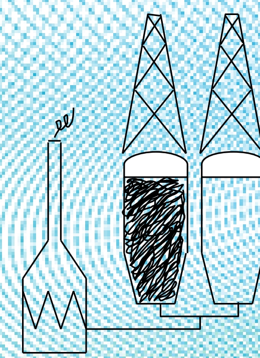
ExxonMobil

Coke Drum MAWP and Coke Bed Quenching Controls

REFCOMM GALVESTON MAY 2-6 2016



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Presented by Mitch Moloney of **ExxonMobil Research & Engineering**

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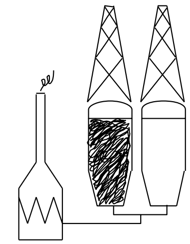
Coke Drum MAWP & Coke Bed Quenching Controls



Topics:

(1) Solution Overview

(2) Key Engineering Analysis Points

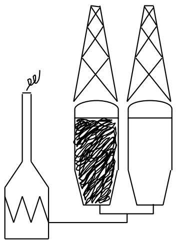
(3) Background
- Pressure Vessel MAWP Protection
- Historical approach to Coke Drum MAWP Scenario Analysis
- ExxonMobil Event October 2012

(4) Quench Ramp Analysis

(5) Probabilistic Contingency Analysis

(6) Facilities Effects

Coke Drum MAWP & Coke Bed Quenching
- Solution Overview



The intent is to set a methodology for protecting coke drums against uncontrolled steam generation during water quenching of the coke bed, which could generate a coke drum pressure greater than 1.16 x MAWP

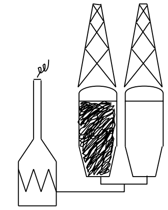
- two or more 'staggered set pressure' PRV's is assumed typical

=> The primary control is the use of two control valves during water quenching, each sized to limit flow rate to a pre-determined maximum.

=> The transition from one control valve to the other must be time- and flow-rate-based *AND* of very high integrity (controlled and reliable).

Coke Drum MAWP & Coke Bed Quenching

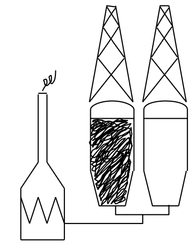
- Solution Overview (cont'd)



=> By evaluation of steam generation rate data and applying normalized statistical distribution techniques, hardware limits can be set such that the probability of exceeding 116% of coke drum MAWP is a remote contingency and exceeding 150% of coke drum MAWP is non-credible

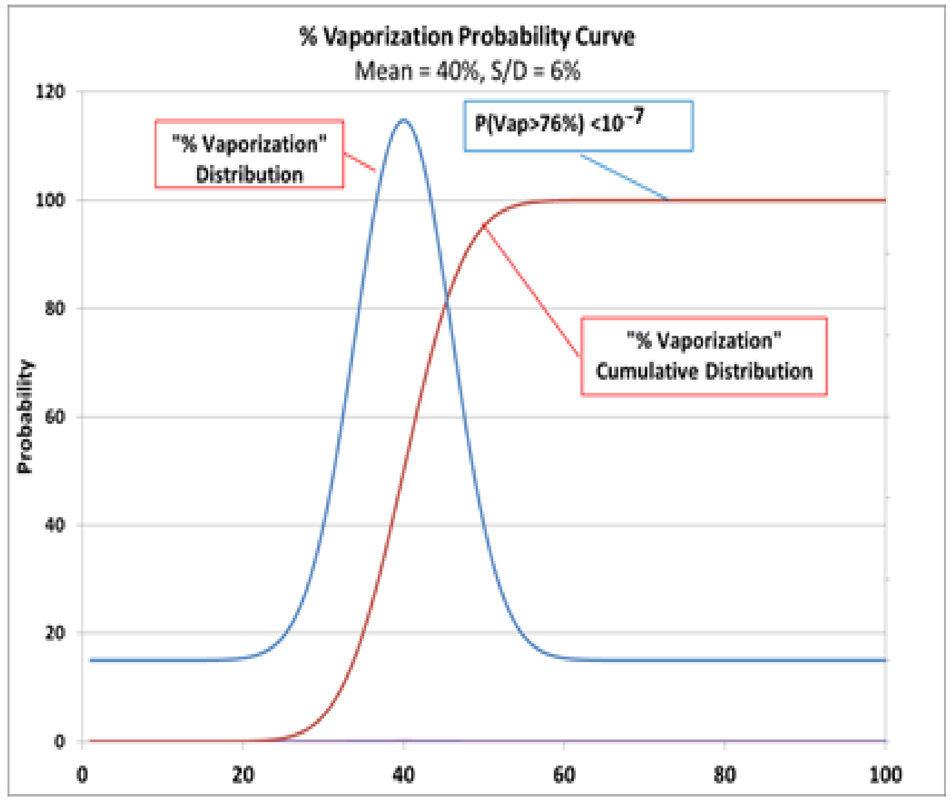
- Grassroots designs will need to select a conservative steam generation basis that references other past coker operating experience
- Two fundamental relationships are envisioned: one for sponge cokers and one for shot cokers

Coke Drum MAWP & Coke Bed Quenching
- Key Engineering Analysis Points



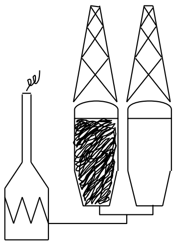
1) Application of probabilities to design, remote and non-credible contingencies and use event tree analysis to evaluate overpressure scenarios.

2) Development of a probabilistic model of the relationship between steam generation and quench water rate.



=> This relationship can be represented by a normal distribution.   Porous sponge coke beds will have a lower standard deviation around the mean % vaporization than shot coke beds.

Coke Drum MAWP & Coke Bed Quenching - Key Engineering Analysis Points (cont'd)



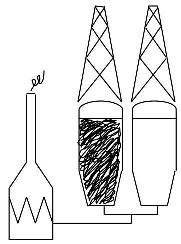
3) Changes required versus current standard coke drum quench operations/facilities:

   => High integrity controls are needed to maintain computer control of the quench water ramp and prevent manual control of the quench water rate

   => Quench water control valve(s) must be sized for a maximum CV based on event tree analysis.

