A Signal Detection Model to Interpret Safety Tests in Offshore Oil Drilling:

A Case Study to Analyze Negative Pressure Test (NPT) Interpretation in Offshore Drilling

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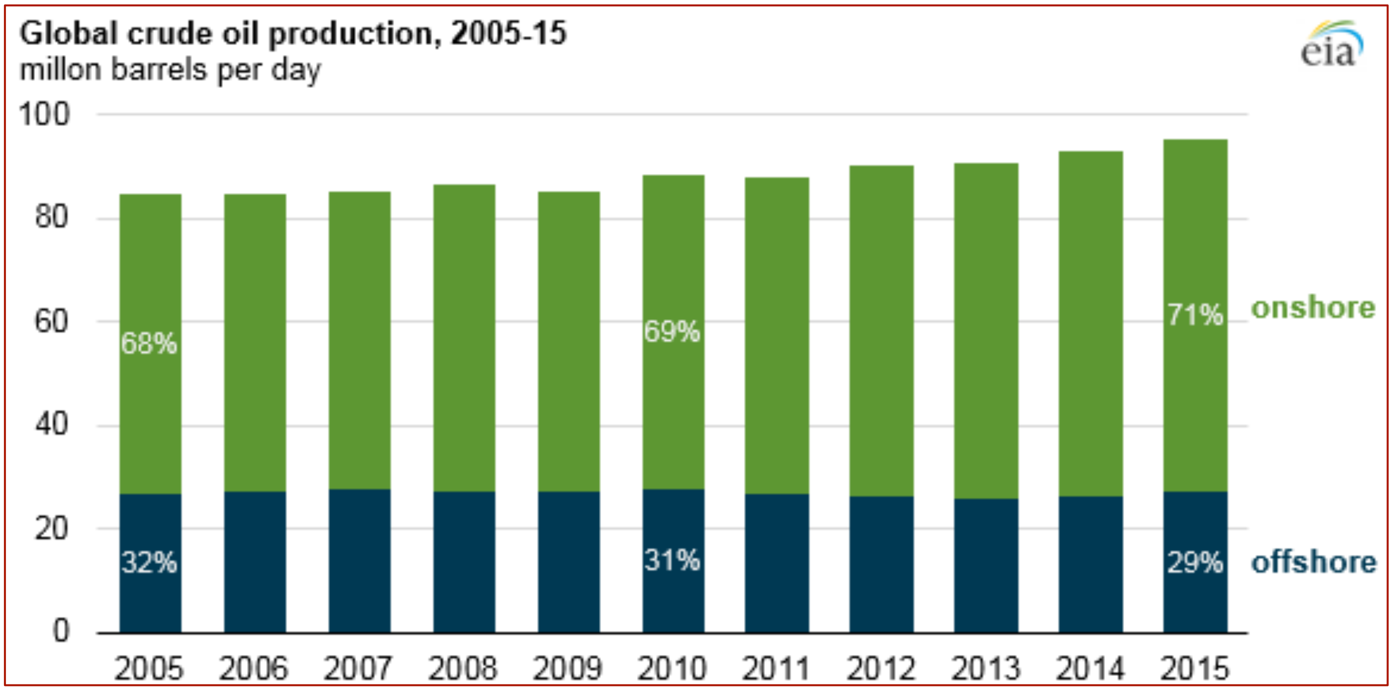
PSAM 14, September 2018

Outline

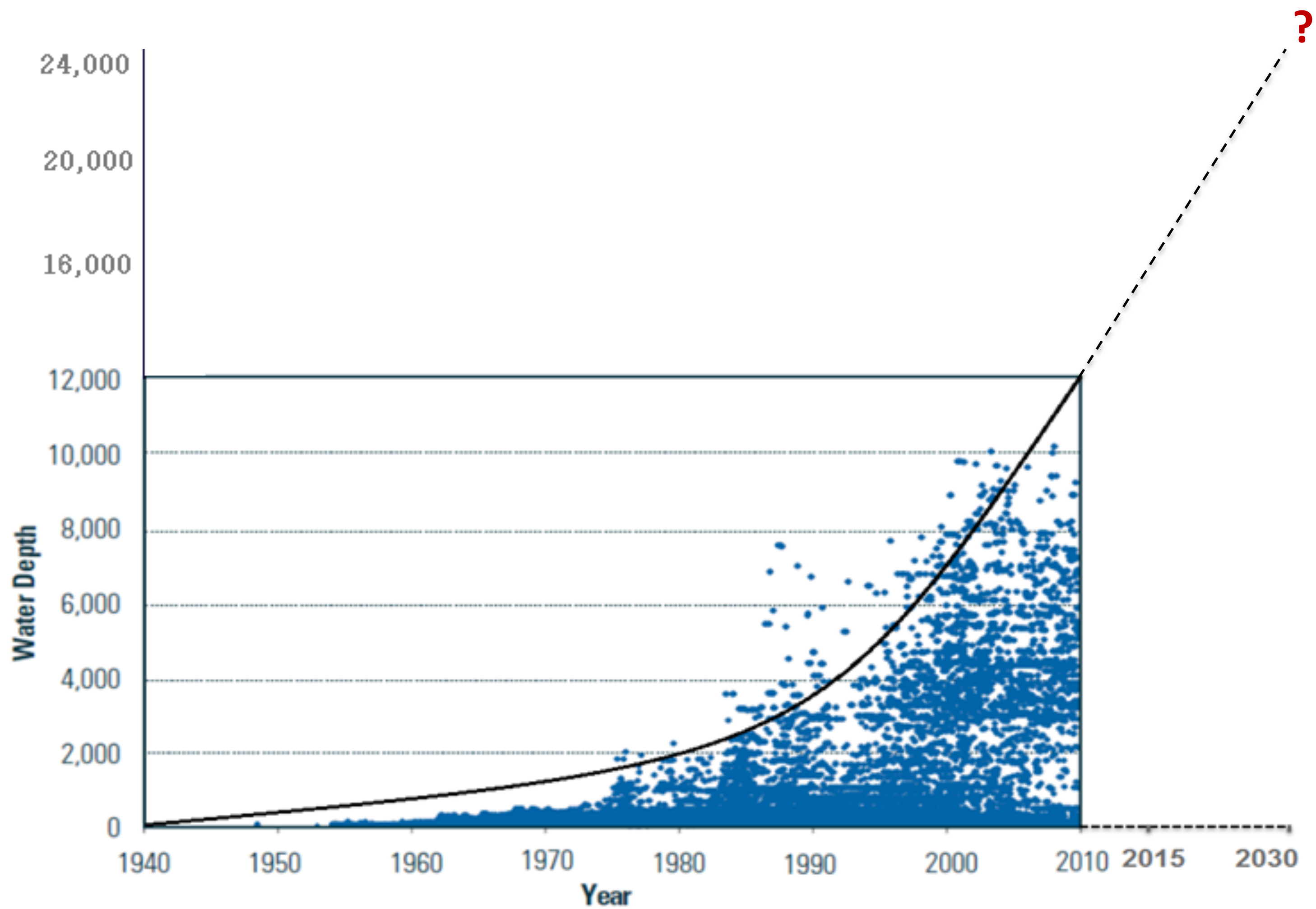
- Vital Need to Offshore and Deep-water Drilling
- Offshore Drilling as a High-Risk Industry
- Why Risk Analysis Practices?
- Analyzing Human and Organizational Factors
- Concentrating on Negative Pressure Test
- Signal Detection Model Parametric Equations
- A Case Study to Quantify the Signal Detection Model
- Sensitivity Analysis
- Summary and Conclusion

Offshore Drilling:
A Vital Source of Oil Supply



(EIA, 2016)

Why Deep-water Drilling Is Noteworthy?



Wells drilled in the Gulf of Mexico by water depth from 1940 to 2010 (Report to the President, 2011, page 41)

