GEOTHERMAL WELL INTEGRITY STUDY

REPORT
FOR

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Well Engineering Partners
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Executive Summary

The geothermal sector in the Netherlands is strongly developing with 15 low enthalpy doublets drilled to date. For the sustainable geothermal energy production in the Netherlands, the need to develop an integral perspective on enhancing well integrity management was identified. One of the key issues was to come up with a set of best practices and measures that need to be incorporated in an asset management approach as part of the SHE management framework to assure proper geothermal well integrity management. The scope of this study was to:

- ✓ Determine which standard will be used as guideline for the study
- ✓ Describe typical wells
- ✓ Define the context for hazard identification
- ✓ Carry out a formal Hazard Identification and risk assessment in drilling and operational well life phases
- ✓ Prepare a Risk matrix
- ✓ Identify Well Barrier Elements s, failure mechanisms, monitoring guidelines
- ✓ Establish a Barrier Philosophy
- ✓ Define an Operating and Maintenance Philosophy
- ✓ Identify innovations in well engineering relevant to the Dutch geothermal sector
- ✓ Include an independent 3rd party review
- ✓ Produce Recommendations/Guidelines for Geothermal Wells

The study was carried out by the following companies; Wood Group Intetech (Project Management and well integrity expertise), Well Engineering Partner (geothermal well design and drilling) and Baker Risk (Hazard and Risk Assessment), the team members having expertise in different areas of well integrity (drilling and operations) and risk management. This report was prepared for the Nederlandse Kennisagenda and the Dutch Association of Geothermal Operators (DAGO).

The project started with a kick off meeting where the objectives and standard to be employed were agreed. A full day HAZID workshop was then carried out with associated risks evaluated for OSH, persons in the direct vicinity of the geothermal location and the environment. A Risk Matrix was produced as well as the risk assessment of listed hazards based on the attendees' knowledge and experience. The project then continued with a review of the Well Barrier Elements, Well Barrier Philosophy, Monitoring and Maintenance strategy and innovations for future wells.

The basis for the project is compliance with the Dutch legislation. Existing recommended practices, checklists, self assessments and the SHE management system were reviewed and guidelines proposed.

Well Integrity Management for geothermal wells in the Netherlands has historically been based on Oil and Gas Industry standards and procedures; this study was commissioned to adapt those standards to the geothermal sector. The Dutch geothermal wells exploited so far have all been non-artesian, not capable of natural flow to the surface, despite many having some co-produced dissolved gas.

The HAZID study resulted in a total of 18 recommendations (please see section 7 for more details). These relate for the operational phase mainly to administration and corrosion issues; concerning the latter; a comprehensive review of the entire well system to optimize and minimize cost for best corrosion mitigation over the well life, the need to gather more data to better inform well design, material selection, data logging and sharing of information between operators. Where possible and feasible, active monitoring of positive applied annular pressure (for example Nitrogen cushion) to quickly detect leaks is proposed. Creation of a project specific risk register during the Basis of design phase that is updated through the well life cycle will be very beneficial to the management of integrity for geothermal wells. Potential for improvement in the human factors and ergonomic issues across the geothermal industry were identified. Two recommendations were also raised to review the economic impact of natural hazards (flooding and extreme ambient temperatures) albeit perceived as low risk.

Well Barrier Elements for the full well cycle were identified and performance standards established so far as is practicable. Well Integrity for low enthalpy wells in the Netherlands are currently managed on a two barrier philosophy based on the well hydrostatic fluid column as the primary barrier and the well casing and wellhead as the secondary barrier. During drilling, the drilling mud is the primary barrier and the casing plus wellhead and BOP forms the secondary barrier. This complies with the two barrier standard for Oil and Gas wells due to the likely presence of dissolved and shallow gas formations. Static inflow test of the Geothermal well may be conducted on regular intervals to confirm the adopted barrier philosophy.

Checklists for handover at different well life cycles has been proposed to aid hazard identification and required controls. A guideline was also proposed on monitoring, maintaining and verification of well barriers during the operational phase. A well barrier acceptance criteria for applicable well components, adapted from ISO 16530, was proposed, as well as fluid (water and gas) sampling requirements.

Composite/non-metallic tubulars, rod driven pumps and installation of a tieback string are some proposed innovations for drilling and completing future geothermal wells. Internally coated, lined and non-metallic casings are some opportunities that should be considered to reduce the risk of casing corrosion thereby reducing operational cost and environmental pollution/contamination of ground and surface waters. These various innovations need evaluation from a life-cycle viewpoint to determine if they are cost-effective over the well life.

In the present geothermal wells there is no casing – casing annulus which can be monitored. To create such an annulus, if so desired or needed, a tieback string can be installed, which is also possible at a later date, hence also possible for present wells, see 5.3 Installation of a tieback string.

By addressing the major hazards and through consideration of the recommendations of the selected well integrity guidance document (ISO16530), the study has provided guidance on the geothermal well barrier elements that are to be monitored, maintained and verified so far as is reasonably practicable to ensure containment of the well fluids. The recommended actions to be taken are well within the capability of the Dutch geothermal operators that will require formal systemising of current practices to provide the necessary confidence in well integrity management. Additional elements of well integrity management recommended for implementing are;

- Proper documentation and administration of well integrity data in the first instance and possible use of a software system for collective data management and information sharing amongst operators and government reporting purposes.
- Well Integrity Assessment method – Well Failure Matrix (WFM)
- Roles and Responsibility
- Well Integrity Training
- Compliance by independent audit

The findings from the study do not impact existing SSM/Dutch regulations. The overall "message" from the review of the Dutch Rules and Regulations is "Protection of the environment and people" in a broad sense. More detail to this effect can be found in Appendix 1. As a result of this study, the main issue is related to the way integrity is monitored, either with or without a casing- casing annulus. The challenging issue is how to monitor and verify the condition of the production casing as a well barrier element by means such as logging, pressure testing during an intervention etc. Ongoing studies should result in a program to determine the way forward.

Adopting the measures and guidelines proposed in this report will ensure that all the correct data is gathered for well integrity assessment and bring a consistency of approach to decision – making across the Dutch geothermal operators based upon commonly held policies.

CONTENTS

1. INTRODUCTION

The Dutch Geothermal Energy sector makes use of geothermal heat as a renewable energy. The heat extraction scheme, known as the geothermal space heating doublet, combines a production well lifting, via an electro submersible pump (ESP) set, the hot fluid to a surface heat exchanger and where needed an injection well pumping the heat depleted brine back into the source reservoir.

Geothermal Operators in the Netherlands cooperate to exchange information and lessons learned and as a result formed the Dutch Association of Geothermal Operators (DAGO). One of the goals is to improve safety management, prepare guidelines, recommended practices and industry standards for the geothermal sector. Most geothermal wells are utilised by the innovative horticultural sector in the Netherlands as early adapters of this sustainable energy production method. The Dutch Ministry of Economic Affairs and the Dutch horticultural sector joined forces in 2014 to set up a Geothermal Research Agenda ('Kennisagenda') to streamline the development and dissemination of geothermal knowledge in the Netherlands.

This report was prepared for the Nederlandse Kennisagenda and the Dutch Association of Geothermal Operators (DAGO). The agenda is 'demand-driven' and the issues addressed are therefore strongly driven by the current operators and their representatives. Well integrity management is one of the current themes of the Agenda.

The study was carried out by the following companies; Wood Group Intetech (Project Management and well integrity expertise), Well Engineering Partner (geothermal well design and drilling) and Baker Risk (Hazard and Risk Assessment), the team members having expertise in different areas of well integrity (drilling and operations) and risk management. The following are the team members:

Ogo Ikenwilo, Wood Group Intetech
Liane Smith, Wood Group Intetech
Henny Cornelissen, Well Engineering Partner
Robert Magraw, Baker Risk

The draft report was reviewed by an external party, Paul Hopmans of TNO and the final report was amended incorporating his feedback where necessary.

1.1 Project Background

The first geothermal wells in the Netherlands were completed in 2007 and to date, 15 low enthalpy geothermal doublets have been drilled[1]. To improve safety, further reduce risk and determine opportunities for improvement, the current status of well integrity management has been evaluated. This study was initiated to upgrade and complete existing guidelines, instructions and recommended practices within the existing SHE management framework. The geothermal operations in the Netherlands are governed by the Mining legislation which states that a licensee of a geothermal prospect should take all reasonably practicable measures to prevent harm to the environment and ensure safety of the operation (ALARP). The private domain has to demonstrate which methods or means are used to comply with the goal – setting requirements of the government. This is achieved by the use of good practices, practical guidelines and industry standards.

At the commencement of geothermal energy operations in the Netherlands, oil and gas standards and procedures have been adopted for drilling and completion of wells. For this project, which considered the whole well life, suitable existing procedures and standards have been selected and adapted to suit the geothermal context (see section 1.5)

1.2 Scope and Objectives of Study

The geothermal sector in the Netherlands is strongly developing, pressing the need to develop an integral perspective on how to best deal with the challenges in ensuring well integrity management. One of the key issues is to come up with a set of best practices and measures that need to be incorporated in an asset management approach to assure proper geothermal well integrity management. A well integrity management system specifically developed for the Dutch geothermal conditions to secure safe and sustainable operation has to be developed.

The objectives of this study were:

- ✓ Determine which standard will be used as guideline for the study
- ✓ Describe typical wells
- ✓ Define the context for hazard identification
- ✓ Hazard identification and risk assessment
- ✓ Preparation of a Risk matrix
- ✓ Identification of WBEs, failure mechanisms, monitoring guidelines
- ✓ Barrier Philosophy

[1] For an overview of geothermal operations in the Netherlands see http://geothermie.nl/english/.

- ✓ Operating and Maintenance Philosophy
- ✓ Independent review and feedback
- ✓ Recommendations/Guidelines for Geothermal Wells

Existing recommended practices, checklists, self assessments and the SHE management system can and will be reviewed and if required updated and upgraded. The basis for the project is compliance with the Dutch legislation.

During the kick off meeting held on the 30th of March 2016, discussion took place around the need for the study to result in a concrete working guideline to be produced, pertinent to the geothermal wells of the Netherlands as currently operated but with principles that can be applied to future wells.

At the kick off meeting, the ISO 16530 standard was proposed by SSM and agreed by all present to be the basis for this Well Interity review. A draft has been issued for review of the ISO 16530 – 1, this was consulted and does not alter the approach taken in this study.

1.3 Synopsis of rules and legislations

The rules and regulations related to the mining activities in the Netherlands have been checked for their relevance related to subjects such as: Integrity; Risk; Hazard; Safety; Protection.

The relevant rules and regulations are listed in Appendix 1. The original language versions of the Mining Act, the Mining Decree, Mining Regulation and Working Conditions Act are presented in the official wording along with unofficial English translations. The sentences and sections that are pertinent to the Dutch geothermal wells have been highlighted in yellow. This allows the reader to understand the well-related regulations in the context of the adjacent text and artikel title etc.

In addition, there is a SHE framework in place for DAGO in which Well Integrity is an integral part of.

1.4 Description of a typical low enthalpy geothermal well

The typical low enthalpy geothermal well has a telescopic casing design, liner in liner. The well starts with a conductor casing installed to protect the fresh and brackish water reservoirs near the surface. This conductor casing is mostly drilled and cemented. . The conductor is usually placed up to the depth of Clay layer to isolate fresh groundwater from salt water; isolate shallow ground water etc. Then a full casing string is installed as first protection against unstable formations and a good casing shoe for pressure containment when drilling deeper. This casing string is cemented to the surface. The depth of the surface casing is determined by the formation strength at the shoe .

Thereafter only liners are installed, finally with a slotted liner or wire wrapped screen over the reservoir section. Except for the final production liner over the reservoir, all liners are cemented from shoe to the liner hanger (with packer) assembly.

A schematic of this typical low enthalpy well is depicted in Figure 1.

1.5 Exclusions

- ❖ The typical wells description refers to current designs and do not include deeper, higher temperature potential wells with increased risk of outflow (subject of a future scope addition and addendum if needed).

- ❖ It was understood that future wells with radically different conditions may require further evaluation (outside of the present scope).

The current work will provide generic principles (but firm pragmatic ideas) for well integrity management approaches to address all the risks identified in the HAZID. These principles can then be used to evaluate all the current wells but that well by well review is outside the scope of this work.

1.6 References

Well integrity in drilling and well operations	NORSOK D-010
Drilling facilities	NORSOK D-001
Recommended Practices for Blowout Prevention Equipment Systems for Drilling Wells	API RP 53
Specifications for Well-head and Xmas Tree Equipment	API Spec. 6A
Recommended guidelines for Well Integrity	Norwegian Oil and Gas Association Guideline no. 117
Guidelines for the Management of Safety Critical Elements/Second Edition, The UK Offshore Operators Association and HSE Offshore Safety Division	March 2007
Well Integrity in the Operational Phase	ISO 16530 -2
Petroleum and natural gas industries – Materials for use in H2S-containing environments in Oil and Gas production Part 3: Cracking-resistant CRAs (corrosion	ISO 15156 -3

resistant alloys) and other alloys	
Risk Management	ISO 31000 or OGP report 451
Minimum standards and specifications for well design, execution and evaluation	SHE Management framework
'Handbook Geothermie'	SHE Management framework
Petroleum and Natural Gas Industries – Offshore Production Installations: Guidelines on Tools and Techniques for Hazard Identification and Risk Assessment (2002)	ISO 17776
NORSOK Z-013: Risk and emergency preparedness analysis (2010)	NORSOK Z-013
Standards for Asset Management	ISO 55000 / PASS 55
Mijnbouwet - Mining Act, effective 1st January 2003 (as amended up to 2012)	
Mijnbouwbesluit -Mining Decree, effective 1st January 2003 (as amended up to 13 October 2011)	
Mijnbouwregeling Mining Regulation, effective 1st January (updated up to 1 April 2014)	
Arbeidsomstandighedenregeling Working_conditions_act_25-3-2013	
Arbeidsomstandighedenregeling Working_conditions_decree_25-3-2013	
Arbeidsomstandighedenregeling Working-conditions_regulation_23-3-2013_excl.annexes-1	
https://www.sodm.nl/onderwerpen/gebruik-chemicalien	SODM requirements for the use of chemicals

1.7 Abbreviations

Please refer to ISO standard 16530 – 2; Section 3 for relevant terminologies

ALARP	As Low As Reasonably Practicable
API	American Petroleum Institute
BOD	Basis of design
BOP	Blow Out Preventer
CBL	Cement Bond Log
DAGO	Dutch Association of Geothermal Operators
ESP	Electrical submersible pump
GRE	Glass Reinforced Epoxy
GRP	Glass Reinforced Polyester
HAZID	Hazard Identification
ISO	International Standards Organisation
Kennisagenda	Dutch Knowledge/research Agenda
LIH	Lost In Hole
MAASP	Maximum Allowable Annulus Surface Pressure
OEM	Original Equipment Manufacturer
PBR	Polished Bore Receptacle
PCP	Progressive Cavity Pump
SHE	Safety, Health and Environment
SOE	Safe Operating Envelope
SSM	State Supervision of Mines
T & G	Test and Grease
USIT	Ultrasonic Imaging Tool
WBE	Well Barrier Element
WBS	Well Barrier Schematic
Xmas Tree	Christmas Tree

2. RISK ASSESSMENT

2.1 Introduction, objectives and scope

A key element of effective management systems is a systematic approach to the identification of hazards and the assessment of the associated risk in order to provide information to aid decision making on risk reduction measures. The three generic steps in this process are;

- Identification of the hazard;
- Assessment of the risk;
- And, elimination or reduction of the risk.

It is important that the tools and techniques adopted for these tasks are appropriate to the scope and previous experience of the activities under scrutiny. Before the risks associated with a particular activity can be assessed, it is necessary to systematically identify the hazards which may affect, or arise from, the particular operation under consideration. HAZID is a technique for the identification of all significant hazards associated with the activity under consideration.

This HAZID (Hazard Identification) study is a key element of this project. The objectives of the HAZID study are:

- To agree a risk matrix appropriate to drilling and operation of deep wells in the Netherlands for low enthalpy geothermal energy production Identify all possible hazards pertinent to the scope
- Identify feasible scenarios giving rise to those hazards
- Determine significant scenarios (Risk assessment)
- For significant scenarios, identify mitigation options
- Identify areas for improvement and/or further analysis where mitigation is considered to be inadequate

A key output of the study is the definition of the main areas of focus for well integrity assessment for low enthalpy geothermal energy systems in the Netherlands.

The study was based on a typical Dutch geothermal doublet well configuration with the study scope defined as the well bore through to the last valve on the Christmas Tree before the facility piping, as shown in Figure 1.