4) If two quench water control valves are used, which is most typical, a PLC-controlled isolation valve is needed to prevent opening the 2nd valve based on 2 permissives – cumulative quench water flow and time

Coke Drum MAWP & Coke Bed Quenching
- Background Points



Coke Drums are "pressure vessels"

=> ASME Section VII applies

=> they must be protected by pressure relief devices

=> typically balanced bellows pressure relief valves are used

API Recommended Practice 521 is the standard for "Sizing & Selection (Part-I) and Installation (Part-II) of Pressure Relieving Devices in Refineries

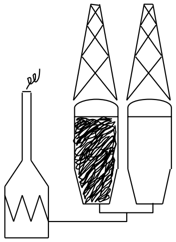
Coke Drum PRV's can relieve to:

1) the Coker Blowdown System (offered by two licensors)
2) the flash zone of the Main Fractionator (offered by 1 licensor)
3) a separate dedicated blowdown system (an older design rarely used anymore).

If a vessel has one PRV, it is allowed 10% accumulated pressure above the set point when relieving

If a vessel has two or more PRV's it is allowed 16% accumulated pressure

Coke Drum MAWP & Coke Bed Quenching
- Background Points



For systems with PRV disposition to the Coker BD System:

Historically Coke Drum PRV sizing is based on the controlling contingency of blocking one coke drum's vapor flow during normal maximum feed rate and operating conditions, while the sister drum was generating normal maximum steam during coke bed drum quenching.

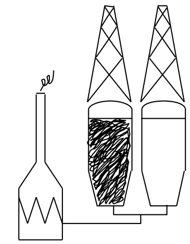
=> This presumes that the BD piping and fin fans are maintained to a minimum required standard of cleanliness

For systems with PRV disposition to the Coker Main Frac Flash Zone:

Coke Drum PRV sizing is based on blocking the drum generating normal maximum steam during coke bed drum quenching

=> This presumes that the Main Frac operating pressure and tower heat removal capacity are maintained to handle the quench steam load and meet PRV accumulation limits

Coke Drum MAWP & Coke Bed Quenching - Background Points



An alternate contingency is opening the quench water control valve wide open and generating an abnormal rate of steam.

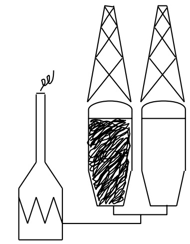
=> This contingency was considered to generate a less severe PRV design event (from the standpoint of PRV capacity and super-imposed back pressure) than the 'blocked outlet' contingency.

=> It was reasoned that the rate of steam generation would be limited during the initial quench stage by the use of the "little water" control valve. Once the coke bed was partially cooled, and the rate of water vaporization less, the "big water" control valve would be used. This continues to be the basic approach taken today.

Past assumptions behind this approach were:

- Coke beds cooled evenly and slow computer-controlled quench ramps limited instantaneous % vaporization of water (especially for 24-hr coking cycles)
- Nominally 30% vaporization at mid-quench ramp was used to set the normal maximum steam generation rate.
- Since the BD system was designed for a worse case, abnormally higher % vaporizations would be remote contingencies and still within 150% of MAWP

Coke Drum MAWP & Coke Bed Quenching - Background Points



Factors that now push us to consider steam generation as a controlling PRV load contingency:

- The prevalence of shot coke beds, which can create a more variable rate of steam generation
- Reduced coker cycle times (12 to 16 hrs) requiring faster water cooling ramps
- Elimination of the "little water" control valve CV limit early in the quench ramp
- Insufficient water quench ramp controls

This largely came to light as a result of an incident during November 2012 *

=> the console supervisor shut off the computer-controlled ramp because the drum was not completely filled with coke as part of furnace spalling

=> manually introduced a very high rate of water, very early in coke bed cooling process, causing a high rate of water vaporization.

=> a poorly formed coke bed, due to inadequate warm-up, was cited as a contributing potential cause.

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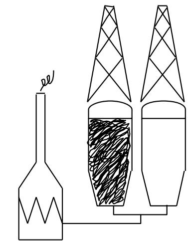
* This was presented at the API Operations Practices Symposium in 2013

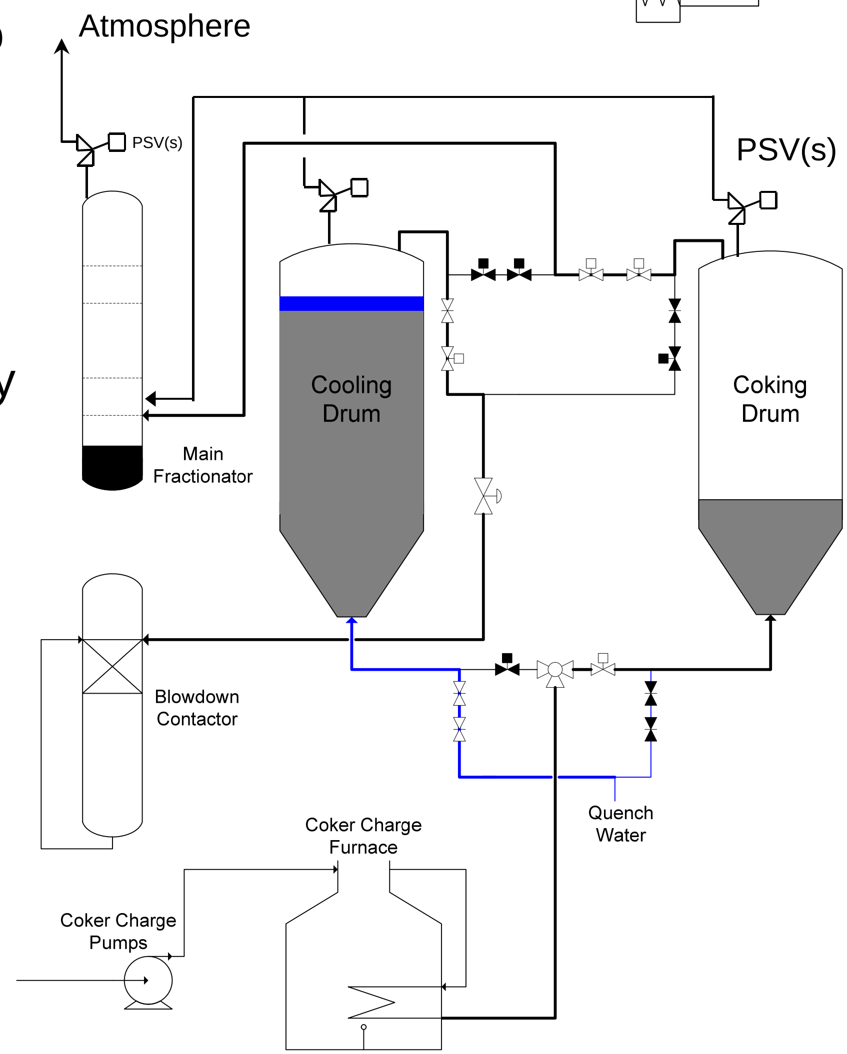
Coke Drum MAWP & Coke Bed Quenching

Background – The Incident

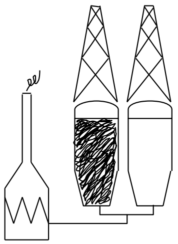


Oct 19, 2012 8:46 AM, the MF PSV's lifted to atmosphere resulting in a hydrocarbon release. Initiating event was a sudden over-pressure on B-Drum during the quench portion of the cycle, causing it's PSVs to relieve to the MF.

