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The topic :

The Contribution Of Well Integrity To Risk Prevention

*Discussed in **10/06/2024** before the review board composed of:*

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Dedication

With great pleasure and immense joy, I dedicate this modest work:

To my dear mother, to whom I owe what I am, and who has never stopped praying for my happiness.

To my dear father, who has supported me immensely throughout my life.

To the memory of my grandmother (May Allah have mercy on her). To you, I dedicate my love, my pen and my thesis, my effort and my life.

To my dearest wife, your encouragement and support were the breath of fresh air that rejuvenated me in moments of weakness. I pray to Almighty God to grant you happiness and prosperity.

To my beloved children.

To my dear brothers and sisters for their constant encouragement.

Not forgetting the contribution and encouragement of all my family members, as well as my friends, the best there are.

To who sacrificed their lives in Gaza, defending the nation's sacred sites and principles. Indeed, Allah is predominant over His affair

To all those who have sacrificed their time for scientific research, our teachers, who enabling science to reach its current stage, to all the researchers who use science for the good and prosperity of humanity.

To all those who are dear to me.

LOUAZENE Mohamed Ali

Dedication

I dedicate this work to:

My precious parents as a sign of recognition and deep gratitude for all the efforts they have made and means to see me succeed in my studies;

My dear brothers and sisters;

All my family;

All my friends without exception;

And to all those who contributed directly or indirectly to make this project possible, I say THANK YOU.

NINI Belgacem

Dedication

I dedicate this modest work to those who gave me life, who encouraged me during all my years of study, to my mother and my father.

To my brothers

To my sister Meriem

To my friends KAMEL Rami and BADRI Oussama and BARR Ziad

To all those who are dear to me, to those who love me, I dedicate this

Work.

DEHANE Nacereddine

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Thank you all.

ملخص

في الوقت الحاضر، أصبحت حقول النفط والغاز تتقدم في العمر وتخلق تهديدات جديدة. هذا دفع الشركات المشغلة والباحثين في الصناعة إلى التركيز المكثف على سلامة الآبار.

تتيح أنظمة إدارة المخاطر لشركات النفط تقييم المشاكل والمخاطر الناشئة عن الحفر والاستكشاف. كما تمكن من وضع خطط طوارئ مناسبة وتطبيق إجراءات تخفيف المخاطر.

يمكّن تقييم المخاطر في سلامة الآبار من تصنيف المخاطر المحتملة وتوفير مصدر لتخفيف المخاطر وتخصيص الموارد بشكل أفضل، تعمل بشكل صحيح، وقادرة على التشغيل بشكل مستمر لتلبية متطلبات الإنتاج المتوقعة.

علاوة على ذلك، تضع شركات الاستكشاف والإنتاج الصحة والسلامة والبيئة، والأصول، والإنتاج، والصورة المحلية والعامة كأولوية قصوى في أعمالها.

أصبحت سلامة الآبار مصدر اهتمام خلال مرحلة تصميم البئر، خاصة بعد بعض الأحداث الأخيرة في ميدان صناعة النفط، مثل حادثة خليج المكسيك التي لا تزال في أذهان الجميع، أصبحت هذه المسألة مصدر قلق كبير، أصبحت مراقبة سلامة الآبار، من الإنشاء وحتى نهاية عمرها، أمرًا لا مفر منه.

الكلمات المفتاحية: *سلامة الآبار، النفط والغاز، أنظمة إدارة المخاطر، تقييم المخاطر، الصحة والسلامة والبيئة.*

Abstract:

Nowadays, oil and gas (O&G) fields are maturing and creating new threats. This urged the operating companies and industry researchers to have intensive focus on well integrity (WI).Risk management systems allow oil companies to assess the emerging problems and risks of drilling and exploration. It also enables to establish appropriate emergency plan and apply risk reduction mitigation. Risk assessment in WI problems enables to rank potential risks and provide source for risk mitigation and better resource allocation. Functions properly in healthy condition, and is able to operate consistently to fulfill the expected production/injection demands.

Moreover, exploration and production (E&P) companies put Health, Safety, and Environment (HSE), assets, production, local and public image as top priority in their businesses.

Well integrity has become a major concern during the well design phase. Especially after some of the recent events in the oil industry, such as Mexico which is still fresh in everyone's mind, it has turned into a critical concern. The need for monitoring well integrity, from the construction through its lifetime, became unavoidable.

Keywords: *well integrity, oil and gas, Risk management systems, Risk assessment, Health, Safety, and Environment.*

List of Abbreviations

AC: *acceptance criteria*
AEGLs: *39*
ALARP: *as low as reasonably practicable*
ALOHA: *areal locations of hazardous atmospheres*
AND: *18 20*
AP: *Applied Pressure*
ASV: *annulus safety valve*
ARH: *Hydrocarbons Regulatory Authority*
BHP: *bottom hole pressure*
BLEVEs: *Boiling Liquid Expanding Vapor Explosions*
BOP: *blow out preventer*
CBL: *cement bond log*
DHSV: *downhole safety valve*
EAC: *element acceptance criteria*
ECD: *equivalent circulating density*
EPA: *Environmental Protection Agency's*
ERD: *Emergency Response Division*
ERPGs: *39*
EMW: *13*
FIT: *formation integrity testing*
FMECA: *Failure modes, effects, and criticality analysis*
FPP: *fracture propagation pressure*
FCP: *fracture closure pressure*
GLV: *gas lift valve*
HMV: *hydraulic master valve*
ICS: *incident command system*
IDLH: *39*
ISO: *International Organization for Standardization*
KV: *Kill Valve*
LEL/UEL: *Lower and Upper Explosive Limits*
LD: *51*
LOCs: *Levels of Concern*
LOT: *Leak off Test*
LPG: *45*
LPR: *15*
MAASP: *Maximum Allowable Annular Surface Pressure*
MARPLOT: *Mapping Application for Response, Planning, and Local Operational Tasks*
MAWOP: *maximum allowable working pressure*
MD: *measured depth*
MMV: *13*
MPR: *15*
MSDP: *15*
MWDP: *maximum well desingn pressure*
NOAA: *National Oceanic and Atmospheric Administration*
NORSOK: *Norwegian Shelf's competitive position*
OL: *32*
OML: *2*
PAC: *39-49*
PLT: *production logging tool*
PMV: *Production Master Valve*
PT: *pressure test*
PSA: *petroleum safety authority*
PIT: *pressure integrity test*
PCT: *Post commandement tactique*
PII: *Plan Interne intervention*
PWV: *Production Wing Valve*
SV: *Safety Valve*
SSR: *15*
TEELs: *39*
TP: *Thermal Pressure*
TS: *27*
TRSV: *22*
TOC: *top of cement*
TVD: *True vertical depth*
IT: *inflow test*
UMV: *52*
UPR: *15*
VDL: *58*
WBE: *well barrier elements*
WH: *well head*
WBS: *Well Barrier Schematic*
WIT: *well integrity training*
XMT /XT: *X-mas Tree*
XLOT: *extended leak off test*

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General Introduction

Well integrity involves implementing technical, operational, and organizational measures to prevent uncontrolled releases of formation fluids throughout the well's life cycle. Proper planning of drilling and completion must ensure that well designs meet minimum safety standards. NORSOK D-0101 specifies the necessity of two well barriers during all operations, including suspended or abandoned wells, to prevent uncontrolled outflow.

Operational practices are crucial for maintaining well integrity. This includes regular testing of sub-surface safety valves and monitoring well pressure to detect and address issues early. Organizational solutions ensure that competent personnel manage well operations and maintain effective communication, especially during shift handovers, to uphold safety standards.

Failures in well barriers must be promptly addressed to restore integrity, either by repairing the barrier, securing the well, or redefining the barrier until the failure can be corrected. This thesis will explore tools and methods for identifying and preventing failures, emphasizing the importance of maintaining well integrity to mitigate risks and ensure safe operations

Based on the above, the primary aim of this thesis is to develop a methodology for applying various well integrity techniques to prevent the negative impact of integrity loss on humans, installations, and the environment.

To achieve this goal, our thesis is organized into three parts as follows:

The first chapter, titled "Introduction to well Integrity," explores the fundamental principles surrounding well integrity, including topics such as the well barriers, the essential criteria for accepting these barriers in schematic form and the loss of well integrity. This chapter underscores the pivotal role that well integrity plays throughout the lifecycle of wells, acknowledging its significance.

The second chapter concentrates on the methodology for anticipating risks connected to integrity loss by examining various methodologies and techniques. Additionally, it explores the application of artificial intelligence to enhance predictive capabilities, allowing for a more comprehensive understanding of the potential impacts of integrity loss on well operations and safety.

In the third chapter, our attention turns to assessing the integrity of Gas Injector Well MD-89, aiming to provide recommendations.

Implementing these suggestions is aimed to reinstating integrity and mitigating the adverse effects of unintentional well integrity loss.

Additionally, we utilize the Aloha simulator to estimate this impact, highlighting the significance of restoring well integrity.

Problematic

History shows some severe examples of losing integrity in wells such as the Phillips Petroleum's Bravo blowout in 1977, Saga Petroleum's underground blowout in 1989, Statoil's blowout on Snorre in 2004, and BP's Macondo blowout in the Gulf of Mexico in 2010,

As well in Algeria some of disastrous accident occurred in Hassi Messaoud oil and gas fields such as Nazla (2006), Gas injector well OML-75bis (2020) and MD-2044 (2020) which created an Emergency situation force Sonatrach to activate its Incident Command System ICS(PII, PCT..).

These serious accidents remind us of the potential dangers in the oil and gas industry and they are some of the main drivers for the current focus on well integrity in the industry.

CHAPTER I: Introduction to well Integrity

Introduction

In this chapter, we will address the concept of well integrity, as integrity plays an essential role in the lifecycle of wells. Therefore, the national company Sonatrach has focused on this subject in recent years with the aim of protecting its wells (production, injection, etc.). This protection must be accompanied by a reliable study, a well-targeted program, and strict implementation in order to achieve the company's objectives. To do this, it is necessary first to understand the causes behind any issues that may lead to integrity failure and affect the production of a well and its lifespan.

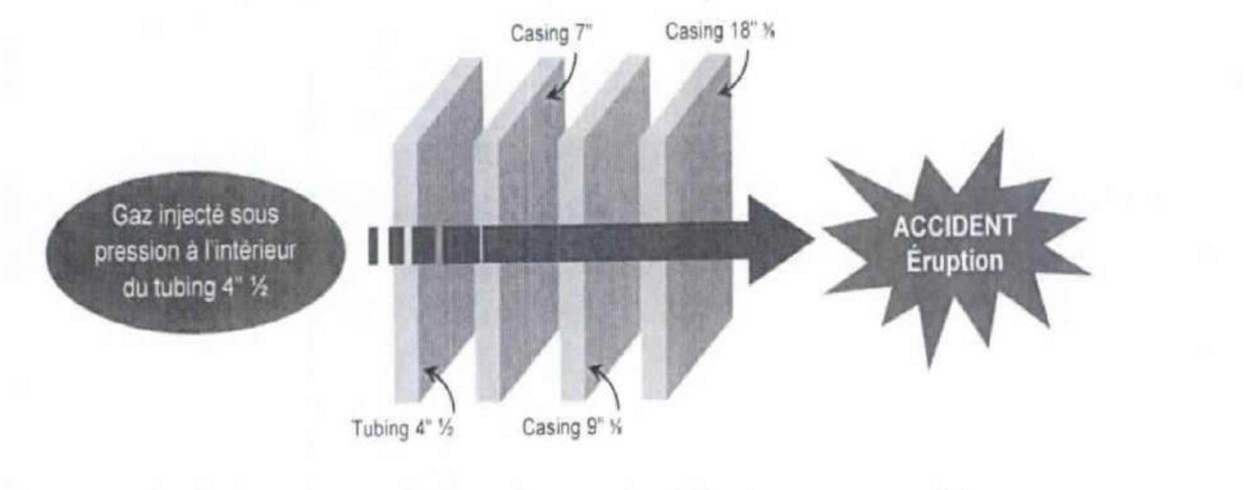
Integrity Issue in Algeria Oil and gas field

A. Nazla 19

One of the most catastrophic accidents in the oil and gas sector occurred on September 15, 2006, at TP 159 well in the Nezla 19 gas field in Hassi Messaoud. The explosion resulted in a gushing flame reaching a height of 50 to 60 meters. [1]

B. OML -75 bis

On January 02, 2020, a major fire broke out in a gas injector well OML -75 bis following a casing failure, as shown in the figure bellow, this incident created an inflammable cloud that extended nearly to 1000 meters. [2]



FigureI.1: Integrity loss in annulus spaces OML bis- 75

FigureI.2 : OML bis -75 on fire

C. MD244

On March 23, 2020, a significant fire occurred on well MD244, primarily due to an integrity issues, such as:

- Advanced corrosion on the well is casing and tubing.
- Erosion due to the pressure of the injected gas.
- Blocked in the closed position of the bottom valve due to corrosion.
- Tectonic movement. **[3]**

FigureI.3: MD244 on fire

FigureI.4: MD244 Extinguishing Operation

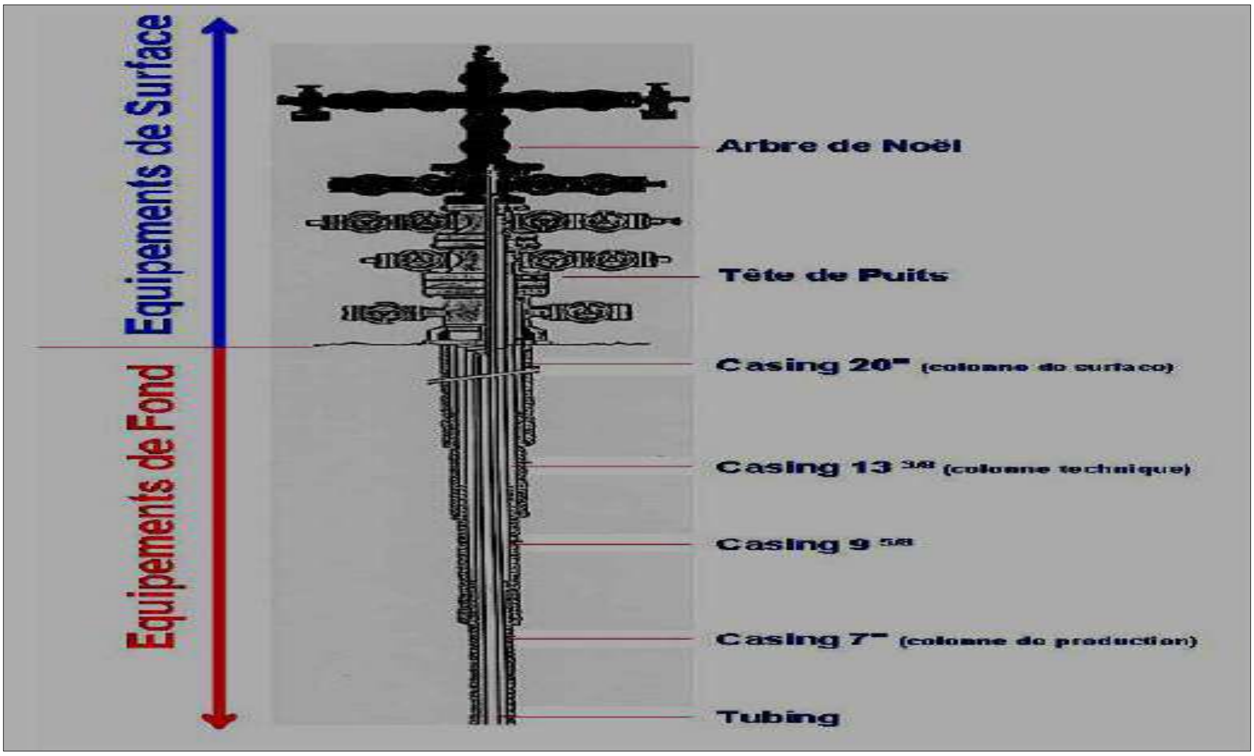
FigureI.5: Both ends of the 7’’ casing at the depth of 167m

1 Well Construction and Field Development

1.1 The well construction:

Oil and gas exploitation requires the drilling of exploration wells. The walls of these wells are supported by steel casings cemented to the rock wall. When indications of gas or oil are encountered, the indications are evaluated using rod tests. If the test results are conclusive, the well will be completed, and production tests will be carried out. The well then enters a production period. At the end of the production period, the well must be closed before being abandoned. The same applies if gas indications do not justify the completion of the well. In this case, the drilling is closed without being completed. In this section, all these steps are presented in detail, as well as a brief overview of the materials used in well construction. A well is divided into two elementary subsets**:**

- **Down hole equipment (casings, completion)**
- **Surface equipment (Wellhead, Christmas tree)** [4]



FigureI.6: Surface and Downhole equipment [5]

1.1.1. Downhole Equipment

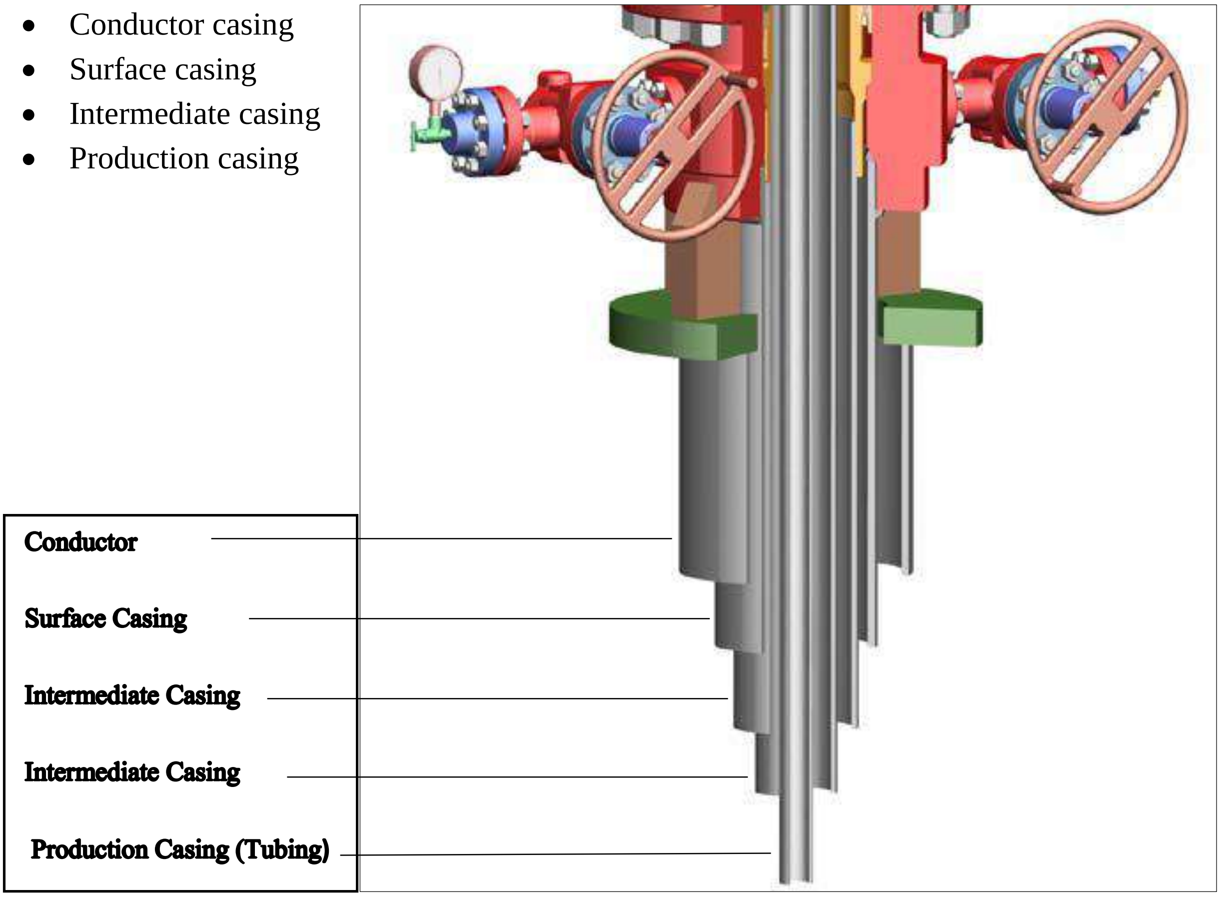
A. Casing

A casing is composed of steel tubes screwed together. The thickness of these tubes varies depending on the type of steel used and the maximum pressure to which they are exposed. Each casing grade corresponds to specific characteristics regarding its mechanical strength.