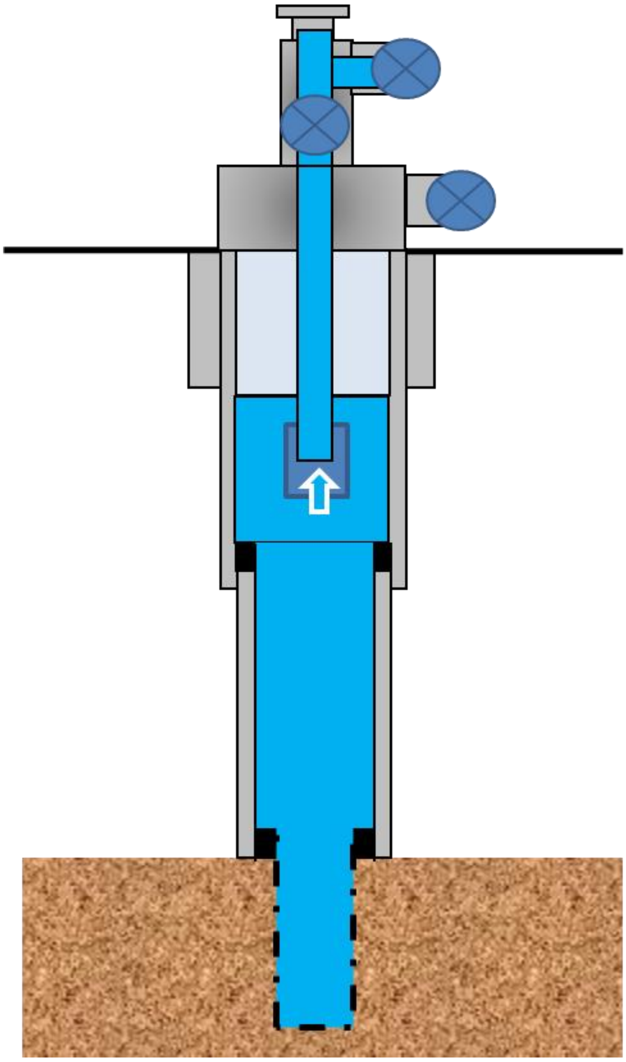


Figure 1. Diagram of Typical Dutch Geothermal Well

2.2 HAZID Study Methodology

HAZID is a technique for the identification of all significant hazards associated with the activity under consideration. The methodology adopted in this HAZID study follows EN ISO 17776:2002, "Petroleum and natural gas industries – Offshore production installations – Guidelines on tools and techniques for hazard identification and risk assessment" as an established good practice. Figure 2 highlights the steps in this process that fall within the objectives of this HAZID study.

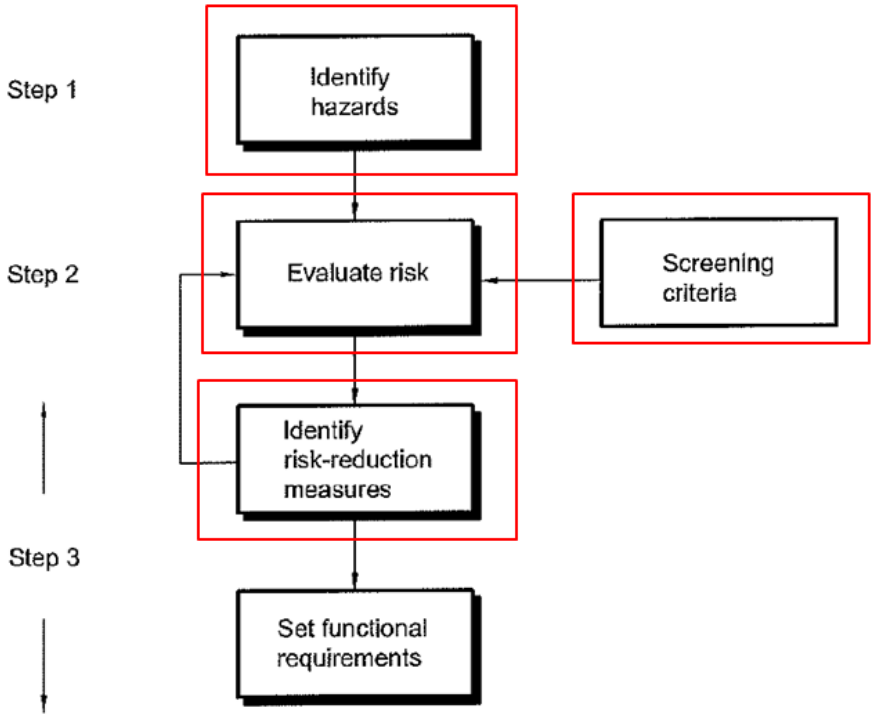


Figure 2. Risk Management Process and HAZID Objectives

2.2.1 Hazard Identification

Prior to the HAZID workshop a hazard list was developed from the guidance provided in ISO 17776:2002 Annex D, which was considered to represent an established and appropriate basis. Hazards not considered relevant to the scope of this study, such as those specific to offshore and hydrocarbon processing operations, were removed. Table 1 shows the resulting hazard list. During the HAZID study workshop this list was again reviewed and used to generate a list of potential hazard scenarios.

Table 1. Hazard List

No.	Hazard
01	Hydrocarbons
02	Other flammable materials
03	Pressure hazards
04	Hazards associated with differences in height
05	Dynamic situation hazards
06	Environmental hazards

No.	Hazard
07	Hot surfaces
08	Hot liquid
09	Electricity
10	Electromagnetic radiation
11	Ionizing radiation
12	Asphyxiates
13	Toxic gas
14	Toxic fluid
15	Toxic solid
16	Corrosive substances
17	Biological hazards
18	Ergonomic hazards
19	Security-related hazards
20	Use of natural resources
21	Noise

2.2.2 Risk Criteria

A key step in the risk assessment process was the development of screening criteria appropriate to Dutch geothermal operations. Prior to the HAZID workshop, existing risk matrices were sought from various operators across the DAGO organisation. These were used to develop an initial set of risk criteria that could be meaningfully applied across all DAGO operators. These were circulated to project stakeholders for comment and then presented at the HAZID workshop for further comment and endorsement. The risk matrices developed are consistent with the guidance provided by EN ISO 17776:2002 and comprise a summary 5x5 consequence versus probability matrix supported by five further matrices in which consequences are rated more explicitly in terms of People, Environment, Assets, Reputation and Social impacts. The endorsed risk matrices for this study incorporating comments agreed at the HAZID workshop are presented in Appendix 7.

2.3 HAZID workshop

A full day HAZID workshop was convened on June 8th, 2016 at the Restaurant Den Burgh, Rijnlanderweg 878, 2132 ML Hoofddorp, Netherlands. The workshop attendees comprised representatives from the project team and a range of well design, drilling and operations experts invited by DAGO. Appendix 8 lists the team members, the organisation they represent, their area of expertise and their role on the team.

During the course of the workshop the team performed the following tasks:

- Team HAZID awareness training
- Review and agreement of Risk Matrices
- Review of Hazard List

The team split into two sub teams to then allow more focused scrutiny of the identified hazards associated with the drilling (subsurface/geological formation) and the operational (operation, workover, abandonment) phases. The membership of each team is indicated in Table 2. Each sub team performed the following tasks:

- Develop a list of credible scenarios from the hazard list
- Qualitatively determine the 'worst case' consequences and likelihood, assuming no mitigation
- Use the risk matrix to assign an <u>unmitigated</u> risk category (High, Medium, Low)
- For those scenarios with an <u>unmitigated</u> risk of High or Medium identify existing mitigations that would either reduce the likelihood or limit the consequences
- Qualitatively determine the consequences and likelihood, assuming existing mitigation
- Use the risk matrix to assign a <u>mitigated</u> risk category (High, Medium, Low)
- For those scenarios with an <u>mitigated</u> risk of High or Medium identify recommendations to achieve further risk reduction

Each sub team was assigned a discussion leader with the HAZID Facilitator providing oversight across the two sub teams. An Excel spreadsheet was used to help guide the sub teams through this exercise in a consistent manner. The resulting drilling and operation worksheets are contained in Appendix 5 and 6 respectively.

2.4 HAZID Findings and Recommendations

2.4.1 Drilling

The Drilling HAZID resulted in a total of five recommendations identified as D1-D5 and listed in the Recommendations sections of this report. One of these scenarios had mitigated risk considered to be HIGH and four scenarios where mitigated risk was considered to be

MEDIUM. Three of these recommendations relate to additional reviews prior to drilling and two relate to insurance cover to mitigate economic impacts. No recommendations were raised relating to inadequacies identified with the actual drilling operations.

It is important to note that drilling activities for geothermal wells follow the same planning and execution process as for hydrocarbons wells. As such, the discussion in the drilling sub-team was focused on the hazards of the drilling operations many of which are common to both geothermal and oil and gas wells. Drilling for oil and gas exploitation is a well-established and controlled activity and is commonly conducted by an experienced drilling contractor rather than the operating company. This experience and understanding of the hazards associated with drilling is reflected in the number and nature of recommendations raised during the HAZID. "Well design shall be competent to assure containment over the wells life cycle" 'this was identified as a safeguard for a number of scenarios. The Dutch geothermal industry does not adopt a particular ISO, API or NORSOK standard but rather uses specific elements of these where applicable, such as defining a Basis of Design, performing a hydrocarbon risk assessment and the development of a Risk Register (as per ISO16530) that carries through the entire well lifecycle.

2.4.2 Operation

The Operation HAZID resulted in a total of thirteen recommendations identified as O1-O13 and listed in the Recommendations section of this report. The majority of these recommendations related to corrosion scenarios and identify the need to gather more data to better inform well design, material selection and optimisation of corrosion management during operation. Also recommended is better understanding of the corrosion risks related to the different water chemistries encountered to optimise the management of the appropriate chemical treatments as both are critical to the success of geothermal well corrosion management. The potential for improvement in the human factors and ergonomic standards across the geothermal industry are identified. One recommendation was raised to review the economic impact of flooding due to natural causes.

2.4.3 Evaluate how risk assessment relevant for well integrity can be improved in future using (semi) quantitative methods or other risk assessment methods.

The HAZID study reported here was conducted based on a representative, generic well configuration and the team's knowledge of current drilling and operation practice, in order to identify areas where improvements are required in the management of geothermal wells in the Netherlands throughout their lifecycle. Potential future activities that would enhance risk management are noted below:

2.4.3.1 Revisit HAZID

The operations phase HAZID identified a number of the recommendations related to gathering data to gain a better understanding of the risks. Consideration could be given to revisiting this study once these recommendations have been completed to determine the adequacy of existing mitigation.

2.4.3.2 Risk Assessment of Operating Wells

Consideration could also be given to conducting a similar HAZID and risk assessment for each operating well doublet to confirm the risks specific to the location have been considered and are adequately mitigated. The study could follow the same basic methodology used here but with a smaller team comprising representatives from the well operator, original drilling contractor, maintenance contractor, well integrity specialist, as appropriate. The risk matrices developed as part of this project are intended to provide a reference point for use by those designing, drilling and operating wells.

A key input to such a study would be the process conditions, characteristics of the specific well (initial and current), surface and subsurface environment and stakeholder proximity. A number of recommendations raised in the HAZID study relate to the identification and consistent recording of key parameters relevant to well integrity.

2.4.3.3 Risk Assessment during Well Design Phase

Regarding future wells, the scope of the risk assessment conducted during the well design phase could be reviewed and a similar semi-quantitative risk based assessment incorporated.

2.4.3.4 Periodic Review / Management of Change

Once a baseline assessment has been performed, consideration should be given to providing guidance on performing periodic risk assessment review throughout the well lifecycle, particularly ahead of any changes to operations. A review could be triggered by changes in the SOE for e.g. water chemistry, well casing degradation and well intervention activities etc.

2.4.3.5 Operator Competence Review

One perceived area for improvement is operator competency with regard to risk management which may vary markedly between companies and sites. Adequacy and effectiveness of any risk management training given to operators could be used to confirm the extent of variability between operators, identify good and poor practice, and be used to develop a competency benchmark for operators.

2.4.4 HAZID Outcome

The HAZID study performed as part of this project benefited from the involvement of a broad range of stakeholders bringing many years of experience and expertise. Drilling, either for oil and gas or geothermal exploitation, is a well-established and controlled activity that is commonly conducted by an experienced drilling contractor rather than the operating company. The Drilling HAZID study identified a limited number of areas for improvement for the drilling phase activities.

By contrast, the Operation HAZID identified the need to gather more data to better understand the risk during the operation phase to inform well design, material selection and optimisation of corrosion management during operation. This area needs to be the main focus to develop a robust set of guidelines relevant to low enthalpy geothermal energy systems in the Netherlands.

A number of suggestions for further risk improvement studies have been made to build on the learning from this generic study.

3. WELL BARRIER

3.1 Well barrier identification in Geothermal wells

The barrier and well integrity management aspect of this study is aimed mainly at safety in the drilling phase and containment in the operational phase.

Most geothermal wells drilled in the Netherlands produce water which show traces of hydrocarbons (mostly dissolved hydrocarbon gas with some carbon dioxide,nitrogen and potentially hydrogen-sulphide). Moreover (shallow) gas pockets cannot be excluded. In most cases, the amount of gas can be attributed to gas that is dissolved in the geothermal water but in one case, small amounts of oil are produced. However, all geothermal wells developed so far in the Netherlands are non-artesian (flow is aided by a submersible pump), thus in the exploitation phase the main concern is containment. Based on this the fluid column is considered as a barrier / barrier element.

Co –production of gas and oil that does not lead to a self flowing well condition is expected to be the most common situation that will be encountered in the low enthalpy geothermal wells in the Netherlands. The barrier philosophy for the geothermal wells drilled to date is based on this current situation.

3.1.1 Types of Barriers

The following categories of barriers have been employed by Geothermal Operators:

- Drilling / Well Testing Barriers
- Well Operation Barriers
- Intervention/Work Over Barriers
- Suspension and Abandonment Barriers

3.1.1.1 Drilling / Well Testing Barriers

- Fluid Column
- BOP stack
- Cement
- Casing
- Liner Hanger
- Wellhead

3.1.1.2 Well Operation Barriers

- Formation water
- Wellhead/Xmas Tree Valves
- Cement

- Casing
- Liner Hanger

3.1.1.3 Intervention / Work Over Barriers

- Formation water
- Plug (Permanent or Retrievable)
- Casing
- Liner Hanger
- Cement

3.1.1.4 Suspension and Abandonment Barriers

- Plugs (Cement plug and Mechanical plug)
- Casing
- Cement
- Liner Hanger

3.2 Barrier Philosophy

This Barrier philosophy is aimed at always maintaining a secure, pressure tight envelope around the constituent parts of the well and fluids that it contains, and thereby, protect personnel, the environment, and equipment. This includes the definition of the characteristics, operational requirements, verification of integrity and maintenance of well barriers.

3.2.1 Dual Barrier strategy

During normal operation of a standard low enthalpy geothermal well in the Netherlands, the well relies on the hydrostatic fluid column and the hardware barrier as two barriers.
The basis for reliance on the fluid column as a barrier element is the fact that without the ESP running, no water production to the surface will arise.

- ✓ The Well produces only because an ESP reduces the pressure at reservoir level;
- ✓ When the ESP is switched off, the fluid flow stops and the well is dead. No free flow from the well;
- ✓ The static level in the "Production annulus" is typically some 20-100 meters below ground level;
- ✓ The dynamic fluid level in the "Production annulus" is typically some 200-300 meters below ground level;
- ✓ There is some associated gas in the produced water, ranging from 1-2 m^3 per m^3 of water, under atmospheric conditions, but
- ✓ Bubble point of the water is low, around a few bar, and so gas evolution is not a major concern (although there has been one high bubble point which was around 90 bar)

3.2.1.1 Double or Redundant Hardware Barrier Consideration

The provision of double or multiple barriers or multiple redundant barriers may relate to concern over potential failure of certain types of single hardware barriers in specific circumstances. Reasons for having secondary barriers may include:

- Failure of a barrier in an emergency situation requiring either protection of the failed barrier or secondary containment.
- The need to achieve a leak-tight 'combination barrier' especially of valves for isolation purposes.
- Providing a second barrier for the purpose of confirming absence of leakage or verification testing of the primary barrier.
- Barrier designs where ongoing verification of the primary barrier / seals is not possible – secondary or tertiary barrier components being provided as insurance / back-up.

3.2.2 Deviation from Barrier Philosophy

If a change of operating conditions or failure of a barrier, requires deviation from this philosophy:

- ❖ The decision to deviate from this Barrier Philosophy shall only be made following assessment of risks by a group of informed, responsible and accountable individuals.
- ❖ Operation out-with this Barrier Philosophy requires formal approval of the SSM.

3.2.3 Cementation of Casings / Monitoring of annulus

Unlike oil and gas wells, where most of the casings are usually run back to the surface, and are partly cemented , the geothermal well only has one full casing string, of a telescopic design (with liners) down to the reservoir. The high thermal stresses imposed on this casing demand uniform cementation over the full casing length, such that the stress is distributed over the length of the casing as uniformly as is possible and such that stress concentration is avoided. There is usually no annulus that can be monitored in a low enthalpy geothermal well in the Netherlands from the well design, apart from a few doublets with cementing issues that created a B annulus that could be monitored. Cement bond is confirmed by CBL when the well is constructed and should be verified by CBL after 10 years in operation.

3.2.4 Requirements for Barrier Integrity

The integrity of barriers is crucial to well operation within the Safe Operating Envelope. The failure of a single barrier should always be considered to have serious potential consequences that need to be monitored and, if required, adressed.

- The barriers shall be defined and criteria for (what is defined as a) failure shall be determined (see Fig 3)
- The integrity of barriers shall be confirmed upon installation and at regular intervals as per the type of barrier.
- It shall be possible to test well barriers. Testing methods and intervals shall be determined.
- The position/status of the barriers shall be known at all times.

3.3 Description of possible failure modes of barriers

Figure 3 below shows the well barrier elements during the full well life cycle. It also lists the associated risks, the barrier failure modes and verification method. Guidelines to ensure safe operations and remediation activities are also included.

