator B (July 24, 2000), Operator C (July 27, 2000), and Operator D (June 29, 2000).

5.11.8 Training on Emergencies

A local policy (HSE A-7) covers the Emergency Action Plan, including reporting emergencies, sounding alarms, operational checks, hot work, evacuation, accounting for employees, organization structure and training. A specific training course (HSEREG007) is provided periodically to train employees in the Plan. All operators and supervisors on the ISOM unit had received this training in 2004/2005 before the incident.

In addition, a course titled “Emergency Response Assistance and Alarms” was held in 2004, and all operators and supervisors received this training. Most operators and supervisors had also taken courses in 2004 related to a new program of emergency response training and gun drills that were being initiated on the unit.

5.11.9 Process Safety Knowledge and Skills

Although efforts had been made to raise general process safety awareness and understanding in the early 1990s when OSHA promulgated the PSM rule, this training had not been effectively refreshed over the intervening years. There was little ongoing training in process hazards risk awareness and identification for either operators or supervisors/managers. PSM-related materials have been distributed through e-mails and VTA, but these communication channels do not appear to have been effective in maintaining awareness and understanding. All ISOM operators and supervisors should have attended training that included the Process Safety Standards and BP’s process safety booklets, which describe hazards of process plant operations and lessons learned from incidents, but there was no record of these topics in VTA.

Some training on specific elements of the PSM rule was received by certain individuals. Four staff employees involved with the ISOM unit attended PHA Leader training in 2002 and 2004, and five received training in the EPA Risk Management Program (RMP) rule. Most ISOM unit personnel took the MOC Awareness Review course via VTA in 2004, while several received MOC PHA Leader and Level A Investigation training.

5.11.10 Training Program Audits

The Texas City Refinery L&D Department leads an audit of the training program at the site annually on a unit basis conducted with the respective unit Training Coordinators. Results of this audit are reported to the site Leadership Team and Operations Superintendents.

The audit covers operator hiring, new operator selection, training plans, training materials and resources, testing and qualification, unit-specific training, training development, performance appraisal and training for new equipment/technology.

The ISOM Unit 2003 and 2004 audits detected deficiencies in the following areas:

- The unit did not have a training plan reviewed and approved by operations management.
- Gun drills were not being conducted.
- Individual development plans were not in place to address identified gaps.

Interviews of L&D personnel and Unit supervision revealed that the Unit Training Coordinator spent approximately 5% of his time on training activities. The site average was estimated to be about 30%. The ISOM Unit Training Coordinator often worked as an Acting Superintendent, fill-in Supervisor, and participated in MOCs and HAZOPs, turnaround activities, and maintenance.

5.11.11 MOC Training

A local site policy (SH-PSM-10) requires the use of qualified MOC leaders to analyze the hazards of the change. Most recently the site held two two-day MOC Leader classes during September 2004 to teach participants how to apply the HAZOP and What-if/Checklist techniques to the MOC process, and to improve leadership skills in the areas of meeting management, conflict resolution, analytical thinking, diversity and inclusion, organizing, communicating, and team leadership. Several staff employees involved with the ISOM unit attended this MOC PHA Leader training.

In the MOCs reviewed by the Investigation Team the level of leadership brought to bear was not always of the required standard, often due to the lack of competence and practice of the leaders. In the past 3 years, 25% of the MOC leaders performed 90% of the hazards analyses. The remaining 10% of the MOC hazards analyses were performed by 50% of the MOC leaders, leaving 25% of MOC leaders that were not utilized. So, much of the training is not applied by those leaders who do not practice.

5.11.2 Conclusions

There was a lack of rigor and follow through in the area of training. Records showed incomplete training and there was little verification that all required training was occurring. The lack of gun drills to reinforce practical knowledge meant that operators' theoretical knowledge was not complete and rarely witnessed. The heavy reliance on computer based training (typically done by individuals on their own) appears to limit the overall effectiveness of the training program.

5.12 Facility Siting

On March 23, 2005, several trailers were being used as temporary offices between the ISOM and the Naphtha Desulfurization Unit (NDU) for BP and contract staff engaged in the adjacent Ultracracker turnaround. The choice of this location site for the trailers is an important factor, which increased the severity of the incident. Past practices certainly influenced siting of the trailers involved in this incident.

5.12.1 Regulation

OSHA promulgated the "Process Safety Management of Highly Hazardous Chemicals" (PSM) regulation (29 CFR 1910.119) in 1992. This requires that regulated processes, such as those at Texas City refinery, conduct a Process Hazards Analysis (PHA). The PHA may be conducted using one of several methodologies allowed, such as HAZOP, What If, and checklists, and must be revalidated at least every five years. The PHA must also address "facility siting," which has been interpreted as applying to the location of occupied buildings in the vicinity of the covered processes.

5.12.2 Industry Guidance

Several tools have been developed to aid companies in complying with OSHA's PSM requirements for facility siting as part of a PHA.

API Recommended Practice 752 "Management of Hazards Associated with Location of Process Plant Buildings" (ref. 8) provides guidance for identifying hazards that may affect process plant buildings and for managing risks related to those hazards. A then BP employee chaired the working group that developed API RP 752.

The Center for Chemical Process Safety (CCPS) "Guidelines for Evaluating Process Plant Buildings for External Explosions and Fires" (1996) provide a practical approach to identifying, evaluating, and managing the process safety considerations associated with process plant building design and siting. Two then Amoco employees participated in the development of the CCPS Guidelines.

Normally occupied temporary buildings are within the scope of the API RP 752 and the CCPS Guidelines.

5.12.3 Amoco Workbook

Amoco developed a "Facility Siting Screening Workbook" (April 1995) to implement the guidance detailed in API RP 752 within their Petroleum Products Sector—Refining. This workbook formed the basis for the Texas City Refinery Management of Change (MOC) procedure requirements related to siting trailers.

The "Amoco Petroleum Products Sector—Refining Facility Siting Reference Manual" was also developed as a ready reference source for field personnel to use when performing refinery facility siting studies. EQE International, a specialist consultancy with structural engineering expertise, was a major contributor to the development of the manual.

5.12.4 Texas City Procedure

The Texas City Refinery has a procedure with specific requirements for siting trailers used as temporary offices which was developed in response to the PSM rule and API RP 752. When trailers are used as temporary offices at the Texas City Refinery, they are sited under a Management of Change (MOC) procedural control process.

Occupied buildings, including portable buildings and trailers, were added to the scope of the MOC procedure in August, 1999. All changes to occupied buildings, including installation of a temporary trailer, require completion of a MOC.

Each MOC is required to include a Process Hazards Analysis (PHA), Supplemental Requirements Checklist, and a Pre-Startup Safety Review (PSSR) prior to commissioning the change. The PHA technique used at Texas City for trailer siting involves a "What If" Hazard Review and a specific Trailer Siting Checklist. If a trailer is to be sited within 350 feet of a process unit, there is a specific requirement that a facility siting analysis be performed. However, neither the What If review nor trailer siting checklist direct the PHA team to consider process upsets or catastrophic risks, relying instead on geographical separation.

5.12.5 Trailers

Like many refineries, Texas City has been using trailers routinely as temporary offices for many years for BP employees and contract workers involved in project work and turnarounds.

On March 23, 2005, there were at least 9 normally occupied trailers on the Ultracracker Unit for the Ultracracker turnaround and Motorization project work. Because of its size and the location of the Motorization project, a J.E. Merit trailer was sited in the northeast corner of the area between ISOM and NDU. As the turnaround approached, it became apparent that not all of the trailers needed for the turnaround could be located on the Ultracracker Unit. Once the available space for siting trailers on the Ultracracker was occupied, the turnaround project team turned to the open area between NDU and ISOM, just south of the Ultracracker. Eventually 8 trailers, 6 to be normally occupied, were placed in the area between the NDU and ISOM close to a permanent building in this area, a normally unoccupied building for storing catalyst.

According to the MOC procedure in effect at the Texas City Refinery, the Operations Superintendent has responsibility for commissioning MOCs, identifying change requirements, and assuring completion of actions generated from the activity. It is clear from interviews and documentation that the MOC requirement was known and understood by those involved in the Ultracracker turnaround and Motorization Project. The MOC was initiated, performed and completed prior to the turnaround per site procedures. However, the Superintendent never gave authorization to proceed with the trailer siting.

The trailer occupied by J.E. Merit for the Ultracracker Motorization Project was the only normally occupied trailer in the area between the ISOM and NDU where the site MOC procedure was partially adhered to. The 5 other occupied trailers in the area between ISOM and NDU were not explicitly addressed in an MOC. Post-incident interviews indicate that it was seen as an acceptable practice to site multiple trailers using a single MOC.

5.12.5.1 J.E. Merit Trailer

A double-wide trailer of wood frame construction was sited for J.E. Merit in the area between the ISOM and the NDU in early September, 2004. This area is classified as "non-hazardous" in the site Hazardous Area Classification (HAC) drawings. The MOC (# MOC-NDU-2004-008) was initiated on September 27, 2004, and the MOC work group completed its evaluation prior to the trailer being occupied. An acting Superintendent gave approval to proceed with the MOC process on October 6. Employee interviews indicate that the trailer was occupied about 2 weeks before telephones were installed on November 8, without some of the action items noted on the MOC having been completed, and without seeking final approval for occupancy from the ISOM/AU2/NDU Superintendent. He never gave final authorization to commission, i.e., proceed with occupancy, as required by site procedures.

A MOC work group met on September 17, 2004, to evaluate the trailer siting. In attendance were the ULC Motorization Project Manager, ULC Motorization Project Engineer, the ULC Asset Coordinator, ULC Training Coordinator, ULC Operator, the JE Merit Safety Specialist, and the PHA Leader. The two union Health & Safety Representatives were not invited, but, on hearing of the meeting, attended anyway. The work group did not include anyone from either the NDU or ISOM Units, although the cover letter for the completed MOC paperwork was addressed to the AU2/ISOM/NDU/ARU Superintendent. The union Health & Safety Representatives reportedly raised a concern about the make-up of the team, i.e., lack of Warehouse, NDU and ISOM representatives, and left the meeting. The union Health & Safety Representatives did not review the MOC checklist, but, seeing a followup e-mail addressed to the AU2/ISOM/NDU/ARU Superintendent, assumed that NDU/ISOM personnel had been involved. The union Health & Safety representatives did not raise any safety concerns regarding the trailer location.

The following documents were completed as part of the MOC:

- "What If" Review Summary Sheet
- MOC Supplemental Requirements Checklist
- Process Hazard Analysis (PHA) Checklist for Trailer Siting
- Facility Siting
- Building Analysis Checklist
- Building Occupants Summary

The “What If” Review Summary Sheet does not contain the scope and guidewords to be used to generate discussion in the work group. This is done by a trained PHA leader together with experienced operational and engineering team members. The Team Leader for the “What If” Review and PHA was a TAR Project Engineer. The “What If” Summary identified the oily water separator as a source of vapor, and forklifts as a source of ignition. There were no consequences identified for the oily water separator. The only safeguard identified was the sealed carbon canisters. The action items identified for this “What If” item were to post the evacuation route and check the area electrical classification. There were no consequences, safeguards, or actions required identified for the item in the “What If” Summary concerning forklifts. The “What If” Summary sheet was inadequately addressed and the documentation incomplete. Consideration of the risk of fire and explosion from the process units was not documented and the proximity to an atmospheric vent was not evaluated. The PHA Preparation section of the MOC Supplemental Requirements Checklist prompts the user to consider using P&IDs. However, electrical classification drawings were not provided in the meeting.

There are 29 issues and concerns listed on the Supplemental Requirements Checklist, all of which were checked off as “N” for no, with the exception of one item (use of P&IDs for the PHA) which is marked as “not applicable.” This checklist did not appear to the investigation team to be relevant to an occupied building with the exception of item no.1, which is, *“Do the unit standing orders need to be updated?”* This question should have prompted the team to consider standing orders around emergency notification and response. This checklist also includes an item on the Group Major Hazards Risk Assessment, pointing out that the PSM Manager should be consulted on any proposed changes that may impact the assessment. The last example given in a list of items likely to require an update of the assessment is *“Introducing a new occupied building.”* This was checked off as “N” for no.

The second question on the PHA Checklist for Trailer Siting prompts the user to consider performing a siting analysis if a trailer is located less than 350 feet from the unit. This was checked off as “N” for no. The closest unit was identified as the NDU, with the F-20 Blowdown stack not being considered as part of the process unit within 350 feet of the trailer. Checklist item no.6 prompted an action item to determine if there were electrical area classification requirements. A determination was made that this trailer was not sited in an area with an electrical classification and the action was closed out by the J.E. Merit Safety Specialist. Employee interviews confirmed that classified electrical tie-ins were not used in providing the trailer with electricity. Item no.14 on the Checklist prompted the work group to consider emergency notification in the event of a release. Hand notes on the checklist by this item were the “Main Fire Alarm” and “Radio Communication.”

Other concerns raised by the investigation team in reviewing the documentation for the J.E. Merit trailer siting MOC were:

- Item 20 on the checklist asks the work group if procedures are in place to restrict nonessential personnel from entering the unit. The group acknowledged this with a handwritten note to “rope off and barricade.” The trailers were physically separated from the ISOM Unit by a pipe alley, and there was no evidence to indicate that the NDU was barricaded from access by trailer occupants.

- The work group filled out the Facility Siting, Building Analysis Checklist and concluded that they had evaluated, “personal work areas within the building…located along walls facing potential blast sources.”
- The Building Occupants Summary Form was found attached to the documentation for the MOC but was not filled out.
- The Asset Coordinator was given the action item to inform operating personnel. The action was closed out in the database on October 22, 2004. The unit can provide no documentation to confirm the actions taken to close out this requirement for change.
- According to the site MOC policy, all action items for a MOC must be completed before a Superintendent can authorize to commission a MOC. There were 2 actions items that remained open. They were:
  - i. Shutting down traffic to the catalyst warehouse between Avenue F and G. Traffic was to be redirected to approach the catalyst warehouse from Avenue G, the road south of the ISOM.
  - ii. Posting of evacuation signs.

In conclusion, this MOC failed to identify the risks that the ISOM Unit and Blowdown Stack posed to the trailer occupants, and was not fully compliant with site procedures.

5.12.5.2 Other Trailers Between the NDU and ISOM Units

Seven additional trailers were sited in the area between the ISOM and NDU in January and February, 2005, in preparation for a turnaround on the Ultracracker Unit, across the road to the north of the ISOM. A MOC was not initiated for any of these trailers.

The BP Investigation Team found no evidence that the Ultracracker Superintendent or TAR Superintendent informed the AU2/ISOM/NDU/ARU Superintendent that the trailers would be placed in the area between ISOM and NDU. No evidence was identified that Operations supervision recognized the siting of the Ultracracker turnaround trailers between the ISOM and NDU would require a MOC to be initiated and completed.

The normally occupied trailers in the area between ISOM and NDU were:

1. A J.E. Merit trailer of a wood frame construction for the Ultracracker Motorization Project, housing 13 people as shown on the office layout for the MOC
2. A Fluor trailer housing 4 workers involved in quality assurance aspects of the turnaround
3. A Contech trailer—wood frame trailer for officing up to 22 workers on the motorization project
4. Another Contech wood frame trailer for workers to take breaks and lunch
5. A Timec trailer for workers requiring office accommodation
6. Another Timec trailer for decontamination of workers involved in the catalyst changeout

The two Timec trailers housed on average between 11 and 13 persons during breaks, decontamination and meetings.

The trailers in the area between ISOM and NDU that were not normally occupied were:

1. A Hahn and Clay truck trailer leased by Timec for storing tools.
2. A Superior trailer (steel construction, similar to a shipping container Conex) on the Southeast side of the area between NDU and ISOM. Not normally occupied, used for storing tools and supplies.

The Contech, Timec, and Hahn and Clay trailers due north of the catalyst warehouse appeared to be located within the hazardous area indicated on the most recent Hazardous Area Classification drawing for the NDU unit. The trailers were not equipped with electrical systems meeting Class 1, Division 2 specifications. The HAC drawings are not to scale and the delineation between hazardous and non-hazardous areas is difficult to accurately determine.

Trailers had been previously sited in the area between NDU and ISOM when the NDU was constructed in 2002 (# MOC-PWR2/OSU-2001-022). Utilities installed in 2002 were still in place and enabled trailers to be readily sited and prepared to be occupied.

The Investigation Team believes that even if a MOC had been performed for these trailers it is probable that they would have been sited in the area between ISOM and NDU. In addition to a low frequency of explosion value (4.0 E-04) used from the Amoco workbook in the vulnerability calculation (see Section 5.12.8.1), precedent had been set that this was an area often used for this purpose.

5.12.6 MOC Procedure as it Applies to Turnarounds (TARs)

The role of the TAR organization is not specifically identified in the Responsibilities and Tracking section of the site MOC procedure. The TAR organization is the liaison between the Asset where the trailer will be placed and the Contractor who is looking to place a trailer. The site MOC procedure identifies the Project Manager for capital projects as being responsible for assuring that actions are completed. The policy assigns responsibility for initiating the MOC to the person performing the work or requesting the work.

The TAR Superintendent has the role of Project Manager and, as such, has a responsibility to verify that any action items from a trailer siting MOC have been completed for any trailers involved in a TAR prior to authorizing their siting. The Investigation Team found no evidence that the TAR organization had requested the status of action items from trailer siting MOCs prior to siting the Ultracracker trailers in the area between ISOM and NDU.

5.12.7 Trailer Site

Several trailers involved in the incident were located between two operating units, the ISOM and the Naphtha Desulfurization Unit (NDU). A normally unoccupied building for storing catalyst is also in this area. The closest trailer, a double-wide J.E. Merit trailer, was located within 150 ft of the base of the Blowdown Drum and Stack (F-20), and is where most of the fatalities were located at the time of the explosion. This area had been used for siting trailers for many years. The plot plan of the ISOM and surrounding areas is depicted in Appendix 4. The practice of siting trailers in this area had become commonplace, with utility connections provided

5.12.7.1 Hazard Analysis of Trailer Site

The earliest facility siting assessment of the Texas City Refinery, including the trailer location, was made in 1995, and followed the guidance in the Amoco Facility Siting Screening Workbook. A report entitled “Facility Siting Screening Project, Guidelines and Results” was prepared to record this work. The report covers a consequence screening approach which focuses on building occupancy levels, congested areas within surrounding process units, and building design/materials of construction.

The determination of congested areas in process units surrounding the occupied building of interest is critical to identifying the potential for explosions. However, the 1995 study found some clearly congested areas with closely packed pipes and equipment, but other areas were more subjective. The study appears to have used a generally conservative approach in an attempt to compensate for this subjectivity.

The 1995 facility siting study reviewed a turnaround trailer in the area west of the ISOM unit and north of the catalyst warehouse (a little further west than the J.E. Merit trailer was located in 2005). The analysis included the number of people occupying the trailer, the duration of time the trailer would be there, types and quantities of hazardous material, congested areas within surrounding process units, and trailer construction. The vulnerability of the occupants to potential explosions from surrounding process units was assumed to be zero (see section 5.12.8.1), and therefore the overall risk to occupants (both Individual Risk and Population Risk) was determined to be zero, concluding that this location was not an area of concern for siting trailers. The specific details were not documented in the 1995 Facility Siting Screening Project report, but were archived in the study working papers.

In the 1995 study, two buildings fell outside of the criteria of the Amoco Facility Siting Screening Workbook: the North Office Building (multiple stories) and Power Station No.3 (internal explosion potential). In addition, the population risk for the Crude Division Control Room was calculated to fall within Zone 1 (“higher risk”). EQE International was retained to complete the facility siting analysis for these three buildings using a more detailed methodology. EQE’s report, “Siting Evaluation of Several Occupied Buildings at the Amoco Texas City Refinery for Vapor Cloud Explosion, Fire, and Toxic Material Hazards,” was issued in March 1997. This report did not evaluate any hazards related to trailer siting.

The 1998 Hazop revalidation of the ISOM unit considered facility siting at each node to identify any areas of concern related to the physical location of equipment, such as control room location, electrical area classification, and location of emergency equipment and evacuation assembly points. No major findings were recorded.

The earlier facility siting work was revalidated in July 2002 in a report entitled “2002 Facility Siting Revalidation.” This study addressed all occupied buildings, buildings that contain critical equipment, and buildings that were occupied on a part-time basis and/or temporary buildings, such as turnaround trailers. The study followed the previous methodology in the Amoco Petroleum Products Sector—Refining Facility Siting Screening Workbook. Although in 2002 BP had adopted and published new Group risk criteria, due to timing considerations the facility siting analysis was based upon heritage Amoco risk guidelines and criteria.

The 2002 Facility Siting study reviewed a trailer in the area west of the ISOM unit. The analysis was based on the earlier 1995 calculations, but the location is a little further east, closer to where the J.E. Merit trailer was sited in 2005. As a result, the closer proximity to the congested space within the ISOM unit produced a higher blast overpressure than the 1995 calculations. The vulnerability of the occupants to potential explosions from surrounding process units was again assumed to be zero (see section 5.12.8.1), and therefore the overall risk to occupants (both Individual Risk and Population Risk) was determined to be zero. The analysis concluded the trailer siting was acceptable. The specific details were not documented in the 2002 Facility Siting Revalidation report, but were archived in the working papers.

The 2003 Hazop revalidation reported that all issues from the 2002 Facility Siting study were resolved. Facility siting issues were considered where releases or fires had the potential to affect personnel, including the location of the satellite control room and maintenance buildings in relation to potential sources of major release of hydrocarbons or toxic materials from the ISOM. No new concerns were reported.

