COMPARATIVE RISK ASSESSMENT FOR COKE DRUM RELIEF VENT AND DISPOSAL

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KEYWORDS

Delayed coking, coke drum relief, quantitative risk assessment, coker quench drum

ABSTRACT

An oil refiner has considered re-routing the destination for reliefs from the coke drum of a delayed coking unit. Currently, coke drum reliefs are vented to atmosphere through a quench drum system. The licensor proposed design, which is more representative of currently design units, vents reliefs to the coker's blowdown system. Both options have strengths and limitations. The quench drum blowdown route has an unrestricted path to atmospheric pressure, but releases hydrocarbons to atmosphere, which presents hazards for personnel exposed to the material or its flammable effects. The blowdown system relief option discharges the relieved hydrocarbons to a safer location (the flare) where they will be safely combusted, but utilizes a more complex relief path that has the potential of getting blocked in under some failure scenarios and rendering the relief unit ineffective.

INTRODUCTION

The objective of this study was to perform a comparative risk assessment of the two options available for the proposed vent and disposal system, based solely upon the risk associated with each option. The risk will be estimated for each scenario and presented in terms of probable loss of life (PLL) associated with a relief event. The PLL is a function of probability that a relief event can not be adequately vented multiplied by the event consequence. It is important to note that environmental and commercial consequences were not considered in this study.

The refiner employs delayed coking process units at its refineries, taking a feedstock of very heavy hydrocarbon, such as vacuum gas oil, and produces a full range of lighter products by thermally cracking the material. In addition to the lighter materials, coke is also created in the reaction. Coke is separated from the other products in the unit's coke drums. Due to the nature of the process, it is typically performed in a semi-batch fashion where the continuous stream of reaction product from the Coker Heater is sent to a coke drum for separation until the drum is filled, at which point the active drum is switched. The off-line drum is then de-coked, and prepared for return to service. While the details of the de-coking process are complex and outside the scope of this analysis, it is important to note that the decoking process uses large amounts of steam and water for which a blowdown system is required (i.e., for steam condensation and water recapture).

The coke drums are subject to a number of overpressure scenarios, so they are protected in accordance with American Petroleum Institute (API) standards 520 and 521, along with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.

Engineering a suitable vent and disposal system for this service is a considerable challenge, because direct connection of the relief to the flare header is not feasible. The material that is released from the coke drum during an overpressure event is the coking reaction products, which include a full range of hydrocarbons along with coke. When this material is released, the developed coke and coke produced from the continual coking reaction will build up and plug off the relief path, resulting in ineffectiveness of the relief system.

Due to the inability to dispose coke drum reliefs to the flare header, alternate designs were developed. Early designs employed atmospheric relief (i.e., not to the relief header) after water quenching in a quench tower. This system employs tower with a water quench to cool the relieved material and knock down and dilute any heavy hydrocarbons or coke. The resulting vented material is a mix of light hydrocarbons that are expected to harmlessly dilute and disperse downwind, not generating any fire or explosion consequences. The quench water is routed to an oily water sewer where it is subsequently processed.

More contemporary designs utilize the plant's blowdown system for a vent and disposal of coke drum reliefs. When the blowdown system is used to process coke drum reliefs, the relieved material is sent to the blowdown drum, where it is cooled and the coke fines and heavy hydrocarbons are removed. From the blowdown drum the relief is routed through the Blowdown Condensers, the Blowdown Settling Drum, and the LCGO Seal Pot, prior to being released to the flare header. While these additional pieces of equipment are important for processing the steam that enters the drum during the coking process, they serve no purpose in terms of vent and disposal of coke drum reliefs. Once the relief is released into the flare header it is combusted at the flare tip, safely processing the release.

Both systems are subject to failure modes that could result in an ineffective vent and disposal scenario with varying effects and consequences. This paper describes the analysis of both systems, with respect to safety consequences only, to determine which option is most appropriate for this project.

Quench Tower System (Existing Design)

Figure 1 presents a typical quench tower vent and disposal system.

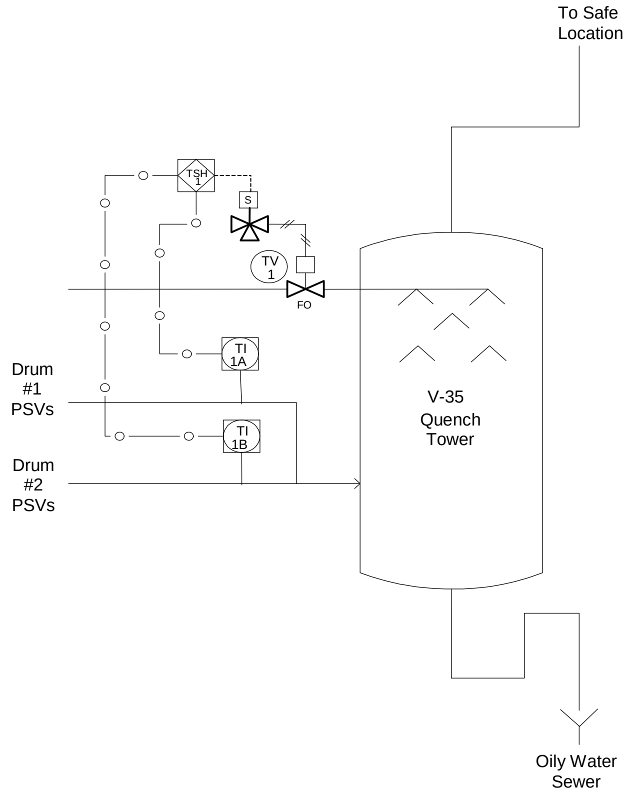

Figure 1 – Typical Quench Tower Configuration

For this refinery, the coke drum relief valves are located near the coke drum and are routed to the quench tower. Each of the lines connecting the relief valve to the quench tower (prior to the point where they are combined) is equipped with a temperature measurement to detect relief and initiate quench water. Upon detection of the relief event, the control system will open the quench water valve and start the quench water pump. Presently, the instrumented function that is responsible for delivering quench water is deployed in the plant's basic process control system (i.e., DCS) and is tested monthly. It is expected that if this option is selected for the future, it will be deployed in the plant's safety PLC instead of the DCS.