Offshore Drilling & Production: High-Risk Industry

Piper Alpha, North Sea, 1988

Fatalities: 167
Cost: $3.4 Billion

Petrobras 36, Brazil, 2001

Fatalities: 11
Cost: $350 Million

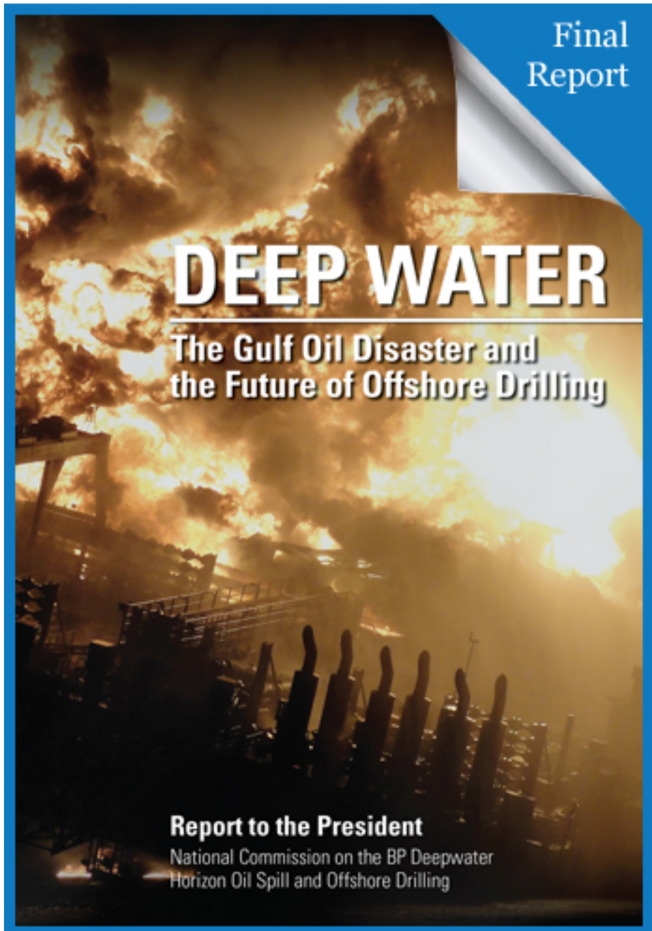
BP DWH, GOM, 2010

Fatalities: 11
Cost: $40-$50 Billion

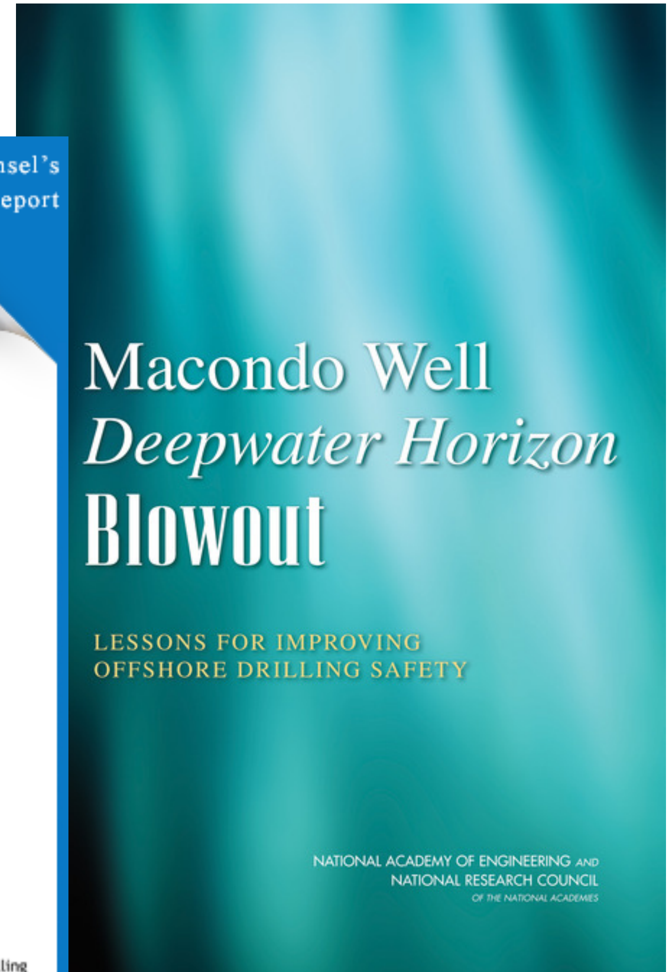
Offshore drilling is one of the high-risk industries with “tightly coupled” and “interactively complex” operations.

Case Study: Deepwater Horizon (DWH) Accident

- April 20, 2010
- 11 people died, 17 injured
- 5 million barrels of spilled oil~682000 tons in 87 days
- Huge environmental damages, influencing small local businesses, and tourism
- Billions of dollars of cost


Final Report
DEEP WATER
The Gulf Oil Disaster and the Future of Offshore Drilling
Report to the President
National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling


Chief Counsel's Report
Macondo
THE GULF OIL DISASTER
Chief Counsel's Report | 2011
National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling


Macondo Well
Deepwater Horizon
Blowout
LESSONS FOR IMPROVING OFFSHORE DRILLING SAFETY
NATIONAL ACADEMY OF ENGINEERING AND NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

DWH Was Due to a Series of Technical Failures

- **Well design:**
  - **Narrow drilling margin**
  - **Long string instead of a liner**
- **Cementing**
  - **Cement material**
  - ***Number of centralizers***
- **Negative Pressure Test (NPT) misinterpretation**
- **Blowout Preventer (BOP) failure**
- **Mud-gas separator**
- **Alarm systems**

Higher Risk of Deep-water Drilling

- More complex casing designs
- Higher pressure
- More difficult formations
- Higher uncertainty of seismology
- Higher challenges in accessing the site and wellhead
- Lower availability of experienced personnel

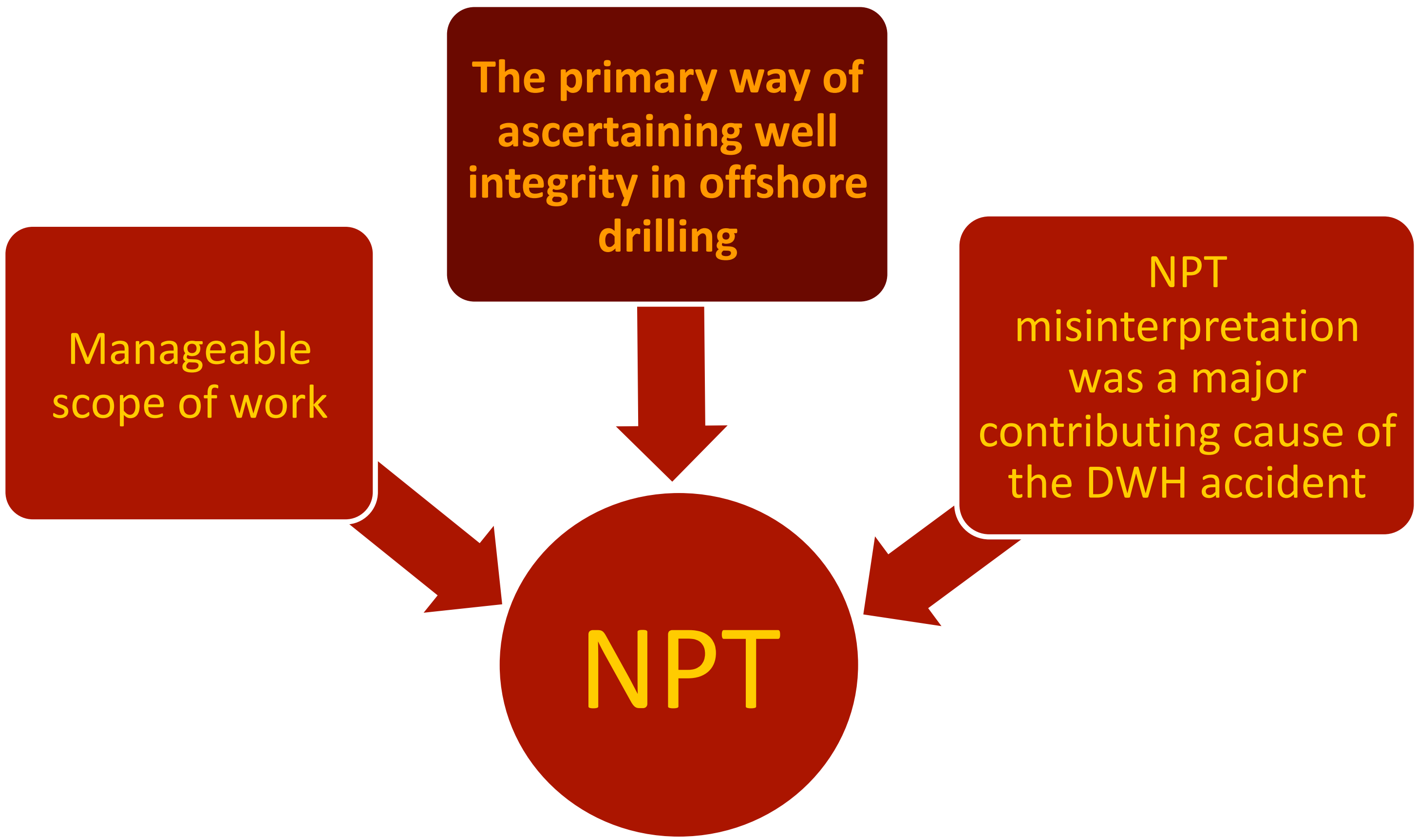
Why Risk Analysis Practices?

Trade-off between high risk of deep-water offshore drilling and the rising dependence of oil and gas supply to it

"Government agencies that regulate offshore activity should reorient their regulatory approaches to integrate more sophisticated risk assessment and risk management practices into their oversight of energy developers operating offshore."

Report to the President,
National Commission on the BP DWH Oil Spill, 2011, Page 251

Why NPT?