Geothermal Well Integrity Study April - Sept 2016	WG INTETECH WEP BAKER RISK

	Situation	Primary Barrier	Secondary Barrier	Risks	Barrier Failure Modes	Testing / Monitoring	Guideline	Remedy
INSTALLATION PHASE	Drill surface hole Conductor	Fluid column		Pollution of ground water Formation instability Fluid losses	Fluid losses Poor cement - no isolation	Pressure graph during cement job; Cement Quality Log, eg CBL, USIT; Monitoring well	Maintain proper fluid properties; Drilling programme Cementing guideline; Drilling programme	Top fill cement; Install short (300 - 500m) extra casing prior to next hole section
	Drill 17 1/2 inch hole Install 13 3/8 inch casing	Fluid column		Shallow gas Formation instability Fluid losses	Fluid losses; Formation failure (frac at shoe)		Maintain proper fluid properties; Drilling programme	
			Cement Conductor		Poor cement - no zonal isolation	Pressure graph during cement job; Cement Quality Log, eg CBL, USIT	Cementing guideline; Drilling programme	Top fill cement; Monitoring well
	Drill 12 1/4 hole Install 9 5/8 inch liner	Fluid column		Overpressures Formation instability Fluid losses	Fluid losses; Formation failure (frac at shoe); Insufficient overbalance – influx		Maintain proper fluid properties; Drilling programme; Well control guidelines	
			Cement Casing Linerhanger Wellhead Spools & BOP	Wrong position of liner shoe Casing damage Bad cement (job), poor isolation Leaking liner hanger Leaking wellhead Failing BOP	Poor cement - no zonal isolation Casing damage - erosion Leaking casing connection Linerhanger leaks Wellhead / BOP leaks	Pressure graph during cement job; Cement Quality Log, eg CBL, USIT Make-up (torque/turn) graphs; Pressure testing; Metal collection; Base line calliper log Pressure tesing Pressure testing	Cementing guideline; Drilling programme Casing installation guidelines; Drilling programme Liner installation guideline Wellhead installation guidelines; Drilling programme	Tieback liner / Scab liner / Casing patch Tieback packer Wellhead repair or replacement; Repair / Replace BOP

	Situation	**Primary Barrier**	**Secondary Barrier**	**Risks**	**Barrier Failure Modes**	**Testing / Monitoring**	**Guideline**	**Remedy**
	Drill 8 1/2 inch hole Install 7 inch WWS / Slotted liner	Fluid column		Overpressures Formation instability Fluid losses Wrong position of liner shoe	Fluid losses; Formation failure (frac at shoe); Insufficient overbalance – kick		Maintain proper fluid properties; Drilling programme Well control guidelines	
			Cement Casing Wellhead Liner hanger Spools & BOP	Casing damage Leaking liner hanger Leaking wellhead Failing BOP	Poor cement - no isolation Casing damage - erosion Leaking casing connection Linerhanger leak Wellhead / BOP leaks	Pressure graph during cement job; Cement Quality Log, eg CBL, USIT Make-up (torque/turn) graphs; Pressure testing; Metal collection; Base line calliper log Pressure tesing Pressure testing	Cementing guideline; Drilling programme Casing installation guidelines; Drilling programme Liner installation guideline Wellhead insatallation guidelines; Drilling programme	Tieback liner / Scab liner / Casing patch Tieback packer Wellhead repair or replacement Repair / Replace BOP
EXPLOITATION PHASE	Production	Fluid Column Cap rock	Casing Wellhead & valves Liner hangers	Well is produced with ESP. When pump stops, well kills itself Corrosion / erosion Leaks Ingression of oxygen	Casing damage Linerhanger leak Wellhead / Valve leaks	Metal loss; Calliper log Pressure tesing Pressure testing	Corrosion monitoring guideline; Corrosion prevention guideline Liner installation guideline Wellhead installation guidelines; Maintenance guideline	Well repair; Regular pressure tesing casing; Tieback liner. Tieback packer Wellhead repair or replacement
			Cement			Cement Quality Log, eg CBL, USIT		

	Situation	Primary Barrier	Secondary Barrier	Risks	Barrier Failure Modes	Testing / Monitoring	Guideline	Remedy
	Intervention	Fluid Column	Casing Wellhead & valves Liner hangers	Well is produced with ESP. When pump stops, well kills itself Ingression of oxygen	Insufficient overbalance - influx Casing damage Linerhanger leak Wellhead / Valve leaks	Monitor well prior to opening Metal loss; Calliper log Pressure tesing Pressure testing	Intervention programme Corrosion monitoring guideline Liner installation guideline Wellhead installation guidelines; Intervention programme	Install BOP Well repair; Regular pressure testing casing; Tieback / Scab liner / Casing patch Tieback packer Wellhead repair or replacement
			Cement			Cement Quality Log, eg CBL, USIT		
ABANDONMENT PHASE	Abandonment	Casing and cement First cement plug in liner hangers		Corroded casing Bad cement behind casing Leaking plugs	Insufficient overbalance - influx Casing damage Bad cement - no isolation Cement plug leaks or remains soft	Monitor well prior to opening Calliper log Cement Quality Log, eg CBL, USIT Pressure tesing Weight test	Abandonment programme Abandonment programme Abandonment programme	Install BOP Mill away casing and cement and set "openhole" cement plug Remove plug and repeat
			Second cement plug Mechanical plug (option)		Cement plug leaks or remains soft Mechanical plug leaks or slips	Pressure testing Weight test Pressure testing Weight test	Abandonment programme Abandonment programme	Remove plug and repeat Remove plug and repeat

Figure 3. Possible failure modes of barriers

3.4 Guidelines for commissioning/handover of completed barriers

3.4.1 Checklists for well handover at different well life cycle phases

The checklist is a type of Well Integrity assessment method where the barrier elements are listed based on analysis of the system, its operating history and lessons learned. This well integrity assessment method requires that well barriers are defined prior to commencement of an activity by identifying which well barrier elements need to be in place, their rating and size, their material specification, the relevant assessment test or monitoring method and specific acceptance criteria. The objectives of the checklists are to;

a. Identify all the hazards relevant to the specific stage of the well life cycle
b. Identify all WBEs and their integrity verification requirements
c. Identify required controls and safeguards for each hazard or WBE failure
d. Check that available controls and safeguards conform to the requirements specified

3.4.1.1 Well Design to Construction Handover Checklist

Well location	
Permit No.	
Well Type	Geothermal Producer/Injector
Well Number	
TD (MD & TVD)	
Completion (ESP)	
Design Life	
Any other key descriptors	

Data	**Well design elements relevant for well integrity performance**	**Design Value**		
Conductor	Cement Sheath Top (m)	xx inch Conductor @yyy m		
Production Casing	Cement Sheath Top (m)			
Liner	Cement Sheath Top (m)	Cemented to the top of liner		
Required Pressure Test Data	**BOP Pressure Test:**	**Intermediate Hole**	**Production hole**	**Liner**
	XXX" Annular Preventer			
	XXX" RAM Preventer			
	XXX" Blind Shear Ram			
	Stand Pipe Manifold?			
	MAASP			
	A Annulus	**B Annulus**	**C Annulus**	
	Casing String Pressure Test:			

	Upon bumping the top cement plug	
	Production Casing (Bar)	
	Liner (Bar)	
	Hanger Seal Test:	
	Production Casing Hanger Seal (Bar)	
	Liner Hanger Seal (Bar)	
	Tubing Hanger Seal (Bar)	
	Cement Bond Log:	
	Production Casing Cement	Without pressure : With xx Bar pressure:
	Liner Cement	Without pressure : With xx Bar pressure:
	Completion Pressure test:	
	Wellhead Side outlet Valves (Bar)	
	Xmas tree valves (Bar)	
	Xmas tree (Bar)	
	TH Neck (Bar)	
Management of change	Add changes from the BOD	
Data Verification	Drilling Department:	
	Signature:	
	Date:	

3.4.2 Advice on monitoring of barriers / Operational Well Integrity

The aim of active monitoring of well barriers is to ensure containment of well fluids within the wellbore, maintain effectiveness of the well barrier envelope and the ability to analyse the well data to predict failure. From the design of geothermal wells in Netherlands, there is no casing – casing annulus that can be actively monitored. Active monitoring of the barriers is not practicable but verification is possible, only when the production tubing and ESP is removed from the producer and the injection tubing from the injector. Operators already have an obligation to run a "wall thickness log" to get an indication on corrosion. This can be followed by pressure testing the entire well from the lowest liner hanger / packer to the well head to confirm pressure containment of the barrier.

Monitoring of operational well integrity parameters also optimises well management and gives cost-benefits by proactively identifying issues that can be addressed before they become serious (e.g. gas separation build up, increasing scaling tendency, scale build up or corrosion etc.)

This can be achieved by:

- ❖ Regular inspection and testing of Xmas Tree/valves to provide confirmation of the integrity of the outer envelope of the well. Inflow testing of the Wellhead/valves may only be possible during well interventions.
- ❖ Regular scheduled collection and analysis of data will lead to better safety performance and ultimately lower operational cost.
- ❖ Scheduled (quarterly) sampling of the produced water or any other determined frequency based on risk assessment and check of the Tubing – Casing annulus if possible to detect the presence of separated gas.
- ❖ Use of personnel who have been trained in relevant Well Integrity management.
- ❖ Pressure recording on surface for reinjection wells.
- ❖ Recovered tubing to be inspected after retrieval to check for corrosion/scaling etc.
- ❖ Wall thickness or ID measurement of the casing during well interventions.
- ❖ Establish gradient and fluid column of Geothermal well versus aquifers to identify risk from out flow over the well life cycle.

3.4.3 Wellhead/Xmas Tree Maintenance

This section provides guidance for the testing, maintenance and verification of all Geothermal Wellhead/Xmas tree and associated valves in the Netherlands. The key objectives are:

- ❖ Standardisation of maintenance and repair strategy across all operators.

- ❖ Compliance with legislative requirements for well examination and verification.
- ❖ Application of API standards for Wellhead, Xmas Tree and valves.

3.4.3.1 Strategy

The Wellhead is considered to be a single barrier together with the production casing, the Tubing Hanger seals in the Wellhead and the Xmas Tree.

The integrity of these barriers must be maintained at all times. This will be done by the following means:

- ❖ Routine visual inspection
- ❖ Routine valve function and pressure testing where feasible
- ❖ Routine maintenance (lubrication)
- ❖ Compilation and upkeep of detailed records of the above activities in a chronological log.

Testing and maintenance should be carried out in accordance with Original Equipment Manufacturer (OEM) instructions.

- ❖ It is very important that the initial construction of the well is good and that the materials and installation be of the correct standard. Any money saved on poor material or workmanship can be quickly lost e.g. if there is a leak or a problem with a valve.
- ❖ Once the well is in service, it is important that a weekly visual inspection be made to detect any signs of leaks or damage.
- ❖ Lubrication is an important maintenance item; this should be carried out during the routine testing.
- ❖ There should be no visible leaks on the wellhead as dissolved gases (CH4, CO2 etc.) that separate from the water may accumulate in the cellar where applicable.
- ❖ Special safety precautions should be taken when working in cellars, where present, due to possible accumulation of poisonous or asphyxiate gases.
- ❖ A buddy system, gas ampoules to measure the gases CH_4, H_2S and CO_2 or gas personal alarms are useful.

3.4.3.2 Schedule of Wellhead/Xmas Tree Maintenance

The following provides guidelines on the scheduling of maintenance:-

1. Regular in service valve integrity testing should be carried out on all Wellhead / Xmas Tree valves at intervals not exceeding twelve months.

2. Any valve, which fails to meet the defined test requirements, must be replaced or repaired as soon as operationally convenient.
3. All integrity testing and inspection should be carried out by trained competent persons.
4. All results obtained during testing and inspection should be recorded and retained for the service life of the respective equipment.
5. Maintenance and testing frequency of the wellhead should reflect changes in the equipment condition caused by erosion or corrosion; well types and individual wells with known corrosion/erosion risks require more frequent testing.
6. Although 12 months is the recommended frequency, Operators can carry out a risk assessment to justify deferring the manintenace if the valves have shown no failures over a certain period of time.

Recommended maintenance frequencies are shown in table 2 below.

Table 2. Maintenance frequency

	Low Enthalpy Geothermal Well	
Frequency	**Tree**	**Wellhead**
12 monthly	T & G	T & G
Five yearly/during Interventions		T & G

Where: T = Test; G = Function and Grease (lubricant or sealant)

3.4.4 Requirements for valve pressure testing

Testing of the integrity of well barriers require that measurements can be made to confirm the barrier prevents fluid flow or transference of pressure within defined acceptance criteria. Besides visual inspection for leaks, the wellhead valves should be pressure tested as per manufacturer's specifications.

3.4.5 Test Failure/Valve leakage

Where a barrier fails to meet the test acceptance criteria, an estimate of the potential leak rate must be made. This estimate shall be used as the basis for risk assessment to determine whether operations can proceed or not.

- ✓ The maximum allowable leak rates for geothermal well components will be based on good industry practise. (see 3.4.5.1)
- ✓ In cases of failure, the valve should be greased where appropriate as per manufacturer's instructions and functioned to ensure correct travel. The test should then be repeated. Valves that fail more than 3 times consecutively in one test campaign are to be repaired replaced.
- ✓ Test reports are to be kept for the life of the equipment.

3.4.5.1 Well Barrier Acceptance criteria

Well barrier acceptance criteria are technical and operational requirements that need to be fulfilled in order to qualify the well barrier or WBE for its intended use. Performance Standards or acceptance criteria must be defined against which the integrity of a barrier can be assessed.

3.4.5.1.1 Standard Acceptance Criteria

API 14B and API 6AV2 recommend leak rate acceptance criteria of 400 cc/minute for liquid or 15 scf/minute for gas for Surface Safety Valves and Underwater Safety Valves for hydrocarbon fluids.

ISO 16530-1 refers to 2 cc per inch diameter per minute as acceptance criteria, a 7 valve would be allowed to leak 14 cc/ min which is quite stringent for a water well with low pressure delta, so the 400 cc/ min is more acceptable norm for water Geothermal wells.

Below is a proposed leak rate acceptance matrix, Operators are encouraged to evaluate and adapt the matrix for their specific conditions as part of their SHE plan.

Table 3 Acceptable Leak rate acceptance matrix (Adapted from ISO 16530 - 2)

Acceptable leak rate matrix for: Operator: Well Type: Other:			
Increasing Allowable Leak Rate →			
Operator to perform a risk based analysis to determine allowable leak rates for various barrier elements and for different well types.	**Zero Leak Rate (bubble tight)**	**2cc/min per inch of valve size**	**Leak rate as defined in API 14B 24 l/hr or 900 scf/hr**

Xmas Tree Valves			
Xmas Tree body			
Wellhead Valve			
Bonnets, Flanges and Fittings			
Installed VR Plug			
Tubing Leak (Sub hydrostatic well)			
Production Casing leak (Sub hydrostatic well)			

3.5 Fluid Sampling / Corrosion & Scale monitoring

- **What to sample** – Water and Gas samples. Hydrocarbons should also be separated if present, or may be analysed as part of the gas and liquid phases.
- **Frequency** –Quarterly but frequency may be reduced once consecutive analyses show consistent data.
- **Sample site** – Inlet Separator (Liquids). Separator (Gas)
- Water analysis at laboratory to include standard water chemistry Cations and Anions plus residual levels of any chemicals injected downhole
- Gas analysis at laboratory to include Hydrocarbon compounds if present, composition(%mol) of gases like CO_2, H_2S, O_2 (Mandatory)
- Install corrosion coupons of same material as the casing and measure materials weight loss on set intervals

Optional data for any hydrocarbon (gas or liquid)

- Gross Calorific Value (kcal/m^3)
- Relative density of liquid hydrocarbon condensate

Evaluation of corrosion and scaling tendency of the downhole tubulars will also require the following inputs, which need to be measured at a higher frequency (at least weekly)

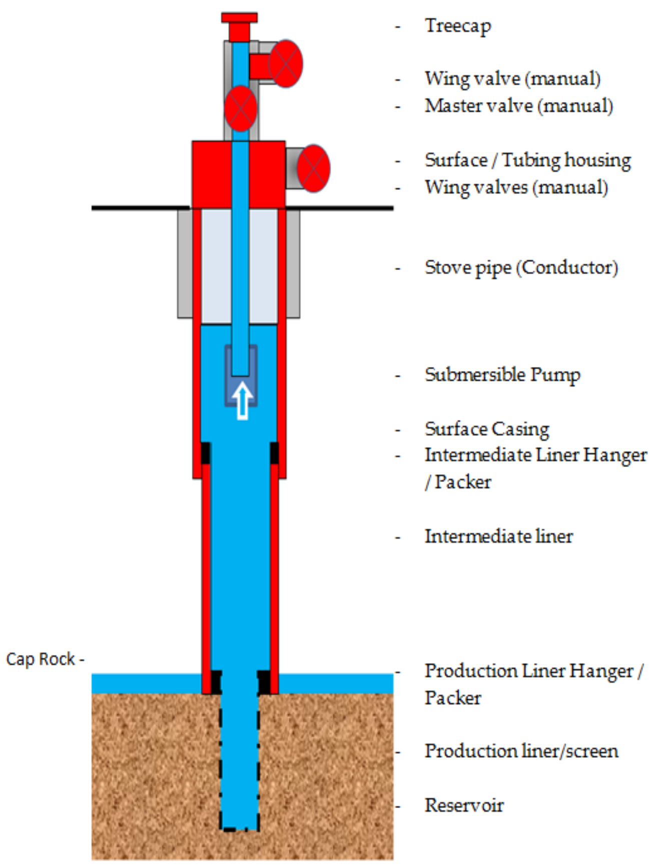
- Producer and Injector wellhead temperature and pressure
- Water flow rate (m3/day)

- Note: The Producer and Injector casing bottom hole temperature and pressure (reservoir conditions) data may be obtained from initial drilling data/tests and the current fluid gradient can be used to extrapolate the formation productivety index. On opportunity basis, a static gradient survey could be run to confirm bottom hole pressuers and temperatures if required.

