Using HAZOP and LOPA Methodologies to Improve Safety in the Coke Drums Cycles

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PETROBRAS

TOPICS

Hazards of DCU Batch Operations

Coke Drum Switching

Permissive Logics Matrix

Coke Drums Hazard Evaluation Process *(General View)*

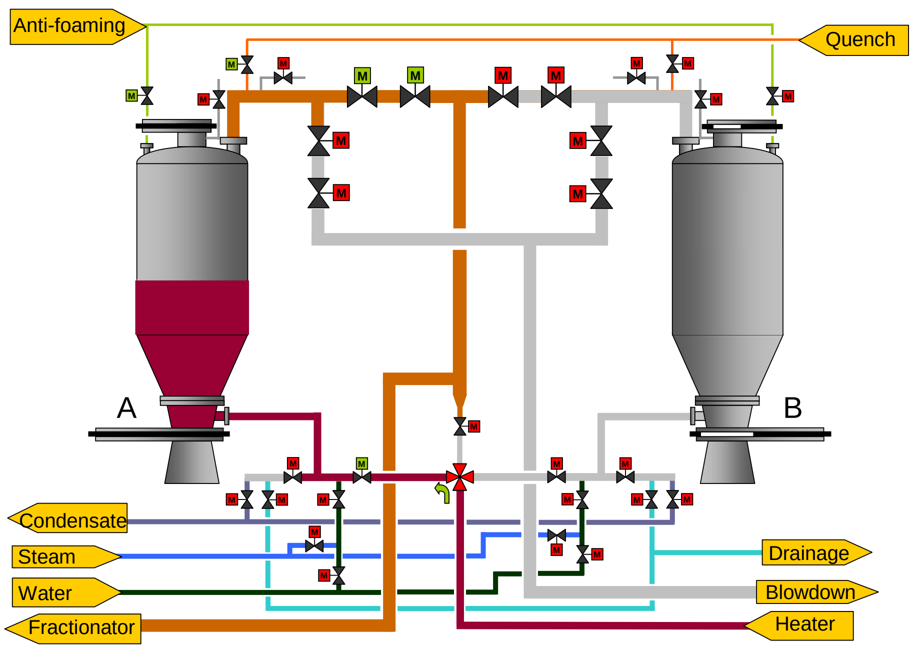
Coke Drums HAZOP Study

Selecting HAZOP scenarios for LOPA

Integrated HAZOP and LOPA Analysis

Coke Drums LOPA Study *(Main Results)*

The Coke Drum Switching



Step	Duration (Hours)
Filling	20.0
Purge with steam	1.5
Quench	6.0
Drain	1.5
Unhead	1.0
Decoke	3.0
Rehead and Test	2.0
Warm-up	5.0

The Problem:

“The batch stage of the operation (drum switching and coke cutting) presents unique hazards and is responsible for most of the serious accidentes attributed to DCUs”.

(US EPA and US OSHA, 2003) Chemical Safety Alert – “*Hazards of Delayed Coker Unit (DCU) Operations*”

Why does drum switching create unique hazards, resulting in relatively frequent and serious accidents?

- The batch operations involve a **series of opening and closing of valves by the operators**;

- The **high frequency of the drum sequence** contributes to increase the likelihood of a human error.

- The inadvertent valve operation can lead to **loss of containment scenarios** with: release of hydrocarbon from an in-service or open drum to atmosphere, fire, release of H2S.

- **High operator exposure** during drum sequence.

<u>Risk of operating:</u>

- The wrong valve on the right drum
- The right valve on the wrong drum

(A unit with more than one pair of drums presents even more risks.)

The Goal:

Improve operator safety, reducing the risk of loss of containment!

How?

How to improve safety in the coke drums cycles?

How to prevent inadvertent valve operations during drum sequence?

Permissive Logics Matrix

- With these logics, some conditions must be met to allow a valve to be opened or closed.

- These conditions can be based either on other valves positions or on process parameter values (e.g. a permissive logic where the coke drum pressure must be lower than a pre-determined value to allow a valve to open).

- All normally operated sequence valves are automated and the instrumentation allows to verify valves position.

Valve Command \ Valves and Instruments	Drilling Stem (Decoking)	HV-001A	HV-002A	HV-003A	HV-004A	HV-007A	HV-008A	HV-009A /010A / 027A	PT – 016A
Open HV-002A				O	O	C	C	C	
Open HV-007A		B	C	C	C			O	< 9.8 kPa
Close HV-007A	Out of drum							O	

HV-001 A: Swith valve
HV-002 A: Feed from the heater to coke drum A
HV-003 A: Coke drum overhead to fractionation tower first blockage
HV-004 A: Coke drum overhead to fractionation tower second blockage
HV-007 A: Automatic top head valve
HV-008 A: Automatic bottom head valve
HV-009A / 010A / 027 A: Coke drum vent valves
PT-016 A: Coke drum pressure

Permissive Logics Matrix (PLM)

Valve Command \ Valves and Instruments	Drilling Stem (Decoking)	HV-001A	HV-002A	HV-003A	HV-004A	HV-007A	HV-008A	HV-009A /010A / 027A	PT – 016A
Open HV-002A				O	O	C	C	C	
Open HV-007A		B	C	C	C			O	< 9.8 kPa
Close HV-007A	Out of drum							O	

HV-001 A: Swith valve
HV-002 A: Feed from the heater to coke drum A
HV-003 A: Coke drum overhead to fractionation tower first blockage
HV-004 A: Coke drum overhead to fractionation tower second blockage
HV-007 A: Automatic top head valve
HV-008 A: Automatic bottom head valve
HV-009A / 010A / 027 A: Coke drum vent valves
PT-016 A: Coke drum pressure

- The team responsible to build the matrix included: experienced DCU operators, automation specialists and process engineers involved in the DCU design and operation.

- This matrix was developed during brainstorming sessions.

- The starting-point to build this matrix is the set of operational procedures.

- If the procedures have not been prepared due to the initial design phase, procedures from existent and similar units can be used as a basis to build the PLM.