5.12.7.2 Update to Major Hazards Risk Assessment

Section 13 of the MOC Procedure requires that the PSM Manager should be consulted to determine if a proposed change may impact the site major hazards risk assessment. It also indicates that introduction of a new occupied building will likely require an update of the assessment. Section 14.9 discusses the application of the MOC policy to occupied buildings and the requirements for facility siting studies of occupied buildings, including portable buildings and trailers.

When the MOC for the J.E. Merit trailer was prepared, the item on the Supplemental Requirements Checklist concerning updating the site Major Accident Risk Assessment when introducing a new occupied building was checked as “No.”

A post-incident assessment by Texas City Refinery management showed at least 50 trailers on site in the areas of blowdown stacks or flares. Of those 50, only 4 were confirmed as having been covered by an Occupied Building MOC. All 4 of these trailers were covered under the same MOC (MOC-DDU-2003-008).

A record of trailer MOCs has been kept since 2001. A post-incident review of the database showed there were a total of 62 MOCs for temporarily occupied buildings, of which 37 had been commissioned, 15 had been cancelled, and 10 were approved to proceed. In that time, a Major Accident Risk (MAR) assessment has been performed, which did not consider the impact of temporary buildings on the site risk profile. Texas City Refinery management did not recognize the impact of trailers at the site and did not commission an update to the MAR assessment.

5.12.8 Comparison of Facility Siting Methodologies

The general screening approach within the API RP 752, CCPS Guidelines, and the Amoco Facility Siting Screening Workbook is similar. The intention is to take a conservative approach to identify and screen out "high risk" buildings requiring more detailed analysis. However, there are some important differences within the detailed methodologies that may influence the interpretation and conclusions of facility siting studies.

5.12.8.1 Occupant Vulnerability

The methodology within the CCPS Guidelines uses a correlation between blast overpressure at the building and the probability of serious injury/fatality to the occupants. This correlation is based upon analysis of past incidents within the industry, and addresses injury and fatality due to all causes, such as collapsing roofs and walls, impact from debris, etc. Graphs are shown for different building types.

The correlation for wooden trailers is:

Peak Side-On Overpressure	Vulnerability of Occupants	Damage to Building
1.0 psi	0.1	Isolated buildings overturn Roofs and walls collapse
2.0	0.4	Near-total collapse
5.0	1.0	Buildings completely destroyed

API RP 752 incorporated the CCPS correlation for different building types, including these data for trailers, as an example of occupant vulnerability.

The Amoco Facility Siting Screening Workbook uses a different correlation for occupant vulnerability, based upon Reflected Pressure at the building. The peak side-on overpressure is approximately 0.5 times the reflected pressure.

The Amoco correlation for wooden trailers is:

Reflected Pressure	Vulnerability of Occupants
5.0 psi	0.1
7.5	0.4
12.0	1.0

The Amoco Refining Facility Siting Reference Manual provides the following additional data for wooden trailer damage as a result of differing reflected overpressures:

Reflected Overpressure	Damage Level	Description of Damage
1.0 psi	Severe damage	Building debris generated
2.0	Partial collapse	Wall and roof failure begins
5.0	Complete collapse	

It can be seen that the Amoco Facility Siting Screening Workbook shows lower vulnerabilities at comparable pressures than the CCPS/API graphs. For example, at 10% vulnerability CCPS/API requires 1.0 psi peak side-on pressure, whereas Amoco requires 5.0 psi reflected pressure (equivalent to approximately 2.5 psi peak side-on pressure). The difference is not as marked at higher vulnerabilities.

The overpressure experienced at the J.E. Merit and Fluor trailers was 2.5 psi peak side-on pressure. This overpressure resulted in the buildings being completely destroyed, with 52% and 100% vulnerability to the occupants.

The impact of differing assumptions is clearly illustrated in the 2002 Facility Siting Revalidation for the trailer location west of the ISOM unit. Using the Amoco Workbook methodology, one congested space on the ISOM unit and nine on the Ultracracker were identified that could potentially effect the trailer. In the event of an explosion, the congested space on the ISOM unit was calculated to produce 3.19 psi reflected pressure (1.54 psi peak side-on overpressure). The congested spaces on the Ultracracker resulted in lower pressures. Based upon a reflected pressure of 3.19 psi, the vulnerability of the occupants was determined to be zero (i.e., less than 5 psi), and therefore zero Individual Risk and zero Population Risk. If the CCPS/API correlation had been used instead, the occupant vulnerability would have been calculated as 25%, resulting in the following calculated risks:

Individual Risk = 2.7 E-05
Population Risk = 1.1 E-03

Although these calculated risks are not high, when considering the trailer occupancy on March 23 they do fall within a zone where risk reduction should be considered. None of the trailers included in the 2002 Facility Siting Revalidation report had calculated risks as high as these risks. If the CCPS/API vulnerability correlation had been used, someone may have questioned the adequacy of the trailer location.

5.12.8.2 Vapor Cloud Explosion Frequency

API RP 752 states that the frequency of explosions should be based upon a company's specific experience. API RP 752 provides some generic industry information guidance for use if data or company-specific experience is not available. This lists the frequency of explosions for various types of refinery process units and includes an average frequency of all process units. For example, catalytic cracking units, such as the Ultracracker, have the highest frequency of explosions. Only catalytic reforming and hydrotreating units have a lower frequency than the average for all types of process units.

The Amoco Workbook refers to the likelihood of vapor cloud explosions data in API RP 752, and then states that:

> *"In order to simplify the risk screening analysis and to help ensure the statistical validity of the database, it was decided that an average unit VCE frequency would be used when evaluating the occupant risk for all buildings within Amoco refineries."*

During witness interviews, the BP Investigation Team became aware of anecdotal evidence of previous incidents involving the ISOM unit and vapor emissions from Blowdown stacks at Texas City. Incident records before 1999 were difficult to locate, and appeared less than complete. Nevertheless there is some reason to believe that the use of site-specific frequency data, if it had been collected and available, would have resulted in higher calculated risks than the use of generic industry data. Even if generic frequency data had to be employed in the absence of reliable site data, the use of process unit-specific frequencies rather than an average frequency would have resulted in higher explosion frequencies at the trailer site due to the proximity of the Ultracracker to the north.

5.12.8.3 Safe Distance

As mentioned earlier, Texas City Refinery has a MOC procedure for siting temporary wooden trailers. An initial screening process considers whether the building may be eliminated from further consideration on the basis of sufficient distance from any process units. Generic "safe distances" have been determined for various building types:

Building Type	Minimum Safe Distance
Wood frame and siding (trailer)	350 feet
Steel frame and siding (sheet metal)	450 feet
Concrete, masonry, brick, or cinder block	700 feet

If a building is to be sited within these minimum safe distances, a facility siting analysis is required. For example, part of the MOC hazard analysis process consists of a Trailer Siting Checklist, which states that, if the trailer is not located at least 350 feet from the process unit, a facility siting analysis must be performed. The first part of the facility siting analysis is another checklist, which is structured so that any "no" answers require further evaluation and potential corrective measures. The site PSM department assists with any additional evaluation that is required.

The rationale for allowing trailers to be sited closer than other building types without a hazard analysis is stated in the Amoco Workbook as:

> *"Data from actual events indicate that trailers tend to roll in response to a VCE, and walls and roofs do not collapse on occupants, resulting in fewer serious injuries/fatalities."*

The basis for these "safe distances" is documented in the Amoco Refining Facility Siting Reference Manual. Firstly, the typical confined volume was calculated to be 200 mscf, using the average from 5 refineries. Using this confined volume, the distance that resulted in a 10% occupant vulnerability for various construction materials was then determined. This approach may not be as conservative as intended for several reasons:

(a) It is based on the less conservative Amoco occupant vulnerability correlation, i.e., 5.0 psi reflected pressure for trailers vs. CCPS/API 1.0 psi peak side-on pressure for onset of casualties.

(b) The typical confined volume data are skewed by the small volumes at Yorktown, Mandan and Salt Lake City refineries. Process units at Texas City refinery are physically larger, and only one out of the ten confined volume examples is smaller than 200 mscf. Larger confined volumes result in higher blast overpressures.

(c) Trailers at Texas City refinery are normally tied down to resist hurricanes, and will flex or roll less in response to explosions.

All of these factors imply that the minimum safe distance for trailers at Texas City Refinery should be greater than the recommended 350 feet from a process unit. Although the trailers involved in the explosion were sited within 150 feet of the ISOM unit, the use of a greater minimum safe distance within the refinery might have made personnel question the suitability of this site.

5.12.8.4 Occupancy

The facility siting analyses for temporary buildings conducted at Texas City site use "annualized" occupancy data, i.e., when calculating risks on a per-annum basis, the duration of the building on site is taken into account. For example, if a trailer will be on site for 3 months, the occupancy is reduced by an additional factor of 4 to reflect the presence of personnel at that location for only one quarter of the year. Under these circumstances, the risks to occupants of temporary buildings may be high, but appear diluted when compared to the risk acceptability criteria.

5.12.8.5 Debris Impact

The CCPS Guidelines recognize that the availability of better tools for estimating occupant vulnerabilities would significantly improve the risk-screening process. In particular it is noted that the current methodology does not take into account the effects of fragments or projectiles from explosions on personnel inside the buildings or in the vicinity. API RP 752 also refers to the hazard to personnel from projectiles. Several of the Texas City casualties were as a result of impact from debris.

Little can be done to protect individuals outdoors from the effects of explosion-induced fragments and projectiles, other than preventing the explosion in the first place or minimizing the number of persons during higher risk operations. However, it is clear that the siting and design of buildings in the vicinity of process units needs to consider the risk of potential damage from debris.

5.12.9 Conclusion

The investigation team believes that any MOC performed would still have allowed trailers to be sited in the area between the ISOM and NDU, due to the assumptions made on the potential frequency of explosion, especially given the custom and practice of using this area for trailer siting.

In addition, it appears that the Amoco workbook uses a less conservative vulnerability when compared with API guidance, which in itself does not appear to provide the degree of safety previously assumed.

5.13 Plant Design, Engineering and Operability

5.13.1 Raffinate Splitter

5.13.1.1 Raffinate Splitter Design

The Heavy Ultraformate Fractionator was modified to become the Raffinate Splitter in 1985 when the Ultraformer was converted to a Naphtha Isomerization Unit. In 1987 the Raffinate Splitter underwent minor changes to improve its ability to split light and heavy raffinate. The unit is a single fractionating column, 164 ft tall with 70 distillation trays (at 2 ft spacing numbered from the top), feed surge drum, fired heater reboiler, fin fan overhead condenser and reflux drum.

The Splitter processes up to 45,000 bpd of raffinate from the Aromatic Recovery Unit (ARU), and separates Light Raffinate from Heavy Raffinate. The feed comes from the ARU to the Feed Surge Drum (F-1101), which provides surge capacity and also allows any water in the feed to be separated from the liquid hydrocarbon. Pressure is maintained by a blanket of natural gas, with excess pressure being vented to the 3-pound system. Any water collected in the drum is drained to the Oil-Water Separator (S-3). The liquid hydrocarbon is pumped from the drum by the Charge Pumps (J-1101/1101A). The discharge from the pumps is heated by recovering heat from the Heavy Raffinate in the Raffinate Splitter Feed / Bottoms Exchangers (C-1104A/B) and additionally by the top convection coil of the Reboiler Furnace (B-1101). It then flows to the Raffinate Splitter tower (E-1101).

Heat for this separation is provided by the Reboiler Furnace (B-1101). The tower overhead is totally condensed by air in the Raffinate Splitter Overhead Condenser (C-1101) and then flows to the Reflux Drum (F-1102), which provides surge capacity. The startup procedure requires that, during startup, pressure is maintained by a blanket of natural gas, and excess pressure is vented to the 3-pound system. Once a level is obtained in the Reflux Drum, the 3-pound system is isolated and pressure is controlled by the Reboiler Furnace firing rate. The liquid is pumped from the drum by the Reflux Pumps (J-1102/1102A), with some returned to the tower as reflux. The rest of the liquid hydrocarbon is cooled by cooling water in the Light Raffinate Cooler (C-1107A/B) and exported from the unit. The bottoms product from the tower is pumped by the Heater Charge Pumps (J-1103/1103A). Some of the pump discharge flows through the Reboiler Furnace (B-1101) and back to the Splitter. The rest of the pump discharge is cooled first in Raffinate Splitter Feed / Bottoms Exchangers (C-1104A/B) and then by cooling water in the Heavy Raffinate Product Cooler (C-1106A/B) and exported from the unit.

About 40% of the total raffinate fed to the unit is recovered overhead as C_5 / C_6 light raffinate and is used as feedstock for the ISOM. The remaining heavy raffinate is used as chemicals feedstock for olefins cracking and for regular unleaded gasoline blending. The Splitter can be run in conjunction with the ISOM or independently when the ISOM is shut down.

The last revision of the Raffinate Splitter process and instrumentation drawings (P&IDs) reflects the current design, with one exception. The drawing of the Raffinate Reflux Drum (no. B-4550-G-2622-1 rev.16, dated June 2003) does not correctly depict the 1½-inch vent valves around the reflux drum relief valve (RV-1002G). The drawing shows only one valve, whereas there are three valves in series on this bypass line around the relief valve. This discrepancy did not contribute to the incident.

The operating envelope of the unit is available electronically in a document called "ISOM Operating Envelope" revision no.4, dated February 26, 2004.

5.13.1.2 Raffinate Splitter Instrumentation

The basic process for the Raffinate Splitter was modified in 1998 to improve performance and is now based upon:

- Bottoms product flow to tankage controls level in column and provides preheat to feed.
- Overhead product flow to tankage maintains flooded reflux drum.
- Reboiler heater firing rate controls column pressure.

In line with generally accepted practice in the 1950s, the Splitter instrumentation is relatively simple. Although most parameters have high and low alarms, there are no trips other than low low fuel gas pressure and low fuel gas flow to the Reboiler Furnace. The Splitter does not have a comprehensive emergency shutdown (ESD) system. The accuracy and sensitivity of the instruments and alarm settings were investigated, as they may pertain to cause of the incident.

A list of all instrumentation on the Raffinate Splitter is contained within Appendix 22.

5.13.1.3 Relief Valve Location

The Splitter relief valves (RV-1001G A/B/C) are located at a similar level as the overhead condenser. API Recommended Practice 521 "Guide for Pressure Relieving and Depressuring Systems," (ref. 4) Section 4.3.2.4, addresses liquid emissions for Relief Valves (RVs) that relieve to the atmosphere through a blowdown stack. The standard states:

> *"To minimize the possibility of a release of flammable liquid, all safety RVs that vent vapor to the atmosphere should be located so that the valve inlet connects to the vapor space of vessels and lines. In some instances, additional safeguards are warranted. ... The potential for such a situation can be greatly minimized by locating safety RVs at a point in the process system where the probability of liquid occurring at the safety RV inlet is considered negligible because of factors related to time and the system's liquid capacity."*

The Splitter RVs are located on the overhead line near the inlet to the overhead condenser, which is an air cooled exchanger (see Figure 5-4). The only way that liquid can occur at the RVs is by overflowing the top of the tower. Loss of the reflux/overhead product pump does not result in liquid at the RVs, as all condensing stops once the condenser fills with liquid.

If the tower has adequate instrumentation and levels of protection for shutdown, locating the relief valves near the condenser is perfectly acceptable. Placing tower RVs at or just above the level of the condenser is a common practice in the industry, and reflects the low perceived likelihood of liquid carryover. RV installation and removal for maintenance is typically much easier on a tall tower, such as the Splitter, when the relief valves are located near the condenser inlet. API RP 521, Section 4.3.2.4, also states:

> *"All possibilities that might allow liquid to gain entrance to the pressure RV should be determined, and appropriate safeguards should be taken to prevent this occurrence."*

The incident might have been less severe if the RVs had been located at the top of the tower. When the RVs lifted, the tower pressure was 21 psig. The head of liquid in the overhead line together with the tower pressure exceeded the RV set point pressure. This high pressure caused the very high liquid flow rate to the blowdown drum. The tower pressure itself did not increase, which allowed for sustained vaporization as more liquid was lifted overhead (see Section 5.3). If the RVs had been at the top of the tower, the tower top pressure would have had to reach 40 psig before the RVs would have lifted. This would have moderated the vaporization, which in turn would have reduced the liquid flow through the RVs. A lower liquid rate to the blowdown drum could have prevented liquid overflow from the top of the stack.

Although in the event of overfilling the Raffinate Splitter, locating the RVs at the top of the tower appears inherently safer than locating them near the condenser inlet, it may not be appropriate for all distillation towers. Each case should be evaluated on its merits to determine the scenarios that would allow liquid to pass through an RV that is normally expected to relieve vapor. For these scenarios, appropriate safeguards and levels of protection should be taken to prevent liquid relief.

5.13.1.4 Raffinate Splitter Modification

The site MOC policy is based upon industry practice and applies to changes in process equipment, process technology, process control and instrumentation, safe operating limits and relief/safety systems. Two Splitter MOCs are of particular note:

- Conversion to operate with a flooded reflux drum
- De-rating the Splitter operating pressure from 75 psig to 40 psig

Flooded Reflux Drum

The Splitter was modified in 1998 to operate with a flooded reflux drum using heater firing rate to control pressure. This change required that the 3-psig vent system, used to purge non-condensables at startup, be isolated during normal operation. Use of the 8-inch vent valve to vent noncondensables and control pressure excursions during startup had become local practice, because, if the 3 psig vent system was used, it was not opened at the beginning of the startup (as specified in the procedure). It is not clear why the procedures were not reviewed to determine if this practice was appropriate, or why it was not brought to the attention of engineering for their approval. The Investigation Team was unable to find any documentation relating to the design intent of the 8-inch vent valve.

The MOC (# R-ISOM-98-09) to convert the Splitter to a flooded reflux drum included a "What If"/Checklist hazard review rather than the more rigorous Hazop technique. The review considered:

- Process control and instrumentation
- Loss of level in the reflux drum
- Flooding the reflux drum (and isolating PT-5002)
- Loss of pressure control and overpressure of the tower

The following safeguards were identified: tower pressure alarms, furnace tube skin temperature alarms, process trends, operator training, and the relief system. The review recommended the following actions, which were completed:

- Reconfigure LAH-5004 as LAL-5004 and retag LAL-5010 as LALL-5010 in DCS.
- Set P-5002 to hold output on bad measurement.
- Set F-5007I to hold output on bad input; put in HI output clamp.
- Reconfigure LSH-5004 as LSL-5004 (alarm on low level).
- Relocate PT-5002 to inlet of overhead condenser.

Tower Derating

After inspection revealed thinning of the Splitter due to external corrosion under insulation, the vessel pressure rating was lowered. As a result, the RV set points were reduced from 70 psig to 40, 41, 42 psig in January 2003. (The normal operating pressure of the Splitter is 10 – 20 psig). The MOC (# ISOM-2003-005) to derate the tower included a “What If” hazard review and a PHA Checklist for Vessel/Exchanger Maximum Allowable Working Pressure (MAWP) Rerate.

The “What If” hazard review considered pressure spikes above 40 psig resulting in tower rupture. Safeguards were identified as the relief system and operator awareness. No actions were generated. The hazard review does not appear to have considered liquid carryover into the overhead line, and that hydrostatic head in the line without any appreciable pressure in the Splitter tower itself would be sufficient to lift the RVs. The subsequent Hazop revalidation in 2003 did not address this MOC.

The MAWP PHA Checklist has 9 questions concerning pressure testing, relief valve capacity and set pressure (see Appendix 29). However, the checklist does not direct the team to consider many other factors: modes of operation, overpressurization scenarios, two phase flow, previous incidents, or whether the system relieves to an atmospheric vent or flare. There is no indication that the team considered the increased likelihood of flow to the Blowdown Drum due to the narrower operating envelope, the presence of liquid or two phase flow, or if the change would affect the design basis for the relief system. The relief valves had been previously studied during a site-wide relief valve study in 1985, but the Investigation Team was unable to find any study that addressed the downstream Blowdown Drum and Stack. Another study by an external engineering agency, Litwin Engineering, apparently stated that the RVs and stack were adequate, but full documentary evidence could not be found. This item was referred to as closed in the ISOM Unit Hazop.

Section III, "Requirements for Change," of the site MOC documentation identifies the need for a Pre-Startup Safety Review (PSSR) and updating of procedures. There is no indication from records that either of these action items was completed. The ISOM startup procedure (SOP 201.0) used on March 23 incorrectly stated that the set point of the tower relief valves was still 70 psig. The Training Coordinator confirmed the action to update the operating procedures was complete on February 24, 2003. The MOC was not authorized to "Commission" until March 3, 2004 by the Asset Coordinator. Subsequently the Operations Superintendent certified that all procedures were current and up to date.

5.13.2 Blowdown Drum

5.13.2.1 Industry Design Standards

The BP Investigation Team did not identify specific guidance on the safe operation of atmospheric releases sent to blowdown systems. The main industry standard providing design principles for pressure relief and disposal systems is API RP 521 "Guide for Pressure Relieving and Depressuring Systems." It states (Page 32) that:

> *"In many situations, pressure-relief vapor streams may be safely discharged directly to the atmosphere if environmental regulations permit such discharges. This has been demonstrated by many years of safe operation with atmospheric releases from properly installed vapor pressure relief valves. ... The decision to discharge hydrocarbons or other flammable or hazardous vapors to the atmosphere requires careful attention to ensure that disposal can be accomplished without creating a potential hazard or causing other problems, such as the formation of flammable mixtures at grade level or on elevated structures, exposure of personnel to toxic vapors or corrosive chemicals, ignition of relief streams at the point of emission, excessive noise levels, and air pollution."*

Section 4 of RP 521 outlines the general principles and design approach for determining the most suitable type of disposal system. This section covers fluid properties, atmospheric discharge, disposal by flaring, disposal to a lower pressure system and disposal of liquids and condensable vapors. Section 5 covers principles and guidelines for the design of disposal systems, including depressurizing calculations and relieving rates.

