Overview of Husky Superior FCC Explosion CSB Final Report

Neal Cammy
Engineering Manager
BLAC INC.

e-mail: neal.cammy@blacinc.com
Office Phone: 630-279-6400
www.blacinc.com

Why this review?

- Industry reluctant to talk about specific incidents
- Public report provides basis for discussion
- CSB makes specific recommendations to our industry
- This review will cover FCC operations and event timelines
- It will not cover site emergency response

Husky Refinery FCC Explosion

- US Chemical Safety and Hazard Investigation Board
  - CSB is an independent US Government agency
  - Investigates and reports on incidents with chemical releases, injuries, fatalities or major property damage
- Final report published 23 December 2022

https://www.csb.gov/assets/1/6/Husky_Superior_Refinery_Report_2022-12-23_(1).pdf

blac inc.
BLACK LIMITED ADVANCED CONTROLS

Superior Refinery

- **Murphy Oil**
  - 1958 to 2011
- **Calumet Specialty Products, LLP**
  - 2011 to Nov 2017
- **Husky Superior Refining Co.**
  - Nov 2017 to March 2021
- **Cenovus acquires Husky**
  - March 2021

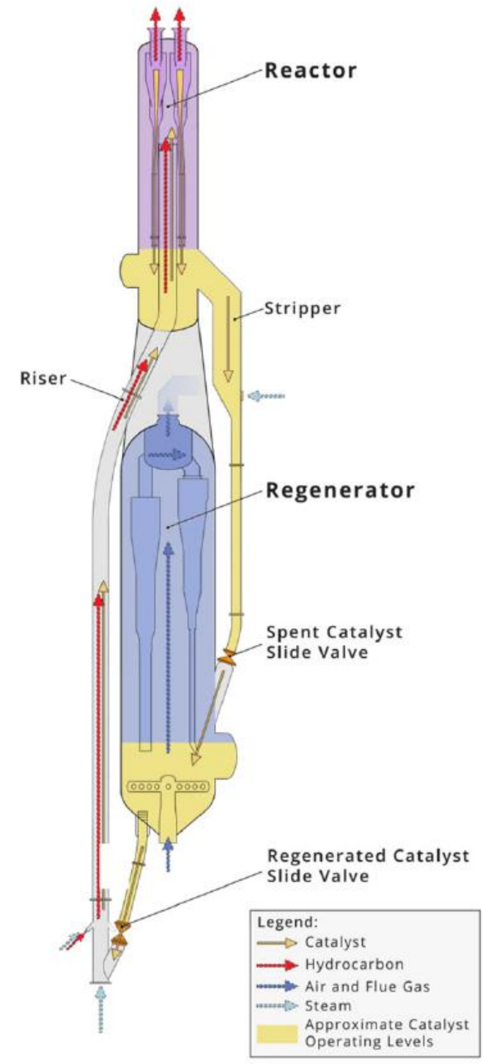


Figure 6. Husky Superior Refinery's stacked FCC reactor/regenerator configuration showing flow paths during normal operation. (Credit: CSB)

blac inc.
BLACK LIMITED ADVANCED CONTROLS

Superior Refinery FCC

- UOP Stacked FCC, operating since 1960
  - Major Revamp by UOP in 1994
- Incident on April 26, 2018
- Explosion in Primary and Sponge (Secondary) Absorbers
- Vessel fragments cause hole in nearby Asphalt tank
- Asphalt leak over dyke causing fire

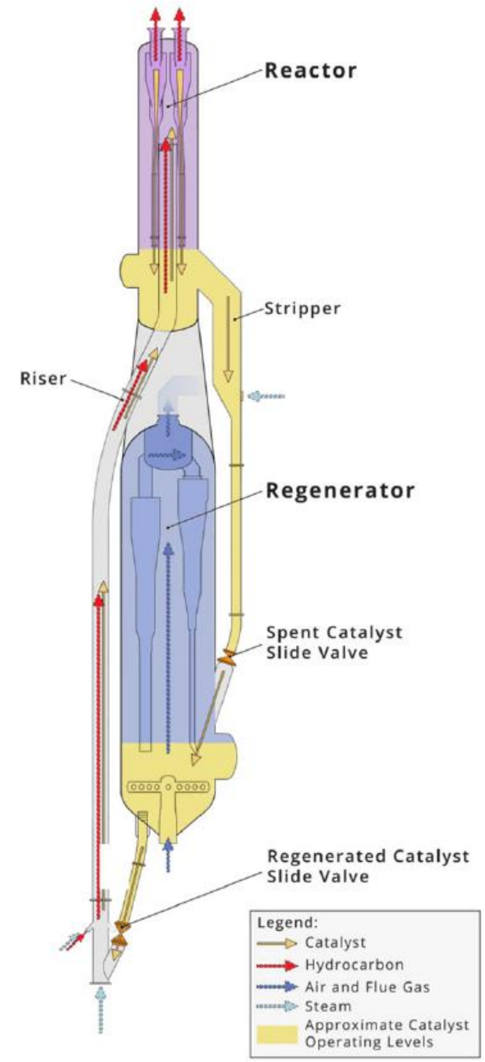
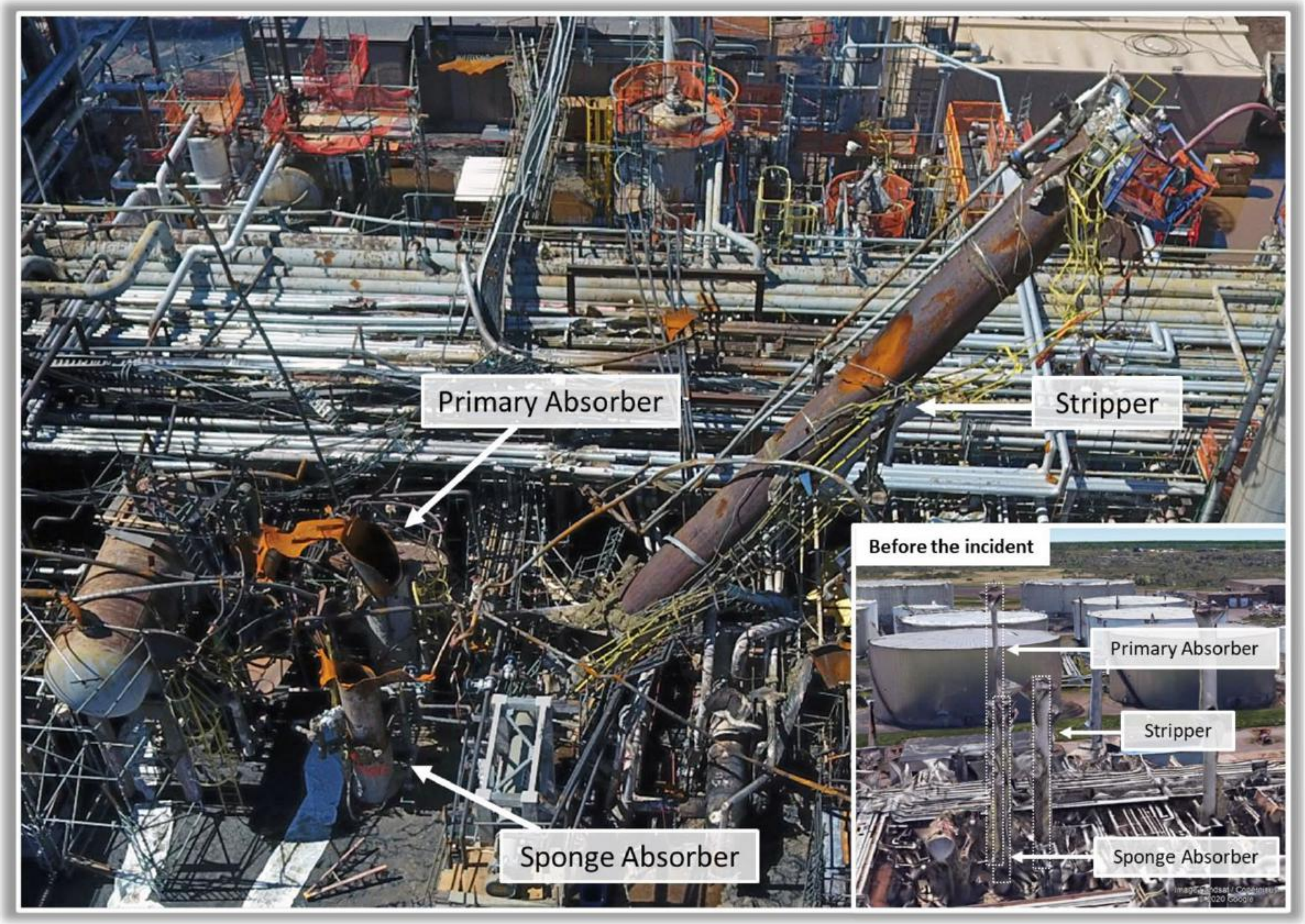