- What type of incidents these logics can prevent?
- What is the availability or the PFD (Probability to Fail on Demand) acceptable for these logics?
- How safe is enough?

HAZOP and LOPA

COKE DRUMS HAZARD EVALUATION PROCESS – GENERAL VIEW

Operational procedures

Brainstorming

Coke Drums Permissive Logics Matrix (PLM) Elaboration

Coke Drums HAZOP

(Hazard identification)

5 days

Selection of HAZOP scenarios for LOPA

(Consequence severity category assignment = scenario tolerable frequency definition)

3 days

Coke Drums LOPA

- *Initiating event frequency estimation;*
- *Risk gap analysis;*
- *IPLs identification and RRF definition;*
- *Definition of a SIF (with a target SIL) to eliminate risk gap, if it is not closed yet.*

• This hazard evaluation procedure was applied to a Petrobras DCU during Basic Design Phase.

• Preferably, the experts responsible for the matrix development integrate the HAZOP team.

• Preferably, HAZOP and LOPA are performed in an integrated approach, with only one facilitated session.

Main Results:

• The permissive logics defined in the matrix were assessed using a risk basis through HAZOP;

• The logics that need to be defined as SIF (*Safety Instrumented Function*) were identified with a target SIL (*Safety Integrity Level*).

Understanding HAZOP through the Anatomy of a Process Incident

All process hazards are contained and controlled.

Key Systems:

1) Primary Containement (pipes & vessels)

2) BPCS (Basic Process Control System)

