Independent Investigation of the Catalyst Release from Martinez Refining Company on November 24-25, 2022

Report prepared by

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I. Foreword

On the night of November 24-25, 2022, the Martinez Refining Company, which is part of the PBF Energy family of refineries, experienced an incident in which a large amount of catalyst from the Catalytic Cracking Unit (CCU) was released into the City of Martinez, California. The Contra Costa [County] Health Hazards Materials Programs (CCHHMP) classified this incident as "Community Warning System (CWS) Level 2 or higher Major Chemical Accident or Release (MCAR). This investigation was conducted as provided in the Contra Costa County Industrial Safety Ordinance (ISO).[1]

Scott Berger and Associates, LLC was chosen by CCHHMP to perform this independent investigation. This report describes the investigation results, including root causes, contributing causes, and human factors. The investigation followed the methodology described in *Guidelines for Investigating Process Safety Incidents*[2]. In performing this investigation, the team relied on both eyewitness and expert testimony of Martinez Refining Company (MRC) employees, along with documents and data provided by MRC, relevant technical references, and the investigators' experience in the field of process safety.

The support and cooperation of MRC employees at all levels, in face-to-face, web-based, and telephone interactions, is to be commended. The investigators believed that employees gave true and accurate statements and honest opinions to the best of their abilities, and that employees felt free to provide their input without retribution.

The investigators have confidence that the root causes of the incident described in this report are accurate to the best of their knowledge and experience in engineering and process safety, and that the recommendations are appropriate.

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[1] Contra Costa County. (2023). § 450-8.016. stationary source safety requirements., Chapter 450-8. risk management, division 450. hazardous materials and wastes, Title 4. health and safety, ordinance code, Contra Costa County. The State of California; Contra Costa County. http://www.contracostaco-ca.elaws.us/code/oc_title4_div450_ch450-8_sec450-8.016

[2] CCPS, *Guidelines for Investigating Process Safety Incidents* (3rd ed.), AIChE/Wiley, (2019).

II. Executive Summary

Shortly after midnight on November 21, 2022, a safety system automatically shut down the MRC CCU due to the failure of control electronics of an air blower. Repairs were made to the blower and the CCU was brought back online overnight on November 24-25. At about 20:30 on November 24, as CCU feed rates were being returned to normal, the CCU catalyst regenerator vessel (Regenerator) overfilled with catalyst, resulting in a release of catalyst to the City of Martinez, California. White catalyst powder was found covering horizontal surfaces on the ground and on resident's vehicles and trash cans, southwest, west, and northwest of the refinery. Based on analysis of samples collected and community complaints, Contra Costa Health Hazards Materials Programs (CCHHMP) staff identified that this incident as a Community Warning System (CWS) Level 2 or higher incident.[3] As a result, it was considered a Major Chemical Accident or Release (MCAR).

None of the catalyst fell in the refinery. Refinery personnel were unaware of the release while it was occurring. and only learned of the incident when neighbors reported it the next morning. As catalyst was being released, refinery personnel continued to incrementally increase the feed rate. The release stopped at about 04:00 on November 25, and the start-up was completed at about 06:15. It was determined that approximately 24 tons of airborne catalyst powder were released to the community. No injuries or damage to the CCU were experienced with this event. The root causes of this incident and recommendations for addressing them are presented in this report.

III. Introduction

A. Objectives

CCHHMP hired Scott Berger and Associates, LLC (see Appendix B) to perform an independent root cause analysis incident investigation. This report describes the findings of that investigation and offers recommendations for improving plant operations in the future.

B. Scope and Approach

The scope of this report includes the timeline of events, and causal factors leading up to the release of catalyst. Work was conducted both on-site at the MRC and offsite, and included review of documents and operational data, personnel interviews, and detailed analysis. The reporting of this incident to Bay Area authorities was specifically excluded from this investigation. Additional details are provided in Appendix A.

C. Report Format

This report describes the process of "cracking" hydrocarbon as the CCU was intended to be operated, the timeline of events leading up to the incident, the root causes, the contributing causes. It identifies gaps in the facility's Process Safety management system along with human factors that contributed to the incident, and offers recommendations to correct these gaps, along with implementation priorities. This report also provides an evaluation of MRC's investigation report to CCHHMP. The appendices in this report summarize the scope of work, present the investigation team experience, and compare the use of wet gas scrubbers to electrostatic precipitators during process start-up of CCUs.

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[3] See https://cwsalerts.com/about-cws/frequently-asked-questions/

IV. Description of the Incident

A. Prior to the Incident

In 2018, the then-owner of the facility, Shell Oil Products, conducted a process hazard analysis (PHA) of the CCU. Shell's PHA identified a process upset condition involving high-high differential pressure (dP) in the Fourth Stage Separator (FSS) leading to a possible catalyst release. However, they classified the scenario as a consequence severity two (2) according to Shell's five (5) level consequence evaluation scale. Based on Shell's risk decision policy, it was determined that no additional mitigating measures were required.

In 2022, the current owner of the facility, PBF Energy, conducted a PHA of the Carbon Monoxide Boilers (COBs), a downstream process that receives flue gases from the FSS. That PHA identified a similar process upset condition. Like Shell, MRC classified it as consequence severity two (2), with no additional mitigating measures needed.

As learned from the experience of this release, the consequences of these upset conditions should have been classified as a consequence severity three (3), based on the need to clean-up the released catalyst. If this had been recognized at the time of these PHAs, Shell's and MRC's risk management policies would have led them to implement additional measures to prevent this type of incident.

B. Shut-down of the CCU

At approximately 01:06 on November 21, 2022, an instrument failure within the CCU Air Blower (J-123) triggered a safety system that shut down the CCU and diverted CCU feed from the Reactor Riser (RR). It also de-energized the Electrostatic Precipitators (ESPs)[4] and performed other safety functions.[5] Shortly after the ESPs were de-energized, the continuous opacity monitors on the COB stacks sounded an alarm indicating high opacity (a reading greater than 4 Ringelmann). It is important to note that while this represented an exceedance of the refinery's air permit condition, the high opacity condition is not the incident being investigated.

Following the CCU shutdown, the Wet Gas Compressor (WGC; J-125) continued to operate. As the quantity of wet gas grew smaller, the WGC total discharge flow control valve (5FC340; spillback valve) automatically opened in an attempt to prevent compressor surge and potential damage to the WGC. Shortly thereafter, this valve was placed in Manual.

C. Establishing Catalyst Circulation

The Air Blower (the equipment that failed, causing the CCU to shut down) was repaired and restarted at around 10:40 on November 21. Feed can be reintroduced only after establishing stable catalyst circulation. Before starting catalyst circulation, the Regenerator bed must first be heated with hot air to about 1000 °F. However, the next step, lighting the Air Preheater (F-65) was initially unsuccessful. As cooler air flowed through the Regenerator, the catalyst bed temperature continued to drop.

Meanwhile, the WGC operation was unstable, operating at or near surge conditions. At around 11:30 on November 21, personnel opened valves to route propane from storage to the WGC via the Main

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[4] The final stage of cleaning CCU flue gases to remove remaining catalyst fines.

[5] See process diagram in Figure 1.

Fractionator (MF) Overhead Accumulator (OHA). This stabilized WGC operation. Propane continued to flow, gradually reducing refinery propane inventory. Propane flow would not be stopped until much later.

Troubleshooting and repair of the Air Preheater ignitor involved a production specialist who had expertise in CCU operation and systems, as well as a deep commitment to the success of the refinery. From the time this specialist began working on the ignitor until after the incident, this individual followed a pattern of working 22–25 hours, resting at home for a few hours, and then returning to work another similarly long period. This individual served in a key decision-making role during this period.

The Air Preheater ignitor was repaired, and light-off occurred about 09:00 November 22. Heating the Regenerator bed and establishing catalyst circulation continued until about noon on November 24.

D. Feed Reintroduction: November 24 Day Shift

A step in the startup procedure prior to the feed re-introduction step involved placing the SSV in Auto (although it did not explain why). Furthermore, the unit process engineer had instructed operating personnel to place the SSV in Auto before starting feed and had added that if it could not be run in Auto, personnel should contact an instrument technician. Per the procedure, personnel put the Stripper Slide Valve (SSV) into automatic control mode (Auto) at 04:45 on November 24. Then at 06:29 on the day shift, personnel reverted the SSV to manual control mode (Manual)[6] to address a transient condition that occurred while establishing stable catalyst circulation. After the transient condition was resolved, the SSV should have been returned to Auto, but this was not done. Nonetheless, feed reintroduction began shortly after noon on November 24 with the SSV in Manual. The SSV remained in Manual until well into the night shift.