The Investigation Team found no evidence to suggest that blowdown stacks at the site had been evaluated against the recommended practices for selection and design of relief systems detailed in RP 521. The Splitter relief system was not designed to handle liquid relief through the relief valves.

5.13.2.2 Amoco Design Standards

Texas City Refinery was owned and operated by Amoco prior to the 1999 merger with BP. As such, the plant and equipment was designed and operated to Amoco and industry engineering codes and standards.

In 1977 Amoco issued Process Safety Standard (PSS) No.6 "Flare, Blowdown, Pressure Relief, Vent, and Drain Systems for Process Units." Although several subsequent revisions to PSS No.6 have been introduced, references to blowdown stacks did not change significantly. The 1986 revision of PSS No.6 stated, *"If still required, existing blowdown systems will be replaced with connections to depressure via another processing unit, a hydrocarbon-recovery system, or a flare when the size of the existing facility is outgrown."* A later 1994 revision added *"... or when major modifications are made to the existing facility."*

The current version of PSS No.6 states that, *"...1) New blowdown stacks which discharge directly to the atmosphere are not permitted. 2) When the size of the existing facility is outgrown or when major modifications are made to the existing facility, existing blowdown systems which are still necessary should be replaced with connections to depressure via another processing unit, hydrocarbon-recovery system, or flare."*

Amoco Corp. Engineering Specification A CV-PLT-DISP-E, "Civil Plant Disposal Systems Engineering Specification," dated 1998, provides technical requirements for design of drain, vent, pumpout, blowdown, and sanitary sewer systems. It states that, *"Discharge of hot hydrocarbon (warmer than 150^0F) shall be accomplished by releasing into a blowdown system where hydrocarbon is quenched with utility water. (a) Blowdown drum and stack shall be provided to discharge vapor to recovery system or flare and liquid into a process drainage system; (b) Blowdown systems shall not discharge directly to atmosphere."*

The Raffinate Splitter blowdown drum and stack was installed in the 1950s, prior to the development of Engineering Specification A CV-PLT-DISP-E. No major modifications have been made to the ISOM unit since 1994 that would require the blowdown drum to be replaced by a flare system in line with PSS no.6. Two opportunities to tie into a flare were not taken when modifications were made to adjacent process units. In 1995, when a new flare system for the adjacent AU-2 unit was installed, and in 2002 when the NDU flare line was routed close to F-20, opportunities for replacing F-20 with a flare system were not implemented.

5.13.2.3 F-20 Design

The Blowdown Drum & Stack (F-20) was originally built in the early 1950s and designed to handle hydrocarbons from one relief line during unit upsets or shutdowns. The original design documentation indicating the capacity of F-20 could not be found. A "like-for-like" replacement of the blowdown drum, stack and internals occurred in 1997 due to corrosion.

F-20 contains internal baffles to assist in disengaging any liquids from the hydrocarbon vapors. Quench water is designed to cascade down over the baffles to help cool any hot hydrocarbon vapors. A steam connection was provided to the drum section below the baffles for extinguishing fires at the outlet from the stack.

Any liquid hydrocarbons released to F-20 should pass through a “gooseneck” seal leg to a closed drain system, then to the West Oily Water Separator, where the oil is skimmed and pumped to slops. The liquid flow to the closed drain system was designed as gravity feed during relief situations. A pump (J-14A) is provided to pump out liquids from F-20 during planned shutdowns and routine maintenance activity. There is no indication of it having been intended for emergency use during, for example, a relief event, and does not have an automatic start capability.

F-20 is equipped with a local level glass to monitor the level and a high level alarm (LAH-5020), which will alarm when F-20 is close to flowing over the top of the gooseneck.

5.13.2.4 F-20 Modifications

Since commissioning, design and operational changes to F-20 have added two additional inlet lines for dry and wet hydrocarbons from the ISOM.

In 1957, the blowdown drum was relocated approximately 200 ft to the northwest corner of the ISOM unit battery limits to eliminate a fire hazard, which prevailed under certain wind conditions. Three nozzles were installed on the drum to ease new line tie-ins in connection with the Ultraformate splitting facilities. These nozzles were retained when the blowdown drum was replaced in 1997.

Despite this additional load, there does not appear to be a documented capacity analysis of the design. The relief valves were studied during a site-wide relief valve study in 1985, but no study addressed the downstream Blowdown Drum and Stack. Another study by an external engineering agency, Litwin Engineering, stated that the RVs and stack were adequate, but full documentary evidence could not be found. This item was referred to as closed in the ISOM Unit Hazop. The derating of the Splitter relief valves did not trigger a review of the blowdown drum capacity.

The Clean Streams Project was established in mid-2002 to address benzene waste NESHAP (National Emissions Standard for Hazardous Air Pollutants) compliance issues throughout the refinery. A MOC (# ISOM-2002-026) was initiated in November 2002 to install new wet and dry maintenance drum systems, leaving only relief valves from the Splitter discharging to the F-20 Blowdown stack. The pipework tie-ins to permit later installation of this modification were made during the ISOM TAR in January 2003. The Process Hazard Analysis was completed and 42 action items generated, but the project was cancelled in November 2003.

The Clean Streams Project also briefly considered the option of rerouting the F-20 blowdown streams to a flare, as an alternative to diverting the benzene containing streams to segregated wet/dry closed systems. The project proposed using F-20 as a flare knockout drum. Under this option both the maintenance streams and the emergency relief streams would have been rerouted to the AU2 flare. However, due to the lack of an up-to-date relief valve study for the ISOM unit, there was insufficient time before the January 2003 TAR to perform a study in order to verify if the F-20 blowdown drum was adequately sized to act as a flare knockout drum. The option was therefore not pursued beyond the investigative phase.

A witness stated that a substantial cost was estimated for implementation of initiatives for handling both benzene maintenance and emergency relief streams across the refinery. Refinery management elected to use the available capital funds to address benzene environmental compliance issues and implement a policy of no deliberate discharge of oil to the refinery sewer. The team could find no consideration of process safety in this project, which was evaluated for environmental reasons.

Subsequently an ISOM relief valve study was scheduled for completion by March 31, 2005, but had not been commenced at the time of the incident. A line item was also added in early 2005 (before the incident) to the Project Database System (PDS) as a potential future capital project for removal of the F-20 blowdown drum.

The blowdown drum experienced severe internal corrosion which damaged some of the baffle plates observed during the 2003 turnaround, and it was decided not to repair and replace them and they were removed. This decision was taken at a turnaround meeting, and the basis for the decision, was that the blowdown drum would be removed from service as part of a future Clean Streams environmental project. A MOC was not initiated for this change. No consideration appears to have been given to the designation of the blowdown drum as Safety Critical Equipment (SCE).

None of these changes (or ISOM modifications) over the years were considered "major modifications" and triggered F-20's disuse in line with PSS no. 6. Two opportunities for converting F-20 to an inherently safer alternative relief system (a flare) were not chosen when modifications were made to adjacent process units.

5.13.2.5 Effect of Pumpout Pump (J-14A)

It has been suggested that if the Pumpout Pump (J-14A) on the Blowdown Drum had been started when the relief to the Blowdown Drum occurred, then liquid hydrocarbon would not have been released from the top the blowdown stack.

5.13.2.5.1 J-14A Operation Overview

The liquid hydrocarbon pumpout is a gathering system utilizing the F-20 Blowdown Drum and the J-14A Pumpout Pump to eliminate liquid hydrocarbon levels from unit towers and drums following a unit shutdown, i.e., during maintenance activities, not process upsets or startups.

J-14A is a 115# steam driven reciprocating pump. Steam is used to power the pump, to give a means of controlling tower and drum levels in case of an electrical power failure. The design of this pump, and necessity of warming the steam cylinder head before use, means it cannot be used in an emergency. J-14A design capacity is 149gpm with a 6-inch suction line and 2 ½-inch discharge line.

5.13.2.5.2 J-14A Modifications

J-14A's original design intent was for pumping out the unit when it was shut down for maintenance and not for emergency relief during a process upset. An "Idea in Action" suggestion was submitted in 1997 to pipe F-20 to the J-450 A/B pumps and have them operate off high level automatically in the F-20 to reduce the chance of getting oil into the sewer system from the gooseneck overflow. Another suggestion was also made in the same year to replace the J-14A pump with the J-450 and/or J-450A to reduce maintenance and eliminate the chance of getting hydrocarbons in the dry weather sump. Neither suggestion was progressed on the grounds of poor cost benefit. These pumps have a 5 hp motor and are rated at 35 gpm, about one quarter of the capacity of J-14A and too small to have had any beneficial effect during the March 23 incident.

5.13.2.5.3 Use of J-14A During the Incident on March 23

When the relief valves opened at 13:14 hrs, an estimated 46,000 US gallons of hydrocarbon liquid was discharged to the blowdown drum in six minutes (an average flow rate of 7,670 gpm). The flowrate of liquid from the blowdown drum to the sewer ranged from 1,800 to 5,000 gpm as the level in the drum and stack rose. Approximately 2,000 gallons was discharged from the top of the blowdown stack.

The design capacity of J-14A is 149 gpm. If it had been running, it would have pumped out less than 900 gallons from the blowdown drum within the 6-minute time frame (i.e., about 2% of the total liquid volume released to the blowdown drum). This would have reduced the quantity of liquid that overflowed the blowdown stack, but the steam-driven reciprocating pump takes several minutes to start pumping.

Taking into consideration that J-14A's intended purpose is for maintenance preparation of equipment and the amount of time it takes to get J-14A heated up with steam to begin operation, the release would have been complete, or near complete, prior to J-14A coming online. Therefore J-14A would not have made a major impact in pumping out any of the released material.

5.13.3 Control Room

The main control board for the Raffinate Splitter is in the NDU/AU2/ISOM Control Room. This control room was built in the late 1950s and subsequently modified internally for the installation of DCS equipment, and, as such, does not reflect current thinking on control room design to facilitate operator alertness. Several aspects of the building's human factors are less than optimal, for instance it is noisy and the lighting is poor. Hard surfaces on the walls and floor, and the proximity of the kitchen facilities and several offices make for a relatively noisy environment. Lighting levels appear to be kept deliberately low to avoid annoying reflections on the control board screens. The location of soft drinks and snack provisions for sale within the control room provides further potential distraction.

A safety meeting, attended by some 15-20 persons, was held within the control room at 12:45 hrs on March 23. A meeting of this nature in the confines of a relatively small control room would be distracting at the best of times, let alone during a critical phase of a process unit startup. A number of potentially distracting external telephone calls were also routed through the ISOM control board extension during the startup.

5.13.4 Hazardous Area Classification

The most recent hazardous area classification (HAC) drawing (# B-2985-E-792-B1 rev 0) for the ISOM unit found is dated July 1991, and based upon API RP 500 (ref. 9) Section A. A note describes all refinery streets and avenues as nonhazardous. This drawing indicates that the entire area around the catalyst warehouse bounded by W-6th Street (on the west side), Avenue G (south), pipetrack south of Ultracracker/north of Avenue F (north), and the ISOM battery limit (east) is nonhazardous. The ISOM unit ISBL is shown as Class 1, Division 2, Group C & D, requiring classified (flameproof) electrical equipment

The HAC was not updated when API published a 2nd edition of RP 500 in 1997. The main change resulting from the 2nd edition was the treatment of closed piping systems with potential point sources for release, such as flanges and manual valves. These point sources were changed from nonhazardous to classified for flammable and highly volatile liquids (HVL). This may have affected the area of the piperack between the ISOM and the trailers/catalyst warehouse, where a distance of 10 ft around each point source (20 ft around HVL) would be Class 1, Division 2, to a height of 2 ft. These additional classified areas would not have impacted the trailer site.

Another note on the HAC drawing states that, "any venting of classified materials to atmosphere and its surrounding area of 5 ft radius shall be Class 1, Division 1, as are below grade areas, such as pits and sumps." The F-20 blowdown stack is not separately identified, but appears to be just within the ISBL of the ISOM unit. The 5-ft radius is only applied to the top of the blowdown stack. The nonhazardous area to the north, comprising Avenue F and its shoulders, is immediately adjacent to the blowdown drum. This is the area where one or two pickup trucks were parked, including one with a running engine observed by a witness.

Another hazardous area classification drawing covers the area to the west of the catalyst warehouse and the later addition of the NDU. This drawing indicates that the Class 1, Division 2, Group D area encroaches over W-5½th Street into the area where the Contech I & E, James Timec and Hahn & Clay trailers were located on March 23. These trailers were not equipped with intrinsically safe electrical equipment.

Although the HAC drawings delineate hazardous and nonhazardous areas, some of the earlier drawings are not to scale, making the exact transition from one area to the other difficult to accurately interpret. The use of multiple HAC drawings in the ISOM/NDU area also does not aid understanding. On the ISOM unit itself there are no signs or barriers to distinguish where, for example, battery limits commence, which roads are controlled or uncontrolled, etc.

5.13.5 Conclusions

The Splitter is a simple separation process with a basic control system and atmospheric relief system. The associated risks could be lowered with more complex controls and a flare system. The relief valve location, while convenient for inspection and maintenance, may have changed the risks. It did not appear to be clearly understood that modifications increased the risks and resulted in a narrower operating envelope, dependent upon human attention for safe operation.

Although the Raffinate Splitter is arguably one of the simplest process units in the refinery, the absence of an automatic emergency shutdown system places reliance upon sound operating practices and procedures to maintain operating parameters within the safe upper and lower limits of the operating envelope. Nevertheless, the design was typical of many older fractionating towers in the industry, and was relatively easy to operate safely if normal standards of operation were observed. The Raffinate Splitter had been started up safely on many previous occasions when the operating procedures were followed correctly to avoid high heatup rates and high furnace outlet temperatures. To overflow the tower required feed/rundown imbalance, high temperatures, and 3 to 4 hours of operator inattention.

The blowdown system could also be safely operated, but the risks inherent in this service were clearly not well understood. Previous Hazops had identified concerns around the adequacy of the relief system, but these issues were closed. A new Hazop action item in 2003 recommended a relief system review, but this had not commenced by the time of the incident. There is no evidence that anyone envisaged the likelihood of liquid overflow as happened on March 23rd, although there were general concerns on the system. No specific evidence was found that the system had been validated against the principles within API 521. Although an option was identified to tie the relief lines into a flare system, this option was not progressed even though opportunities existed.

5.14 Equipment Testing

5.14.1 In-Situ Testing

Equipment in the Raffinate Splitter area of the ISOM unit was tested in-situ in the as-found condition to evaluate functionality, and to check signal output from instruments. The equipment consisted of:

- Control valves
- Level transmitters
- Level switches
- Flow transmitters

All tests were performed according to protocols agreed to by BP, CSB, OSHA, and plaintiff experts. The ISOM unit was without DCS and utilities during the tests, and it was necessary to test each device locally with hand held meters and bottled compressed air (where needed for instrument air connections). A third party instrumentation company, Industrial I&E, handled all instrument connections, measured instrument output, and provided control valve input signals. Tests were conducted between 21 June 2005 and 18 July 2005. Below is a summary of the results of tests organized by type of equipment.

Control Valves

Seven control valves were tested from 21-23 June 2005. Initial tests consisted of stroking the valves and conducting a 5-point test (0, 25, 50, 75 and 100% positions) using a handheld loop calibrator to input a 4-20 mA signal. Instrument air was provided by a compressed air cylinder and pressure regulator. The control valves tested were:

ARU Raffinate to Feed Drum:	**FCV-5003**
Raffinate Feed to Tower:	**FCV-5000**
Reflux Drum vent to 3# System:	**PCV-5002**
Reflux flow to Tower:	**FCV-5007**
Light Raffinate jump-over to Heavy Raffinate**:**	**PCV-5012**
Heavy Raffinate to Reboiler Furnace:	**FCV-5005**
Raffinate Tower Heavy Raffinate Rundown**:**	**LCV-5100**

All of these control valves functioned properly, with two exceptions. PCV-5002 stopped functioning mid-way through the test. It was successfully stroked open and closed, but did not move thereafter. During a subsequent protocol when DCS operation was restored, PCV-5002 functioned normally throughout the test.

FCV-5007 functioned but would not fully open after the initial stroke. It closed and opened to about 75% successfully on all attempts, but would not open more than 75%.

Subsequent to restoring DCS operation, three of the control valves were stroked under DCS control. The valves were PCV-5002, FCV-5000 and LCV-5100, all of which functioned properly under DCS control. In addition, FCV-5000 and LCV-5100 were subjected to an additional test under DCS control to observe any movement between 0% and –6.9% DCS output settings. There was no movement of either valve between 0% and –6.9%, the closed position for both valves.

Level Transmitters

Level transmitters on the Raffinate Splitter tower and associated Feed Surge Drum and Reflux Drum were tested. The transmitter designations are:

Feed Drum: **LT-5007**

Raffinate Splitter Tower: **LT-5100**

Reflux Drum: **LT-5008**

LT-5100 was a displacer cell instrument with a pneumatic signal output. Both drums used differential pressure transducers to measure liquid height. Tests were performed from 27-29 June 2005 using the raffinate remaining in the tower and drums.

All level transmitters functioned properly. The tower level transmitter, LT-5100, had a local display connected to the pressure-to-current (P/I) transmitter that provided an indication of level on a 0-100% scale. The output signal to the DCS functioned properly, which was verified later during tower deinventory when the DCS system was working.

The DCS was programmed with alarms for each of the level switches. The DCS alarms settings were checked when the system was repowered. The alarm settings were:

Instrument	Alarm Settings (% of range)			
	High-High	High	Low	Low-Low
LT-5007 Feed Drum	80	70	45	35
LT-5008 Reflux Drum	----	----	98	----
LT-5100 Raffinate Splitter Tower	----	72	45	35

The as-found feed drum level was 30%, and it was not in alarm. The Reflux Drum was at 97.7% and showing a low alarm. The Tower was at 99% and showing a high alarm.

Level Switches

Five level switches were tested, which were:

Feed Surge Drum (F-1101): **LSH-5006**

Raffinate Splitter (E-1101): **LSH-5102**
LSL-5104

Reflux Drum (F-1102): **LSL-5004**
LSLL-5010

Tests were performed from 9-15 June 2005 using the raffinate remaining in the tower and drums. None of these tests could be completed due to problems with block valves and drain valves for the level switches. Several block valves would not seal sufficiently to allow liquid level in the level switch housing to be reduced. A blocked drain valve prevented bottom filling for one switch. The functional tests could not be performed.

One electrical lead to LSL-5104, the tower low level switch, pulled loose from the wire lug when handled by the instrument technician as part of the testing protocol. It is unknown if this wire had proper continuity prior to being pulled loose. A replacement wire lug was installed in preparation for deinventory of the tower.

Level switch status was checked by a continuity test. As-found switch status is shown in the following table. Once the DCS system was restored to operation, the as-found alarm status of each of the switches was checked, which is also shown in the table below. "Normal" alarm status in the DCS indicates that a device is not in alarm. The alarm status was consistent with the liquid level in all cases, except the Raffinate Splitter tower high level, LSH-5102, which should have been in alarm.

After deinventory of the tower and drums, the alarm status of all of the level switches were again checked. Neither of the Raffinate Splitter tower level switches changed status during deinventory, indicating a fault in both switches. The reflux drum level switches changed status properly. No determination could be made for the feed surge drum, as the liquid level was already below the high level switch.

Level Switch No.	Switch Status	Alarm Status
LSH-5102 Raffinate Splitter E-1101	Closed	Normal
LSL-5104 Raffinate Splitter E-1101	Closed	Normal
LSH-5006 Feed Surge Drum F-1101	Closed	Normal
LSLL-5010 Reflux Drum F-1102	Closed	Normal
LSLL-5010 Reflux Drum F-1102	Closed	Normal

Flow Transmitters

Eight flow transmitters were tested. All of these flow measurement devices used orifice plates with pressure taps mounted in the orifice flanges. Differential pressure transducers supplied 4-20 mA output signals to the DCS. The tested flow meters were:

Feed from ARU (South Feed): **FT-5001**

ARU Raffinate (North Feed): **FT-5003**

Raffinate Splitter Flow from Feed Drum: **FT-5000**

Heavy Raffinate Rundown: **FT-5015**

Heavy Raffinate to Reboiler: **FT-5005**

Reflux flow to Raffinate Splitter: **FT-5007**

Light Raffinate Rundown: **FT-5106**

Fuel Gas to Heater: **FT-5008**

Tested were conducted from June 30 – July 8, 2005. All differential pressure transducers were found to have pressure communication from the taps at the orifice plates to both high and low pressure sides of the differential pressure sensor (FT-5008 was not tested for pressure communication since the fuel gas system was depressured, but block valves were verified to be open). None of the differential pressure transducer manifolds had leak-through from high to low pressure sides. All flow transmitters functioned properly, with the exception of FT-5003. The P/I on FT-5003 initially provided only a 20 mA output regardless of pressure input, and subsequently went to 0 mA output. FT-5003 appeared to be functional during the incident as the signal was trending, but the P/I did not function properly when tested after the incident.

Subsequent to restoring DCS operation and after the Raffinate Splitter section was de-inventoried and depressured, the indicated flow rates for FT-5000, the Raffinate Splitter tower feed, was displayed on the DCS as about 5 MBPD, with full range being 48.19 MBPD. Concurrently, FT-5015, the heavy raffinate rundown, was indicated as about 2 MBPD for a range of 40.86 MBPD.

Pressure Transmitter
The calibration of the Raffinate Splitter Pressure Transmitter (PT-5002) was tested on 31 August 2005. The transmitter functioned properly throughout the full range.