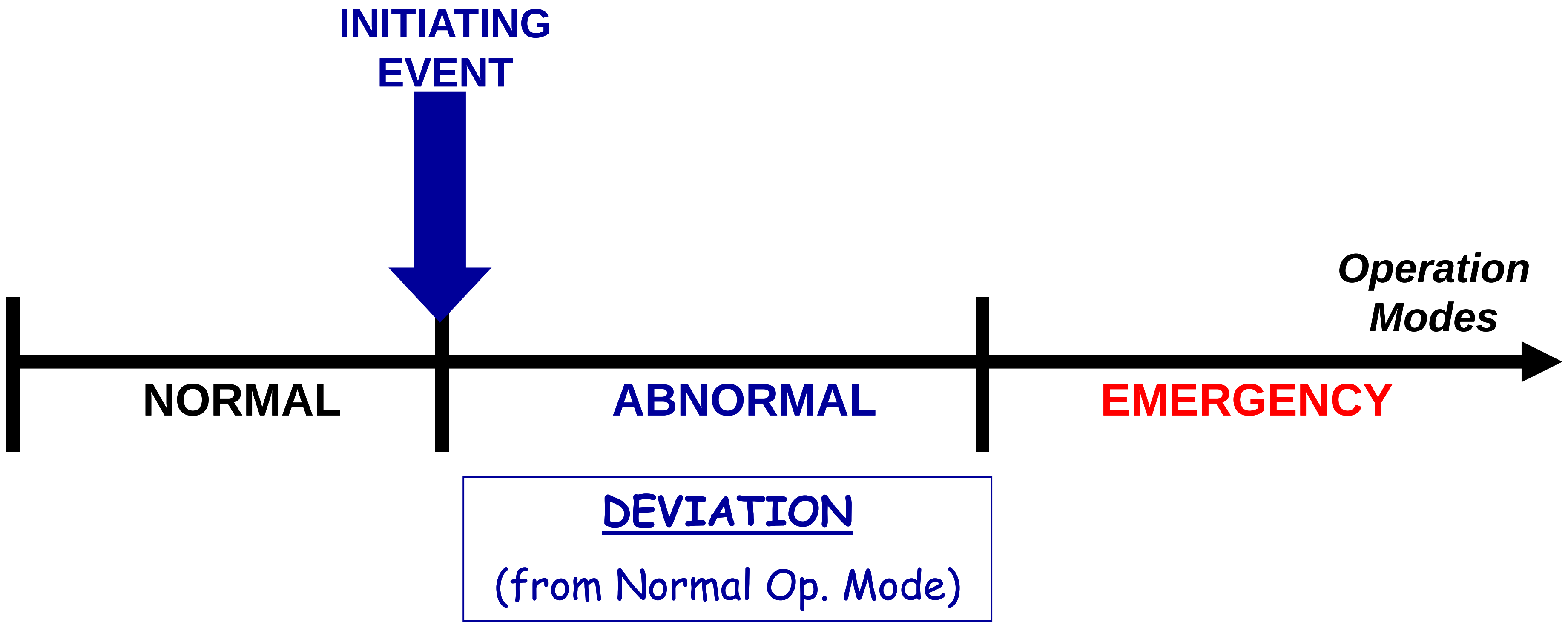
3) Process Equipment

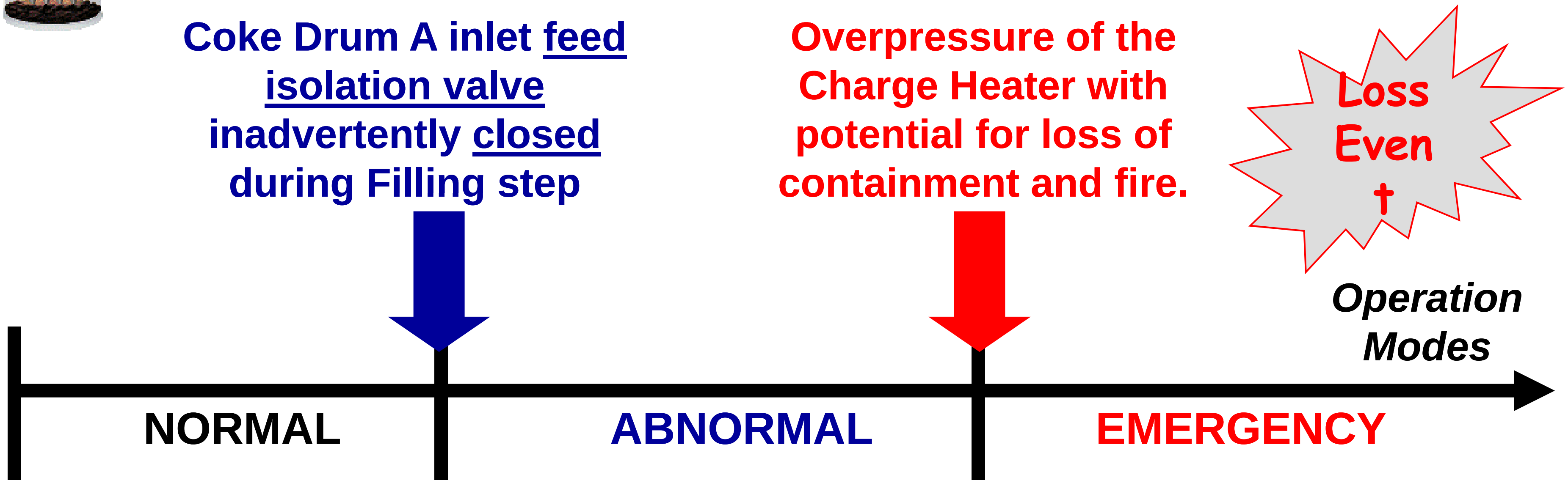
4 Operational Procedures

Goals:

1) Keep the facility in normal operation mode.

2) Optimize production.


INITIATING EVENT
Operation Modes
NORMAL
ABNORMAL
EMERGENCY
DEVIATION
(from Normal Op. Mode)



DEVIATION

("No Flow" of Heater effluents)

Goals:

1) Return to Normal Operation Mode

2) If it's not possible, bring the plant to a safe state (shutting down the unit before a loss event occurs).

Coke Drum A inlet <u>feed isolation valve</u> inadvertently <u>closed</u> during Filling step

Overpressure of the Charge Heater with potential for loss of containment and fire.

Loss Event

Operation Modes

NORMAL | **ABNORMAL** | **EMERGENCY**

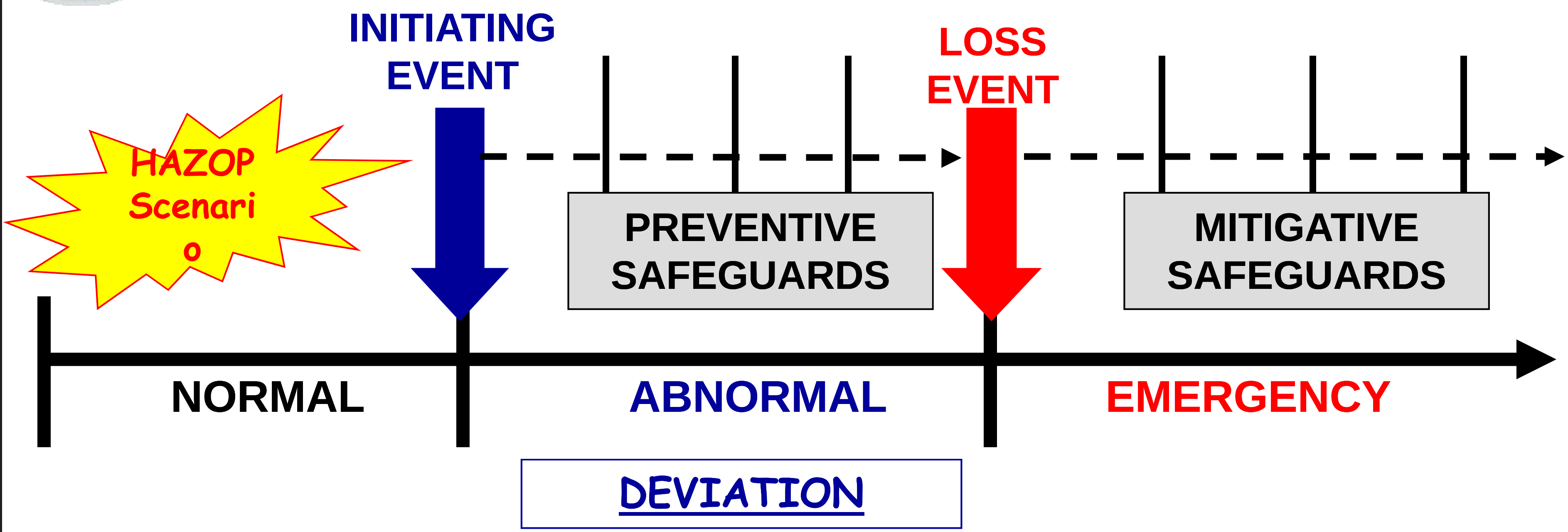
<u>DEVIATION</u>

("No Flow" of Heater effluents to Coke Drum)

<u>Goals:</u>

The goal changes to the minimization of injuries and losses.