3.6 Well Barrier Schematics

Well barriers and their role in ensuring containment may be illustrated as a schematic. It is an important tool for reliability and risk assessment of the well in all phases of its life cycle and for well integrity assessments. (See Figure 3 and Appendix 3)

XYZ Operator			
Well:	Prepared by:	Date:	Primary Well Barrier to the reservoir
Well type:	Approved by:	Date:	Secondary Well Barrier to the reservoir
Date Original Well Completed:		Tree is rated to:	
Date Workover 1 Completed:		Wellhead is rated to:	
Date Workover 2 Completed:		Tubing is rated to:	
Drawing Ref:		Drawing Rev:	
Current Well Status: *Producing* Date:			



Barrier Element Table	
Barrier Element	**Element Verification**
Primary Well barrier to Reservoir	
Cap Rock Formation/Well Fluid	Xxx Equivalent mud gradient from LOT or FIT s.g Fluid S.G. and static fluid level
Secondary Well Barrier to the reservoir	
X-mas Tree Cap	PT to xxx. Leak detection
X-mas Tree Wing Valve	PT to xxx. Leak detection
Production Liner Hanger / Packer	PT to xxx w/ MW yy s.g
Intermediate Liner Cement	TOC at TOL – Cement quality Logging (e.g. CBL):
Intermediate Liner	PT to xxx w/ MW yy s.g. Caliper or wall thickness logging
Intermediate Liner Hanger / Packer	PT to xxx w/ MW yy s.g
Surface Casing	PT to xxx w/ MW yy s.g. Caliper or wall thickness logging
Surface Casing / Tubing Housing	PT to xxx w/ MW yy s.g. Leak detection
Wellhead Wing Valve	PT to xxx w/ MW yy s.g. Leak detection
Master Valve	PT to xxx w/ MW yy s.g. Leak detection
Well Integrity Notes:	
1. Xxxxxxxx	

Figure 4. Well Barrier Schematic

4. DATA MANAGEMENT

The categories of data that should be collected for geothermal wells are:

Well design data

- The basis of design document
- Well design document
- Well as-built structure including: casing configuration, tubing details, ESP type, well completion schematic and wellhead configuration
- Wellhead valves design data (supplier, model, pressure rating, diameter, material, date of installation, date of any replacement)

Well construction data

- Well test results after construction
- Well logs (CBL, casing calipers, tubing caliper run at any stage of the well life)
- End of well report
- Record of bottom hole pressure and temperature
- Well Schematics showing data for Operation and well integrity management.
- Integrity checklist from construction to operation
- Changes or variatio from basis of design and effects on operating limits
- Well handover

Well operation data

- ❖ Well Integrity history log showing relevant data below.
    - ✓ Date of wellhead valves lubrication and date and result of testing plus any reason for failure
    - ✓ Date of any fluid sampling, location of fluid sample, chemical analysis of gas and of water (specified species to be collected on consistent basis
    - ✓ Record of calculated scaling index of water phase.
    - ✓ Date and record of visual examination of wellhead and cellar (photgraphic record) including notification of any signs of leak, estimate (measurement) of leak rate
    - ✓ Date and value of routine monitoring of temperature and pressure at wellhead of producer and injector well.
    - ✓ Date and value of flow rate of fluid from the wellhead (liquid an gas) either from meter or from well tests.
    - ✓ Date and details of chemicals injection rates and types.
    - ✓ Date of ESP pump replacement. Record of reason for replacement and of any inspection report.

- ✓ Date and inspection report of tubing removed from the well
- ✓ Date and record of any other well intervention
- ✓ Tracking of any other data related to the well equipment change-out or data gathered or tests carried out.
- ✓ Changes to well operating limits or variations, deviations during the operating period

Well suspension and abandonment data

In the Netherlands, abandonment requires a separate work program and SHE plan.

- Date of any well suspension and details of well condition.
- Date and record of well abandonment plan and details of abandonment design.

Whilst these data may be gathered and stored in various electronic formats manually (Excel, MS Word etc) in the first instance, it is recommended that an appropriate software is used. There are various specialist well integrity software products on the market that would be appropriate. Besides acting as a relevant repository of informaation, such software can schedule when tasks should be done and alert if any activities are behind schedule or if data entered exceeds the safe operating range or any other integrity controls.

The operators within DAGO could potentially share a single cloud based software system but with privileges controlled so that only the individual operators would be able to input data for their own location. Consideration might be given to the value of sharing across all the operators the capability to “view” all the data in the system, for the purposes of lessons learnt and improvement of the statistical significance of information (more tests).

5. INNOVATIONS FOR DRILLING AND WELL COMPLETIONS

The purpose of innovative (or alternative) approaches should be aimed at:

- Improving the ability to monitor barrier integrity;
- Reduction of corrosion or wear;
- Prevention of barrier failure;
- Cost reduction without jeopardising the above.

5.1 Composite/Non - Metallic Tubulars

The use of composite tubulars has the following advantages:

- The material is absolutely corrosion resistant;
- Hence reduced operational cost over the life cycle;
- The tube has a weight which is only some 14 – 15% of that of a steel tube of the same size;
- Smaller rigs can be used, resulting in cost reduction.

Some disadvantages of the use of composite tubulars are:

- The wear resistance is less than that of steel;
- Care must be exercised when working inside the pipe, e.g. wireline work
- Internal diameters may be less than comparable steel tubulars

Non-metallic casing uses solid GRE or GRP (glass reinforced polyester) for the casing. The performance of this product is well established for water handling for piping at the surface. Issues for consideration downhole are connection design and integrity.

5.2 Rod Driven Pumps

A rod driven downhole pump has its electric motor at surface; hence maintenance is easier than for an ESP. The pump is driven by a long shaft. There are two versions:

- A PCP version - Progressive Cavity Pump, which is similar to a Moyno Pump;
- A turbine version - Similar to the pump part of an ESP, but driven by a shaft. The capacity of this pump can be as high as 120 l/s (> 400 m3/hr) or even higher. A rod pump that could be retrieved by crane will save on costs and time.

The major advantage of both pumps is the ability to put a tail pipe underneath the pump, which can then be stabbed into the PBR of the liner hanger. By doing so, a closed annulus can be created between the production tubing and the casing, which can be easily monitored. Furthermore, the produced fluid is no longer in contact with the casing, hence no associated corrosion or scaling. The initial costs for rod driven pumps are however higher but this might be offset by reduced operational cost over the lifetime of the system.

5.3 Installation of a tieback string

At any point after the drilling of the well, even after several years of production, a tieback string can be installed in the well. This string can be stabbed in the PBR of the lowermost liner hanger. A closed annulus will hence be created between the tieback liner and the casing, which can be easily monitored. At surface the tieback liner has to be hung off in an additional wellhead spool.

One of the major advantages of a tieback liner is the ability to retrieve it at any point in time. The major disadvantages are a reduced inner diameter of the well and the additional costs. The reduced diameter also has an effect on the selection of the ESP. The additional costs may be offset by a reduction in operational costs. For repair of a well with a leaking casing, the installation of a tieback string may be a good option to restore integrity to the well. Other technologies established in the oilfield are casing patches using expandable casings.

A tie back string does not have to be run to max depth. In case the top of the well fails, a tie back to conductor or intermediate casing foot may also work and has the added bonus that the diameter can be bigger making this option more feasible.

5.4 Internally coated casings

Thicker wall selection may be an option for increasing the “corrosion allowance” on the tubing wall thickness which effectively “buy’s” additional service life. However, the economic cost is usually weighed up against the option of coatings. There are a variety of options for internally coated casings. The selection of possible coatings is generally made on the highest temperature, i.e. shut-in bottomhole conditions. Coatings will generally give good protection of the underlying steel for a specific design life, assuming the coating is giving complete coverage of the steel and has been correctly selected for the temperature of service.

The limitations of using coated casings that are typically cited are:

- “Aging” of the polymer over time, particularly where permanently immersed at the highest temperatures. Aging results in a change in the chemical structure which can result in swelling, embrittlement, disbanding. These processes are usually the life-limiting factors and hence design life is a criterion in the selection of the coating type.
- Connection design and integrity, since the coating at pin and box ends can be easily damaged during make-up. Localised exposure of the underlying steel can result in

concentration of corrosion precisely in the part of the casing where there is an easier potential leak path.

- Potential for damage of coated casing if there is any need for wireline or other intervention methods, or during tubing removal. Again, localised damage can lead to local enhanced corrosion rate and possible tendency for corrosion under the edge of the coated area adjacent to the damage.

5.5 Lined casings

This uses a reinforced liner (e.g. Glass reinforced epoxy, GRE) which is cemented into position. This product has been used with quite good success in the oil industry for water injection wells. It is considerably more robust than a coated casing. Historically there were issues with the connections, but these are now apparently resolved with improved connection design. A problem which can arise in water injection wells, but which may be less acute in geothermal wells, though requires design consideration is the reduced bore diameter of these products compared to un-lined casings. This can be sufficient to reduce production or injection rates, and may require consideration of the tubing diameter installed.

High quality polymeric coatings, liners or solid pipe will all offer some benefits in reducing the risk of corrosion, which may reduce the need for chemicals to control corrosion, so these has benefits both in terms of operational cost and also reduced risk of contamination of the environment (both subsurface at the injectors and at the surface in the event of any leak). The tendency for scale adhesion to the surface and build up may be positively affected as well, but scaling will not be entirely prevented simply by changing the casing material.

The use of any option for casing other than conventional API steel casing grades will result in higher capital cost. The life cycle cost benefit of casing material selection needs to be run to provide a basis for casing selection. The cost benefit of corrosion –resistant casing materials will, in general, be favoured for projects with a longer design life.

5.6 Use of Y-tool

Investigate the use of the Y - tool as an option for corrosion logging, dimensions to be checked for sizing purposes and it should also be plugged at the bottom with a wireline removable plug.

6. CONCLUSIONS

Well Integrity Management for geothermal wells in the Netherlands has historically been based on Oil and Gas Industry standards and procedures; this study was commissioned to adapt those standards to the geothermal sector. The Dutch geothermal wells exploited so far have all been non-artesian; not capable of natural flow to the surface, despite many having some co-produced dissolved gas.

This study included a stakeholder analysis to identify the potential hazards, a detailed risk assessment and based on those outputs, generation of guidance on the management of well integrity for low enthalpy geothermal wells in Netherlands.

The HAZID study resulted in a total of 18 recommendations (please see section 7 for more details. These relate mainly to corrosion issues; a comprehensive review of the entire well system to optimize and minimize cost for best corrosion mitigation over the well life, the need to gather more data to better inform well design, material selection, data logging and sharing of information between operators. On closed annuli, positive pressure may be applied (for e.g. Nitrogen cushion) to quickly detect leaks. Annulus alarm and shutdown system to be set up with trigger pressures where possible is encouraged. Creation of a project specific risk register during the Basis of design phase that is updated through the well life cycle will be very beneficial to the management of integrity for geothermal wells. Potential for improvement in the human factors and ergonomic issues across the geothermal industry were identified. Two recommendations were also raised to review the economic impact of natural hazards (flooding and extreme ambient temperatures) albeit perceived as low risk.

Well Barrier Elements for the full well cycle were identified and performance standards established so far as is practicable. Well Integrity for low enthalpy wells in the Netherlands is managed on a dual barrier philosophy based on the hydrostatic fluid level as the primary barrier. The primary barrier (fluid level) needs to be monitored against the gradient of geothermal reservoir versus aquifer gradients / pressures to assure the potential risk of out flow in event of a leak is managed. Futher the risk assessment should include the fluid composition and potential toxic ingredients to fully understand the consequeces of a failed barrier (corroded casing). In the event of capability of natural flow, the fluid level can not be regarded as a barrier. A secondary barrier may be required in the form of an extra casing, however, this would have to be risk assessed based on the likelihood and consequence as explained in ISO 16530-2.

Checklists for handover at different well life cycles has been proposed to aid hazard identification and required controls. A guideline, which can be used as a basis for operators, ammended for any local specific requirements, was also proposed on monitoring, maintaining and verification of well barriers during the operational phase. This included a well barrier acceptance criteria for applicable well components, adapted from ISO 16530, as well as fluid (water and gas) sampling requirements.

Composite/non-metallic tubulars, rod driven pumps and installation of a tieback string (or (expandable) casing patches) are some proposed innovations for drilling, completing and repairing future geothermal wells. Internally coated, lined and non-metallic casings are some opportunities that should be considered to reduce the risk of casing corrosion thereby reducing operational cost and environmental pollution/contamination of ground and surface waters. These various innovations need evaluation from a life-cycle viewpoint to determine if they are cost-effective over the well life.

By addressing the major hazards and through consideration of the recommendations of the selected well integrity guidance document (ISO16530), the study has provided guidance on the geothermal Well Barrier Elements that are to be monitored, maintained and verified so far as is reasonably practicable to ensure containment of the well fluids. The recommended actions to be taken are well within the capability of the Dutch geothermal operators that will require some formal systemising of current practices to be able to provide the necessary confidence in well integrity management.

7. RECOMMENDATIONS

7.1 HAZID Recommendations

The recommendations resulting from the drilling HAZID and operations HAZID are included in the worksheets in Appendices 5 and 6 respectively. As per the defined HAZID methodology, recommendations were raised when the mitigated risk (i.e. accounting for existing safeguards and mitigation) was determined to still be Medium or High on the risk matrix. A small number of recommendations were also raised against scenarios where the mitigated risk was deemed Low but where the team considered the opportunity for further risk reduction improvements existed.

The main issues during the Drilling HAZID were: shallow gas release to wellbore leading to loss of containment and to potential fire; Stuck Pipe; Flooding and Noise Pollution. For the Operations HAZID, the main hazard was gas separating from the brine solution, corroding the upper tubulars and seals, resulting in loss of containment and fire potential. The other main operational hazard was produced and precipitating solids resulting in blockages both in the well bore and of the formation (Injectivity issues) and scale formation. Problems of corrosion, scaling and solids precipitation can be managed in practice by modelling or monitoring to anticipate their severity and by targeted chemical treatment at dosage rates dependent on flow rates.

The recommendations from the Drilling HAZID are the use of independent examination system and external reviewers, use of insurance for unforeseen or unpreventable disasters and rigorous drilling consent/programme review to consider all/most eventualities. The recommendations from the Operations HAZID relate mostly to corrosion issues; a comprehensive review of the entire well system to optimize and minimize cost for best corrosion mitigation over the well life. The need to gather more data to better inform well design, material selection, data logging and sharing of information between operators was recommended. On closed annuli, positive pressure may be applied (for e.g. Nitrogen cushion) to quickly detect leaks. Annulus alarm and shutdown system to be set up with trigger pressures where possible is encouraged. Creation of a project specific risk register that is updated through the well life cycle will be very beneficial to the management of integrity for geothermal wells. Potential for improvement in the human factors and ergonomic issues across the geothermal industry were identified. One recommendation was also raised to review the economic impact of flooding due to natural causes.

7.2 Elements of well integrity management

7.2.1 Software system

Adoption of a well integrity software system will:

- Provide real time management of all data related to well integrity
- Meet the full requirements for Well Integrity Management including real time risk analysis from collected data.
- Provide for the collection, storage, presentation and evaluation of fluid monitoring data needed for corrosion and scaling risk analysis (a need identified by the HAZID)
- Evaluate the corrosion and scaling risks of the wells as the environment conditions in them change over time (fluid composition, temperature and pressure).
- Track chemical usage relative to corrosion and scaling risks and as a means to minimise chemicals volumes and costs
- Interface to any existing databases
- Meet internal and external reporting requirements
- Meet well review requirements
- Provides the basis for continuous improvement by capturing lessons learnt

7.2.2 Well Integrity Assessment method – Well Failure Matrix (WFM)

The Well failure Matrix (WFM) is described in ISO 16530 – 2 as a method for well integrity assessment of wells in the operational phase of the well life. **Objectives**

a. Identify all well barrier elements (WBE)
b. Decide how the integrity of each WBE will be confirmed
c. Define the acceptance criteria for each WBE for each type of integrity check
d. Assign a risk ranking to each single WBE failure event and to combination events. The risk ranking is a semi-quantitative value which considers the well type and well location.

- **Application**
  a. Initially developed to be used during the operational phase but can also be applied to wells at any stage of the well life.
  b. The risk ranking value can be linked to an Action time frame based upon the perceived risk level (i.e. Repair on an opportunity basis, or Repair immediately or within a defined number of months etc).
- **Advantages**
  a. Is recognized by the ISO16530 standard as an internationally applied methodology.
  b. Uses the experience of operator personnel as part of the workshop.
  c. Is systematic and comprehensive, and should identify all WBE assessment tests.

d. Is effective for considering both technical faults and human errors (failure to conduct required tests).
e. Considers single WBE failure events and the escalation of risk associated with combined events.
f. Can be automated in software (e.g. Figure 4) to provide a real time risk ranking which could also be useful for benchmarking of wells in different locations.

- **Limitations**
    a. Value depends upon the experience of the contributors to the workshop where the WFM logic is established.