5.14.2 Shop Testing

Certain items of equipment were removed from the Raffinate Splitter and tested by third party instrumentation companies, Groquip and Stress Engineering Services, at their workshops to evaluate functionality. All instruments were transported to the relevant workshops under the scrutiny of ESI, who were charged with ensuring chain-of-custody. The equipment consisted of:

- Relief valves
- Level transmitter
- Level switches
- Control valves

All shop tests were performed according to protocols agreed to by BP, CSB, OSHA, and plaintiff experts. Tests were conducted in November and December 2005. Below is a summary of the results of tests organized by type of equipment.

Relief Valves
Five relief valves were tested on 1 November 2005. Each valve was pop tested three times to check consistency, and the pressures were recorded when the valves started to lift and when they popped. The relief valves tested were:

	Set Pressure (psig)	Start to Lift Pressure (psig)	Pop Pressure for Each Test (psig)
Raffinate Splitter Overhead: **RV-1001GA**	42	37 to 38	41, 41, 41
Raffinate Splitter Overhead: **RV-1001GB**	41	36	41, 40, 40
Raffinate Splitter Overhead: **RV-1001GC**	40	35	39, 39, 39
Reflux Drum: **RV-1002G**	70	66, 68 on last test	72, 68*, 68*, 72
Light Raffinate Rundown: **RV-1199G**	175	165 to 167	170, 170, 171

* These two tests were not a full pop.

All five relief valves performed within their specified limits. The Light Raffinate Rundown relief valve (RV-1199G) had a very small leak at 50 psig upon the first test. After the first pop, the relief valve did not leak at pressures below 160 psig.

After the tests, the valves were dismantled for inspection. The Raffinate Splitter Overhead relief valve internals were very clean and looked good as new. The Light Raffinate Rundown relief valve sealing surfaces were dirty upon inspection. This is most likely the cause of the very small leak that occurred at 50 psig.

Level Transmitter

The raffinate splitter level transmitter LT-5100 was tested for function and linearity using liquids with three densities: water (density 1.0 $g/cm^{3)}$, low sulfur diesel fuel (density 0.8349 g/cm^3 at 60°F), and Viscor leak detection fluid 130BT (density 0.7593 g/cm^3 at 60°F). Highly linear relationships between liquid height and the level sensor output signal were obtained over the operating range with all three test fluids, see figure below. As expected, indicated level varied in proportion to fluid density. The local readout meter on the Rosemont transmitter functioned normally and gave linear responses between liquid heights and indicated level.

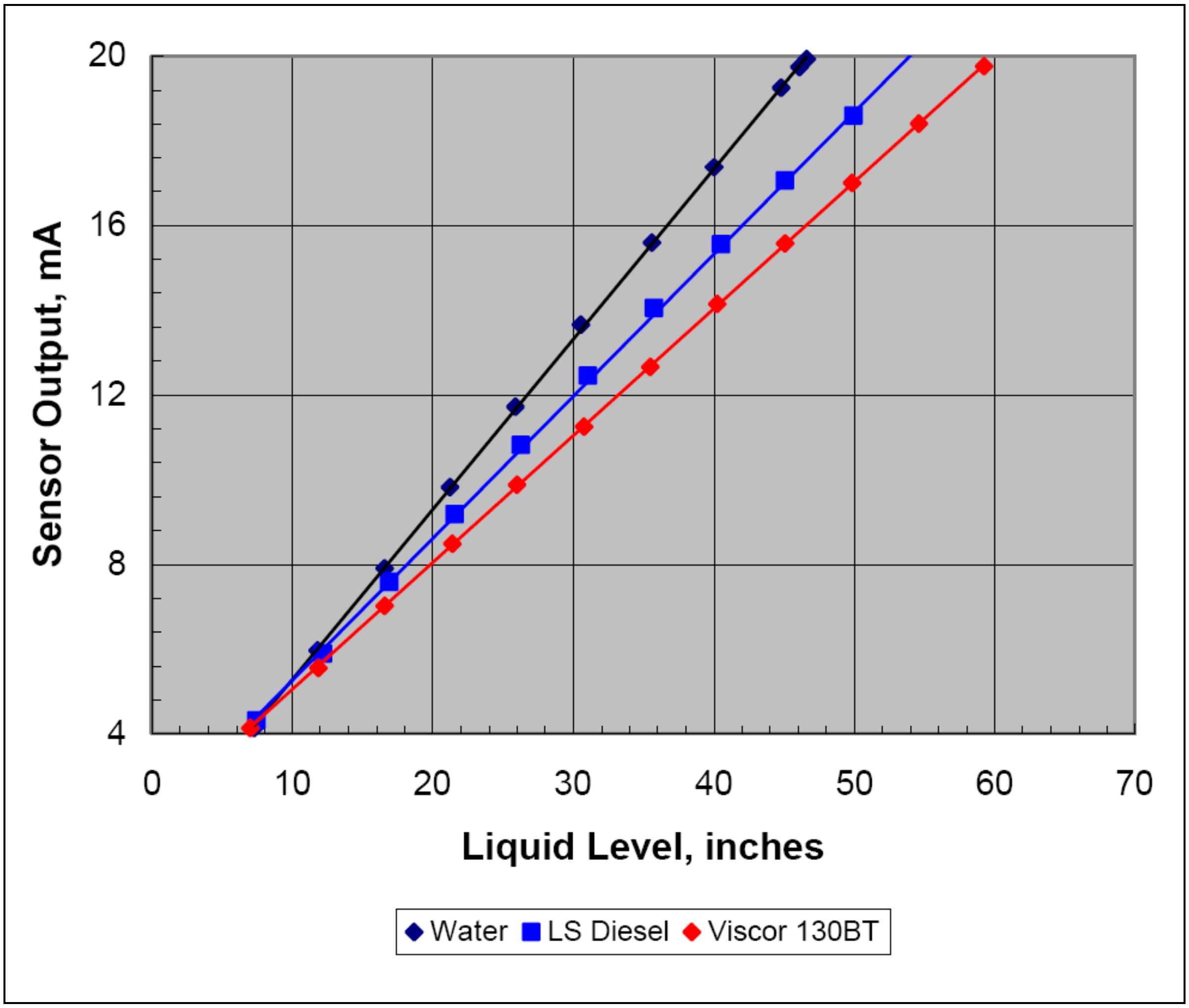


Figure 5-12

LT-5100 Tower Level Sensor Test

Level Switches

The raffinate splitter high level alarm switch, LSH-5102, and low level alarm switch, LSL-5104, were bench tested using Viscor leak detection fluid 130BT. Neither level switch changed state when filled and emptied of liquid. Upon disassembly, LSH-5102 did not change state when its float was raised and lowered either by hand or using water. LSL-5104 did not change state when water was used to raise and lower its float, but it did change state when operated manually, pulling its float downward below its normal at-rest position in air.

The blowdown stack high level alarm switch LSH-5020 was disassembled and inspected, but not tested since it was damaged by fire. A small hole was found in the top of its hollow metal float, which contained 650 ml of liquid. The float did not float when submerged in water. The float mechanism and mercury switch were mechanically operable and the switch moved properly when the float was raised by hand.

Control Valves

Control valves LCV-5100, FCV-5000, and PCV-5002 were bench tested for function and leak rate after removal from the ISOM unit. Shop air and a control 4-20 mA signal were supplied to the valves. A displacement measurement instrument was used to measure valve stem position changes during the three point testing. A video camera directed inside the inlet flange recorded motion of the valve plug. LCV-5100 and FCV-5000 operated normally. PCV-5002 functioned normally in all cases except that in a few trials it did not open completely (stem motion of approximately 1.2 inch, compared to approximately 1.4 inch in other instances).

During leak rate testing, FCV-5000 was found to be bubble tight at nitrogen gas pressures of 20 and 70 psig. LCV-5100's leak rate using nitrogen was approximately 150 ml/s at 4.7 psig. When tested using water, its leak rate was approximately 60 ml/min (0.5 BPD) at 18 psig and 275 ml/min (2.5 BPD) at 75 psig. PCV-5002's leak rate was approximately 140 ml/s at 7 psig when tested using compressed nitrogen gas.

5.15 Maintenance/Mechanical Integrity

5.15.1 Maintenance Program

The Texas City Refinery maintenance program consists of a combination of planned preventative maintenance and non-routine repair in the event of breakdown. ISOM pressure vessels are subject to Risk Based Inspection (RBI). The planned preventative maintenance (PPM) covers rotating machinery, control and instrumentation systems, relief valves, and inspection of pressure vessels and pipework.

The SAP maintenance database used at Texas City refinery is primarily an accounting system, and it does not have the functionality of a custom designed maintenance management system such as Maximo. It is difficult to discern from records on an individual work order basis whether work was actually done to address each work order. The only indication is invariably that a charge has been made against a work order, but the charge could be for parts and materials, and/or craftsman's time. PPM work orders are generated automatically by SAP.

5.15.2 Raffinate Splitter

The Raffinate Splitter is covered by the Texas City Refinery maintenance program. Prior to the planned temporary outage for catalyst replacement in February/March 2005, the unit was operating satisfactorily, with no reported control or instrumentation problems that the Investigation Team was able to find. The last turnaround was in 2003 and the next was planned for 2008.

OEM and vendor manuals for inspection, testing and maintenance of process equipment and instrumentation on the Splitter are available from a variety of sources. The absence of a single database or library sometimes makes it difficult to locate a particular document or procedure.

Work order notifications on the ISOM unit are handled in one of several ways: sometimes an operator sends an e-mail to the Asset Coordinator; sometimes the Shift Supervisor writes the notification; and sometimes the Shift Supervisor sends a note to the Asset Coordinator. The notification is then forwarded to the Maintenance Planner, who creates a work order and determines the necessary logistics. Work orders are prioritized and issued to craftsmen. There is no signoff on jobs that are completed. The maintenance work order process is detailed in Appendix 30 for the example of an ISOM instrument problem.

The majority of work is planned and completed via the SAP Maintenance Order (MO) work process described in Appendix 30. The following data are recorded in SAP:

- “Date Created”, i.e., date the work order was entered into SAP.
- “Date of Confirmed Hours” represents the date that someone charged specific labor hours.
- “Technically Completed” represents the date the work order was closed.
- Cost of parts, materials and labor.

Not all work orders have confirmed hours entered into SAP, which makes it difficult to determine if and when work was actually completed. When the work order is closed as technically complete, no further purchase orders, requisitions, or warehouse materials can be charged against the work order. The technically complete date is normally entered within a few days of work completion, but can be longer, depending on how busy the individual is. The SAP data for the Splitter indicates three PPM work orders that were technically completed on May 25, 2005, i.e., post incident.

Urgent requests for troubleshooting and repair are handled on an “as needed” basis, without being entered into SAP as an MO or being scheduled. If materials need to be ordered or if it is a major job, an MO will be generated for the work after it commences to capture it in SAP. If it is a minor job with minimal/warehouse materials required, the craftsman’s time is confirmed/charged to a blanket work order. A Rule of Thumb used is if the work requires less than two hours of a craftsman’s time and/or is estimated to cost less than $1,000, it is handled through a blanket work order.

As a result it is difficult to verify the details of “minor” work at a later date. The blanket work order does not contain any details of the individual tasks actually performed.

In fact, due to the use of an accounting database, SAP, there was a general paucity of documentation on maintenance details (e.g., instrumentation calibration) that would be expected if a fully functional maintenance management database was employed.

A search of the SAP and Documint (formerly Loveland) databases was conducted, looking for all relevant work orders over the last two years for the Raffinate Splitter relating to alarms, control valves, and relief valves, as follows (see Appendix 31):

5.15.2.1 Sensors, Switches and Alarms

Texas City Refinery had a program of periodic PPMs to check alarms on the Raffinate Splitter. The following list indicates frequency and date of confirmed hours booked to the work order in SAP:

- Raffinate Splitter tower (LSH/LSL) 12 monthly 09/16/2004
- Raffinate Splitter charge drum (LSH/LSL) 6/12 monthly 10/12/2004
- Raffinate Splitter reflux drum (LSLL/LSL) 6 monthly 10/13/2004
- Annual Critical Alarm Calibration 12 monthly 01/17/2005

There are 6 critical alarms on the Raffinate Splitter recorded in the refinery Documint records system. All pertain to shutdowns of the Raffinate Furnace (B-1101). The following list indicates frequency and date of the next calibration:

- Furnace Charge low flow trip (FSL-5000) 12 monthly 02/27/2006
- Furnace Reboiler circulation low flow (FSL-5005A) 12 monthly 02/27/2006
- Furnace fuel gas manual trip (HVLC-5009) 12 monthly 02/28/2006
- Furnace fuel gas K.O. drum (LSH-5009) 12 monthly 01/11/2005
- Furnace fuel gas low pressure (PSL-5019) 12 monthly 01/11/2005
- Furnace fuel gas low low pressure (PSLL-5016) 12 monthly 02/28/2006

It appears that two of the critical alarms (LSH-5009 and PSL-5019) were not tested during the temporary outage of the Splitter. Documint indicates that a turnaround is not required to perform testing of these critical alarms.

Some of the Splitter alarms also received non-routine maintenance, as follows:

- Raffinate Splitter tower
  - Tower high level (LAH-5102) 11/03/2003
  - Tower high level (LAH-5102) 06/09/2003
  - Tower low level (LAH-5104) 06/09/2003
- Raffinate Splitter reboiler furnace
  - Furnace fuel gas low low pressure (PALL-5016) 11/08/2002
- Raffinate Splitter charge drum

  - Charge drum high level (LAH-5006) 03/18/2005

The Raffinate Splitter high and low level alarms required attention in 2003 because they were not working. The Splitter was started up on June 16, 2003, just a few days after the two work orders, dated June 9, 2003, were created. Labor costs were charged to these work orders on October 20, 2003, but it is not clear when the work was physically completed. The work was signed off as technically complete on October 22, 2003.

The Splitter was shut down and restarted on October 29, 2003. Four days later another work order was created on November 3, 2003, for LAH-5102. This was signed off as technically complete on May 17, 2004. No labor costs were charged to this work order, and it appears that a blanket work order was used to cover this work. SAP does not record when the work was completed.

5.15.2.2 Control Valves

Some of the control instrumentation also received non-routine maintenance, as follows:

- Raffinate Splitter tower
  - Tower pressure (PCV-5002) 03/03/2003
  - Tower level (LCV-5100) 12/31/2002
- Raffinate Splitter reboiler furnace
  - Furnace fuel gas pressure (PCV-5019) 04/07/2003
- Raffinate Splitter charge drum
  - ARU feed (North) (FCV-5003) 05/01/2003
  - ARU feed (PCV-1650) 05/16/2004

No work orders were found in the SAP database over the last two years for the pressure control valve (PCV-5012) or the 3# vent valve (H-5002).

5.15.2.3 Relief Valves

The Raffinate Splitter tower overhead RVs were reset during the 2003 turnaround following derating of the tower, as follows:

- RV1001GA 42 psig 01/25/2003
- RV1001GB 41 psig 01/25/2003
- RV1001GC 40 psig 01/25/2003

The springs, spring washers and O-rings were renewed on RV1001GA & B in 2003, but the spring material was not changed. RV1001GC only required a new O-ring. The PCMS notes stated that the BP test/repair data sheets were not filled out correctly.

The Raffinate Splitter reflux drum RV was replaced and calibrated in 2003 also:

- RV1002G 70 psig 01/29/2003

The Splitter tower overhead relief valves appeared to operate satisfactorily during the incident, lifting around 40 psig, apparently due to the hydrostatic head of liquid in the overhead line.

5.15.2.4 Level Transmitters

A revised Job Note (no.05-009R Rev.1) was issued on March 10, 2005, for additional scope to the temporary outage. This included replacement of the upper and lower isolation block valves on the Raffinate Splitter tower level controller (LT-5100). This transmitter had needed repairs in the past, and the isolation valves were known to pass, preventing repairs while the splitter was operating. The Job Note was approved by the Reliability Supervisor and Operations Superintendent, and the work was completed prior to the startup. There were no work orders or other reports that the level transmitter was not functioning properly immediately prior to the temporary outage. No repairs were performed on the level transmitter during the outage. The Day Shift Board Operator and other operators and supervisors stated that they were not aware of any instrumentation problems prior to the startup.

The tower level transmitter (LT-5100) worked as designed during the startup on March 23. During the packing of the tower on the night shift, the level transmitter clearly indicated the liquid level rising in the base of the tower. When the Reboiler flow control valve (FCV-5005) was opened to pack the reboiler circuit, the level transmitter correctly indicated a falling level, which then gradually rose again in line with the incoming feed and absence of any outflow. The level indicator's associated level alarm alarmed at 72% (approximately 5′5″ height above tangent) and was acknowledged by Operator A. Shortly afterwards, Operator A reduced the feed rate to the Splitter and the tower base level continued to rise at a slower rate. Within four minutes of the level reaching 100% (about 10 feet in the base of the tower), Operator A closed the feed to the Splitter.

At the start of day shift on March 23, the level indicator was showing 100%. The level indicator is not designed to show levels greater than 100%, and is not designed to function when the upper instrument tap is flooded. The indication slowly drifted downwards as more feed and heat was added to the tower with no outflow. After 3½ hours of adding feed at a rate of 20,000 BPD, and a bottoms temperature of 304˚F (vs. 275˚F called for in the startup procedure), the day shift board operator began removing liquid from the tower for the first time, when the flow of heavy raffinate to tankage was established. At this point, the level transmitter indicated 80%. (Section 5.8.4 explains the effect of decreasing liquid density, caused by heating of the liquid, on the indicated level when the upper tap is flooded.)

5.15.3 Blowdown Drum (F-20)

The Blowdown Drum has been frequently inspected since 1955, revealing a history of significant internal corrosion requiring repair to baffles and support beams. Repairs were carried out in 1959, 1977, 1981, and 1985. F-20 underwent a major rebuild in 1997 when the stack, drum and internals were replaced. This replacement involved engineering support from the Amoco Worldwide Engineering & Construction (WE&C) organization.

Several examples of potential deficiencies in equipment maintenance and mechanical integrity on F-20 have been found. Specifically, these were:

- Upon its last inspection in 2003, baffles within F-20 had corroded and collapsed, and it was decided not to repair them. A MOC was not initiated for this change to the blowdown drum, which is designated as safety critical.
- Service water is supplied to F-20 to cool any hot process streams that may be diverted to the blowdown or pumpout systems during an upset or in a unit shutdown. This quench system had been out of service for some time, and no work orders for repair were identified. An alternative manual supply of service water was available.
- Finally, the 6-inch drain connection from the gooseneck to the closed drain system had a small leak. After the incident it was found cracked, but it is not known if this occurred in the explosion. A job note was identified to rectify corrosion to this line as part of the work scope for the outage, but it was not repaired. A new section of pipework was fabricated, but the blowdown drum could not be taken out of service, as the Desulfurizer was circulating during the temporary outage.

The Blowdown Drum has a critical alarm (LSH-5020) to protect the relief valve headers against backpressure when relieving into a high liquid level in the drum. The Documint records system shows the wrong service description (Cooling Tower Sump Low Level) for this alarm. However, the description “F-20 Blowdown Drum high level” clearly applies to this instrument. The confusion appears to stem from another critical alarm (LSL-5020) that is located on the cooling tower sump.

The level alarm on the Blowdown Drum was included in the refinery program of periodic PPMs. The frequency and date last checked from Documint were as follows:

- Blowdown Drum (F-20) (LSH-5020) 6/12 monthly 02/28/2005

Documint requires a 12-month test frequency, and a 6-monthly PPM is set up in SAP to check LSH5020 (see Appendix 31). The Documint records show that LSH-5020 was tested seven times between November 1999 and February 2005, and on each occasion the level switch passed the test in its “As Found” condition.

There was a regular task on a weekly checklist for the operators to “flush out F-20 high level alarm” using water, although it appears that steam was used on occasion. This was allegedly because rust/scale could block the taps of the level gauge. Although the inspection history shows significant corrosion within the blowdown drum, the Documint critical alarm data indicates that this did not apparently affect the proper operation of high level alarm (LSH-5020). The most recent completed weekly checklist found was dated October 13, 2003, and it appears that regular testing stopped being documented at that time. However, some operators appear to have continued the tests, and the DCS alarm log shows that LSH-5020 activated on numerous occasions in 2004, and on January 29, February 12, 14, 25, and March 20, 2005. This last test clearly shows that the level switch worked three days before the incident.

The local level gauge on the blowdown drum is monitored every shift by the operators on their rounds and manually recorded in the PRIDE database. Records stopped at the time of the temporary outage in February/March 2005, but the level gauge appeared to be working satisfactorily prior to the shutdown.

The high level alarm switch (LSH-5020) was disassembled and inspected, but could not be tested since it was damaged by fire. A small hole was found in the top of its hollow metal float. It is not known when this hole occurred. Following the fire on March 23, 2005, the level switch, and the liquids within it, had been left undisturbed for several months before it was tested in November 2005. However, the float mechanism and mercury switch were still mechanically operable and the switch moved properly when the float was raised by hand. As indicated above, the level alarm activated when the operators last tested the switch on March 20, 2005.

5.15.4 Safety Critical Equipment

In general, process safety information (PSI) was available for the Raffinate Splitter and blowdown drum equipment and instrumentation and is archived in a variety of databases and systems.

There is no single database or register of safety critical equipment (SCE) critical to the management of major accident hazards. These are the items of equipment that ensure the prevention, control and mitigation of the major hazards, and therefore are required to have a high reliability and availability before and during a major incident. Typically SCE includes RVs, flares, vent stacks, knockout drums, relief header valves, emergency shutdown systems, critical alarms, high integrity protection systems, safety instrumented systems, critical corrective action systems, control systems, UPS, deluge, and quench systems. Many of these SCE will require preventive maintenance (PMs) to ensure their reliability and calibration.