Figure 6. Husky Superior Refinery's stacked FCC reactor/regenerator configuration showing flow paths during normal operation. (Credit: CSB)

blac inc.
BLACK LIMITED ADVANCED CONTROLS



blac inc
BLACK LIMITED ADVANCED CO

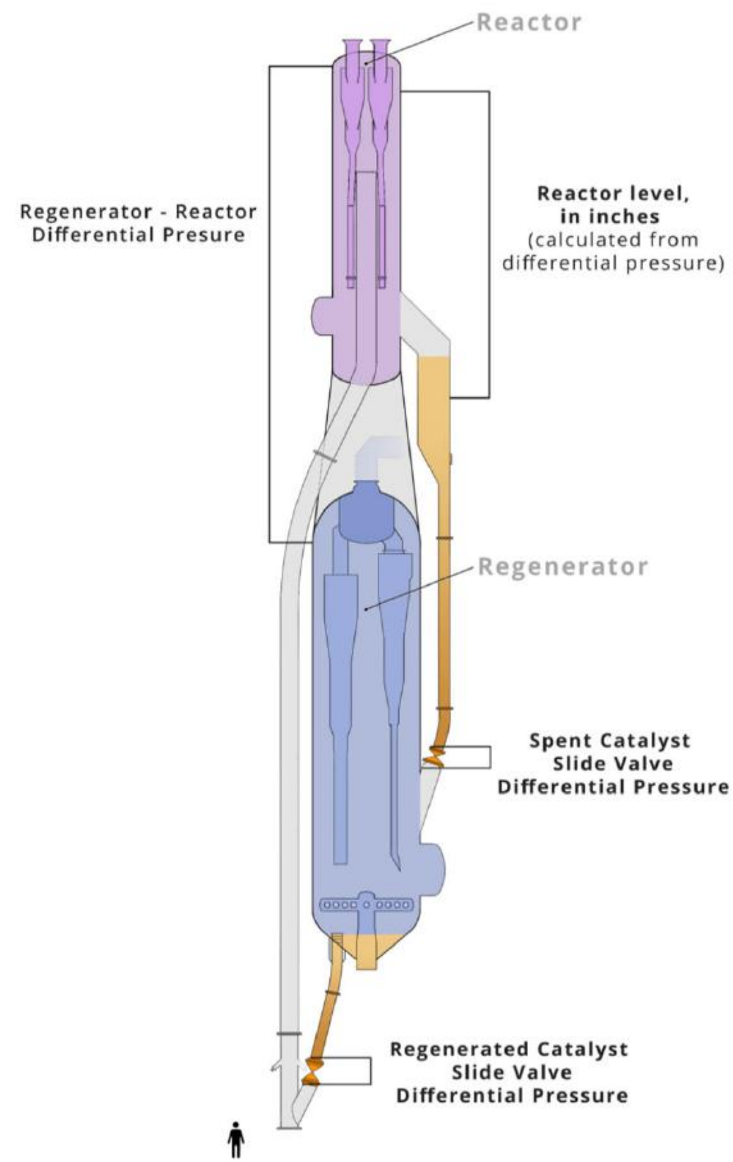
Figure 44. Primary absorber, sponge absorber, and stripper before and after the incident.[a]
(Credit: Husky Superior Refinery and Google Earth with annotations by CSB)

Figure 18. Asphalt tank puncture and leak. (Credit: CSB [left], Duluth News Tribune [right])

Figure 21. Smoke from the fire at Husky Superior Refinery. (Credit: WDIO ABC News)

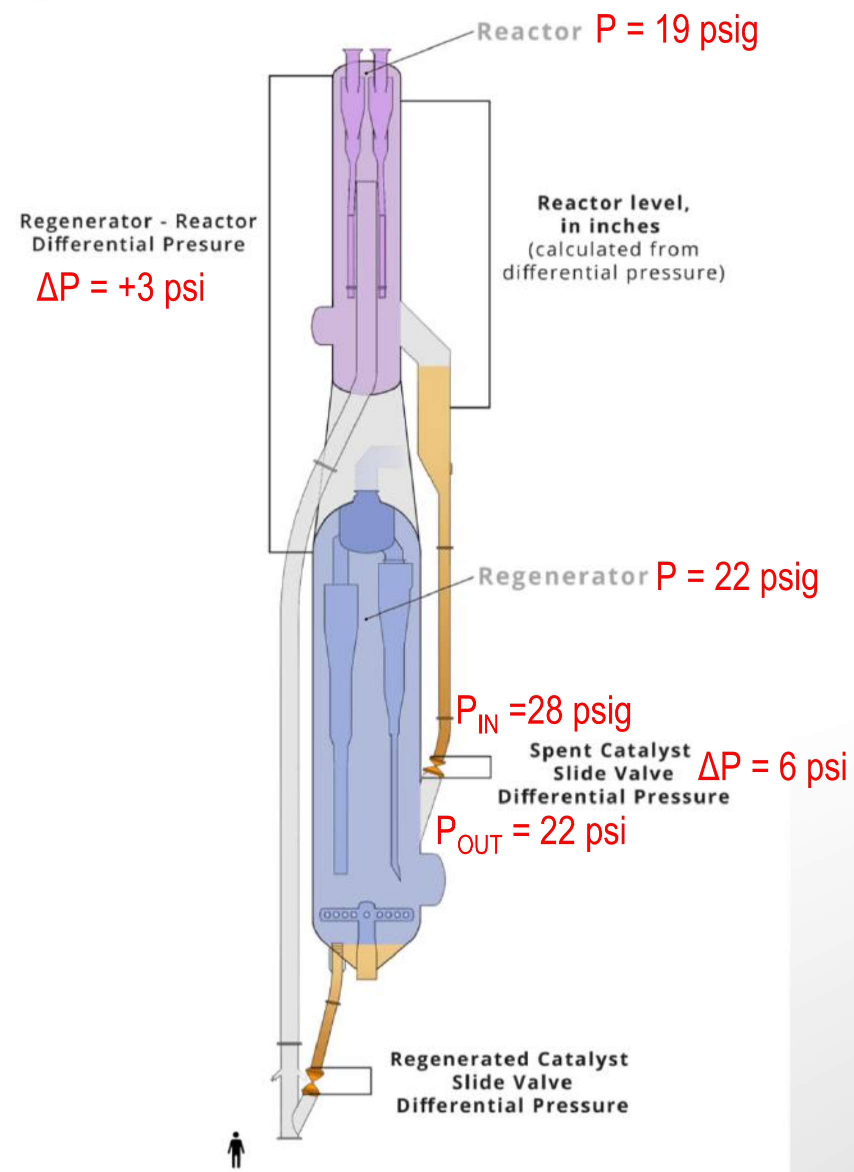
The Incident

Unit shutting down for Turnaround



blac inc.
BLACK LIMITED ADVANCED CONTROLS

Conditions just before feed out



blac inc.
BLACK LIMITED ADVANCED CONTROLS

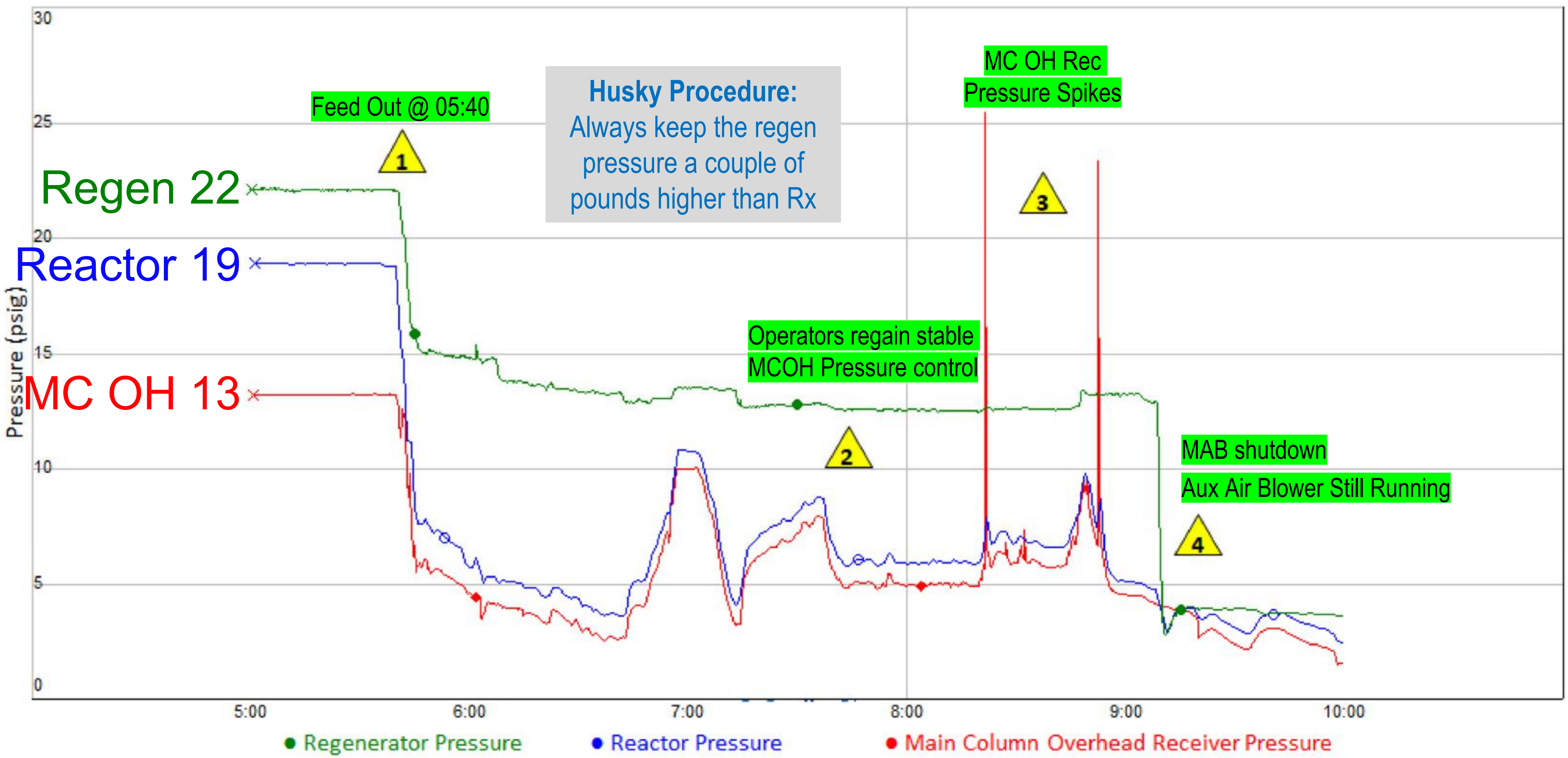


Figure 15. Pressure trends from 5:00 a.m. until the explosion. (Credit: CSB)