Search:

Well Failure Action Matrix

Field	Platform	Well	Well Type	Well Status	Risk Category	Action Schedule
Darwin	Darwin Gold	DAR021		In operation	5	details
Capital Territory	NONE	CAP071		In operation	5	details
Capital Territory	NONE	CAP031		In operation - awaiting suspension	5	details
WFAM	NONE	WFAM014		In operation	4	details
WFAM	NONE	WFAM013		In operation	4	details
WFAM	NONE	WFAM012		In operation	4	details
WFAM	NONE	WFAM011		In operation	4	details
Darwin	Darwin Gold	DAR071		Drilling in progress	4	details
Capital Territory	NONE	CAP021		In operation	3	details
Melbourne	NONE	MEL001		Unknown	3	details

Showing 1 to 19 of 19 entries First Previous 1 Next Last

Figure 4 – An example well failure action matrix output used for risk ranking wells in real time, throughout the well life cycle.

7.2.3 Roles and Responsibility (RACI chart)

Roles and responsibility for Well Integrity need definition at each location.

- ✓ Who monitors?
- ✓ Who do they report to?
- ✓ Who fixes?
- ✓ Who manages the well integrity system?
- ✓ Job descriptions

7.2.4 Well Integrity training

Due to the different teams involved in drilling, operating and maintaining the geothermal wells and greenhouses (where applicable), there is need for customised geothermal wells specific well integrity training for all personnel involved. This should be standardised, kept up to date and made available to DAGO and their contractors. Frequency for refreshers should be agreed with DAGO and documented.

7.2.5 Well by well review

Well by well review based on the findings of this document is recommended and shall be implemented not more than 12 months after the report has been issued.

7.2.6 Well Integrity Audit

A well integrity audit is recommended to be carried out by an independent auditor and frequency can be proposed by DAGO and approved by SSM.

8. FURTHER STUDIES REQUIRED

Further studies and research recommended to further develop the Dutch geothermal sector are;

- Corrosion risk assessment and mitigation study
- Tubing and casing material selection life cycle cost study Casing coating selection.
- Composite/Non-metallic tubulars - The long term performance of this product for casing needs investigation.
- Asset integrity management guidance for the complete surface facilities.
- Review of common well integrity challenges with potential mitigation steps set-out for evaluation in any specific case.

APPENDIX 1 RELEVANT RULES AND REGULATIONS

The rules and regulations related to the mining activities in the Netherlands have been checked for their relevance related to subjects such as: Integrity; Risk; Hazard; Safety; Protection.

The relevant rules and regulations are listed below

NATIONAAL:		
Legislation	Specific for mining	Mijnbouwwet *
	Other	Arbeidsomstandighedenwet
Algemene Maatregel van Bestuur	Specific for mining	Mijnbouwbesluit *
		Wijziging Mijnbouwbesluit (Staatsblad 236, 5 juni 2007)
		Besluit algemene regels milieu mijnbouw (Staatsblad 125, 3 april 2008)
	Other	Arbeidsomstandighedenbesluit *
Uitvoeringsmaatregelen	Regulations	Mijnbouwregeling *
		Arbeidsomstandighedenregeling *
	Policy regulations	Beleidsregels arbeidsomstandighedenwetgeving *

*** English translation of the Mining Act etc.**
The original versions of the Mining Act, the Mining Decree and Mining Regulation have been translated into English. These English versions have no legal status, but have been prepared to enlarge the accessibility for non-Dutch speakers.

- Mijnbouwet - Mining Act, effective 1st January 2003 (as amended up to 2012)
- **Mijnbouwbesluit** -Mining Decree, effective 1st January 2003 (as amended up to 13 October 2011)
- **Mijnbouwregeling** Mining Regulation, effective 1st January (updated up to 1 April 2014).
- **Arbeidsomstandighedenregeling** Working_conditions_act_25-3-2013
- **Arbeidsomstandighedenregeling** Working_conditions_decree_25-3-2013
- **Arbeidsomstandighedenregeling** Working-conditions_regulation_23-3-2013_excl.annexes-1

In the following sections a summary is presented from the relevant text of the articles from the different rules and regulations.

Mijnbouwwet (Mining Act)

Mijnbouwwet	**Mining Act**
Artikel 33 De houder van een vergunning als bedoeld in artikel 6 of 25, dan wel, ingeval de vergunning haar gelding heeft verloren, de laatste houder daarvan, neemt alle maatregelen die redelijkerwijs van hem gevergd kunnen worden om te voorkomen dat als gevolg van de met gebruikmaking van de vergunning verrichte activiteiten: a. nadelige gevolgen voor het milieu worden veroorzaakt, b. schade door bodembeweging wordt veroorzaakt, c. de veiligheid wordt geschaad, of d. het belang van een planmatig beheer van voorkomens van delfstoffen of aardwarmte wordt geschaad.	**Article 33** The holder of a licence as referred to in Articles 6 or 25, or, if the licence has lost its validity, the last holder of the licence, must take all steps that can reasonably be required of him to prevent that as a result of the activities carried out by using the licence: a. adverse consequences for the environment are caused, b. damage as a result of soil movement is caused, c. safety is jeopardized or d. the interest of a systematic management of reservoirs of minerals or of terrestrial heat is jeopardized.
Artikel 49 **1.** Bij of krachtens algemene maatregel van bestuur kunnen regels worden gesteld met betrekking tot: a. het opsporen van delfstoffen of aardwarmte; b. het winnen van delfstoffen of aardwarmte; c. het opslaan van stoffen; d. het instellen van een verkenningsonderzoek; e. boorgaten, anders dan ten behoeve van het opsporen of winnen van delfstoffen of aardwarmte dan wel het opslaan van stoffen, dieper dan 500 meter beneden de oppervlakte van de aardbodem; f. pijpleidingen en kabels die worden gebruikt ten behoeve van het opsporen of winnen van delfstoffen of aardwarmte, dan wel ten behoeve van het opslaan van stoffen; g. de stoffen die samen met CO_2, worden getransporteerd en opgeslagen. **2.** De in het eerste lid bedoelde regels kunnen worden gesteld ten behoeve van:	**Article 49** **1.** By or by virtue of an order in council, rules can be set in respect of: a. the exploration for minerals or terrestrial heat; b. the production of minerals or terrestrial heat; c. the storage of substances; d. the conduct of a reconnaissance survey; e. drill holes, other than those for the exploration for or production of minerals or terrestrial heat or for the storage of substances more than 500 metres beneath the surface of the earth; f. pipelines and cables that are used for the purpose of the exploration for or the production of minerals or terrestrial heat, or for the storage of substances; g. the substances that jointly with CO2 are transported and stored. **2.** The rules meant in Article 49.1 may be set for the purpose of:

a. een planmatig beheer van voorkomens van delfstoffen, aardwarmte en andere natuurlijke rijkdommen; b. de bescherming van de veiligheid; c. de bescherming van het milieu; d. het beperken van schade ten gevolge van beweging van de aardbodem.	a. a systematic management of deposits of minerals, terrestrial heat and other natural resources; b. the protection of the safety; c. the protection of the environment; d. the limitation of damage as a result of soil movement.

Mijnbouwbesluit (Mining Decree)

Mijnbouwbesluit	**Mining Decree**
Artikel 3 **1.** Bij het verrichten van mijnbouwactiviteiten worden maatregelen genomen ter voorkoming van schade. **2.** Indien bij het verrichten van mijnbouwactiviteiten ernstige schade dreigt te ontstaan of is ontstaan, wordt hiervan onmiddellijk mededeling gedaan aan de inspecteur-generaal der mijnen.	**Article 3** 1. When mining activities are carried out, measures shall be taken to prevent damage. 2. If during the course of mining activities serious damage threathens to occur, or serious damage has occurred, this shall be notified to the Inspecteur-generaal der mijnen immediately.
Artikel 40 **1.** Het sluitingsplan bevat ten minste: a. een beschrijving van de wijze waarop bij het mijnbouwwerk behorend materiaal zal worden afgevoerd; b. een beschrijving van op het mijnbouwwerk aanwezige afvalstoffen en de bestemming ervan; c. een beschrijving van de maatregelen die worden genomen ter voorkoming van schade; d. een beschrijving van de maatregelen die worden genomen om het terrein waarop het mijnbouwwerk is opgericht zoveel mogelijk in de oorspronkelijke staat terug te brengen; e. voor zover onderdeel d niet mogelijk is: een beschrijving van de toestand waarin het mijnbouwwerk wordt achtergelaten en, voor zover van toepassing, de	**Article 40** 1. The closing plan closure shall contain at least: a. a description of the manner in which the material belonging to the mining work will be removed; b. a description of the waste substances present at the mining work and their intended destination; c. a description of the measures to be taken to prevent damage; d. a description of the measures to be taken to return the site on which the mining work is erected int to its original condition as much as possible; e. in so far as Article 40.1.d is not possible: a description of the condition in which the mining work is left behind and, to the extent applicable, its intended purpose;

bestemming ervan; f. het tijdstip waarop met de beschreven werkzaamheden wordt aangevangen en waarop deze worden beëindigd, en g. het beoogde tijdstip van de sluiting. **2.** Zodra de uitvoerder een mijnbouwwerk, geheel of gedeeltelijk, buiten gebruik heeft gesteld, doet hij hiervan melding aan de inspecteur-generaal der mijnen. **3.** Bij ministeriële regeling kunnen nadere regels worden gesteld omtrent het sluitingplan.	f. the moment in time when the described activities will commence and when these will be completed, and g. the planned moment in time time of closure. 2. As soon as the operator has decommissioned a mining work, either in whole or in part, he shall notify the inspecteur-generaal der mijnen thereof. 3. Further rules may be set by ministerial regulation concerning the closing plan.
Artikel 67 **1.** Bij het aanleggen, gebruiken, onderhouden, repareren en buiten gebruik stellen van een boorgat worden maatregelen genomen ter voorkoming van schade. **2.** Het aanleggen, onderhouden, repareren en buiten gebruik stellen van een boorgat geschiedt onder verantwoordelijkheid en in aanwezigheid van de uitvoerder. Het gebruiken van een boorgat geschiedt onder verantwoordelijkheid van de uitvoerder.	**Article 67** 1. When constructing, using, maintaining, repairing and decommissioning a borehole, measures shall be taken to prevent damage. 2. The construction, maintenance, repair and decommissioning of a borehole shall take place under the responsibility and in the presence of the operator. The use of the borehole shall take place under responsibility of the operator.
Artikel 69 **1.** Een boorgat wordt voorzien van een geschikte verbuizing. **2.** Elke serie van de in het eerste lid bedoelde verbuizing wordt over voldoende afstand gecementeerd en daarna op deugdelijkheid getest. **3.** De eerste serie van de verbuizing wordt onmiddellijk nadat deze is gecementeerd deugdelijk afgesloten.	**Article 69** 1. A borehole shall be fitted with suitable tubing. 2. Each series of tubing as referred to in Article 69.1 shall be cemented over a sufficient distance and then tested for reliability. 3. The first series of tubing shall be properly sealed immediately after it has been properly cemented.
Artikel 70 De uitvoerder draagt tijdens de werkzaamheden	**Article 70** The operator shall during the work for the

ten behoeve van het aanleggen, repareren en buiten gebruik stellen van een boorgat er zorg voor dat: a. een boorgat ter afsluiting wordt voorzien van beveiligingen; b. de deugdelijkheid van de beveiligingen periodiek wordt getest, en c. bij het boorgat betrokken personen periodiek deelnemen aan oefeningen in het gebruik van beveiligingen.	purpose of construction, repair and decommission of a borehole, ensure that: a. a borehole is fitted with safety facilities for sealing purposes; b. the reliability of the safety facilities is periodically tested, and c. persons involved in the borehole periodically take part in exercises in the use of safety facilities.
Artikel 71 Een boorgat wordt niet eerder voor winning van delfstoffen of opslag van stoffen in gebruik genomen dan nadat het daartoe deugdelijk is ingericht en afgewerkt, alsmede ter afsluiting van deugdelijke beveiligingen is voorzien.	**Article 71** A borehole shall not be taken into service for the production of minerals or the storage of substances until it has been properly equipped and finished for this purpose and reliable safety facilities for the sealing have been installed.
Artikel 72 **1.** Een boorgat wordt niet eerder buiten werking gesteld dan nadat: a. voldoende maatregelen zijn genomen ter voorkoming van schade, en b. de delfstofhoudende lagen en de delfstofafzettingen, voor zover daaraan door water schade kan worden toegebracht, waterdicht zijn afgesloten.	**Article 72** 1. A borehole shall not be decommissioned until: a. sufficient measures have been taken to prevent damage, and b. the mineral-bearing strata and mineral deposits, in so far as they can be damaged by water, have been sealed in a water-tight manner.

Mijnbouwregeling (Mining Regulation)

Mijnbouwregeling	**Mining Regulation**
Artikel 8.2.1.1 **1.** Een werkprogramma voor de aanleg van een boorgat bevat: a. nvt b. voor boorgaten op land: 1°. de naam van de gemeente waarin het boorgat zal worden aangelegd; 2°. de benaming van het boorgat; 3°. de plaats van het aanzetpunt daarvan uitgedrukt in het coördinatenstelsel van de Rijksdriehoeksmeting; 4°. een opgave van de hoogte van het maaiveld in meters ten opzichte van N.A.P alsmede de hoogte van de boortafel of in plaats van de boortafel een ander, nader aan te geven referentiepunt in meters ten opzichte van N.A.P.	**Article 8.2.1.1** 1. A work programme for the construction of a borehole shall contain: a. na b. in the case of boreholes on land: 1º the name of the municipality in which the borehole will be constructed; 2º the name of the borehole; 3º the location of the spudding point thereof expressed in the coordinatenstelsel of the Rijksdriehoekmeting. 4 º a notification of the height of the ground level in meters relative to N.A.P. and the height of the drilling table, or, instead of the drilling table, another point of reference relative to N.A.P. to be further specified.
2. Voorts bevat het werkprogramma ten minste: a. de precieze locatie waar een boorgat het voorkomen zal binnendringen en de voorgenomen diepte van het boorgat; b. een schematische opgave van: 1°. de selectiecriteria waarop de verbuizingsdiepten zijn gekozen, rekening houdend met de maximaal toelaatbare instromingsvolumes bij de verwachte formatiesterkten; 2°. de geologische formaties, welke vermoedelijk zullen worden doorboord; 3°. de verbuizingsdiepten van nabijgelegen boorgaten met hun gebruikte spoelingsgewichten, temperatuur en formatiesterktetesten vergeleken met die van het aan te leggen boorgat met de gecorreleerde stratigrafische kolom; 4°. de in het boorgat te verwachten poriëndrukken en bezwijkdrukken van het gesteente met de beoogde boorspoelingsdrukken, en 5°. elke plaats waar: – spoelingverliezen kunnen optreden;	2. The work programme shall further contain at least: a. the exact location where a borehole will penetrate the deposit and the proposed depth of the borehole; b. a schematic report on: 1º the selection criteria on the basis of which the casing depths have been chosen, taking into account the maximum allowable inflow volumes based on the expected formation strenghs; 2º the geological formations that will probably be penetrated by drilling; 3º the casing depths of adjacent boreholes with their mudweights used, temperature and formation strenght tests, compared with those of the borehole to be constructed, together with the correlated stratigraphical column, 4º the pore pressure that can be expected in the borehole and the rock deformation pressure at the planned drilling mud pressures, and 5 º each location where: - mud losses can occur;