=> Automatic pressure override immediately removed water from the drum



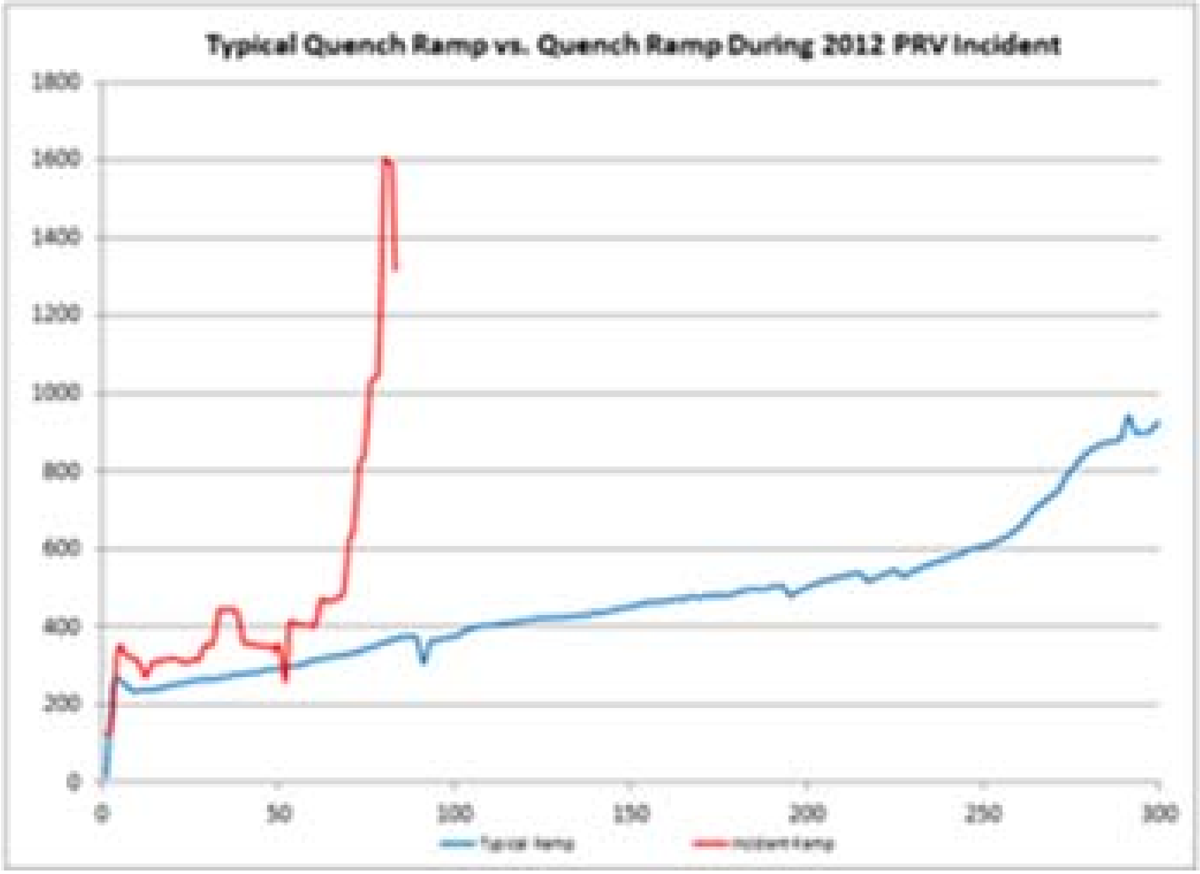
Coke Drum MAWP & Coke Bed Quenching
Background – The Incident



This Coker has an older design (over 40 years old), that sends coke drum PRV discharge to the Main Frac Flash Zone. PRV sizing contingency was blocked in coke drum while quenching at peak steam generation.