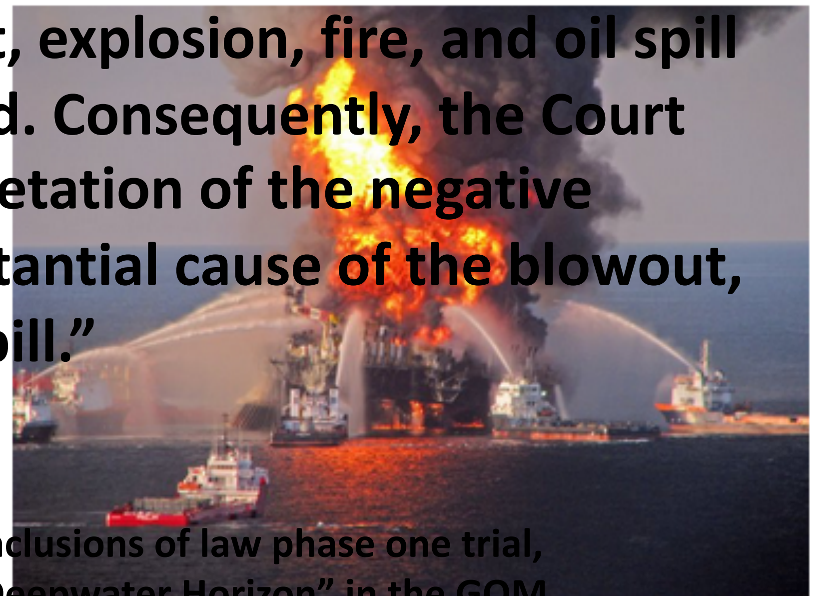
NPT: Negative Pressure Test

Significance of Negative Pressure Test

BP May Be Fined Up to $18 Billion for Spill in Gulf

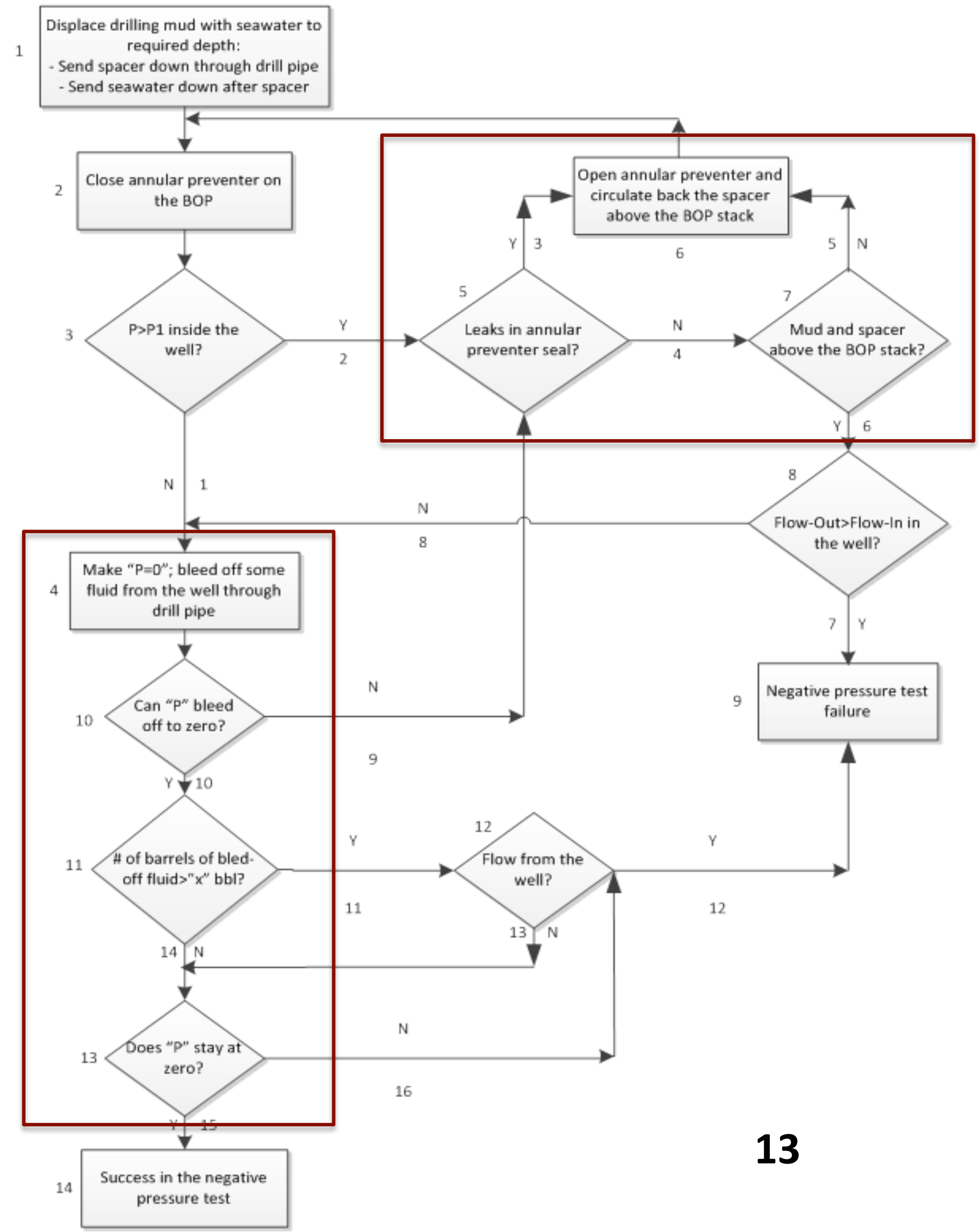
By CAMPBELL ROBERTSON and CLIFFORD KRAUSS SEPT. 4, 2014

"If the negative pressure test had been correctly interpreted, the blowout, explosion, fire, and oil spill would have been averted. Consequently, the Court finds that the misinterpretation of the negative pressure test was a substantial cause of the blowout, explosion, fire, and oil spill."



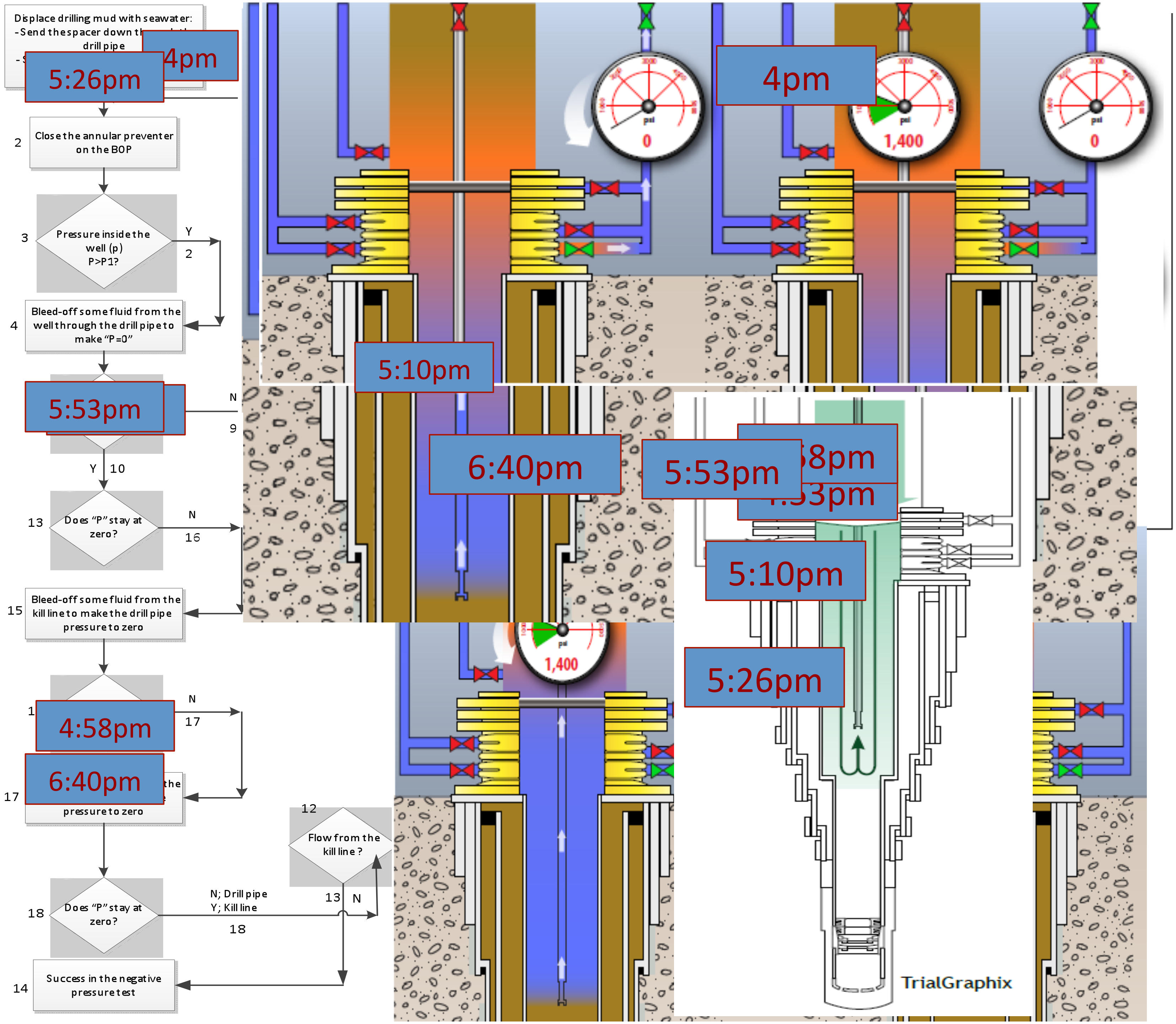
The fire aboard the Deepwater Horizon drilling rig killed 11 workers.

Findings of fact and conclusions of law phase one trial, Oil Spill by the Oil Rig "Deepwater Horizon" in the GOM, The United States District Court for the Eastern District of Louisiana, September 2014, Page 65



Dissecting

"Standard" (Shou ld be Done) Negative Pressure Test



Displace drilling mud with seawater:
-Send the spacer down the drill pipe
4pm
5:26pm
2
Close the annular preventer on the BOP
3
Pressure inside the well (p) P>P1?
Y
2
4
Bleed-off some fluid from the well through the drill pipe to make "P=0"
5:53pm
N
9
Y
10
13
Does "P" stay at zero?
N
16
15
Bleed-off some fluid from the kill line to make the drill pipe pressure to zero
4:58pm
N
17
6:40pm
17
pressure to zero
12
Flow from the kill line?
18
Does "P" stay at zero?
N; Drill pipe
Y; Kill line
13
N
18
14
Success in the negative pressure test
0
1,400
4pm
0
5:10pm
6:40pm
5:53pm
5:10pm
1,400
5:26pm
TrialGraphix

Why Human and Organizational Factors (HOFs)?

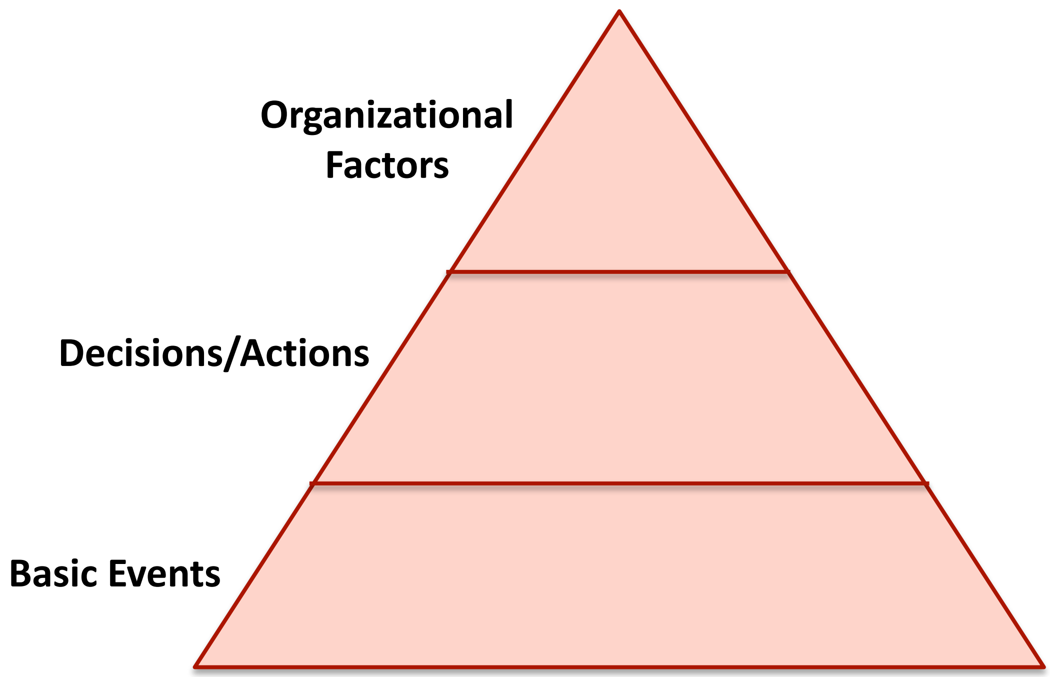
Long-term study (1988-2005) of more than 600 well documented major failures in offshore structures: approximately 80% of the major failures were due to HOFs

Chief Counsel's report (2011) on the DWH: "what the investigation makes clear, above all else, is that management failures, not mechanical failings, were the ultimate source of the disaster."