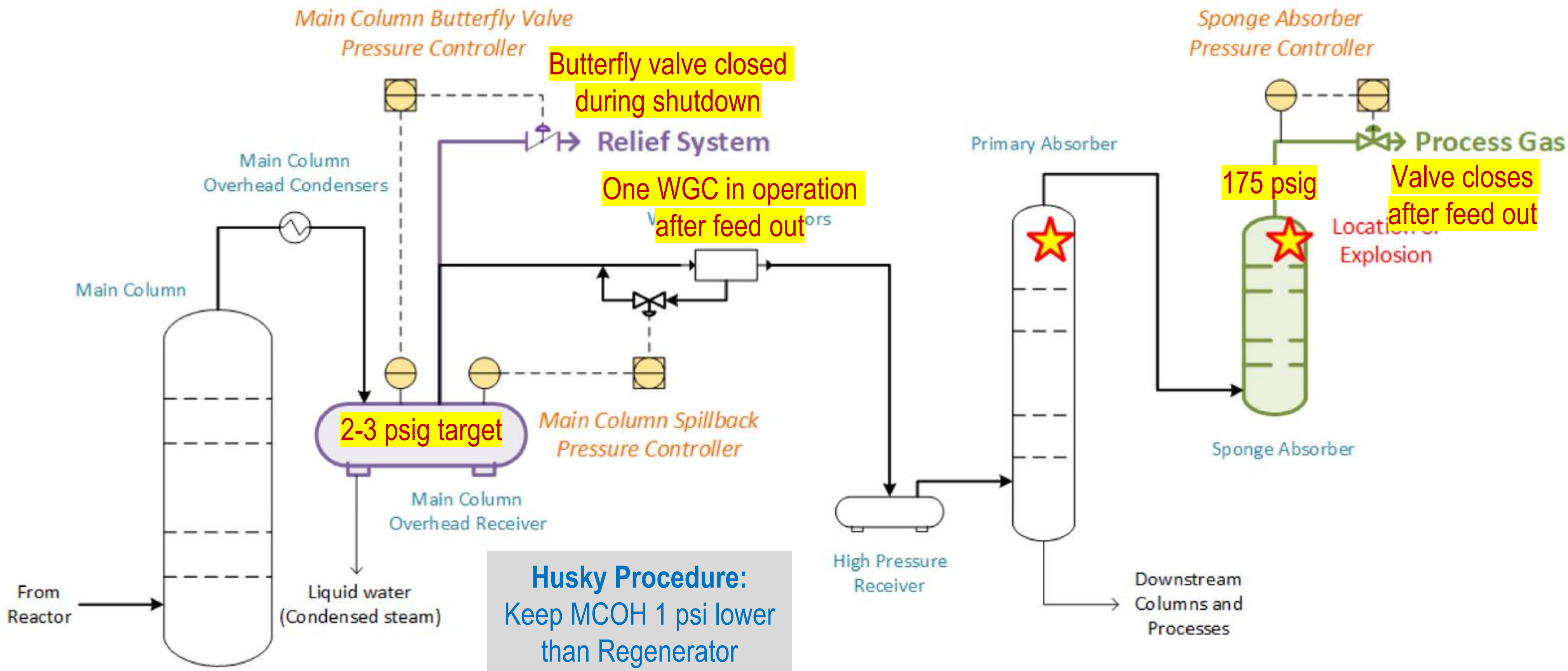
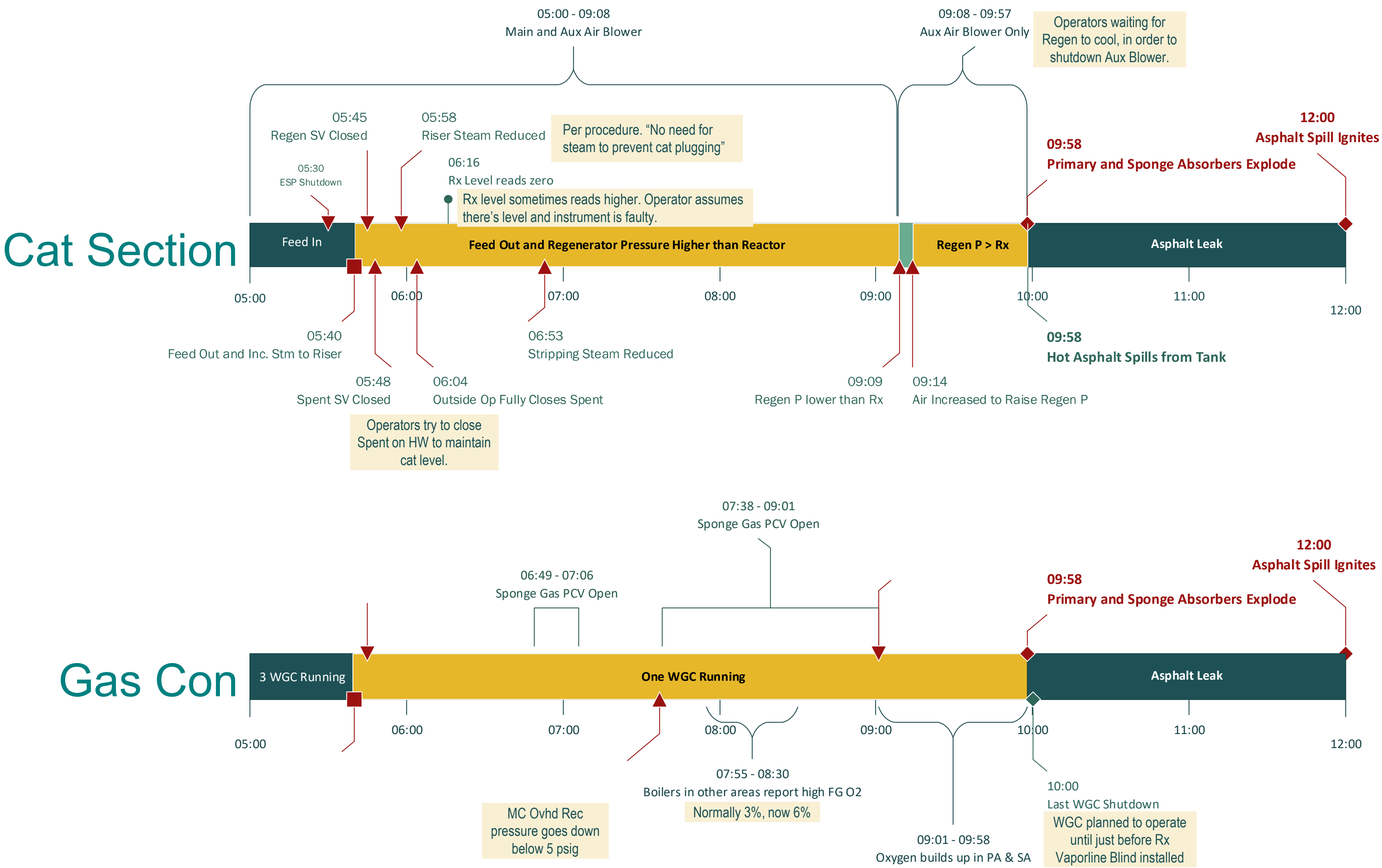


Figure 13. Simplified main column and sponge absorber pressure control scheme used during the shutdown. (Credit: CSB)