Around the time that feed reintroduction began, the refinery inventory of propane had dropped to a level at which Refinery Logistics was required by refinery policy C(A)-20 to notify operating units of impending low propane inventory. Following this policy, Logistics and CCU personnel evaluated the rate of propane consumption compared to the minimum required inventory. Personnel considered that as feed increases, the CCU would start to make propane and heavier hydrocarbons and ultimately relieve the need for propane to the WGC. Therefore, they decided to continue drawing propane at the same rate. As feed was slowly increased, personnel manually cut back on propane to the OHA, and simultaneously worked the WGC spillback closed in Manual. The WGC was placed in Auto at 23:10 on November 24. Monitoring and managing the propane inventory and flow to the OHA required additional operator attention.

With the initial reintroduction of feed, a pressure surge occurred. Because the WGC spillback was in Manual, it did not automatically respond to the increased pressure. The brief pressure rise automatically opened a pressure control valve from the OHA to the flare system. Normally, two compressors in the flare system would redirect the released gases to a location in the refinery where those gases could be recovered. However, one of the two compressors was down for maintenance,

[6] When starting up a process unit, changing conditions can require personnel to temporarily take manual control (Manual) from time-to-time, because automatic controls (Auto) are tuned preferentially to operate under normal reaction conditions.

so a portion of those gases were briefly released to the flare. This was the second flaring event experienced by the day shift. The Cracked Gas Plant (CGP), the unit that receives cracked products from the CCU and shares a control console with the CCU, was also opened to flare earlier that day.

E. Feed Reintroduction: November 24 Night Shift

Normally, the feed reintroduction procedure would be conducted by two console operators, one focused on operating the Compressed Gas Plant (CGP) while the other focused on the CCU. However, on the night shift, the fatigued production specialist took charge of some of the CGP and CCU console operations. This changed the dynamics and situational awareness of operating the CCU console.

When the night shift personnel started their shift at 18:00 on November 24, they found the SSV still in Manual. This reinforced to them a preconception that this valve was sticky and balky. Among the personnel working that evening, there was a general belief that the SSV could be given a series of small manual input changes to valve position without a response, and then the valve would move suddenly, potentially more than desired. The SSV remained in Manual until 23:25.

Between 19:10 and 20:20 on November 24, the SSV remained at 37.0% open. During this period, the dP across the SSV increased from 2.9 to 5.9 psi, significantly increasing the rate of catalyst flowing from the Stripper to the Regenerator. As a result, by 20:07 the Regenerator Catalyst Bed level rose steadily from about 30 feet to above the critical high alarm level of 34 feet, where it remained until 20:57. The high catalyst level overwhelmed the first and second stage cyclones, sending a much higher than normal load of catalyst fines to the third stage separator (TSS) and fourth stage separator (FSS). The FSS high dP alarm sounded at a 20:32, and the high-high alarm sounded at 20:34, indicating that the FSS was too full with catalyst.

Other than for a ten-minute period after midnight around 02:45, the FSS remained at high-high dP until shortly after 04:00 on November 25. During this period, catalyst passed on to the CO Boilers (COBs), from there to the ESPs (that were de-energized[7]), and then out the stack.

It is clear that the rate of release of the catalyst was highest from about 20:32 until at least 20:56 when the Regenerator Catalyst Bed dropped below the critical high alarm level. It is not known at what time the First and Second Stage Cyclones returned to full function. A doorbell camera of a person living near the refinery captured catalyst falling from about 20:40 until about 23:30. Because the FSS remained in high-high dP alarm (and therefore was impaired) until shortly after 04:00 on November 25, the release of catalyst could be expected to have continued until then, albeit at a rate too low to have been detected by the camera. It is expected that the rate of catalyst emission returned to the high opacity condition that existed before the incident. As discussed above, the high opacity condition is not considered part of this incident.

The WGC spillback was placed in Auto at 23:10 on November 24 and the SSV was placed in Auto at 23:26. Full feed rate to the RR operation was reached at approximately 06:15 on November 25, and the ESPs were re-energized shortly afterward.

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[7] The release rate was well in excess of the capacity of the ESPs. Had they been energized, the quantity of catalyst released would have been only somewhat less.

V. Background

Figure 1 provides an overview of the Catalyst Cracking Unit (CCU) process, the primary focus of this incident. Connected processes mentioned in the figure include the CO Boilers (COBs), the Cracked Gas Plant (CGP), and the Flare Gas Recovery Unit.

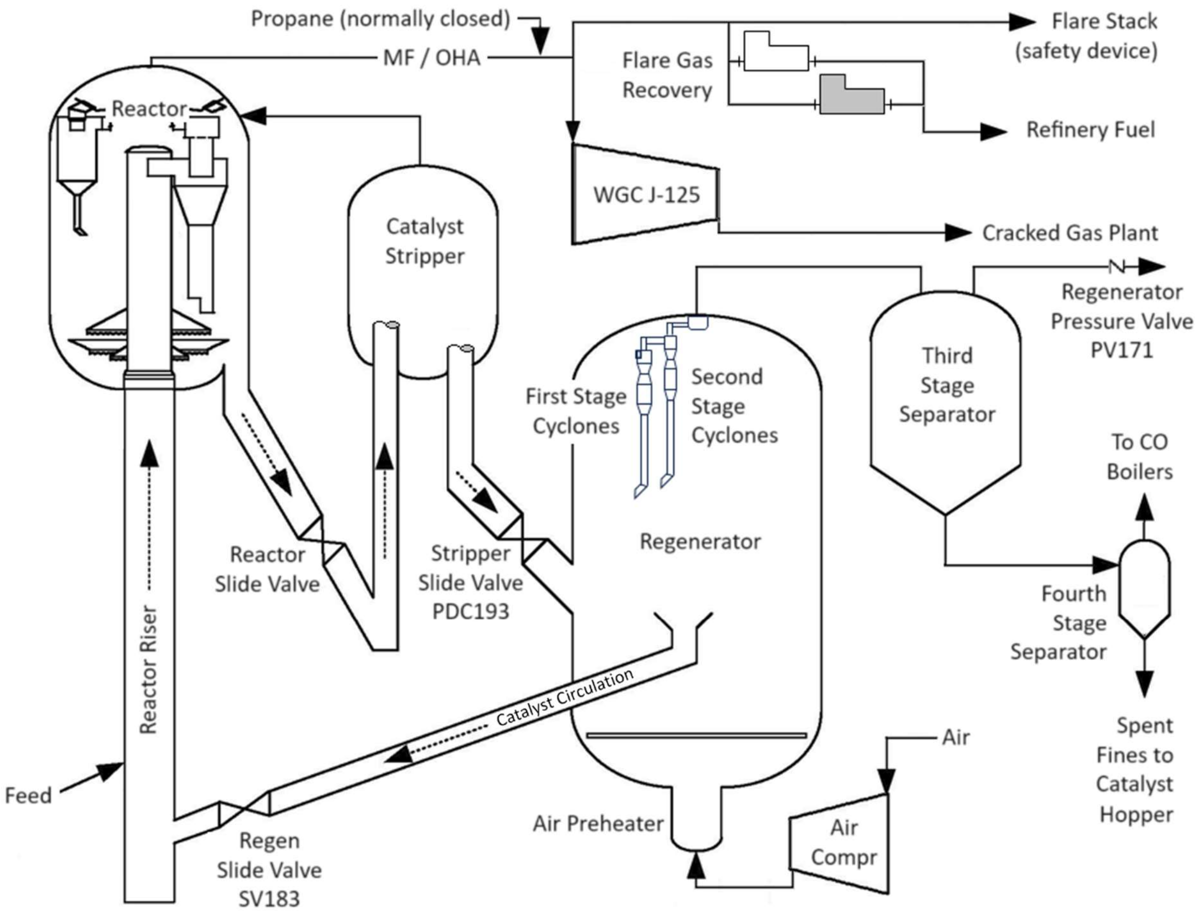

Figure 1: Catalytic Cracking Unit

Catalytic cracking was developed and commercialized circa 1940. This technology increases the yield of high-quality products by reducing, or "cracking," larger complex hydrocarbon (HC) molecules into lighter products. Larger HC oils are heated and pumped into the Reactor Riser (RR) where they contact nearly 1300 °F powdered catalyst. In the RR, the larger HC molecules are cracked into smaller molecules such as gasoline, butane, or propane. This reaction also deposits carbon on the catalyst. At the top of the RR, cyclonic separators (cyclones) separate the now-spent catalyst from the HC vapor.