The blowdown drum is designated as SCE. A decision was made in 2003 not to repair the corroded baffles in the blowdown drum. This should have received additional review prior to the final decision being made. No evidence of additional review has been identified nor of the decision for taking the service water system out of service.

5.15.5 Internal Inspection

After deinventorying and steaming to gas-free the Raffinate Splitter, the manway doors were opened for initial internal inspection on August 12, 2005, without full entry into the tower. The tower was then prepared for entry, and internal inspection was performed on August 17, 2005.

The internals were observed to have a thin coating of what appeared to be carbon and/or iron oxide, and there was no sign of any debris or sludge. The fractionating trays that were visible appeared to have suffered no damage or distortion, with good joints around the tower periphery and tray section to tray section. A few valves were stuck open on the trays, and a few valves were dislodged and/or missing. These effects appeared to increase slightly on the higher trays, but are in line with normal experience following several years' operation.

5.15.6 Conclusion

The maintenance program for the raffinate splitter and blowdown drum was generally up to date with no backlog of work orders, although it is difficult to discern from documentation on a work order basis whether work was actually done to address each work order.

Three planned preventative maintenance (PPM) work orders had not been technically closed out at the time of the incident, but involved jobs that were being worked on as part of the temporary outage.

When decisions are taken on the deployment of available resources for inspection, testing and maintenance, the identification of SCE allows management to optimize resources without deferring PMs or other maintenance tasks associated with SCE. Although most of the information is generally available, the absence of a single database or register with links to the required maintenance and testing practices does not facilitate performance monitoring and understanding of overall status.

The F-20 blowdown drum is designated as safety critical equipment (SCE), and several aspects of its maintenance did not appear to be up to SCE standards.

The lack of damage to the internal trays in the Raffinate Splitter indicates that the tower internals were in a satisfactory mechanical integrity condition.

5.16 Emergency Response

It is good practice for procedures to provide clear instructions for emergency shutdown. This should include the conditions under which emergency shutdown is required, the assignment of shutdown responsibility to ensure that emergency shutdown is executed in a safe and timely manner, and explicit evacuation and notification requirements. These emergency response instructions should also be routinely practiced through interactive gun drills or other training exercises. Safe-off procedures provide basic emergency instructions, including emergency shutdown when necessary, to the ISOM operators. Local policy (# PSM – 4.4) at

Texas City also requires that unit specific emergency response information be communicated in the form of a Process Safety Overview to employees, contractors, and visitors.

The raffinate splitter startup procedure does not contain explicit instructions on the process upset conditions which should have triggered stopping the startup and/or initiating emergency shutdown procedures. Operators were late to shut off the fuel gas to the furnace when they lost control of the Raffinate Splitter. The feed to the Splitter was not shut down, even after the explosion, and did not stop until power was lost around 14:45 hrs. In addition, no evacuation alarms were sounded.

5.16.1 Emergency Response Plans

The Emergency Response Procedure (ERP) and Emergency Response Matrix (ERM) focus on the immediate steps that operations personnel (asset operator and board operator) must perform when a Major Emergency Event takes place that results in an emergency shutdown or idling of the plant. The Emergency Response Actions within the ERM specify who should perform which activity, and were seen as similar to gun drills.

The board operator is responsible for executing all ERP steps unless otherwise stated. One of the critical primary responses to an emergency requires the board operator to evacuate nonessential personnel. The means of evacuation is not expressly stated in the procedures, but, as the board operator should not leave the control board, it can be inferred that the warbler alarm in the control room should be activated.

MOC and incident investigation actions had noted a lack of gun drills, as had the Operator Competency Assurance Model (OCAM) audit. While gun drill formats had been devised and training provided, they had not been carried out.

Local policy HSE A-7 is the Emergency Action Plan for the Texas City site, and provides procedures for employee response during a plant emergency. It includes evacuation, employee accountability, organizational structure, line of responsibility, and training. This policy was communicated to everyone by e-mail and via VTA in May 2004. It is not clear though that these plans were actually practiced on a routine basis to ensure thorough understanding of them.

5.16.2 Evacuation Alarm

The ISOM unit, like other process units at Texas City, was equipped with an emergency warbler horn to notify facility personnel, maintenance personnel, and others of a developing emergency. Types of emergency action should be indicated by a five-second blast of the unit's emergency warbler horn. Signals are as follows:

One blast	Test or resume work
Two blasts	Stop all hot work
Three blasts	Evacuate unit (except essential unit personnel)

Continuous blast   Total unit evacuation (all personnel)

HSE Policy A-7 covers sounding the alarm in the event of a serious incident, described as fire; uncontrolled hydrocarbon releases, which could result in an explosion and/or liquid spills; and uncontrolled toxic chemical or hazardous material release which could result in health hazards. In particular, the policy addresses operation of emergency warbler evacuation alarms on the relevant process unit to alert persons in the immediate and adjacent areas. Responsibility for sounding the warbler alarm is not expressly stated within TCS HSE Policy A-7, but the Raffinate Emergency Response Procedure indicates that the Board Operator is responsible for evacuating nonessential personnel from the unit. There is a weekly requirement to test emergency alarms and record the details in unit logbooks. Process Safety Overviews inform temporary workers and visitors of unit evacuations and use of the warbler alarm.

Operator E observed heavy vapors discharging from the Blowdown Stack at 12:40 hrs, when the 8-inch chain-operated vent valve was opened. The more experienced Operator C told Operator E not to be concerned, and the Board Operator was not informed. The emergency warbler evacuation alarm at the ISOM unit was not sounded. Again at 13:15 hrs, when vapors and liquid were reported discharging from F-20 after the relief valves opened, the emergency warbler evacuation alarm at the ISOM was not sounded. From interviews it is evident that Operators C and E clearly heard the RVs lifting. Operator C told the other outside operators to leave the area, and was running towards the blowdown drum to warn other personnel when the explosion occurred.

The results of the weekly emergency alarm test were not recorded in the ISOM unit logbook as required by HSE Policy A-7.

5.16.3 Conclusions

Responsibility for sounding the emergency evacuation alarm is not expressly defined, although the investigation team felt that it was clear that the Board Operator is responsible for evacuating nonessential personnel in an emergency. No warning of the impending startup was given to adjacent process units and personnel, and no alarms were sounded prior to the explosion. The ISOM warbler evacuation alarm was not sounded when vapors were emitted from the blowdown stack, nor later when the relief valves opened and hydrocarbon liquid and vapors were seen discharging from the stack, although Operator C ran towards the blowdown drum to warn personnel in the area. Outside operators did not inform the board operator of the need from their evidence to sound the alarm. Ultimately, the absence of supervision on the unit meant there was no one in charge to reinforce evacuation procedures, including sounding the warbler alarm.

5.17 Previous Incidents

Requirements from applicable regulations such as OSHA 1910.119 and EPA Risk Management Program (RMP) and Amoco internal requirements have been incorporated into Process Safety Standard No. 38, “Process Incident Investigation.” It gives guidance on incidents to be investigated, initial response, incident investigation team makeup, interviews, reporting findings, and followup. The Incident Investigation policy (SH-ADM-11) spells out the Texas City site's approach to incident investigations, which is in compliance with PSS no. 38.

The Process Safety Management (PSM) Manager plays the key role in coordinating incident investigations. He reviews the makeup of incident investigation teams for all Level A incident investigations, actively participates in the investigation process as requested, reviews the investigation draft report for all Level A investigations, determines which Level A or B investigations are classified as OSHA 1910.119 or EPA RMP incidents, and maintains the records for all investigation reports classified as OSHA 1910.119 or EPA RMP incidents. The PSM Manager also schedules with the site's Process Safety Committee any process safety related incident followups.

The Process Safety Committee (PSC) reviews all process safety related major incident investigation reports and applies appropriate lessons learned. A simple trend analysis of incidents was performed and reported monthly, and consisted of number, nature (property damage, environmental, near-miss, etc.), location (process unit), negative event (injury, spill, etc.) and first aid cases. It is not apparent how this was used by site management for intervention.

It is apparent that numerous process upsets (such as pressure excursions and lifting of RVs) are not being reported and therefore not being investigated or included in any trending analyses conducted or PSC reviews.

5.17.1 Raffinate Splitter and Blowdown Drum

There have been a number of previous incidents (hydrocarbon leaks, vapor releases, and/or fires) involving the Raffinate Splitter and/or F-20 Blowdown Drum. Interviewees made references to several previous incidents, and the Investigation Team identified the following from document searches:

- March 8, 1991, incident involving the Preflash Tower relief valve discharging to F-20 blowdown drum.
- April 15, 1991, leak from the Ultrafiner (Desulfurizer Section) Effluent Cooler to F-20 blowdown drum.
- May 27, 1992, incident when Stabilizer relief valve discharged to F-20 blowdown drum.
- Two separate incidents on July 21, 1992, involving relief valves on both the Deisohexanizer (DIH) Tower and the Flash Drum lifting to F-20 blowdown drum.
- February 12, 1994, incident involving vapors from F-20 stack, following level control problems with the Deisohexanizer (DIH) Tower.
- February 18, 1994, incident involving vapors from F-20 stack during startup of Preflash Tower and Deisohexanizer (DIH) Tower.

- February 27, 1994, incident when Stabilizer relief valve discharged to F-20 blowdown drum.
- May 8, 1995, incident when the 8-inch chain-operated vent valve was left open during a startup of the Raffinate Splitter.
- December 20, 1995, incident when oil mist believed to have come from F-20 blowdown stack was found on cars parked at the ISOM unit.
- March 22, 1995, incident involving vapors from F-20 blowdown stack disturbing workers at the Ultracracker.
- June 2, 1996, incident involving blowthrough a Water Collection Pot to F-20 blowdown drum.
- September 1, 1997, incident involving Deisohexanizer (DIH) Tower relief valves lifting to F-20 stack when 3# vent system blocked in.
- January 13, 1999, involving venting an estimated 13,000 lbs of hydrocarbons through F-20 from the Penex Reactor.
- April 19, 1999, incident when the Product Separator relief valve discharged to F-20 blowdown drum.
- Two separate incidents on April 22, 1999, involving venting of hydrocarbons through F-20 from both Penex Reactors.
- February 9, 2002, Scrubber tower relief valve lifted, releasing 56 lbs vapor to F-20.
- January 9, 2003, unintentional release of liquid hydrocarbons to F-20 blowdown drum during temporary outage preparation.
- March 25, 2004, Deisohexanizer (DIH) Tower relief valves lifted to F-20 blowdown drum during upset due to power failure.
- February, 2005, incident with liquid hydrocarbons leaking to the sewer during the deinventory of the Splitter.

Note that the Investigation Team identified other incidents on the ISOM unit, but these did not involve the Raffinate Splitter and/or the Blowdown Drum.

None of these incidents which involved F-20 included liquid hydrocarbons overflowing the stack and collecting at ground level.

Incident records before 1999 were difficult to locate, apart from logs from the site Fire Department and environmental release calculations. The severity of many incidents was difficult to assess. The incident investigation records reviewed appear less than complete, with recommendations of corrective actions focusing on training and procedures, with little examination of the adequacy of operating philosophy. For example, procedures were revised following the potentially serious incident on May 8, 1995, when the 8-inch vent valve was inadvertently left open. The Investigation Team was unable to find any documentation for the design intent of this valve.

Incident records after 1999 are generally captured in the Traction database and were more complete. A few near-misses are also recorded in Traction (243 in the whole of the West Plant in 2004), although they were not complete enough to provide effective early warning and learning opportunities.

There is not an effective system, nor are the behaviors in place, to report or investigate process upsets, such as relief valves lifting during a startup, although local policy (SH-ADM-11) requires that they should also be reported in Traction and investigated.

Two previous incidents on the ISOM unit involved departures from the recognized operating procedures. In 2000, an investigation of high temperatures on the Recycle Gas Compressor recommended training in retrieval of latest up-to-date procedures and use of pre-startup meetings. In 2002, investigation of a runaway reaction on the Penex Reactor recommended:

- Training all operators on the location of unit procedures and the need to use procedures for all tasks
- Use of gun drills and other training techniques that will train operators in potential unit upset situations
- Operator review of safe-offs on a more frequent basis than the current practice of one year

Neither of these incidents involved the Splitter or Blowdown Drum, but the corrective actions were to apply generally to the AU2/ISOM/ARU complex.

5.17.2 Previous Startups

When the Raffinate Splitter is shut down, the cooling liquids on the 70 distillation trays drain down into the tower base for some time. It is therefore not unusual to have a high level indicated on the tower level transmitter (LT-5100) prior to starting the unit again if the tower has not been drained before startup. A level indication of 100% is well below the bottom tray and is approximately 10 ft 3 in. above the tangent line of the tower. Over the last 5 years, several startups have commenced with liquid levels in the range of 9 – 35 ft above tangent. There have been 18 startups of the Raffinate Splitter over the past five years in addition to the startup on March 23, 2005 (see section 5.10.6).

All but two of these were warm startups; the splitter had not been fully drained prior to restarting. Of these startups, some form of process upset, i.e., pressure spike within 10% of the RV set point, occurred during 5 startups. Only two of these previous startups resulted in RVs lifting, and in both of these cases only vapors were released to F-20. The highest level seen (35 ft) covered the bottom 9 trays but was well below the feed inlet at tray 31. None of these startups resulted in a fire or explosion type incident. The key difference between these startups and the startup on March 23, 2005, was that the Heavy Raffinate rundown flow was started before or shortly after the feed was introduced to the tower on all of the previous startups. The longest delay in starting the rundown previously was 46 minutes, with most averaging about 15 minutes, compared to more than 3 hours on March 23.

Since the Raffinate Splitter was rerated from 70 psig to 40 psig in 2003, there have been two other occurrences where the Splitter pressure exceeded 40 psig, the Overhead RV settings, during startup. Although the RVs relieved pressure to the blowdown drum and stack, the vapors dispersed without further incident. There is also evidence from the PI data system that on some previous startups the 8-inch chain-wheel valve, in parallel to the Overhead RVs, was opened temporarily to control Splitter pressure below the RV set points. On these occasions, other than dispersal of vapors from the blowdown stack, there was no further incident.

The distinguishing characteristics of a good startup, where the maximum pressure is controlled well within the relief valves set point, are:

- Start Heavy Raffinate rundown before/as soon as feed started
- 3# system open to purge noncondensables
- Slow heatup rate (not exceeding 50˚F per hour)
- Low reboiler outlet temperature (not exceeding 275˚F)

By contrast, abnormal startups have the reverse characteristics and experience pressure excursions. The start of Heavy Raffinate rundown for the March 23 startup was so late, compared to other abnormal startups that the tower filled to an excessively high liquid level and overflowed due to vaporization at the high temperatures. The liquid overflow out of the top of the tower actually led to the overpressurizing of the RVs, not the pressure inside the Splitter itself. The lack of reporting of abnormal startups made it difficult to determine whether control system or procedural changes were required and limited the effectiveness of MOCs and Hazops, including 5 yearly revalidations.

It is unclear how cognizant the MDL, Superintendent, engineering staff and Shift Supervisors were of the previous startup history, but some of the previous incidents involving the blowdown drum and process upsets were not fully investigated nor documented with corrective actions identified to prevent reoccurrence. ISOM management/supervision also appeared unaware of the narrower operating envelope and increased risk of relief valves lifting due to liquids in the event of liquid overfilling of the tower following the tower derating. There appeared to be no effective feedback loop to capture the lessons learned from previous incidents and process upsets into operating procedures and training programs.

5.17.3 External Incidents

The Process Safety Committee (PSC) is also charged with reviewing lessons learned in the industry, and disseminating process safety information throughout the Texas City site.

Quarterly Safety Bulletins (QSB) are routinely reviewed by the PSC to identify any gaps related to existing standards, policies, or practices. Any gaps or concerns raised by the review are addressed by developing action items to address the deficiencies. These action items are then tracked to completion by utilizing the PSM action item tracking system. The Quarterly Safety Bulletins are also sent out via e-mail to all personnel on the site. Copies of historical QSBs are available on the PSM website.

The *Process Safety Beacon,* published by the Center for Chemical Process Safety (CCPS), is a monthly one-page document that covers the breadth of process safety issues. Each issue presents a real-life accident, and describes the lessons learned and practical means to prevent a similar accident in our plants. This publication is sent out to all BP personnel at the Texas City site on a routine basis.

The HSSE Lessons Learned Library is a web-based library that allows an individual access to lessons learned in the industry, both at BP and at other companies. Lessons can be researched under various categories, such as MIA, HIPO, HiPlus, non-BP incident, Manufacture safety alert, or QSB. Lessons Learned can be subscribed to by interested personnel, and are sent out via e-mail on a weekly basis.

Process Safety Booklets highlight potential hazards in refineries and petrochemical plants and related operations, and ways and means of correcting or eliminating them. These booklets, available via the PSM website, cover many topics, including Hazards of Water, Hazards of Air and Oxygen, Safe Furnace and Boiler Firing, Safe Ups and Downs for Process Units, Hazards of Electricity and Static Electricity, Hazards of Steam, Safe Handling of Light Ends, Safe Operation of Refinery Steam Generators & Water Treating Facilities, Engineering for Safe Operation, Hazards of Nitrogen and Catalyst Handling, Hazards of Trapped Pressure & Vacuum, Tank Farm and (Un)Loading Safe Operations, Hazardous Substances in Refineries, and Integrity Management Lessons.

The Texas City Site engineering community also develops and distributes via e-mail *"Engineering Lookouts*," covering pertinent engineering information that is usable in the everyday job of personnel working in the plant. Copies of historical Engineering Lookouts are available on the PSM website.

While there are some systems in place, such as Quarterly Safety Bulletins (QSB) and the Process Safety Committee (PSC) to import learning from outside Texas City, there did not appear to be any effective process to learn and implement lessons from significant incidents outside the Texas City site. There was little evidence that accepted BP group programs were in place, nor had that incident learnings from other refineries, such as ladder modifications following a fall from height, been absorbed.

5.17.4 Conclusions

The trend of previous startups since the Raffinate Splitter was derated in 2003 indicates that there is a narrower operating range for pressure excursions, and therefore greater likelihood of the relief valves lifting. Because of the poor communications (reporting in particular) within the ISOM, no one was aware of the complete trend around the startups or was able to paint a complete picture of the relationship between engineering and the operating practices on the plant. This in turn indicates a potentially greater risk around the blowdown drum. However, the operating envelope of the unit is well within the range where, although minor vapor releases could be envisaged, it would be unreasonable to anticipate major liquid carryover. There should have been more focus on training, gun drills and the presence of supervision during startups following the derating. Control system modifications could have been considered to reduce these risks by minimizing the scope for human error and mitigating the narrower operating envelope.

5.18 Audit Programs

The ISOM unit had received many audits and assessments as part of the Texas City site program over recent years, including:

- PSM audits
- Getting HSE Right audit
- Safety theme audits (such as Control of Work, and "Big 4")
- Operator Competency Assurance Model (OCAM) audit
- ISO 14001 audit

5.18.1 PSM Audits

Amoco Process Safety Standard no.2.13, "Guidelines for Refining Process Safety Management External Assessments," outlines the purpose, approach and format for the three yearly PSM external assessments undertaken at the Texas City site.

BP's Refining SPU has developed a PSM Assessment Protocol to provide consistency globally. The protocol is divided into two sections: the "Management System Assessment" portion focuses on the facility process safety management systems (e.g., delineation of responsibility, policies, procedures, documentation requirements, etc.), and the "Verification" section focuses on verifying that policies and procedures within these systems are being practiced at the unit level.

External PSM audits were conducted at the Texas City site in 2001 and 2004. These audits focused primarily upon management systems, not on verification that policies and procedures were actually being practiced.

Appendix 32 highlights some of the principal findings from other process units that indirectly applied to the ISOM unit. Two categories of action item were raised: "safety" action items addressed gaps in delivering PSM performance targets, and "operability" items applied to opportunities for continuous improvement in PSM systems.

2001 PSM Audit

Process Hazard Analyses (PHAs) and Incident Investigations on the ISOM unit were audited as part of the 2001 PSM audit. There were no major findings on the ISOM. However, findings on some other topics indirectly affected the ISOM unit. One of the principal findings was that some operating procedures were not current on those process units audited, and a general recommendation was made to audit procedures on all other process units. This was closed out on the basis that procedures would be reviewed during the 5-year HAZOP revalidation. This was performed in 2003 for the ISOM unit, but the derating of the Splitter, and the consequent updating of the relief valve set point in the startup procedure, was not addressed in the revalidation.

Other findings of relevance to the ISOM unit addressed permitting of ignition sources, closure of MOCs, PSSR after turnarounds, and emergency/evacuation exercises.

2004 PSM Audit
As part of the 2004 PSM audit the following topics were audited on the ISOM unit: PHAs, Operating Procedures, Contractors, Pre-Startup Safety Reviews, Mechanical Integrity, Safe Work Permits and Incident Investigations. There were no major findings on the ISOM, although some findings on other topics indirectly affected the ISOM unit. General findings of relevance to the ISOM unit addressed training of newly assigned supervisory staff and engineers, and zero tolerance for PSM noncompliance and timely closure of action items.

5.18.2 gHSEr Audit

The framework for the BP Group's HSE management system is titled "getting HSE right" (gHSEr), and comprises 91 expectations organized under 13 elements. Sites are normally audited every three years against these mandatory expectations. An internal gHSEr audit of the Texas City site was conducted in 2004.

The ISOM unit was not audited as part of the 2004 gHSEr audit, and there were no specific ISOM findings. Several general gaps applying to the whole site were identified. The principal gaps were the ad-hoc nature of trending and analysis, and the lack of engagement of the hourly workforce in development of procedures and periodic self-assessments. Other gaps included formalizing risk assessments and JSAs, improving incident reporting, independence of incident investigations, timely closure of action items, and corrosion due to feedstock/product changes.