Cat Section
05:00 - 09:08
Main and Aux Air Blower
09:08 - 09:57
Aux Air Blower Only
Operators waiting for Regen to cool, in order to shutdown Aux Blower.
05:45
Regen SV Closed
05:58
Riser Steam Reduced
Per procedure. "No need for steam to prevent cat plugging"
05:30
ESP Shutdown
06:16
Rx Level reads zero
Rx level sometimes reads higher. Operator assumes there's level and instrument is faulty.
12:00
Asphalt Spill Ignites
09:58
Primary and Sponge Absorbers Explode
Feed In
Feed Out and Regenerator Pressure Higher than Reactor
Regen P > Rx
Asphalt Leak
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
05:40
Feed Out and Inc. Stm to Riser
06:53
Stripping Steam Reduced
09:58
Hot Asphalt Spills from Tank
05:48
Spent SV Closed
06:04
Outside Op Fully Closes Spent
09:09
Regen P lower than Rx
09:14
Air Increased to Raise Regen P
Operators try to close Spent on HW to maintain cat level.
Gas Con
07:38 - 09:01
Sponge Gas PCV Open
06:49 - 07:06
Sponge Gas PCV Open
12:00
Asphalt Spill Ignites
09:58
Primary and Sponge Absorbers Explode
3 WGC Running
One WGC Running
Asphalt Leak
05:00
06:00
07:00
08:00
09:00
10:00
11:00
12:00
07:55 - 08:30
Boilers in other areas report high FG O2
Normally 3%, now 6%
MC Ovhd Rec pressure goes down below 5 psig
09:01 - 09:58
Oxygen builds up in PA & SA
10:00
Last WGC Shutdown
WGC planned to operate until just before Rx Vaporline Blind installed

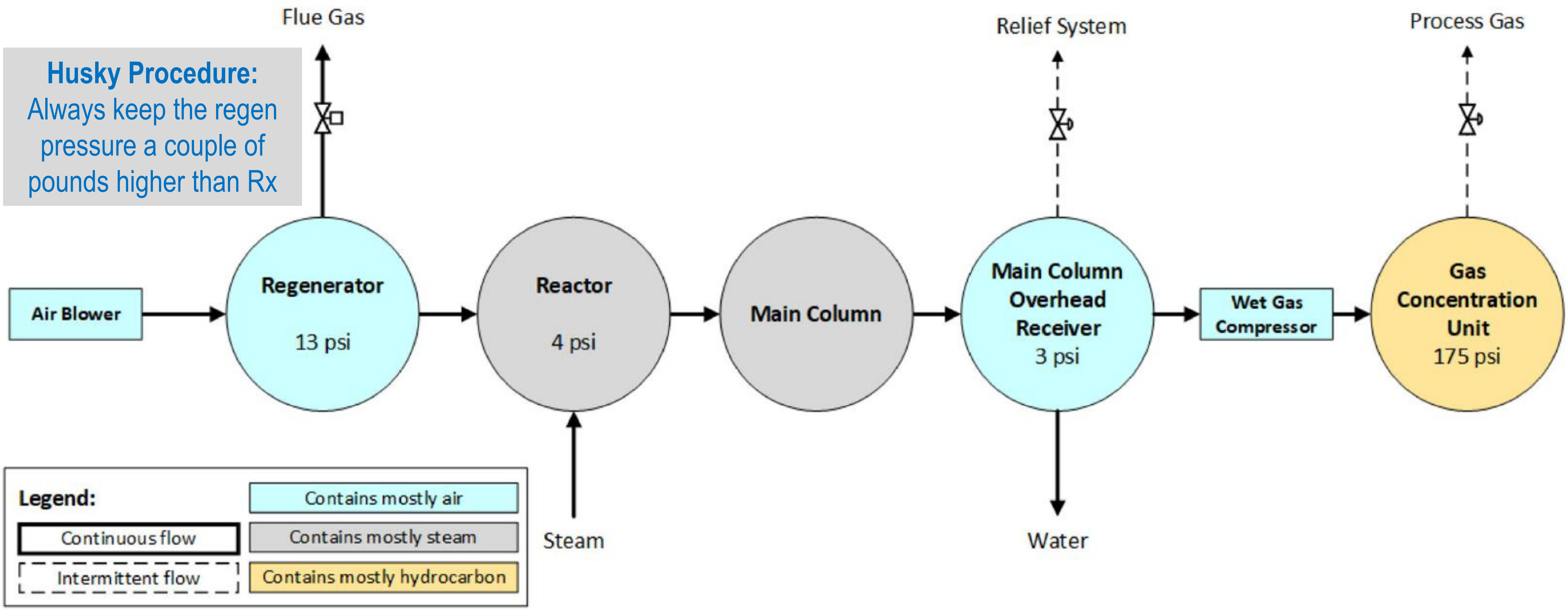
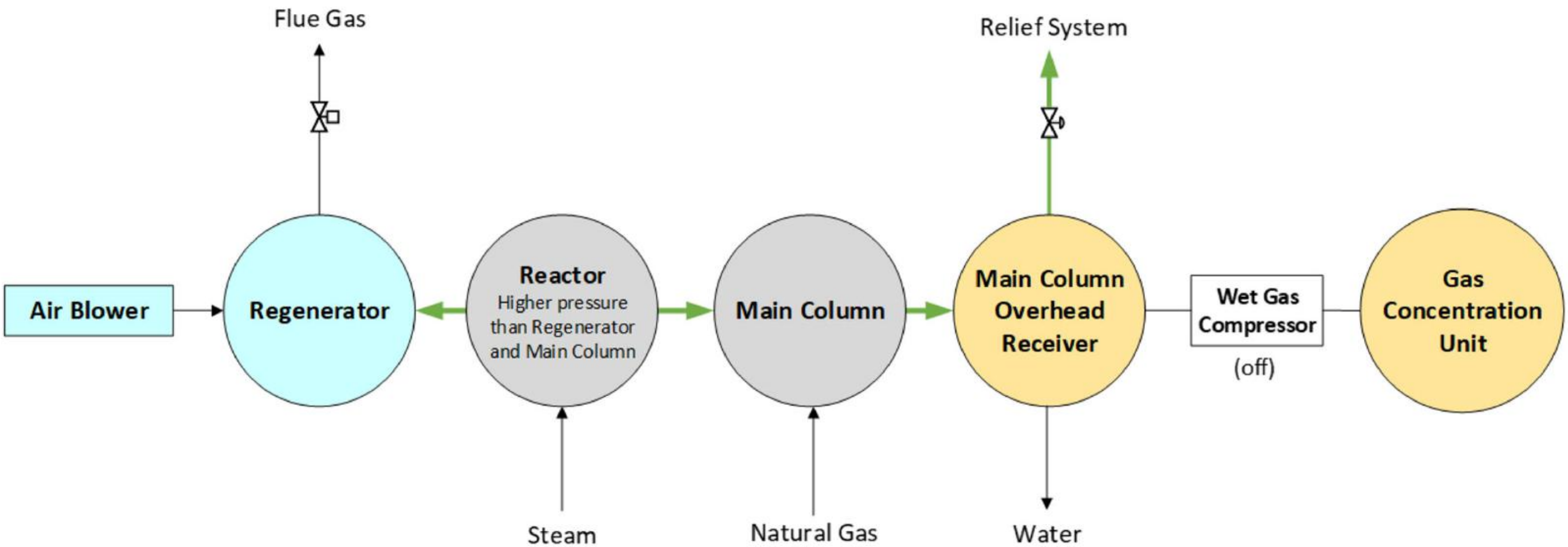


Figure 14. Pressure profile in the first few hours of the shutdown. (Credit: CSB)

Desired flow directions during shutdown (UOP guidance)



blac inc.
BLACK LIMITED ADVANCED CONTROLS

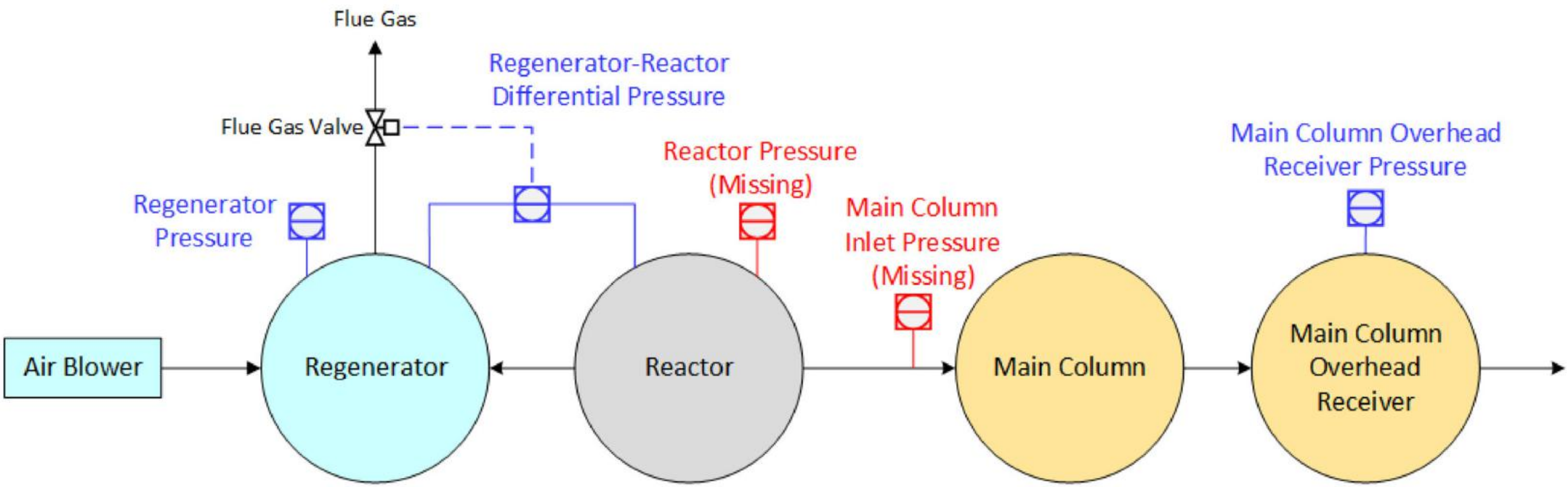


Figure 29. Missing steam barrier instrumentation at Husky Superior Refinery. (Credit: CSB)

Key Facts

- Refinery operators followed their written procedures
- Procedures deviated from UOP (and FCC industry) procedures
- Refinery operators not aware of the Reactor Steam Barrier concept
  - Thought riser steam during shutdown was for “blasting the riser out” and “at some point you can cut back….I’m not exactly sure why you just keep having steam going in”

Key Facts

_____ _____ 3. Cut Steam to Riser to 85% open, keep Main Column Receiver Pressure 1 pound lower than the Regenerator pressure.