The vapor continues to the Main Fractionator (MF) where liquid products are separated, and the vapor is further cooled before being collected in the Overhead Accumulator (OHA). Off-gas from the OHA is routed to the Wet Gas Compressor (WGC) which compresses it for processing in the Cracked Gas Plant (CGP). The WGC also functions to regulate the OHA pressure. This in turn controls Reactor pressure and the pressure above the Stripper slide valve (SSV).

The spent catalyst flows to the Catalyst Stripper, where steam is used to strip HC from the spent catalyst. The SSV valve maintains a level in the Catalyst Stripper, and then the catalyst flows through that valve, returning to the Regenerator.

An Air Blower provides combustion air to the Regenerator where carbon is burned off the catalyst. This also provides heat to maintain the desired temperature of catalyst flowing to the RR.

The catalyst in the Regenerator is fluidized by the upward flow of air and combustion gases. The catalyst is suspended in a dilute phase near the top of the Regenerator and in a dense phase below. The interface between the dilute phase and the dense phase constitutes the "catalyst level." The level indication is calculated from differential pressure (dP) between the bottom and top of the Regenerator.

Regenerator combustion gases (flue gas) entrain fine catalyst (fines). Most of these fines are removed as they pass through the First Stage Cyclones. The catalyst fines fall through the dip leg into the dense phase of the Regenerator. The small amount of fines remaining in the flue gas continues to the Second Stage cyclones. These and the downstream, external, Third Stage Separator (TSS) and Fourth Stage Separator (FSS) work in a similar manner. Personnel periodically remove catalyst fines from the TSS and FSS for disposal.

If the Regenerator catalyst level is too low, the dip legs lose their seal, allowing catalyst from the dense phase to overload the TSS and FSS. Likewise, if the Regenerator catalyst level is too high, the dip legs become choked, also resulting in catalyst carry-over to the TSS, FSS, and beyond.

The Regenerator pressure is controlled by a pressure control valve, PV-171, routing flue gas to the COBs via the Flue Gas Expander Turbine. Flue gas from the FSS carries the small amount of remaining catalyst fines which are removed by the three (3) Electrostatic Precipitators (ESPs). Each ESP discharges its treated exhaust to atmosphere via an associated COB stack.

VI. Facts

A. Sequence of Events

Table 1 describes the timeline and sequence of events for the catalyst release incident. As detailed above in section III.C. The key events, shown in **bold**, are discussed further below.

Table 1: Sequence of Events

Day	Approx. Time	Event
2018, 2022		**Related scenarios considered in PHAs. Conclusion: no action required**
Monday, November 21	01:06	Air Blower (J-123) Vane Controller tripped; CCU to feed diversion
		ESP tripped, shut down
	Morning	Blower repairs began
	10:42	Air Blower restarted
		Air Preheater (F-65) Ignitor problems
	11:01	WGC Spillback placed in Manual
Tuesday, November 22	09:00	Air Preheater Lightoff
Thursday, November 24	01:20	Catalyst circulation established
	04:45	Stripper SV partially opened to start catalyst circulation
		Stripper Bed level controller (SSV) placed in Auto mode
	06:29	**Stripper SV placed in Manual mode**
	08:00	Delay, Debutanizer bottoms, CGDP pressure
	09:49	FSS high dP, drained to normal
	12:15	Torch oil increased to raise catalyst bed temp to 1100 °F
		Gasoline column depressurizing valve was still open to flare (CGP)
	12:42	Opened one feed nozzle to RR about 25%
		MF OHA PC to flare (in Auto) opens 1-2 minutes with initial introduction of feed
		Approximately six incremental feed rate increases over 8-1/2 hours
	Soon after	**Decision that additional flaring was off-limits**
	12:50	Open remaining RR feed nozzles to 25%
	13:00	Apparent time of propane inventory alert
	Soon after	Decision to limit propane use
	20:00 - 20:30	**Regenerator bed high-high level**
	20:02	RR outlet temp dropped from 950 °F to 900 °F over five minutes; sour water to the riser cut from 24 to 9 GPM; presumed decrease in wet gas production
	20:03	**Apparent feed change event continuing until 20:08**
	20:12	FSS dP dropped (catalyst dumped)
	20:26	**FSS dP increased rapidly (20 minutes)**
	20:30	**Fourth Stage Separator (FSS) high-high dP, release began**
	23:00	WGC spillback flow controller placed in Auto (already closed at this point)
		Place WGC J-125 Recycle Gas flow controller 5FC-364 valve CV-364 in Auto
	23:30	SSV placed in Auto; FSS level begins to drop
		Regenerator Air Blower rate adjusted
		FSS remained at high-high dP three hours, release continued
Friday, November 25	02:45 - 03:00	FSS apparently emptied twice
		FSS dP erratic for ten minutes
	03:00 - 04:00	**High-high FSS dP (again)**
	04:00 - 04:15	**FSS dP returned to normal, catalyst release apparently ended**
	06:15	CCU began operating stably at full rate; ESP re-energized

B. Causal Chain

The causal tree for this incident is shown below (Figure 2). The key links in the causal chain are described in this section.