<u>MITIGATE</u>

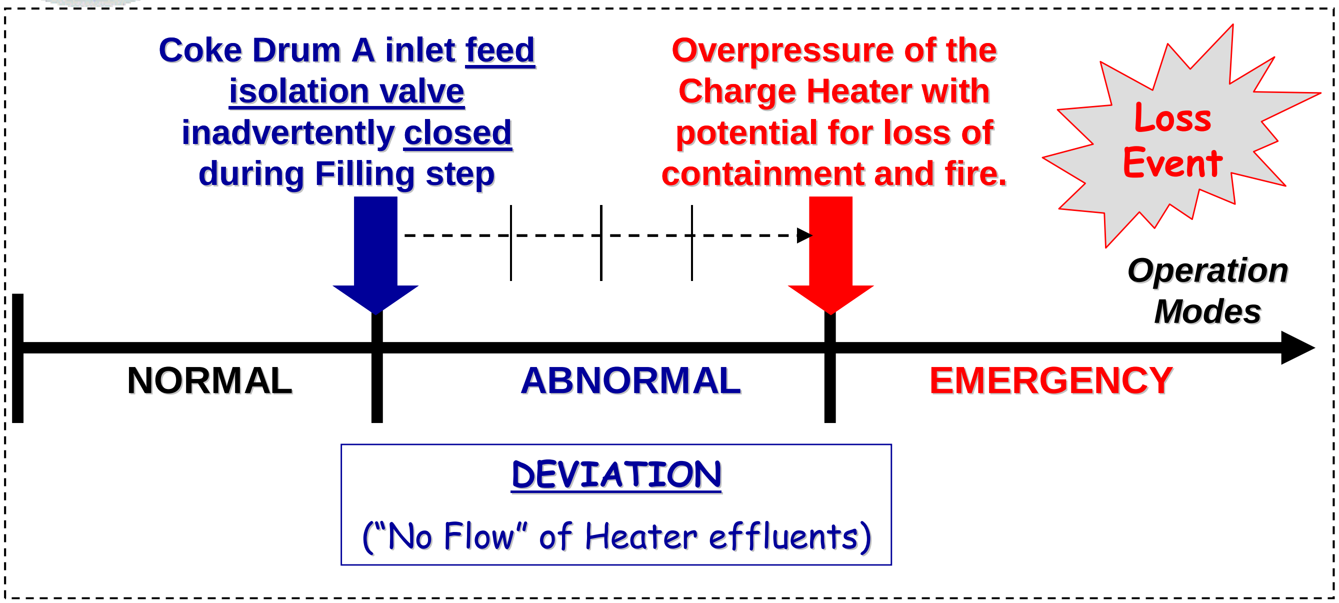


PREVENTIVE SAFEGUARDS: any device, system or action that can interrupt the chain of events following an initiating cause and prevents the loss event from ensuing.

↓ **the likelihood of occurrence of the loss event.**

MITIGATIVE SAFEGUARDS:

↓ **the severity of consequences.**



Possible safeguards for this scenario:

- Permissive logic that allows the closure of Coke Drum A feed isolation valve <u>only if</u> the Switch valve is turned to Coke Drum B.
- PSV located on Heater outlet, sized for the blocked flow scenario;
- Heater Low Low Flow Trip

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Heater Coke Up Due to Switch Valve Relay Failure

Maloperation of Velan switch valve due to shorting of slow release relay (component failure) in the remote panel circuit.

While on routine operation of coke drum switching, operator had finished the vapour heating of drum but was yet to open the feed isolation valve to vapour heated drum.
As soon as switch valve selector switch was put on remote position (as safety interlock exists in this mode) and operator went to open feed isolation valve, switch valve rotated on its own towards the heated drum and further to bypass position sticking there at physical stopper bar (pin).

This created complete block flow of heater effluents and heater oil pressure rose to 72 kg/cm2 causing smoke at switch valve inlet and operator could not approach the selector switch again to reverse/correct the position. Heater firing however tripped due to lo-lo flow

Heater completely coked up (all coils) and caused 26 days s/d for hydrojet cleaning. production loss 3 mm usd.

Post analysis shows inherent fault in the vendor supplied remote panel relay circuit as it gave direct power to the rotor motor bypassing all safety interlock.

- For the switch valve inadvertently switched into a closed inlet isolation valve, some permissive logics were also defined in order to avoid dead-heading the heater.

www.Coking.com

Send mail to CompanyWebmaster with questions or comments about this Delayed Coker (www.coking.com) web site.

For each "NODE":
(each step of drum sequence)

DEVIATION → CAUSE → SAFEGUARDS → CONSEQUENCES

Parameter — Temperature

Deviations → High Temperature

Guide-Word — More

Process Parameter + Guide-Word = Deviation

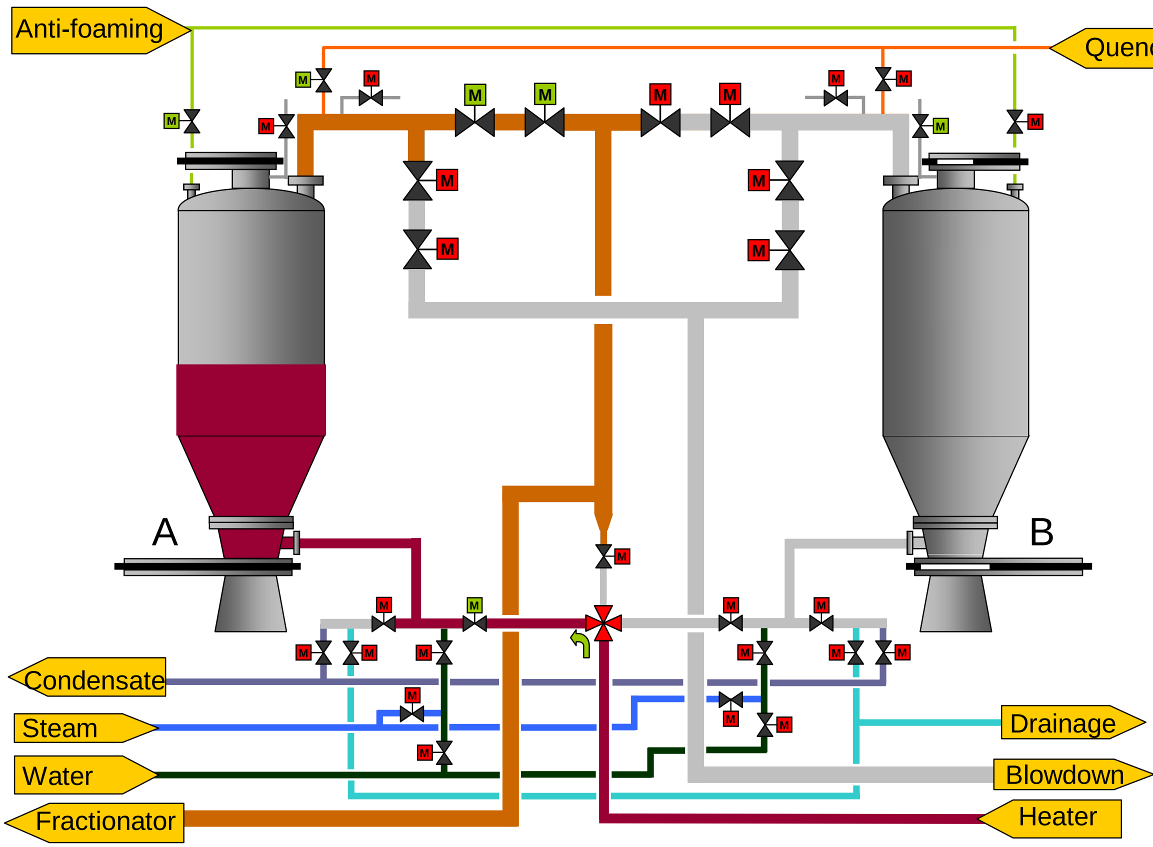
High Temperature
Low Temperature

High Level
Low Level

High Pressure
Low Pressure

High Flow
Low Flow
No Flow
Reverse Flow
Contamination

"NODES" Definition:



- Each step of the drum sequence is a "NODE"of analysis.