When drilling a section of the well is completed, these tubes are lowered into the hole and then cemented to the rock wall. After the first casing is in place, drilling will continue with a tool whose diameter is smaller than the inner diameter of the previously installed casing. Thus, drilling is a telescopic operation since each casing installed reduces the diameter of the hole that can be drilled later.

Successive casings protect the well from collapses and isolate the rock formations from each other, thereby preventing fluids from porous zones from communicating with each other or rising to the surface. Thus, it is generally necessary to install more than one sequence of casing due to the different functions specific to each type of casing, which are as follows **(FigureI.7)**:

- Conductor casing
- Surface casing
- Intermediate casing
- Production casing



FigureI.7: Type of casing [6]

B. Cementing of Casings

Cementing involves filling the space between the outer casing wall and the rock wall, known as the "annular space." To achieve this, cement is injected under pressure into the casing until the bottom of the section to be cased. The cement then rises through the annular space to the surface. To prevent cement from returning inside the casing, a mechanical plug is installed at the base of the cemented casing section. The return of cement to the surface through the annular space confirms that it is properly filled. Operations are then suspended for 24 to 48 hours to allow the cement to harden. [7]

1.1.2. Surface Equipment

A. Wellhead

Wellhead refers to all permanent equipment between the uppermost portion of the surface casing and the tubing head adapter connection.

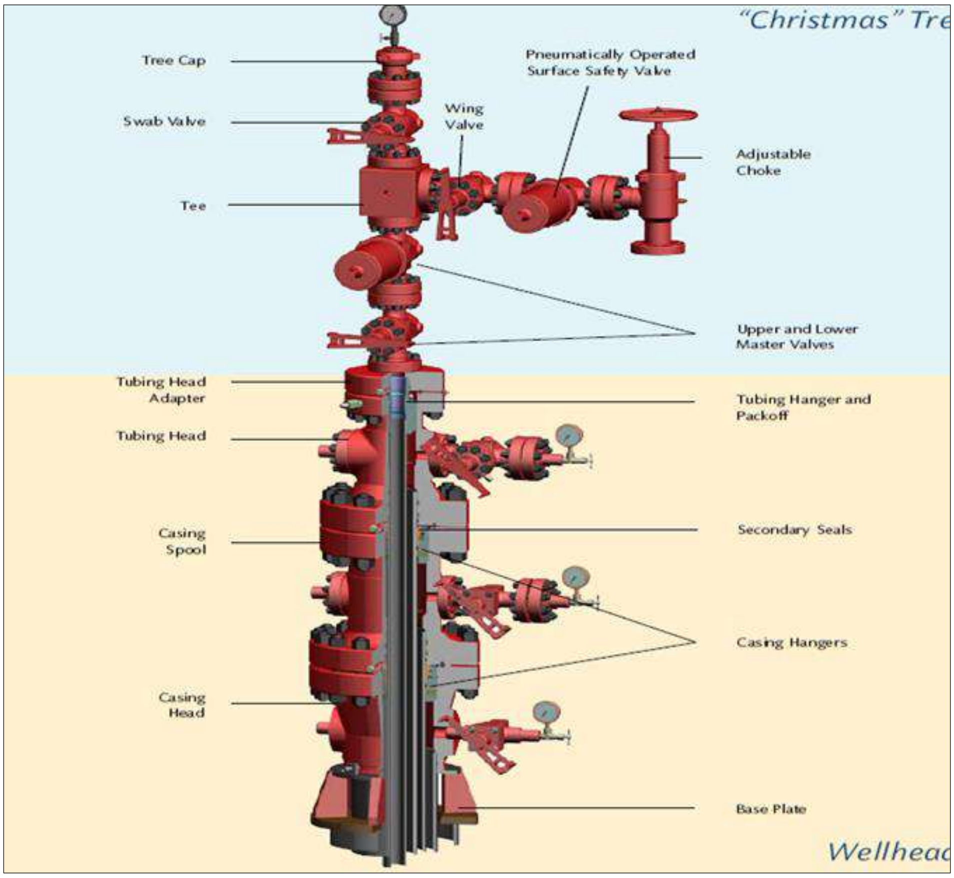
This equipment is one of the most important components of the well in terms of safety. The wellhead concerns the equipment used during drilling. Thus, the wellhead consists of three main parts:

- Casing head (casing spool)
- Tubing head
- Production head (Christmas tree)

We also remind that the wellhead is used as a means to:

- Support the weight of all casing and production tubing strings
- Ensure the sealing of the suspensions of the tubing strings
- Support the production head (Christmas tree)
- Isolate the annular spaces from the inside tubing
- Provide access for pressure control in the annular space and inside the tubing

The equipment of a well used to control the flow of the effluent is called a "Christmas Tree" (Xmas Tree). It is located above the wellhead and consists of: Lower master valve, Upper master valve, Choke valve, Side wing valve, and kill valve.



FigureI.8: Surface Wellhead and X-mas"Christmas Tree» tree [6]

As a reminder, the different types of wells are:

Producing wells: They transport the effluent from the bottom to the surface.

Injection wells: They transport the effluent from the surface to the bottom.

Observation wells: They allow for the monitoring of certain reservoir parameters.

2. Well Barriers; definitions, classification, and requirements

2.1. Well barriers

Well barriers are used to prevent leakages and reduce the risk associated with drilling, production and intervention activities.

The main objectives of a well barrier are to:

- Prevent any major hydrocarbon leakage from the well to the external environment during normal production or well operations.
- Shut in the well on direct command during an emergency shutdown situation and thereby prevent hydrocarbons from flowing from the well.

A well barrier has one or more well barrier elements. The well barriers shall be defined prior to commencement of an activity or operation by identifying the required well barrier elements (WBE) to be in place, their specific acceptance criteria and monitoring method.

In general, there are four main ways in which hydrocarbons can leak from the system to the environment:

1. Through the downhole completion tubing string.
2. Through the downhole completion annulus.
3. Through the cement between the annuli.
4. Outside and around the well casing system.

2.2. Well Barrier Requirements

The performance of a well barrier may be characterized by its:

1. Functionality; what the barrier is expected to do and within what time
2. Reliability (or availability); the ability, in terms of probability, to perform the required functions under the stated operating conditions and within a specified time.
3. Survivability; the ability of the barrier to withstand the stress under specified demand situations.

As well to satisfy the requirement below:

1. At least two independent and tested barriers shall, as a rule, be available in order to prevent an unintentional flow from the well during drilling and well activities.
2. The barriers shall be designed so as to enable rapid re-establishment of a lost barrier.

3. In the event of a barrier failure, immediate measures shall be taken in order to maintain an adequate safety level until at least two independent barriers have been restored. No activities for any other purposes than re-establishing two barriers shall be carried out in the well.
4. The barriers shall be defined and criteria for (what is defined as a) failure shall be determined.
5. The position/status of the barriers shall be known at all times.
6. It shall be possible to test well barriers. Testing methods and intervals shall be determined. To the extent possible, the barriers shall be tested in the direction of flow. [8]

2.3. Well Types and Well Life Cycle

There are basically two types of wells:

- Exploration well: The main purpose of an exploration well is to find potential reservoirs for future development and production. These wells are normally plugged after logging / testing.
- Production / injection wells: After drilling, these wells are completed for production and / or injection. Water or gas is normally injected into the reservoir to maintain pressure. After the production phase has ended, plugging and abandonment of the well takes place.

2.4. Barriers Types

1. Technical barriers

Equipment and system involved in creating a barrier.

2. Organizational barrier

Staff with defined roles or functions and specific skills involved in the construction and maintenance of a barrier.

3. Operational barrier

The actions or activities that personnel must carry out to achieve and maintain a barrier in order to manage the risks incurred at all times, through a systematic and continuous process, this is achieved by putting in place barriers which contribute to the reduction of risks in the failure situation, and danger and accident.

2.5. Barrier design, construction and qualification of barriers for life cycle

A general and important principle for all barrier elements is that they are to be designed to withstand all the possible loads they can be exerted to during the well lifecycle. For the different load cases minimum design factors or other equivalent acceptance criteria are to be pre-defined for:

- Burst loads
- Collapse loads
- Axial loads
- Tri-axial loads

2.6. Technical option for well barriers elements

A. Fail-safe functions:

For a well in operation, some barrier elements need to be in an open position to be able to produce the well. This is typically the DHSV, PMV and PWV. It is therefore critical that these valves automatically close in situations when power or hydraulic supply is lost, or if a fire should occur. It is a general requirement that these valves are to be fail-safe, meaning that the valve is designed to move to the safe position when such a failure occurs. [8]

B. Safety systems

Safety systems are needed both to ensure operational limits are not exceeded, and to ensure that the well is closed in potentially dangerous situations.

It is critical to have safety systems to ensure that the well is closed in when emergency situations occur on the installation. Also, safety systems closing the well in when the pressure in the well becomes too low are to be implemented, as such low pressure would indicate a leak. [8]

C. Fire resistance

It is crucial that the well barrier envelope is fire resistant in case a fire occurs in the wellhead area. Therefore, all the barrier valves shall automatically move to safe position ensuring fire resistance in such cases. In addition, all XT and wellhead seals that are part of the barrier envelope shall be fire resistant.

Any lack of fire resistance will increase the risk of a fire, as the risk of putting the whole well on fire will become evident. [8]

3. Well barrier schematics

A well barrier schematic (WBS) is a static illustration of the well and its main barrier elements, where all the primary and secondary well barrier elements are marked with different colors. A well barrier schematic (WBS) are developed as a practical method to demonstrate and illustrate the presence, or non-presence of the required primary and secondary well barriers.

Well barrier schematics (WBS) shall be prepared for each well activity and operation **(see figure I.9):**

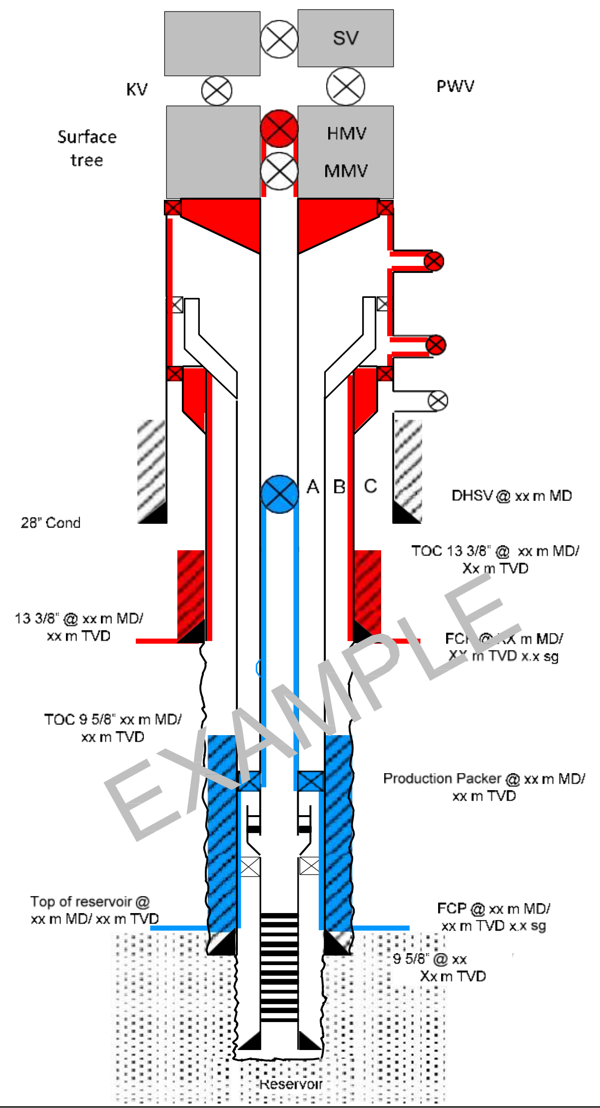
- When a new well component is acting as a WBE;
- For illustration of the completed well with XT (planned and as built);
- For recompletion or work over on wells with deficient WBEs; and
- For final status of permanently abandoned wells.

The WBS should contain the following information:

1. Drawing illustrating the well barriers, with the primary well barrier shown with blue color and secondary well barrier shown with red color.
2. The formation integrity when the formation is part of a well barrier.
3. Reservoirs/potential sources of inflow.
4. Tabulated listing of WBEs with initial verification and monitoring requirements.

5. All casings and cement (including TOC) defined, as WBEs should be labelled with its size and depth (TVD and MD).
6. Component should be shown relatively correct position in relation to each other.
7. Well information: field/installation, well name, well type, well status, well/section design pressure, revision number and date, “Prepared by”, “Verified/Approved by”.
8. Clear labelling of actual well barrier status – planned or as built.
9. Any failed or impaired WBE to be clearly stated.
10. A note field for important well integrity information (anomalies, exemptions, etc.) [9]

Well information (as built)	
Field/Installation:	
Well name:	
Well type:	Producer
Well status:	Shut-in
Well design pressure:	xx bar
Revision number:	Version 1.0
Date prepared/revised:	
Prepared by: Verified/Approved by:	



Note 1: Well shut-in due to tubing leak above DHSV.

Nomenclature:

PT: Pressure test IT:
Inflow test

FCP: fracture closure pressure
XLOT: extended leak off test AC:
acceptance criteria

Well barrier elements	EAC Table	Verification Monitoring	
Primary well barrier			
In-situ formation (cap rock)	51	FCP: x.x s.g. Based on field model	N/A after initial verification
Casing cement (9 5/8")	22	Length: xx mMD Cement bond logs	Daily pressure monitoring of B-annulus
Casing (9 5/8")	2	PT: xx bar with x s.g. EMW	n/a after initial verification
Production packer	7	PT: xx bar with x s.g. EMW	Continuous pressure monitoring of A-annulus
Completion string	25	PT: xx bar with x s.g. EMW	Continuous pressure monitoring of A-annulus See Note 1.
Completion string component (Chemical Injection valve)	29	PT: xx bar with x s.g. EMW	Periodic leak testing AC DHSV: xx bar/xx min
Downhole safety valve (incl. control line)	8	IT: xx bar (DHSV) PT: xx bar (control line)	Periodic leak testing AC DHSV: xx bar/xx min
Secondary well barrier			
In-situ formation (13 3/8" shoe)	51	FCP: x.x s.g. Based on XLOT	n/a after initial verification
Casing cement (13 3/8")	22	Length: xx mMD Method: Volume control	Daily pressure monitoring of C-annulus
Casing (13 3/8")	2	PT: xx bar with x s.g. EMW	Daily pressure monitoring of C-annulus
Wellhead (Casing hanger with seal assembly)	5	PT: xx bar	Daily pressure monitoring of C-annulus/ Periodic leak Testing
Wellhead / annulus access valves	12	PT: xx bar	Periodic leak testing of valve AC: xx bar/xx min.
Tubing hanger (body seals and neck seal)	10	PT: xx bar	Periodic leak testing
Wellhead (WH/XT Connector)	5	PT: xx bar	Periodic leak testing
Surface tree	33	PT: xx bar	Periodic leak testing of valves AC: xx ba

Figure I.9: Example WBS for Platform production/injection/observation well capable of flowing [10]

In addition, primary and secondary well barriers can be illustrated using the Swiss cheese model, as it was performed for Macondo field accident in Figure I.10.

As shown in the figure below, some other blocks that represent defensive physical (e.g. BOP) or operational barriers (e.g. well monitoring) that mitigate hazards could be added in the Swiss cheese model.