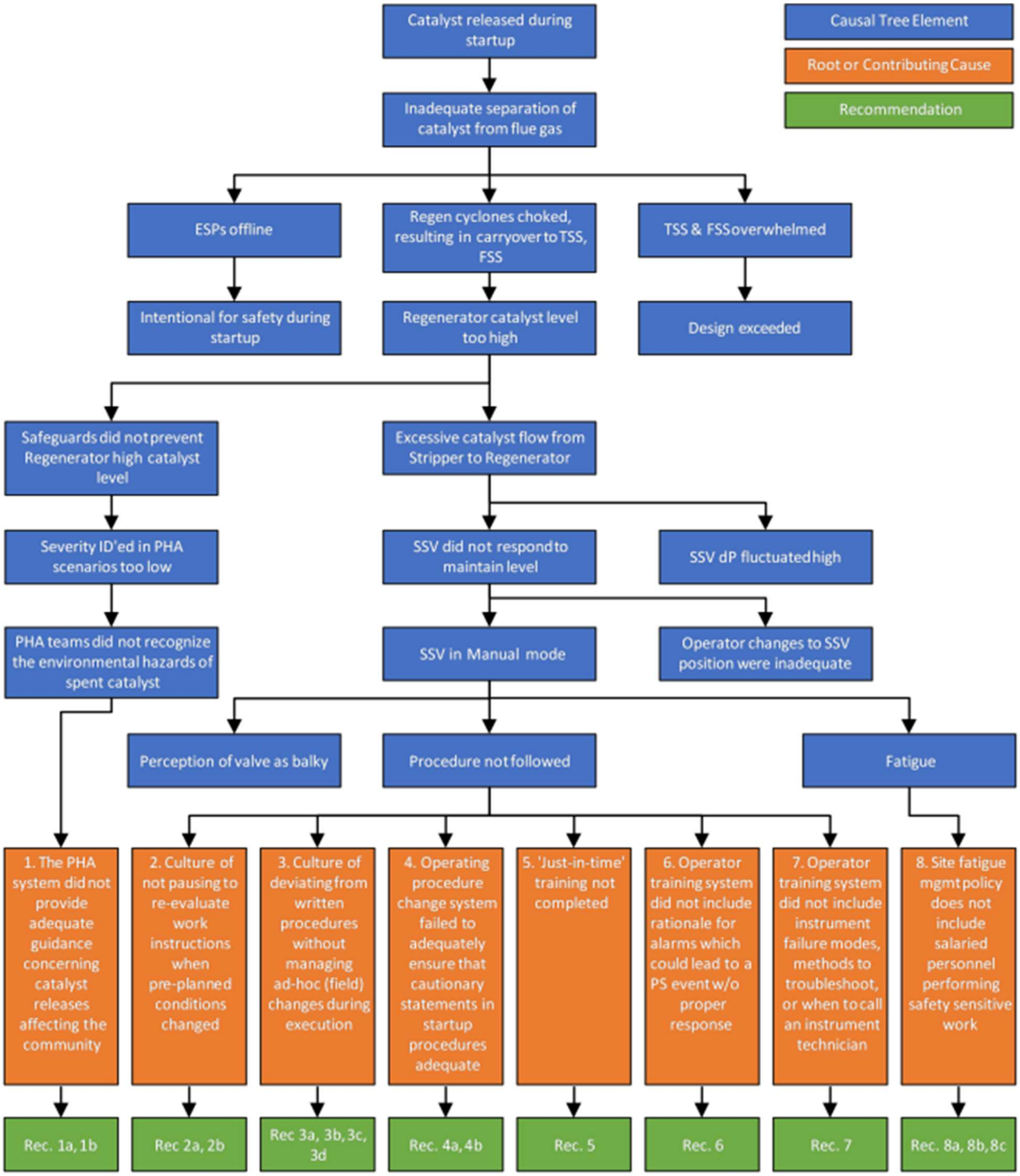

Figure 2: Causal tree of November 24-25, 2022, Catalyst Release Incident

Evaluation of PHA scenarios as "No Action Required": Long before this incident, two separate process hazards analyses (PHAs) had been conducted. Each considered causes that could lead to catalyst carryover: the Shell Oil Products CCU PHA in 2018, and the MRC/PBF CO Boilers PHA in 2022. Each PHA team identified scenarios with a potential for a severity two (2) environmental consequence (meaning, minor or no lasting environmental effect, RQ with agency notification, or short duration remediation). After evaluating the 2022 catalyst release, CCHHMP determined that the event was a Community Warning System (CWS) Level 2 or higher MCAR due to the need to clean up the released catalyst. The Shell and MRC/PBF assigns a consequence category of 3 if environmental cleanup is required.

Stripper SV not in Auto for feed re-introduction: Operating procedures call for the Stripper SV to be placed in Auto before introduction of feed. Additionally, the unit process engineer instructed personnel that the SSV must be placed in Auto before starting feed. The engineer further instructed operations personnel that if the SSV could not be run in Auto, that they should contact an instrument technician to correct the problem. The valve was placed in Auto at 04:45 on November 24 while catalyst circulation was being established. However, at 06:29, together with a procedural step to adjust Regenerator and OHA pressures for correct dP's across the SV's, the Stripper SV was placed in Manual. The procedure and the engineer's instructions were disregarded, and the SSV remained in Manual until 23:25, well after the release began. Instead of operating in Auto per procedure, personnel manually adjusted the SSV position in response to process conditions.

According to the unit process engineer, if the SSV had been in Auto mode according to the procedure, there may have been a brief period in which catalyst circulation stalled, but the regenerator level would not have gone high, and therefore the release would not have occurred.

Culture of accepting deviation from procedures: In discussions with MRC's operating and professional personnel, it was learned that the refinery broadly considers operations to be "Objective-based." In such a culture, personnel are expected to use their training to operate the process however they feel necessary to achieve operational objectives. With this mindset, MRC personnel investigating this incident focused on personnel operating the SSV too slowly, rather than on the fact that they did not follow either the procedure or the verbal instructions about operating in Auto that were given prior to feed re-introduction.

Procedures exist to drive consistency in performance and to identify the safest way to operate. Therefore, if automatic controls are specified, it is because that is the safest way to operate. Automatic controls are not perfect, though. Sometimes personnel must take manual control. For example, if automatic controls are over-reacting or reacting too slowly, manual control would be used to correct the situation. Once the situation is corrected, personnel need to restore automatic control as soon as possible. Or, if the problem with automatic control is more serious, personnel need to bring in an instrument technician or engineer to troubleshoot and correct the problem. And if the procedure needs to be changed during execution, there is a process by which the proposed "redlined" changes are analyzed and approved by the process engineer and possibly others. During this incident, none of these actions occurred.

It's worth noting that the reason for operating the SSV in Auto was not given in the feed reintroduction procedure (CCU-1110), nor in the CCU Unit Console Operator Task Training Workbook Rev. 1. Lacking a specific written basis regarding the rationale for needing the SSV in Auto prior to the introduction of feed, and with a “tribal belief” that the SSV was unreliable (“sticky and balky”), the valve was not returned to Auto prior to the introduction of feed to the RR.

The failure to ensure the SSV was in Auto before introducing feed is a deviation from procedures that had a direct causal link to the incident. Several other deviations from procedures (discussed in section VI.C) served as distractions to personnel and therefore contributed to the incident.

Inadequate training of personnel: MRC policy requires that prior to executing infrequently used procedures, personnel must receive “just-in-time training,” as specified in a note in the CCU Console operator training workbook.

> *"Just-In-Time" Training: Any procedure that is used infrequently (would not be expected to be used at least once a year) will be trained "just-in-time." Just-in-time training is usually associated with operating procedures that are used for special events like normal startups & normal shutdowns for scheduled turnarounds, temporary operations, non-routine tasks, non-routine maintenance events, project work, etc. Just-in-time training would only be required for those individuals that would be involved in the execution of the procedure. Any operator using a procedure that requires just-in-time training will be trained to a Skill Level (as described above) to assure the operator 1) understands their responsibilities with the procedure and 2) can safely execute the procedure as written prior to starting the procedure activities.*

This training is needed to familiarize operators with the challenges they are likely to encounter while executing the procedures and how to respond if those challenges should arise.

At the time of the catalyst release, the CCU Console was being operated by the production specialist and a shift supervisor. While the specialist certainly had deep knowledge of all aspects of CCU operation, the two experienced personnel did not routinely run the CCU. The shift supervisor became qualified to run the CCU console in 2018, but didn’t routinely do this task. There were no records to indicate that either the specialist or the shift supervisor received the just-in-time training for operating the CCU Console.

It is not known how personnel came to view the SSV as sticky and balky, even though it worked adequately. This incorrect view was broadly held.

Excessive work hours for key personnel and superhero culture: For each refinery unit, MRC recognizes key personnel as specialists due to their experience and deep knowledge. These individuals are highly respected by other refinery personnel and management. Specialists believed that they had to be “superheroes,” coming to the rescue to resolve any difficulty that arose in their units.

When the initial Air Blower trip occurred, a CCU production specialist began working extremely long hours. Each day, the specialist worked 22–25 hours straight, went home for a short rest, then worked another 22–25 hours, repeating this pattern until the CCU reintroduction of feed process was complete. The specialist’s excessive hours in performing the safety-sensitive work would have been against refinery fatigue policy G(A)-34[8], but it applied only to hourly personnel. Additionally, the policy focuses more on equalizing overtime than on fatigue management.

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[8] The Refinery Scheduling and Hours of Service Limits Policy G(A)-34 (referred to here as the fatigue policy policy), places strict limits on working more than 14 hours consecutively and limits unavoidable workdays longer than 18

On the night shift of November 24, this individual decided to work the control board alongside the two personnel required to perform the feed reintroduction procedure. Including an additional person as a console operator blurred console responsibilities, contributing to the temporarily overlooked FSS high-high dP alarm. The production specialist operated the controls for the WGC, leaving the rest of the CCU to another individual. The production specialist directed this other operator to avoid flaring and not ask for additional propane for the WGC. The specialist also reinforced that the SSV should be kept in Manual and moved in small increments. Later, when the operator realized that they had missed the FSS high-high dP alarm, the specialist told them they hadn't missed it, when they clearly had.

There are several reasons why the production specialist may have deviated so far from operating procedure and disregarded the process engineer's instructions to keep the SSV in Auto and contact the instrument technician if it could not be run that way. Fatigue almost certainly played a role in these decisions. That fatigue resulted from the specialist's perception of needing to personally be involved in resolving every difficulty. In addition to fatigue, the production specialist was faced with multiple distractions due to the concurrent operational changes. Meanwhile, although they were tasked with performing complex, non-routine start-up procedures, neither was a regular console operator. And finally, there are no records that the specialist (or the other console operators) completed the required just-in-time training. It would be appropriate, in the face of these factors, to have paused reintroduction of the feed. The refinery stop-work authority did not consider difficulties in running the process in the way intended.