- The node is defined considering the drum and all alignments needed to perform that phase.

- When explaining the design intention of the node, the valves position to perform the step under analysis are clearly defined.

Node – Filling Step: from the switch valve, passing through the coke drum, as far the Fractionator, including: the anti-foaming and quench injection lines.

For each "NODE":

(each step of drum sequence)

Qualitative Approach

DEVIATION → CAUSE → CONSEQUENCES

SAFEGUARDS

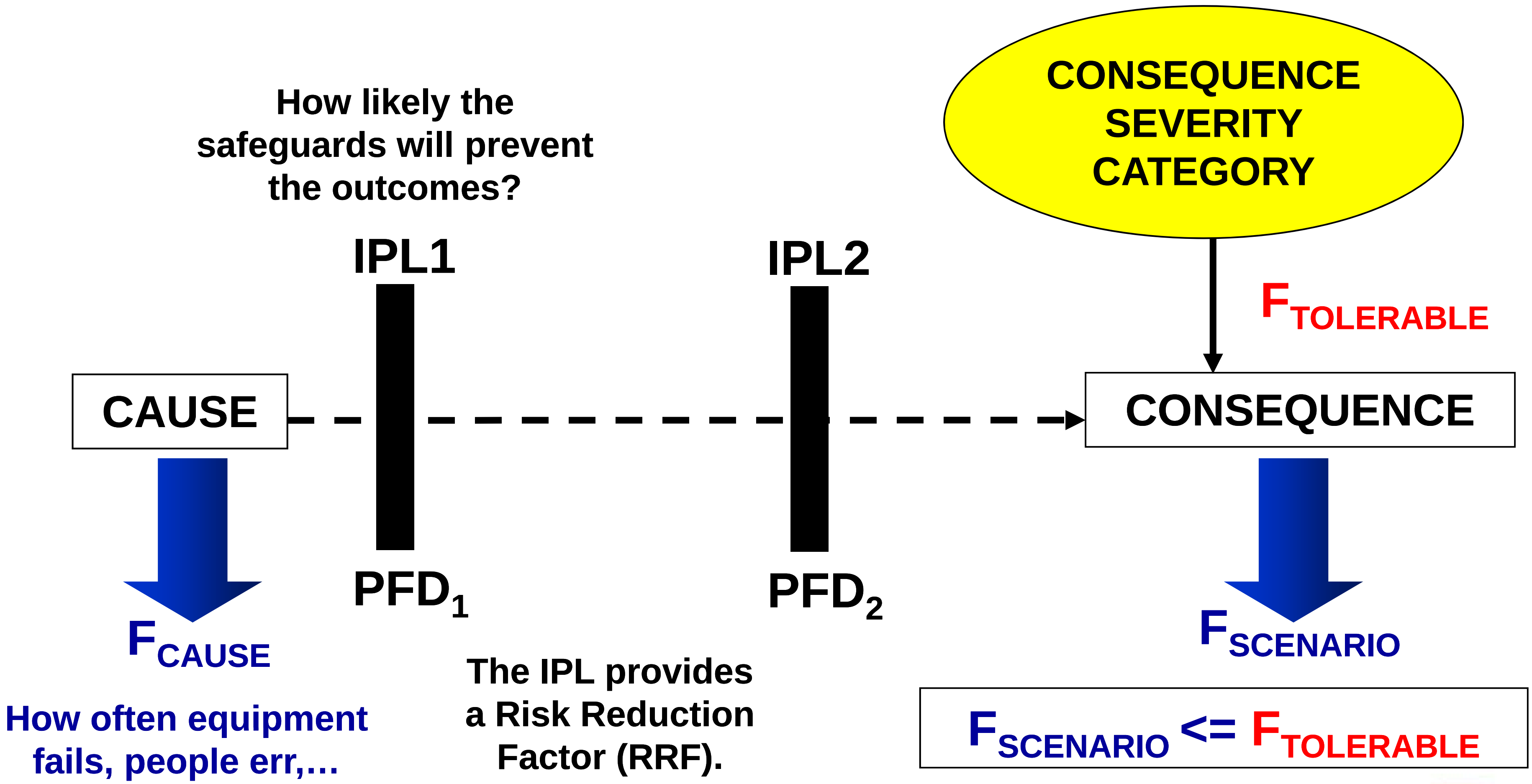
- -How safe is enough?
- -How many safeguards are needed?
- - What is the SIL target required for the SIFs?