_____ _____ 4. After 15 minutes of catalyst circulation with steam, close the Regenerated Slide Valve, put on manual control, take Slide Valve off hydraulic control, put on hand-wheel, and close valve.

NOTE: WHEN DOING # 5, ALWAYS KEEP THE REGENERATOR PRESSURE A COUPLE POUNDS HIGHER THAN THE REACTOR PRESSURE. YOU MAY HAVE TO HAVE SOME CATALYST IN THE REACTOR STRIPPER TO HOLD A SEAL ACROSS THE SPENT SLIDE VALVE. A SHARP TEMPERATURE RISE IN THE REACTOR WILL INDICATE A REVERSAL.

_____ _____ 5. Close Spent Slide Valve, put it on manual if you haven't already done so.

Figure 26. Excerpt from the shutdown procedure used on the day of the incident. (Credit: Husky Superior Refinery with annotations by CSB)

Key Facts

- Air from Regenerator flowed continuously through Spent and Regen SV's for 4 hours
- Refinery had ability to use fuel gas purge to dilute air in frac
  - Written procedures did not mention this safeguard
- With no hydrocarbons to dilute air, O_2 accumulated in Gas Con
  - To minimize flaring, WGC planned to remain operating until just before Rx Vapor Blind installation
- Pyrophoric materials on walls of Primary and Sponge Absorber
  - O_2 likely reacted with pyrophoric deposits generating heat and providing ignition source
- Flammable mixture in Primary and Sponge Absorber ignited, causing the explosion

Operating Proc Changes to Minimize Venting

- 2010 EPA Consent Decree with Murphy Oil

> Murphy shall at all times and to the extent practicable, including during periods of Startup, Shutdown, and/or Malfunction, implement good air pollution control practices to minimize emissions from its Flaring Devices as required by 40 C.F.R. § 60.11(d) [74, p. 36].

- EPA 2015 Refinery Sector Rule (finalized in 2020)
  - Requires equipment depressure to controlled system

blac inc.
BLACK LIMITED ADVANCED CONTROLS

Operating Proc Changes to Minimize Venting

- 2018 TA first time Superior would vent to flare instead of atm
  - Due to EPA Refinery Sector Rule
- Lead to Superior practice of running WGC until last minute
  - Units with centrifugal compressors and modern anti-surge controls can also run with little to no net forward flow.
  - Older centrifugal WGC's with minimal controls make this difficult
- In previous shutdowns
  - possible some oxygen entered the MC
  - vented to atmosphere or flare instead of through WGC

blac inc.
BLACK LIMITED ADVANCED CONTROLS

Slide Valves

- Preliminary CSB report initially blamed explosion on leaking slide valves
  - We now know this was not the primary cause
- Refinery personnel understood that closing the slide valves formed a catalyst "seal" or a "solid plug" that prevented air from flowing from the regenerator to reactor
  - Shutdown procedures stated "You may have to have some catalyst in the reactor stripper to hold a seal across the spent slide valve."
- Husky's slide valve standard described the slide valves as: "designed for complete shut-off of flow"

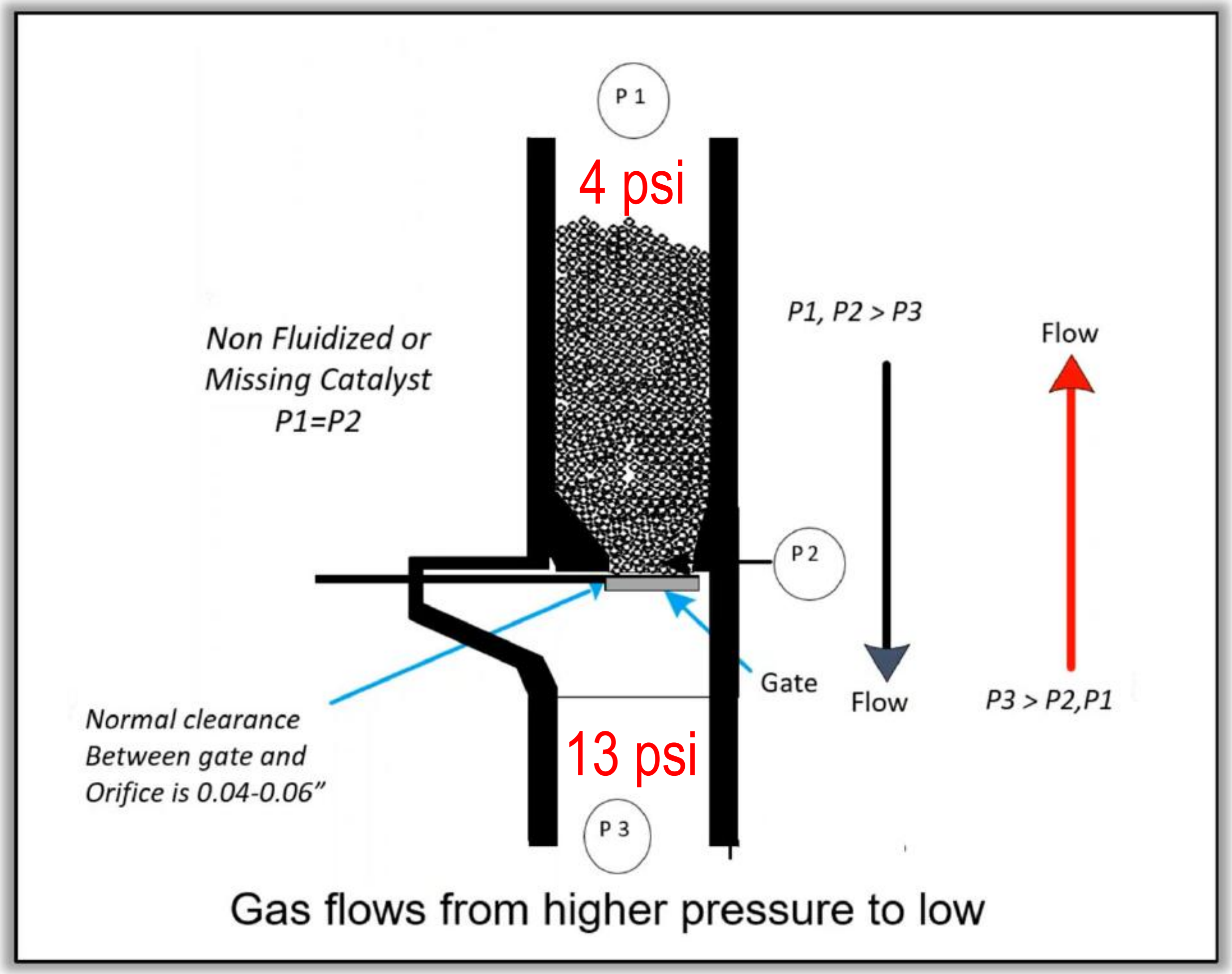


Figure 36. Sketch of a standpipe with a closed slide valve. (Credit: AFPM [68])