C. Contributing Factors

Distractions: Four deviations from procedures occurred that, although not strictly causes of the catalyst release, occupied personnel's attention and potentially either slowed or delayed the manual adjustments to SSV position needed to prevent the release.

- *Operating the WGC in manual spillback control*: Evaluation has shown that the WGC should have been run in Auto mode, requiring less attention from personnel. The procedure called for the WGC to be run in Auto from the beginning of feed reintroduction. However, this didn't happen until approximately 23:00, 2.5 hours into the catalyst release. It appears that the decision to remain in Manual mode was influenced, at least in part, by the call from Refinery Logistics regarding low propane inventory. That call, in turn, was premature in view of the slow and decreasing consumption of propane by the WGC.
- *Decision that flaring was off-limits*: The flare system is a critical safety system for relieving excessive pressure excursions in the Reactor and MF systems. No operator wants to rely solely on the activation of a critical safety system to prevent an incident. This is especially true when that critical safety system is a flare (a release of gas) that irks members of the local community. However, operating the controls with the specific aim of avoiding flaring is contrary to procedures and is an added distraction to personnel.

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hours. The fatigue policy is informed by Recommended Practice (RP) 755, published by the American Petroleum Institute (API) to help companies avoid having workers whose abilities and judgements are compromised by fatigue. However, API RP 755 specifically prohibits greater than 18 consecutive work hours, while MRC's G(A)-34 does not.

- *Sticky Regenerator Slide Valve*: While this valve rarely needed to be moved, it required periodic adjustment during start-up, and would sometimes stick, requiring operator attention.
- *Coordination with the CGP and MF start-up*: These units tied to the CCU were experiencing additional operational difficulties.

Engineering design: Two engineering designs common to other refinery's CCUs may have helped MRC avoid the incident:

- *Cascade control of the Reactor/Regenerator dP to the Regenerator Pressure Controller*: In MRC's CCU, operators would manage this dP by changing the Regenerator pressure setpoint. In similar refineries, the Regenerator pressure control valve setpoint is determined in Cascade[9] from the Reactor/Regenerator dP indication, helping to more consistently control the SSV dP.
- *Direct measurement and control of Reactor feed rate during feed reintroductio*n: MRC measures the feed rate to the reactor with a flow meter and controller located upstream of the point of feed diversion. As a result, as feed begins to be introduced, an unknown fraction of the measured flow rate goes to the Reactor, while the rest remains diverted. Without a measurement of flow rate during feed reintroduction, it is possible for a larger than intended increment of feed to be introduced. Indirect evidence indicates this may have happened in the 20:00–20:30 time frame, providing personnel with an added challenge in controlling dP and Regenerator level. This was not a causal factor for the catalyst release, however, because if the SSV had been in Auto, it would have responded adequately.

The Holiday: November 24, 2022, was Thanksgiving. While MRC personnel stated that holidays were like any other operating day, this was clearly not the case. The console operators who normally would have worked the evening shift took time off, leaving a shift supervisor and a production specialist to operate the CCU. MRC personnel denied that personnel were reluctant to call an instrument technician or process engineer for support when the incident started because of to the holiday, but such reluctance would be understandable.

VII. Root Causes, Contributing Causes, and Recommendations

This section summarizes the root causes and contributing causes of the incident and the supporting evidence for these classifications. It also puts forward recommendations regarding safer operations in the future and the priority for addressing these recommendations.

Root and contributing causes are identified in four categories, pertaining to the Process Safety management system (MS), to the culture of the workplace (CL), to Engineering Design (ED), or to human factors (HF). Table 2 lists the root causes of the incident along with recommendations for MRC. Table 3 lists the contributing causes, also with recommendations for MRC. Additional recommendations for MRC and for CCHHMD follow the tables.

[9] Cascading is a control scheme in which the setpoint for an automatic control is derived from another process variable. As that process variable changes, the controller setpoint automatically adjusts.

Table 2: Root Causes and Recommendations for MRC

#	Type[10]	Root Cause	Evidence	Recommendations	Priority[11]
1	MS	The PHA system did not provide adequate guidance concerning how catalyst releases affect the community.	PHA scenarios evaluated in the 2018 CCU PHA and the 2022 COB PHA related to this incident were classified as consequence severity two (2), rather than consequence severity three (3); as a result, additional mitigation measures were not recommended.	a. Clarify scenario consequence assessment guidance in corporate risk assessment policy to provide more accurate guidance regarding environmental consequences of catalyst releases.	PI
				b. Review relevant refinery PHAs for similar scenarios where environmental consequences of PHA scenarios may be underestimated.	PI
2	CL	A culture existed which was not conducive to pausing to re-evaluate work instructions when pre-planned conditions changed (lack of situational awareness, Stop Work Authority did not address).	MRC proceeded with non-normal startup: • on a holiday • with technical personnel who are not normally console operators • some of whom didn't complete required just-in-time training • while operating multiple dynamic process conditions in manual control • with multiple operational challenges and while executing a complex, non-routine procedure • with highly fatigued key personnel • while addressing other distracting and challenging factors	a. Add consideration of situational factors to Pre-startup Safety Review/Prepare to Operate instructions in refinery start-up procedures.	PI, RR
				b. Update stop-work policy/program and associated training to include evaluation of complex situations in non-routine work.	PI, RR

[10] CL = Culture, ED = Engineering Design, MS = Management System

[11] LR = Long range effort which should start soon but can be expected to continue, NT = Next Turnaround, PI = Priority implementation, RR = Routine reminders, RV = Routine verification

Table 3: Root Causes and Recommendations for MRC (Continued)

#	Type[12]	Root Cause	Evidence	Recommendations	Priority[13]
3	CL	A culture existed of deviating from written procedures without managing ad-hoc changes (i.e., making "redline" field changes which include review and approvals).	• MRC's MCAR investigation focused on adequate control of SSV in Manual, instead of why SSV was operated in Manual when the procedure and training said it should be in Auto. • Procedure also was not followed for WGC control and feed reintroduction.	Review and revise the site procedure for managing operating procedure changes made during procedure execution (i.e., "field changes") as needed to ensure that a. The means for 'redlining' changes, ad-hoc review, approvals, and training for subsequent shifts are addressed b. Affected personnel are educated as needed for compliance c. That the system provides prompt review and revision of executed procedures to incorporate approved changes d. That the system includes metrics which provide management oversight of adherence to written procedures.	PI
4	MS	The operating procedure development and change system failed to adequately ensure that cautionary statements in the startup procedure were adequate.	The operating procedure to Startup from Unplanned Feed Outages (CCU-1110) did not address the rationale and importance of operating the SSV in Auto during feed introduction to prevent high regenerator catalyst level.	a. In the operating procedure development and change system, review criteria for the use of cautionary statements prior to critical procedural steps. Revise the procedure review checklist to confirm that cautionary statements are included when appropriate.	PI
				b. Update operating procedure CCU-1110 to include a caution statement explaining the rationale for ensuring that the SSV is in Auto mode when feed is introduced to the RR.	PI

[12] CL = Culture, ED = Engineering Design, MS = Management System

[13] LR = Long range effort which should start soon but can be expected to continue, NT = Next Turnaround, PI = Priority implementation, RR = Routine reminders, RV = Routine verification

Table 4: Root Causes and Recommendations for MRC (Continued)

#	Type[14]	Root Cause	Evidence	Recommendations	Priority[15]
5	MS	The training program did not ensure that just-in-time training was being completed as prescribed.	There is no record to document completion of just-in-time training on an infrequently used procedure (CCU-1110) by personnel involved with performing the procedure	Modify the training management system to ensure that "just-in-time" training for this and other relevant procedures is conducted as prescribed in the CCU Unit Console Operator Task Training Workbook and other refinery task training workbooks.	PI