– een plastisch gesteente te verwachten is, of – koolwaterstofaccumulatie aanwezig kan zijn;	- plastic rock is to be expected, or - hydrocarbon accumulation can be present;
c. het type van de te gebruiken boorinstallatie;	c. the type of the drilling installation to be used;
d. een beschrijving: 1°. de wijze van isolatie van de zoet- en zoutwaterlagen onder opgave van: – de lokale grondwaterhydrologie; – de identificatie van zoet- en zoutwaterlagen; – de beoogde isolatie na het doorboren van de zoet- en zoutwaterlagen; – de wijze van verificatie van de nieuwe isolatie na doorboring;	d. a description: 1 º the method of isolation of the sweet and salt water layers stating: - the local groundwater hydrology; - the identification of sweet and salt water layers; - the intended isolation after the drilling through the sweet and salt water layers; - the manner of verification of the new isolation after penetration by drilling.
2°. met tekeningen van elke verbuizingsserie met vermelding van de diameter;	2º with drawings of each casing series with details of the diameter;
3°. van de soort materiaal, het gewicht per lengte eenheid, en de diepte waarop het inbouwen van elk serie wordt voorzien, en	3º of the type of material, the weight per unit of length and the depth envisaged for the incorporation of each series, and
4°. van de voorgenomen diameter van het boorgat over het boortraject tot elk van de onder 2° bedoelde diepten;	4º of the planned diameter of the borehole in the drilling trajectory to each of the depths as meant in Article 8.2.1.1.2 d.2 º;
e. een opgave van alle voorkomende belastingsituaties van iedere serie van de verbuizing onder correctie van invloeden door corrosie, slijtage en vermoeiing alsmede de ontwerp- en veiligheidsfactoren die worden gebruikt om de verbuizing zeker te stellen bij deze belastingsituaties;	e. a report on all occurring charge situations of each series of casing with correction for influences by corrosion, wear and tear and fatigue, and design and safety factors that are used to secure the casing in these charge situations;
f. een schematische opgave van het triaxiale spanningsanalysediagram waarin wordt aangetoond dat de berekende triaxiale spanningen voor alle voorkomende belastingssituaties met de bijbehorende veiligheidsfactoren niet kunnen leiden tot plastische vervorming van iedere serie van de verbuizing;	f. a schematic report of the triaxial tension analysis diagram in which is demonstrated that the calculated triaxial tensions for all occurring charge situations with the pertaining safety factors can not lead to plastic deformation of each casing series.
g. een opgave van de aan te brengen cementatie van elke verbuizingsserie met vermelding van de voorgenomen diepte van de top van de annulaire cementkolom;	g. details of the cementing of each casing series to be applied, with details of the planned depth of the top of the annular cement column;
h. een opgave van de beproevingsdruk van elke verbuizingsserie;	h. details of the test pressure of each casing series;
i. een opgave van de te houden petrofysische metingen;	i. details of the petrophysical measurements to be performed;
j. een opgave van de toe te passen	j. details of the methods to be applied for

methodes van formatiesterkte testen;	formation strength testing;
k. een opgave van de te nemen kerntrajecten;	k. details of the core trajectories to be taken;
l. een opgave van de te gebruiken boorspoeling alsmede een gedetailleerde toelichting op de gemaakte keuze;	l. details of the drilling fluid to be used and a detailed explanation of the choice made;
m. een opgave van de bij de aanleg van het boorgat te gebruiken chemicaliën, hun hoeveelheden alsmede een beschrijving van het gebruik van die chemicaliën waaruit blijkt dat wordt voldaan aan:	m. a report on the chemicals to be used at the construction of the borehole, their quantities, and a description of the use of those chemicals showing that compliance is established with:
1°. de EG-verordening registratie, evaluatie en autorisatie van chemische stoffen en de bij of krachtens titel 9.3 van de Wet milieubeheer voor de uitvoering van die verordening gestelde voorschriften;	1º. the EC Directive registration, evaluation and authorization of chemical substances and the conditions set by or by virtue of section 9.3 of the Wet milieubeheer for the implementation of that Directive;
2°. de EG-verordening indeling, etikettering en verpakking van stoffen en mengsels en de bij of krachtens titel 9.3a van de Wet milieubeheer voor de uitvoering van die verordening gestelde voorschriften en	2º. The EC Directive categorization, labelling and packaging of substances and mixtures and the conditions set by or by virtue of section 9.3a of the Wet milieubeheer for the implementation of that Directive;
3°. de biocidenverordening en de bij of krachtens de Wet gewasbeschermingsmiddelen en biociden voor de uitvoering van die verordening gestelde voorschriften;	3º. the biocides Directive and the conditions set by or by virtue of the Wet gewasbeschermingsmiddelen en biociden for the implementation of that Directive;
n. indien een boorgruisreiningingssysteem zal worden gebruikt: een opgave van het systeem dat zal worden gebruikt alsmede van de eventueel daarbij te gebruiken chemicaliën;	n. if a bore dust cleaning system is to be used: details of the system to be used as well as any chemicals that may be used thereby ;
o. een situatietekening van het voorgenomen verloop van het boorgat en een opgave van de met betrekking tot het verloop van het boorgat toe te passen meettechniek;	o. a site drawing of the proposed profile of the borehole and details of the measurement technique to be used in relation to the profile of the borehole;
p. indien het boorgat op zodanige plaats nabij een of meer, al dan niet buiten gebruik gestelde, bestaande boorgaten zal worden aangelegd dat gevaar voor het boorgat of een ander reeds bestaand boorgat niet is uitgesloten: een berekening van de te verwachten minimale afstand alsmede de te verwachten minimale scheidingsfactoren op basis van de gebruikte meetinstrumenten;	p. if the borehole is to be constructed on a location near one or more existing boreholes, whether or not decommissioned, in such a way that a danger to the borehole or another borehole already in existence is not excluded: a calculation of the expected minimum distance and the expected minimum separation factors on the basis of the measurement instruments used;
q. een beschrijving van de ten behoeve van elke verbuizingsserie te gebruiken beveiligingsinstallatie, met vermelding van:	q. a description of the safety protection installation to be used for each casing series, detailing:
1°. het type van elk onderdeel waaruit de installatie bestaat, en	1º the type of every component of the installation, and

2°. de maximale druk die elk onderdeel kan weerstaan en die waarop elk onderdeel wordt getest; r. indien het boorgat wordt getest een beschrijving van: 1°. de te volgen werkwijze; 2°. de inrichting van het boorgat, en 3°. de daarmee samenhangende bovengrondse uitrusting; s. een opgave van de te gebruiken technische hulp- en andere beveiligingsinstallaties en van de tijdstippen waarop deze worden opgesteld, en t. een beschrijving met tekening van de voorgenomen afwerking van het boorgat.	2º the maximum pressure that every component can withstand and that at which every component is tested; r. if the borehole will be tested, a description of: 1º the procedure to be followed; 2º the layout of the borehole, and 3º the associated above surface equipment; s. details of the technical auxiliary and other safety protection installations to be used and the times when these are set up, and t. a description with a drawing of the intended finishing of the borehole.
Artikel 8.2.3.1 **1.** Een werkprogramma voor de reparatie van een put bevat: a. nvt b. voor putten op land: 1°. de naam van de gemeente waarbinnen de te repareren put zich bevindt; 2°. de benaming van de put; 3°. De plaats van het aanzetpunt van de put uitgedrukt in het coördinatenstelsel van de Rijksdriehoeksmeting en 4°. een opgave van de hoogte van zowel het maaiveld als de boortafel of een ander, nader aan te geven referentiepunt, een en ander in meters ten opzichte van N.A.P. **2.** Voorts bevat het werkprogramma ten minste: a. de reden van de reparatie alsmede een kort overzicht van het gedrag van en problemen met de put sinds de aanleg of, indien deze eerder is gerepareerd, de laatste reparatie; b. de datum van de oorspronkelijke afwerking of van de laatste reparatie; c. een schets van de deviatie, indien van toepassing; d. een opgave van het referentievlak van waaruit de dieptematen worden opgegeven; e. een beschrijving met tekeningen van:	**Article 8.2.3.1** 1. A work programme for the repair of a well shall contain: a. n.a. b. in the case of wells on land: 1º the name of the municipality in which the well to be repaired is located; 2º the name of the well; 3º the location of the spudding point of the well expressed in the coordinatenstelsel der Rijksdriehoekmeting , and 4º details of the height of both the ground level and the drilling floor or another reference point, to be specified in more detail with all this being quoted in metres relative to N.A.P. 2. The work programme shall further contain at least: a. the reason for the repair and a brief summary of the behaviour of and problems with the well since construction or, if this well has been repaired earlier, the last repair; b. the date of the original completion or of the last repair; c. a sketch of the deviation, if applicable; d. details of the reference plane from which the depth measurements are quoted; e. a description with drawings of:

1°. de productieverbuizing met specificaties; 2°. de cementatiediepte, en 3°. de diepte van de top van de annulaire cementkolommen;	1º the production tubing with specifications; 2º the cementing depth, and 3º the depth of the top of the annular cement columns;
f. over de integriteitsbeheersing van de put een beschrijving van: 1°. de deugdelijkheid van de aanwezige annulaire cementkolommen onder opgave van de hiertoe uit te voeren integriteitsmetingen, en 2°. de wijze waarop de integriteit van de put voor en na de diverse activiteiten wordt zeker gesteld;	f. on the integrity management of the well a description of: 1º the solidity of the annular cement columns present, with a statement on the integrity measurements to be made for that purpose, and 2º the manner in which the integrity of the well before and after the carying out of the various activities is secured;
g. een beschrijving met tekeningen van de afwerking boven of onder oppervlaktewater, inclusief specificaties van het spuitkruis;	g. a description with drawings of the completion above or below surface water, including specifications of the X-mas tree;
h. een beschrijving van de ondergrondse afwerking van de put; i. de verwachte maximale ingesloten bovengrondse druk en de drukken in de diverse annulaire ruimtes; j. de formatiedruk en de referentiediepte; k. de ondergrondse en bovengrondse temperatuur van de put; l. de inhoud van de opvoerserie en van de annulaire ruimten; m. het productiemechanisme; n. de maximale productiecapaciteit (open flow potential); o. de naam of typeaanduiding van de installatie waarmee de putreparatie wordt uitgevoerd alsmede de naam van de drilling contractor;	h. a description of the subsurface completion of the well; i. the expected maximum enclosed above surface pressures and pressures in the various annular spaces; j. the formation pressure and the reference depth; k. the subsurface and above surface temperature of the well; l. the content of the production string and of the annular spaces; m. the production mechanism; n. the maximum production capacity (open flow potential); o. the name or type designation of the installation with which the well repair is carried out and also the name of the drilling contractor;
p. een beschrijving van de te gebruiken beveiligingsinstallatie voor de afsluiting van de put in de diverse fasen; q. een chronologisch overzicht van de voorgenomen opeenvolgende reparatiewerkzaamheden, waarbij zoveel mogelijk rekening wordt gehouden met van tevoren aangenomen alternatieve mogelijkheden voorzien van in het bijzonder een toelichting op uit veiligheidsoverwegingen of anderszins kritische operaties;	p. a description of the safety protection installation to be used for sealing the well in the various phases; q. a chronological overview of the proposed successive repair works, with as much account as possible being taken of alternative possibilities adopted beforehand together with, in particular, an explanation of operations that are critical from a safety point of view or otherwise;
r. gezien de ligging van de te repareren put en voor zover van toepassing: de methode waarop putten in de nabijheid worden veiliggesteld;	r. in view of the location of the well to be repaired and, where applicable: the method by which wells in the vicinity will be made safe;
s. een opgave van de afwerking van de put	s. details of the completion of the well after the

na de reparatie; t. de geschatte tijdsduur van de reparatie, en t. een beschrijving van de stoffen en hoeveelheden stoffen die bij de reparatie worden geïnjecteerd met een vermelding van de registratie en autorisatie van de stof, waaruit blijkt dat wordt voldaan aan: 1°. de EG-verordening registratie, evaluatie en autorisatie van chemische stoffen en de bij of krachtens titel 9.3 van de Wet milieubeheer voor de uitvoering van die verordening gestelde voorschriften; 2°. de EG-verordening indeling, etikettering en verpakking van stoffen en mengsels en de bij of krachtens titel 9.3a van de Wet milieubeheer voor de uitvoering van die verordening gestelde voorschriften en 3°. de biocidenverordening en de bij of krachtens de Wet gewasbeschermingsmiddelen en biociden voor de uitvoering van die verordening gestelde voorschriften.	repair; t. the estimated duration of the repair; u. a description of the substances and volumes of substances that are injected on the occasion of such repair, stating the registration and authorization of the substance, showing that compliance is established with: 1º. the EC Directive registration, evaluation and authorization of chemical substances and the conditions set by or by virtue of section 9.3 of the Wet milieubeheer for the implementation of that Directive; 2º. the EC Directive categorization, labelling and packaging of substances and mixtures and the conditions set by or by virtue of section 9.3a of the Wet milieubeheer for the implementation of that Directive; 3º. the biocides Directive and the conditions set by or by virtue of the Wet gewasbeschermingsmiddelen en biociden for the implementation of that Directive.
Artikel 8.2.4.1 **1.** Een werkprogramma voor het buiten gebruik stellen van een put bevat: a. nvt b. voor putten op land: 1°. de naam van de gemeente waarbinnen de buiten gebruik te stellen put zich bevindt; 2°. de benaming van de put; 3°. de plaats van het aanzetpunt van de put daarvan uitgedrukt in het coördinatenstelsel van de Rijksdriehoeksmeting en 4°. een opgave van de hoogte van zowel het maaiveld als de boortafel of een ander, nader aan te geven referentiepunt, een en ander in meters ten opzichte van N.A.P. **2.** Voorts bevat het werkprogramma ten minste: a. de reden voor het buiten gebruik stellen van de put; b. de datum van de oorspronkelijke afwerking of, indien de put eerder is gerepareerd, de	**Article 8.2.4.1** 1. A work programme for the decommissioning of a well shall contain: a. na b. in the case of wells on land: 1º the name of the municipality in which the well to be decommissioned is located; 2º the name of the well; and 3º the location of the spudding point of the well expressed in accordance with the system of coordinate of the Rijksdriehoekmeting, and 4º details of the height of both the ground level and the drilling floor or another reference point to be specified in more detail, all this being quoted in metres relative to N.A.P. 2. The work programme shall further contain at least: a. the reason for the decommissioning of the well; b. the date of the original completion or, if the well has previously been repaired, the last repair;

laatste reparatie;	
c. een schets van de deviatie, indien van toepassing;	c. a sketch of the deviation, if applicable;
d. een opgave van het referentievlak van waaruit de dieptematen worden opgegeven;	d. details of the reference plane from which the depth measurements are quoted;
e. een beschrijving met tekeningen van: 1°. verbuizingen; 2°. de cementatiedieptes, en 3°. de dieptes van de top van de annulaire cementkolommen;	e. a description with drawings of: 1º casing; 2º the cementing depths, and 3º the depths of the top of the annular cement columns;
f. de diepte waarop de put is afgewerkt en de diepte van het geperforeerde deel van de productieverbuizing;	f. the depth at which the well has been completed and the depth of the perforated part of the production tubing;
g. een beschrijving van de afwerking van de put boven of onder oppervlaktewater, inclusief specificaties van het spuitkruis;	g. a description of the completion of the well above or below surface water, including specifications of the x-mastree;
h. een beschrijving van de ondergrondse afwerking van de put;	h. a description of the subsurface completion of the well;
i. de verwachte maximale ingesloten bovengrondse druk en de annulaire drukken;	i. the expected maximum enclosed above surface pressure and the annular pressures;
j. de formatiedruk en de referentiediepte;	j. the formation pressure and the reference depth;
k. de ondergrondse en bovengrondse temperatuur van de put;	k. the subsurface and above surface temperature of the well;
l. de inhoud van de opvoerserie en van de annulaire ruimten;	l. the content of the production string and of the annular spaces;
m. de naam of typeaanduiding van de installatie waarmee de put buiten gebruik wordt gesteld alsmede de naam van de drilling contractor;	m. the name or type designation of the installation with which the well is decommissioned and also the name of the drilling contractor;
n. een beschrijving van de te gebruiken beveiligingsinstallatie voor de afsluiting van de put;	n. a description of the safety protection installation to be used for sealing the well;
o. een chronologisch overzicht van de opeenvolgende werkzaamheden, waarbij zoveel mogelijk rekening wordt gehouden met van tevoren aangenomen alternatieve mogelijkheden voorzien van in het bijzonder een toelichting op uit veiligheidsoverwegingen of anderszins kritische operaties;	o. a chronological overview of the successive activities, with as much account as possible being taken of alternative possibilities adopted beforehand together with, in particular, an explanation of operations that are critical from a safety point of view or otherwise;
p. gezien de ligging van de buiten gebruik te stellen put en voor zover van toepassing: de methode waarop putten in de nabijheid worden veiliggesteld;	p. in view of the location of the well to be decommissioned and, where applicable: the method by which wells in the vicinity will be made safe;
q. een beschrijving met tekeningen van de afwerking van de put na het buitengebruik stellen, en	q. a description with drawings of the completion of the well after the decommissioning, and
r. de geschatte tijdsduur van het buiten gebruik stellen.	r. the estimated duration of the decommissioning.