The relief material enters the drum near its base, and then travels upward through the tower. As it travels upward, the material is cooled and any entrained or formed coke and condensed hydrocarbons will be collected and carried back down to the tower bottom. The cooled light relief gases will then travel out the top of the tower and through a 20" pipe to a safe location, located above the top derrick deck at 350 feet above grade. The released material is expected to be mostly methane and ethane, along with a small amount of propane and heavier hydrocarbons. The release of this material is expected to result in momentum jet dispersion at the release point which will entrain air and quickly dilute the material below its lower flammability limit (LFL). Furthermore, the release is expected to disperse in a buoyant fashion, and not return to grade level at any significant hydrocarbon concentration.

The liquid from the quench tower, which is mostly water with some coke and heavier hydrocarbon liquids, is routed to the oily water sewer after going through a seal leg. The seal leg is maintained and filled with Light Coker Gas Oil (LCGO). The liquid leaving the quench tower is cool and dilute, in terms of hydrocarbons, and can be safely processed in the oily water sewer.

Strengths:

1. Unobstructed relief path from the coke drum to the ultimate relief point

2. Cooling and knockdown of the relief; when it reaches the ultimate relief point it is unlikely to return to grade or result in a fire or explosion

3. Coke and coke-producing materials are scrubbed out of the relief stream, preventing plugging of the vent and disposal system

Limitations:

1. Unignited flammable hydrocarbon gases are released to atmosphere

2. Quench Tower creates additional maintenance and operating expenditures

3. Failure of the water quenching action by any means could result in a range of consequences. The material traveling through the Quench Tower will remain at elevated temperature. The relieved material may deposit coke in the quench drum outlet piping, causing a blockage of relief path. The Material that ultimately reaches the relief point will have a heavier molecular weight and may "rain out" liquids and drift down toward grade where flash fires or pool fires could result. Uncooled material released near auto-ignition temperature could ignite and cause a jet fire at the release point 10 feet above the top coker derrick platform, which is sometimes occupied.

The liquid outlet can be blocked as the result of water accumulation that freezes, resulting in loss of liquid release path and a release of liquid, including quench water, condensed liquids, and coke fines, from the relief outlet and spill down the coker structure.

Blowdown System (Proposed Design)

Figure 2 presents a typical delayed coking unit blowdown system.

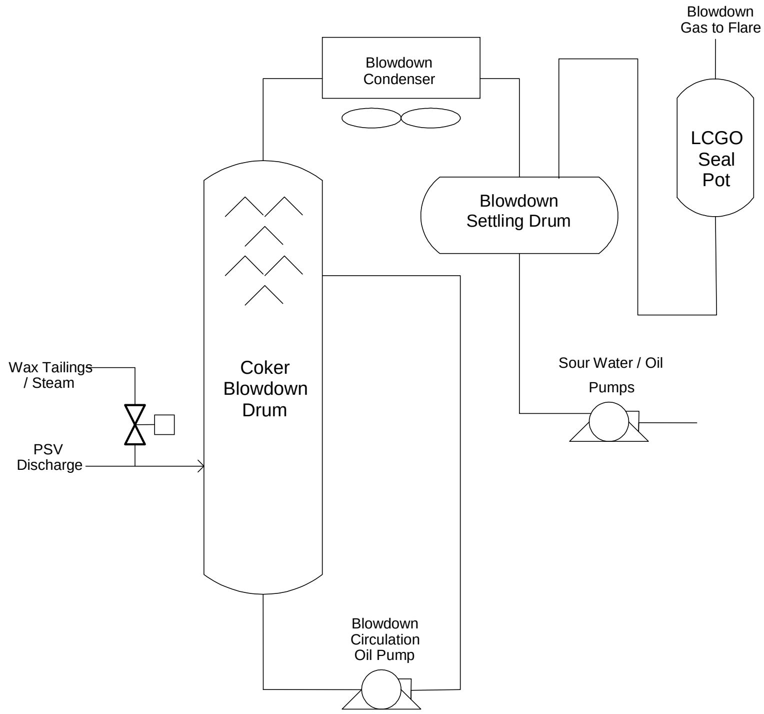

Figure 2 – Proposed Blowdown System Configuration

In this proposed configuration, the coke drum relief valves are vented to the blowdown system. The coker blowdown drum is equipped with a circulating oil loop whose primary purpose is to absorb any heavy hydrocarbons in the material routed to the drum, specifically any hydrocarbons contained in the steam used to steam out coke beds prior to decoking. The circulating oil is pumped by the blowdown circulation oil pump at the bottom of the vessel up to near the top where it is re-introduced into the vessel. Material is withdrawn from this loop on level control to either the Coke Drums or Coker Fractionator. From the Coker Blowdown Drum, blowdown material is sent through the Blowdown Condenser. The condenser is a set of multiple air coolers that condense steam used during steam-out of a coke drum, and return the condensate to service. From the condenser, blowdown material is routed to the Blowdown Settling Drum, where water, hydrocarbon liquid, and hydrocarbon vapor are separated. The water is pumped off to the sour water / oily water sump, the hydrocarbon liquids are pumped back into the Coker Blowdown Drum through the circulation oil system, and during a relief scenario the hydrocarbon vapors are sent to the flare systems after going through the LCGO seal pot (normally the vapors are compressed and sent to the Coker Wet Gas Compressor).

Strengths:

1. Relieved material is processed in a safe and similar manner to other hydrocarbon reliefs

2. Coke and coke-producing materials are scrubbed out of the relief stream, preventing plugging of the vent and disposal system

Limitations:

1. Circulating oil pump failure (or failure of level control such that the liquid inventory is drained) could result in a situation where relief would not be cooled, resulting in plugging of the blowdown system with coke

2. Circulating oil level control system failure could result in overfill of the Blowdown Drum, flooding the vessel and the downstream piping. The additional static head of liquid would result in a higher back pressure at the coke drum relief valve during relief.