In this case, steam was able to flow to the Blowdown System AND the Main Frac

Still, Main Frac PRV opened and 150% of Coke Drum MAWP was exceeded



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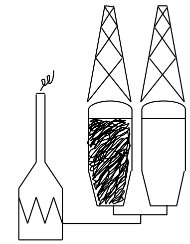
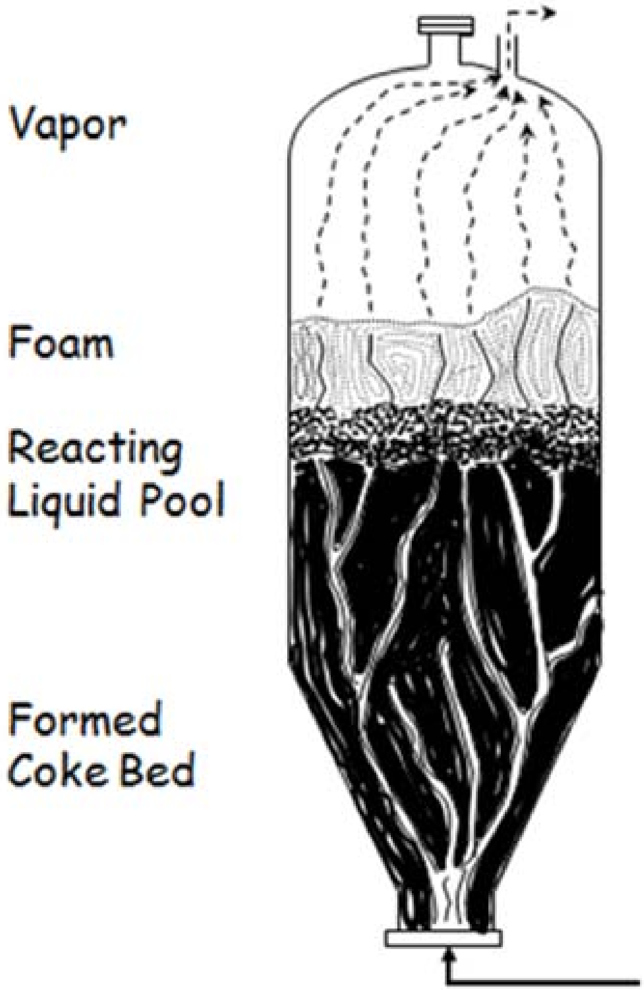
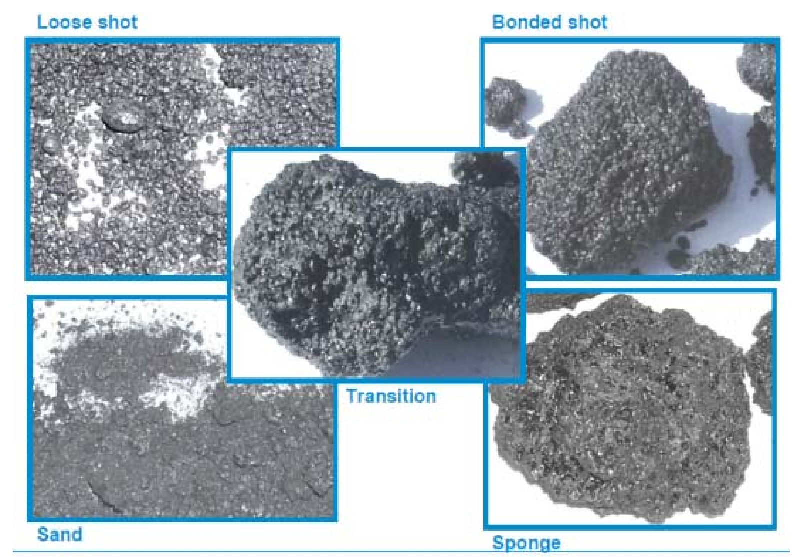
Coke Drum MAWP & Coke Bed Quenching
- Steam Generation is Random around a Mean

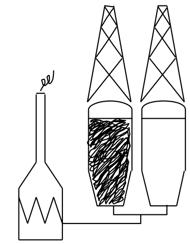




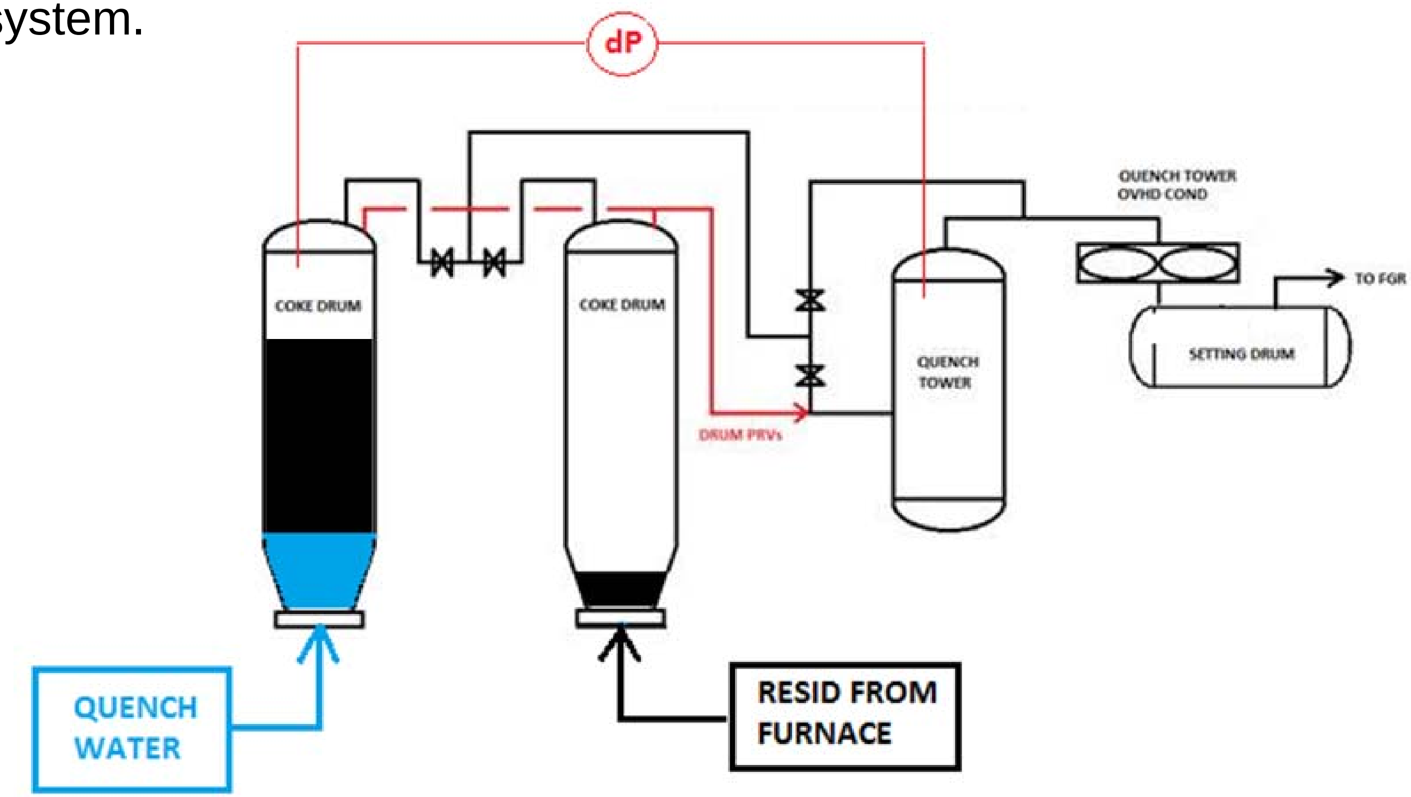
There are a lot of factors to consider when cooling a coke bed:
- Porosity
- Channeling
- Operating Conditions
- 4-Phase dynamics (liquid, vapor, foam & solid)



Coke Drum MAWP & Coke Bed Quenching



- Quench water injection rate is controlled through a TDC-based ramp program. Logic includes an override on drum pressure.
- Steam generation can be calculated based on the measured pressure drop from the coke drum to blowdown contactor and a detailed hydraulic model of the piping system.