A concern was raised regarding little use of the gHSEr audit results to drive HSE action plans. The BP Investigation Team could find no evidence of formal action items to address the gaps, and most employees at the site appeared unaware of the gHSEr audit.

5.18.3 Other Audits

A Control of Work review was conducted in May 2004. This review addressed site practices related to BP's Golden Rules of Safety, such as permit to work, energy isolation, ground disturbance, confined space entry, working at heights, and MOC. Three primary areas of concern were raised:

- Inconsistent application of task risk assessment due to unclear understanding of JSA.
- Wide use of nitrogen without appreciation of the risks and necessary control measures.

- Small lifts did not receive appropriate level of review, and inspection of rigging equipment was inadequate.

An Operator Competency Assurance Model (OCAM) audit was conducted and identified the lack of gun drills to ensure emergency preparedness of the ISOM crews.

An external ISO 14001 audit was conducted in October 2004. The audit report did not contain any ISOM-specific issues, but identified two general weaknesses:

> *"Management must make their expectations related to facility environmental risks clear. The total impact of the facility on the environment, and mechanisms to reduce those impacts must be consistently understood; even for those impacts that are within regulatory limits or those risks that may not be regulated."*

> *"By not robustly addressing issues identified through inspections and audits, and ensuring that a preventative element is included in the corrective action, management is not taking advantage of the opportunity to prevent undesirable outcomes. Management must ensure that when environmental concerns are recognized, the mechanism employed to address the concern allows the root cause(s) to be identified and appropriate actions to be taken to eliminate future recurrences (i.e. preventive actions) where appropriate across the site."*

The site also had a program of self-audits, some of which were conducted on the ISOM unit.

In January 1999 an audit of Recommended Good Practices addressed Isomerization, Light Ends and Hydrogen Sulfide, and identified actions concerning updating of P&IDs, and light ends training for supervisors. Operating procedures, instrumentation checks, environmental release/incident reporting, relief system capacity, and other training issues, including gun drills, were identified as satisfactory, with no action required.

A "Big 4" audit (Hot Work, Confined Space Entry, Authorization to Work, and LockOut/TagOut) was conducted on the ISOM unit in November 2003. Findings involved improper form filling, missing signatures, improper gas tester calibration, improper use of group locks, and return-to-service steps not followed for locked out equipment. The Investigation Team was unable to find any record of the corresponding audit in 2004.

5.18.4 Corrective Actions

Audit action items are tracked to completion via a site PSM action item tracking system. The PSM and gHSEr audits conducted in 2004 both found that action items from PHAs, incident investigations and audits were not always resolved in a timely manner. The BP Investigation Team could find no evidence of formal action items to address the findings from the 2004 gHSEr, "Big 4" and OCAM audits. There were several open action items from the ISO 14001 audit, but none of them were past due. Four action items were past due from the Control of Work audit, but they did not directly apply to the ISOM unit. There did not appear to be an effective system in place to verify that recommendations from audits were satisfactorily resolved.

An action from the 2004 PSM audit requiring unit-specific training for newly assigned managers, superintendents, supervisors, and engineers remained open awaiting development of specific training matrices for each position. A target date of end 2005 was set with a followup audit within 12 months to check compliance.

5.18.5 Conclusions

The Texas City site has been subject to several audits in recent years, but these audits focused on documented management systems and processes rather than actual practices, such as following operating procedures. The audits also appeared to ignore the history of previous incidents, process excursions, and near-misses. Verification and audit processes were inadequate to provide early warning of process safety risk. There also appeared to be few self-verification processes, such as documented assessments by supervisors and superintendents of the units they were accountable for, for example, that procedures were being followed. Action items did not appear to be tracked and effectively closed, especially those of nonspecific and cultural aspects.

5.19 Risk

5.19.1 Risk Awareness

As discussed in Section 5.11.9, process safety knowledge and skills within management and the workforce were generally poor. This was most evident in the area of risk awareness, where hazard/risk identification skills appeared to be generally poor throughout the supervision and crew of the ISOM unit. This was also evident in the PHA conducted as part of the MOC for the J.E. Merit trailer siting.

There was no ongoing training program in risk awareness and identification for either operators or supervisors/managers. There were two trainee outside operators on the Raffinate Splitter, and their hazard training was largely passed down by experience from others. Sometimes this guidance was poor, perhaps due to an element of complacency, such as when heavy vapors were seen emitting from the blowdown stack at 12:40 hrs, and a more experienced operator told the trainee not to be concerned.

The poor understanding of risk is also reflected in some of the Process Hazard Analyses (PHAs), including Hazop studies and the MAR assessment. For example, the MAR did not address blowdown stacks in the top 80 risks considered, and Hazops on the ISOM unit did not adequately address explosion risks. It is interesting to note that the site environmental aspect and impact assessment, conducted for ISO 14001 certification, identified blowdown drums during shutdowns and RV releases as the second highest impact ranking. However, it is apparent that blowdown drums did not receive the same focus for safety risks as they did for environmental risk.

There are two contributory factors for the poor identification of risk in these studies. Independent leaders/hazard analysts are preferred for these PHA teams due to their greater objectivity, and are responsible for probing the team members for local input, but may not have done so effectively. However, if team members have no training or motivation, and do not recognize local risks, the extent of probing will not change the final work product. If key risks are not addressed in PHAs, then the cycle is somewhat self-sustaining and lesser risks will likely be considered the most important, leading to complacency that no high risks remain. Similarly, the MOC risk review for the J.E. Merit trailer placement did not include any consideration of the risks associated with the blowdown stack, located within 150 feet.

There were no plans to systematically reduce safety risks in the refinery. No individual or group seems to have the accountability for driving process risk reduction across the site. There were no plans, for example, regarding the ultimate replacement/reconfiguration of the blowdown stacks in the site. Site management did not appear to be focused on understanding and reducing the highest risks.

5.19.2 Risk Acceptance

When risks were identified, management and the workforce appeared to tolerate a high level of risk. The investigation team observed many examples of a high level of risk being accepted within the site. Two simple examples concerned vehicles and trailer siting.

A significant number of vehicles were allowed access into the site. Without designated parking areas, parking appeared to be tolerated almost anywhere, often on the shoulder of refinery roads in close proximity to hydrocarbon processing units and piperacks. Sometimes vehicle engines were left running.

The extensive use of trailers for housing people in close proximity to hydrocarbon processing units has already been addressed in detail in Section 5.11. The absence of a MOC for some trailers, and the superficial nature of the checklist risk assessment for others, reinforces the tolerance of risk.

To visitors, the risks associated with vehicles and trailers appeared unnecessary and seemed to have grown incrementally by custom and practice.

During the course of the investigation, there were several minor fires within the site, in addition to the serious incident on the RHU. Rather than major concern that any fire doesn't have a place in an oil refinery, employees generally appeared unconcerned, as fires were considered commonplace and a "fact of life" in the refinery. The lack of formal reporting, in part driven by the incomplete use of Traction, other than reference in ERT logs and investigation around previous fires, further supports the high tolerance level of risk.

Other examples of high risk tolerance concerned the failure to conduct a review of the Splitter startup procedure with the operations crew prior to the startup, as required by the procedure; unbalanced crews with all the PTs on the night shift; and the absence of both the Superintendent and Shift Supervisor during the startup, when it is common knowledge that startup is a potentially higher risk activity. The decision to split the startup between two shifts coupled with an ineffective shift relief process are also clear examples, as was the decision to continue with startup despite operational issues and the lack of onsite supervision.

Finally, the risks associated with allowing F-20, an item of safety critical equipment, to continue to operate with appreciable internal corrosion were apparently accepted following its last inspection.

5.19.3 Conclusions

There was a general inability to see key process risks, and both management and the workforce appeared to routinely tolerate a high level of risk. Numerous observations pointed to a high level of risk having become accepted. This was largely due to poor hazard/risk identification skills throughout management and the workforce, exacerbated by a poor understanding of process safety.

5.20 Communication

5.20.1 Operations

The startup procedure includes the following note on the importance of good communication for safety:

> *"Through all phases of a startup, maximum attention must be paid to safety, details and communications. This must be shared between involved units, shifts and individual crewmembers. Good planning, scheduling, judgment and communication make safe and efficient startups."*

The acting Superintendent (who was the Training Coordinator stepped up) was aware that the Splitter was being started up, but did not visit the unit to review progress with the operators. The startup was not mentioned at the Shift Director's morning meeting to indicate to those in proximity that the unit was to be started. Attendance at the Shift Director's meeting is not mandatory, and there is very limited time allocated for discussion of process unit operations. In fact, there is only 15-minutes duration for this primary cross-unit communication. The acting Superintendent appears to have devoted most of his time on March 23 to the turnaround on the ARU.

The Day Shift Supervisor did not advise adjacent process units or others in the immediate vicinity of the ISOM unit that the Splitter was being started up. In addition to the occupants of the trailers, there were several hundred contractors involved in the Ultracracker turnaround who were unaware of the startup.

The Day Shift Supervisor did not clearly leave someone in charge when he left the site on the morning of March 23 for a personal family matter. There were varying views on who was in charge of the Raffinate Splitter between the acting Superintendent, Day Shift Supervisor and Operators.

The startup took place over two shifts, but there was no apparent effort to ensure additional communication between the two shifts to allow for the potential added risk. The handover at shift relief was less than adequate; no passdown between the Shift Supervisors, and the passdown between outside operators was brief and did not occur on the unit. There were no written expectations with explicit requirements for shift handover.

The Superintendent and Training Coordinator stated in interviews that they were unaware that operators were routinely deviating from the written startup procedure by using the 8-inch vent valve to control pressure excursions. Operators had not informed supervision of these departures from procedures, and there was no system in place to verify that practices conformed to procedures.

5.20.2 Process Safety

General awareness in PSM appeared low throughout the organization. When the PSM rule was promulgated in 1992, there were training and awareness initiatives which had not been systematically refreshed. The use of e-mail to distribute information and bulletins does not appear to have been effective in maintaining process safety knowledge. Management, supervision and the workforce were largely unaware of regulatory requirements and Company standards, and local practices, such as MOC, were geared towards a minimal compliance basis. Sometimes these local practices were not followed and not enforced. Process safety did not appear to be a priority.

Examples of this lack of understanding of PSM and effective implementation of process safety included the following: The Operations Superintendent did not approve the J.E. Merit trailer for occupancy, and did not ensure that actions items from the trailer MOC were properly resolved. He allowed the other trailers to be sited in his area without a MOC being initiated. The Training Coordinator did not update the ISOM operating procedure for startup after a turnaround, and the Operations Superintendent certified that procedures were accurate and up to date without verifying. The Training Coordinator and Operations Superintendent allowed gaps in the training of some operators, and some training records were incomplete. The Shift Supervisor did not enforce, and the operators did not follow, the startup operating procedure.

As previously stated (see section 5.13.2.2), Amoco Process Safety Standard No.6 required blowdown drums on light hydrocarbon duty be considered for phasing out. Although this was known by the refinery PSM team, there was a general lack of awareness within the line organization, including the MDL and Operations Superintendent. This state of affairs existed despite one of the principal objectives of the site Process Safety Committee being:

> *"Effectively communicating and disseminating process safety related information throughout the refinery and chemical plants."*

The incomplete maintenance of an item of safety critical equipment (F-20) following its last inspection, without submission of a MOC or work order for subsequent repair, also supports the lack of focus on process safety.

5.20.3 Conclusions

There was a general lack of emphasis on operations and an erosion of process safety knowledge. This was manifested in a lack of effective implementation of PSM, and supervision and operators did not appear to appreciate the necessity of rigorously following procedures. Vertical communication was poor, and ISOM management was generally unaware of local practices. There needs to be greater line management understanding and ownership of PSM.

5.21 Business Plans

The Texas City site had a mixture of plans, with the HSE element typically focused on projects for reducing personal injuries and enhancing environmental compliance. For example, there was a 1000-Day plan, containing the following elements:

- Don’t Hurt Anyone (injuries, HSE action item closure)
- Be a Good Neighbor (spills, reportable incidents)
- Be Reliable (availability, maintenance spend)
- Create Value (productivity, commercial performance)
- Great Place to Work (employee survey)

The site budget for capital expenditure (capex) and operating expenditure (opex) had steadily increased over the last ten years. Capex averaged less than $50 million/year from 1996 to 2000, but increased significantly to an average of $125 million/year from 2001 to 2004, primarily for investment in clean fuels and other environmental projects. Fixed cash costs, including wages, maintenance and TARs, increased from $300 million/year to $540 million in 2004. Specific expenditure on maintenance turnarounds averaged $40 million/year from 1998 to 2000, and had increased markedly to an average of $115 million/year from 2001 through 2004.

There were no comprehensive and consistent business plans focused on the systematic reduction of process risks. A Major Accident Risk (MAR) assessment was conducted in March – April 2003, based upon the top 80 risks within the site. Despite Amoco Process Safety Standard (PSS) no.6, recommendations regarding blowdown stacks on light hydrocarbon duty, the MAR failed to address blowdown stacks within the top 80 risks considered. Neither did the ISOM unit feature in the top risks. Subsequently, there were no plans for risk reduction based on the top 80 risks addressed.

There were no plans to eliminate use of the blowdown stack on the ISOM unit. Several interviewees stated that concerns had been raised about blowdown stacks. The Clean

Streams Project considered an option to modify F-20 by tying the relief lines into a flare system, but this was not progressed as the focus was on environmental compliance issues. Elimination of F-20 does not appear to have been proposed in any business plan, nor subsequently removed from a draft plan, over the last ten years. Even when F-20 was replaced in 1997, no consideration appears to have been given to an alternative flare system. In early 2005, prior to the incident, a line item was added to the PDS as a potential future capital project for removal of F-20, but no plans had been developed.

There also did not appear to be any plans for systematically enhancing process safety competency in the workforce or, in fact, competency in general across the workforce. However, the site training budget had increased over the last few years (see 5.11.1.2).

5.22 Measurement and Monitoring

The Texas City site has numerous measures for tracking various types of operational, commercial, environmental, and safety performance. These Key Performance Indicators (KPIs) were not prioritized, and did not clearly focus on the leading indicators that would provide early warning of potential catastrophic and major incidents, nor were the important ones visible or obviously tracked.

The safety measures were primarily focused on lagging indicators for personal or occupational safety, such as Days Away From Work Cases (DAFWC – lost time) and Recordable Injury frequency (RIf). Both measures show a downward trend leading to a sense within the site that safety was improving.

There was no obvious priority or management focus on KPIs for process safety. By definition, catastrophic and major process incidents are rare events, and performance measures need to be preferably focused on leading indicators, or at least lagging indicators of relevant, more frequent smaller incidents. While a few leading indicators were measured within the site HSSE function, site management was not focused on trend analysis of measures that were much more likely to deliver an accurate sense of process safety performance at the site. There was limited visibility on lagging measures, such as loss of containment incidents, spills, hydrocarbon fires, and process excursions/upsets, for which basic trend analysis did not facilitate management intervention.

Loss-of-containment incidents and process upsets/excursions, including relief valves lifting, generally did not receive the attention they warranted. Many of these incidents were not formally reported and even fewer were investigated. As a result, meaningful trend analysis to provide early warning of existing and impending process safety issues was not possible, and corrective actions were not identified and resolved.

While the Investigation Team did not find any direct evidence of deliberate under-reporting of incidents, the reward system employed within the site appears misaligned. The system rewarded employees for having fewer incidents, and it is possible that this incentive could drive reporting tendency downwards.

5.23 Organization

The Texas City facility is a large, complex site with 30 process units, tankage, power generation and other infrastructure. The organization (structure and key management personnel) has changed several times over the last several years to merge and align the refinery and the chemical plant, on separate sites, under a single leadership team. The previous organizations had differing practices and procedures across the range of operations, maintenance, engineering and HSSE activities. The process of consolidating on a standard set of consistent practices and procedures across the whole facility has not been facilitated by an inwardly looking, fragmented ("siloed") culture that appears resistant to change.

5.23.1 Operations

The most recent Operations Department organization has multiple levels (see Appendix 33), apparently to address the span of control across such a large site. Several spans of control appeared large and did not allow the level of supervisory presence necessary on the site. The Operations Manager is a member of the site leadership team, and, prior to March 23, had four direct reports, the Manufacturing Delivery Leaders (MDLs). Each MDL has a number of direct reports, Operations Superintendents, who are responsible for the operation of certain process units and infrastructure. Each Superintendent has Shift Supervisors with Board and Outside Operators on each of four shifts, plus a Training Coordinator.

Since the HiPRO organization was introduced in 1996, responsibility for optimization of production has been separated from other operations roles. The position of Optimization Engineer (OE) was created. An Optimization Supervisor position also existed until 2004. Each OE is responsible for ensuring efficient production (optimized yields, throughputs, energy efficiency) for a number of process units, and works with the Shift Supervisors, Board Operators, Outside Operators, Reliability Engineers and Maintenance. They also perform environmental calculations, support reliability efforts, projects and TARs. Other services, such as maintenance, engineering, HSSE, etc. are provided by other departments within the site.

This large complex organization has many interfaces requiring clear accountabilities and good communication both horizontally and vertically throughout the organization. In reality, the Investigation Team found examples 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. Examples of this lack of clarity around roles includes the following: The MDL stated that he was not aware that he was accountable for the location west of the ISOM where the trailers were sited, and there was no communication to personnel in the adjacent trailers to warn them of the startup.

During turnarounds or other extraordinary activities, certain employees are asked to step up into supervisory roles. For example, during the ARU turnaround and temporary outage of the ISOM unit, the Operations Superintendent for the ISOM concentrated on the ARU turnaround and the Training Coordinator was stepped up as acting Superintendent for the running units, AU2/ISOM/NDU. A Board Operator, who was receiving step-up pay but not acting as Night Shift Supervisor, took over the Board Operator's role in packing the Splitter. Roles and responsibilities for step-ups are sometimes unclear, as individuals sometimes did not receive specific training in the new role, and appeared to have competing priorities. In the case of the Training Coordinator, he devoted most of his time on March 23 to assisting with the ARU turnaround, despite being responsible for the Raffinate Splitter that was starting up. During the last 12 months, the Training Coordinator spent only 5% of his time on training. Other examples of supervision covering more than one job included the Night Shift Supervisor, who was also covering the ARU.

5.23.2 ISOM Unit

From February 21, 2005, the operators and supervisors of the AU2/ISOM/NDU units were assigned to day and night crews during the temporary outage. The day crew comprised seven operators and two trainees, while the night crew was eight operators, two of which were Process Technicians (PT). One shift supervisor on the day shift was covering the running units (AU2, NDU), while another supervised the ISOM. The normal contingent for the AU2/ISOM/NDU units is one shift supervisor, one board operator, one PT and two outside operators. The normal crew for the ISOM comprises the board operator and one outside operator. Other operators are responsible for the AU2 and NDU, which are operated from the same control room. The organization chart is shown in Appendix 33.

Under certain explicitly defined circumstances, a second board operator is sometimes required on the ISOM Unit.

The startup of the ISOM Penex unit requires additional operator and supervisory support. The ISOM startup procedure (SOP 101.0) states:

> *"This procedure shall not be executed simultaneously with any other scheduled unit Start-Up or Shutdown procedure of the ARU, the AU2, or the NDU without additional supervisory and operations staff, depending on the unit."*

Two sections of the ISOM Startup Procedure from Long Loop Circulation or Running Down to Tankage (SOP 101.4) state:

> *"Note: For this procedure a second board operator will be on hand to assist and watch the AU2 board until the ISOM is on stream and operating properly."*
>
> *"Note: From this point on in the procedure a second board operator will be on hand to assist and watch the AU2 board until the ISOM is on stream and operating properly."* (SOP 101.4, Section E)

The startup procedures for the Raffinate system did not require additional operation support for the activities underway on March 23rd.

On March 23, the Day Shift Supervisor left the site at 10:47 hrs and it was not clear who was then in command of the operations. The crew believed it to be Operator B, while the acting Superintendent and the absent Day Shift Supervisor stated that they believed it was a Supervisor from the ARU turnaround, who denies this.

Due to the temporary outage, the ISOM was staffed with a larger than normal operating contingent, i.e., double the normal number of outside operators, although two of these outside operators were trainees. In addition to the Shift Supervisor, there were six operators assigned to the Raffinate Splitter startup on the March 23 day shift, as follows:

- Board operator
- Board operator receiving step-up pay for temporary outage duties
- 2 outside operators (ISOM certification for one not found)
- 2 trainee outside operators

Following catalyst replacement, the Penex Reactor section of the ISOM unit remained shut down on March 23, awaiting a new gasket for the reactor. The only other part of the ISOM unit in operation was the Desulfurizer, which was stable in circulation with the Hydrogen Compressor running. Operator D conducted routines on the Desulfurizer, but spent most of the shift assisting with startup of the Splitter.

5.23.3 Engineering

Since 1996, when the HiPRO organization was introduced, the engineering resources have been organized into three main groups: Optimization Engineers, Reliability Engineers, and Project Engineers. Resources for direct support to the process units generally appear appropriate, although additional contract engineers are needed to supplement project engineering resources. The range of experience varies considerably between these engineers, and some relatively inexperienced engineers would benefit from mentoring and/or role models.

The Optimization Engineer (OE) provides day-to-day advice, guidance and troubleshooting support to Operations. The OE is expected to monitor process unit performance closely, especially during transient operations such as a unit startup. The Raffinate Splitter is considered a very simple process unit compared to other units at Texas City, and appears to have received minimal involvement and support from the optimization group. The history of pressure excursions in previous Splitter startups, and the adoption of local practices such as use of the 8-inch vent valve, does not appear to have received any critical engineering involvement or review. It is not evident that they were aware of field operating practices.