3. Significant pluggage of the Blowdown Condenser may result in excessive pressure drop across the exchangers during a relief event, resulting in increased backpressure on the relief valves

4. Steam tracing failure of the Blowdown Condensers during very low ambient temperatures could result in liquid freezing in the condensers and potential condenser blockage, or increase in pressure drop across the condensers during a relief event and increased back pressure at the relief valves

5. Hydrocarbon level control system failure in the Blowdown Settling Drum or Blowdown Slop Oil Pump failure could result in liquid overfill of the Blowdown Settling Drum resulting in additional pressure drop for a relief event due to increased static head in the vessel. This could result in increased back pressure at the relief valves.

6. Low ambient conditions in the LCGO seal pot could result in any water that accumulates in the seal leg freezing and potentially blocking the relief path.

ANALYSIS

Quench Tower Consequence Event Tree

Relief through the quench tower can result in a variety of consequences, depending on the mitigating factors and other events that may be in place at the time of a relief event. The range of consequence outcomes that might occur as the result of a relief event are depicted in the event tree in *Figure 3*.

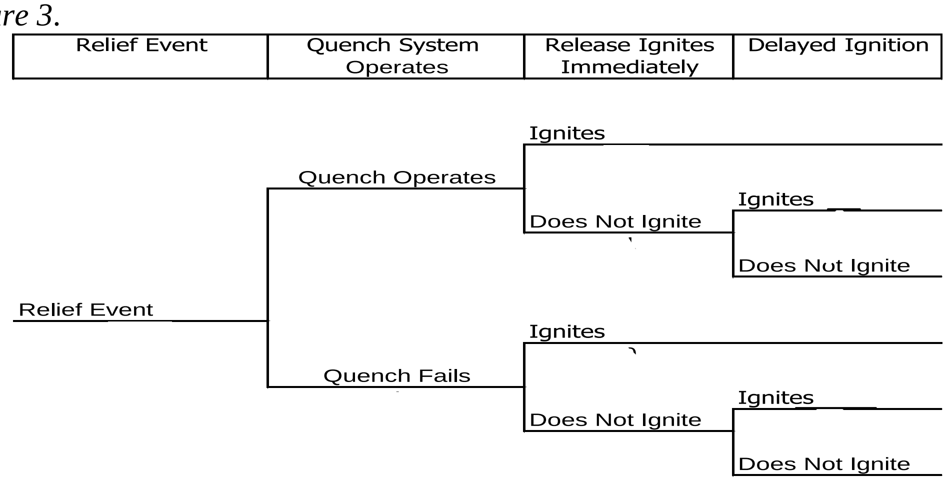

Figure 3 – Quench Tower Consequence Event Tree

Consequences of Quench Tower Relief

The first incident outcome represents where the quench operates and the release is immediately ignited. A rigorous consequences analysis for this scenario was not modeled because the scenario is highly unlikely. For immediate ignition to occur, the material being released would have to be near or above its auto-ignition temperature (~700°F), or an immediate source of ignition at the release point would need to be present, neither of which is true for this case.

The second incident outcome represents the case where the gas cloud develops and there is a delayed ignition downwind of the release point. No consequence model (i.e., flash fire, or vapor cloud explosion) was performed for this scenario after the results of dispersion modeling were reviewed. *Figure 4* presents a side view of the release for various typical weather cases that might be seen at the refinery. The results shown indicate the extents of Lower Flammability Limit (LFL) after the release. In all three scenarios, the release momentum dominated initially, and then transitioned to neutrally buoyant. The worst case weather condition (1.5 meter/second wind speed and F atmospheric stability) results in the cloud traveling downwind a distance of about 360 feet and still being flammable, but the cloud stays essentially at its release elevation of about 350 feet. As a result of the location and size of the cloud, it is very unlikely that a source of ignition would be contacted as the cloud does not pass through any areas where equipment or people are located. In fact, the cloud primarily exists only in open air. It should also be noted that the weather conditions used to model relief are very pessimistic. This type of weather condition is somewhat likely at ground level, but wind speed increases with elevation, so the weather conditions at the release point will be better represented by the 1.5A case shown in *Figure 4* (i.e., the yellow line).

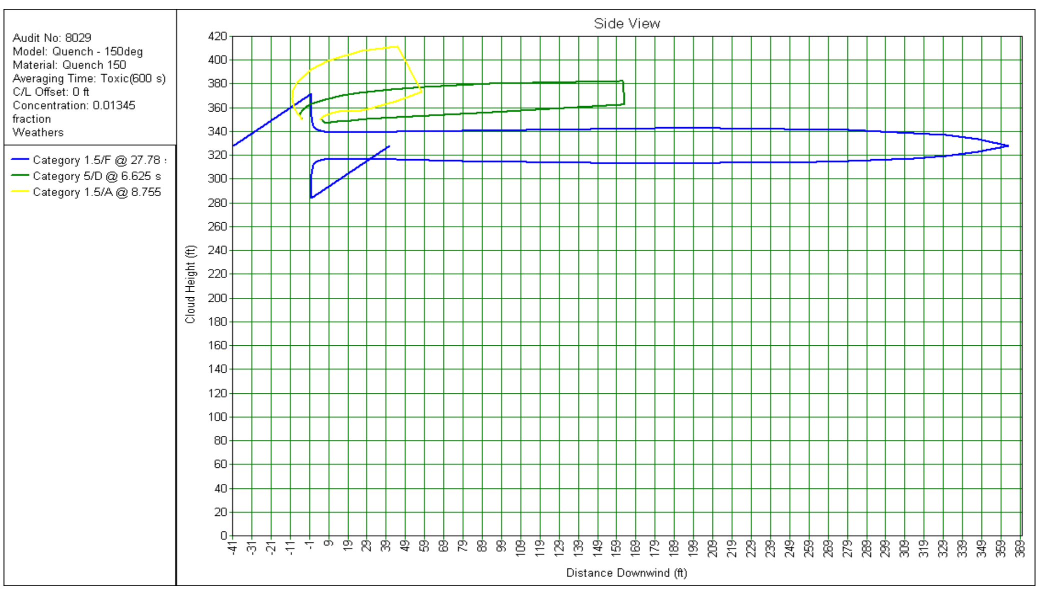

Figure 4 – Blowdown Drum Quenched Relief Dispersion
Side View – LFL Isopleth

The third incident outcome represents a quenched, unignited release. The consequences of an unignited release were qualitatively deemed negligible. The release material is primarily light hydrocarbons with some hydrogen sulfide; without ignition, the effects of fire and explosion are not applicable to the scenario. Exposure to hydrogen sulfide is a potential concern, but based on dispersion modeling results, significant concentrations will buoyantly disperse at the release elevation where personnel are not present.