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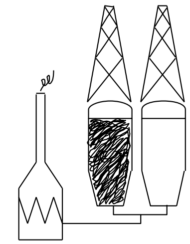
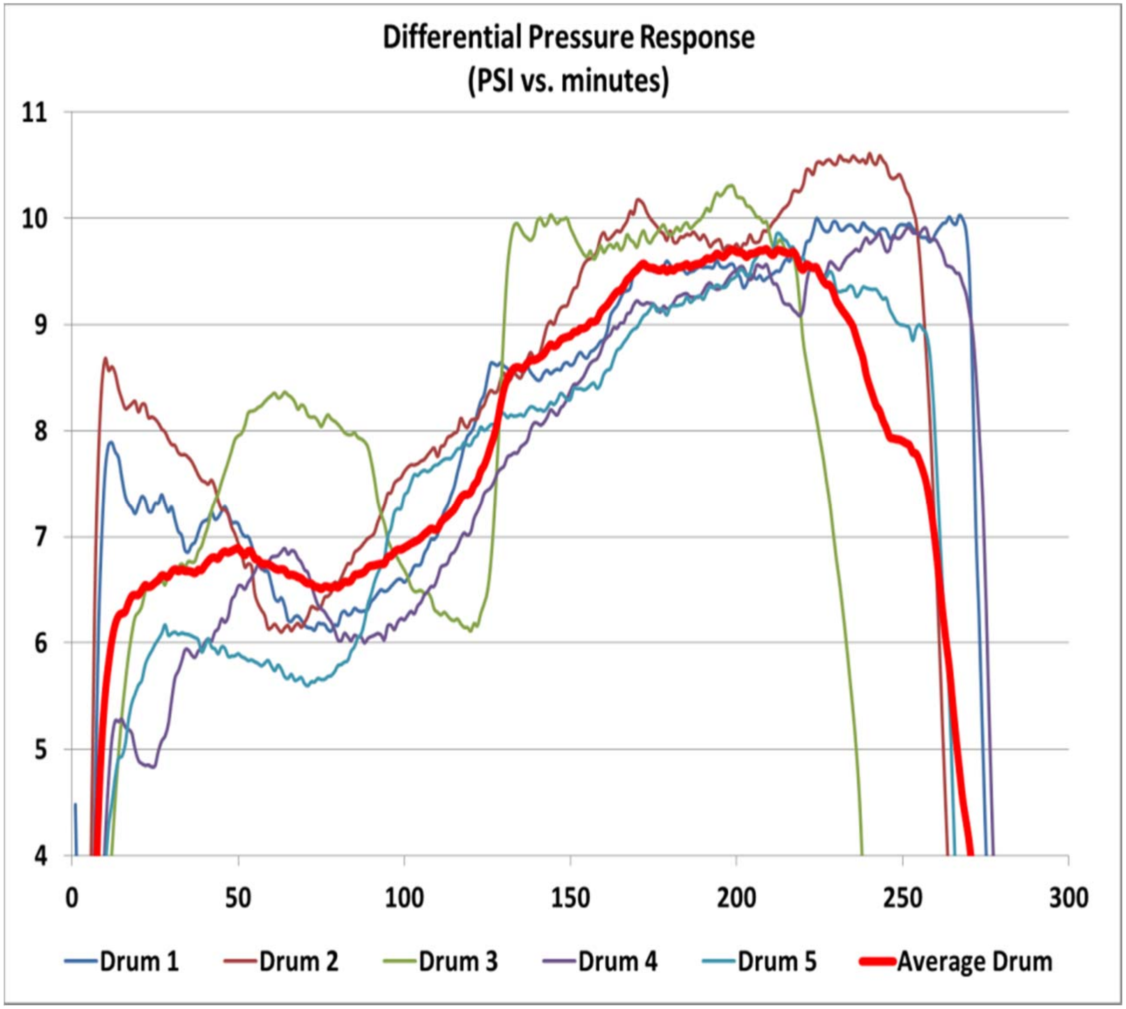
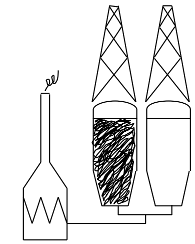
Coke Drum MAWP & Coke Bed Quenching