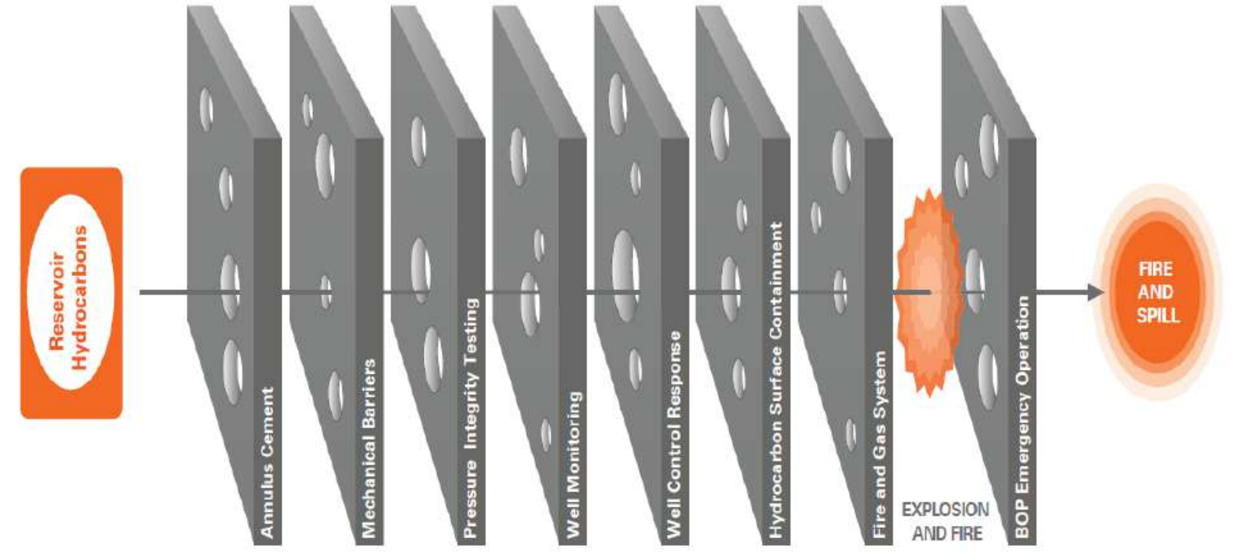
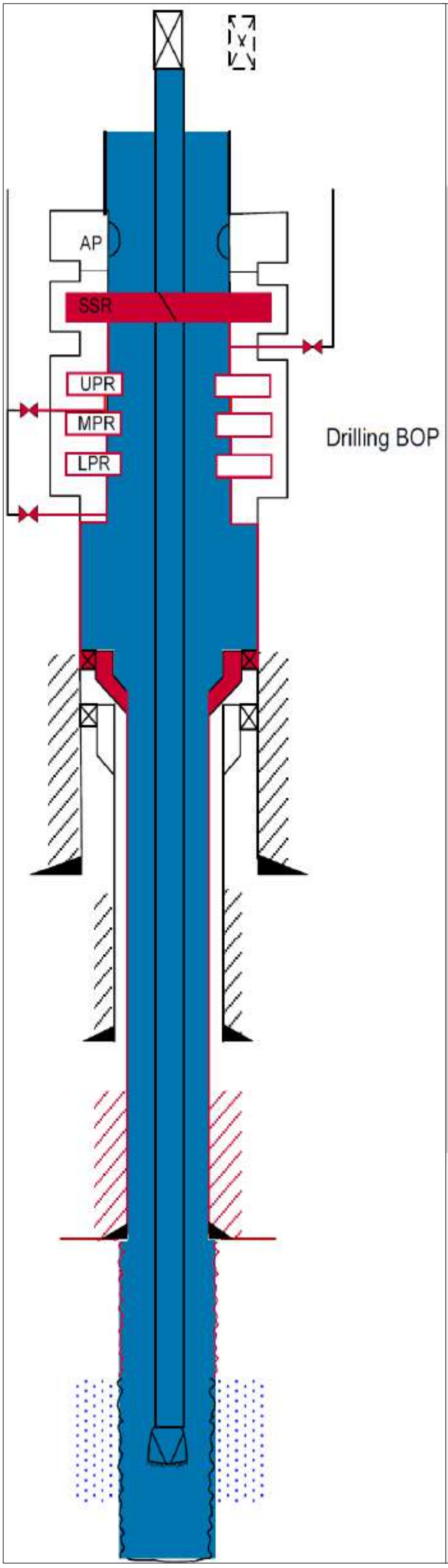


Figure I.10: Swiss cheese model - barriers breached in Macondo field [8]

During the drilling phase, well integrity is mainly associated with keeping the formation under control and ensuring that the casing used is suited for the well, so that the forces exerted on the casing string do not compromise its integrity.

The following well barrier schematic shows the typical setup for the drilling phase, where the primary barrier is the fluid column in the well. The secondary barrier is the last set and cemented casing, along with the BOP, casing hanger and wellhead. All barrier elements, fluid column, production casing etc., found in the primary or the secondary barrier have a demand for verification. This verification can be found in the rightmost column and it is typically a test that needs to be done on the installed element, for instance a pressure test of the BOP. Other verifications can be to monitor the status of the well barrier, i.e. the mud weight during drilling.

One important thing in the WBS is the part describing any well integrity issues with the well. Here limitations can be written about for instance production rate, annulus pressure build up etc. These limitations/issues will be important for those who will operate the well on a daily basis. Restrictions such as these are becoming more and more important over the lifetime of the well since equipment deteriorates and is more sensitive to high loads. The restrictions put on the well will vary from well to well and for what purpose it was designed for originally.



Well data			
Installation/Field:		xxxxx	
Well no:	xx/xx-xx	Drilling start date:	DD.MM.YYYY
Well type:		e.g. oil producer	
MSDP:		xxx bar	
Revision no:	x	Date:	DD.MM.YYYY
Well status:		Drilling.	
Prepared:		xxxxx (Name and signature)	
Verified:		xxxxx (Name and signature)	

Well barrier elements	Ref. WBEAC tables	Verification of barrier elements
PRIMARY - reservoir		
Well fluid	52	Flow checks/ stable fluid level
SECONDARY - reservoir		
Formation at casing shoe	51	FIT to x.xx sg EMW.
Production casing cement	22	Length: xx mMD > casing shoe Method: volume control/logs and FIT/LOT to x.xx sg EMW at casing shoe
Production casing	2	PT: xxx bar with x.x sg
Production casing hanger with seal assembly	5	PT: xxx bar with x.x sg
WH	5	PT: xxx bar with x.x sg
High pressure riser	26	PT: xxx bar with x.x sg
BOP	4	PT: xxx bar with x.x sg

Notes:

Disp. no. well integrity issues	Comment
None	

Figure I.11: WBS for the drilling phase [10]

4. Acceptance criteria for well barrier elements

To accept an element as a barrier, this element must meet certain criteria and conditions.

Among the well barriers we have: drilling mud, casing, drill string, drilling BOP, wellhead, production packer, down hole safety valve, safety valve, olive, annular valve, coiled tubing, coiled tubing bop, casing cement, cement plug, completion packing, well test packing, snubbing packing, Christmas tree, test packer, and other elements, we take an example to cite the criteria acceptance in the NORSOK 10 standard, for example casing. [9]

Table I.1: Example of Casing Acceptance criteria [11]

Features	Acceptance criteria	See
A. Description	This element consists of casing/liner and/or tubing in case tubing is used for through tubing drilling and completion operations.	
B. Function	The purpose of casing/liner is to provide an isolation that stops uncontrolled flow of formation fluid or injected fluid between the casing bore and the casing annulus.	
C. Design construction selection	1. Casing/liner strings, including connections shall be designed to withstand all loads and stresses expected during the lifetime of the well (including all planned operations and potential well control situations). Any effects of degradations shall be included. 2. Minimum acceptable design factors shall be calculated for each load type. Estimated effects of temperature, corrosion and wear shall be included in the design factors. 3. All load cases shall be defined and documented with regards to burst, collapse and tension/compression. 4. Casing design can be based on deterministic or probabilistic models. 5. Casing exposed to hydrocarbon flow potential shall have gas-tight threads. Exception: Surface casing which is exposed or can be potentially exposed to normal gradient shallow gas.	ISO 11960 ISO 13679 ISO 10405
D. Initial test and verification	1. Casing/liner shall be leak tested to maximum differential pressure. 2. Casing/liner that has been drilled through after initial leak test shall be retested during completion activities. 3. The leak test of casing shall be performed either when cement is wet (immediately after pumping) or after cement has set up. No pressure testing should be performed while the cement is setting up.	

E. Use	Casing/liner should be stored and handled properly to prevent damage to pipe body and connections prior to installation.	
F. Monitoring	1. The A-annulus shall be continuously monitored for pressure anomalies. Other accessible annuli shall be monitored at regular intervals. 2. All casing strings shall be logged for wear after drilling if simulation indicates excessive wear which exceeds allowable wear based on casing design. Metal shavings should be collected by the use of ditch magnets.	
G. Common well barrier	1. During drilling operations with surface BOP, the annulus outside the current casing shall be monitored continuously and alarm levels be defined. 2. Actual status of the casing shall be known and confirmed capable of withstanding maximum expected pressure after expected wear. 3. Pressure test should include safety margin to cover expected wear after testing. 4. Magnet shall be in the mud return flow line to measure metal and assess changes in the nature of the metal filings. 5.If drilling through an old casing: **A)** Prior to drilling activity commences, casing wear log(s) should be run (caliper and/or sonic). The logs shall be verified by qualified personnel and documented. **B)** Logs that can identify localized (1 m interval between measurements) doglegs (gyro or similar) should be run.	

5. Testing, Verification, and Monitoring of Well Barrier Elements

The well operator must define control and monitoring requirements to ensure that the wells are operated within their envelope. The well operator must determine the frequency of control and monitoring based on the risk and consequence of breaching barrier envelopes and the ability to respond. Monitoring involves observing the operating parameters of a well, using instrumentation, at a predefined frequency to ensure they remain within operating limits (e.g., pressures, temperatures, flow rates). The well control and monitoring program should consider, at a minimum, the following key elements:

- Well status: injection, production, closure, suspension, abandonment.
- Operating limits.
- Corrosion.
- Erosion.

- **Maximum well design pressure MWDP**

In addition to verifying that the well is designed for the load cases, all well barrier elements are to be pressure tested to the maximum pressure that the barrier elements may be exerted to when a well kill operation is ongoing, or during injection (whichever is the highest pressure). **[12]**

6. Diagnostic Methodology

The diagnostic methodology for oil and gas wells involves a comprehensive approach to assess the performance and health of the well. Various methods and tools are employed to gather data and analyze different aspects of well behavior. Here is an overview of the diagnostic methodology for oil and gas wells. **[13]**

- **Well Logging**

Well logging techniques are often the only means to assess the condition of certain barrier elements such as cement, casing, tubing, etc. These logging and monitoring techniques may be part of a predetermined surveillance program or may be initiated in response to an observed event or anomaly.

Well logging can be approached in various ways:

- On an individual well basis, meaning the assessment of a single well's condition.
- On a field-wide basis, where sampled wells are evaluated and the results projected across the entire field.

Well logging may include the following types of measurements:

- Corrosion caliper.
- Acoustic.
- Sonic and ultrasonic.
- Magnetic.
- Temperature.
- Pressure.
- Production logging.
- Video and down hole camera.**[14]**

- **Well Testing**

(Conducting pressure transient analysis helps determine reservoir Properties AND Buildup and drawdown tests are performed to assess well deliverability and identify potential issues).

- **Fluid Sampling and Analysis**

Collecting fluid samples from the well provides valuable information about reservoir fluids, including composition, phase behavior, and potential contaminants.

- **Wellhead Monitoring**

Continuous monitoring of wellhead parameters such as pressure, temperature, and flow rate can provide real-time data on well performance.

- **Wellbore Integrity Assessment**

Cement bond logs and other wellbore integrity tools are used to evaluate the condition of the well casing and cement job to identify potential leaks or failures**.**

- **Down hole Camera Surveys**

Deploying downhole cameras allows visual inspection of the wellbore to identify issues such as scale buildup, corrosion, or mechanical damage. **[15]**

7. Well Examination after Drilling

After drilling an oil and gas well, some examination should be conducted to assess the well's integrity, gather crucial information, as well to ensure that it meets safety and regulatory standards Sache as :

- **Casing and Cement Evaluation**

Verify the integrity of the casing and cementing job to ensure there are no leaks or integrity issues. Tools such as cement bond logs may be used for this purpose.

- **Wellhead Inspection**

Inspect the wellhead for any signs of damage or leaks. Ensure that all components, including valves and seals, are in proper working condition.

- **Pressure Testing**

Conduct pressure tests to evaluate the integrity of the wellbore and surface equipment. This involves pressurizing the well and checking for any pressure drops, which could indicate leaks.

- **Fluid Sampling and Analysis**

Collect samples of formation fluids to analyze the composition and properties. This information is crucial for reservoir characterization and production planning.

- **Perforation and Completion Verification**

Confirm that the well has been properly perforated and completed according to the design. Ensure that completion equipment, such as screens and liners, are in place and functioning correctly.

- **Well Logging**

Perform well logging to gather data on the geological formations penetrated by the well. This includes logging tools that measure resistivity, porosity, and other formation properties.

- **Well Testing**

Conduct initial well tests to assess reservoir productivity and characteristics. This involves measuring pressure, flow rates, and other parameters to understand the well's potential.

- **Formation Integrity Testing (FIT)**

Perform FIT to assess the integrity of the formations and identify any potential issues, such as lost circulation zones or unstable formations.

- **Fluid Loss Testing**

Determine the fluid loss characteristics of the well to optimize drilling fluid properties and prevent formation damage.

- **Wellbore Stability Analysis**

Assess the stability of the wellbore to ensure that it can withstand the downhole conditions without collapsing or causing other issues AND Environmental and Safety Compliance Check AND Ensure that the well complies with environmental regulations and safety standards. This includes assessing the well site for any potential. [14]

8. Causes of Integrity Loss and Failure

Accidental hydrocarbon releases and their consequences represent one of the major risks in the oil industry, which its causes may include:

- **Misused Mud circulation for conditioning, hole cleaning.**
- **Stuck pipe:**
- **Differential pressure sticking:**
  - The pressure difference between the well and the formation (differential pressure).
  - The presence of a porous and permeable formation.
  - The presence of cake on the formation walls.

- **Mechanical sticking related to:**
  - Drilling equipment, ongoing operations, and personnel.
  - Formations encountered.
  - Object falls.
  - Cementing: ensuring its integrity against constraints, pressure, and temperature throughout the well's lifespan, from construction to permanent closure, is crucial. Oil companies have developed a pioneering approach to assess cement sheath integrity and simulate its mechanical behavior to ensure safety in all types of operations.
  - Casing (collapse, buckling).
  - Hole diameter smaller than the tool.
  - Formation instability (creep, collapse).
  - Well tortuosity.
  - Casing rigidity.

- **Equipment failure:**
  - Drill string, tool, and cable (logging, wire line).
  - Casing, completion.
  - Difficult drilling conditions (highly deviated drilling, etc.).
  - Equipment used beyond its limit.
  - Failure to adhere to industry standards.
  - Poorly maintained or damaged equipment.

Figure I.12: Hole in the production tubing

- **Aging**

The Petroleum Safety Authority Norway (PSA) initiated a pilot study in 2006, which has resulted in a continuous activity in well integrity. The pilot study was based on supervisory audits and input from seven operating companies, including 12 offshore facilities and 406 wells and presents a snapshot of the well integrity status of the selected wells at the time. The results indicated that 18 % of the wells in the survey had integrity failures, issues or uncertainties and 7 % of these were shut in because of well integrity issues. A later study indicated that each fifth production well and each third injection well may suffer from well integrity issues. An interesting observation was that old wells had few well integrity issues, actually most problems occurred in the age group 5-14 years. These conclusions are not general but are limited to the studies referred to. **[8]**

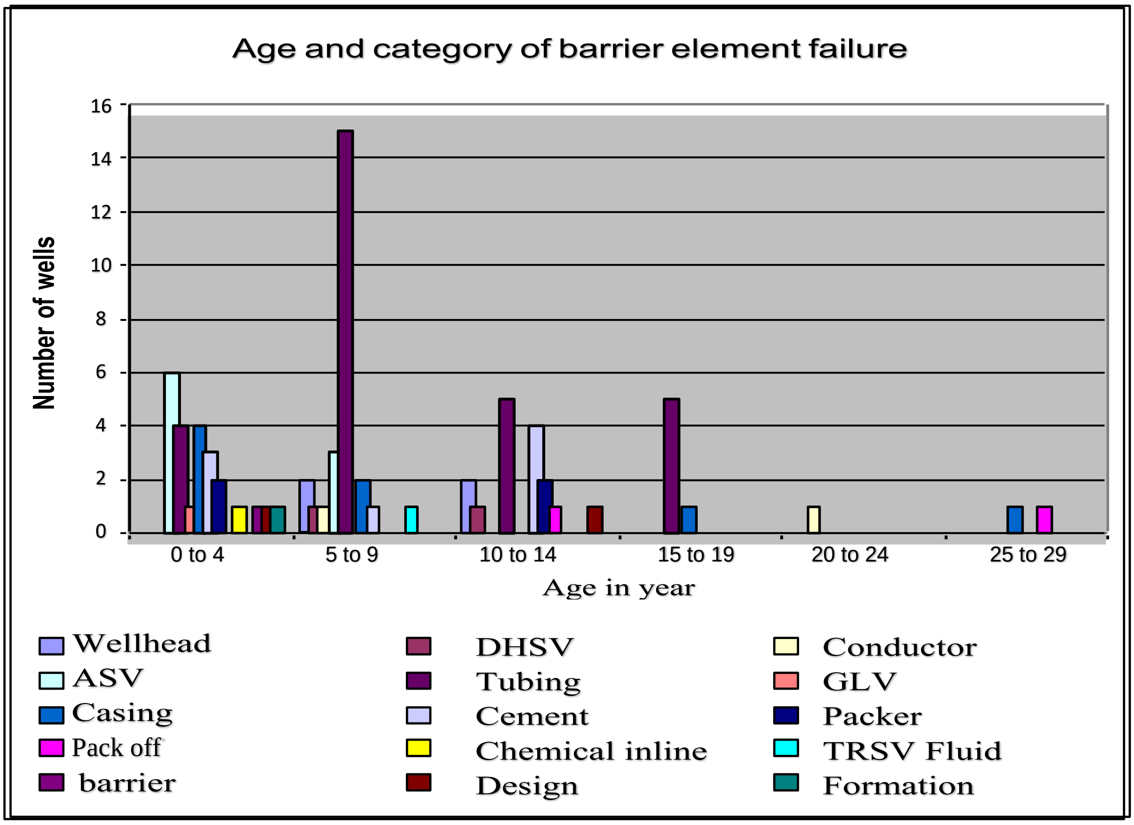


Figure I.13: Example of failure statistics with age [16]

9. Revamping of Well Barrier Elements

After describing the problems encountered during the life cycle of oil and gas wells, it is necessary to have a modernization plan in place to anticipate any integrity failure. Thus, these means of modernizing wells are grouped into two parts:

Group 1: Preventive revamping of Well Barrier Elements

- Snubbing
- Wire line
- Coiled tubing

Group 2: Corrective revamping of Well Barrier Elements

- Work over

9.1. Preventive revamping

These types of interventions require the use of a lightweight unit such as wire line, coiled tubing, or snubbing and do not require the well to be shut down.

A. Coiled Tubing

Coiled tubing is a steel tube wound on a large-diameter reel. It is continuously uncoiled and run into the well. In addition to saving time, the absence of connections minimizes the risk of leakage.

The coiled tubing unit consists of a continuous metal tube with a diameter of approximately ¾" to ½" (about 19 to 38 mm) wound on a coil or drum and can be raised or lowered into a pressurized well. The tube is maneuvered by an injector through a sealing system (BOP). Its implementation requires a specialized team of at least three people.