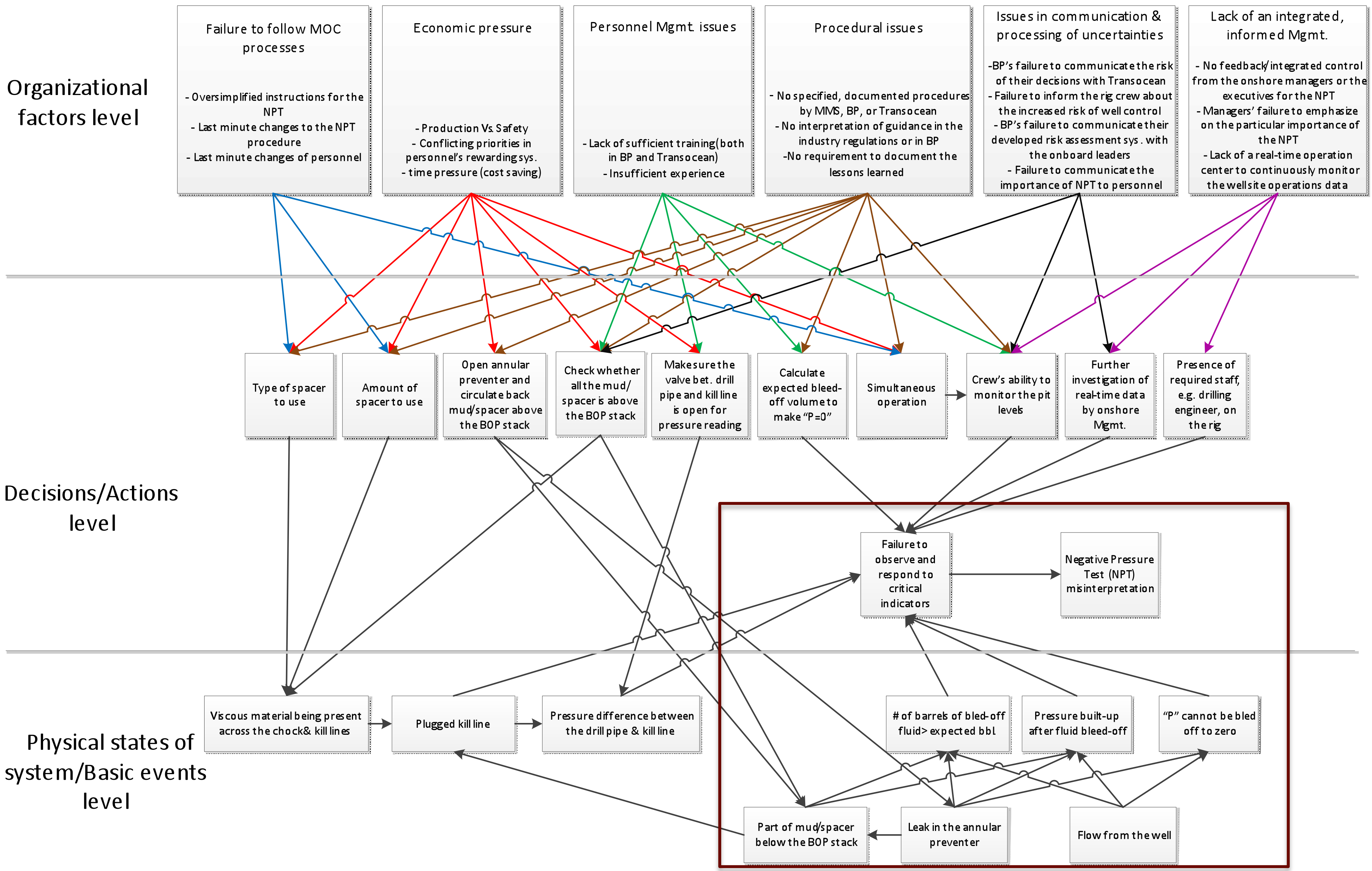
Lord Cullen in the 25th anniversary of Piper Alpha (2013): "as I dug down to the background of what happened, I discovered it was not just a matter of technical or human failure. As is often the case, such failures are indicators of underlying weaknesses in management of safety."

There is a critical gap in the literature regarding the existence of enough risk assessment approaches analyzing the crucial role of HOFs

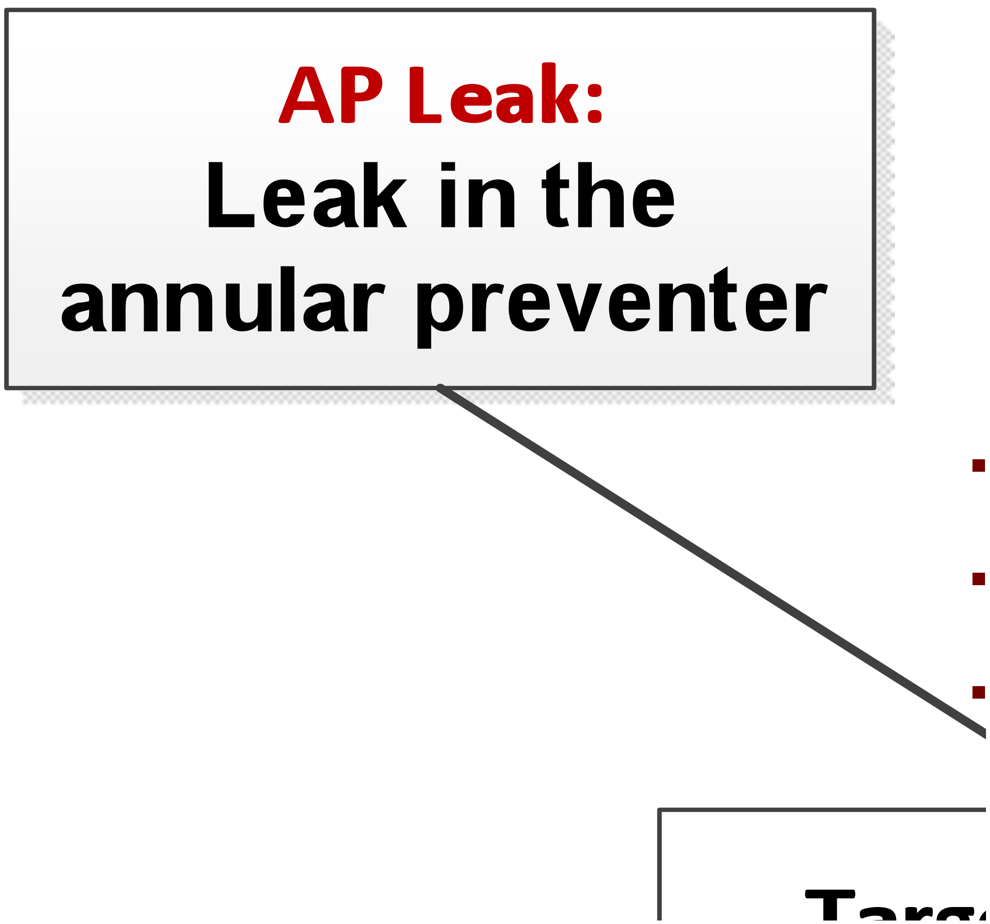
Conceptual Risk Analysis Framework for NPT Misinterpretation



Conceptual Risk Analysis Framework for NPT Misinterpretation

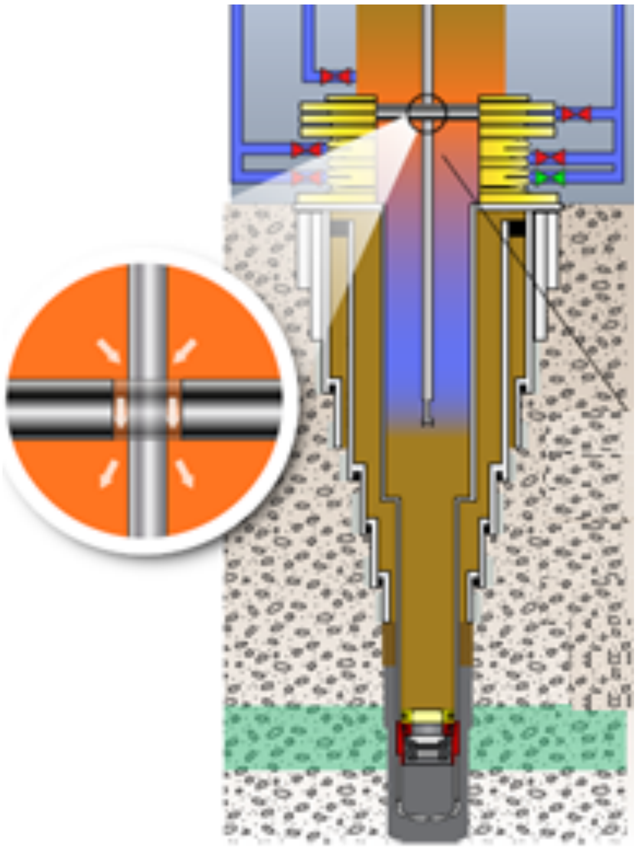


A Snapshot of the
Signal Detection Model for NPT Interpretation

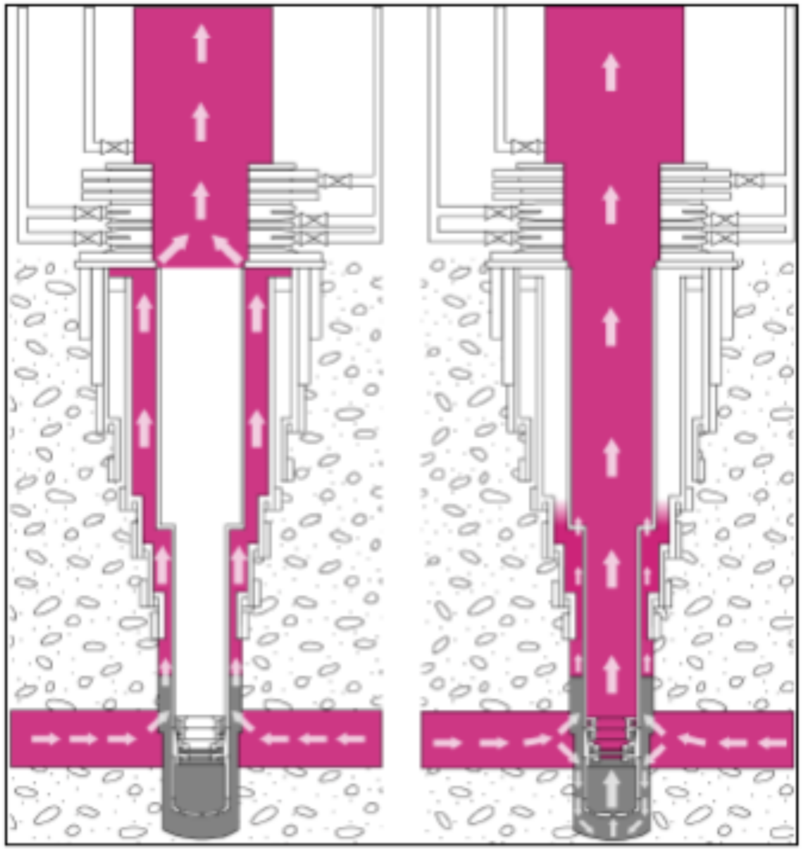


- AP Leak & Well Leak: Yes/No
- Target variable: Finite continuous
- Decisions/judgments: OK/NOT OK