6	MS	The operator training system did not include rationale for process alarms which could lead to a process safety event without proper operator response.	• The CCU Console Operator Task Training Workbook did not address the following:
			  ○ The rationale and importance of maintaining the regenerator catalyst bed level below 30 feet
			  ○ The rationale and importance for the high-high dP alarm on the FSS, particularly when the ESPs are de-energized.
			• Personnel involved in starting up the CCU did not recognize the potential catalyst release as serious; thus, they were merely dealing with the symptom of high-high dP on FSS.
				Develop or update the criteria for operator training and conduct a review of materials to ensure that the bases for alarms involved as safeguards in process PHA scenarios are included in the training materials.	LR

[14] CL = Culture, ED = Engineering Design, MS = Management System

[15] LR = Long range effort which should start soon but can be expected to continue, NT = Next Turnaround, PI = Priority implementation, RR = Routine reminders, RV = Routine verification

Table 5: Root Causes and Recommendations for MRC (Continued)

#	Type[16]	Root Cause	Evidence	Recommendations	Priority[17]
7	MS	The operator training system did not include the information needed to understand how instruments fail, simple troubleshooting methods, and when to call an instrument technician.	Personnel involved in starting up the CCU incorrectly believed the SSV (and other instruments) to be sticky and balky yet did not call out an instrument technician to resolve the balky valve.	Standardize the approach for response to malfunctioning instrumentation and educate affected operations personnel. Address basic types of instruments, how they malfunction, simple troubleshooting methods, instrument criticality, when to ask for instrument technician assistance. Include a reference to the MRC program for bypassing a safety device.	PI
8	MS	The site policy for managing fatigue does not include salaried personnel performing safety sensitive work.	• The intent of the fatigue policy is to "distribute overtime as equally and as reasonably practical among eligible employees while remaining in compliance with company and legal requirements limiting hours of service." • The fatigue policy does not apply to non-hourly personnel, even for safety-sensitive work. • An individual working the CCU console during startup worked significantly more than fatigue management requirements prescribed in the fatigue and scheduling policy. • The excessively long shifts continued unchallenged throughout the incident.	a. Modify the fatigue and scheduling policy to include both all hourly and all salaried personnel performing safety-sensitive activities.	PI
				b. Educate affected individuals who weren't previously covered by the policy.	PI
				c. Provide leadership oversight of fatigue policy, supported by relevant metrics.	PI

[16] CL = Culture, ED = Engineering Design, MS = Management System

[17] LR = Long range effort which should start soon but can be expected to continue, NT = Next Turnaround, PI = Priority implementation, RR = Routine reminders, RV = Routine verification

Table 6: Contributing Causes and Recommendations for MRC

#	Type	Contributing Cause	Evidence	Recommendations	Priority (*)
1	ED	Personnel had difficulty managing the dP between the Reactor and the Regenerator during CCU startup.	This contributing cause is documented in operational data from startup performed in November 2022.	Consider upgrading the control scheme of Reactor/Regenerator dP to Cascade control of the Regenerator pressure setpoint.	NT
2	ED	Lack of flow indication of feed to the RR increased the difficulty of managing the WGC suction pressure / Reactor pressure / SSV dP.	This contributing cause is documented in operational data from startup performed in November 2022.	Consider adding a flow meter to inform operators of actual feed flow rate to the RR.	NT

Additional Recommendations to MRC

The system that MRC used to manage fatigue, Policy G(A)-34, did not specify how to monitor performance of a fatigued individual, or the means to ensure that performance was monitored. The exceedance form reviewed in this investigation merely indicated “Increased monitoring,” and there was no means of indicating that this was done. The following changes to this policy are recommended:

- Update Attachment B, *Critical Exceedance Form* for fatigue management, to clearly identify the nature of the exceedance.
- Specify in the policy specific management actions to be used monitor the performance of the fatigued individual to prevent mishap.
- Require documentation that the required management actions were conducted.

VIII. Review of MRC’s Investigation Report and Status of Action Plan

MRC delivered their investigation report to CCHHMP on February 3, 2023. In the report MRC, identified two root causes and one contributing factor, along with a Human Factors analysis, and presented eleven corrective actions. In this section the MRC report is reviewed, taking into account the information assembled through the independent investigation. MRC also included in their report an analysis of their incident reporting. MRC’s reporting of this incident was outside the scope of this independent investigation and therefore is not discussed here.

MRC’s Root Cause 1[18]: *As the Reactor pressure increased, the set point changes to Regenerator pressure control valve PV-171 were being made manually and did not effectively offset the increased Reactor pressure and the resulting flow of catalyst from the Reactor and Stripper into the Regenerator.*

> Analysis: The result of this investigation shows that manual adjustment of control valve PV-171 may have been a contributing cause. If this valve’s control system had been designed according to common industry practice and operated in the appropriate mode, it would have helped prevent the incident.

MRC’s Root Cause 2: *As the Regenerator catalyst bed level increased, the changes to the position of the Stripper slide valve were being made manually and were insufficient to prevent the Regenerator catalyst bed level from continuing to increase.*

> Analysis: This investigation found that the Stripper slide valve was supposed to have been placed in Automatic prior to the first reintroduction of feed. However, it remained in Manual in the time leading up to the incident and for several hours into it. If it had been operated in Automatic, the incident would not have occurred. Therefore, while it may have been possible for personnel to have made more aggressive changes to the valve position to control Regenerator catalyst bed level, the root cause was the deviation from the procedure by not operating the valve in Auto.

MRC’s Contributing factor: *During the re-introduction of feed to the CCU, the Wet Gas Compressor (WGC) was near surge conditions and required the injection of propane into the Main Fractionator (MF) Overhead Accumulator to increase the molecular weight of the gas and prevent flaring. The MF overhead pressure, which ultimately controls the Reactor pressure, could not be reduced to help balance Reactor and Regenerator pressures because of low propane inventory in the refinery.*

[18] This and the other root causes, contributing causes, and human factors were excerpted from MRC’s MCAR report.

Analysis: The result of this investigation showed that the propane situation may have been somewhat of a distraction to operating personnel.

MRC's Human Factor Analysis: *This analysis [MCA's MCAR Report] revealed two (2) instances in which MRC personnel did not comply with refinery policy and procedure during the incident. First, there was a deviation from the refinery's Work Schedule Expectations for Staff (Exempt and Non-Exempt) policy regarding an individual who exceeded his hours limitation. Second, some End of Shift Reports were not properly completed pursuant to the refinery's Roles and Responsibilities SOSO procedure.*

However, it was concluded that these deviations do not appear to have directly contributed to the root causes of the incident because the individual who exceeded his hours limitation was not directly involved in the pressure and catalyst bed regulations discussed above.

Analysis: This investigation determined that one worker was so far in excess of hours-of-service requirements that it was almost inevitable that bad decisions would be made. This worker did not have direct control over the SSV but sat next to and was a significant influence on the worker operating those controls. This individual was in a role that was not covered by the refinery fatigue policy G(A)-34. As such, this investigation found root causes in the refinery's Work Schedule Expectations for Staff policy.

The absence of end of shift reports was confirmed in this investigation. While it does not appear to have been a root cause, the lack of reports hindered the investigation and represents a lack of operational discipline that may carry into other activities.

MRC's Corrective Action No. 1: *Based on the learnings from this incident, develop a control strategy for automating the differential pressure control between the Regenerator and Reactor during startup and feed re-introduction.*

Analysis: The control strategy envisioned by MRC for this scenario would bring MRC's CCU up to date with common industry practice. If the update control strategy from this corrective action had previously been implemented, it would have helped prevent this incident.

Status of MRC's Action: As of July 31, 2023, MRC had developed the strategy, and plans to implement it during the 2025 turnaround. It was also learned that this modification was planned by Shell for the 2018 turnaround but was deferred for economic reasons.

MRC's Corrective Action No. 2: *Based on the learnings from this incident, CCU Operator alarm actions for Regenerator/Reactor differential pressure and Regenerator catalyst bed level will be updated to provide additional alarms and response guidance to MRC personnel in the event of such alarms.*

Analysis: This investigation showed personnel were receiving more than ten (10) alarms per ten-minute period between 20:00 and 20:30, more than the industry-recommended maximum of ten (10) per ten–minutes for two consecutive periods. This investigation does recommend providing additional response guidance for alarms, especially the FSS high-high dP alarm. MRC should continue the work currently in progress to rationalize alarms (reduce distracting alarms) towards the industry-recommended alarm rationalization target.