- **A.1. Scope of Application**
    - ➢ Drilling and milling with hydraulic motors
    - ➢ Fluid circulation (neutralization)
    - ➢ Tubing cleaning (salt, paraffin, hydrates, etc.)
    - ➢ Cementing
    - ➢ Starting or Restarting the Well
    - ➢ Well cleaning (sand deposits, etc.)
    - ➢ Selective acidification or global
    - ➢ Logging
    - ➢ Tool fishing
    - ➢ Perforation
    - ➢ Hydraulic fracturing
- **A.2. Advantages and Disadvantages**

Advantages:

- Used on pressurized wells
- High maneuvering speed
- Easy to move
- Reduced assembly and disassembly time
- Cost savings (the well is not shut down)
- Reduced environmental impact
- The operation can be executed by three people
- Logging can be performed on horizontal wells (reducing wire line limitations)

Disadvantages:

- Low tensile strength
- Delicate maintenance
- Pressure: Working under pressure quickly degrades the mechanical properties of the tube
- Fatigue: Stored on a reel
- Friction **[17]**

B. Snubbing

Snubbing operations is a technique for deployment of tools and equipment by use of jointed pipe and as a conduit for circulating or placing fluids in the well. Snubbing string can be deployed in pressurized wells or in dead wells. In snubbing operations, the number of BOPs used can be very large, as in the case of high-pressure wells with mixed tubing strings where it is preferable to have replacement rams for each tube diameter run into the well.

In the case of snubbing operations in a well neutralized by isolating the producing layer or by a fluid in the well with a density higher than the equilibrium density, the number of BOPs can be reduced.

Hydraulic work over is normally performed at sites where it will be difficult to rig up a mast for technical or economic reasons.

The stacking of BOPs in this type of intervention will be as follows:

- Blind shear rams at the bottom

- Pipe rams in the middle

- Annular rams at the top

- **B.1.Scope of Application**
  - Installation and retrieval of completions
  - Fishing operations
  - Circulation and cleaning of deposits and sediments inside the wellbore
  - Acidification and cleaning of perforations
  - Milling operations
  - Abandoning oil or gas wells

- **B.2. Advantages and Disadvantages**

Advantages:

- Rapid assembly and disassembly
- Ease of transfer
- Reduced risk of formation damage by the control fluid
- High lifting capacity compared to coiled tubing
- Replaces coiled tubing when the torque applied to the bottom tool exceeds the maximum torque provided by the turbine or down hole motor
- Replaces coiled tubing when the working pressure may exceed the burst limit
- Replaces the work over rig in cases where rigging up a mast is not possible
- Perforation without the presence of a drilling rig
- Replaces coiled tubing in work performed on highly deviated or horizontal wells
- Ability to run completion after moving the drilling rig
- Ability to perform interventions on a rig less platform
- Ability to perform drilling operations in a underbalanced condition
- Ability to perform operations with reduced diameter as in the case of lateral drilling

Disadvantages:

- Difficult to use on submersible devices due to the device movements caused by wave action
- Working under pressure increases the error and accident rate
- The maneuvering time is relatively long
- Significant buckling in snubbing operations accelerates fatigue of tubing and rods **[18]**

C. Wire line

Wire line work is a technique that allows intervention on wells using a steel wire line to introduce, lower, place, and retrieve tools and measurement instruments necessary for rational operation into the tubing. Wire line work encompasses operations that involve intervention in a pressurized well. These operations employ various types of tools that must be safely lowered and raised. These tools are maneuvered from the surface through a cable (smooth or braided) connected to a winch. Generally, steel cable called Slick line is used, but some tools lowered into the well use a conductor electrical cable called Wire line.

C.1. Scope of Application

- Control and cleaning of tubing
- Measurement operations (recording of bottom pressure and temperature, sampling, down hole logging)
- Deployment and retrieval of tools (installation and retrieval of gas-lift valve, such as the storm choke valve)

C.2. Advantages and Disadvantages Advantages:

Advantages:

- Ability to intervene in the well without killing it and stopping production
- Rapid execution due to lightweight, highly mobile equipment
- Cost savings due to:
  - Production not stopped or minimally stopped
  - Producing layer not damaged by killing (well not shut in)
  - Simple material and human resources and quick implementation

Disadvantages:

- Work is impossible in the presence of very hard deposits
- Wire line work is not applicable for horizontal wells **[19]**

9.2. Corrective revamping of Well Barrier Elements (Figure I.12)

A. Work over (Well Intervention)

The definitions of the term "Work over" are numerous and not always very clear. However, it is generally agreed to refer to any intervention on a well that has already been drilled, cased, and put into service.

A.1. Scope of Application:

Well intervention can be required in order to carry out the following:

- Production performance monitoring or enhancement;
- Reservoir surveillance;
- Well integrity diagnostic work;
- Repair or replacement of down hole components;
- Repair or replacement of wellhead and tree components;
- Changing production or injection zones;
- Plug back and side track operations;
- Well suspension;
- Final well abandonment

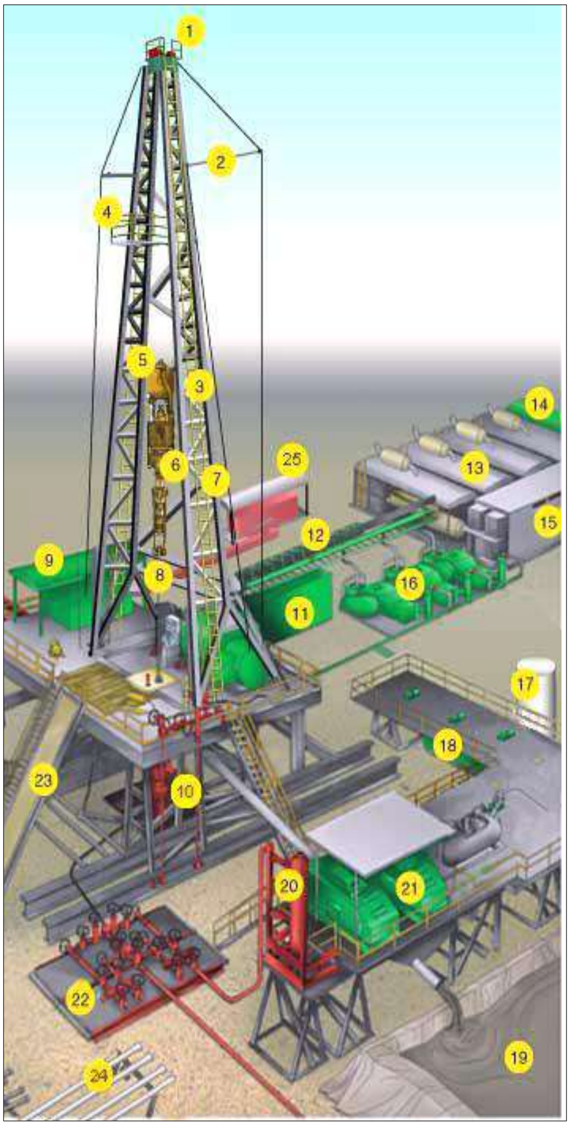


Figure I.14: Work over Rig

A.2. Advantages and Disadvantages

Advantages:

- Completely or partially disassemble the well
- Equip the well with new equipment adapted to its new production characteristics
- Well conversion (from a producer to an injector)
- Optimization of equipment
- Control of water and gas influxes
- Installation or modification of an artificial production system (Gas-lift, pumping)
- During the work over, various operations such as milling, fishing, cutting, and re-forging can be performed

Disadvantages:

- Work over operations require the use of large material and financial resources
- This intervention on the well requires it to be shut in for safety reasons. In oil industry terms, "shutting in a well"
- It can last for weeks or even extend over several months, depending on the problem encountered in the well
- Work over operations are very costly
- The duration of assembly, disassembly, and transportation is very long**[20]**

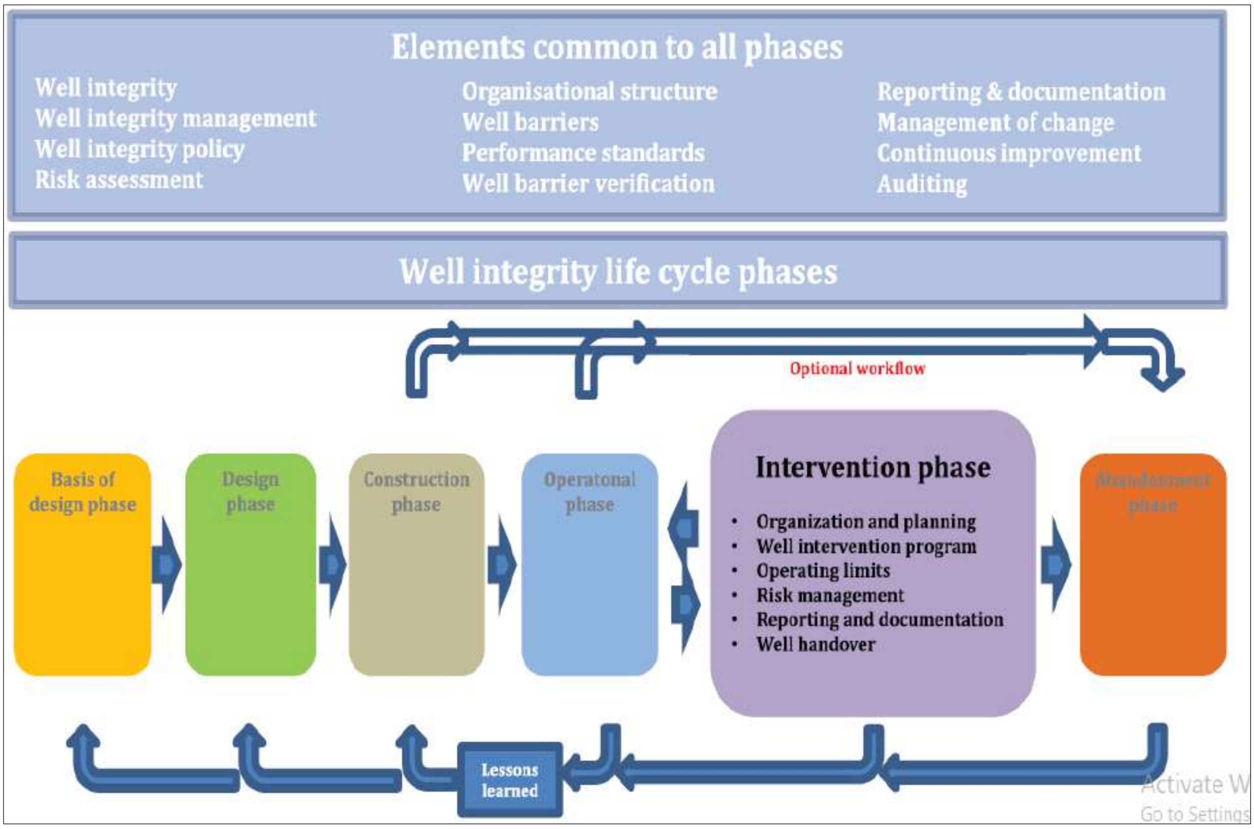


Figure I.15: Well integrity in Intervention phase [20]

10. Regulatory and Normative Part

Algerian Regulation

Regarding the Algerian regulations concerning the modernization of oil and gas wells, the following decrees address the subject**:**

- Executive Decree No. 14-349 of December 8, 2014, setting the conditions for compliance of installations and equipment related to hydrocarbon activities.
- Executive Decree No. 15-09 of January 14, 2015, establishes the procedures for the approval of specific hazard studies in the hydrocarbon sector and their content. One of the instructions given is to adopt and implement procedures and instructions for the management and control of risks associated with the aging of equipment, installations, and structures.

ISO/TS 16530 Standard

The normative part related to the modernization of wells is presented in ISO/TS 16530, specifically Part 2: Well Integrity. The main axes of this standard are:

1. Well Integrity Management System
2. Well integrity policy and strategy
3. Resources, roles, responsibilities, and authority levels
4. Risk assessment aspects in well integrity management
5. Well barriers
6. Well component performance standard.
7. Well operating and component limits
8. Well monitoring and surveillance

9. Annular pressure management
10. Well handover
11. Well maintenance
12. Well integrity failure management
13. Management of change
14. Well records and well integrity reporting
15. Performance monitoring of well integrity management systems

Compliance audits [21]

CHAPTER II: Risk Assessment and Impact Simulation Study

1. Risk Assessment Techniques for Well Integrity

Risk assessment techniques are used to assess the magnitude of well integrity risks, and whether they are potential risks, based on an assessment of possible failure modes, or actual risks, based on an assessment of an anomaly that has been identified. When determining an acceptable level of risk, a methodology called “as low as reasonably practicable” (ALARP) is often applied. Applying the term ALARP means that risk-reducing measures have been implemented until the cost (including time, capital costs or other resources/assets) of further risk reduction is disproportional to the potential risk-reducing effect achieved by implementing any additional measure.

A risk assessment process typically involves:

- Identification of the types of anomalies and failure-related events that are possible for the well(s) that are being assessed;
- Determination of the potential consequences of each type of well failure-related event; the consequences can affect health, safety, the environment, cause business interruption, societal disruption or a combination of these;
- Determination of the likelihood of occurrence of the event;
- Determination of the magnitude of the risk of each type of well failure-related event based, on the combined effect of consequence and likelihood.

1.1. Well Ranking

All wells must be subject of a risk assessment through risk screening process to determine the threat posed by the failure, an appropriate course of action to restore well integrity and prioritization order for intervention, repair or work over. The risk assessment must consider the following factors but not limited to:

- Well type, pressures and effluent
- Well structural failure, cement degradation
- Fluid corrosively and/or presence of H2S
- Tubing / casing corrosion condition
- Annuli communication with reservoir

1.2. Wells Risk Ranking

- Well Risk Ranking is a process which enables us to identify the risk based on the probability of hazards occurrence and associated severity. Potential hazards should be identified and analyzed to define the possible effects on people, asset and environment.
- Risk ranking process should be carried out according to **WELLS Risk Rank Matrix** and should define the prevention and / or mitigation measures for risk reduction.
- As per **WELLS Risk Rank Matrix**, the risk rank can be classified into three categories, i.e. Risk Rank-1, 2 and 3.

Safe well: A well is considered safe when there are at least two independent integral confinement barriers on each potential leak path of hydrocarbon. (Refer to ISO standards).

Unsafe Well: A well is considered unsafe when there are less than two independent integral confinement barriers on each potential flow leak path.

1.2.1. High Risk (Risk Rank-1) Well:

a. A well is defined as high risk well if one of the following conditions occurs:

a.1 If there is a hydrocarbon surface leak.

a.2 If sustained annulus pressure exceeds MAASP value.

a.3 If at least one of the barriers in the flow path is damaged permanently and resulting in effluents leak rates more than allowable.

b. Requires immediate mitigation of risk which includes well shut-in & securing/killing as per responsible division recommendations.

c. If the risk cannot be mitigated by shut-in or securing and conditions remain at high risk, further actions like mobilizing the rig/snub-unit to kill/work over should be taken on priority.

d. Dispensation from the management is required if a high risk well needs to be placed in operation. Proper dispensation procedures as per company guidelines should be followed.

e. Well should be operated strictly as per guidelines from dispensation and any deviation desired by any party, should again be referred back to same process.

f. The high risk wells shall be reported mitigated wells after successful temporary mitigation measures.

1.2.2 Medium Risk (Risk Rank-2) Well:

a. A well is defined as medium risk well if one of the following conditions occurs:

a.1 If the barrier(s) is (are) partly damaged but the effluents leak rates are within the allowable.

a.2 If the risk of the particular integrity situation is manageable and at ALARP level.

a.3 If the original design components have failed and overcome by temporary solution (A3 valve, sealants, etc.)

b. It requires frequent monitoring and maintenance to prevent the risk status of the well to convert to high risk.

c. All short term actions should be immediately conveyed to concerned personnel by **WIT** and follow up accordingly.

d. If a risk rank-2 well is planned for work over (due to other issues), all well integrity requirements should be included in planning phase.

e. Medium risk wells are considered complying with the COMPANY WI Standard and are online for frequent monitoring and extra precautions.

1.2.3 Low Risk (Risk Rank-3) Well:

a. A well is defined as low risk if all of its barriers are intact and apparently, no integrity problem reported.

b. It should be monitored and maintained as per defined frequency.

c. All monitoring and maintenance should be recorded in standardized sheets.

d. WI Team shall follow up on pending actions.

e. Low risk wells are healthy wells and complying with WI Standards. **[22]**

1.3. The methodology for well categorization

The methodology for categorizing DP/SH wells is based on the failure mode of the technical barriers following the well failure mode mentioned in Article 148 of Decree 94-43 and ISO 19530 standard as well as OL-117 standards, and the presentation of the ARH made during the December 2017 Workshop, taking into consideration the annular pressures, inspection results, verification, and the condition of barrier integrity.

The table below summarizes the well categorization system of the Production Division. **[23]**

Table II.1: Well integrity categories [19]

Category	Principle
Red	**One barrier failure and the other is degraded/not verified, or leak to surface**
Orange	**One barrier failure and the other is intact, or a single failure may lead to leak to surface**
Yellow	**One barrier degraded, the other is intact**
Green	**Healthy well – no or minor issue**

- **Red**: indicates a very high risk and non-compliance. Remediation actions will be necessary before the well can be put into operation.
- **Orange**: indicates a high risk and non-compliance. Urgent remediation actions will be necessary as soon as possible.
- **Yellow:** (with minor integrity issues), may continue to operate with continuous monitoring.
- **Green:** (No integrity issues), may continue to operate with normal monitoring according to the specified frequencies.

1.4. X-Mas Tree Risk Ranking Matrix

a. The integrity of a X-mas tree is very critical as it is the last surface barrier of the well, therefore it should be risk ranked as a single independent barrier.

b. The Xmas tree valves should be integral at all times but valves develop leak with passage of time because of erosion, corrosion and lack of maintenance. Integrity status of each valve is ranked against allowable which are described in terms of rate of pressure build-up/ drop-off for each valve type.

1.5. Risk Register

a. It is a format designed to register the risk ranking of a well. The well is divided into different subsystems and it includes the description of possible hazards, associated risk related to each barrier, short/long term action plans and responsible person for plan execution. The integrity status of each barrier is evaluated and risk ranked in accordance with Xmas tree risk ranking matrix and guidelines.

b. Risk register logs the sequence of integrity reviews of a well which provides historical integrity status.

c. Whenever the integrity of a well is reviewed, a fresh risk register shall be filled, which will replace the old register.

d. The risk register will define the overall integrity status of a particular well. It provides a quick view of the latest risk ranking of the well and it helps to track the recommended actions to restore the integrity of that well.

e. Short/long term actions shall be communicated to the responsible person for execution and followed up by WI Team.