Two Variables Affecting our Target Variable (Pressure Deviation)

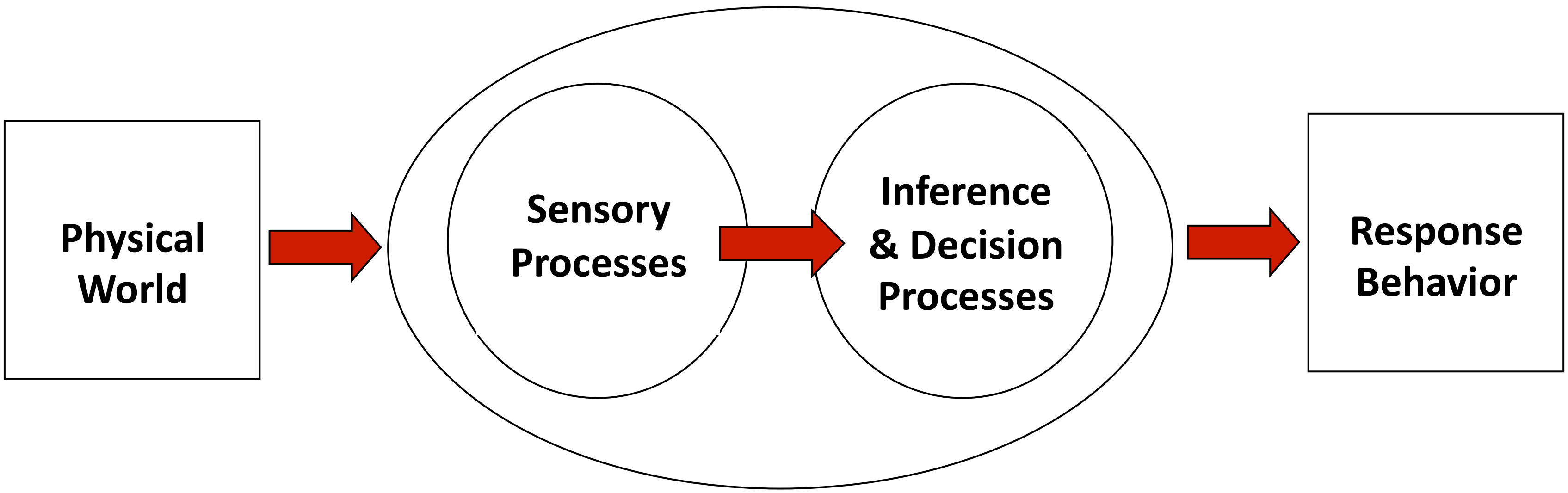


Leak in the BOP annular preventer
(Source of image: Chief Counsel's Report, 2011, page 154)



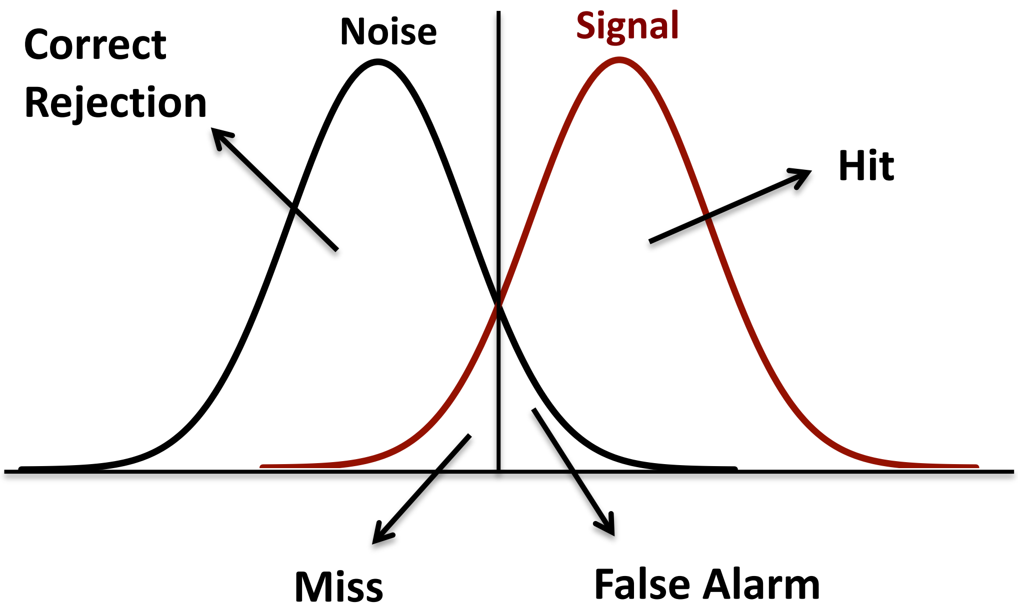
Possible flow paths for hydrocarbon
(Source of image: Chief Counsel's Report, 2011, page 39)

Decision Processes in Signal Detection Theory



Signal detection theory and decision processes
(Green and Swets, 1974; Deplancke and Sparrow, 2014)

Signal Detection Theory



	No	Yes
Noise	Correct Rejection	False Alarm
Signal	Miss	Hit

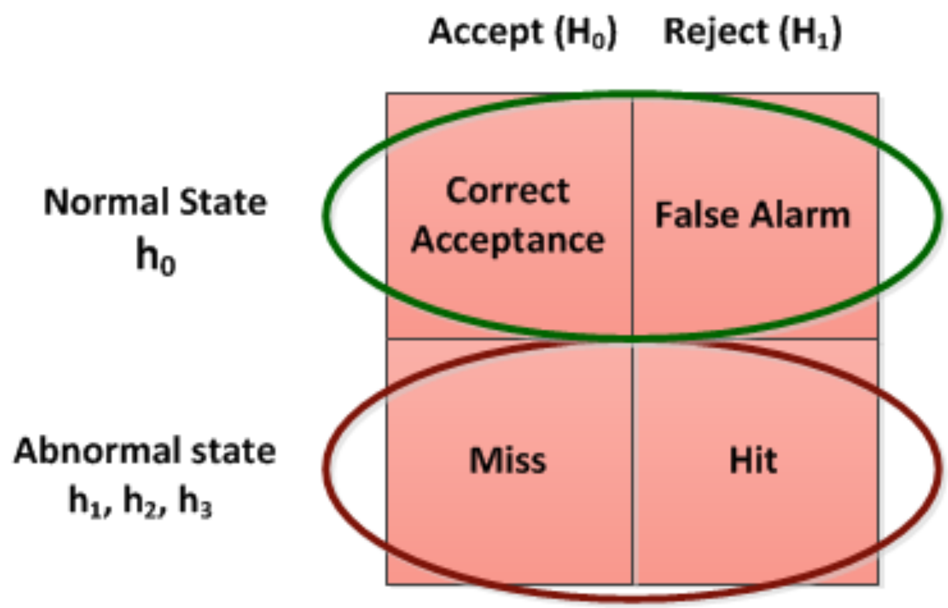
States of the System

Classification of states: AP Leak, Well Leak

- **Normal sate:**
  h_0: NN

- **Abnormal states:**
  h_1: YN
  h_2: NY
  h_3: YY

- $P(h_0) = P(NN)$
- $P(h_1) = P(YN)$
- $P(h_2) = P(NY)$
- $P(h_3) = P(YY)$



Signal Detection Model Notations

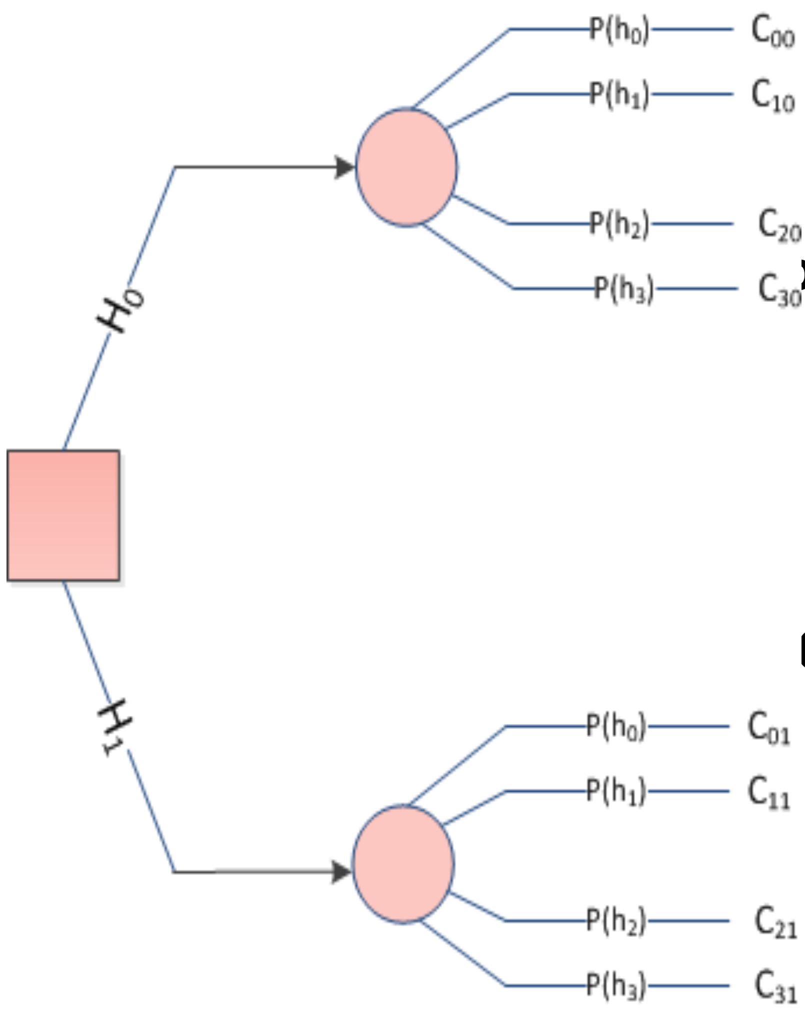
Probability of each state for (AP Leak , Well Leak):

P(AP Leak , Well Leak)= P(AP Leak)*P(Well Leak)

e.g.

P(NN)= P(AP Leak=N)*P(Well Leak=N)

Signal Detection Model for NPT Interpretation



C_{ij}: Cost of saying "H_j" when the state is "h_i"

Say "H_0" or OK iff:

→

a value for pressure

om the system; AP-EP=d

: Likelihood Ratio

is the judgment?