The fourth incident outcome represents the case where the water quench of the relief fails to operate with immediate release ignition. During coking, the material being relieved from the coke drum will be released at an operating temperature of about 800°F. At this temperature, a several components of the relief are near or above their auto-ignition temperatures. As such, ignition can occur in the presence of sufficient oxygen. The refiner has had experience with unquenched reliefs. In all cases, the relief did not ignite. The reason is most likely related to cooling of the relieved material prior to release to atmosphere, where combustion can occur. Even without quenching, the heat sinking capability of all of the equipment on the way to the release point can probably keep the temperature of released material below auto-ignition for a significant period of time (i.e., until the entire relief system "warms up"). Conservatively, it was assumed that ignition at the release point was possible. Since ignition did not occur during two known unquenched relief events, it was assumed that another event would result in immediate ignition. This results in an assumed probability of 33% that a release will immediately ignite and a 67% probability that the release will not ignite.

If immediate ignition occurs, the incident outcome case would be a jet fire at the release point. The consequences of a jet fire are a function of the distance from the jet fire that the receptor is located. In order to determine the potential consequences, Kenexis modeled the amount of thermal radiation that would be present at each of the coker decks and at ground level as a result of the jet fire. The "end point" of concern for thermal radiation was set at 12.5 kW/m^2, and the vulnerability was set at 100%, meaning any person inside the 12.5 kW/m^2 isopleth was assumed to be fatally injured by the fire. *Table 1* summarizes the results of the jet fire analysis.

Deck	Impact Area (sq. ft)	Occupancy (persons/sq. ft)	Consequence (PLL)
Coker Derrick – Elevation 3	2626	2.63 E-07	6.91 E-4
Coker Derrick – Elevation 2	2626	1.88 E-07	4.93 E-4
Coker Derrick – Elevation 1	0	1.88 E-07	0
Coke Cutting Deck	0	1.11 E-04	0
Vapor Deck	0	1.45 E-04	0
Ground Level – General Refinery	0	5.59 E-05	0
Total			1.18E-3

Table 1 – Jet Fire Consequence Summary

It was determined that the lethal effects of the jet fire do not extend down to the coker derrick at Elevation #1 (i.e., thermal radiation is less than 12.5 kW/m2), but are present at the top two coker derricks whose entire area is in the fatal vulnerability zone. Considering the occupancy of these decks, the overall probable loss of life given that a jet fire occurs is about one chance in one thousand. *Figures 5* and *6* summarize the projected foot print for a jet fire occurring at Elevation #3 and Elevation #2, respectively.