1.6. Short/Long Term Actions Plan

After each risk ranking session, the recommended actions should be defined clearly in terms of well safety, remedial cost and time.

a. Once the well is risk ranked, actions are chalked out for monitoring, maintenance, mitigation and investigation. These actions will help to ensure well integrity compliance to WI Standards and to manage risk status.

b. Short-term items will typically include increased monitoring, data acquisition and additional investigative tasks.

c. Short term actions are required to be taken immediately to finalize the risk status evaluation of a well or to ensure timely maintenance to prevent possible aggravation of risk conditions. It may also include shutting down, securing or suspending the well.

d. Long term actions are usually listed for a condition like work over which includes casing logs, covering of exposed perforations etc. and abandonment of well.

e. Follow up on short term and long term actions should be ensured through routine coordination with site and other divisions by WI Team.

f. When the short term mitigation actions have been carried out, the well will be risk ranked again.

g. It is the responsibility of the WI team to coordinate for the remedial measures for a risk rank-1 well to be mitigated by snub-unit or rig.

1.7. Wells Work-Over Priority for High Risk Wells

a. The risk ranking of Risk Rank-1 well as per WI criteria and Wells Risk Matrix will be finalized in a well review meeting with concerned division.

b. A high risk or Risk Rank-1 well will be considered as Risk Rank-1 well even after securing/killing the well as the securing/killing of the well reduces the associated hazards temporarily but does not mitigate the problem permanently.

c. The risk rank will be reduced to 2 or 3 accordingly after the integrity problem is solved permanently or the well is worked over successfully.

d. Each Risk Rank-1 well due to integrity problem shall be prioritized on the basis of production loss for placing on work-over schedule. The priority is defined as below.

Priority-1:

If a Risk Rank-1 well is secured and results in significantly undesired production loss, the well will be declared Priority-1 requiring work over as soon as possible.

Priority-2:

If the securing of a Risk Rank-1 well is not impacting production significantly, the well will be Priority-2 and will be worked over as per plan.

1.8. Frequency of Wells Risk Ranking

a. The newly drilled and worked over wells shall be risk ranked after putting on-line.

b. The wells which may develop an apparent integrity problem shall be risk ranked on priority.

c. The well shall be reviewed after the apparent integrity problem is mitigated.

d. Each well shall be reviewed and risk ranked every three years in **Normal Conditions**.

Analysis steps

A well barrier analysis should be structured and may include the following steps:

1. Define and become familiar with the system.
2. Identify failure modes and failure causes
3. Construct a reliability model of the well barrier system
4. Perform a qualitative analysis of the fault tree
5. Perform quantitative analysis of the fault tree
6. Report results

FMECA

Failure modes, effects, and criticality analysis (FMECA) is a widely used method for system reliability assessment. The method provides an intuitive and structured approach to failure analysis, and FMECA is therefore adopted in many industry sectors. An FMECA is carried out to answer the following questions:
a. In what ways can system components fail?
b. What are the underlying causes of failures?
c. How can failures be detected?
d. What are the failure effects, on the failed component and on the system as such?
e. How critical are the failure effects, in terms of damage to humans, the environment, or material assets?

An FMECA is easy to conduct and easy to comprehend without any advanced analytical skills. The person conducting the FMECA should have a basic knowledge of the failure concepts and analysis, including the understanding of main terms such as:

- Failure modes
- Failure mechanisms
- Root causes
- Failure classification strategies that are commonly used in the industry
- Modes of operation

The bow tie

The bow-tie schematic is a useful methodology for identifying and documenting hazards, consequences, barriers (number required, prevention and recovery measures), and escalation factors and controls. Identified hazards are mitigated to an acceptable level through imposing barriers. An example of use of the bow-tie method is illustrated in Figure II.1:

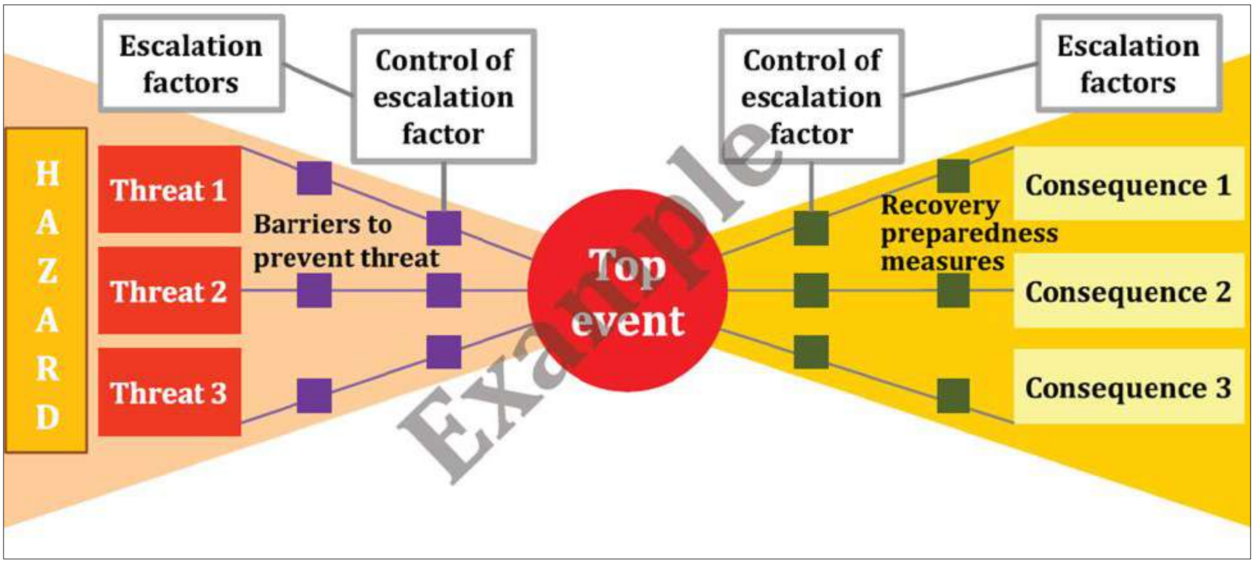


Figure II.1: General example of a bow-tie schematic

2. Presentation of Aloha simulation software

ALOHA, a stand-alone software available for Windows and Macintosh is developed and maintained by the Emergency Response Division (ERD) of the National Oceanic and Atmospheric Administration (NOAA) in collaboration with the Environmental Protection Agency's Office of Emergency Management (EPA). Its primary aim is to aid emergency responders by estimating the spatial extent of hazards resulting from chemical spills. While also suitable for training and contingency planning, its focus remains on spill response. ALOHA specializes in estimating the hazards associated with short-term releases of volatile and flammable chemicals, focusing on human health risks like inhalation of toxic vapors, thermal radiation from chemical fires, and pressure wave effects from vapor-cloud explosions. It employs graphical interfaces to visualize threat zones, areas of potential exposure to toxic vapors or flammable atmospheres, and provides data on transient exposure levels over time. [24]

The threat zone estimates are shown on a grid in ALOHA and they can also be plotted on maps in MARPLOT (Mapping Application for Response, Planning, and Local Operational Tasks), Esri's Arc Map, Google Earth, and Google Maps. The red threat zone represents the worst hazard level, and the orange and yellow threat zones represent areas of decreasing hazard. [25]

2.1. Levels of Concern

ALOHA employs Levels of Concern (LOCs) as threshold values for various hazards such as toxicity, flammability, thermal radiation, or overpressure. These thresholds indicate when a potential threat to people or property may arise. When analyzing a chemical release scenario in ALOHA, users must select one or more LOCs, either from default values provided or by customizing their own. For each chosen LOC, ALOHA estimates a threat zone where the hazard is projected to exceed that threshold at some point following the release. These zones are depicted together on a single threat zone picture.

ALOHA's LOCs model different types of hazards, cover:

- Overpressure LOCs
- Thermal Radiation LOCs
- Flammable LOCs
- Toxic LOCs

2.1.1. Overpressure Levels of Concern

In ALOHA, an Overpressure Level of Concern (LOC) denotes a threshold pressure level from a blast wave, typically indicating the presence of a hazard. ALOHA's default overpressure values are based on recognized sources, including 8.0 psi (destruction of buildings), 3.5 psi (serious injury likely), and 1.0 psi (glass shattering). Overpressure, or blast waves, generated by an explosion, travel at the speed of sound and can cause severe damage to structures and pose health risks. ALOHA estimates threat zones where overpressure exceeds specified LOCs, aiding in assessing potential damage and injury. Users can also input custom LOCs for more tailored analyses.

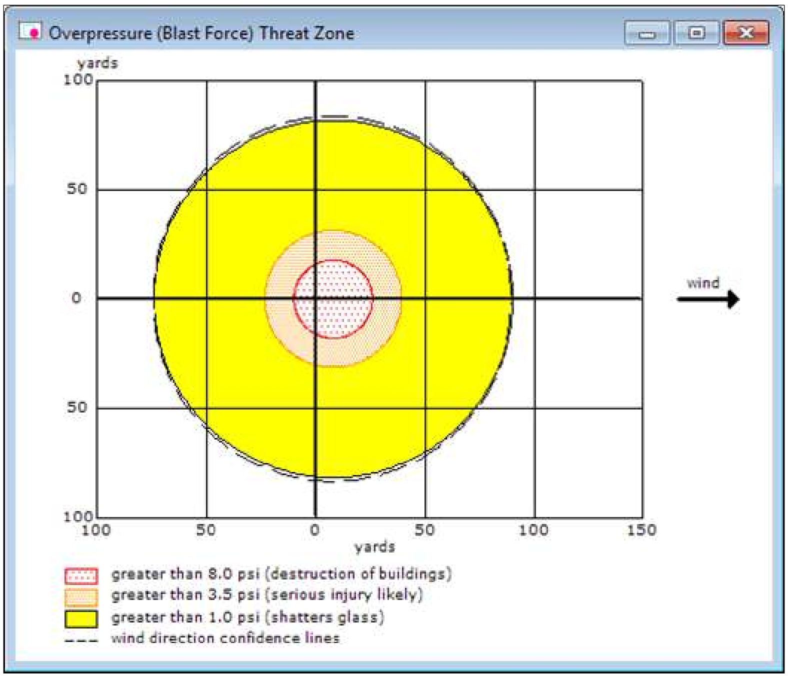


Figure II.2: Overpressure LOCs

Table II.2: Level of damage expected at specific overpressure values [26]

Overpressure* (psig)	Expected Damage
0.04	Loud noise (143 db); sonic boom glass failure.
0.15	Typical pressure for glass failure.
0.40	Limited minor structural damage.
0.50-1.0	Windows usually shattered; some window frame damage.
0.70	Minor damage to house structures.
1.0	Partial demolition of houses; made uninhabitable.
1.0-2.0	Corrugated metal panels fail and buckle. Housing wood panels blown in.
1.0-8.0	Range for slight to serious laceration injuries from flying glass and other missiles.
2.0	Partial collapse of walls and roofs of houses.
2.0-3.0	Non-reinforced concrete or cinder block walls shattered.
2.4-12.2	Range for 1-90% eardrum rupture among exposed populations.
2.5	50% destruction of home brickwork.
3.0	Steel frame buildings distorted and pulled away from foundation.
5.0	Wooden utility poles snapped.
5.0-7.0	Nearly complete destruction of houses.
7.0	Loaded train cars overturned.
9.0	Loaded train box cars demolished.
10.0	Probable total building destruction.
14.5-29.0	Range for 1-99% fatalities among exposed populations due to direct blast effects.
* These are peak pressures formed in excess of normal atmospheric pressure by blast and shock waves.	
Lees, Frank P. 1980. *Loss Prevention in the Process Industries*, Vol. 1. London and Boston: Butterworth's.	

2.1.2. Thermal Radiation Levels of Concern

In ALOHA, a thermal radiation Level of Concern (LOC) signifies the threshold level of thermal radiation (heat) above which a hazard may exist in scenarios involving fire, such as pool fires, jet fires, or BLEVEs (Boiling Liquid Expanding Vapor Explosions). ALOHA uses default thermal radiation values based on recognized sources, including 10 kW/(sq m) (potentially lethal within 60 seconds), 5 kW/(sq m) (causing second-degree burns within 60 seconds), and 2 kW/(sq m) (causing pain within 60 seconds). These values aid in estimating threat zones where thermal radiation exceeds specified LOCs. Users can also input custom thermal radiation values for more tailored analyses.

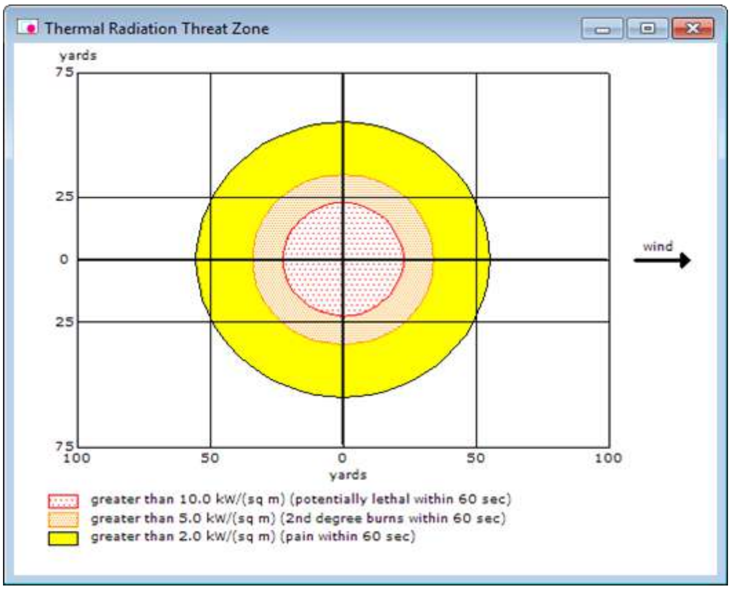


Figure II.3: Thermal Radiation LOCs

Time for physiological effects (on bare skin) to occur following exposure to specific thermal

Table II.3: Radiation levels and its physiological effects [27]

Radiation Intensity (kW/m^2)	**Time for Severe Pain (seconds)**	**Time for 2nd Degree Burns (seconds)**
1	115	663
2	45	187
3	27	92
4	18	57
5	13	40
6	11	30
8	7	20
10	5	14
12	4	11

Federal Emergency Management Agency, U.S. Department of Transportation and U.S. Environmental Protection Agency. 1988. Handbook of Chemical Hazard Analysis Procedures. Washington, D.C Publications Office.

2.1.3 Flammable Levels of Concern

In ALOHA, a flammable Level of Concern (LOC) represents a threshold concentration of fuel in the air where a flammability hazard may exist. ALOHA predicts the flammable area within a vapor cloud, considering concentrations between the Lower and Upper Explosive Limits (LEL and UEL). Default flammable LOCs in ALOHA are fractions of the LEL (60% for the red threat zone and 10% for the yellow threat zone) due to concentration patchiness within dispersing vapor clouds. These values indicate areas where fuel-air concentrations exceed the LOC, potentially leading to flame pockets. Users can also input custom flammable LOCs for tailored analyses.

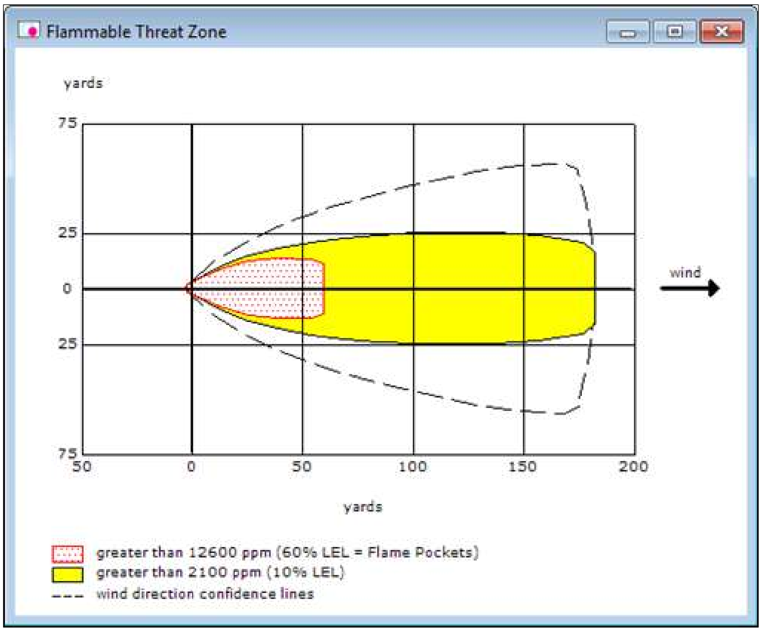


Figure II.4: Flammable LOCs

2.1.4 Toxic Levels of Concern

In ALOHA, toxic Levels of Concern (LOCs) are thresholds indicating the concentration of a chemical that could pose a hazard to human health if inhaled for a defined duration. ALOHA primarily utilizes public exposure guidelines for default toxic LOCs, such as AEGLs, ERPGs, and TEELs, which offer tiers of exposure values designed to assess potential health effects. AEGLs are preferred due to their comprehensive review process and consideration of sensitive individuals, followed by ERPGs, PACs, and IDLH limits. The default toxic LOCs guide the prediction of threat zones, where pollutant concentrations exceed the specified levels, aiding emergency response or planning efforts. Users can override default choices or input custom LOCs for tailored analyses.