OK) or "H_1" (NOT OK)

: Prior odd for state "h_i" comparing to "h_0"

: Conditional probability of the pressure deviation knowing that the state is "h_i"

Calculate the cut-off point value "e" for the pressure deviation: Judgment is "H_1" or NOT OK for any observed pressure more than "e"

Signal Detection Model Required Inputs

The cut-off point value depends on three main inputs:

1) **$P(h_i)$: Prior probability of the state "h_i"; i=0,1,2,3**
2) **$f(x|h_i)$: Conditional probability of pressure deviation for state "h_i"**
3) **C_{ij}: Cost of saying "H_j" while the state is "h_i"; i=0,1,2,3 and j=0,1**

Results of Signal Detection Model Analysis

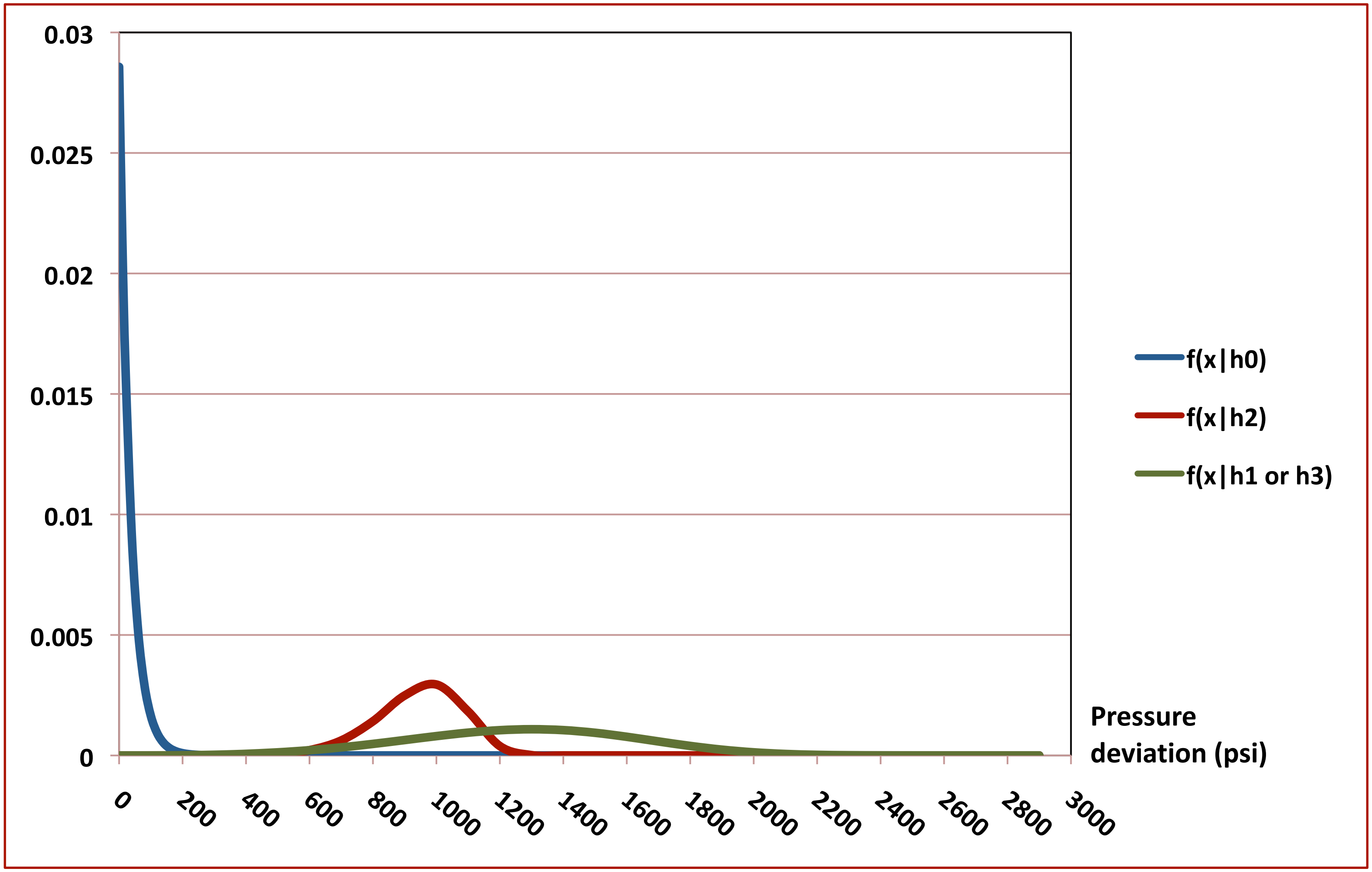
How a pressure deviation as high as “1400psi” was accepted by the DWH crew?

- Cut-off … equality knowing the values for the … s:

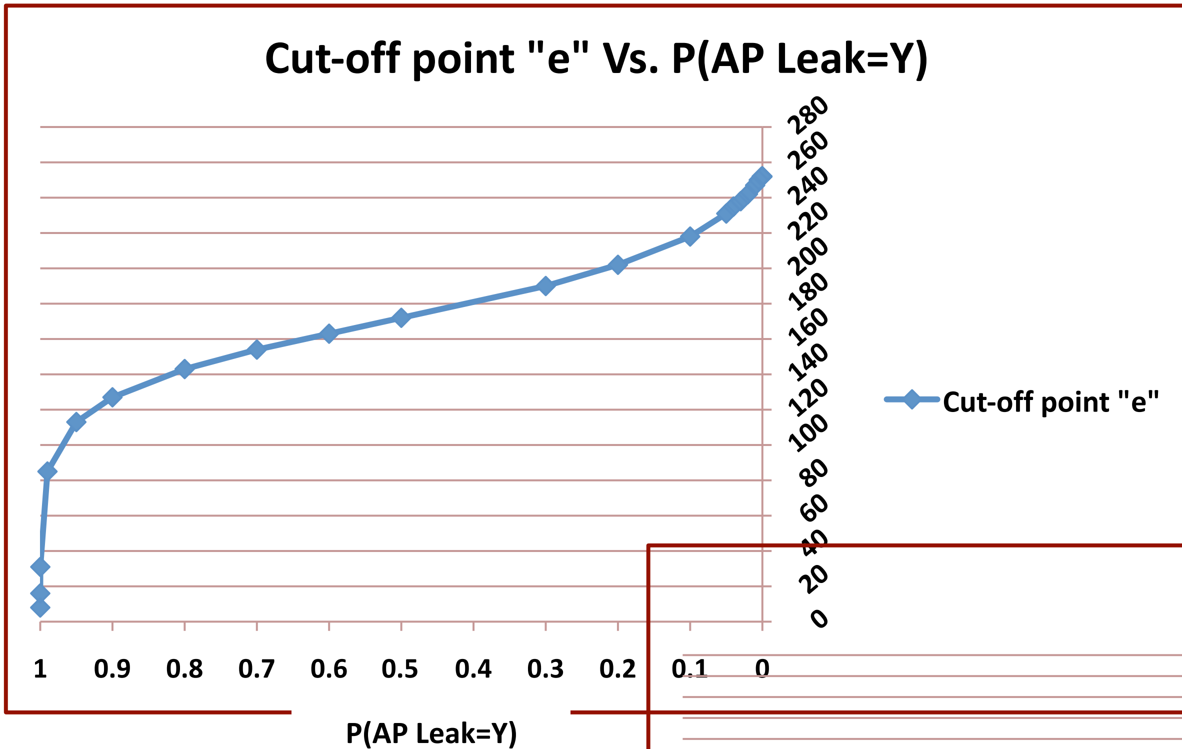
  e= 247psi

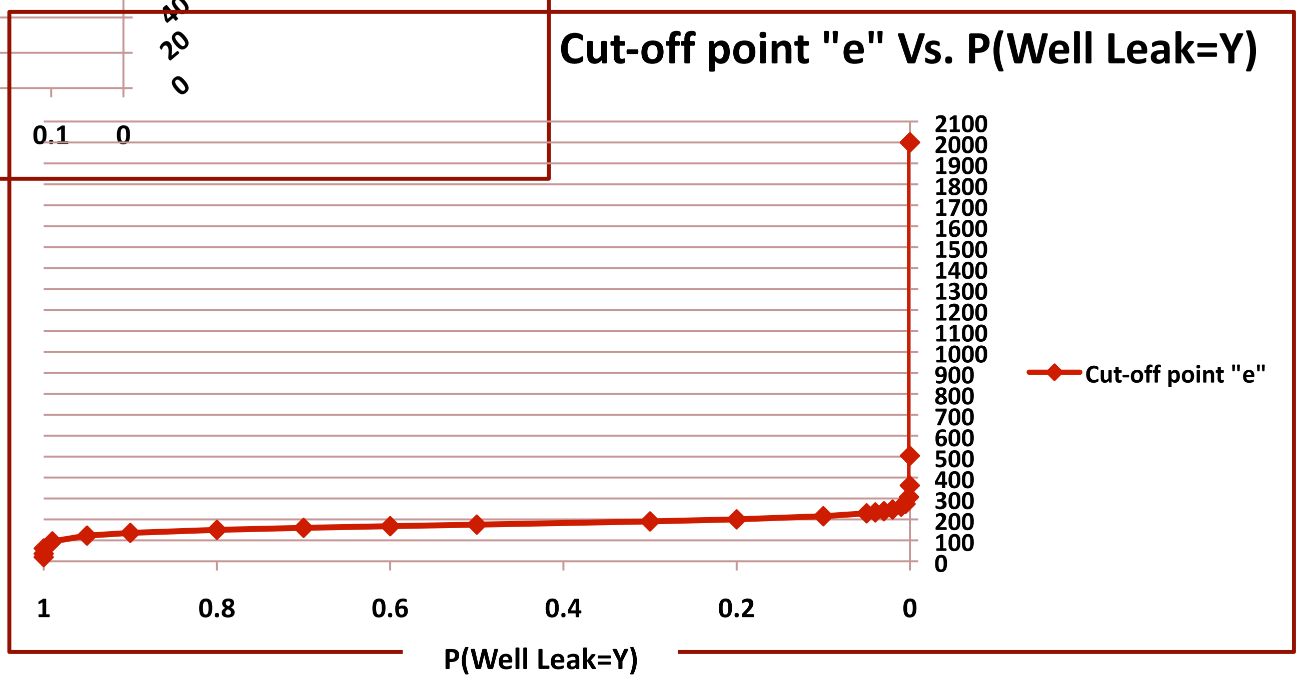
- For any observed pressure built-up more than 247psi: say “H_1” or NOT OK