Status of MRC's Action: As of July 31, 2023, MRC stated that the response guidance for these alarms had been added to the console.

MRC's Corrective Action No. 3: *Based on the learnings from this incident, develop additional operator training on steps to take to address high Reactor/Regenerator differential pressure as well as high or low Regenerator catalyst bed level.*

Analysis: As described in section VI.B., this investigation found that MRC had a culture of deviating from procedures. MRC's Corrective Action No. 3 supports that finding. While this finding is necessary, it is more important to reinforce through training the importance of following procedures, the need to return controls to Auto after correcting process deviations in Manual, and the need to evaluate and approve redline changes to procedures.

Status of MRC's Action: As of July 31, 2023, MRC stated that the training materials were developed. As of November 13, 2023, training was in progress.

MRC Corrective Action No. 4: *Based on the learnings from this incident, modify Operating Procedure CCU-1110 and other relevant procedures to provide additional instructions on when to put the Stripper slide valve into level control to regulate the flow of catalyst to the Regenerator.*

Analysis: The procedure as it existed on November 24, 2022, did specify when to put the SSV into level control. It was learned in this investigation that Corrective Action No. 4. was intended to mean that additional explanation of the rationale for placing the SSV in Auto level control should be provided in the procedure. This is consistent with Root Cause 4 of this investigation, which also recommends a broader evaluation of procedures across the refinery to review, and if necessary, define criteria for when cautionary statements are required.

Status of MRC's Action: As of July 31, 2023, MRC stated that warnings were added to procedure CCU-1110, with the added requirement that if the SSV cannot be put in Auto, approval of either of two (2) supervisors was required to run in Manual.

MRC Corrective Action No. 5: *Based on the learnings from this incident, evaluate options to increase the molecular weight of wet gas sent to the WGC during CCU startup and feed re-introduction.*

Analysis: This is a worthwhile option to consider for various operational reasons. However, this investigation concluded that propane limitation did not affect WGC operation during this incident, other than through being an added distraction.

Status of MRC's Action: As of July 31, 2023, MRC stated that the inventory requirements of procedure C(A)-20 had been updated. As of November 13, 2023, a strategy for using butane as an alternative to propane was in the engineering evaluation stage.

MRC Corrective Action No. 6: *Based on the learnings from this incident, reiterate to MRC personnel the expectations and requirements to comply with the refinery's Work Schedule Expectations for Staff (Exempt and Non-Exempt) policy.*

Analysis: This investigation concluded that the refinery fatigue policy addressed only hourly workers, even though some salaried workers do perform safety-sensitive work, such as occurred in this incident. Root Cause 8 of this investigation provides deeper recommendations, one of which is covered in MRC Corrective Action No. 8.

Status of MRC's Action: As of July 31, 2023, MRC stated that the policy was updated. As of November 13, 2023, training was being implemented.

MRC Corrective Action No. 7: *Based on the learnings from this incident, reiterate to MRC personnel the expectations and requirements to complete End of Shift Reports and audit to ensure compliance with the refinery's Roles and Responsibilities SOSO [sic: Start of shift operations] procedure.*

Analysis: This certainly should have been happening, and the missing day shift report made this investigation more challenging. While the missing report did not appear to have a direct or indirect impact on this incident, it reflects a potential cultural issue that should be addressed, for example by management tracking the metrics related to End of Shift Reports.

Status of MRC's Action: As of July 31, 2023, MRC stated that this had been reiterated to personnel and that a new required learning module on this topic had been implemented.

MRC Corrective Action No. 8: *Based on the learnings from this incident, develop additional tools to increase the effectiveness of oversight of staff employee work schedules and fatigue management.*

Analysis: This corrective action goes hand-in-hand with MRC Correction No. 6 and this investigation's Root Cause 8. Having better tools is helpful, but the tools must be routinely used by refinery leadership to manage compliance with the fatigue management policy.

Status of MRC's Action: As of July 31, 2023, MRC stated that the reporting tool had been implemented.

MRC Corrective Action No. 9: *Based on the learnings from this incident, add an indication of the CCU FSS pressure differential to the Utilities Console with the appropriate alarm and response guidance to MRC personnel to better assess the potential for release.*

Analysis: This would help increase awareness of a potential catalyst release. Additionally, actions for CCU operations personnel to take when this alarm sounds on the CCU Console should be defined.

Status of MRC's Action: As of July 31, 2023, MRC stated that the indication had been added.

MRC Corrective Action No. 10: *Based on the learnings from this incident, update the MRC community monitoring procedures to include activation and MRC personnel response for defined opacity events.*

Analysis: This investigation concluded that the high-high dP condition in the fourth stage separator should be one trigger for community monitoring.

Status of MRC's Action: As of July 31, 2023, MRC stated that the procedure was updated. A copy of the updated procedure was provided to the investigators and verified on November 13, 2023.

MRC Corrective Action No. 11: *Based on the learnings from this incident, evaluate Operating Procedure CCU-1110 and other relevant procedures to determine if the ESPs can be safely activated in the CCU startup process.*

Analysis: Even if MRC's ESPs had been operating at the time of the incident, the quantity of catalyst released would not have been substantially reduced. Furthermore, because of the 2006 Shell-affiliated FCC Unit incident and the 2015 ExxonMobil Torrance incident, both of which involved HC flowing into an ESP during shutdown/startup and resulting in explosions, the refining industry has determined that it is important to deactivate ESPs during shutdown and startup procedures to preventing similar incidents.

Status of MRC's Action: As of July 31, 2023, MRC concluded that it was important to continue following industry guidance, which continues to recommend against this.

Appendix A: Scope of Work

The focus of this report is the events leading up to the release of catalyst (in the form of a white powder) into the City of Martinez sometime between 20:00 on November 24, 2022, and 04:00 on November 25, 2022. Within the refinery, the scope includes the CCU, the COB unit, and the bulk propane storage facility, as well as the oversight and support functions for these units located elsewhere in the refinery.

The scope of this investigation excluded reporting the release of catalyst to the relevant agencies, as this is being handled via other channels.

The information and conclusions described in this report were obtained through:

- Review and analysis of documents and data provided by the refinery
- Interviews of employees directly running the CCU at that time
- Interviews of other refinery employees who oversaw or supported CCU operations
- Experience in Process Safety and refinery operations of the investigators

Most of the interviews were conducted on the MRC site, in the presence of the refinery attorney and outside counsel representing the individuals being interviewed. Nonetheless, the scope of this investigation focused on identifying causes related to Process Safety management systems and intentionally avoided assigning blame to any individual.

Appendix B: Investigation Team Makeup

The independent investigation team included Scott Berger, President of Scott Berger and Associates, LLC. Working with Tim Mullowney, Founder of Petrochor, LLC under subcontract. Their distribution of labor during the investigation is shown in table 4.

Table 7: Investigation Team Members and Roles

Role	Performed by
Team leader	Scott Berger
FCC process operator	Tim Mullowney
FCC technology expert	Tim Mullowney
Process engineer	Scott Berger
Process Safety specialists	Both
Human factors specialists	Both
Mechanical integrity specialist	Tim Mullowney

Scott Berger, CCPSC has forty-five years of experience in process safety, environment, health, and safety (EHS) management, chemical engineering, chemical manufacturing, process engineering, and human factors. Since 2015 he has worked as a consultant in process safety with focus on process safety leadership, process safety management systems, training for basic process safety competency, incident investigation, and litigation support. During this period, he also co-authored three books on process safety for the Center for Chemical Process Safety (CCPS), *Driving Process Safety Improvement from Investigated Incidents, Process Safety Leadership from the Boardroom to the Frontline,* and *Essential Practices for Creating, Strengthening, and Sustaining Process Safety Culture.*

From 2001 to 2015 he served as Executive Director of CCPS. He is a CCPS-Certified process safety professional (CCPSC), a Fellow of the American Institute of Chemical Engineers, and a Fellow of the Center for Chemical Process Safety.

Tim Mullowney has more than thirty-five years of broad experience in oil and gas, production, refining, and process safety. Following twelve years operating a Fluidic Catalytic Cracking unit (console and field) and other processes, Tim worked in the Mechanical Integrity / Reliability group, and for three years was responsible for the site Incident Investigation program where he began leading major investigations. His final roles at Phillips 66 were in the corporate HSE group where he was Process Safety Director and Senior Process Safety Consultant, roles which included responsibility for the global refining incident investigation program.