Measured Steam Flow DP during Bed Quenching

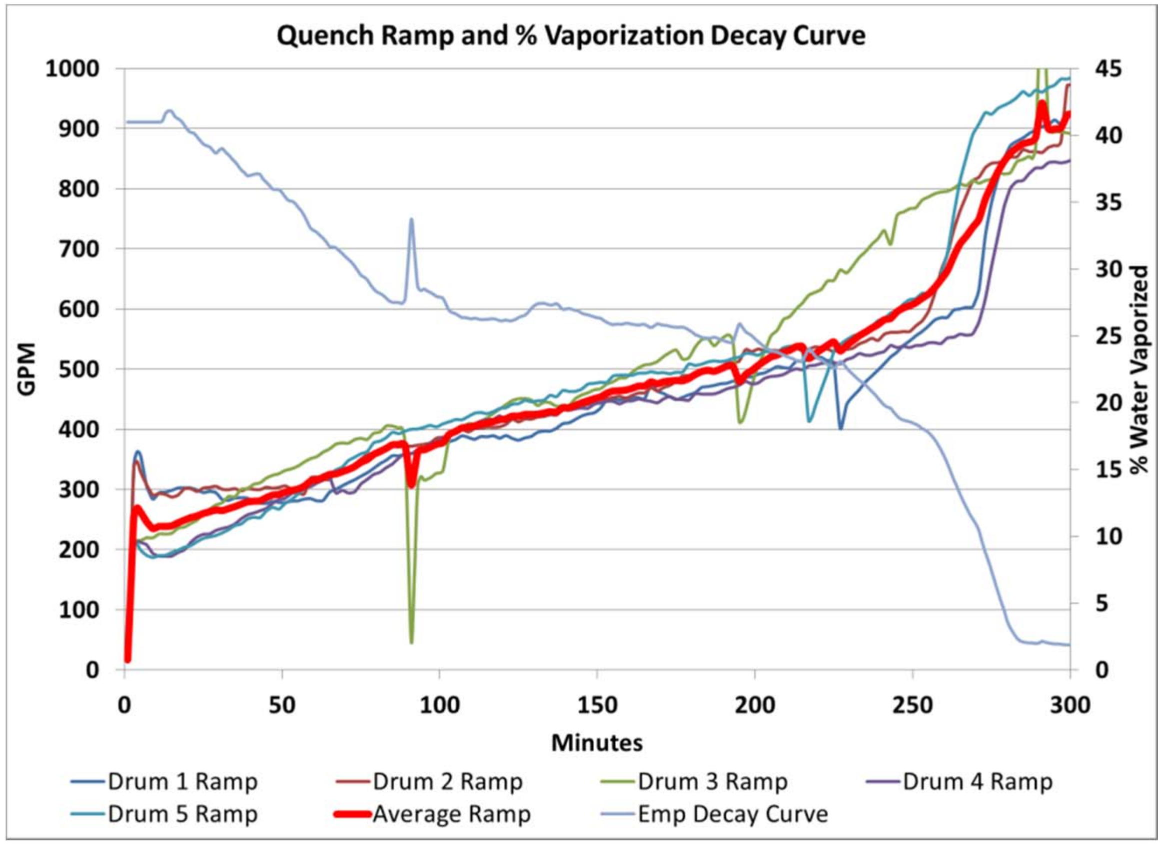


Coke Drum MAWP & Coke Bed Quenching



- The degree of instantaneous vaporization of quench water as it contacts the hot coke bed (% Vapor) is a highly dynamic function of:
  - Local coke bed characteristics
  - Amount of coke bed cooling achieved to that point
  - Quench water rate

The classical design contingency for the blowdown system involves a blocked-in drum while the other drum is at peak steam generation rate (industry standard of ~30% vaporization).



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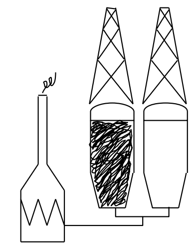
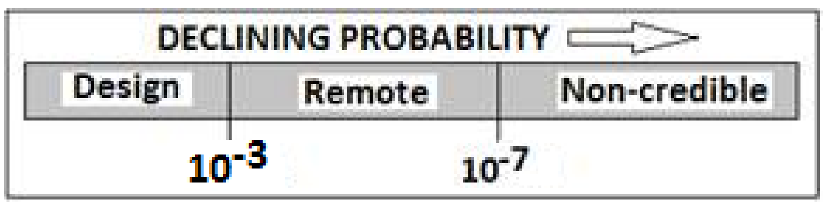


The Heart of the Calculation – Using Quantified Probabilities

(1) Specific annual probability definitions are applied to a "remote" and a "non-credible" event.

The following values are provided as an example. At this point in time, the owner/operator must decide what value is appropriate, since there is currently no written guidance in the Codes or Practices.



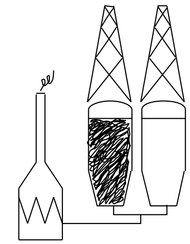
In this example, all scenarios

=> with a probability < 10^{-3} must no exceed 1.16 x MAWP

=> with probabilities between 10^{-3} and 10^{-7} must not exceed 1.5 x MAWP.

Addition of excessive quench water has proven to be a *remote* contingency, that must be converted to *non-credible*

Coke Drum MAWP & Coke Bed Quenching



The Heart of the Calculation – Using Quantified Probabilities

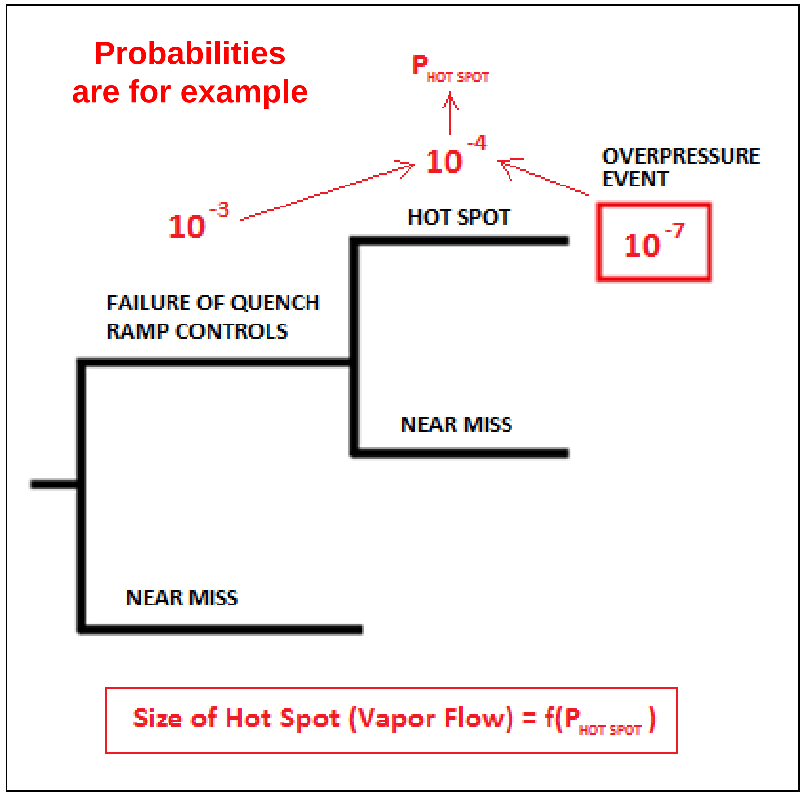
(2) Random behavior of coke bed hot spots is probabilistically quantified and hardware limits are established to make overpressure a remote or non-credible scenario during "quench" operations.

$$P_{\text{Hot Spot}} * P_{\text{Off Ramp}} = P_{\text{Remote (10-3) or Non-credible 10-7)}}$$

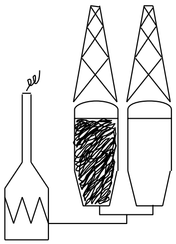
$$P_{\text{Hot Spot}} = \frac{P_{\text{Remote (10-3) or Non-credible 10-7)}}}{P_{\text{Off Ramp}}}$$

Size of the Hot Spot = $f(P_{\text{Hot Spot}})$

Off ramp includes:
- in manual plus operator error
- control valves fail open
- controller fails
- interlock fails plus operator error`