blac inc.
BLACK LIMITED ADVANCED CONTROLS

Eroded Spent Slide Valve

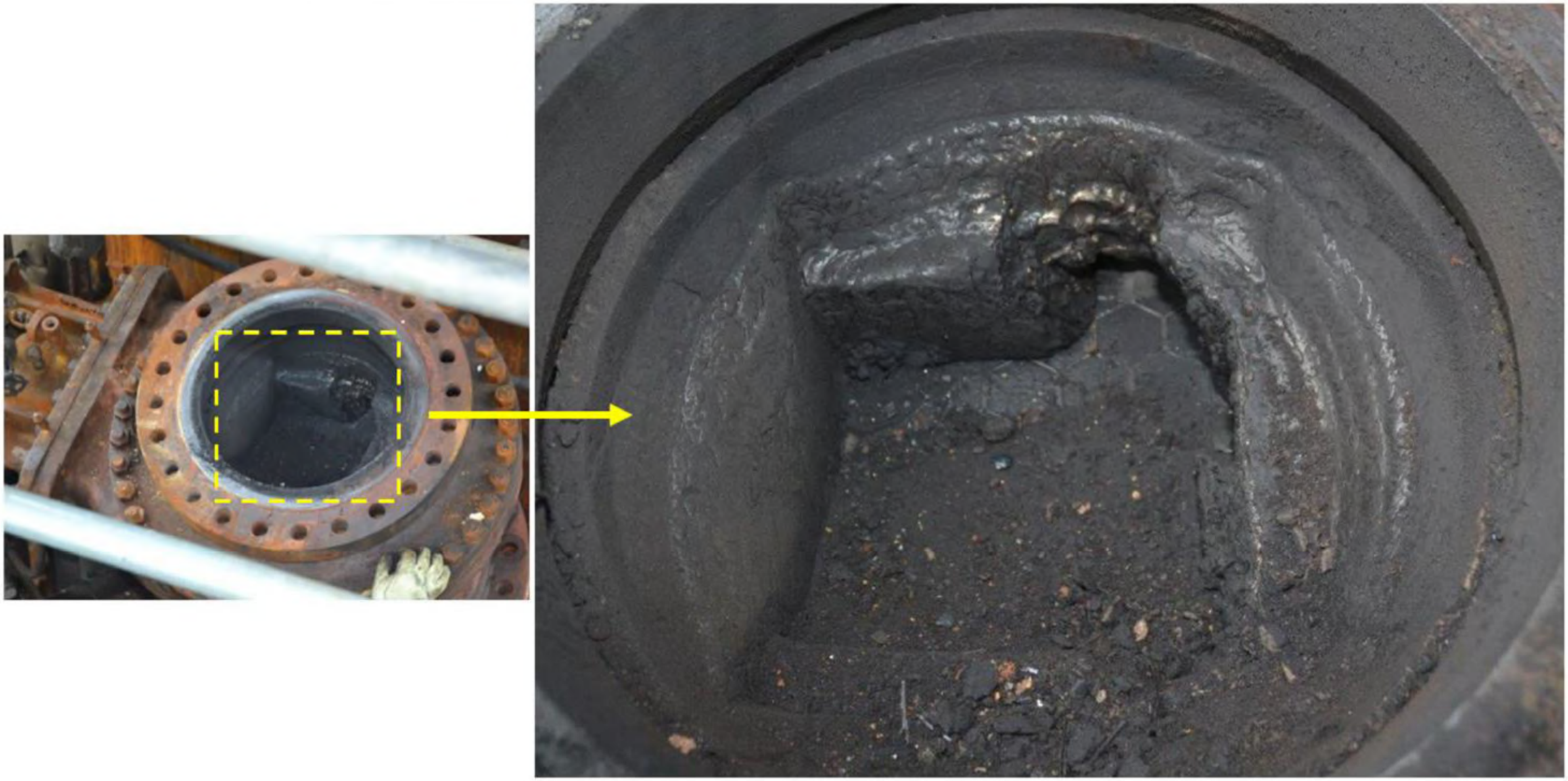


Figure 33. Spent catalyst slide valve in-situ. (Credit: Husky Superior Refinery with annotations by CSB)

Table 2. Typical FCC unit safeguards to prevent explosive process conditions during transient operations.

Safeguard	Description	Implementation	Control Type
Reactor steam barrier	Sufficient steam[a] flow into the reactor maintains the pressure inside the reactor as the highest pressure point in the system. This critical steam barrier separates the air and hydrocarbon systems on either side of the reactor by flowing outward from the reactor, preventing the air and hydrocarbons from forming an explosive mixture.	Operators set the pressure inside the reactor higher than both the regenerator and main column pressures using flow and pressure control valves [35, p. 11]. Operators take emergency actions if target pressure differences between the equipment cannot be achieved. These actions are not automated in most FCC units.	Procedural
Main column gas purge	A continual vapor flow through the main column into the flare system prevents oxygen accumulation in the main column system.	Operators introduce non-condensable gas to the main column to maintain a slightly open position on the main column's pressure control valve. Some sites monitor the equipment's oxygen content during this operation.	Procedural
Catalyst slide valves[b]	Closed slide valves reduce gas flow between the reactor and the regenerator. ***These valves are not designed to be gas-tight. Small amounts of vapor continue to flow through the valves from high to low pressure.***	Spent and regenerated catalyst slide valves close automatically based on predetermined process conditions (such as low differential pressure across the valves). During shutdowns, operators also close the valves manually.	Active/ Procedural
Catalyst levels	Catalyst remaining in the reactor, regenerator, and standpipes reduces	Typically, it is difficult to monitor and control unfluidized catalyst.	Passive/ Procedural

BLACK

Gas Con

- Primary Absorber
  - A-212 Grade B (per UOP spec)
- Sponge Absorber
  - A-201 Grade B (UOP spec'd Grade A)
- Failure was "brittle fracture"
  - Many fragments
- Since 1967, ASTM recommends A-516/A-515
  - More ductile

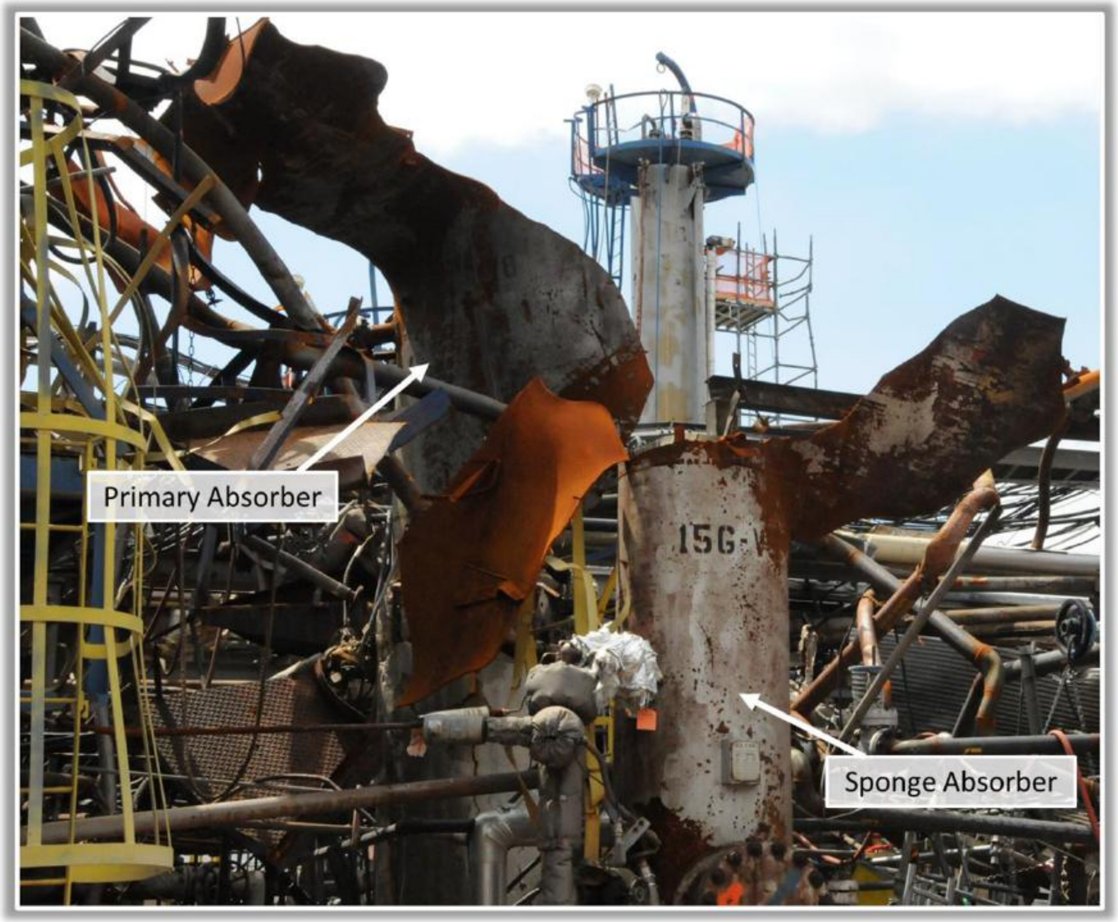


Figure 45. Primary and sponge absorbers after the incident. (Credit: CSB)

blac inc.
BLACK LIMITED ADVANCED CONTROLS

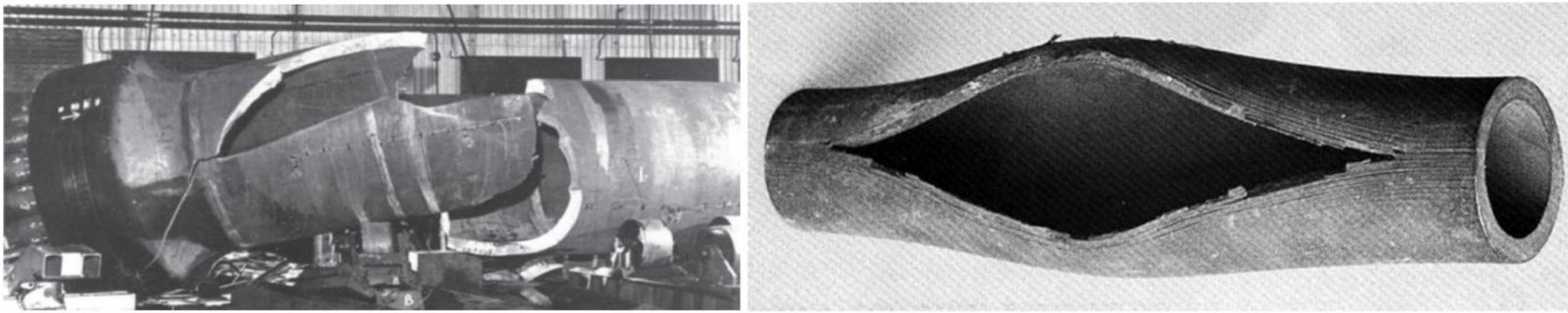


Figure 47. Examples of brittle fracture *(left)* and ductile fracture *(right)*. (Credit: [137], [138])

- If modern, more ductile metallurgy (A-516) used:
  - Explosion would cause fish mouth rupture (like a zipper)
  - Less fragmentation and fewer dangerous projectiles
  - Asphalt leak almost certainly would not have occurred
- Rebuild is using A-516 steel

CSB Conclusions

- 50 Spec… Findings…

2. While Husky Superior Refinery's FCC unit was shutting down, the regenerator continued operating at a higher pressure than both the reactor and the main column. As a result, some air continually flowed from the regenerator, through the reactor, and into the main column for approximately four hours.