Artikel 8.3.2.1	Article 8.3.2.1
Bij een persproef tot de maximale druk die zich naar berekening in de serie der verbuizing kan voordoen, treedt, na het stilzetten van de perspompen en na de stabilisatie van de druk, geen lekkage op gedurende een periode van ten minste: a. 10 minuten, indien het volume dat wordt beproefd 3 m3 of minder bedraagt, of b. 20 minuten, indien het volume dat wordt beproefd groter is dan 3 m3.	During a pressure test up to the maximum pressure that may occur in the casing series according to calculations, no leakage shall, following shutdown of the pressure pumps and stabilisation of the pressure, occur for a period of at least: a. 10 minutes, if the volume tested is 3 m^3 or less, or b. 20 minutes, if the volume tested is greater than 3 m^3.
Artikel 8.4.4	**Article 8.4.4**
1. Bij producerende, injecterende en ingesloten putten worden de drukken in de tubing/casing annulus en in de eerste casing/casing annulus gecontroleerd. De geconstateerde afwijkingen in het in de eerste volzin bedoelde drukpatroon worden geregistreerd. Bij een onder oppervlaktewater afgewerkte put is de tweede volzin niet van toepassing op het controleren en registeren van de druk in de annulaire ruimte van de productie verbuizingsserie, die in verbinding staat met de ondergrond en waarbij de annulaire ruimte is afgedicht bij de afhangconstructie. **2.** Ten aanzien van annulaire drukken wordt op zo kort mogelijke termijn een diagnose gesteld van de oorzaak van die druk. **3.** Indien afwijkingen in annulaire drukken ontstaan als bedoeld in het eerste lid, wordt de inspecteur-generaal der mijnen schriftelijk ingelicht onder het overleggen van een actieprogramma voor het in te stellen onderzoek en eventueel te nemen maatregelen. In urgente gevallen wordt onmiddellijk telefonisch melding van die afwijkingen gedaan.	1. In the case of producing, injecting and shut in wells, the pressures in the tubing/casing annulus and in the first casing/casing annulus shall be inspected. Anomalies found in the pressure pattern as meant in the first sentence shall be recorded. In the case of a completed well below surface water, the second sentence does not apply to inspecting and recording of the pressure in the annular space of the production piping series connected to the subsoil whereby the annular space has been sealed off at the suspension construction. 2. With regard to annular pressures the cause of the said pressure shall be diagnosed as quickly as possible. 3. If deviations in annular pressures arise as meant in Article 8.4.4.1, the inspecteur-generaal der mijnen shall be informed in writing, and an action programme for the investigation to be conducted and possible action to be taken shall be submitted to him. In urgent cases, the said deviations shall be reported immediately by telephone.
Artikel 8.5.1.2	**Article 8.5.1.2**
1. Voordat een put buiten gebruik wordt gesteld, is deze gevuld met een vloeistof van een zodanig soortelijk gewicht dat iedere in de put te verwachten druk kan worden weerstaan en van een zodanige samenstelling dat corrosie	1. Prior to being decommissioned, a well shall be filled with a liquid of such specific gravity that any pressure to be expected in the well can be withstood and be of such composition that corrosion is prevented and no damage is done to

wordt voorkomen en geen schade kan worden toegebracht aan eventuele delfstofvoorkomens. **2.** Elke in de put gebruikte afsluiting is duurzaam en volledig. **3.** Waar in deze paragraaf een "cementplug" wordt voorgeschreven, kan een ander middel worden gebruikt, mits dat resulteert in ten minste een gelijkwaardige afsluiting.	any mineral reservoir. 2. Every seal used in the well shall be durable and complete. 3. Where a “cement plug” is prescribed in this paragraph, another device may be used provided that this results in at least an equivalent sealing.
Artikel 8.5.2.1 **1.** Elke afsluiting van een put die buitengebruik wordt gesteld, wordt getest met behulp van: a. een gewichtstest van ten minste 100 kN (10 250 kg), b. een beproevingsdruk van ten minste vijftigmaal 100.000 Pa (vijftig bar) gedurende een tijd van vijftien minuten, of c. onderdruk in de put waarbij geconstateerd wordt dat geen vloeistof of gas vanuit het reservoir de put instroomt. **2.** De afsluiting doorstaat de testen goed. **3.** Het eerste en tweede lid zijn niet van toepassing op een afsluiting als bedoeld in artikel 8.5.2.7, tweede lid.	**Article 8.5.2.1** 1. Each seal of a well that is decommissioned shall be tested by means of: a. a weight test of at least 100 kN (10 250 kg), b. a test pressure of at least 50 times 100.000 Pa (50 bar) for a period of 15 minutes, or c. negative pressure differential in the well whereby it is established that no liquid or gas from the reservoir flows into the well. 2. The seal shall withstand the tests well. 3. Article 8.5.2.1.1 and Article 8.5.2.2 do not apply to a seal as meant in Article 8.5.2.7.2.
Artikel 8.5.2.2 **1.** Indien een gedeeltelijk onverbuisde put buiten gebruik wordt gesteld, wordt in de diepste verbuizingsserie vanaf de schoen naar de oppervlakte een afsluiting aangebracht die bestaat uit: a. een cementplug van ten minste honderd meter lengte, of b. een mechanische plug met daarop een cementplug van vijftig meter lengte. **2.** Indien een put buiten gebruik wordt gesteld waarvan het onverbuisde deel zich in een	**Article 8.5.2.2** 1. If a partially uncased well is decommissioned, a seal consisting of the following shall be installed in the deepest casing series from the shoe to the surface: a. a cement plug of at least 100 metres in length, or b. a mechanical plug with a cement plug of 50 metres in length mounted thereon. 2. If a well whose uncased part is located in a reservoir is decommissioned, this reservoir shall

reservoir bevindt, wordt dit reservoir met behulp van cementpluggen ter hoogte van of boven het reservoir volledig afgesloten. **3.** Indien het in het tweede lid bedoelde onverbuisde gedeelte meer dan één reservoir doorsnijdt, worden deze reservoirs van elkaar geïsoleerd met behulp van cementpluggen. De lengte van de cementplug is 100 meter of gelijk aan de natuurlijke afstand tussen de reservoirs.	be fully sealed with the aid of cement plugs at level with or above the reservoir. 3. If the uncased part as meant in Article 8.5.2.2.2 intersects more than one reservoir, these reservoirs shall be insulated from one another by means of cement plugs. The length of the cement plug shall be 100 meter or equal to the natural distance between the reservoirs.
Artikel 8.5.2.3 **1.** Indien een put buiten gebruik wordt gesteld waarvan de verbuizing is geperforeerd, wordt ter hoogte van of boven het geperforeerde gedeelte een afsluiting aangebracht die bestaat uit: a. een cementplug die zich honderd meter uitstrekt boven het geperforeerde gedeelte; b. een mechanische plug, geplaatst zo dicht mogelijk boven het geperforeerde gedeelte, met daarop een cementplug van vijftig meter lengte, of c. een mechanische plug, geplaatst boven het geperforeerde gedeelte, waardoor in de verbuizing een cementplug van vijftig meter lengte over de gehele lengte van het geperforeerde deel is geperst met direct op de mechanische plug een cementplug van vijftig meter lengte. **2.** Indien in de verbuizing perforaties ter hoogte van verschillende reservoirs zijn aangebracht, worden deze reservoirs van elkaar geïsoleerd met behulp van één van de afsluitingen, bedoeld in het eerste lid. De cementplug, bedoeld in het eerste lid, onderdelen a of b, kan in dit geval vijftig meter korter zijn dan in het eerste lid is aangegeven of even lang zijn als de natuurlijke afstand tussen de reservoirs.	**Article 8.5.2.3** 1. If a well whose casing has been perforated is decommissioned, a seal consisting of the following shall be installed at level with or above the perforated part: a. a cement plug that extends more than 100 metres above the perforated part; b. a mechanical plug located as closely as possible above the perforated part, with a cement plug of 50 metres in length mounted thereon, or c. a mechanical plug of 50 metres in length located above the perforated part through which, in the casing, a cement plug is pressed over the entire length of the perforated part with a cement plug mounted directly on the mechanical plug. 2. If perforations have been made to the casing level of various reservoirs, these reservoirs shall be insulated from one another by means of one of the seals referred to in Article 8.5.2.3.1. The cement plug referred to in Article 8.5.2.3.1a or Article 8.5.2.3.1b may in this case be 50 metres shorter than indicated in Article 8.5.2.3.1 or be just as long as the natural distance between the reservoirs.
Artikel 8.5.2.4 Indien een put buiten gebruik wordt gesteld	**Article 8.5.2.4** If a well containing cemented suspended casing

waarin zich een gecementeerde afgehangen verbuizing bevindt, wordt ter hoogte van de bovenzijde van deze verbuizing een afsluiting aangebracht bestaande uit: a. een cementplug die zich uitstrekt over ten minste vijftig meter onder de bovenzijde van de afgehangen verbuizing tot ten minste vijftig meter daarboven; b. een mechanische plug geplaatst circa tien meter onder de bovenzijde van de afgehangen verbuizing met daarop een cementplug van ten minste zestig meter, of c. twee mechanische pluggen, waarvan één geplaatst dicht onder de bovenzijde van de afgehangen verbuizing en de ander dicht boven dit punt.	is decommissioned, a seal consisting of the following shall be installed at level with the top of this casing: a. a cement plug extending over at least 50 metres below the top of the suspended casing to at least 50 metres above it; b. a mechanical plug located approximately 10 metres below the top of the suspended casing with a cement plug of at least 60 metres mounted thereon, or c. two mechanical plugs, with one being placed just below the top of the suspended casing and the other just above this point.
Artikel 8.5.2.5 **1.** In elke annulaire ruimte tussen de series van de verbuizing van een buiten gebruik te stellen put wordt een afsluiting aangebracht over een lengte van tenminste honderd meter vanaf de schoen van de daaraan direct voorafgaande verbuizing. In het in artikel 8.2.4.1 bedoelde werkprogramma wordt aangegeven op welke wijze wordt vastgesteld dat deze afsluiting afdoende is aangebracht. **2.** Indien niet aangetoond kan worden dat de annulaire ruimte tussen twee series is afgesloten: a. wordt de kleinste verbuizing die de annulaire ruimte begrenst, over een zo groot mogelijke lengte teruggewonnen, met dien verstande dat de afsnijding van deze serie zo dicht mogelijk boven de schoen van de daaraan direct voorafgaande verbuizing geschiedt, terwijl het gedeelte dat in de put achterblijft overeenkomstig artikel 8.5.2.4 wordt afgesloten, of b. wordt de verbuizing ter hoogte van de daaraan direct voorafgaande schoen geperforeerd, in de annulaire ruimte een cement plug over een lengte van tenminste honderd meter geplaatst en de afsluiting van de annulaire ruimte door een drukproef gecontroleerd.	**Article 8.5.2.5** 1. In every annular space between the series of casing of a well to be decommissioned, a seal shall be fitted over a length of at least 100 metres from the shoe of the casing directly preceding it. The work programme as meant in Article 8.2.4.1 shall indicate in what manner it is established that this seal has been adequately fitted. 2. If it can not be demonstrated that the annular space between two series has been sealed off: a. the smallest casing limiting the annular space shall be reclaimed over the greatest possible length, with the proviso that the cut-off of this casing series takes place as closely as possible to the top of the shoe and the casing directly preceding it, while the part left in the well is sealed off in accordance with Article 8.5.2.4, or b. the casing shall be perforated at level with the shoe directly preceding it, a cement plug shall be placed in the annular space over a length of at least 100 metres and the seal of the annular space shall be inspected by means of a pressure test.

Artikel 8.5.2.6 Indien een buiten gebruik te stellen put door een reservoir gaat, waarvan de inhoud mogelijk naar het oppervlak kan stromen, wordt ter hoogte van de annulaire afsluiting, bedoeld in artikel 8.5.2.5, eerste lid, die zich het dichtst boven het reservoir bevindt, in zowel de put als alle annulaire ruimten op hetzelfde niveau een cementplug van ten minste honderd meter aangebracht.	**Article 8.5.2.6** If a well to be decommissioned passes through a reservoir whose contents may possibly flow to the surface, a cement plug of at least 100 metres shall, at level with the annular seal as meant in Article 8.5.2.5.1,that is located as closely as possible to the top of the reservoir, be fitted in both the well and all the annular spaces on the same level.
Artikel 8.5.2.7 **1.** De verbuizing van een buiten gebruik te stellen put wordt verwijderd: a. tot ten minste drie meter onder het maaiveld, of b. tot ten minste zes meter onder de zeebodem. **2.** In de verbuizing van de buiten gebruik te stellen put wordt zo dicht mogelijk onder het in het eerste lid bedoelde punt een afsluiting aangebracht, bestaande uit: a. een cementplug van ten minste honderd meter, of b. een mechanische plug met direct erop een cementplug van ten minste vijftig meter. **3.** De minister kan ontheffing verlenen van het eerste en tweede lid.	**Article 8.5.2.7** 1. The casing of a well to be decommissioned shall be removed: a. to at least 3 metres below ground level, or b. to at least 6 metres below the sea bottom. 2. In the casing of the well to be decommissioned a seal comprising the following shall be fitted as closely as possible below the point referred to in Article 8.5.2.7.1: a. a cement plug of at least 100 metres, or b. a mechanical plug with a cement plug of at least 50 metres mounted thereon. 3. The Minister can grant exemption from Article 8.5.2.7.1 and Article 8.5.2.7.2.

Arbeidsomstandighedenregeling (Working Conditions Regulations)

Arbeidsomstandighedenregeling	Working Conditions Regulations
Artikel 3.2. Definities In deze paragraaf wordt verstaan onder: a. risico-analyse: systematisch onderzoek van risico's voor de veiligheid en de gezondheid op basis waarvan een beoordeling van die risico's wordt gemaakt als bedoeld in artikel 5 van de wet; b. acceptatiecriteria: de grenzen waarbinnen risico's aanvaardbaar zijn; c. prestatienormen: duidelijke en meetbare parameters ten aanzien van die prestaties van een procesinstallatie of componenten daarvan, van apparatuur en van beheerssystemen, die direct bijdragen aan de verwezenlijking van veiligheids- en gezondheidsdoelstellingen; d. mijnbouwwerk: een werk als bedoeld in artikel 1, onderdeel n, van de Mijnbouwwet; e. mijnbouwinstallatie: een installatie als bedoeld in artikel 1.1, derde lid, onderdeel f, van het besluit; f. veiligheids- en gezondheidszorgsysteem: een systeem als bedoeld in artikel 2.42e van het besluit; g. veiligheids- en gezondheidsdocument: een document als bedoeld in artikel 2.42f van het besluit. **Artikel 3.2a. Bepaling risico's en grenzen** **1.** De risico's in het kader van de risico-analyse, bedoeld in artikel 3.2, onderdeel a, worden kwalitatief en, voor zover mogelijk, kwantitatief bepaald. **2.** De grenzen in het kader van bepaling van de acceptatiecriteria, bedoeld in artikel 3.2, onderdeel b, worden, voor zover mogelijk, kwantitatief bepaald. Voor zover dit niet mogelijk is, worden deze grenzen kwalitatief bepaald.	**Article 3.2. Definitions** The following definitions apply in this section: a. risk analysis: systematic investigation of risks to safety and health on the basis of which an assessment of these risks is produced as described in Article 5 of the Act; b. acceptance criteria: the limits within which risks are acceptable; c. performance benchmarks: clear and measurable parameters relating to those performances of a process installation or components thereof, of equipment and management systems, that make a direct contribution to meeting health and safety objectives; d. mine working: a working as defined in Article 1, under n, of the Mining Act; e. mine installation: an installation as defined in Article 1.1, paragraph three, under f, of the Decree; f. health and safety protection system: a system as defined in Article 2.42e of the Decree; g. health and safety document: a document as defined in Article 2.42f of the Decree. **Article 3.2a. Determination of risks and limits** **1.** A qualitative (and where possible quantitative) assessment of the risks associated with the risk analysis referred to in Article 3.2, under a, shall be carried out. **2.** Where possible, a quantitative determination of the limits associated with the acceptance criteria referred to in Article 3.2, under a, shall be carried out. Where this is not possible, a qualitative determination of these limits shall be carried out.
Artikel 3.6. Veiligheids- en gezondheidsdocument **1.** Er wordt een veiligheids- en	**Article 3.6. Health and safety document** **1.** A health and safety document shall be

gezondheidsdocument opgesteld voor de volgende mijnbouwwerken: a. ieder mijnbouwwerk op het land; b. iedere vast opgestelde mijnbouwinstallatie; c. iedere als een geheel verplaatsbare mijnbouwinstallatie, en d. iedere andere verplaatsbare installatie met behulp waarvan boorgaten worden geboord of werkzaamheden in of aan een bestaand boorgat worden uitgevoerd; **2.** Het veiligheids- en gezondheidsdocument, bedoeld in het eerste lid, is op de mijnbouwwerken, bedoeld in het eerste lid, aanwezig.	produced for the following categories of mine workings: a. every land-based mine working; b. every permanent mine installation; c. every mine installation that can be transported in its entirety, and d. every other transportable installation used to drill mineshafts or to carry out activities in or on existing mineshafts; **2.** The safety and health document referred to in paragraph one shall be present at the mine workings referred to in paragraph one.
Artikel 3.7. Veiligheids- en gezondheidsdocument voor werkzaamheden **1.** Voor zover niet reeds bij het opstellen van het veiligheids- en gezondheidsdocument, bedoeld in artikel 3.6, hiermee rekening is gehouden, wordt er een veiligheids- en gezondheidsdocument opgesteld voor de volgende bijzondere werkzaamheden: a. het boren van een boorgat; b. het uitvoeren van werkzaamheden in of aan een bestaand boorgat, en c. het gelijktijdig uitvoeren van werkzaamheden op een mijnbouwwerk of op of in de nabijheid van een mijnbouwinstallatie, indien het gelijktijdig uitvoeren van deze werkzaamheden een gevaar voor de veiligheid en de gezondheid vormt. **2.** Het veiligheids- en gezondheidsdocument, bedoeld in het eerste lid, is bij de uit te voeren werkzaamheden aanwezig.	**Article 3.7. Safety and health document for activities** **1.** Unless this is already specified in the provisions when preparing the safety and health document, referred to in Article 3.6, a safety and health document shall be prepared for the following specific activities: a. drilling a well; b. carrying out activities in or on an existing well, and c. the simultaneous performance of activities on a mine working or on or close to a mine installation, where the simultaneous performance of these activities forms a danger to safety and health. **2.** The safety and health document referred to in paragraph one shall be present at the location where the activities in question are being carried out.
Artikel 3.8. Onderdelen veiligheids- en gezondheidsdocument voor mijnbouwwerken **1.** Het veiligheids- en gezondheidsdocument, bedoeld in artikel 3.6, onderdelen a en b, bestaat uit de volgende onderdelen: a. het voorontwerprapport;	**Article 3.8. Parts of the safety and health document for mine workings** **1.** The safety and health document referred to in Article 3.6, under a and b, shall comprise the following parts: a. the pre-design report;