The Reliability Engineers (REs) are responsible for process unit reliability, availability and general maintenance. A number of more experienced engineers are available to provide advice and guidance to the OEs and reliability engineers.

The Project Engineers (PEs), including additional project and process engineering support through third party contractors, are responsible for large/small projects and MOCs.

The site does have a nominally independent process for ruling on exceptions. The Engineering Authority (EA) at the site is responsible for maintaining engineering best practices and specifications, such as Amoco Corp. Engineering Standards (ACES). The EA rules on engineering issues when questioned by exception. The EA is not automatically involved in the MOC process or in issues concerning SCE, and does not have any designated and experienced engineers (sometimes termed "Technical Authorities") to provide assistance.

5.23.4 Safety Committees

5.23.4.1 Joint Health and Safety Committee

This committee is defined by Union Contract with equal membership between Union and Management personnel and is co-chaired by one Union and one Management Leader. The committee represents a cross section of the plant population, and meets monthly. Its mission is to ensure safety in the refinery, with special attention given to health concerns. It strives to be proactive in identifying any and all issues that may impact the health and safety of all employees in addition to being available to address specific employee issues. A union member is nominated for each incident investigation team.

The committee appears to have devoted its time to discussing relatively minor HSE risks, and not addressing the big issues, based upon detailed trend analysis of the root causes of previous incidents. It was not focused on identifying ways to reduce major risks. There was no record of the committee discussing F-20 or any of the other blowdown stacks in the last five years.

5.23.4.2 HSSE Procedure Council

The HSSE Procedure Council consists of management representatives, approves all HSSE procedures, and directs the work of the HSSE Procedure Committee.

5.23.4.3 HSSE Procedure Committee

The HSSE Procedure Committee consists of hourly and salaried members, and is charged with developing and revising Texas City HSSE procedures as directed by the HSSE Procedure Council.

5.23.4.4 Manufacturing Area Team HSE Councils

The ISOM unit falls within the purview of the West Plant HSE Council, which was established in July 2004 and comprises hourly and staff employees. The intent of the Council is to involve a broader set of employees in HSE and achieve greater ownership. The principal tasks of the Council are:

- Select measurable actions, and act as resource to achieve 1,000-Day Goals.

- Review requests for policy exceptions or extensions, including MOCs, to identify indications of increased risk tolerance or policy breakdowns.
- Identify solutions to HSE related issues or trends.
- Provide input into budgets based on identified, prioritized HSE issues.
- Address maintenance-specific HSE concerns.
- Communication of ongoing activities, and HSE concerns.
- Create an easily accessible way to track area HSE related issues.

5.23.4.5 Process Safety Network Council (PSNC)

The Process Safety Network Council (PSNC) is the "stakeholder" of the Process Safety Standards and the process safety strategies developed by the Process Safety Network (PSN). The PSN is composed of representatives from each BP Group refinery, including Texas City, and the PSNC is a smaller subset of leaders drawn from the PSN. Specific PSNC tasks are:

- Promote efforts to improve process safety performance.
- Promote the understanding and use of Process Safety Standards.
- Promote the formation and development of local refinery Process Safety Committees.
- Promote the PSN assurance process.
- Mentor the development and training of future PSN leaders.
- Manage the balloting process for Process Safety Standards.
- Assist in securing resources for PSN initiatives.

5.23.4.6 Process Safety Committee (PSC)

The Process Safety Committee (PSC) is led by a senior site manager with operations experience, and consists of salaried representatives from operations, maintenance, engineering, front-line supervision and process safety, and one hourly representative. The PSC sponsors process safety related activities and provides guidance on the safe operation of refinery and chemical facilities involved in the handling, processing, and storage of hydrocarbons and highly hazardous chemicals. It meets monthly, and its goal is to eliminate process related incidents. Specific tasks of the PSC include:

- Sponsoring PSM and Risk Management Program (RMP) compliance in the site
- Communicating and disseminating process safety related information
- Auditing compliance with federal, state and local process safety regulations, industry guidelines, and recommended good practices
- Establishing local process safety standards

- Reviewing all process safety related major incident investigation reports and applying appropriate lessons learned
- Tracking progress on the resolution of action items from hazard reviews, incident investigations, pre-startup safety reviews, and compliance audits
- Critically reviewing and approving requested variances from process safety and industry standards and engineering specifications
- Reviewing and approving the plot plan, critical alarm list, and operating procedures for new processes or major modifications
- Reviewing maintenance procedures, inspection records, unusual maintenance techniques, and equipment reliability
- Reviewing and auditing process safety training programs for refinery and chemical plant personnel

Despite the efforts of the PSC to promote process safety within the site, the workforce was generally unaware of the Process Safety Standards, such as PSS no.6, covering blowdown drums. The PSC proposed a policy to prohibit siting of trailers near flare stacks in November 2002, but did not address blowdown drums.

5.23.4.7 Employee Safety Awareness Committee (ESAC)

The ESAC is hourly driven and promotes and encourages injury free and healthy daily living on the job as well as away from the workplace. It holds quarterly safety meetings for employees to attend. It sponsors health and safety educational programs, training, and safety intervention and resolution from all levels of employees.

5.23.4.8 Organizational MOCs

At least nine MOCs were initiated from 1995 to 2003 to review the consequences of proposed staffing changes within the Texas City site (see Appendix 26). The conduct of these organizational MOCs appeared adequate to address the organizational changes. Action items associated with three of the MOCs appear related to the circumstances of the incident on March 23, 2005.

Alarm Display
A 1999 MOC (# MOC-ISOM-1999-006) identified an action to:

> *"Consider repositioning the ISOM active alarm display to provide better visibility to the board operator."*

This action was not completed due to project economics, as implementation would have required $20,000 per workstation. The ISOM active alarm display visibility was not identified by the Board Operator during post-incident interviews as having a role in the incident on March 23.

Two Control Board Operators
A MOC was initiated in 2001 to combine the responsibilities of the NDU board operator with those of the AU2/Isom board operator. The hazard analysis for the MOC (# MOC-NDU-2001-002) identified an action item to have two control board operators under certain conditions, as follows:

> *"Extend the requirement to have two control board operators for any planned startup or planned shutdown activities to include the NDU."*

This action item was resolved by inserting statements to this effect in the relevant startup and shutdown procedures. For example, the NDU startup procedure (SOP 12) contains several statements concerning staffing requirements:

Under the heading of "Health, Safety and Environmental Precautions," it states:

> *"This procedure shall not be executed simultaneously with any other scheduled unit Start-Up or Shutdown procedure of the ARU, the AU2, or the ISOM without additional supervisory and operations staff, depending on the unit."*

Under the heading of "Preliminaries," it states:

a. "Ensure there is adequate staffing, one additional board operator and one additional asset operator."

b. "The NDU will not startup concurrently with any other scheduled startup or shutdown of the AU2 or ISOM units."

c. "The NDU will not startup concurrently with any other scheduled startup or shutdown of the ARU without additional Asset Supervisory staff on hand."

The NDU shutdown procedure (SOP 21) contains similar language concerning staffing requirements.

Startup of the ISOM Penex unit requires additional operator and supervisory support, as stipulated below:

Similarly, the ISOM startup procedure (SOP 101.0) states:

> *"This procedure shall not be executed simultaneously with any other scheduled unit Start-Up or Shutdown procedure of the ARU, the AU2, or the NDU without additional supervisory and operations staff, depending on the unit."*

Step 31 of SOP 101.0 states:

> *"Once all low point drains are free of water and when directed by supervision, cut naphtha through the Penex reactors as per SOP 101.4"*

ISOM Startup Procedure from Long Loop Circulation or Running Down to Tankage (SOP 101.4) states:

> *"Note: For this procedure a second board operator will be on hand to assist and watch the AU2 board until the ISOM is on stream and operating properly."*

SOP 101.4, Section E, Cut Naphtha through the Isomerization Reactors, states:

> *"Note: From this point on in the procedure a second board operator will be on hand to assist and watch the AU2 board until the ISOM is on stream and operating properly."*

Operating procedures for the AU2 and ARU units also have statements concerning staffing requirements that are consistent with the statements contained in the NDU and ISOM procedures. However, operating procedures for the Raffinate Splitter do not require additional operation support. Testimony from witnesses confirmed this interpretation, and the Board Operator stated that he was not overwhelmed during the startup of the Raffinate Splitter.

The startup procedure for the Raffinate Splitter did not require a second board operator. However, a minority of the BP Investigation Team thought that this was unclear and required clarification.

Additional Supervisor

A MOC was initiated in 2002 to address the addition of the NDU Asset Supervisor's operating responsibilities to the ARU/AU2/ISOM Asset Supervisor and the West Plant Optimization Supervisor. The MOC (# MOC-NDU-2002-003) was "commissioned" (i.e., approved) on March 3, 2003, and included the following recommendation:

> *"Simultaneous scheduled startups or shutdowns will not be permitted without having additional supervisory staff on hand."*

The above references to NDU and ISOM operating procedures include this requirement. However, it does not appear to apply to the Raffinate Splitter, as the Splitter operating procedures make no reference. The ARU (A side) had started up on March 22, and had separate supervision to the NDU/ISOM/AU2 units. The acting Superintendent spent much of the day shift on the ARU assisting with troubleshooting some issues. The ARU also had its own board operator.

The "What If" Review for this MOC included an item concerning *"Shift Supervisor off the unit or gone."* The review team understood the importance of supervision, and specified a "relief supervisor or step-up supervisor" as the appropriate safeguard. As previously identified, on March 23 it was unclear who was actually in charge after the Day Shift Supervisor left the site.

5.23.5 Conclusions

The Texas City site had an overly complex and changing organization which was not conducive to good communication and clear accountability. The site had been reorganized on several occasions to align the previously separate refinery and chemical plant organizations. The spread of control of the MDL and supervision's apparent lack of focus and knowledge of process safety did not facilitate effective safety management of the startup.

The site has numerous committees and many processes, which increases the number of interfaces within an already complex organization. The effectiveness of some of the committees is questioned, and should be reviewed to ensure that they have the appropriate membership and are focused on the big issues in alignment with the key site priorities.

5.24 Leadership

The Texas City site organization had many layers and interfaces, and appeared to be a compromise between senior leaders having an extended span of control and simpler, shorter lines of communication vs. a more reasonable span but convoluted communication. The leadership team appeared relatively small given the scope and scale of the refinery and did not have senior visibility in the areas of HSSE, PSM and other "support" functions. The MDLs had a broad span of control and at all levels there appeared little coverage for peak workloads such as turnarounds.

The leadership team had limited visibility within the site and had no Advanced Safety Audit (ASA) type program to drive leadership visibility with the workforce. They relied upon middle management/supervision at the actual job site and, as a result, there was little direct leadership team oversight of operations and process safety. There was little investment in supervisory/management training, and. an absence of role models within supervision, and, as a result, supervisory/management behaviors were inadequate. There were no clearly documented expectations for supervisors' roles, including those stepping up to an acting supervisory role. For example, the acting Superintendent was not present at key stages during the Splitter startup, and did not ensure that a pre-startup review of the procedure was conducted with all involved. The MDL was not aware of the Splitter startup or his accountability for the trailer siting in the area between the NDU and ISOM.

There was a failure by leadership to hold employees at all levels accountable for executing defined processes/procedures. A workplace environment characterized by poor motivation, unclear expectations around supervisory/management behaviors, no clear system of reward and consequences, and high distrust between leadership and the workforce, had developed over a number years within the site. The working relationships between leadership and workers, and employees and contractors were poor. The annual independent survey of the workforce yielded PAS scores for the site in the bottom quartile, further emphasizing the low morale and distrust of site management. Sometimes, due to a lack of adequate verification, site leadership was unaware of issues, such as poor shift relief practices, and operating procedures that were not updated or reflective of local practices. The workplace culture was also inward looking and not open to initiatives or learning from sources external to the site.

There was a distinct preference for local programs, and the site was isolated from BP Group/Segment/SPU initiatives and best practices.

Site leadership had, in part, started to recognize this poor working environment and culture, but had not influenced the workplace culture quickly enough to avoid the incident on March 23. A number of relatively recent initiatives directed at changing the culture were already under way, for example:

- 1000-day goals.
- Compliance delivery process improvement, including improved training on critical safety policies (toolbox, quarterly classes), enhanced site audit/verification, site leadership engagement in weekly audits, FLL away days, and BUL/Supervisor engagement on root causes.
- Cultural assessment survey.
- Shift Director role had been created in attempt to improve cross-unit communication.
- HSSE Councils formed.
- After Action Reviews instituted.
- Leadership had significantly increased maintenance and capital expenditure at the site.

Despite all of these, it is apparent that they were insufficient, not specific enough or not followed through and added to the already cluttered working environment of many processes and committees. It was relatively easy for management, supervision and the workforce to lose sight of the basic fundamental requirements for safe efficient operation.

Generally, leadership had a poor understanding of risk and process safety in general, and accepted what to others appear high levels of risk. When OSHA promulgated the PSM rule in May 1992, there were initiatives to raise awareness and knowledge of process safety within the Amoco refining organization, including the Texas City site. Over time, knowledge and skills in process safety had been allowed to degrade. Process safety presentations to management appear to have been ineffective in maintaining understanding and gaining priority. The overall approach to process safety was one of minimum compliance with regulatory requirements, with leadership not as clearly focused on process safety as it was with occupational safety and environmental performance.

Some local management systems had also been allowed to degrade over time; for example, training. Site management had many KPIs and audits for performance monitoring, but little, if any, for providing feedback on potential catastrophic or major risks. In essence, leadership had no effective early warning system for process safety exposures.

With an inability to see risk and no effective early warning system, coupled with a difficult workplace environment, cumbersome organization, and poor communication, it is perhaps not surprising that site leadership was unable to identify and clearly articulate priorities around process safety (e.g., trailer siting, blowdown stack removal, investigating process upsets) and operations excellence (e.g., following procedures, supervisory oversight).

5.24.1 Conclusion

The degree of change in individuals and organization coupled with the broad span of control meant that there was inadequate visible leadership evident on the ISOM unit over time. On the day of the incident this was exacerbated by the number of step-ups in place and personal circumstances causing a supervisor to leave the site.

6. 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 methodology. The underlying Cultural Issues were then distilled from the Management System Causes by using a "5 Whys" type of analysis.

The following charts indicate the relationship between the Critical Factors, Immediate Causes, Management System Causes, Cultural Issues, and Corrective Actions. The numbers in parentheses refer to sections of the following text. The Critical Factors are the same as those identified in the Interim Report issued by the Investigation Team in May 2005.

Table 6-1
Causal Analysis

CRITICAL FACTOR	IMMEDIATE CAUSE	MGMT SYSTEM CAUSE (Root Cause)	CULTURAL ISSUES	CORRECTIVE ACTION
	• Violation by Individual	• Poor judgment		• See Recommendations for Other Critical Factors, especially:
	• Violation by Supervisor	• Inadequate training effort	• Business Context (6.3.1)	• Leadership (7.1.1)
				• Supervision (7.1.2)
• CF-1. Loss of Containment (6.2.1)	• Improper decision making or lack of judgment	• Inadequate leadership	• Safety as a Priority (6.3.2)	• Individual Performance (7.1.4)
				• Training (7.1.8)
	• Defective safety devices	• Inadequate adjustment/ repair/ maintenance	• Inability to See Risk (6.3.4)	• Organization (7.1.9)
				• Procedures (7.2)
	• Inadequate equipment	• Inadequate enforcement of Policies/Standards/ Procedures	• Lack of Early Warning (6.3.5)	• Underlying Systems (7.5)

CRITICAL FACTOR	IMMEDIATE CAUSE	MGMT SYSTEM CAUSE (Root Cause)	CULTURAL ISSUES	CORRECTIVE ACTION
• CF-2. Raffinate Splitter Startup Procedures and Application of Knowledge and Skills (6.2.2)	• Violation by individual • Violation by supervisor • Lack of knowledge of hazards present • Improper decision making or lack of judgment • Distracted by other concerns	• 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	• Business Context (6.3.1) • Safety as a Priority (6.3.2) • Organizational Complexity and Capability (6.3.3) • Inability to See Risk (6.3.4) • Lack of Early Warning (6.3.5)	• Leadership (7.1.1) • Supervision (7.1.2) • Workplace Environment (7.1.3) • Individual Performance (7.1.4) • Resourcing (7.1.5) • Communications (7.1.6) • Operators (7.1.7) • Training (7.1.8) • Organization (7.1.9) • Procedures (7.2) • Safety Critical Equipment (7.3.2) • Underlying Systems (7.5)

CRITICAL FACTOR	IMMEDIATE CAUSE	MGMT SYSTEM CAUSE (Root Cause)	CULTURAL ISSUES	CORRECTIVE ACTION
				• Leadership (7.1.1) • Supervision (7.1.2) • Communications (7.1.6)
	• Lack of knowledge of hazards present	• Inadequate leadership	• Business Context (6.3.1)	• Training (7.1.8) • Procedures (7.2)
	• Improper decision making or lack of judgment	• Inadequate correction of worksite/job hazards	• Safety as a Priority (6.3.2)	• Trailers (7.3.1) • Facility Siting (7.3.3)
• CF-3. Control of Work and Trailer Siting (6.2.3)	• Failure to warn	• Inadequate identification of worksite/job hazards	• Organizational Complexity and Capability (6.3.3)	• Hazardous Area Classification (7.3.4)
	• Routine activity without thought	• Inadequate evaluation and/or documentation of change	• Inability to See Risk (6.3.4)	• PHA/MOC/Hazop (7.3.5)
	• Fire and explosion	• Inadequate implementation of Policies/Standards/ Procedures, due to deficiencies	• Lack of Early Warning (6.3.5)	• Alarm Systems (7.4.3)
	• Inadequate workplace layout	• Inadequate communication between different work groups		• Underlying Systems (7.5)
				• Investigation & Reporting of Incidents (7.6)

CRITICAL FACTOR	**IMMEDIATE CAUSE**	**MGMT SYSTEM CAUSE (Root Cause)**	**CULTURAL ISSUES**	**CORRECTIVE ACTION**
• CF-4. Design and Engineering of Blowdown Drum and Stack (6.2.4)	• Improper decision making or lack of judgment • Inadequate equipment • Inadequate workplace layout	• 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	• Business Context (6.3.1) • Safety as a Priority (6.3.2) • Organizational Complexity and Capability (6.3.3) • Inability to See Risk (6.3.4) • Lack of Early Warning (6.3.5)	• Leadership (7.1.1) • Supervision (7.1.2) • Communication (7.1.6) • Training (7.1.8) • Organization (7.1.9) • Safety Critical Equipment (7.3.2) • PHA/MOC/Hazop (7.3.5) • Accountabilities (7.4.1) • ISOM Design & Engineering (7.4.2) • Underlying Systems (7.5) • Investigation & Reporting of Incidents (7.6)

6.1 Critical Factors

The following Critical Factors were identified:

CF-1. 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 & STACK (F-20) RESULTED IN LIQUIDS OVERFLOWING THE STACK, CAUSING A VAPOR CLOUD, WHICH WAS IGNITED BY AN UNKNOWN SOURCE.

The very high liquid level and base temperature, and the late startup of the Heavy Raffinate rundown, contributed to the Splitter overflowing liquid out of the top of the vessel and the subsequent overpressure at the relief valves' location. The Heavy Raffinate was very hot when the rundown was started late in the startup process, which led to rapid heating and vaporization of the incoming feed. This, in turn, accelerated the overflow of liquids out of the top of the Splitter and into the large diameter overhead line down to the relief valves. The head of liquid in the overhead line coupled with the relatively normal tower pressure exceeded the relief valve set pressures. A large quantity of liquid hydrocarbon was discharged through the relief valves and overwhelmed the blowdown drum. Stopping feed, and/or increasing offtake and/or reducing heat input earlier would have probably prevented the incident. Witnesses described the discharge of hydrocarbon liquid and vapors from the Blowdown Stack during the startup of the Splitter, the formation of a vapor cloud at ground level and subsequent ignition, resulting in an explosion. Numerous potential ignition sources were present in the surrounding area (vehicles, trailers etc.), as the area was seemingly uncontrolled. Witness statements suggest that a truck engine might have been the source of ignition, but it has not been possible to confirm this.

CF-2. RAFFINATE SPLITTER STARTUP PROCEDURES AND APPLICATION OF KNOWLEDGE AND SKILLS

FAILURE TO FOLLOW THE STARTUP 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 STARTUP.

As described earlier in this report, several steps in the startup procedure were omitted and others deviated from. The Day Shift Board Operator overfilled the Raffinate Splitter and overheated its contents without understanding the true status of the unit. There was a three-hour-plus delay in starting the Heavy Raffinate rundown, which led to the overfilling. The heat was added to the Splitter before heavy raffinate rundown had been initiated and at a much higher rate than specified in the startup procedure. In addition, the maximum temperature utilized was much higher than specified in the procedure. Intervention steps were inadequate and late, and may have actually made the situation worse. The feed into the splitter was never actually shut off, even after the relief valves lifted. Supervisory staff did not verify the correct procedure was being used or followed, and were absent from the unit during shift relief, pre-startup, and during heating and filling (startup). The decision to stage the startup over two shifts increased the potential risks.

The absence of key personnel, confusion around who was in charge and the behavior of supervision eroded the chain of command to the point that decision-making authority was unclear. Although the startup procedure was not fully up to date, if the procedure had been followed, or if different intervention had been made earlier, this incident would not have happened.

CF-3. 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 (F-20) DURING THE STARTUP OPERATION. THEY WERE CONGREGATED IN AND AROUND TEMPORARY TRAILERS AND WERE NEITHER EVACUATED NOR ALERTED.