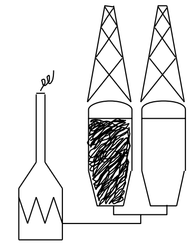
Coke Drum MAWP & Coke Bed Quenching



Achieving High Quench Ramp Performance and Availability

1) Automatic Programmed Water Flow Ramp (Sludge and Water)
2) High Pressure Water Flow Cut-Out
3) Quench control valve position versus flow is tracked for abnormal behavior; with auto flow cut-out when out of normal range
4) Cumulative water addition tracked versus time for abnormal behavior and validated based on water level detection
5) High Priority Alarm if taken off control
6) Auto-reset of ramp computer control after 20 seconds
7) If manual override is unavoidable, are written procedures clear on controls and monitoring needed to avoid improper water ramping
8) All alarms and deviations included in Shift Report and provided to Operations Manager

Coke Drum MAWP & Coke Bed Quenching

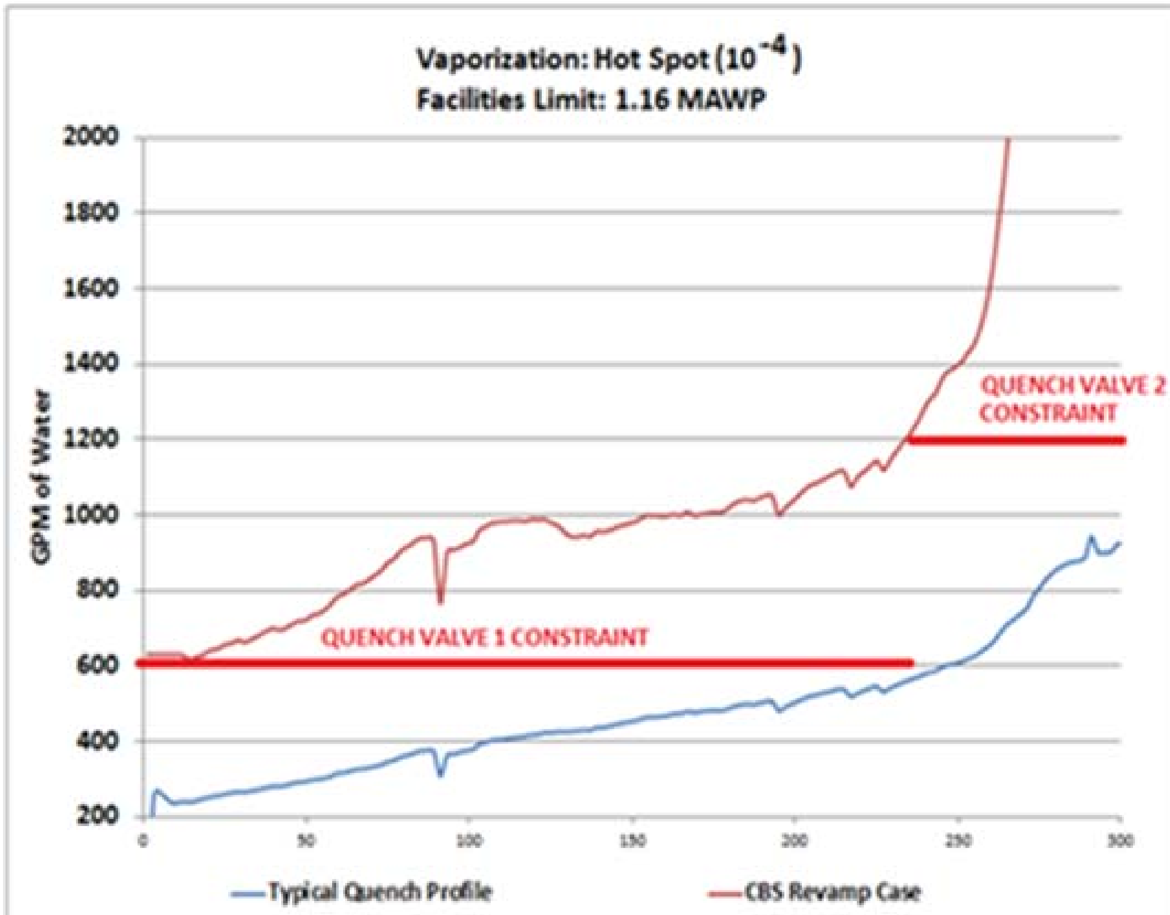


The "little water" valve is sized to meet both design and remote probability constraints

The "big water" valve is sized such that the sum of little and big water valve CV's meets both constraints

Size of the Hot Spot = f($P_{Hot\ Spot}$)

$P_{Hot\ Spot} * P_{Off\ Ramp}$ = $P_{Remote\ (10\text{-}3)\ or\ Non\text{-}credible\ 10\text{-}7)}$



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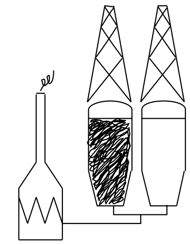
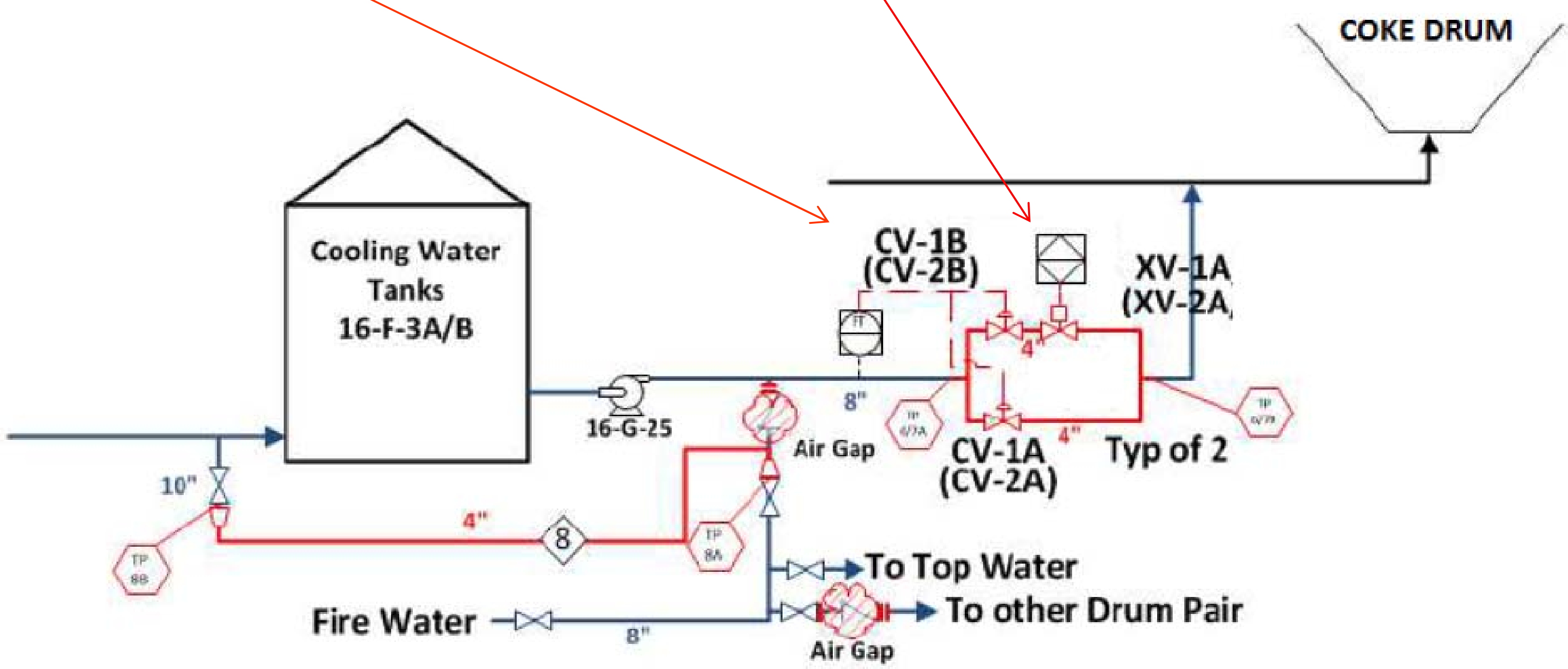