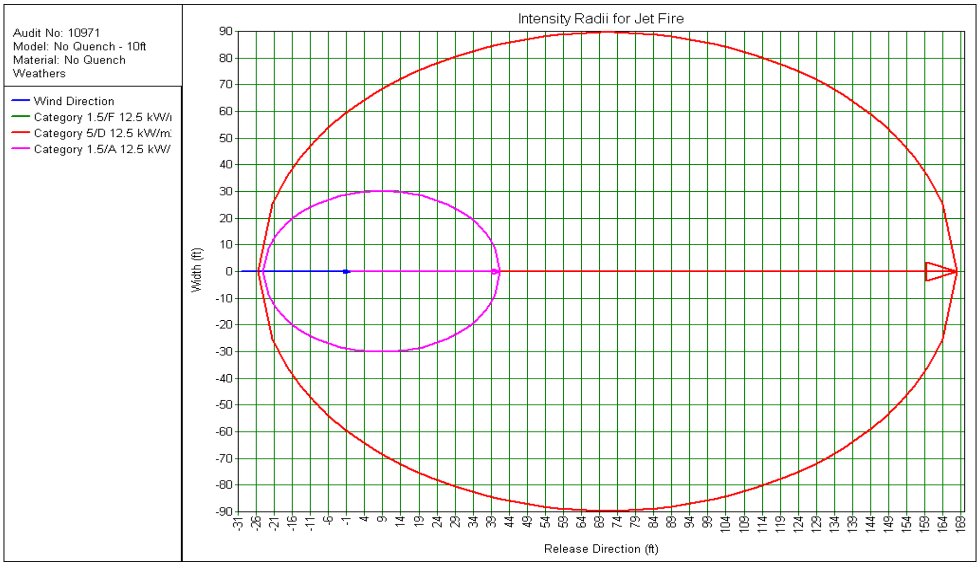

Figure 5 - Jet Fire Foot Print Plot for Coker Derrick at Elevation #3

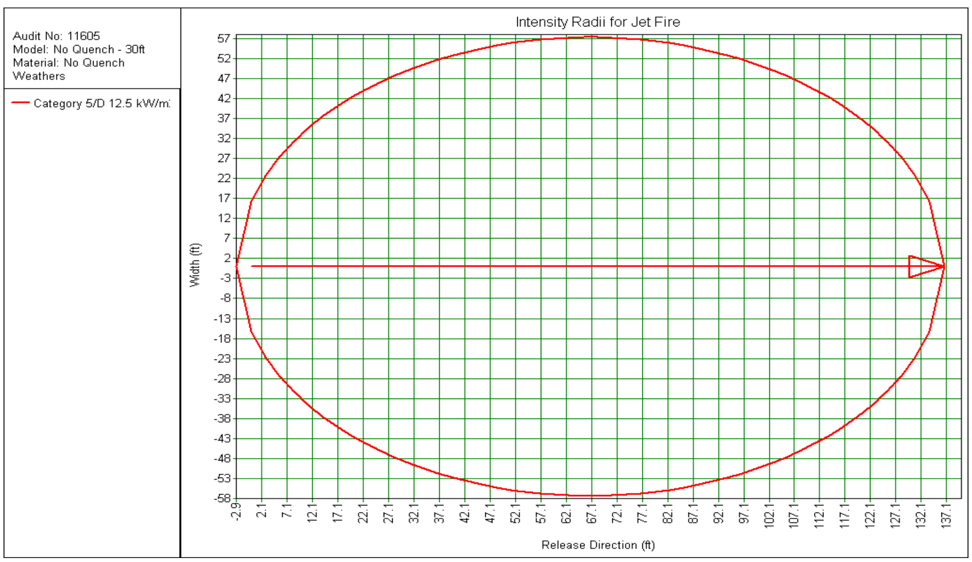

Figure 6 - Jet Fire Foot Print Plot for Coker Derrick at Elevation #2

The fifth incident outcome represents the case where an unquenched relief occurs and is subsequently ignited after delay, downwind from the release point. The release of hot material will result in a cloud that is very similar in dispersion profile to the one that was generated for the quenched case (see *Figure 7*). The difference with this cloud is that it will travel further before reaching the LFL and will contain a significant portion of heavy hydrocarbons, which will tend to condense as the released material cools. This will make the release look cloudy in comparison to the quenched relief which will likely be clear and not readily visible from grade. Furthermore, the condensing vapors will agglomerate and form droplets which will "rain" down to grade level. If the wind and atmospheric conditions are steady this material will form a pool.

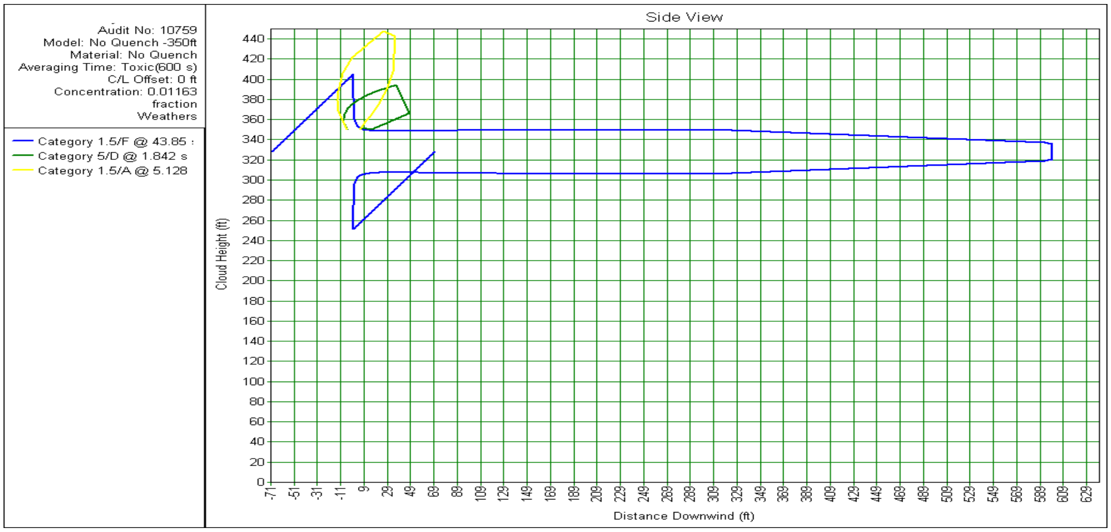

Figure 7 – Blowdown Drum Unquenched Relief Dispersion
Side View – LFL Isopleth

Approximately 4% of the total material mass is expected to be subject to liquid rainout. It is expected, based on prior experience, that the material that rains out will be distributed under the entire relief, but more highly concentrated toward the release point. Prior experience has shown that the "rain out" creates a thin coating over a large area with minimal pool formation. In order to be conservative, this study assumes that half of the liquid that rains out collects into a single pool. *Figure 8* illustrates that if this material were to pool together over a 5 minute duration (which is a conservative estimate for the duration of a relief event) and ignite, a pool fire would be created which would generate thermal radiation. Based on an analysis of the effects of thermal radiation, it is expected that the size of the effect zone to the 12.5 kW/m2 endpoint would extend 65 ft in the direction of the wind and 58 feet in the cross wind direction giving an effect zone of 2,595 square feet.

Considering average refinery occupancy of 5.59 E-05 persons per square foot, this yields a probable loss of life for this incident outcome of 0.145. While the PLL for the consequence is 0.145, delayed ignition is not a certain event. Based the prior experience that no ignition has occurred in more than 10 similar release events, it was pessimistically assumed that the ignition probability is less than 10%.

It should also be noted that for this case, the potential that a ground level ignition might back flash through the misty rainout and cause an ignition of the main gas cloud from the release point was considered but dismissed as a non-credible. Due to the nature of the rain out, it is very unlikely that a flame front would be able to propagate any appreciable distance. The nature of the rain out is such that small droplets of liquid are somewhat suspended in air. In order for a flame front to propagate in this situation, the heat of reaction from the combustion of one droplet would need to travel to an adjacent droplet and cause its ignition, which is not considered likely. Furthermore, if the flame front were able to propagate back to the main cloud, there is no confinement. Due to the lack of confinement, development of the rather weak ignition source provided by the back flash into a detonation or even significant deflagration is unlikely. The most likely consequence that could occur if back flash were possible would be a flash fire, whose consequences would not be significant at grade level.