Several trailers were located west of the ISOM and acted as a congregating point for personnel working on the Ultracracker turnaround. This location was within 150 ft of F-20, which had not been considered as a realistically potential hazardous source in any site study. The Management of Change process did not consider the possibility of significant release of hydrocarbons at the stack. Site communication processes did not function as specified with regard to this startup.

The injured were not notified in advance of the impending startup, or when hydrocarbons were discharged from the stack. Plans could have been made to move them away before the startup operation, and the subsequent failure to sound the evacuation alarm at crucial times led to them remaining in place and being exposed to the hazard. Both the trailer location and not alerting personnel increased the severity of the incident.

CF-4. DESIGN AND ENGINEERING OF BLOWDOWN DRUM AND STACK

THE USE OF BLOWDOWN DRUM AND STACK (F-20) AS PART OF THE RELIEF AND VENTING SYSTEM FOR THE RAFFINATE SPLITTER, AFTER SEVERAL DESIGN AND OPERATIONAL CHANGES OVER TIME, CLOSE TO UNCONTROLLED AREAS.

Blowdown stacks have been recognized as potentially hazardous for this service, and the industry has moved more towards closed relief systems to flare. Opportunities to tie the Splitter relief lines into a flare system were not taken when it appears that it could have been efficiently done in either 1995 or 2002, nor in 1997 when F-20 was replaced due to corrosion. Design and operational changes to the Splitter over time resulted in increased use of F-20. Incremental changes to F-20 itself included failing to replace the internal baffles, decommissioning the quench system, and adding additional inlets, possibly reducing its effectiveness. Several uncontrolled areas were close to F-20, e.g., roads and trailer sites, all within 150 ft, with the permanent catalyst warehouse located within 350 ft. The use of a flare system or other closed relief system would have probably significantly reduced the impact of the incident.

6.2 Causal Analysis of Critical Factors

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, which provides a systematic method of considering possible root causes associated with an incident. Predefined trees are one of the main Root Cause Analysis methodologies used within the petrochemical industry. This approach encourages investigators to contemplate a wide range of factors and not just those that come to mind through brainstorming. 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 predefined trees is available from CCPS incident investigation guidelines (ref. 4).

The Possible Immediate Causes and Possible Management System Causes are presented in Appendix 34.

6.3 Underlying Cultural Issues

The significant number of identified immediate and management system causes (root causes), 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 have been distilled from the system causes:

6.3.1 Business Context

The investigation identified the lack of clearly defined and broadly understood context and business priorities for the Texas City site as the first cultural issue for the incident. The investigation team was not able to identify a clear view of the key process safety priorities for the site or a sense of a vision or future for the long term.

- 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

This led to a workplace environment characterized by poor motivation, unclear expectations around supervisory/management behaviors, no clear system of reward and consequences, low trust between groups (such as between employees and contractors, and workers and management), and highly inward looking.

- 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 behaviors 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 behaviors 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 behavior at either supervisory/management or operator level (The “Just Culture” had not been fully implemented at the time of the incident).
- An explicit description of the desired behaviors 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 startup 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 encourages supervisors and operators to work for extended periods of time (circa 30 days of straight 12-hour shifts throughout) 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 last independent survey of the workforce produced bottom quartile People Assurance Survey (PAS) scores for the site, further emphasizing the low morale and distrust of site leadership.

The “check the box” approach to processes, such as MOC, is indicative of the poor motivation and reluctance to go beyond minimum compliance, and sometimes even the minimum was ignored (e.g., no/incomplete MOC for trailers). The inward-looking, closed environment resulted in BP Group and/or Refining Segment initiatives receiving limited attention as a "not invented here" culture was tolerated. The learnings from external incidents, circulated in BP's QSB, were largely ignored at the site.

6.3.2 "Safety" as a Priority

The investigation identified the second cultural issue as the lack of safety and basic operations as a priority through the operations on the ISOM.

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, such as a 1000-day plan, 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. Several individuals stated that concerns had been raised about these. The Clean Streams 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. The incomplete maintenance of an item of safety-critical equipment (F-20) following its last inspection, without submission of a MOC or work order for subsequent repair, also supports this lack of focus on process safety.

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 include the absence of reporting (in some cases) and investigation (in most cases) around loss of containment incidents (e.g., fires) and key process upsets (e.g., pressure spikes and atmospheric relief during previous startups of the Splitter).

The Investigation Team did not find any clear plans 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 behaviors 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.

6.3.3 Organizational Complexity and Capability

The third cultural issue is unclear accountabilities and inadequate communication, due to a complex organizational structure which has been modified frequently without improving the required behaviors. The Texas City facility is a large, complex site with multiple levels within the organization, apparently to address the span of control across such a large site. This organization has many interfaces requiring clear accountabilities and good communication both horizontally and vertically throughout the organization. In reality, the Investigation Team found examples 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 is cluttered with many processes, committees, etc., such that it is 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. The reported accountabilities varied between the Operations Superintendent for the ISOM/NDU/AU2 units, the Utilities Superintendent, and the West Area MDL. 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 startup to the adjacent work sites. One individual stated that contractors working inside the battery limits (ISBL) of the ISOM unit 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 appears to operate in walled silos.

Specifically, the team observed that the relationship between operations and engineering was inconsistent and fractured; evidence of this was the fact that engineering was not called during the startup problems; nor did the team find evidence that engineering rounds were being conducted. In addition, the “independent” functions, such as training and PSM, had become underresourced 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 is not mandatory and discussion for the entire site is compressed into about 15 minutes, which, on its own, is not adequate for genuine communication. Communication works better within immediate work groups but not well outward or upward. An example of this is the West Plant MDL, who was unaware of the actual shift relief practices utilized in the ISOM unit.

As previously stated, 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 is exacerbated by a lack of reward or recognition for those who step across boundaries and stand in personal leadership.

This complexity creates an organization which requires behaviors across boundaries, between different groups and companies, but the clear divisions seen ensure that people are unlikely to communicate with or influence across these boundaries. Because of this, natural teams are often incomplete or incoherent.

6.3.4 Inability to See Risk

The fourth cultural issue is the inability to see risks and, hence, toleration of a high level of risk. This is largely due to poor hazard/risk identification skills throughout management and the workforce, exacerbated by a poor understanding of process safety. Although some effort had been expended to raise awareness and understanding 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

As previously stated, there were not effective holistic plans to systematically reduce risks in the refinery. Examples of this include no plan in place regarding the ultimate replacement/reconfiguration of the blowdown stacks in the site. The most recent Major Accident Risk (MAR) 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 J.E. Merit trailer placement did not include any consideration of the risks associated with the blowdown stack, located within 150 feet.

The Investigation Team observed many examples of a high level of risk 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 the 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 startup procedure with the crew, as required by the procedure; the absence of supervision during the startup, when it is common knowledge that startup is a higher risk activity; and the lack of reporting of significant process upsets, such as relief valves lifting during previous startups.

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

6.3.5 Lack of Early Warning

The fifth and final cultural issue is the lack of a holistic early warning system for process safety exposures. The site has 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 this investigation.

- Vertical communication is 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 include 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.

7. Proposals for Corrective Actions

The following recommendations address the root causes and underlying cultural issues that the Investigation Team identified on the ISOM unit. Many of these recommendations are already documented in existing policies and procedures, but are either not being followed or are not specific enough. The site must ensure that actions are followed through and that verification processes are reinforced to ensure that all existing policies and procedures are being followed. In addition, adequate resources will need to be provided in order to complete all action items in this report in a timely manner, and to ensure that the actions achieve the desired outcomes. Site leadership should determine if these recommendations apply more widely within the site than the ISOM unit.

7.1 People

7.1.1 Leadership

- Drive the Just Fair Culture with visible leadership, especially in the matter of verification; ensure the work force is competent to deliver their accountabilities and self-verify using job content audits for compliance; participate and communicate at all levels. Design new "diagonal slice" processes.
- Set clear and explicit Accountability and "Chain of Command organizational chart," including geographical responsibility for Simultaneous Operations.
- Develop clear measurements for leading indicators of catastrophic incidents (e.g., process upsets, loss of containment, fires, High Potential incidents (HIPOs), and indicators of major risk) vs. lagging indicators (i.e., reportables, spills, slips, trips and falls) and use to manage performance.
- Staffing plans for turnarounds and high workload periods must show explicit consideration for fatigue.
- Define and set expected behaviors, competencies and accountabilities, for leadership and supervision (Superintendents and Supervisors, applying to all step-up personnel as well), including explicit expectations for sounding emergency alarms.
- Site management must set and communicate a clear safety priority relative to activity and expenditure. They must ensure that sufficient resources and investment are available for integrity management and risk reduction at the site.
- Reset Line Management priorities to make management team members more visible on the process units and regularly engage employees in face to face communication.
- Implement Advanced Safety Audit (ASA) on a site-wide basis with clear expectations for the need to perform quality ASAs with face-to-face conversations. Provide training as required at all levels.

- Define, budget and implement a site Risk Reduction Plan. This should include a re-evaluation of major risk. Both of these should be done on an ongoing basis.
- Reduce activity by ensuring that all work is aligned with site priorities, and instigate upgraded planning and control mechanisms to maintain focus on priorities.
- Define and implement an action plan to improve the relationship with regulatory agencies, and achieve site removal from OSHA's Enhanced Enforcement Program.
- Establish mechanisms to openly encourage importing to Texas City best practices from the BP Group, such as the Golden Rules of Safety, which are not currently used, or where existing local standards have not been updated.

7.1.2 Supervision

- Supervisors must be present at shift relief on the unit to make sure that procedures are correct, signed off, and up to date. In addition, at key stages of startup and shutdown, the Superintendent must be present at relief, and the Supervisor must be onsite throughout the operation. They must maintain a chain of command at all times, any changes to which must be understood and approved by the Manufacturing Delivery Leader.

7.1.3 Workplace Environment

- Rebuild trust with the workforce as measured by PAS scores and/or other explicit employee feedback tools. Prepare and execute a plan to improve morale as measured by PAS scores and link PAS score enhancements to Supervisory Performance Evaluations.
- Make safety and people management the top priorities in management Performance Evaluations.
- Set expectations for employees to raise safety concerns, and the ability to say "no" to unsafe practices without fear of retribution.
- Build quality (vs. "tick the box" approach) into work processes, and establish a verification mechanism to ensure that work is actually completed and not just signed off.
- Define explicit conditions under which hourly employees step up into supervisory positions or higher level management positions. When employees step up, there needs to be absolute clarity of the chain of command. Minimize occurrence where possible.
- The site should evaluate if there are other positions where additional pay may be merited, and, if so, agree with the Union.
- In addition to emphasizing communication through the line, publicize and positively encourage greater use of Open Talk to ensure that workplace issues are identified and addressed in a timely manner.

7.1.4 Individual Performance

- Complete holistic individual competency assessments (including skills, attitudes and behaviors) through individual performance appraisals and developmental plans for all employees to improve skills and performance. The assessment should be owned and performed by the supervisor/line manager with oversight by an independent person. The performance appraisal and competency assessment should feed into the individual's performance improvement plan.

7.1.5 Resourcing

- Perform an independent overall staffing study to evaluate the correct resourcing in all support functions, as many people were "wearing multiple hats" or stepped into other roles without adequate coverage. Especially in the areas of Process Safety, Training and HSE.
- Clarify situations where additional staffing is needed, e.g., two supervisors or two board operators.
- Develop site-wide guidelines for overtime working, i.e., maximum number of hours/day, days/week, days/month that can be worked, for all BP employees and contractors.

7.1.6 Communications

- Create a daily operational meeting with compulsory attendance and membership, as the current Shift Director's meeting appears ineffective and primarily focuses on commercial issues.
- Define an explicit policy for how shift relief is to be conducted with an emphasis on face-to-face communication and required review of written procedures for any work that is in progress.
- Define at least two explicit mechanisms to ensure that communication of impending unit startups to all adjacent areas/personnel occurs.
- Define an explicit policy for the timely upward notification of impending unit startups.
- Enhance the Texas City home website to provide one-stop shopping for all necessary links in a user-friendly and consistent format.

7.1.7 Operators

- Complete a Human Factors Assessment of the Board Operator position and work environment to identify gaps and implement optimal work rotation. Assure the Board Operator maintains operational awareness through regular outside work.
- Establish sanctity of Control Room (i.e., remove distractions).

7.1.8 Training

- Review all ISOM Training to ensure it is up to date and correct. Complete quality refresher training and assessment of operators on a routine basis (i.e., simulators for Board Operator and P/Ts), including process upset management, troubleshooting and explicit expectations for sounding emergency alarms.

- Design and implement a risk identification program to raise understanding and skills of the Texas City Site workforce to identify risk, including potential catastrophic risks and simultaneous operations (SimOps).
- Develop a defined training matrix to cover clear requirements for all levels of staff training needs, including:
    - Core training
    - Required regulatory training
    - Periodic refresher training
    - Verification that all training is completed
- Provide ongoing Process Safety training to all employees to improve their level of understanding and awareness of PSM, especially hazard/risk identification, SimOps, MOC, and related policies. (Note: The North American Gas Onshore Business Unit has developed a program designed to help people see risks better.)
- Implement enhanced Hazard Analysis training for specialists, PHA leaders and MOC leaders, e.g., current "What If" and checklist tools are not as detailed as, say, the ABS Training tools.
- Provide process simulators, and incorporate certification training for Board Operators, Process Technicians and Shift Supervisors, and use to augment outside operator training.
- Adequately resource the Training Department, and ensure that Training Coordinators are not deflected from their role by performing other tasks, and the budget is adequate and utilized for training.
- Increase classroom and on-the-job training, with more emphasis upon upset/troubleshooting training and gun drills, and demonstration of understanding/capability, rather than just VTA tests. Explicit expectations for gun drills need to be defined and based upon a practical walk-through with an external observer for assurance of lessons learned for continuous improvement.
- Set people management competency expectations for everyone in supervisory positions, to include people management, handling conflicts, performance appraisals, motivation, receiving and resolving employee concerns, etc.
- Focus on First Level Leaders' (FLLs) development to provide additional and better tools to meet the new clear expectations, while ensuring that the MDLs and Superintendents hear the same message.
- Ensure all step-ups, stand-ins and replacements (Supv, Supt.) have the same competencies as the person they are deputizing for, and that a MOC is performed by the responsible line manager.
- Instigate a new start engineers' PSM training program, and allocate a mentor. Use new engineers as team scribes so they can learn the process and risk questioning.

7.1.9 Organization

- Drive integration throughout the organization from the top by reducing the number of interfaces and barriers between different parts of the organization. Simplify the organization and define clear accountabilities. Areas of focus should be Engineering, Maintenance and HSSE.
- Enhance the quality and reporting level of independent functions at the site, including PSM, Training, Audit and HSSE with explicit accountability for monitoring follow-up tracking on all aspects of PSM training, Operator Competency Assurance Model (OCAM) response, etc..
- Establish a simple transparent reporting system to ensure that senior site management is aware of what is being found and how audits are being followed up.
- Audits must include physical verification of the work activity being undertaken to verify if the practice matches the documented procedure.
- Improve competency of MOC leaders by creating a smaller central group that is trained and regularly practice.
- Create a central group specifically to investigate inherently safer design developments and industry advances, and design an implementation program. Ensure linkage with BP's Global Refining Network.
- Simplify the HSE committee structure. There are many committees (ESAC, SPSC, TCR JH&S, TCC JH&S, MAT HSE Councils, TCS Procedures Committee, TCS Procedures Council, TCR PULSE, TCC CATS) which appear disparate and unfocused.

7.2 Procedures

- Improve practices for updating and following procedures (i.e., pre-job safety walkthroughs, signing-off steps, checking instrumentation, engineering involvement, shift relief). Supervision (Superintendents and Supervisors) must verify and audit that procedures are being followed, and be supported by Management conducting random verification audits.
- Conduct a thorough review of ISOM operating procedures to verify they are accurate and up to date; incorporate improved troubleshooting guidance; reflect operating practices; and are being followed.
- Modify startup and shutdown procedures to include steps to:
    - Notify personnel on all surrounding units
    - Evacuate all non essential personnel from the unit and surrounding area
    - Incorporate formal "go/no go" decision to proceed with charging feed
- Ensure that operating procedures include safe upper and lower operating limits, and actions to correct deviations from the operating envelope.

7.3 Control of Work and Trailer Siting

7.3.1 Trailers

- When the Facility Siting Study is complete, determine if trailers may be moved to a safe location to create a central trailer park. Until then, all trailers within the site boundary should be locked. Site security should verify daily that trailers remain unoccupied.

7.3.2 Safety Critical Equipment (SCE)

- Create a single safety-critical-equipment register (including RVs, flares, vent stacks, knockout drum, relief header valves, emergency shutdown system, critical alarms, high integrity protection system, safety instrumented system, critical corrective action system, control systems, UPS, deluge, quench). This register should include links to the required maintenance and testing practices. Identify the level of authority needed to approve changes to these practices. (Note that E&P Guidelines for the Integrity Management Standard include definition of SCE).

7.3.3 Facility Siting

- Conduct a new, independent third-party-led Facility Siting Study of the Texas City Site to determine all hazards to personnel on the ISOM Unit from normal and abnormal operations of the ISOM and surrounding process units, including catastrophic events. This study should address fire, explosion, and toxic hazards to occupied buildings, mobile equipment, temporary facilities, muster points, TAR staffing and roads, to ensure that personnel are located appropriately (defined maps, explicit procedures, approval authority, etc.).
- Incorporate the lessons of the third-party modeling of the ISOM blast to set damage thresholds for the interpretation of the new Facility Siting Study of all buildings, including shops, warehouses, labs, and temporary buildings at the Texas City Site.
- Review all existing buildings for expedient "quick fixes", i.e., install shatter-resistant film on windows, secure light fixtures, book cases, etc. against the likelihood of impact in the event of blast damage.

7.3.4 Hazardous Area Classification (HAC)

- Re-evaluate the hazardous area classifications for the ISOM and surrounding areas to determine the extent of controlled areas. Use hot work permits to control all potential ignition sources, including vehicles within controlled areas, and restrict vehicular traffic on adjoining roads when there are planned operational condition changes (i.e., startups and shutdowns).
- Make the HAC drawings readily available as a controlled document that is kept up to date.
- Define and delineate the transition between ISBL and OSBL more clearly.

- Place a physical barrier, such as a chain, across the roadway or entry locations into the battery limits.

7.3.5 PHAs/MOCs/Hazops

- Reduce the number of MOCs by accepting less work, to increase the degree of control of change and emphasize the importance of the quality of the MOC process, by:
  - Improving ownership by management
  - Enhancing the competency and makeup of MOC review teams
  - Enhancing the training/competency of PHA team leaders
  - Learning from previous history and actual operating practices
  - Improving signoff/approval of PHAs, and action item signoff/verification
- Improve the quality of MOC hazard reviews by greater use of the Hazop technique and reduce the dependence on "What If" Review analysis. If "What If" Review is to be used, it must evaluate a comprehensive list of risks.

7.4 Design and Engineering

7.4.1 Accountabilities

- Define an Engineering Authority (EA—Single Point of Accountability) with discipline-specific Technical Authorities to continually reduce the risk factors and evaluate potential catastrophic failures.
- Review the Engineering structure to simplify the interface between Engineering and Operations, in order to improve the feedback of operational reality of the ISOM unit into Engineering.
- Assign clear accountability for the unit to one individual, who is responsible for determining the operating envelope in the event of cumulative changes, including operating changes. This ongoing determination must be reviewed by the EA as part of the 5-year PHA revalidation, and must consider any safer design opportunities.
- Prepare a document for the unit, integrating the safety risks, accountabilities, required competency levels, and safety design improvements. Periodically update this document at a frequency not exceeding 5 years.

7.4.2 ISOM Design and Engineering

- Redesign the ISOM relief and vent system to a closed system, eliminating the use of F-20 as a hydrocarbon relief/venting system to atmosphere. When designed, conduct an independent third-party Process Hazards Analysis (PHA).
- Re-evaluate the control and instrumentation system of the Raffinate Splitter and implement enhancements. In particular, perform a Layer of Protection Analysis (LOPA)

to ensure that there are the appropriate levels of process control (not relying on operator intervention) to prevent a catastrophic incident.

- Evaluate the overall Splitter relief system, including the relief valves location (RVs, header, knockout drum, and future flare), and revalidate at a defined frequency.

7.4.3 Alarm System

- Conduct an independent third-party study of existing emergency alarm systems to identify deficiencies of the system and required improvements.
- Clarify and reinforce the use of alarms with all facility personnel, including activating alarms in simulation exercises with Board Operators.
- Create a system to ensure all site workers are fully briefed on alarm systems and evacuation routes, especially during periods of high maintenance/construction activities.

7.5 Underlying systems

- Revamp the Control of Work system to integrate different work scopes (including SimOps), risks hazards and competencies.
- Conduct a complete review of the underlying systems and processes used to control the site. Integrate, where appropriate, the disparate databases that track actions (TRACKS for MOCs and Audits; Traction; SAP for PPMs; Documint for SCE instrumentation; Over Speed Trip database; PCMS for RVs; other inspection databases; etc.).
- Replace or upgrade the current maintenance management system, SAP, which does not have the functionality and central documentation storage capability of competitor systems, leading to its disuse for critical data storage. Evaluate the functionalities of other sytems such as Maximo.
- Simplify the interface with Traction and provide training to facilitate user-friendly, less cumbersome data entry for all employees and systematic follow through.

7.6 Investigation and Reporting of Incidents

- Define incidents that need reporting, such as process upset (RVs relieving, vent valves being opened, etc.), loss of containment, fires, etc.
- Set an expectation of zero tolerance for nonreporting of incidents, and make supervisors accountable, so that all incidents will be investigated.