4. Husky Superior Refinery's FCC unit shutdown procedure contradicted UOP's technical guidance by instructing refinery personnel to operate the regenerator at a higher pressure than both the reactor and the main column. Following this procedure directed air into the hydrocarbon-filled main column and downstream equipment, creating an explosive atmosphere within the equipment. Had Husky Superior Refinery aligned its shutdown procedure with UOP's guidelines or industry good practice, the procedure would have properly instructed operations personnel to keep the air and hydrocarbon systems separate using a reactor steam barrier, which could have prevented the incident.

a non-condensable gas purge of the main column during the FCC unit shutdown, as recommended by UOP, the oxygen could have been swept out of the system, preventing the explosion.

8. On the morning of the incident, Husky Superior Refinery did not recognize the elevated oxygen readings in the boiler flue gas as a potential indication of oxygen entering the refinery process gas system from the FCC unit as it was shutting down.

the main column and contributed to this catastrophic event.

17. FCC catalyst differential pressure instruments, such as catalyst level and slide valve differential pressure indicators, may not be reliable process indicators during a shutdown. Husky Superior Refinery's operations staff's reliance on these instruments led them to believe that both standpipes were full of catalyst and air was not entering the reactor. Had operators understood the limitations of these

CSB Conclusions

13. Husky Superior Refinery’s slide valve standard did not properly describe the flow isolation capability of slide valves, indicating the refinery’s incomplete knowledge and contributing to the lack of recognition by most Husky Superior Refinery employees associated with the FCC unit that catalyst slide valves were not an adequate safeguard for preventing a catastrophic explosion.

15. Husky Superior Refinery’s spent catalyst slide valve was eroded and damaged such that it could no longer maintain a catalyst level in the reactor. In addition, the severely eroded slide valve allowed more air to pass through from the regenerator into the reactor than it would if it were in good condition….

16. FCC practitioners should eliminate or otherwise dispel the misleading term “catalyst seal” from future safety discussions….

CSB Conclusions

29. While changing its FCC unit shutdown procedure for the 2018 turnaround, Husky Superior Refinery did not recognize that eliminating the use of atmospheric vents made it more likely for oxygen to accumulate in the main column and increase the potential for an explosion. Because the refinery's staff did not have process knowledge of oxygen accumulation risk in the FCC unit during transient operation, they may not have identified the risk even had they completed a management of change or risk assessment on their procedure changes.

procedures, with guidance from a subject matter expert, the technical errors and omissions could have been identified and resolved to match the process technology information provided by the licensor, and the explosion could have been prevented.

22. Husky Superior Refinery's FCC technology-specific process knowledge did not adequately address unit safety in transient operations, including shutting down the unit for a turnaround. Gaps in knowledge management filtered through procedures, training, and hazard assessments, leaving refinery employees unequipped with the knowledge necessary to control the FCC unit's potential transient operation hazards, such as the inadvertent mixing of air and hydrocarbon that could lead to an explosion inside process equipment.

23. For much of Husky Superior Refinery's history, its FCC expertise was mostly in-house, with minimal engagement with other refineries. Though Husky Superior Refinery's management encouraged individuals to attend industry events and UOP's training classes, this individual training did not establish sufficient knowledge or competency within the organization to prevent the April 2018 incident.

24. Husky Superior Refinery's use of external technical experts was limited to efforts aimed at assessing and improving the FCC unit's performance during normal operation. Had the refinery effectively

Not only did the refinery's procedures omit major industry-known safeguards, but they also lacked clear instructions, consequences of deviation, and steps required to correct or avoid deviations that operators should be able to discuss during their training.

29. While changing its FCC unit shutdown procedure for the 2018 turnaround, Husky Superior Refinery did not recognize that eliminating the use of atmospheric vents made it more likely for oxygen to accumulate in the main column and increase the potential for an explosion. Because the refinery's staff did not have process knowledge of oxygen accumulation risk in the FCC unit during transient operation, they may not have identified the risk even had they completed a management of change or risk assessment on their procedure changes.

30. The Superior Refinery's PHA study teams lacked adequate licensor or industry guidance to evaluate its FCC unit's technology-specific transient operation hazards.

31. Husky Superior Refinery's policies did not include requirements or guidelines for performing PHAs on its operating procedures. Had the refinery performed a PHA on its FCC shutdown procedure with a multidisciplinary team, it could have identified and controlled transient operation hazards such as inadvertent air and hydrocarbon mixing during a shutdown.

Select CSB Recommendations to Cenovus

- Establish specific safeguards
  - Rx Steam Barrier
  - Gas dilution to prevent O_2 accum
  - Monitor MC O_2 levels during S/U and S/D
  - Document consequences of deviation
  - Train operators on above
- Determine when to shutdown all WGC's
- Create slide valve mech integrity program
- Emergency procedures for loss of slide valve function
- Guidelines for transient operations
- Training incorporating licensor guidance

CSB Recommendations to Gov't and Industry

- **To EPA**
  - Develop program to prioritize inspections for FCC units in refineries with HF Alky's
- **To OSHA**
  - Develop guidance for performing PHA's to address transient ops
- **To UOP**
  - Participate in the API committee
- **To API**
  - Develop publicly available tech publication for safe operation of new and existing FCC units
  - Modify API RP553 (Refinery Valves..) or create new RP for FCC slide valves.
  - Incorporate lessons learned in API RP 2023 (Guide for Safe Storage…of Heated…Asphalt..) or RP 2021 (Management of Atm Tank Fires)

blac inc.
BLACK LIMITED ADVANCED CONTROLS

7 Key Lessons for the Industry

To prevent future chemical incidents, and in the interest of driving chemical safety change to protect people and the environment, the CSB urges companies to review these key lessons:

1. Transient operations, such as startups, shutdowns, and standby operation, may require a different set of safe operating limits compared with normal operation. For startup, shutdown, and standby operating modes, consider creating separate console screens and state-based alarms to help operators manage critical process variables for transient operation.[a] These parameters should be incorporated into operator training and operating procedures.

2. During transient operation for any process involving flammable materials, operators need to understand how air (or oxygen) could enter and accumulate inside equipment, and how oxygen should be purged out of the system to prevent the development of a flammable mixture. The effectiveness of a purge should be verified by engineering calculations or direct measurements of oxygen content inside the equipment.

3. The piping from process equipment to a refinery flare system is a critical safety system, especially during startups and shutdowns. Refineries should understand why and how to vent and purge equipment to their flare system to start up and shut down a process unit safely. Changes to venting and purging procedures must be evaluated for their impacts on the process units.

4. Most process hazard analysis (PHA) studies for continuously operating processes focus on hazards during normal operation. However, a significant portion of process safety incidents occur during transient operations, such as startups, shutdowns, and standby. Companies should perform PHAs on critical operating procedures to better identify hazards that arise during transient operations with an interdisciplinary team of operators, engineers, maintenance, management, and other relevant disciplines.

5. Subject matter experts' and consultants' reviews of a process unit's performance should not be limited to normal operations. Even old and established operating procedures might contain errors, inadequacies, or deviations from current generally accepted industry practices. For specialized technologies, companies should consider periodic audits of a unit's existing process safety information, such as operating procedures, by subject matter experts. Companies that do not have centralized subject matter expert departments to review process safety information should consider hiring consultants.

6. Facilities should participate in process safety knowledge-sharing with their peers. Each site should focus on expanding its process knowledge and draw on sister sites and industry organizations to avoid siloes. The refining industry has many opportunities for technology-specific process safety information-sharing networks.

7. Operator training should include hands-on training opportunities for rare but critical tasks, such as shutting down a process unit safely for a turnaround, which typically occurs once every five years in many refineries.

[a] The CSB's investigation of the Pryor Trust gas well blowout and fire included discussion, analysis, and recommendations on using state-based alarming [151].

8. FCC catalyst slide valves and catalyst levels are not gas-tight. They should not be relied upon as an independent protection layer in hazard assessments.

9. During FCC unit transient operations, which include startup, standby, and shutdowns, the reactor should be the point of highest pressure in the system until it is isolated from the main column to prevent inadvertent air and hydrocarbon mixing. Operators should understand how to manage pressures and flows to avoid entering explosive process conditions.

10. During FCC unit shutdowns, facilities should assess the timing of shutting down the wet gas compressor to minimize or otherwise prevent sending air into the gas concentration unit. Most FCC units have centrifugal compressors, which are typically shut down earlier due to surge concerns; however, reciprocating compressors can operate at low rates for prolonged periods.

11. Technology licensors should seek to continually improve the inherent safety of their equipment designs and clearly communicate process safety hazards to the owners and operators of their technology.