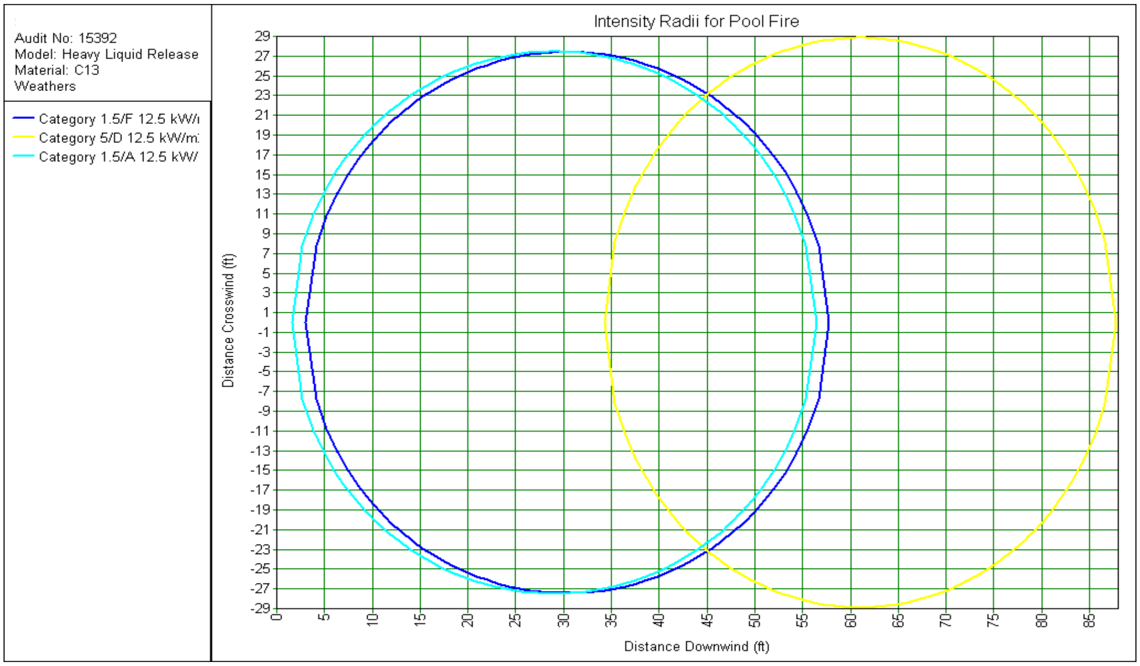

Figure 8 –Unquenched Relief Rain-Out Pool Fire Footprint

The sixth and final incident outcome represents the case where an unquenched relief occurs but is not ignited. In this case, the hydrocarbon vapor cloud, which contains hydrogen sulfide will draft downwind and dissipate without entering any occupied areas. The liquid hydrocarbons will rain out and puddle in the process areas of the refinery, but without a source of ignition, there will be no safety consequence.

Quench Function Failure

As presented in the discussion of the Quench Tower consequence event tree, the consequence of a Quench Tower Relief is a function of whether or not the quench system operates. The quench system operates by measuring the temperature of the relief material in relief valve discharge piping on its way to the quench drum. Upon detection of high temperature in the relief discharge piping, a control valve opens, to allow water to the quench tower and starts the water pumps. In the existing design, this functionality is accomplished in the plant DCS. Based on this configuration, the quench function could fail on demand if either: the temperature sensor fails, the DCS loop fails, the control valve/solenoid fail to operate, or the water pumps fail to operate. This system is tested on a monthly basis. This analysis breaks the quench system into two components to simplify the analysis: the instrumented loop that controls the quench function and the pump system.

The study includes analysis of four configurations for the instrumented loop that controls quench system. The first is the base case, which represents the existing design as described above. The first option utilizes a safety PLC as the logic solver that performs the safety action, but utilizes the same field equipment, with the exception that the thermocouples employ a transmitter to convert the millivolt signal to a 4-20 mA analog loop. The second option is similar to the first, but employs a two-out-of-three (2oo3) voting temperature measurement arrangement to detect the hazardous condition. Finally, the third option builds upon the 2oo3 sensor configuration of the second option and adds a pair of quench valves in parallel to provide a one-out-of-two (1oo2) voting arrangement.

The base case failure probability was determined to be about a 1 in 600 chance of failure. Improvement of the logic solver system improves the results to 1 in 900, and use of 2oo3 voting sensors further improves the probability to about 1 in 1200. The results of improvement for options 1 and 2 over the base case are incremental because the bulk of failures in this function (and most safety instrumented functions in general) are associated with final element (e.g., valve train) failures. Option 3, which improves the valve configuration by providing a degree of fault tolerance, provides a significant improvement over the base case and other options, with a failure probability of about 1 in 14,000. All of these cases were utilized in analyzing the sensitivity of the risk of the Quench Tower relief to various equipment configuration options.

In addition to instrumented loop failure, failure of the water pump(s) and water supply could also result in inability of the quench system to perform its intended action. This could occur as the result of failure of the pumps to start, insufficient water supply, and failure to divert necessary water from the coke cooling operation.

The analysis results for the various options for instrumented system type are summarized in *Table 2*.

Scenario	Unavailability
Base Case	3.82E-02
Option 1	3.77E-02
Option 2	3.74E-02
Option 3	3.67E-02

Table 2 Quench System Options Unavailability Summary

Based on the above results, the probability of a quench failure is substantial (~4%). Furthermore, the results show that failure of the control loop initiating the quench is not the primary cause of failure. About 96% of the failure probability of failure of the quench system lies in the unavailability of water for quenching or failure of the quench pumps. Very significant improvements in the control loop that delivers quench water will not have a substantial impact on the availability of the system. In order to improve reliability of the system process modifications, continuous access to a high volume / high pressure source of water that does not rely on starting a pump should be considered if the Quench Tower system is selected as the optimal design.

Blowdown System Consequence Event Tree

The consequence event tree for the blowdown system case is not as complex as the one for the blowdown system due to its binary nature. If the blowdown system fails, relief will not be possible and that will result in the failure to relieve consequence. If the blowdown system is operational, there will be no consequence (in terms of safety). The event tree is presented in *Figure 9*.

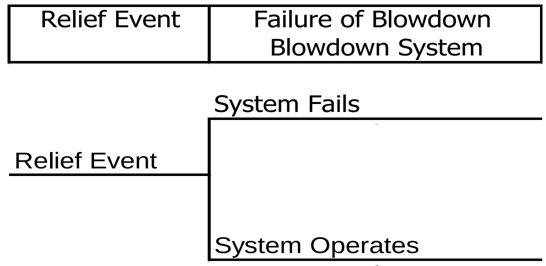

Figure 9 – Blowdown System Consequence Event Tree

Consequences of Blowdown System Relief

The consequences of a failure in the blowdown relief system are all related to system response to overpressure. The refiner developed guidance for determining the consequence of an overpressure event for prior project work. *Table 3* presents the criteria established for overpressure consequence.