He founded Petrochor, an independent process safety consulting firm, in 2017. His practice includes development of process safety management systems for refining companies, providing a variety of process safety competency trainings, risk assessments, and incident investigations.

Appendix C: Discussion of Wet Gas Scrubbers vs. Electrostatic Precipitators Functionality During Process Startup Application in Fluid Catalytic Cracking Service

Electrostatic precipitators (ESPs) have become a common tool for preventing the emission of any catalyst fines that have not already been removed and recovered by the four (4) stages of cyclones and separators used to clean CCU Regenerator flue gas. In general, ESPs work well and are quite reliable. The primary challenge of operating any ESP is to prevent flammable vapors from flowing to them, because these vapors are a potential source of ignition. It is also important to keep flammable vapors out of the Regenerator; the measures that accomplish this also keep flammables out of the ESP.

The ExxonMobil Torrance ESP explosion in 2015 demonstrated how some abnormal, upset conditions can lead to hydrocarbon vapors reaching the ESP and causing an explosion. Learning from Torrance, companies across the industry now provide for automatic de-energizing of ESPs during upsets. Feed diversion, such as occurred at MRC on November 21, 2022, is one example of how this works. Refineries do not re-energize their ESPs until the CCU is back to full, stable operation.

An alternative to the use of ESPs for controlling catalyst emissions, is to install wet scrubbers. These have the advantage of not providing an ignition source, and therefore can be left running during times when ESPs cannot. Wet scrubbers are used in a few refineries, but they have several potential drawbacks. They occupy a large footprint, so many refineries don't have space in which to locate them. They also can be large consumers of water, which is in limited supply in many areas.

More importantly, a wet scrubber designed to handle the same emission load as an ESP would be equally ineffective in addressing the overload conditions experienced in this incident. As noted earlier in this report, even if MRC's ESP had been in service during the catalyst release event on November 24-25, 2022, the release would have overwhelmed the ESP's capacity. Similarly, if MRC had been using a wet scrubber instead of an ESP during the November 24 incident, the scrubber would have only slightly reduced the release.

Appendix D: Glossary

Term	Definition
AIChE	American Institute of Chemical Engineers.
API	American Petroleum Institute; a trade and standards organization supporting the petroleum industry.
Automatic (Auto)	A control mode where a component (e.g., a valve) is automatically adjusted to maintain a process parameter (e.g., a level) at a set value.
C(A)-20	A policy of MRC that controls minimum and maximum inventory levels of products, by-products, and intermediates.
Cascade	A control mode in which a controller set point is obtained based on some other process variable or condition.
Causal factors	A factor that contributed to the incident, and that, if eliminated, would have prevented the incident or reduced its severity or probability.
Causal Tree	A diagram used to determine root causes; in general, causes lower in the tree drive events higher in the tree, leading to the incident (top event).
Catalyst	For the CCU process, a proprietary material that facilitates the chemical reactions that "crack" large hydrocarbon molecules into smaller ones.
Catalyst Stripper	A section of the CCU Converter where hydrocarbon is removed from catalyst with steam.
CCHHMP	Contra Costa Health Hazards Materials Programs.
CCPS	Center for Chemical Process Safety; a global technical organization operated by AIChE that supports the petroleum, chemical, and related industries with guidance and training for managing Process Safety.
CCU	Catalytic Cracking Unit; a grouping of refinery equipment that converts (cracks) high molecular weight hydrocarbons into hydrocarbons with lower molecular weight.
CCU-1110	The procedure used by MRC to re-introduce feed to the CCU.
COB	CO Boiler; a boiler in which carbon monoxide in the Regenerator flue gas is oxidized to carbon dioxide, reducing the toxicity of CCU emissions and producing heat that is used to generate steam.
Console	A group of computer screens and keyboards used to control the process and monitor process conditions and alarms.
Contributing cause	A factor that contributed to the incident.
CWS	Community Warning System of the Contra Costa Industrial Safety Ordinance.

Term	Definition
Culture	A set of beliefs, customs, and behaviors that become embedded in the way the group thinks and works.
Cyclone	A conical device that separates particles from air streams by a swirling action that pushes the particles to the wall and then down to the bottom of the cone, while cleaner air exits the top.
Day shift	Work hours starting 06:00 and ending 18:00.
dP	Differential pressure; the difference between the pressures as measured at two different points.
ESP	Electrostatic Precipitator; a pollution control device that uses static electricity to remove small particles from process exhausts.
Fines	Particles of catalyst that are much smaller than the average particle size.
Flare	A device in which emergency hydrocarbon releases from refinery processes are safely burned in a controlled fashion, generally at a high elevation and far away from occupied areas.
Flue Gas	Combustion gases from the Regenerator.
FSS	Fourth Stage Separator; the fourth stage in a series of devices that remove catalyst fines from the flue gases of the Regenerator.
G(A)-34	MRC's "Scheduling and Hours of Service Limits Policy." The policy by which MRC manages worker fatigue (fatigue policy).
GPM	Gallons per minute.
HC	Hydrocarbons; chemicals made up of carbon and hydrogen.
Hot standby	A phase of CCU operation where feed is diverted, either with or without catalyst circulation.
Human factors	The evaluation of how people interact with equipment, controls, and their work environment.
ISO	The Industrial Safety Ordinance of Contra Costa County.
Management system	Policies, procedures and standards that describe how specific functions are to be carried out, performance is verified, and performance is improved.
Manual	A control mode in which control devices (e.g., valves) respond only to operator input.
MCAR	Major Chemical Accident Release, as defined by CCHHMP.
MF	Main Fractionator; the column that receives product from the Reactor.
MRC	Martinez Refining Company, a unit of PBF Energy.
MW	Molecular weight.

Term	Definition
NDA	Non-disclosure agreement; an agreement binding two parties to protect each other's confidential business information.
Night shift	Work hours starting 18:00 on one day and ending 06:00 the next day.
OHA	Overhead Accumulator; a tank which receives the two-phase overhead flow from the CCU Main Fractionator (MF). The pressure of the Reactor depends upon the pressure of the MF, which depends on the pressure of this tank.
Opacity	The degree to which visibility of a background (i.e., blue sky) is reduced by particulates, measured either in % or Ringelmann.
Operating procedures	Written, step-by-step instructions and information necessary to operate equipment, compiled in one document including operating instructions, process descriptions, operating limits, chemical hazards, and safety equipment requirements.
Operator	An individual who is trained and qualified to operate a process or some portion of a process.
PHA	Process Hazard Analysis; a study in which process hazards are identified and a wide range of deviation scenarios are analyzed to determine if the unit's safeguards are adequate.
Reactor	A vessel where the catalytic cracking reaction occurs and hot catalyst is disengaged from HC vapor.
Redlined changes	Field changes made during execution of a procedure that have been reviewed and approved by the appropriate personnel.
Regenerator	A vessel in the CCU system in which coke is burned off spent catalyst, reheating catalyst.
Ringelmann	A unit of opacity. 1 Ringelmann is approximately 20% opacity.
Root causes	Gaps in Process Safety management systems, including human factors.
RR	Reactor Riser; the section of the CCU Reactor where the cracking reaction takes place.
Slide valve	A valve that operates by sliding a paddle over an opening to control the flow of catalyst from one vessel to another.
SOSO	Start of shift operations; a procedure with formal reporting used at MRC to handover operations from one shift to the next.
Spillback valve	A valve which routes compressor discharge back to the suction to maintain minimum flow through the machine, preventing compressor surge.
Stripper	A vessel in the CCU system in which residual hydrocarbon is removed from catalyst with steam.

Term	Definition
SSV	Stripper slide valve; the valve which regulates the flow of catalyst from the Stripper to the Regenerator.
Top event	The release event being investigated.
TSS	Third Stage Separator; the third of four devices that removes catalyst from Regenerator flue gases.
Wet gas scrubber	A system where exhaust gases are contacted with water to remove particles and water-soluble gases.
WGC	Wet Gas Compressor; a multi-stage centrifugal compressor designed for condensable hydrocarbons which takes suction on the OHA and increases the pressure of the gaseous vapor allowing it to flow to the Cracked Gas Plant.