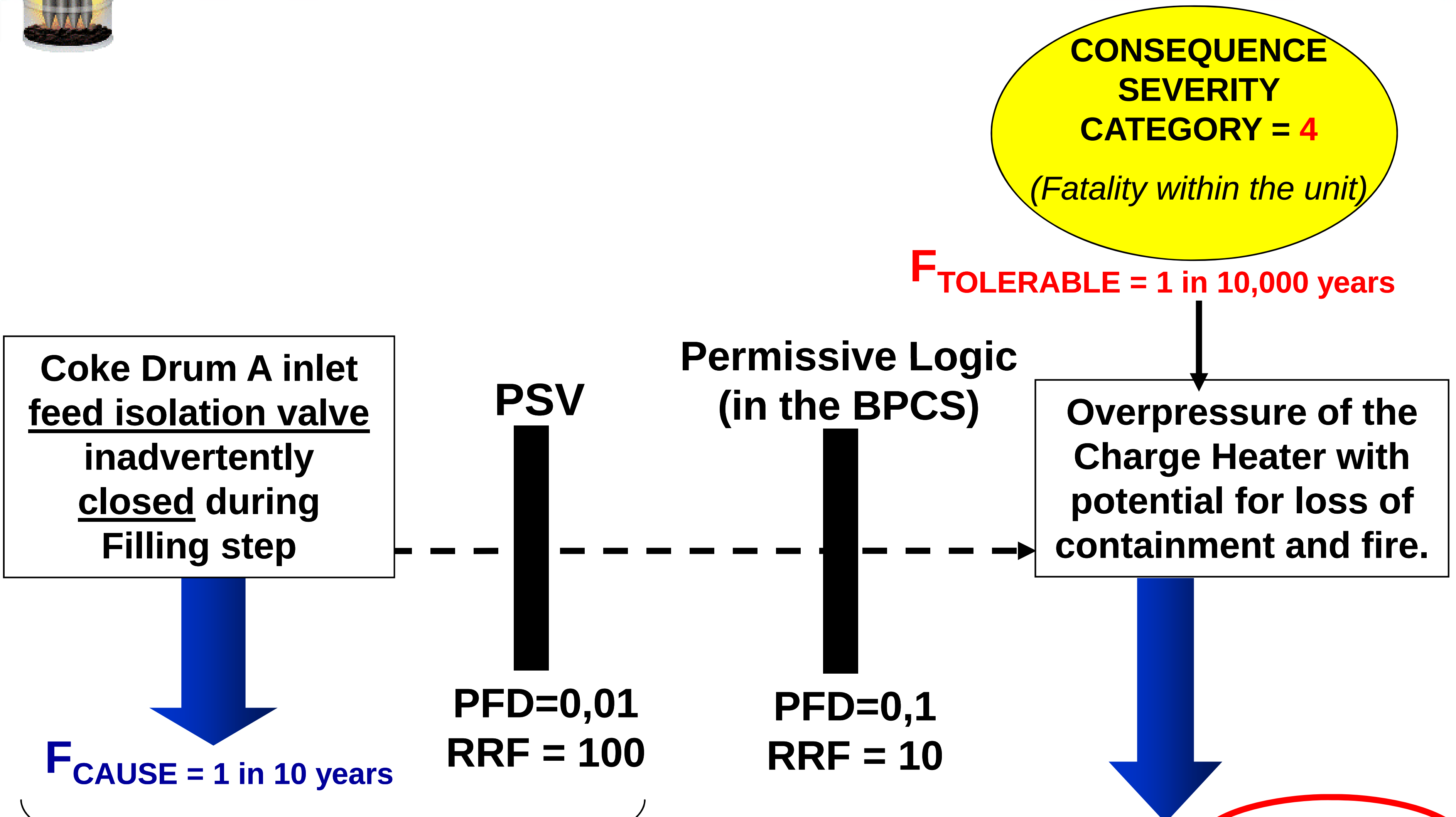
Semi-Quantitative Approach

LOPA
Layer of Protection Analysis

IPL = Independent Protection Layer
PFD = Probability to Fail on Demand

The worse the consequence, the lower the tolerance for the incident!





$$F_{Scenario} = F_{Cause} * PFD_1 * PFD_2 = 1 \ in \ 10{,}000 \ years$$

$$F_{Scenario} = F_{Cause} * PFD_1 = 1 \ in \ 1{,}000 \ years$$

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Valve Command \ Valves and Instruments	HV-001A	HV-002A	HV-003A	HV-004A
Open HV-023A/024A	B	C	C	C

HV-001 A: Switch valve
HV-002 A: Feed from the heater to coke drum A
HV-003 A: Coke drum overhead to fractionation tower first blockage
HV-004 A: Coke drum overhead to fractionation tower second blockage
HV-023A / 024A: Quench Water block valves

CONSEQUENCE SEVERITY CATEGORY = 4

(Fatality within the unit)

$F_{TOLERABLE}$ = 1 in 10,000 years

Permissive Logics (in the BPCS)

Coke Drum A Quench Water Valves inadvertently opened in an "in-service" drum

Rapid vaporization with potential overpressure on drum and Fractionator (possible loss of containment)

F_{CAUSE} = 1 in 10 years

PFD=0,1
RRF = 10

- Risk reduction required of two orders of magnitude to eliminate Risk Gap!

$$F_{Scenario} = F_{Cause} * PFD_1 = 1 \ in \ 100 \, years$$

SIF = Prevents the drum quench water valve from opening if drum bottom temperature is too high.

SIL target = SIL 2 (PFD of 0,01)

CONSEQUENCE SEVERITY CATEGORY = 4

(Fatality within the unit)

$F_{TOLERABLE}$ = 1 in 10,000 years

Coke Drum A <u>Quench Water Valves</u> inadvertently <u>opened</u> in an <u>"in-service"drum</u>

F_{CAUSE} = 1 in 10 years

Permissive Logics (in the BPCS)

PFD=0,1
RRF = 10

SIF (in the SIS)

PFD=0,01
RRF = 100

Rapid vaporization with potential overpressure on drum and Fractionator (possible loss of containment)

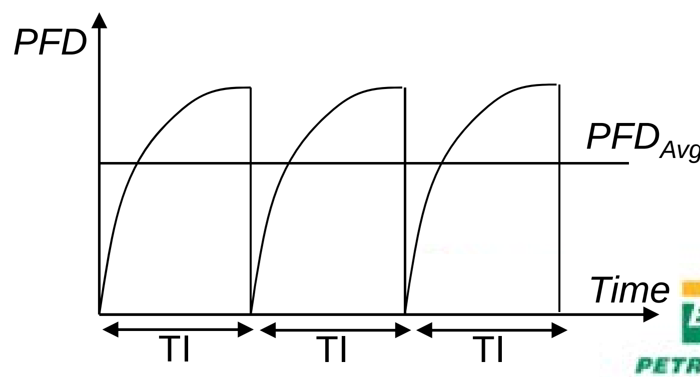
$$F_{Scenario} = F_{Cause} * PFD_1 * PFD_2 = 1 \ in \ 10{,}000 \ years$$

What does SIL mean?