The relief valves of the coker are designed for a blocked in condition during quenched (i.e., with hydrocarbon) coking operation. If the relief were to be blocked in at this point the ultimate pressure seen at the vessel would be determined by three factors: pressure delivered by the Coker Feed Charge Pump, relief set points of other devices that would limit the pressure seen at the coke drum, and pressure generated as a result of the cracking reaction.

In a relief event (during the coking step) where the relief system for the Coke Drums was unavailable, the mechanical pressure seen in the Coke Drums would be limited to the set point of the relief valves at the Coker Heater outlets, which is about 150 PSIG. If a relief were to occur during other filling on the other hand, the pressure would not be limited to the heater outlet relief valves, which are not lined up. This is tempered by the fact that the MAWP is limited by the high temperatures that are present during the coking step, and much higher pressures are allowable under the cooler conditions of filling. Therefore, the maximum pressure that the pumps are capable of discharging at would not be seen at the Coke Drums. Additional pressure increase due to continued cracking in the Coke Drums was considered, but determined not to be a credible source of increased pressures due to the highly endothermic nature of the coking reaction.

Based on these factors described above, it was determined that during a failure to relieve during coking operation, the pressure in the coke drum would be about 150 PSIG, which is about 200% of the roughly 70 PSIG drum MAWP. This magnitude of overpressure is expected to result in a catastrophic vessel rupture (Category E), which correlates to a Probable Loss of Life (PLL) of 1.0. This same category would have been selected even without considering the limiting effect of the Coker Heater outlet relief valves.

Vessel Overpressure (% of MAWP)	Significance	Potential Hazard	Hazard Consequence Severity Rating	Probable Loss of Life Estimate (PLL)
Up to 10%	ASME code allowable accumulation for process upset cases (non-fire) protected by a single relief device.	No expected consequence.	--	0
Up to 16%	ASME code allowable accumulation for process upset cases protected by a multiple relief devices.	No expected consequence.	--	0
Up to 21%	ASME allowable accumulation for external fire relief cases regardless of number of relief devices	No expected consequence.	Category A	0.001
Up to 50%	ASME hydrotest pressure	No catastrophic vessel rupture; associated instrumentation/ piping leaks	Category B	0.01
Up to 90%	Minimum yield strength (dependent upon materials of construction)	Catastrophic vessel rupture possible, but unlikely. Significant leaks probable.	Category D	0.1
Up to 300%	Ultimate tensile strength (dependent upon materials of construction)	Catastrophic vessel rupture likely to occur.	Category E	1.0

Table 3 Consequence Severity Ratings for Vessel Overpressure

Blowdown System Unavailability

Failure of the blowdown system could potentially occur as the result of a large number of failures. A fault tree analysis of relief system unavailability was performed to assess these failures, and it was determined that potential failures in the blowdown system occurred as a result of plugging in either the blowdown condenser (3.68E-11 occurrences per relief event) or the LCGO seal pot (9.79E-7 occurrences per relief event). It is important to note that the failure rate for plugging of the LCGO seal pot is dependent upon an assumed probability of no more than 1×10^{-3} that vent gas condenses in the inlet of the piping during freezing conditions, forming a plug, between periods of preventative maintenance (PM). It was recommended to the refiner to track the rate of water development and adjust PM procedures and frequencies so that this criteria was not violated.

Several other events, such as vessel overfill and vent line pluggage, were included in the fault tree analysis but not further developed. Pluggage of the vent line is an event considered common to the quench tower system and the proposed blowdown system. In the case of the Blowdown Settling Drum and LCGO Sealpot, or the Coker Blowdown Drum, the increased static head (13 and 18 PSIG respectively) from overfill in addition to relief valve backpressure would not exceed the lower set pressure rating of the relief valve or the MAWP of the coke drum.

Relief Event Frequency

The risk, or expected magnitude of loss, is the product of the consequence of the undesired event and its frequency. For this scenario, the frequency at which an undesired event consequence will occur is dependent upon the frequency at which a coke drum relief event occurs. The coke drum relief is the initiating event that generates all of the other consequence scenarios analyzed in this report.

The expected future frequency of relief events from the coke drums was estimated based on prior experience with coke drum relief events at the refinery. For the more than nine years that this new data tracking system was in place, the coker on the site suffered nineteen (19) relief incidents, and only three (3) occurred during the coking step, where mostly hydrocarbons would be released to the flare system.

In the 9.02 coker-years of data that was compiled, a relief event of any kind occurred at a frequency of 2.1 per coker-year, and a relief event during the coking portion of a drum cycle occurred at 0.16 per coker-year.

Assessment of Quench Tower Relief

The Quench Tower vent and disposal system was analyzed utilizing a variety of analysis techniques, as described in detail in previous sections of this report. The results of each individual analysis step were then compiled to determine an overall probable loss of life (PLL) associated with a Quench Tower relief. The results of this analysis are presented in the Event Tree shown in *Figure 10*.