The Cut-off Point Illustration and Meaning

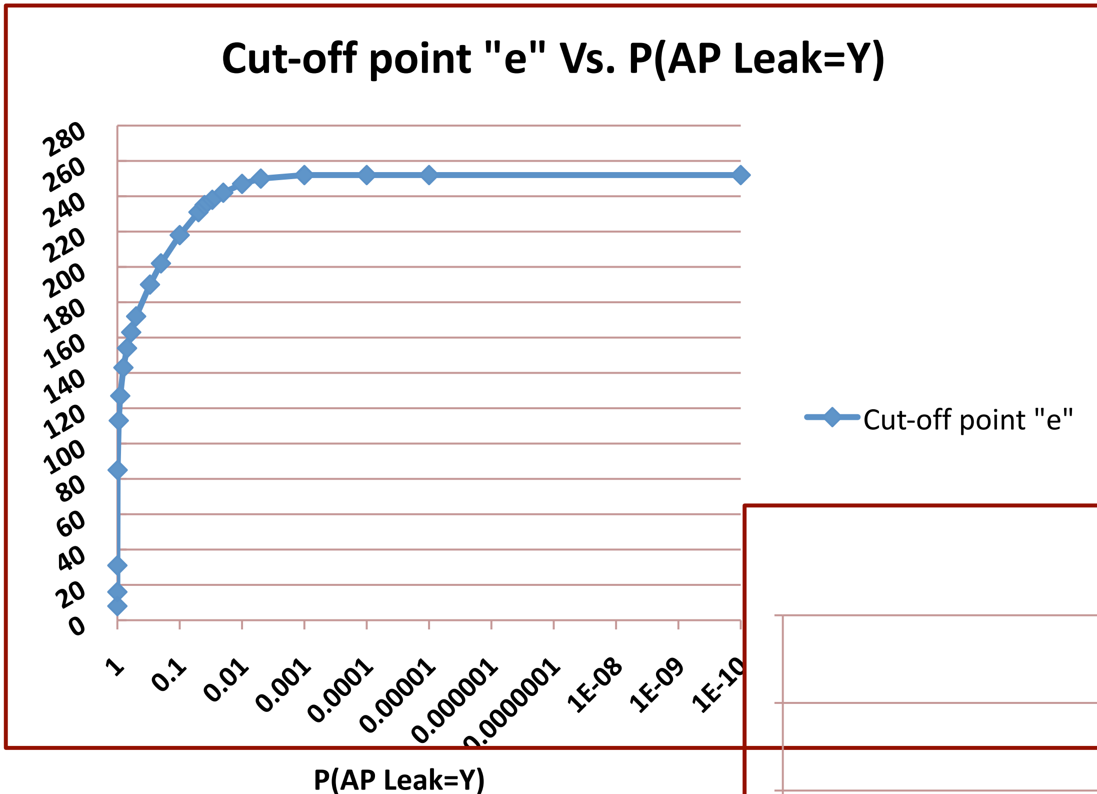


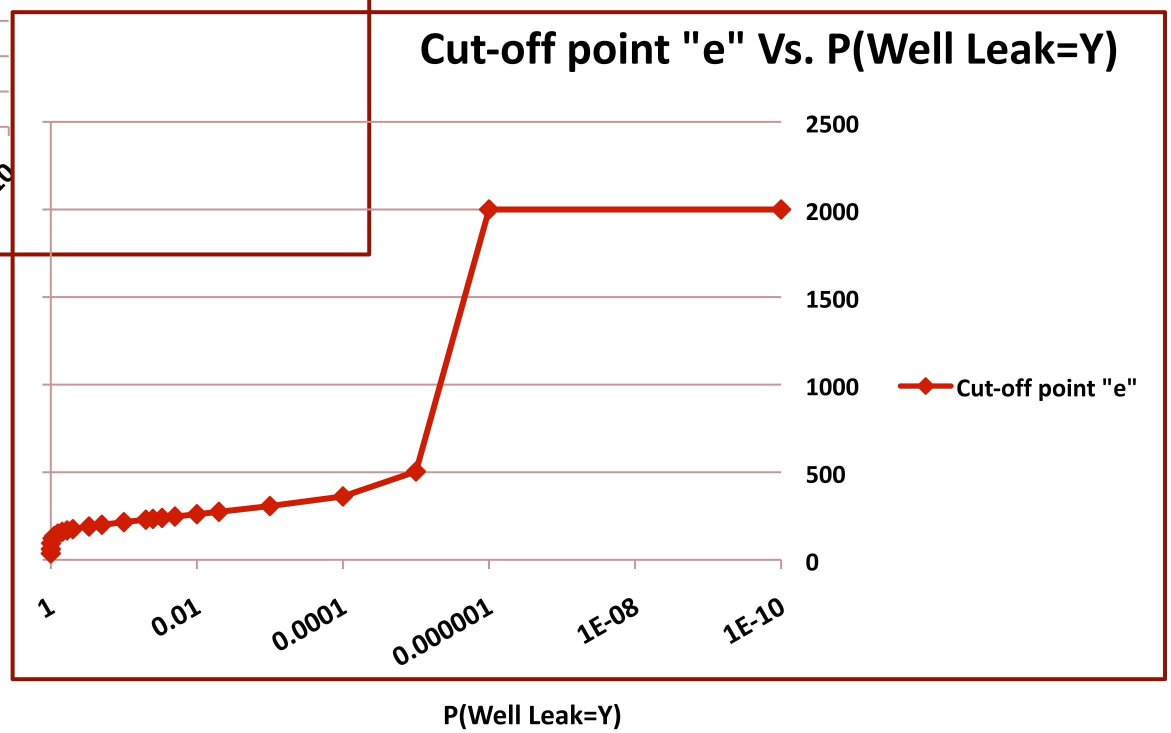
Bias 1: Underestimating Prior Probability of Abnormal States





Bias 1: Underestimating Prior Probability of Abnormal States-Cont'd





Root Causes of Biases

Organizational factors are the root contributing causes of biases:

- **Economic pressure**
- **Personnel management issues**
- **Issues in communication and processing of uncertainties**
- **Lack of an integrated, informed management**

Summary and Conclusion

- **There is a need for more sophisticated risk analysis methodologies to reduce the high risk of accidents and blowouts in future offshore drilling.**
- **The developed methodology in this study is an attempt of utilizing sophisticated risk analysis practices, and this methodology can be generalized to other applications as well.**
- **We proposed a <u>structured</u> signal detection model with <u>parametric equations</u> for it in order to analyze critical decision making situations and involved biases. This model can be used in different safety-critical systems such as oil and gas industry, healthcare, transportation and financial systems.**
- **Biases, such as underestimating the prior probability of abnormal states, affect rational decision making and increase the risk of a false negative situation or misinterpreting a negative pressure test.**
- **Misinterpretation of a conducted NPT can mostly occur due to the confluence of different biases rather than just one specific bias.**
- **Organizational factors are the root causes of involved decision making biases.**

Acknowledgements

- **Petroleum engineering experts:**
  - **Mr. Stan Christman, retired ExxonMobil executive engineering advisor**
  - **Mr. Fred Dupriest, retired ExxonMobil chief drilling engineer and lecturer at the Texas A&M University**
  - **Mr. Roger Gatte, BP retired wells superintendent**
  - **A retired ExxonMobil Worldwide drilling manager**

Thank you!

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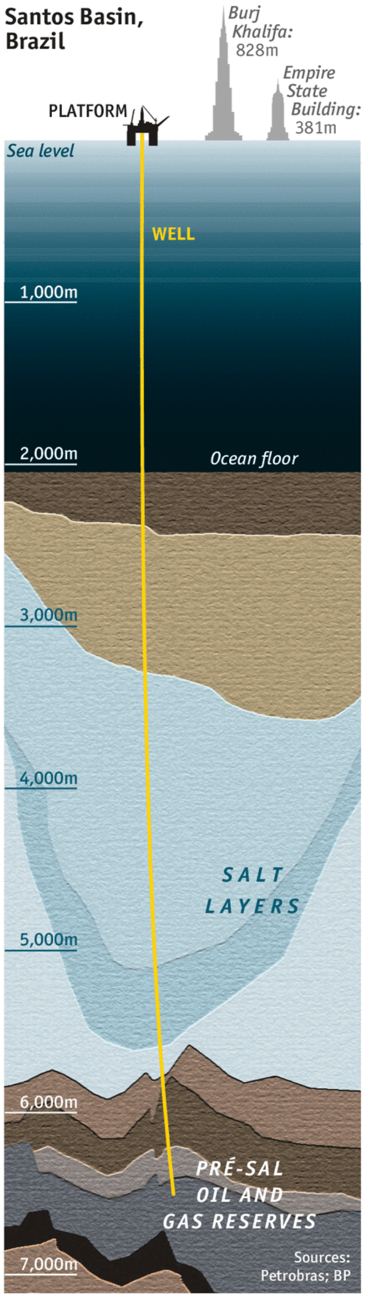
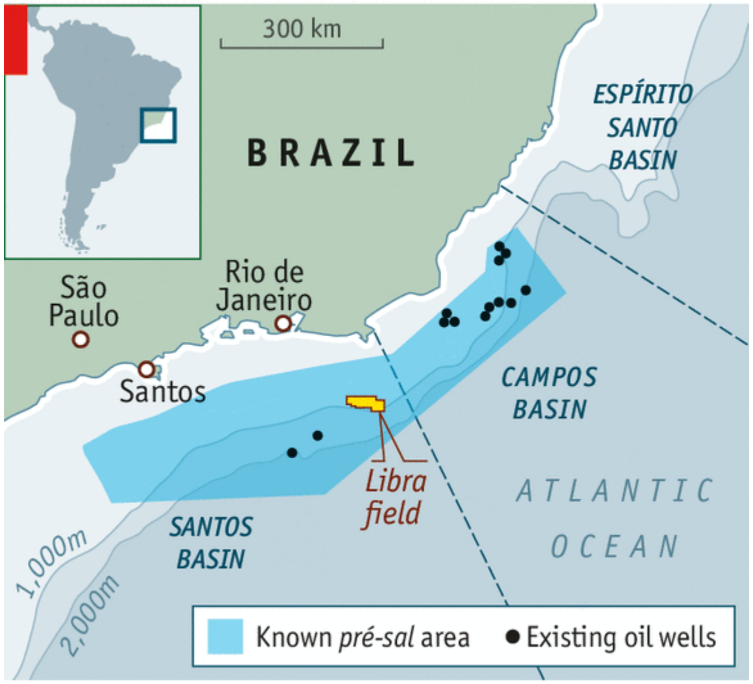
Projection of Deep & Ultra Deep-water Drilling