12. Fitness-for-service assessments do not always evaluate extreme events, such as an explosion inside the vessel. Selecting materials that remain in a ductile zone in all modes of operation can be an inherently safer design, because should the equipment fail, a fish-mouth rupture is likely preferred over a more dangerous brittle fracture failure.

13. When siting storage tanks and designing secondary containment dikes, consider evaluating tank head pressure where a tank leak could be above the dike wall, as needed.

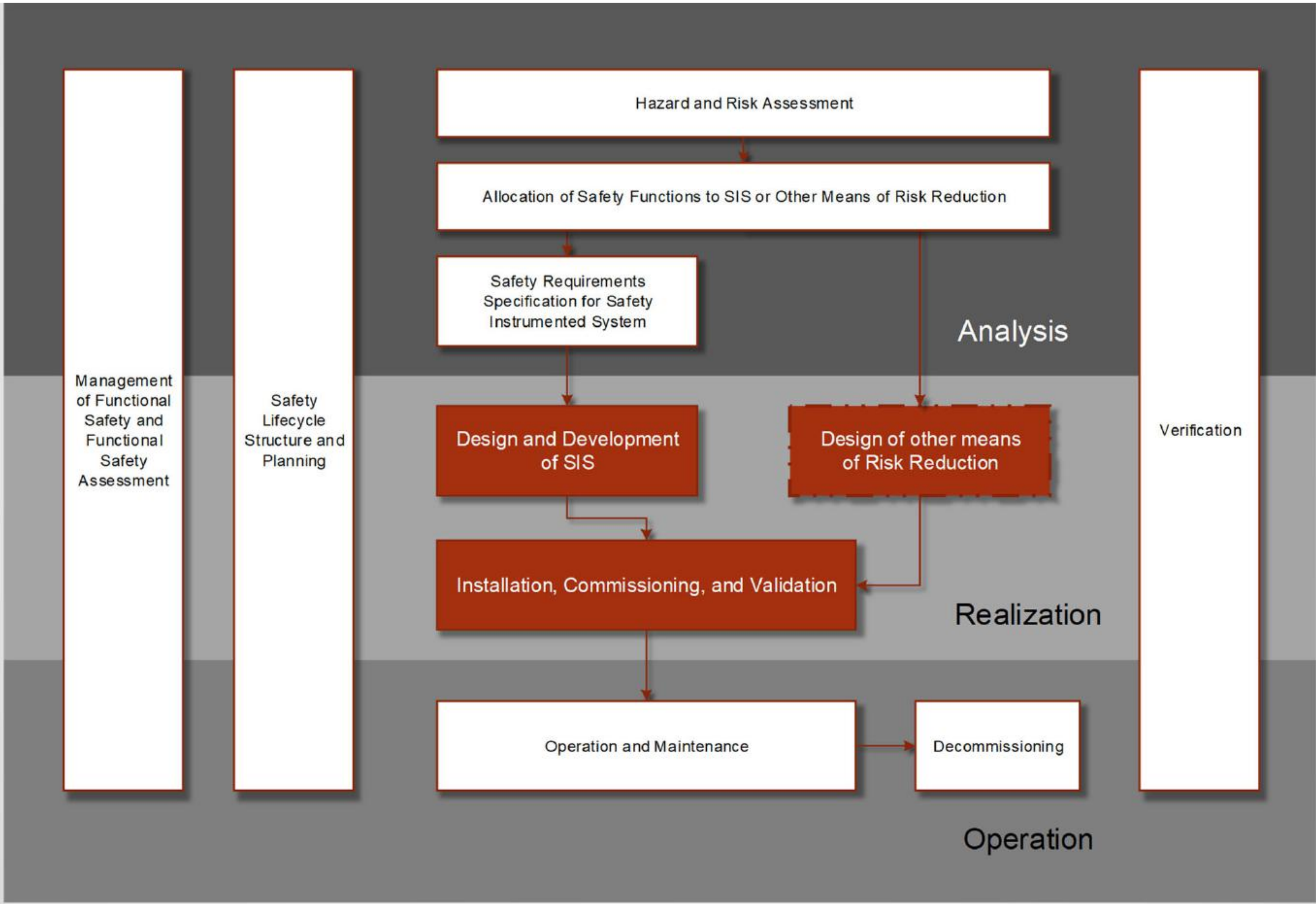
14. Materials such as asphalt, which have high (>200 °F) flash points, are ignitable when stored, handled, or processed above their flash point. For ignitable liquids with high flash points that are stored at temperatures near or above their flash points, companies should ensure that the safety data sheet includes relevant flammability information.

CSB Key lessons for Industry Summary

1. Transient operations perhaps need dedicated DCS screens and state-based alarms
2. Operators should understand how O_2 can accumulate
3. Refiners should understand how to vent & purge to flare during S/U and S/D
4. Most PHA's don't cover transient operations & should
5. SME should review op procedures periodically
6. Participate in process safety knowledge with peers & industry organizations
7. Operator training should be hands-on for rare critical tasks like T/A's
8. Slide Valves are not gas tight and should not be an IPL
9. During transient ops, Rx should be high pressure point
10. Facilities should address timing of WGC shutdown to prevent air in Gas Con
11. Technology licensors should seek to continually improve inherent safety of equipment.
12. Fitness for service does not take into account extreme events. Mat'ls should remain ductile in all op modes
13. Tank containment should consider head pressure if leaks can be above dike.
14. High flash pt mat'l stored above flash point should ensure SDS includes flammability info

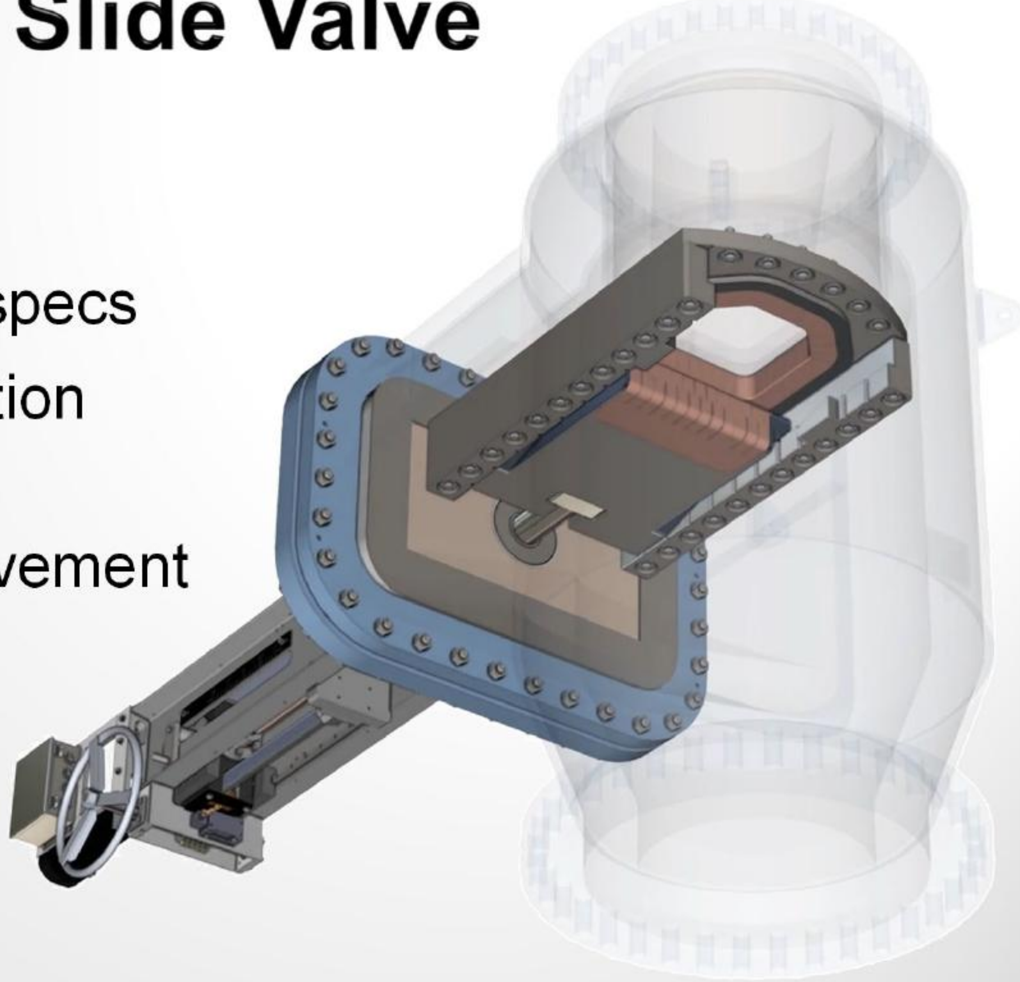
blac inc.
BLACK LIMITED ADVANCED CONTROLS

SIS Safety Life Cycle



BLAC INC. TightCat™ Slide Valve

- ANSI Class IV Shutoff
- Meets all licensor mechanical specs
- ***Can*** be an independent protection layer
- Provides *inherent safety* improvement CSB suggests



blac inc.
BLACK LIMITED ADVANCED CONTROLS

Questions?

blac inc.
BLACK LIMITED ADVANCED CONTROLS


blac inc.
BLACK LIMITED ADVANCED CONTROLS