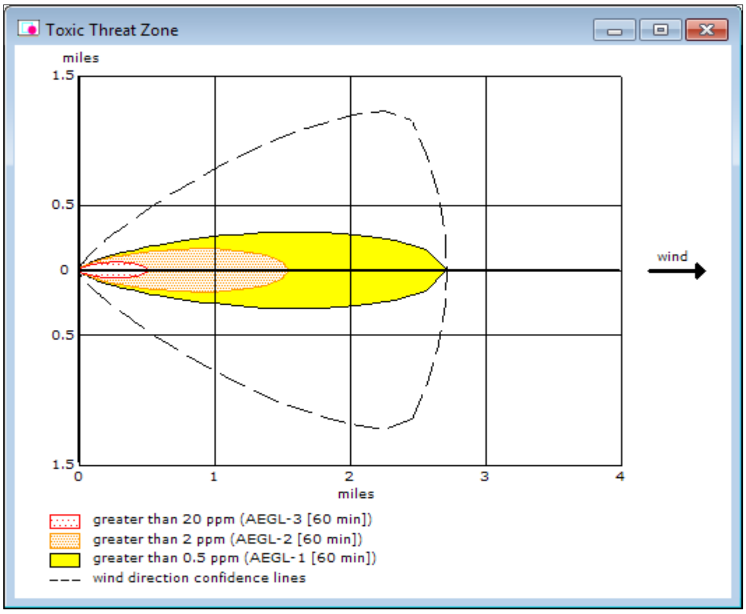


Figure II.5 : Toxic LOCs

3. ALOHA Limitations

The accuracy of ALOHA's results heavily relies on the quality of input data. However, even with precise data, ALOHA may not be reliable in certain situations and cannot model certain types of chemical releases. Here are the conditions under which ALOHA's results are particularly uncertain:

1. **Very low wind speed:** Wind direction becomes less predictable when wind speed is low. ALOHA generally predicts minimal wind direction changes, but this can vary.
2. **Wind direction change:** ALOHA assumes wind speed and direction are constant across the entire chemical release area, which may not hold true in urban areas or around obstacles.
3. **Presence of obstacles and terrain:** ALOHA does not consider site topography or obstacles, assuming the ground is flat and obstacle-free.
4. **Very stable atmospheric conditions:** ALOHA does not account for gas accumulations in low-lying areas, leading to potentially high pollutant concentrations over extended periods.
5. **Presence of gas mixtures:** ALOHA does not model gas mixtures, only handling pure compounds or liquid solutions.
6. **Concentration distribution near the source:** ALOHA provides time-averaged concentrations, but turbulence around the source can lead to variable concentrations.
7. **Presence of fire by-products:** ALOHA ignores combustion by-products or chemical reactions, potentially causing significant differences between predictions and reality.
8. **Presence of hazardous debris:** ALOHA does not model trajectories of hazardous fragments in case of an explosion.
9. **Presence of particles and aerosols:** ALOHA does not account for particle or aerosol dispersion.

10. **Other limitations:** Certain phenomena like jets are not considered, and ALOHA does not provide results within distances less than 100 meters. Additionally, the rise of hot or light gases is not factored, and releases from liquid pipelines are not modeled. ALOHA does not calculate chemical reactivity but describes the types of reactions and expected products. **[1]**

4. Setting up the Scenario in ALOHA

Setting up the scenario is straightforward. Just follow these steps:

- **Accident Location:**

Enter information about the accident location either through existing databases or by providing GPS coordinates.

- **Building:**

Infrastructure refers not to the chemical storage area but to the type of building that could be within the pollutant cloud after the accident. With this option, ALOHA can calculate the infiltration rate of the pollutant into buildings.

- **Selection of Chemical:**

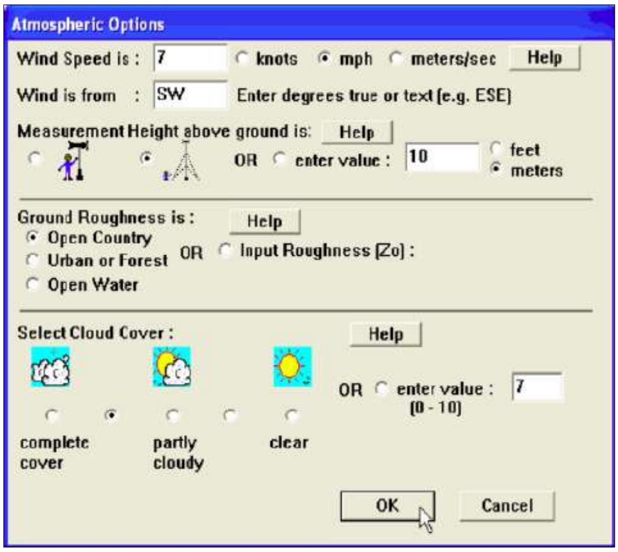
This step allows you to select the desired chemical compound.

- **Description of Atmospheric option:**

In this option, fill in the following fields:

- Wind speed
- Wind direction
- Wind measurement height
- Ground roughness
- Cloud cover
- Air temperature
- Temperature inversion
- Humidity

These characteristics should be filled in the respective application windows.


Atmospheric Options

Wind Speed is : 7 ○ knots ● mph ○ meters/sec

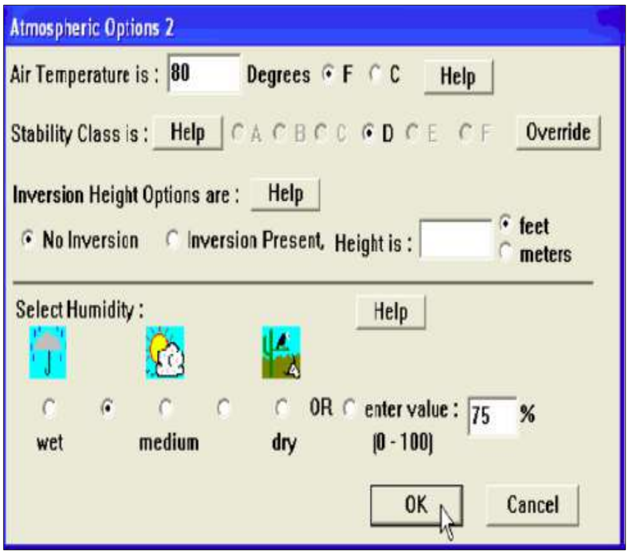
Wind is from : SW Enter degrees true or text (e.g. ESE)

Measurement Height above ground is: ○ ● OR ○ enter value : 10 ○ feet ● meters

Ground Roughness is : ● Open Country ○ Urban or Forest ○ Open Water OR ○ Input Roughness (Zo) :

Select Cloud Cover : ○ ● ○ ○ ○ OR ○ enter value : 7 (0 - 10)

Figure II.6: Application Window "Atmospheric Option" 1


Atmospheric Options 2

Air Temperature is : 80 Degrees ● F ○ C

Stability Class is : ○ A ○ B ○ C ● D ○ E ○ F

Inversion Height Options are : ● No Inversion ○ Inversion Present, Height is : ● feet ○ meters

Select Humidity : ○ ● ○ ○ ○ OR ○ enter value : 75 % (0 - 100)

Figure II.7: Application Window "Atmospheric Option" 2

- **Setting the Source :**

The source refers to the origin point, like a vessel or pool, from which a hazardous chemical is released. Source strength is the rate at which the chemical enters the atmosphere or burns, determined by factors like the release mechanism. ALOHA can model four source types:

- Direct release (user-determined),
- Puddle formation,
- Tank leakage,
- Gas Pipeline rupture.

Users select scenarios for each source type, with options varying based on the source and chemical. After inputting source details, ALOHA calculates source strength, providing results such as release duration, rates, and total amount released on both textual and graphical displays. [28]

- **Calculations :**

Once all the necessary characteristics are entered into ALOHA, the user can decide whether to apply a Gaussian model, a heavy gas model, or let ALOHA decide.

Subsequently, the user can request ALOHA to plot three types of threats: the toxic zone, the potential flammability zone, or the explosion zone, depending on the characteristics of the pollutant.

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CHAPTER III: Application Well Integrity evaluation and Aloha Modeling

Introduction

In This chapter we will evaluates the integrity of Gas injector Well MD-89 with the objective of proposing a set of recommendations that once implemented, can help restore this integrity and reduce the risk to personnel and/or the environment that can be caused by an uncontrolled release of well.

The well has been categorized according to the Norsok D10 standards, and a well failure modeling has been generated in order to address potential barrier failure modes, possible causes, associated risks, and mitigation plan to alleviate these risks and avoid unwanted release of well effluents and subsequent consequences.

Detailed recommendations on how to address the current integrity impairments are listed.

To mention that this evaluation, modeling and impact simulation are conducted under supervision of Engineers and supervisor of well Integrity Department in Sonatrach Hassi Messaoud Region.

Section 01: Presentation of the Directional Region of Hassi Messaoud

1. Hassi Messaoud Field Overview

The Hassi Messaoud field is located 650 km southeast of Algiers and 300 km from the Tunisian border. This vast oil field is bounded by several notable areas:

- **Northwest:** Haoud Berkaoui, Benkahla, and Guellala fields.
- **Southwest:** El Gassi El Agreb fields.
- **Southeast:** Rhourde El Baguel and Mesdar fields.
- **East:** Berkine Basin.

Geological Features:

- **Age:** Cambrian
- **Discovery:** First well (MD1) drilled in January 1957
- **Proven Accumulations:** Spanning 3,300 km²
- **Depth:** Approximately 3,400 meters
- **Thickness:** Up to 250 meters.

The map below depicts the regional location of the Hassi Messaoud field within Algeria.

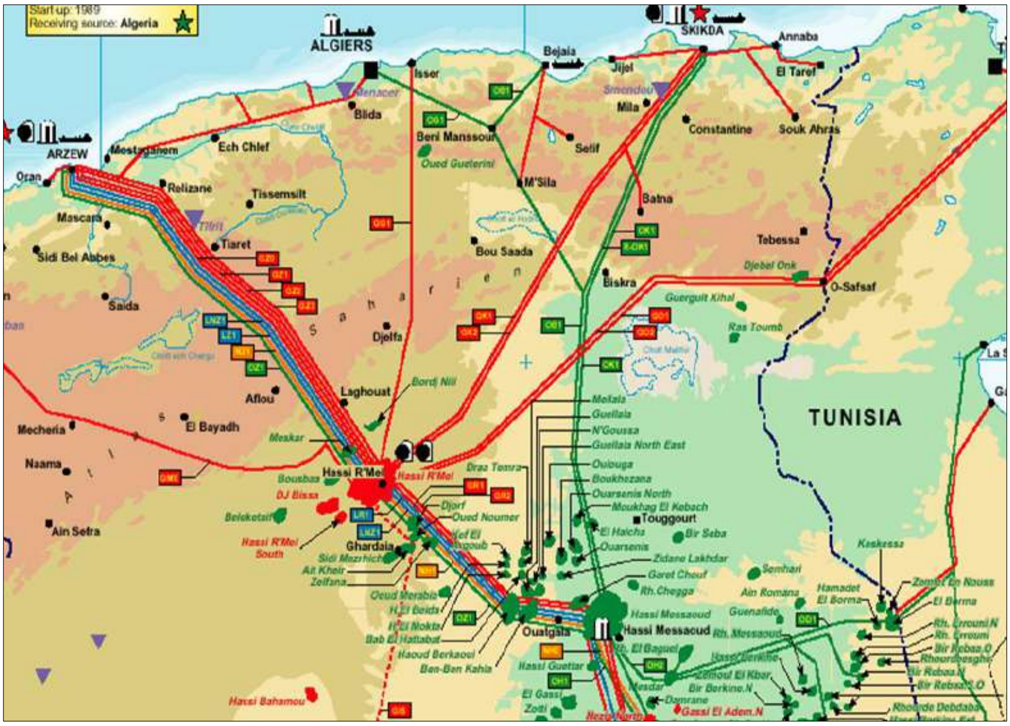


Figure III. 1: Geographical location of the DP HMD

2. The organic structures

The Directional Region of Hassi Messaoud is composed of the following organic structures:

-HSE Direction

-Exploitation Direction

-Technical direction

-Maintenance direction

-Engineering & Production Direction

-Law Division

-Supply and Purchasing Division

-Division Moyen Généreaux

-Logistic Direction

-Finance Division

3. The missions of the Production Division

The PD's missions include:

- The development and operation of hydrocarbon fields located almost entirely in southeastern Algeria.

- The production of liquid and gaseous hydrocarbons (crude oil, condensate, LPG, and gas).

- The operation and maintenance of hydrocarbon production facilities and equipment, as well as reservoir maintenance.

- The management and operation of the Hassi Messaoud and In Amenas refineries.

4. The PD organization chart

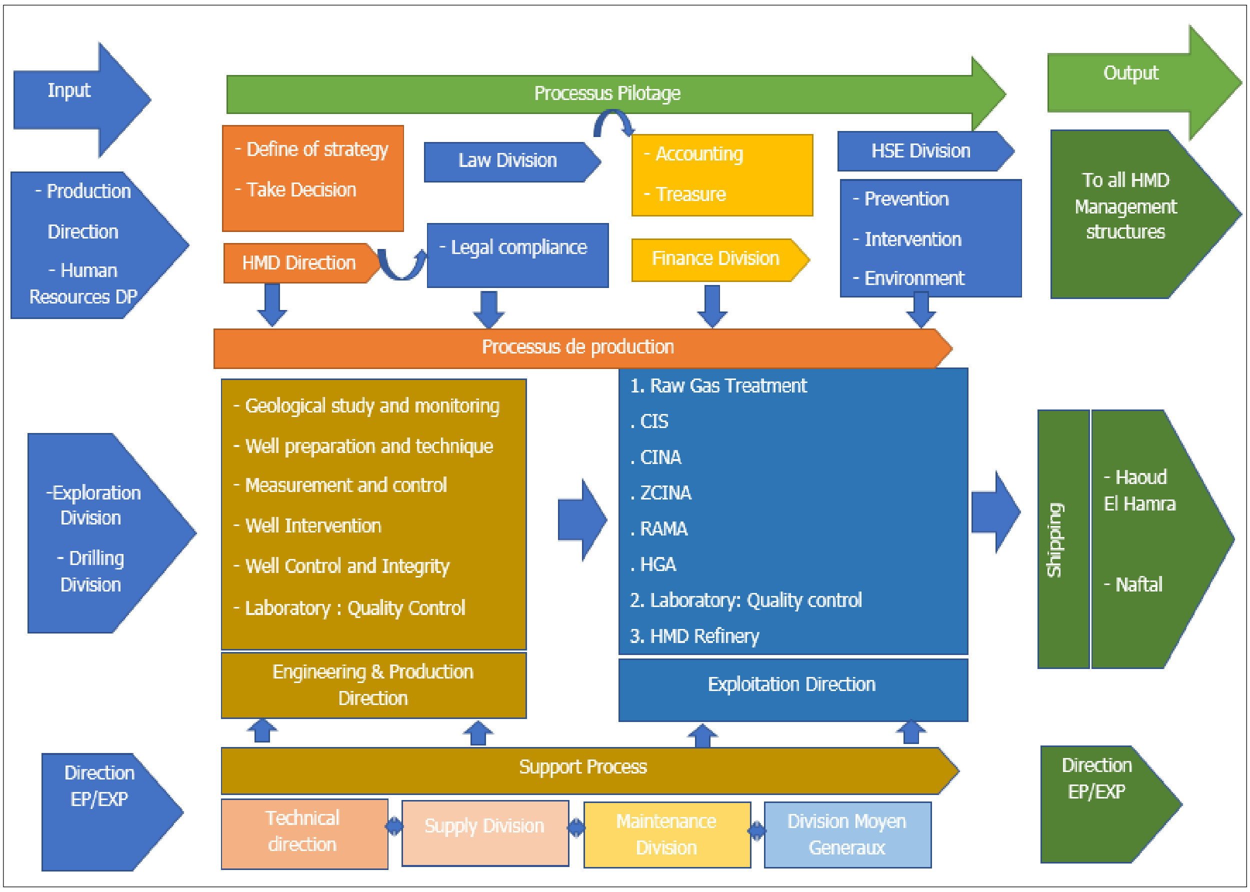


Figure III.2: Mapping of Sonatrach Hassi Messaoud

Section 02: Application Well Integrity diagnostic and Aloha Modeling at the Sonatrach Hassi Messaoud production department

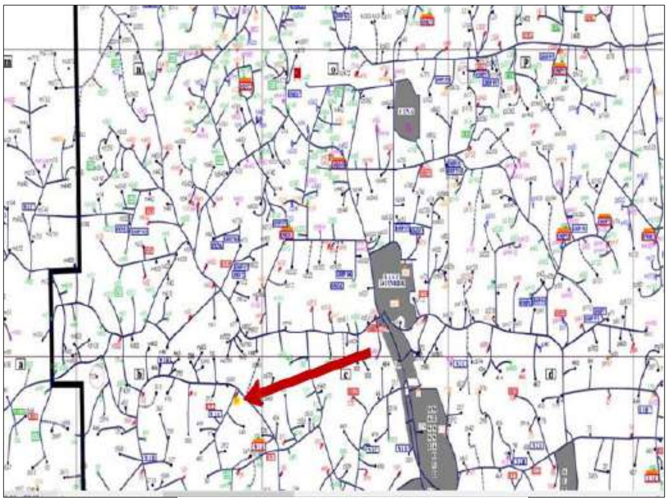
1. **Well General Information**

1.1. Well Data

- Well Name: MD-89 Field: HMD
- Date Drilled 1966
- Well Type & Status: Gas Injector/Open

1.2. Well Location

The well is located in Hassi Messaoud, as indicated in the map below:



FigureIII.3: Well Location

1.3. Well Schematic

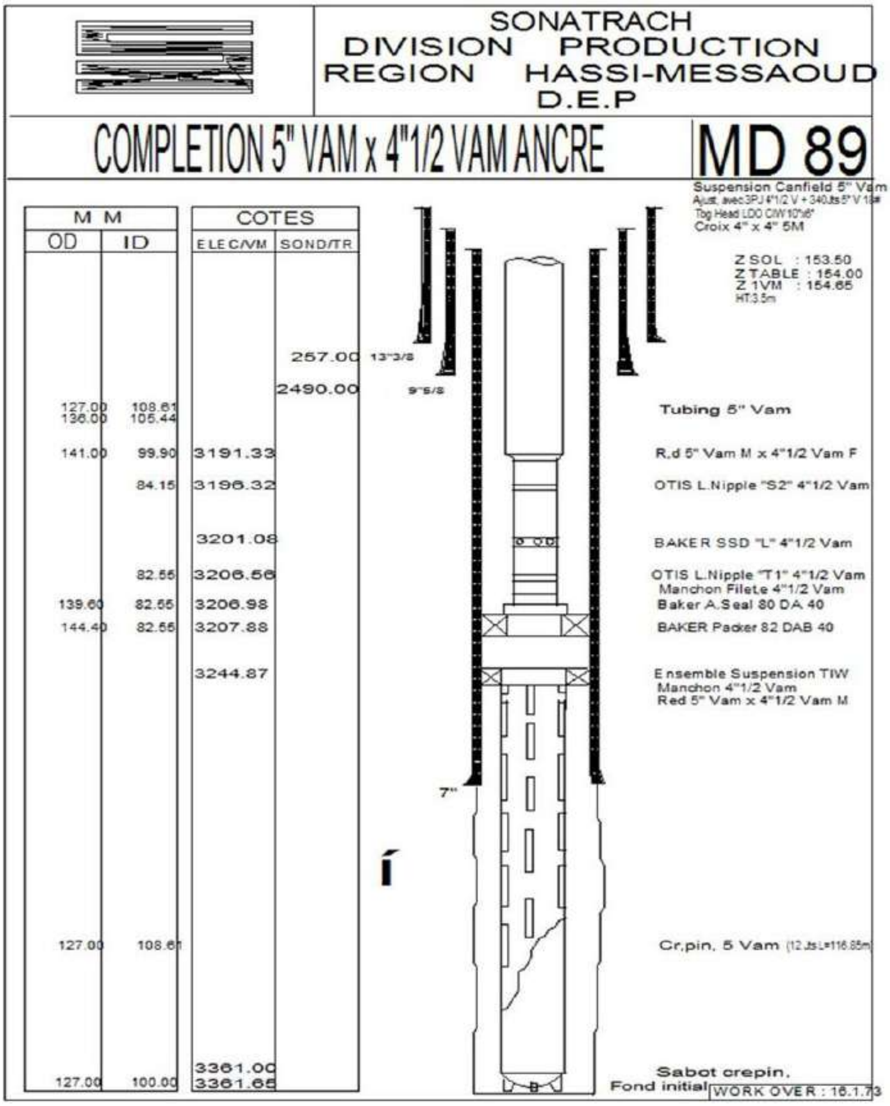


Figure III.4 : Well Schematic

2. Wellhead Findings

2.1. Annular Pressure Monitoring & Fluid Analysis

Below is a table indicating annular pressure monitoring and bleed offs executed, with associated results:

Table III.1: Annular pressure monitoring

Monitoring Date	Annular Section	Start Pressure (bars)	Bleed off (Y/N)	End Pressure (bars)	Observations
2-Jun-2024	A	90	Y	90	gas
2-Jun-2024	B	0	N	/	/

- Well open at 170 bar wellhead pressure. Pressure section A, 90 bars, sustained. Pressure section B, zero. Pressure section C not determined.