SIL	AVAILABILITY REQUIRED (%)	PFD *(Probability to fail on demand)*	RRF = 1/PFD *(Risk Reduction Factor)*
1	90,00 - 99,00	0,01 – 0,1	100 – 10
2	99,00 - 99,90	0,001 – 0,01	1000 – 100
3	99,90 – 99,99	0,0001 – 0,001	10.000 - 1000
4	> 99,99	0,00001 – 0,0001	100.000 – 10.000

The SIL (*Safety Integrity Level*) indicates the availability or the PFD of a SIF (*Safety Instrumented Function*) when a process demand occurs.

E.g.: The acceptance of a SIL 1 means that the risk is sufficiently low that a function with an availability of 90% (or 10% chance of failure) is acceptable.



When is SIS used?

A **SIS** (*Safety Instrumented System*) is a combination of sensors, logic solvers and final elements that performs **one or more *safety instrumented functions* (SIFs)**, which are installed for the purpose of mitigating the hazard or bringing the process to a safe state in the event of a process upset.

(*) The SIS is used for any process in which the process hazard analysis has determined that the mechanical integrity of the process equipment, the process control, and other protective equipment are insufficient to mitigate the process hazard.

SISs are covered by:

IEC 61511 – *Functional Safety: Safety Instrumented Systems for the Process Industry Sector*

ANSI/ISA 84.00.01-2004 (IEC 61511 modified)

ISA TR84.00.04.04 – 2005 – *Guidelines for the Implementation of* ANSI/ISA 84.00.01-2004 (IEC 61511 modified)

(*) Summers, A. (1998), "Techniques for assigning a target safety integrity level", ISA Transactions 37 (1998) 95 – 104.

Do I have to apply LOPA to all HAZOP scenarios?

• One way to define the events of interest for LOPA is to **determine the scenarios that result in release of hydrocarbon and H_2S from an in-service or open drum during switch** and unheading.

Operating Mode	Initiating Events
In-Service	- Vent valve opening - Drain valve opening - Top head opening - Bottom head opening
Open Drum	- Overhead to Fractionator valve opening - Inlet feed valve opening - Blowdown valve opening - Condensate Vessel valves opening

Zachary, B. 2005. *Applying SIS Standards to Coker Processes,* 10th Annual Universal Delayed Coking Seminar, Long Beach, CA, August 1-3, 2005.

When to move beyond qualitative risk judgment?

• Besides this list, Petrobras Coke drums analysis identified some other initiating events, not necessarily directly related to hydrocarbon relase to atmosphere.

Other Initiating Events Identified with Petrobras Coke Drums Analysis

- Quench water valve opening to an in-service-drum (leading to a coke drum overpressure due to the rapid water vaporization, with potential for loss of containment, hydrocarbon leakage and equipment damage);
- Coke drum inlet feed valve closing (with potential overpressure to the upstream segment, which includes the heater; loss of containment, fire and equipment damage);
- Switch feed valve inadvertently turned to a blocked segment (out-of service drum “B” or coke drums by-pass line to fractionation tower);
- Coke drum to Fractionator valve closing in an in-service drum (with potential drum overpressure);
- Coke drum to Blowdown valve opening in an in-service drum (with potential Blowdown System overpressure);

Other Initiating Events Identified with Petrobras Coke Drums Analysis

- coke cutting operational error, raising the drilling stem out of the drum (potentially exposing the operator to high pressure water jet);
- out-of-service coke drum safety relief valve leaking (with potential hydrocarbon release to the atmosphere from the fractionation tower, which this relief valve discharge is aligned to).
- high pressure drilling water delivery hose failure;

- A similar solution was recommended during HAZOP to the water hose disconnection or rupture scenario.

Decoking Hose Failure - A Safety Threat

There was a near miss incident in our coker unit about a year back. One of our decoking water hoses had failed from its top rotary joint end and fell down on the cutting platform. There was no indication that it was about to rupture (that's why "near miss"). The hose had failed from its coupling portion due to improper bonding/curing of the glue used. Fortunately, nobody was beneath the falling hose when it failed and a major accident got avoided. We replaced the hose with a new one of another manufacturer, in addition to providing 2 strong safety clamps with chains fastened to the top flange to prevent falling down for the other potential hoses.