The Facilities

(1) Quench Ramp Control Watchdog

(2) Two properly-sized quench water control valves

(3) PLC Interlock on the "big water" valve



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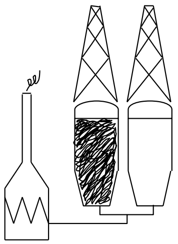
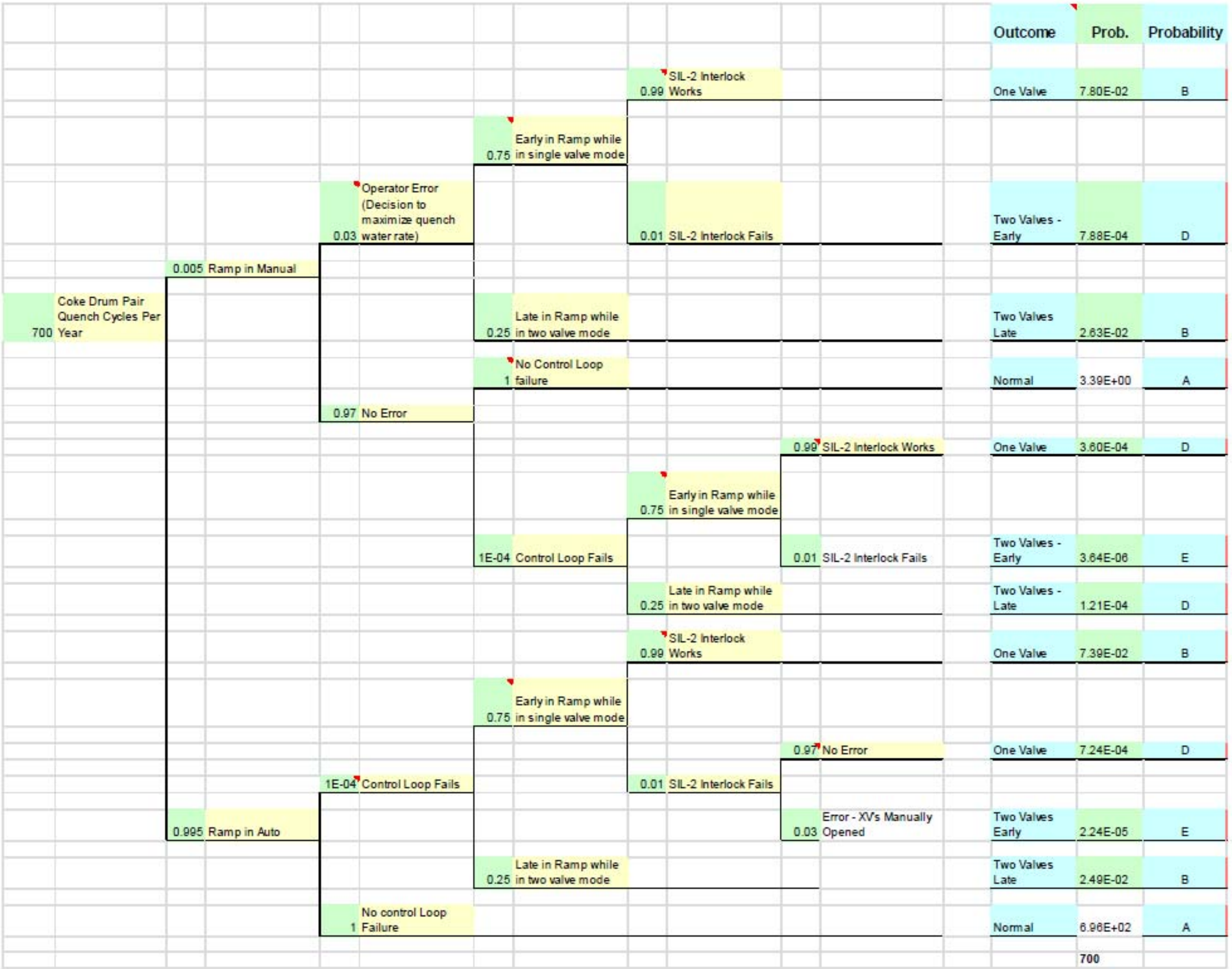


Probabilistic Event Tree Analysis of "Off Ramp" Causes



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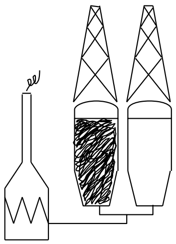
Coke Drum MAWP & Coke Bed Quenching



Why is ExxonMobil bringing this forward to industry and licensors?

=> Previously we believed that this event was non-credible in regard to exceeding 150% of MAWP. Based on our recent analysis, while the probability of such events is low, it is still a credible event in the absence of proper controls.

=> We are in the process of speaking with Licensors.

=> Our planned follow-ups:
- Complete a data analysis study of a Sponge Coker
- Review how this analysis would be used by and affect grassroots designs

=> With completion of those follow-ups, we plant to publish the work through one or more industry publications