- More investigation is required to determine the leak source and path to surface.

2.2. Wellhead Components Condition

- Tree assembly: All tree valves operate.
- A section: Both casing valves operate stiff.
- B section: Casing valve stuck in open position and mild corrosion.
- C section: The valve stuck in closed position and heavy corrosion.

3. Well Dispersion Modeling by ALOHA

Well dispersion modeling evaluates the area surrounding the well that provides a possibility of exposure to toxic vapors, a flammable atmosphere, and overpressure from a vapor cloud explosion and thermal radiation from the gases release and potential fire.

The evaluation is simulated utilizing the ALOHA software, and each risk assessment model is represented mathematically in addition to graphically when the Level of Concentration (LOC) is exceeded as determined threat zones.

The threat zones represent the area within which the ground-level exposure exceeds the user-specified level of concern at some time after the beginning of a release.

3.1. Inputs

The input parameters provide information about the accident location, the chemical substance involved, the atmospheric conditions, the characteristics of the site and the pipeline, as well as the release conditions.

A. SITE DATA:

- **Time:** May 22, 2024
- **Site location**: MD89 in Hassi Messaoud, OUARGLA, ALGERIA

B. CHEMICAL DATA:

- **Chemical substance studied**: Methane
- **Molecular Weight:** 16.04 g/mol
- **Ambient Boiling Point:** -161.7° C
- **Saturation Concentration:** 1,000,000 ppm or 100.0%

C. SOURCE STRENGTH: [29]

- **Direct Source:** 10907928 pounds/hr
- **Source Height:** 0
- **Release Duration:** 60 minutes
- **Release Rate:** 82,500 kilograms/min
- **Total Amount Released:** 4,947,753 kilograms

D. ATMOSPHERIC DATA: (MANUAL INPUT OF DATA):

The meteorological parameters (wind speed, air temperature, relative humidity, ground roughness) are presented in the following table:

Table III.2 : Scenario Parameters

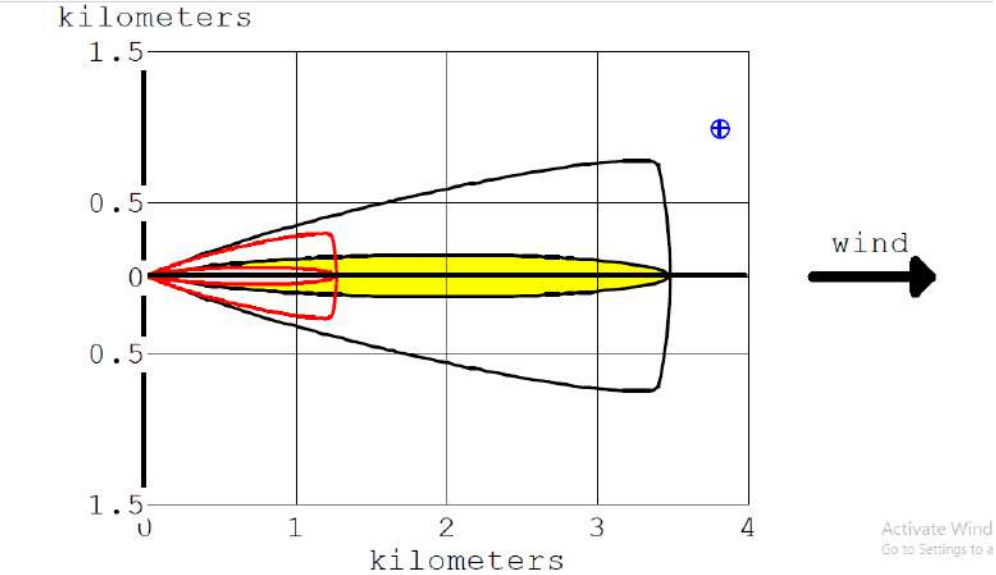
Characteristics	Value
Wind speed	6 m/s
Air temperature	37°C
Humidity	3%
Ground Roughness	open country

3.2. Modeling of Pollutant Concentration, Flames and Overpressure

ALOHA provides the results for pollution and flame effects, as presented in the following figures:

THREAT ZONE:

A. Threat Modeled: Flammable Area of Vapor



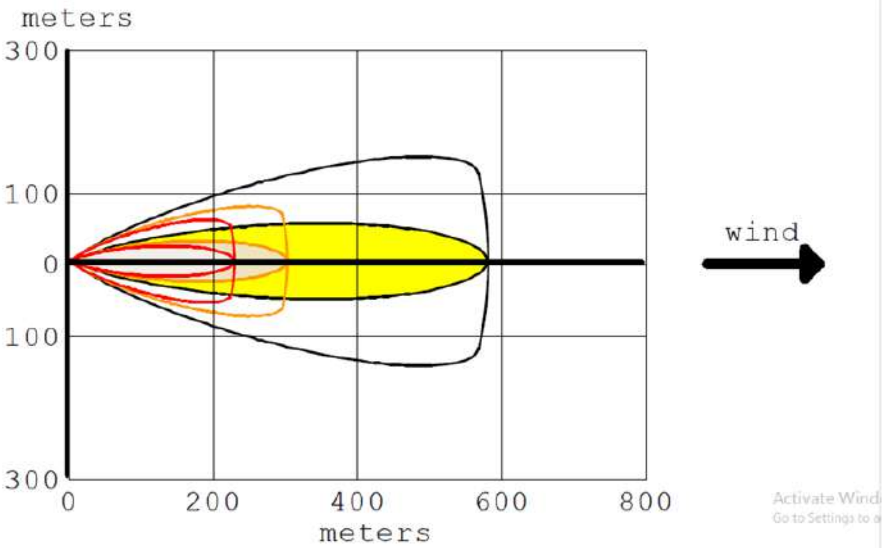
▨ Greater than 30000 ppm (60% LEL = Flame P) 1.3 kilometers

🟨 Greater than 5000 ppm (10% LEL) 3.5 kilometers

— Wind direction confidence lines

Figure III.5 Flammable LOC

B. Threat Modeled: Toxic THREAT ZONE



▨ Greater than 400000 ppm (PAC-3), 229 meters

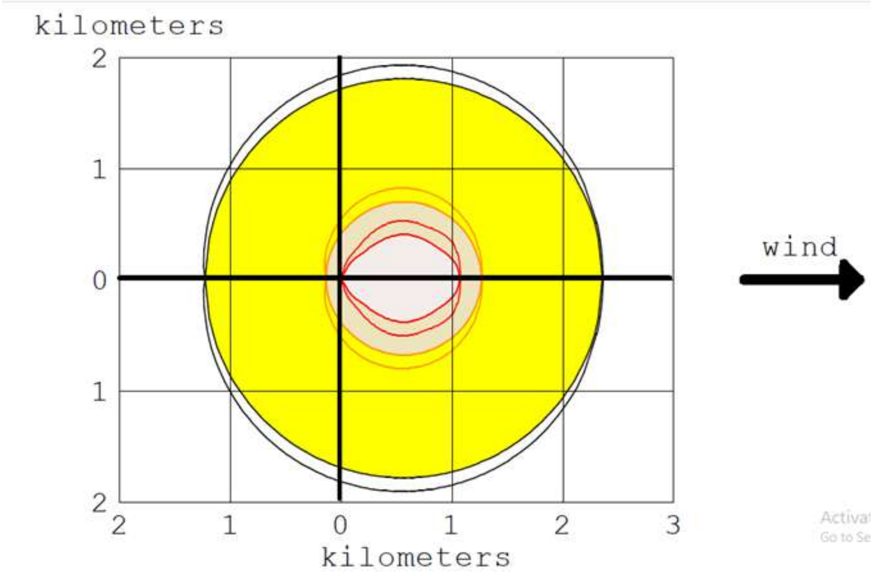
▨ Greater than 230000 ppm (PAC-2), 304 meters

🟨 Greater than 65000 ppm (PAC-1), 582 meters

— Wind direction confidence lines

Figure III.6: Toxic LOC

C. Overpressure (Blast Force) Threat Zone



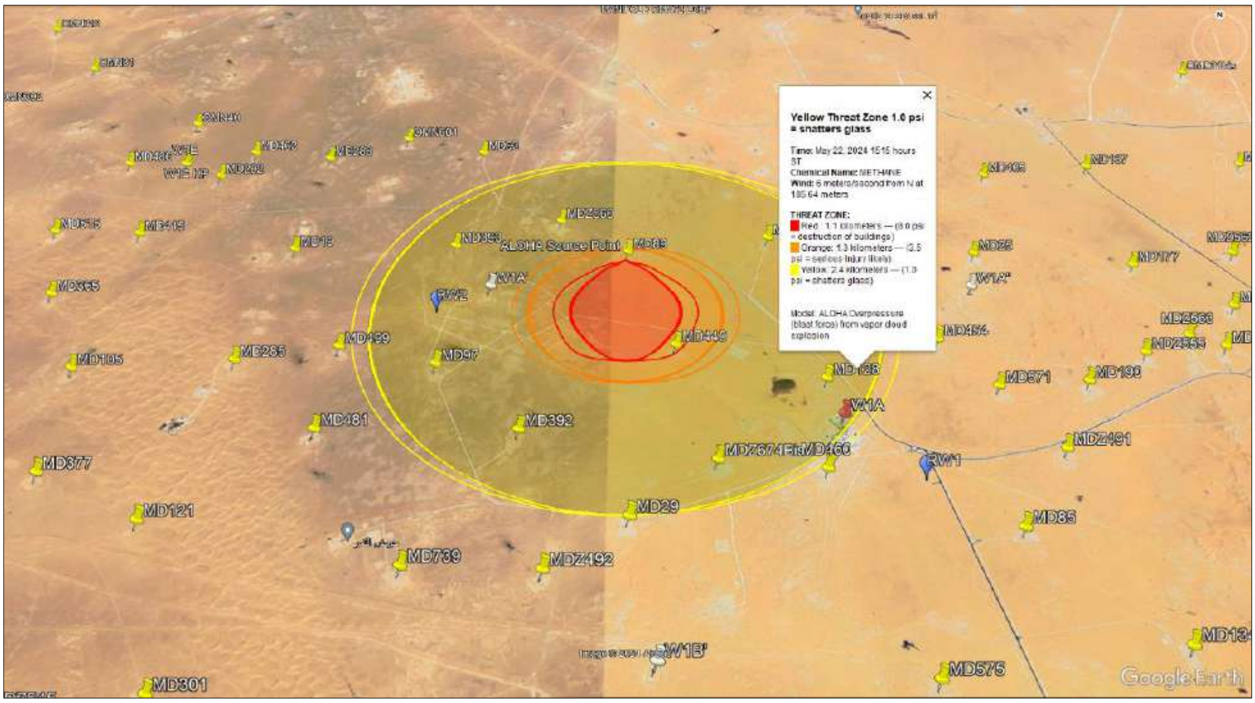
▨ Greater than 8.0 psi (destruction of building) 1.1 kilometers

▨ Greater than 3.5 psi (serious injury likely) 1.3 kilometers

🟨 Greater than 1.0 psi (shatters glass) 2.4 kilometers

— Wind direction confidence lines

Figure III.7: Overpressure LOC



Yellow Threat Zone 1.0 psi = shatters glass

Time: May 22, 2024 1515 hours ST
Chemical Name: METHANE
Wind: 6 meters/second from N at 185.64 meters

THREAT ZONE:
🟥 Red : 1.1 kilometers — (8.0 psi = destruction of buildings)
🟧 Orange: 1.3 kilometers — (3.5 psi = serious injury likely)
🟨 Yellow: 2.4 kilometers — (1.0 psi = shatters glass)

Model: ALOHA Overpressure (blast force) from vapor cloud explosion

Figure III.8: Threat zone on google earth map

4. Wellbore Findings

4.1. Work over History

No information available on work over history.

No information on casing patches being run in the well.

No corrosion logs available.

4.2. Cement Quality

Poor cement quality across the LD-2 and very poor quality of cement across the Albien.

4.3. MAWOP & MAASP Summary

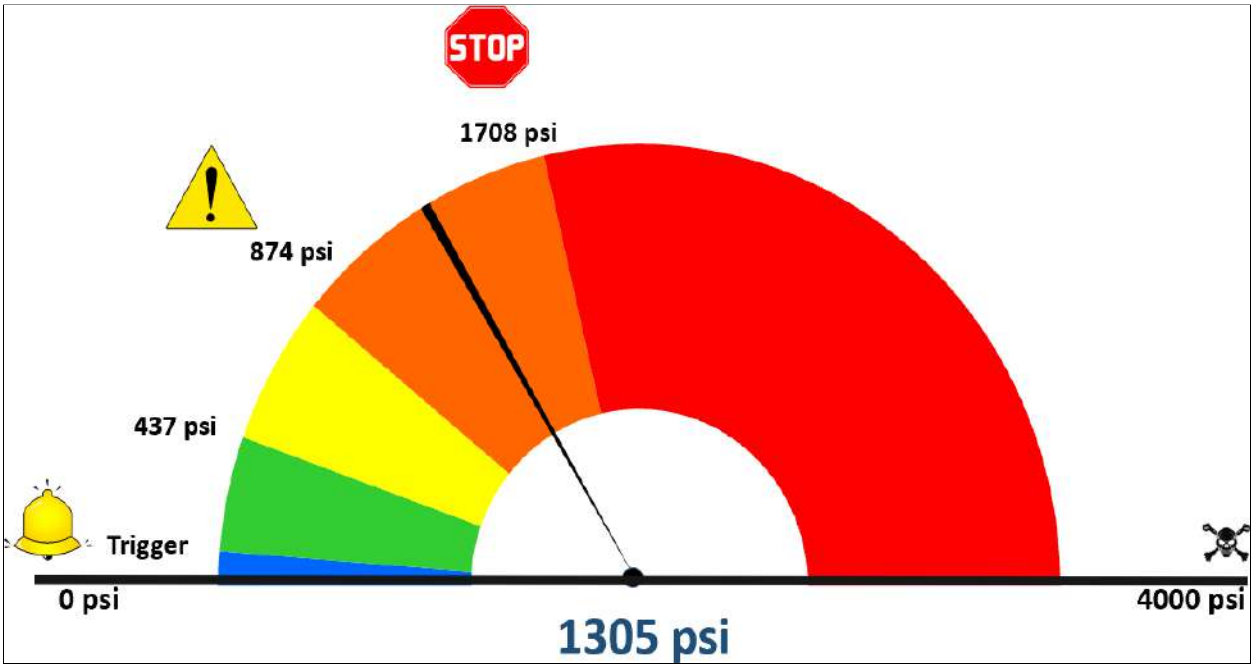


Figure III.9: Section a Pressure Summary

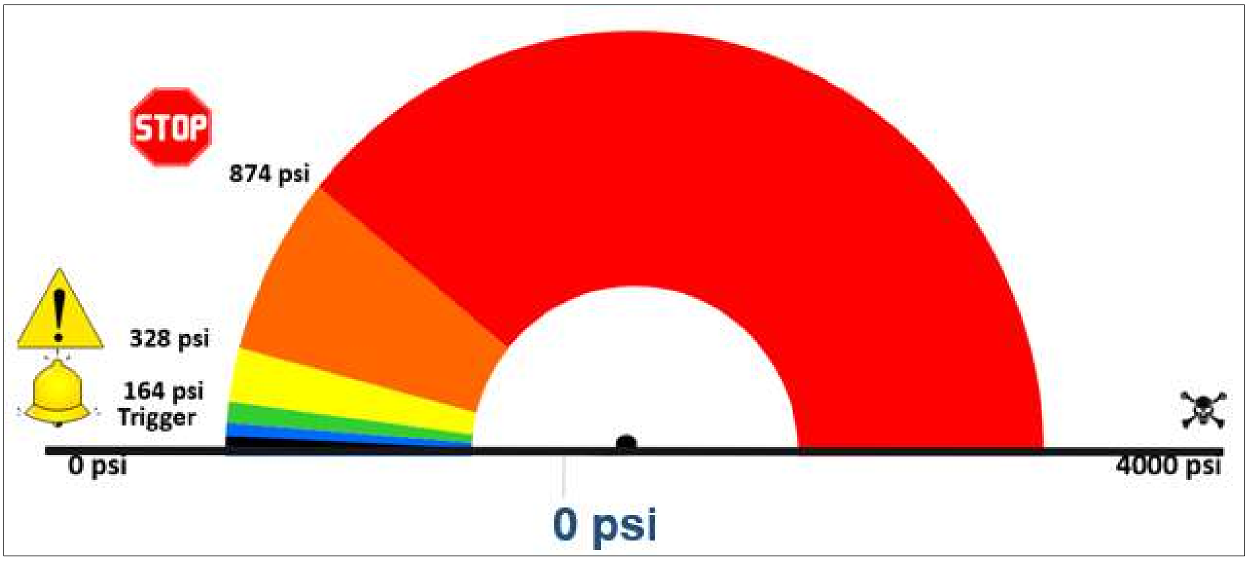


Figure III.10: Section B Pressure Summary

Figure III.11: Section C Pressure Summary

5. Well Categorization & Integrity Scoring

5.1. Well Barrier Envelopes

Table III.3: Well barrier list

Primary Barrier Elements*	Secondary Barrier Elements**
4 ½” Tubing	Surface X-Mas Tree with UMV
4 ½” Production Packer	Tubing Hanger
7” Production Casing	Spool Wellhead Access “A” with Access Valve
7” Production Casing Cement	Spool Wellhead Access “B” with Access Valve
Formation at Production 7” Casing Shoe	9 5/8” Casing
4 ½” Liner Packer	9 5/8” Casing Cement
	Formation at 9 5/8” Casing Shoe

A. Primary Barrier Envelope:

First set of barrier elements that the produced and/or injected fluids contact and that is in-place and functional during well operations.