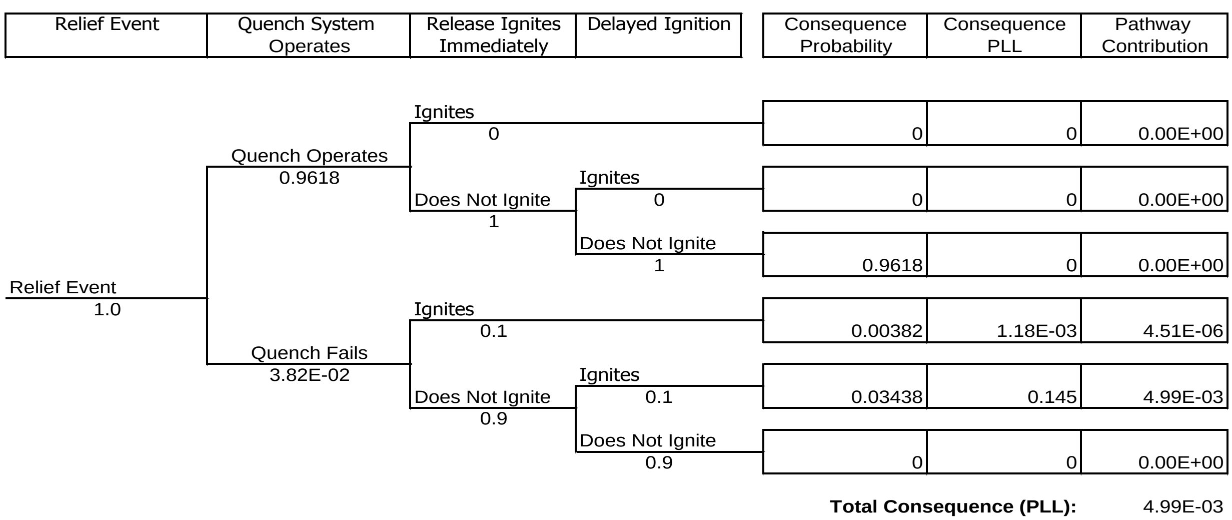

Figure 10 Quench Tower Option Event Tree - Quantified

The PLL figure simply represents the probability of a fatal injury, given that a coke drum relief has been attempted. In this case, it is about 5.0×10^{-3}, or about one chance of fatality per 200 relief events. In order to put the figure into a context that is more relevant to overall risk, the frequency of a potentially fatal accident should be calculated and compared with corporate guidelines on the tolerability of such an event. Relief events occur at the coke drums at a rate of about 0.16 events per year per coker – during coking operation, which is the only phase of operation where a safety consequence is likely to occur as the result of Quench Tower misoperation. When considering the initiating event frequency (i.e., relief) with probable loss of life, the fatal accident rate (FAR) of Quench Tower operation is about 8.0 x 10^{-4}, greater than the corporate tolerable threshold of 1.0 x 10^{-5}. As such, the current level of risk is not acceptable to the refiner and steps should be taken in the future to reduce the risk.

Assessment of Blowdown System Relief

The blowdown system vent and disposal option was also analyzed. The results of each of the individual analysis steps were then compiled to determine an overall probable loss of life (PLL) associated with a Quench Tower relief. The results of this analysis are presented in the Event Tree shown in *Figure 11*.

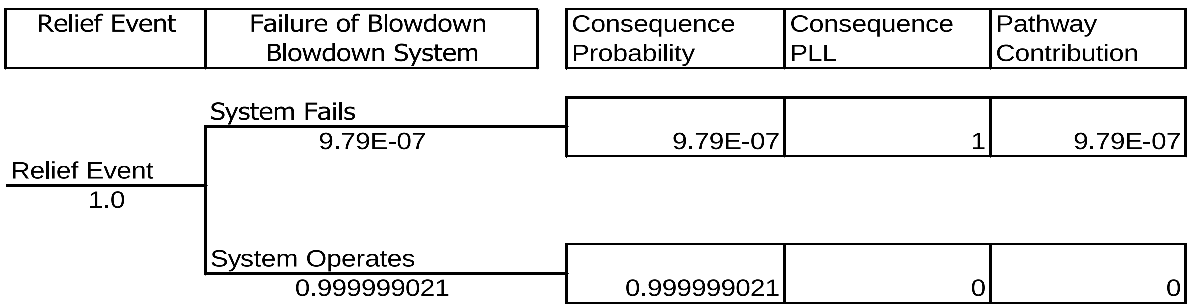

Figure 11 Blowdown System Option Event Tree - Quantified

For the blowdown system relief case, the PLL for a relief event is 9.79E-07, or about one chances of fatality per 1,000,000 relief events. In order to determine the FAR of relief through the blowdown system, the PLL is multiplied by relief frequency. While relief events at the coke drums during coking occur about 0.15 events per year per coker, any type of relief, especially those during steaming, could result in the consequence when using the blowdown system for relief. As a result, all forms of relief must be considered, resulting in the use of 2.1 events per coker-year. When considering the initiating event frequency (i.e., relief) with the probable loss of life, the fatal accident rate (FAR) of the Blowdown System option is about 2.1 x 10^{-6}, which meets corporate tolerability of risk criteria. It is important to note that this level of performance is only possible after the implementation of recommendations for preventive maintenance and administrative controls on coker operation that minimize the unavailability of the blowdown system.

CONCLUSION

After analysis of both options, it was determined that the proposed blowdown system approach is the safer option and meets refiner corporate criteria for tolerability of risk (contingent upon implementation of recommendations), resulting in a fatal accident rate (FAR) of 2.1×10^{-6} per year. Since the blowdown system will allow the refiner's tolerable risk criteria to be achieved with fewer modifications and special considerations and reflects current industry practice, it was recommended to the refiner to employ the blowdown drum approach, contingent upon implementation of the following recommendations for preventive maintenance and administrative controls.

1. Creation of a preventive maintenance program, including procedures and appropriate test intervals, to justify the 0.001 probability of development of an accumulation of water sufficient to plug up the LCGO seal pot inlet piping; the frequency of the maintenance task should be based on facility monitoring of how quickly water can develop in this location after startup of the unit, when monitoring should be performed very frequently.

2. Implementation of a program to perform a preventive maintenance on the blowdown condensers (air coolers) to verify that the flow path through the condenser is clear and clean out any potential wax build up, performed at a rate of about once per year per condenser.

3. Implement administrative controls to prevent operation of plant without blowdown header in operation. This would require shutdown of the coker unit if the steam system or condensate return system failed, prior to the point where any freezing in the blowdown system could occur; even 18 hours of unavailability (one coke drum cycle) in the event of a loss of the condensate header results in an unacceptable FAR of 1.39 x 10-4.

The existing quench tower system results in a FAR of 8.0×10^{-4}, which does not meet the refiner's tolerability of risk of 1.0×10^{-5}. However, the FAR of the quench system will decrease to 1.5×10^{-6} if modified to include an "always on" water supply and fully fault tolerant controls for quench activation. The majority of failures of the quench tower system is due to unavailability of water, which is a function of inability to start or use the required pumps. The use of an "always on" source of water, such as utility water or high-pressure water from continually running supply pumps will be required. In addition, a fully fault tolerant water introduction control system will also be required.

It is important to note that this technical paper is not meant to be a prescriptive document for the replacement of quench towers in coke drum relief. It is the responsibility of each refinery to assess the benefits and consequences of existing and alternative design relevant to its purpose and determine the best method available based on reasonable and generally accepted engineering practices.