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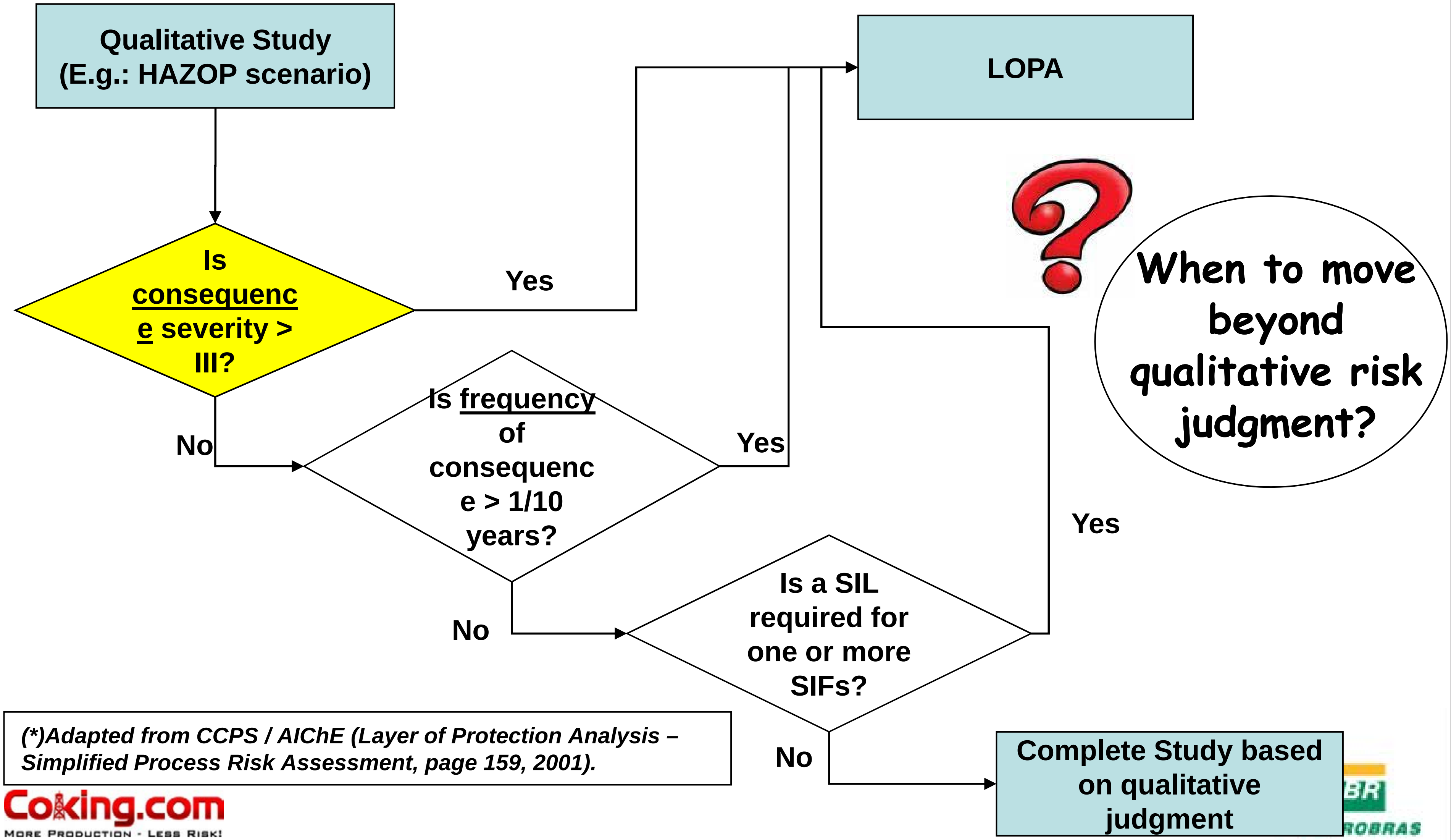
Do I have to apply LOPA to all HAZOP scenarios?



(*)Adapted from CCPS / AIChE (Layer of Protection Analysis – Simplified Process Risk Assessment, page 159, 2001).

Other Results

Typical scenario when there are multiple coke drums with its PSVs discharge aligned to Blowdown system or to Fractionator.

→

Possible backflow of blowdown (or fractionator) vapors to an open drum, leading to release of hydrocarbons / H_2S with potential fire.

Other design alternative: motorized block valves located on the discharge of the coke drum PSVs

Deviations	Frequency Evaluation		Possible Effects	Conseq. Severity	RRF Required	Safeguards	IPL (Independent Protection Layers)	IPL Type	RRF	Overall RRF	RRF Gap
	Possible Causes	Freq.		S	S						S
Reverse Flow	- Open Drum PSV leaking.	100	Backflow of fractionator vapors to the open drum, leading to release of hydrocarbons / H2S with potential fire.	4	100	- Provide limit switches for the block valves located on PSV discharge and a permissive logic that prevents these blockages from opening if the top head valve is opened.	- Provide limit switches for the block valves located on PSV discharge and a permissive logic that prevents these blockages from opening if the top head valve is opened.	BPCS	10	100	TR
						- Provide a permissive logic that prevents the top and bottom head valves from opening if the blockages located on PSV discharge are opened.	- Provide a permissive logic that prevents the top and bottom head valves from opening if the blockages located on PSV discharge are opened.				
						Operator by procedure closes the block valves located on PSV discharge before opening the drum.	Operator by procedure closes the block valves located on PSV discharge before opening the drum.	Operat. Procedure	10		

Integrated HAZOP and LOPA/SIL Analysis

icrosoft Excel - Integrated HAZOP and LOPA.xls

Deviations	Frequency Evaluation: Possible Causes	Freq.	Possible Effects	Conseq. Severity S	RRF Required S	Safeguards	IPL (Independent Protection Layers)	IPL Type	RRF	Overall RRF	RRF Gap S
(As Well As) Contamination	- Coke drum A to Blowdown Tower valves (HV-011 and 012) inadvertently opened (in an "out of service" drum).	10	- Release of hydrocarbons from blowdown system to atmosphere through drum top (which is opened in the "out of service"drum).	4	1000	- Provide a permissive logic which prevents HV-011/012 from opening in case top or bottom head valves are opened.	- Provide a permissive logic which prevents HV-011/012 from being opened in case top or bottom head valves are opened.	BPCS	10	1000	TR
							- Prevents the Drum to Blowdown Tower valves from opening on low drum overhead pressure.	SIF (SIL 2)	100		

Only one facilitated session is required and only one database is generated.

The integrated approach is less time consuming and more consistent, since the HAZOP and LOPA teams are the same.

Conclusions

•"No one system has proven effective in eliminating all incidents associated with incorrect valve activation due to mistaken coke drum operation."

(US EPA and US OSHA, 2003) Chemical Safety Alert – "Hazards of Delayed Coker Unit (DCU) Operations"

•However, the **definition of a set of permissive logics** that prevent inadvertent valve operations during the coke drums batch steps has been an improvement adopted by some refiners. **The set of logics are defined based on operational procedures, during brainstorming sessions involving a multidisciplinary team.**

•**HAZOP and LOPA methodologies** can provide a risk decision basis to assess the set of permissive logics, defining **what accident scenarios these logics can prevent**, **the amount of risk reduction needed to achieve a scenario tolerable frequency of occurence** and **the availability or SIL required for those logics which will be defined as SIFs**.

•The integrated HAZOP and LOPA Analysis is presented as a more consistent and less time consuming approach.