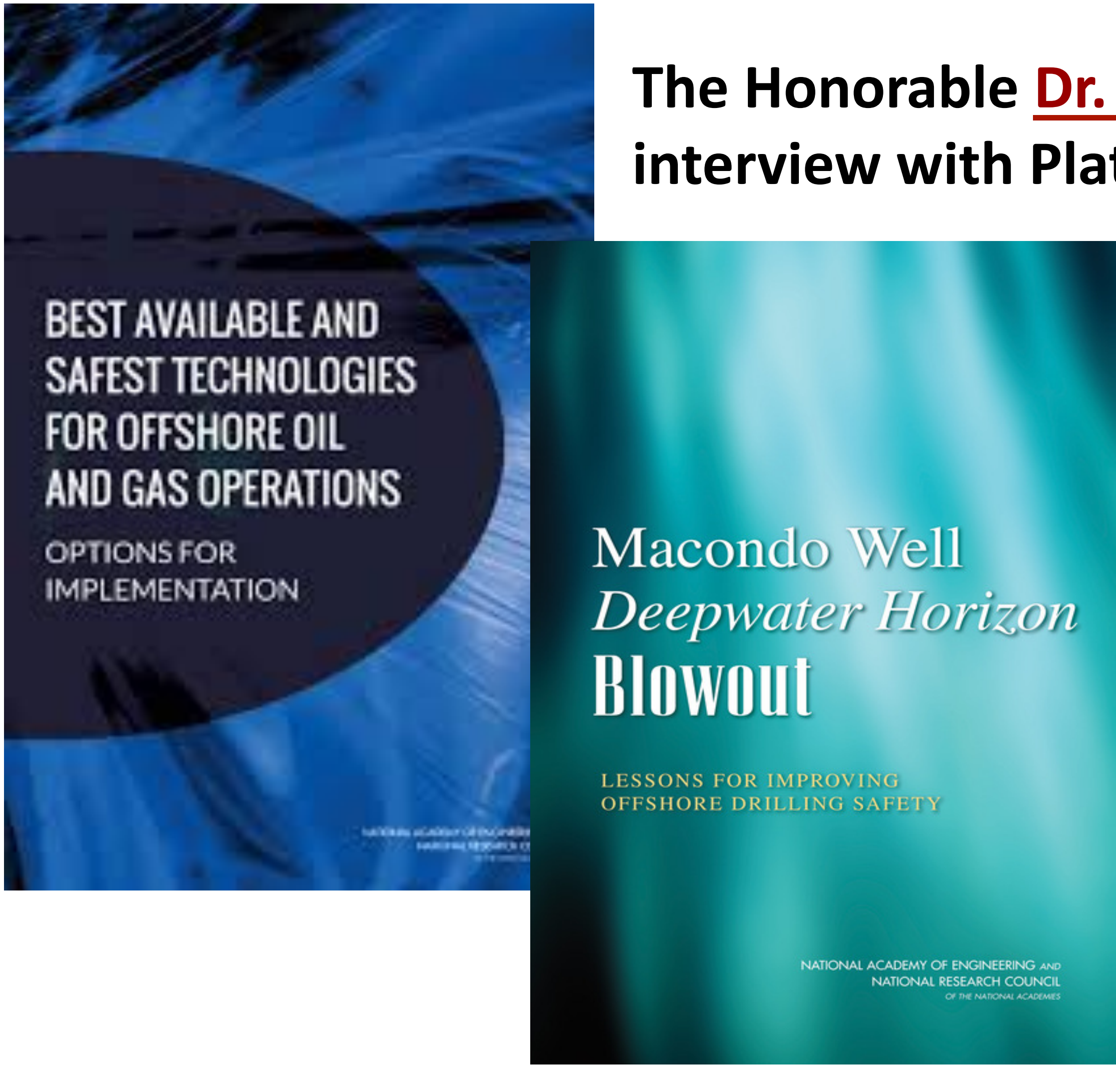
Libra field; Brazil:

- Off Rio de Janeiro coast
- 7000 meters ~ 23000ft depth
- 8-12 billion barrels of oil



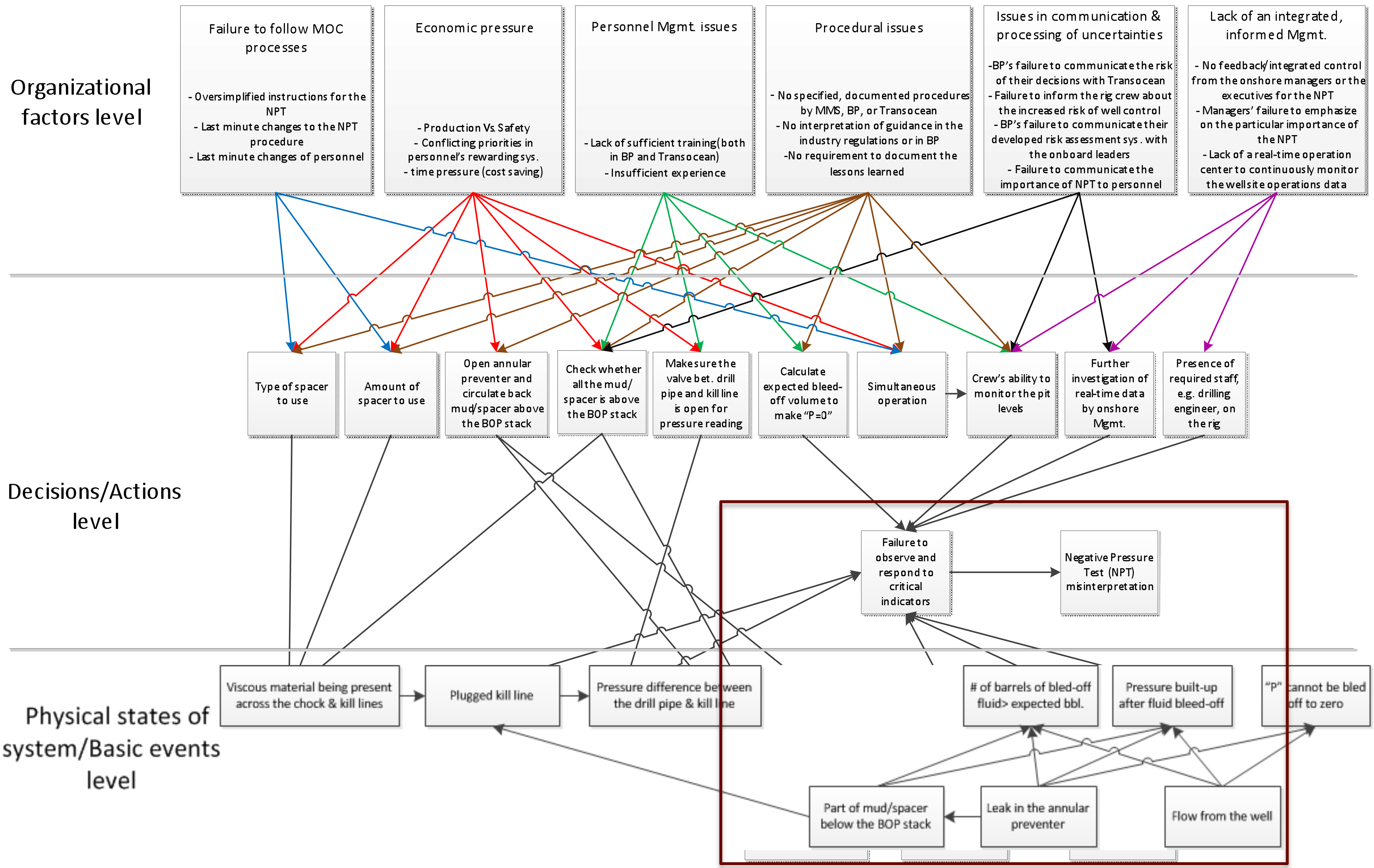
Economist, October 26, 2013

Significance of Negative Pressure Test



The Honorable Dr. Donald Winter in his interview with Platts: BP Deepwater Horizon was precipitated "not by a piece of hardware, but by the decision to proceed to temporary abandonment in spite of the fact that the negative pressure test had not been passed" **(November 4, 2013).**

Conceptual Risk Analysis Framework for NPT Misinterpretation



Observations from the 3-Layer Conceptual Model

- **Organizational factors are root causes of accumulated errors and questionable decisions/actions made by personnel and management.**

- **The first three organizational factors with the highest influence:**

  1. **Personnel Management issues**
  2. **Issues in communication and processing of uncertainties**
  3. **Economic pressure**

Conditional Probabilities and Well Characteristics

- Specifications and range of each conditional probability distribution for the target variable in each state depends on the analyzed well characteristics, such as depth of drilling, depth of displacement, formation characteristics, and type and amount of used fluids (e.g. oil based mud vs. water based mud, spacer)

- Considered values for each conditional probability are based on characteristics of a well like the Macondo.

  For example:
  When there is leaking in the annular preventer (state "h_1"), for a case like the DWH, based on the 421bbls of used spacer, in the worst case, the bottom of the spacer can be at 8367ft and the top at about 3000 ft.

Parametric Decision Making Equations-1

Say "H_0" or OK iff:

↓

Expected value for saying or judging H_i after observing the value "d" from the system for our target variable

1.1

→

2.1

Parametric Decision Making Equations-2

By substituting the equality (2.1) in (1.1):

1.2

By simplifying inequality (1.2):

1.3

For the expected cost:

1.4

Post-Mortem Analysis of the DWH NPT

Under what circumstances could the DWH crew accept the negative pressure test results with a pressure built-up of "1400psi"?

- **Basic scenario:**
  - **P(AP Leak=Y)= 0.01**
  - **P(Well Leak=Y)= 0.02**
  - **C_{20}/C_{01} and C_{30}/C_{01}= 2000**

  Cut-off point= 247psi

- **Scenario 1:**
  - **P(AP Leak=Y)= 0.01**
  - **P(Well Leak=Y)= 0.00001**
  - **C_{20}/C_{01} and C_{30}/C_{01}= 300**

  Cut-off point= 837psi **(Which is still less than 1400psi)**

- **If the above cost ratios reduce to 250: the cut-off point will be infinity, which means accepting the test for any observed pressure built-up; no matter how high it is.**

Root Causes of Biases

Organizational factors are the root contributing causes of the stated biases:

- **Economic pressure**; if there is too much pressure on cost and time saving, that can cause underestimation of the described cost ratio (cost of accepting the test for an abnormal state to the cost of rejecting the test for a normal state).
- **Personnel management issues**; if personnel does not receive proper training or does not have enough experience, that can cause the described biases.
- **Issues in communication and processing of uncertainties**; if managers do not communicate the risk of complex operations such as NPT procedures to personnel, that can contribute to the described biases.
- **Lack of integrated, Informed management**; existence of no integrated feedback system from managers (both onshore and offshore) to the crew can contribute to the described biases.