B. Secondary Barrier Envelope:

Second set of barrier elements that prevent flow from a source.

5.2. Well Integrity Categorization – Norsok D-10 Standards

The principles and color designations for the different categories are as follows:

Table III.4: Well integrity categories

Category	Principle
Red	**One barrier failure and the other is degraded/not verified, or leak to surface**
Orange	**One barrier failure and the other is intact, or a single failure may lead to leak to surface**
Yellow	**One barrier degraded, the other is intact**
Green	**Healthy well – no or minor issue**

The principles in more detail are as follows:

Green: A well will fall into the green category if the barrier philosophy is considered intact by adherence to company requirements fulfilling the intention of the regulations or if there are only minor well integrity issues not leading to degradation of the well barriers.

Yellow: A well will fall in the yellow category if a degradation in the well barrier or well barriers is present without jeopardizing the barrier function of the envelope/element. A well categorized as yellow might be deemed acceptable for continued operation. In these wells, no single failure will lead to an unacceptable release of well fluids to surface or to the formation.

Orange: A well will fall in the orange category if one barrier has failed and the remaining barrier is evaluated to fully maintain its function. A single failure may lead to an unacceptable release of well fluids. These wells may have a barrier philosophy outside the requirements and will require remedial work or mitigating measures, to operate the well. However, it may not be considered any urgent need for action.

Red: A well will fall in the red category if one barrier has failed and the remaining barrier is degraded or is not expected to maintain its function. A single failure of the remaining degraded barrier will lead to an unacceptable release of well fluids. These are wells with barrier philosophy outside the requirements and that have been evaluated to get the highest priority and focus for immediate remedial work or other mitigating measures.

It should be stressed that the categorization system does not replace risk assessments; it is only a means of reporting barrier status for the well inventory.

WARNING:

MD-89 has section A exposed to sustained casing pressure. As a result, the well falls in the ORANGE category, and requires immediate intervention to restore integrity.

6. Well Integrity Scoring

The well integrity scoring is a subjective system, which is intended to be a consistent method to identify integrity impairments by applying a set of evaluation criteria, divided in technical, operational, and organizational categories. It consistently evaluates the status of each metric selected and compares wells among each other, with the objective of setting priorities for intervention. Identifying a well with low priority for intervention does not necessarily mean the well is exposed to low risks during its remaining life span; as such, integrity should be continuously monitored.

The photos below show the wellhead situation and how its integrity affected by the corrosion as part our well integrity diagnostic:

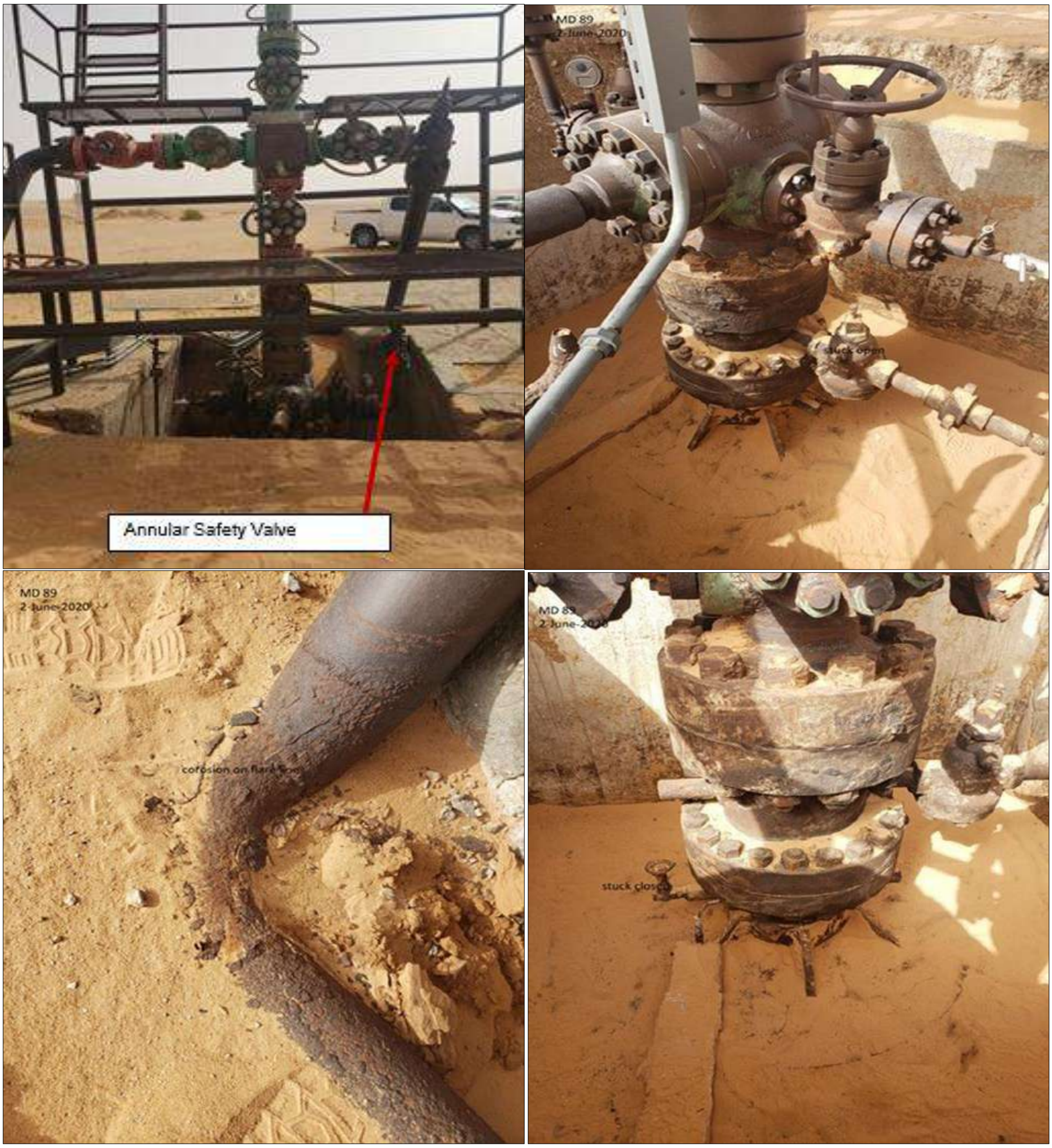


Figure III.12: MD-89 Wellhead Situation

Well Integrity Scoring

Table III.5: Well integrity scoring system MD-89

Category	Sub-Category	Metric	Score (0-10)	Justification	Category Score (%)	Well Score (0to1)
Technical	Construction	Casing & Tubing	7	1) Tubing & Casings weights & grades adequate for well life environment 2) Premium tubing thread used. A score of 7 has been assigned	70.0%	0.49
		Completion	7	1) No anomalies detected with completion design A score of 7 has been assigned		
		Wellhead & XMT	7	1) The wellhead & tree are rated for 10,000 psi A score of 7 has been assigned		
	Barriers	Primary	7	1) Well schematic shows adequate number of primary barriers. A score of 7 has been assigned		
		Secondary	7	1) Well schematic shows adequate number of secondary barriers. A score of 7 has been assigned		
	Annular Pressures	Section A	2	1) Sustained pressure is between MAWOP & MAASP A score of 2 has been assigned	37.9%	
		Section B	6	1) Zero pressure A score of 6 has been assigned		
		Section C	2	1) Pressure note determined A score of 2 has been assigned		
	Wellhead & XMT	Section A	4	1) Both valves operate stiff A score of 4 has been assigned		
		Section B	3	1) Casing valve stuck in open position and mild corrosion A score of 3 has been assigned		
		Section C	2	1) Needle valve stuck in closed position and heavy corrosion A score of 2 has been assigned		
		XMT	6	1) Tree assembly: All tree valves operate A score of 6 has been assigned		
	Cement Quality	7" Casing	2	1) Poor cement quality across the LD-2 A score of 2 has been assigned(CBL)		
		9 5/8" Casing	2	1) Very poor quality of cement across the Albien A score of 2 has been assigned		
		13 3/8" Casing	6	1) No CBL available A score 6 has been assigned		
	Well History	well age	3	1) Well age is less than 60 years A score of 3 has been assigned		

	Well History	Patches	5	No information on patches in the casing No information on patches in the /8" casing A score of 5 has been assigned		
		Pressure Tests	4	1) No information on pressure tests done A score of 4 has been assigned		
		Other Anomalies	6	1) No other anomalies A score of 6 has been assigned		
Organizational	**Monitoring**	Corrosion	2	1) No corrosion logs available A score of 2 is assigned	40.0%	
		annular pressure monitoring	4	1) No evidence of annular pressure monitoring or bleed offs 2) Pressure data is only recently updated on annular pressure monitoring database A score of 4 has been assigned		
		Fluid analysis	6	1) No fluid analysis required A score of 6 has been assigned		
		Injection in Reservoir	5	1) No PLT or spinner survey to confirm injection into reservoir A score of 5 has been assigned		
		Telemetry	6	1) Well is connected to telemetry A score of 6 has been assigned		
	Controls	Annular Valve Plugging	6	1) No evidence of valve plugging A score of 6 has been assigned		
		Annular Safety Valve	0	1) No evidence annular safety valve is being tested 2) No data available on pre-set value A score of 0 has been assigned		
	Records	Handover from Drilling	4	1) No proper handover from drilling to production with list of integrity impairments A score of 4 has been assigned		
		Injection Parameters Recording	0	1) Annular pressures seem to be changing with no recording of human intervention. Data is not reliable A score of 0 has been assigned		
		Data Availability	7	1) Most of the data is available on Sonatrach data bank A score of 7 has been assigned		

Metric Scoring Definition

- 0: No evidence of risk management available. High risks ahead if operation is continued, on a metric-by-metric basis.
- 10: Good risk management processes are in place. No potential threats. Safe to continue with.

Well Scoring Interpretation

- Well Score < 0.5: High priority for intervention
- 0.5< Well Score < 0.75: Medium priority for intervention
- Well score > 0.75: Low priority for intervention

7. Well Failure Modeling: Gas Injector in HMD region

Table III.6: Well failure modeling – Gas Injector MD-89

Item	Typical Barrier Failure Mode	Causes	Associated Risks	Mitigation Plan
1	Tubing annulus leak	1) Completion packer seals leak 2) Wellhead tubing hanger seals leak 3) Storm choke failure 4) Any other completion component failure 5) Tubing corrosion 6) Use of non premium connections	1) Loss of primary barrier 2) Injecting out of zone 3) Loss of production from other wells (case of injector) 4) Release of reservoir fluid to surface (case of gas injector)	1) Monitor A section pressure 2) Run spinner surveys periodically 3) Connect well to telemetry 4) Use coated tubing on injector wells 5) Re-evaluate material specs on new wells or new completions, such as gas tight premium connections on gas injectors 6) Install storm chokes above the reservoir for gas injectors and ensure proper maintenance 7) Ensure proper wellhead/tree maintenance & review frequency of visits 8) Re-head rusted wellheads
2	Loss of mechanical properties of production tubing	1) Collapsed tubing (or collapsed packer) 2) Erosion due to fluid/gas velocity 3) Tubing age 4) Cementing	1) Loss of primary barrier 2) Loss of injection capability	1) Monitoring of A annulus 2) Confirm annular integrity before and after frac and before any post frac cleanout w/ CT 3) Do not cement tubing in place to avoid excessive fatigue cycles

3	**Loss of mechanical properties of production casing**	**1) Casing corrosion** **2) Casing collapse** **3) Cement seal loss** **4) Well age**	**1) Loss of primary barrier** **2) Loss of injection capability** **3) Inter zonal communication** **4) Borehole stability**	**1) Monitoring of annular pressure** **2) Using cementing best practices** **3) Bleed off annulus, sample collection & fluid analysis** **4) Running CBL/VDL tools** **5) Use cathodic protection (new & existing wells)** **6) Run corrosion logs, de-rate tubulars based on corrosion logs** **7) Monitor annular pressure** **8) Use advance cement design simulators, finite element stress, ductile cement, cementing best practices, monitor cementing job/ECD's in real-time** **9) Use advanced centralizer simulators for improved pipe eccentricity (new wells)** **10) Use appropriate float equipment and avoid keeping the casing under pressure after cement job while cement is setting** **11) Monitor production/injection parameters**
4	**Corrosion of surface & intermediate casings**	**1) Insufficient zonal isolation(Cement)against water aquifers** **2)Micro-annulus of cement against salt zones** **3) Brittle cement due to high concentrations of salt cement, as designed** **4) Well age**	**1) Contamination of water table and Albien aquifer** **2) Loss of secondary barrier**	**1) Monitor annular sections** **2) Use cementing best practices as for production casings** **3) Running CBL/VDL logs** **4) Consider using low concentration of salt cement for new wells** **5) Address cement losses efficiently where they are expected**

5	**Sustained annular Pressures**	**1) Casing corrosion** **2) Casing collapse** **3) Cement seal loss** **4) Fracturing out of zone during a frac job** **5) Leaking tubing hanger or casing hanger seals** **6) Breakdown of formation, pipe collapse or burst** **7) Formation fluids leaking to annulus**	**1) Loss of primary/secondary barrier** **2) Production tubing collapse** **3) Burst of outer casing**	**1) Install a pressure relief valve on annular section A to release excessive pressure on injector wells in case of a leak** **2) Continous monitoring of annular pressures** **3) Necessary bleed offs and sample fluid analysis** **4) Annular communication tests** **5) Monitor A & B annulus during frac job** **6) Ensure sufficient barriers above and below the target zone** **7) Observe BHP in real time during the frac treatment**

8. Conclusion and Recommendation

After analyzing data obtained from the well integrity scoring, and Well Failure Modeling – Gas Injector HMD, the following points can be considered into account in order to avoid critical integrity issue as is clearly showed by Aloha software:

- Section A is subjected to a sustained pressure.
- The well has some integrity impairments with lack of maintenance of surface equipment, already affected by corrosion in the lower section of the wellhead.
- Poor cement quality across the LD-2 [29] and very poor quality across the Albien are adding to potential impairments, and therefore the well needs a close follow up and be included in a priority list, as it may pose an important level of risk to environment/personnel.
- The annular safety valve installed on section a needs to be re-set to below the MAASP value for this section, i.e. 1,708 psi. Its performance needs to be tested every 6 months or less.
- The well performance as a gas injector needs to be verified periodically, in particular if well operation parameters indicate the possibility of injection out of the desired zone. A good performance of an injector will increase its ability to support oil producers in the nearby zone, as it is intended to.
- A spinner Production Logging Tool (PLT) survey can be used, if necessary, to verify a gas injector performance in order to ensure gas is being injected into the reservoir.
- To mitigate part of the risk from operating the well, the storm choke needs to have its functionality verified. Such a procedure is to be performed at the minimum every five years or whenever completion tubing is pulled out to surface, whichever comes first.
- With current data at hand, the communication path cannot be verified and thus requires further investigation.
- For B section, fill up annulus with kill fluid (Treated Water), and when safe, change annulus gate valve. Clean and paint all equipment with rust preventative.
- Hot tap section C and evaluate pressure.
- For a better understanding of the leak path, annular pressure testing is recommended. Section A is bled off first and pressure tested to no higher than the MAASP value of 1,708 psi, while observing any pressure changes in the tubing and other annular sections.
- Remaining annular sections need to be tested to verify their abilities to withstand pressure. Do not exceed the MAASP value for each section during the process.
- If this step is not practical, or no conclusions can be drawn in relation to source (s) of fluid and leak path (s), a noise/temp log should be immediately run to determine the required information.
- Once the above data is determined, a remedial program to restore well integrity can be prepared accordingly.
- As a temporary measure, and until such log is run, section A annular pressure needs to be monitored to ensure a MAASP value of 1,708 psi is not to be exceeded. Likewise, section B should not exceed a MAASP value of 874 psi, and section C not to exceed a MAASP value of 328 psi.
- This measure is only temporary and should not be considered as a replacement of well integrity impairment repairs, or even become a reason to delay addressing such impairments.

- Partial bleed offs to below the indicated limits can be performed, but only to bring section pressure to below the MAASP calculated value. Excessive bleed offs are not recommended however, as this will induce erosion problems and reduce the life of tubulars.
- Under no circumstances should annular sections be intentionally bled off to zero. Always leave positive pressure when bleeding off.
- To mitigate further risks, a mitigation plan is to be followed. This plan is included in the well failure modeling for a gas injector MD89.

General conclusion

This study has thoroughly examined the critical importance of well integrity in preventing significant accidents in oil and gas operations. By conducting comprehensive data analysis using well integrity scoring and Well Failure Modeling for Gas Injector well in Hassi Messaoud, we have identified several key measures necessary to address and mitigate integrity issues.

The Threat Zones modeled by Aloha Software emphasize the severity of these risks. For instance, the Flammable Area of Vapor extends beyond 30,000 ppm (60% LEL = Flame P) for 1.3 kilometers, indicating a substantial risk of fire. Similarly, the Overpressure (Blast Force) Threat Zone shows pressures greater than 8.0 psi, which can cause the destruction of buildings within a radius of 1.1 kilometers. This scenario implies a significant explosion risk if well integrity fails.

Moreover, the Toxic Threat Zones are equally concerning:

- Greater than 400,000 ppm (PAC-3) extends 229 meters, posing an immediate danger to human health.
- Greater than 230,000 ppm (PAC-2) extends 304 meters, indicating severe risk.
- Greater than 65,000 ppm (PAC-1) extends 582 meters, highlighting the widespread potential for harmful exposure.

These findings illustrate the critical nature of maintaining well integrity to prevent catastrophic events that could harm personnel, damage the environment, and disrupt operations.

The analysis underscores that well integrity techniques are not merely procedural but are vital safeguards essential for the safe and efficient functioning of oil and gas wells.

This thesis emphasizes that proactive well integrity management is indispensable for preventing major accidents

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