b. het gedetailleerd ontwerp, opstarten en gebruik; c. het addendum gebruik; d. het addendum grote wijzigingen, en e. het addendum verlaten en verwijderen. **2.** Het veiligheids- en gezondheidsdocument, bedoeld in artikel 3.6, onderdelen c en d, bestaat uit de volgende onderdelen: a. het gedetailleerd ontwerp, opstarten en gebruik; b. het addendum gebruik, en c. het addendum grote wijzigingen.	b. the detailed design, start-up and use report; c. the addendum on use; d. the addendum on major alterations, and e. the addendum on closure and removal. **2.** The safety and health document referred to in Article 3.6, under c and d, shall comprise the following parts: a. the detailed design, start-up and use report; b. the addendum on use, and c. the addendum on major alterations.
Artikel 3.9. Inhoud veiligheids- en gezondheidsdocument voor mijnbouwwerken Het veiligheids- en gezondheidsdocument, bedoeld in artikel 3.6, bevat: a. een duidelijke en nauwkeurige beschrijving van het mijnbouwwerk alsmede van de werkzaamheden die op het mijnbouwwerk worden uitgevoerd, met inbegrip van een aanduiding van de voorzieningen die in het ontwerp van het mijnbouwwerk zijn opgenomen ter uitsluiting of vermindering van de risico's; b. in aanvulling op onderdeel a, de informatie, bedoeld in bijlage IV bij deze regeling; c. de informatie, bedoeld in bijlage V bij deze regeling, met betrekking tot het brandbestrijdingsplan; d. de informatie, bedoeld in onderdeel c, is gebaseerd op de opgave, bedoeld in artikel 2.42f, eerste lid, onder a, van het besluit; e. een opgave van de acceptatiecriteria; f. een lijst van alle geïdentificeerde en geanalyseerde risico's, inclusief een samenvatting van het onderzoek dat in dit kader is verricht voor het mijnbouwwerk op het land of de vast opgestelde mijnbouwinstallatie als bedoeld in bijlage VI bij deze regeling of voor de als een geheel verplaatsbare mijnbouwinstallatie of een andere verplaatsbare installatie met behulp waarvan boorgaten worden geboord of werkzaamheden in een bestaand boorgat worden uitgevoerd,	**Article 3.9. Content of the safety and health document for mine workings** The safety and health document referred to in Article 3.6 shall comprise: a. a clear and accurate description of the mine working and the activities carried out on the mine working, including information on provisions made in the design of the mine working to exclude or minimise risks; b. in addition to the information referred to under a, the information referred to in annex IV to this Regulation; c. the information referred to in annex V to this Regulation dealing with the fire-fighting plan; d. the information referred to under c shall be based on the statement referred to in Article 2.42f, paragraph one, under a, of the Decree; e. a statement of acceptance criteria; f. a list of all risks that have been identified and analysed, including a summary of the investigations that have been carried out in this context for the land-based mine or the permanent mine installation as referred to in annex VI to this Regulation, or for the mine installation that can be transported in its entirety or other transportable installation used to drill mineshafts or to carry out activities in or on existing mineshafts as referred to in annex VII to this Regulation;

bedoeld in bijlage VII bij deze regeling;	
g. een specificatie van de bronnen, die zijn gebruikt bij het identificeren, analyseren en evalueren van de risico's, met inbegrip van een beschrijving van de wijze waarop de geschiktheid en betrouwbaarheid van de bronnen is vastgesteld;	g. information on the sources used to identify, analyse and evaluate the risks, including a description of how these sources were found to be suitable and reliable;
h. een beoordeling van de doeltreffendheid en geschiktheid van het veiligheids- en gezondheidszorgsysteem voor het mijnbouwwerk met inbegrip van de resultaten en de noodzakelijk bevonden wijzigingen of aanvullingen van dat zorgsysteem;	h. an assessment of how effective and suitable the health and safety protection system is for the mine working, including the results and any changes or additions found to be necessary to the system;
i. een samenvatting, in niet-technische terminologie, van het onderzoek, bedoeld in bijlage VI en VII bij deze regeling, dat is verricht in het kader van het opstellen van het veiligheids- en gezondheidsdocument;	i. a summary in lay terms of the investigation referred to in annexes VI and VII to this Regulation carried out in preparation of the health and safety document;
j. een opgave van de noodzakelijk geachte risicoverminderende maatregelen, inclusief een samenvatting van al het onderzoek dat in dit kader is verricht;	j. a statement of the measures found necessary in order to minimise risks, including a summary of all the investigations carried out in this context;
k. een opgave van de prestatienormen;	k. a statement of performance benchmarks;
l. de grenzen waarbinnen de op het mijnbouwwerk gebruikte apparatuur en beheerssystemen normaal kunnen functioneren;	l. the limits within which the equipment and management systems used at the mine working can operate normally;
m. een actieplan met tijdpad voor de realisatie van de maatregelen, bedoeld in onderdeel j;	m. a plan of action with a timetable for implementing the measures referred to under j;
n. een toetsing van de vermelde risico's aan de acceptatiecriteria;	n. an examination of reported risks on the basis of the acceptance criteria;
o. een toetsing van de prestaties van een procesinstallatie of componenten daarvan, van apparatuur en van beheerssystemen aan de prestatienormen, en	o. an examination of the performance of a process installation or components thereof, equipment and management systems on the basis of the performance benchmarks, and
p. een schriftelijke verklaring dat de risico's ten minste binnen de van tevoren vastgestelde acceptatiecriteria en prestatienormen vallen.	p. a written declaration that the risks at least fall within the acceptance criteria and performance benchmarks that have been established in advance.

Artikel 3.10. Inhoud veiligheids- en gezondheidsdocument voor werkzaamheden	**Article 3.10. Content of the safety and health document for activities**
1. Het veiligheids- en gezondheidsdocument, bedoeld in artikel 3.7, bevat:	**1.** The safety and health document referred to in Article 3.7 shall comprise:
a. een overzichtstekening waarop de combinaties, bedoeld in het tweede lid, zijn aangegeven;	a. a diagram showing the combinations referred to in paragraph two;
b. een opgave van de acceptatiecriteria;	b. a statement of acceptance criteria;
c. een beoordeling en een evaluatie van de gevaren en de daarmee samenhangende risico's die specifiek zijn voor de locatie en voor de werkzaamheden waarop het veiligheids- en gezondheidsdocument betrekking heeft;	c. an assessment and evaluation of the dangers and associated risks that are specific to the location and activities covered by the safety and health document;
d. een specificatie van de bronnen, die zijn gebruikt bij het identificeren, analyseren en evalueren van de risico's, met inbegrip van een beschrijving van de wijze waarop de geschiktheid en betrouwbaarheid van de bronnen is vastgesteld;	d. information on the sources used to identify, analyse and evaluate the risks, including a description of how these sources were found to be suitable and reliable;
e. een evaluatie van alle beheerssystemen die bijdragen aan de vermindering van de risico's;	e. an evaluation of all management systems that help minimise the risks;
f. een opgave van de noodzakelijk geachte risicoverminderende maatregelen, inclusief een samenvatting van al het onderzoek dat in dit kader is verricht;	f. a statement of the measures found necessary in order to minimise risks, including a summary of all the investigations carried out in this context;
g. een opgave van de prestatienormen;	g. a statement of performance benchmarks;
h. een toetsing van de vermelde risico's aan de acceptatiecriteria, en	h. an examination of reported risks on the basis of the acceptance criteria, and
i. een toetsing van de prestaties van een procesinstallatie of componenten daarvan, van apparatuur en van beheerssystemen aan de prestatienormen.	i. an examination of the performance of a process installation or components thereof, equipment and management systems on the basis of the performance benchmarks.
2. In het veiligheids- en gezondheidsdocument, bedoeld in het eerste lid, worden de maatregelen, die noodzakelijk zijn voor het beheersen van risico's, afgestemd op het veiligheids- en gezondheidsdocument, bedoeld in artikel 3.6, indien bij het uitvoeren van werkzaamheden gebruik wordt gemaakt van een combinatie van:	**2.** The measures needed to manage risks, as set out in the safety and health document referred to in paragraph one, shall be aligned to the safety and health document referred to in Article 3.6 if the activities are to be performed using a combination of:
a. een vast opgestelde mijnbouwinstallatie als bedoeld in artikel 3.6, eerste lid, onderdeel b en een als een geheel verplaatsbare mijnbouwinstallatie als bedoeld in artikel 3.6, eerste lid, onder c;	a. a permanent mine installation as referred to in Article 3.6, paragraph one, under b, and a mine installation that can be transported in its entirety as referred to in Article 3.6, paragraph one, under c;

b. een andere verplaatsbare installatie met behulp waarvan boorgaten worden geboord of werkzaamheden in een bestaand boorgat worden uitgevoerd als bedoeld in artikel 3.6, eerste lid, onderdeel d en een vast opgestelde mijnbouwinstallatie als bedoeld in artikel 3.6, eerste lid, onderdeel b;	b. another transportable installation used to drill mineshafts or to carry out activities in or on existing mineshafts as referred to in Article 3.6, paragraph one, under d, and a permanent mine installation as referred to in Article 3.6, paragraph one, under b;
c. een als een geheel verplaatsbare mijnbouwinstallatie als bedoeld in artikel 3.6, eerste lid, onderdeel c en een andere verplaatsbare installatie met behulp waarvan werkzaamheden in een bestaand boorgat worden uitgevoerd als bedoeld in artikel 3.6, eerste lid, onderdeel d, of	c. a mine installation that can be transported in its entirety as referred to in Article 3.6, paragraph one, under c and another transportable installation used to drill mineshafts or to carry out activities in or on existing mineshafts as referred to in Article 3.6, paragraph one, under d, or;
d. een mijnbouwwerk op het land als bedoeld in artikel 3.6, eerste lid, onderdeel a en een andere verplaatsbare installatie met behulp waarvan boorgaten worden geboord of werkzaamheden in een bestaand boorgat worden uitgevoerd als bedoeld in artikel 3.6, eerste lid, onderdeel d.	d. a land-based mine as referred to in Article 3.6, paragraph one, under a and another transportable installation used to drill mineshafts or to carry out activities in or on existing mineshafts as referred to in Article 3.6, paragraph one, under d.

APPENDIX 2 TYPICAL GEOLOGICAL FORMATIONS AND RISKS INVOLVED IN DRILLING AND WELL OPERATIONS

Lithostratigraphic Column					Gas	Common Hazards
Era	Group	Formation	Member	Lithology		
Cenozoicum	Upper North Sea NU	"Diverse"		Diverse continental deposits, mostly fluvial sands and silts intercalated by some thin layers of grey or greenish-grey, silty clays.	No gas	Mudlosses, cavings, stuck pipe
		Maassluis NUMS		Fine to medium coarse sand, calcareous, micaceous and with marine shells. Small intercalations of silty clays, grey to dark grey. Trace of lauconite. Locally some wood, reed and roots are present.		
		Oosterhout NUOO		Succession of sands, sandy clays, and grey and greenish clays. The glauconite content is moderate to low. Locally rich in shells and bryozoans.		Possible cavings
		Breda NUBR		Sequence of marine, glauconitic sands, sandy clays and clays. In many places a glauconite-rich layer occurs at the base.		
	Middle North Sea NM	Rupel NMRU	Rupel Clay NMRFC	Clays that become more silty towards basis and top. It is rich in pyrite, contains hardly any glauconite and calcium carbonate tends to be concentrated in the septaria layers.		Slight swelling clays; Clayballs, swabbing, overpuls
			Vessem NMRFV	Silty to clayey sands with a low glauconite content; flint pebbles or phosphorite nodules commonly occur at the base.		
	Lower North Sea NL	Dongen NLDO	Asse NLFFB	Dark greenish-grey and blue-grey, plastic clays. The unit locally shows indications of bioturbation, and may be glauconitic and somewhat micaceous.	< 100 ppm	Slightly swelling clays
			Brussel Sand NLFFS	Green-grey, glauconitic, very fine-grained sand with a number of hard, calcareous sandstone layers of some dm thickness . Towards the base of the unit the clay content increases, and the calcium carbonate content and amount of glauconite decreases.	Negligible	
			Ieper NLFFI	A soft, tough and sticky to hardened and friable clay. The lower part has a brown-grey colour, contains pyrite, coalified plant remains and is non-calcareous. The upper 2/3 has a green-grey colour with a nr of sandstone beds, it is somewhat calcareous and glauconitic.	Negligible	Slight to very swelling clays
			Basal Dongen Sand NLLFD	Light green-grey, locally glauconitic, usually thin sand with a fining-upward character. It can be very argillaceous, and may locally contain some well-cemented layers.	Negligible	
		Landen NLLA	Landen Clay NLLFC	Dark-green, hard, flaky clay, somewhat silty, containing glauconite, pyrite and mica. The basal part of the member can be marly and of a lighter colour.	Negligible	Some swelling clays, Pyrite
	Chalk CK	Ekofisk CKEK		White, chalky limestones containing rare white and grey nodular and bedded chert layers, and thin, grey to green clay laminae. Some glauconite can occur in the basal interval.	Negligible	
		Houthem CKHM		Max 30m of light grey to light yellow calcareous arenites. The arenite can contain calcareous concretions, fossils and hardgrounds with shell fragments.	Negligible	
Mesozoicum		Ommelanden CKGR		Succession of white, yellowish-white or light-grey, fine grained limestones, in places argillaceous. Layers of chert nodules can be very common over thick intervals. Along the basin edge coarse, bioclastic limestones and tongues of sandstone occur.	< 190 ppm peaks max. 360 ppm	Overpulls, stuck pipe, swabbing, severe mudlosses at base, chert
		Texel CKTX	Plenus Marl CKTXP	Dark-grey, partly black, calcareous, laminated claystone.	No gas	Overpulls, stuck pipe, swabbing, severe mudlosses at base, chert, pyrite
			Texel Marlstone CKTXM	White to light-grey, locally pinkish, limestones, marls and marly chalks.		
			Texel Greensand CKTXG	Greenish, glauconitic, calcareous sandstones with intercalated marls.		
	Rijnland KN	*Holland* KNGL	Upper Holland Marl KNGLU	Sequence of light to medium grey and white chalks, chalky marls and marls. Increasingly marly with depth.		Pyrite
			Middle Holland Claystone KNGLM	Grey and/or red-brown calcareous shaly claystone with a distinctly lower lime content than the under- and overlying members. Intercation of sandstone beds.		
			Holland Greensand KNGLG	Alternation of greenish grey, very glauconitic, very fine- to fine-grained, argillaceous sandstones, locally silt-stones with calcareous or sideritic cement, and olive-grey claystones or grey marlstones.		
			Lower Holland Marl KNGLL	Grey and red-brown marl or calcareous, fissile claystone, frequently with intercalated bituminous claystone beds and sandstone beds.		

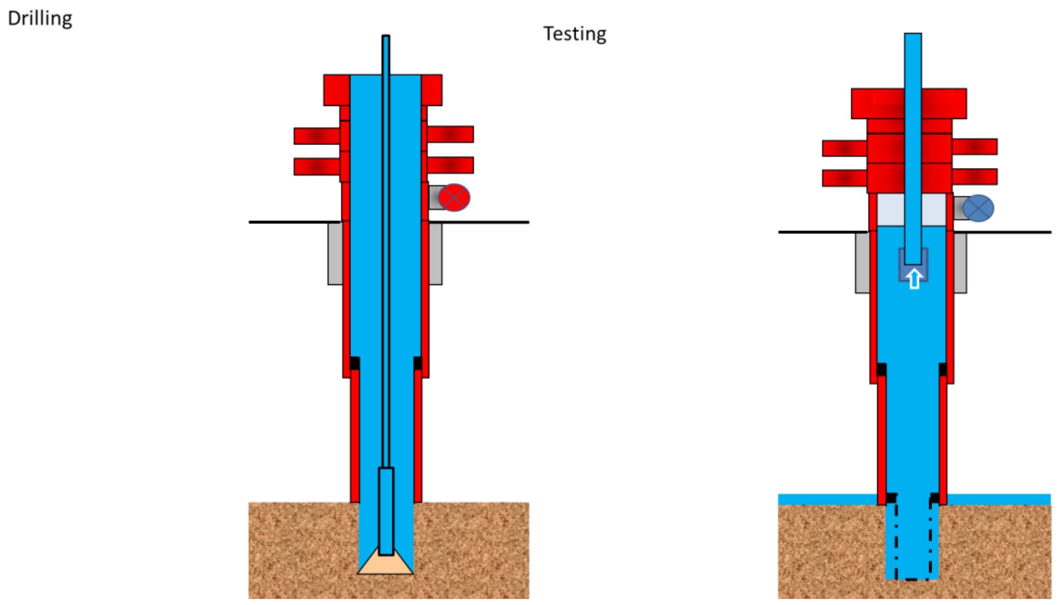
Lithostratigraphic Column					Gas	Common Hazards
Era	Group	Formation	Member	Lithology		
Mesozoicum	Rijnland KN	Vlieland Sandstone KNNS	De Lier Sandstone KNNSL	Alternation of thin-bedded, very fine- to fine-grained argillaceous sandstones, generally glauconitic and lignitic, and sandy claystones, commonly glauconitic and with shell fragments and frequent bioturbation.	No gas	Plastic clays: clayballs, overpulls, stuck pipe swabbing
			Vlieland Clay KNNCM	Dark brownish-grey to grey claystone. Mica and very fine lignitic matter are common. The formation can be very silty to sandy with many intercalated siltstone and very fine sandstone beds. Slightly calcareous.		
			Berkel Sandstone KNNSB	Sandstone, light-grey, very fine- to fine- and medium- to coarse-grained, locally gravelly, lignitic, locally glauconitic or with sideritic concretions. Especially in the upper part calcareous cemented beds		
			Berkel Sand/Claystone KNCC	Alternation of fine-grained, argillaceous sandstones and brown-grey silty to sandy claystones. Locally sideritic concretions are present.		
			Rijswijk Sandstone KNNSR	Light- to medium-grey sandstones with a very fine to medium and locally gravelly grain size; mica, lignitic matter and siderite concretions are common.		
	Schieland SL	Nieuwerkerk SLDN	Rodenrijs Claystone SLDNR	Medium- to dark-grey and dark brown, silty to sandy lignitic claystones with laminated or contorted bedding, and lignite/coal beds. Traces of mollusc shells, pyrite and siderite.		
			Delft Sandstone SLDND	Light-grey massive sandstone sequence, fine to coarse-gravelly, fining upward, lignitic.		
			Alblasserdam SLDNA	The upper part consists of grey to greyish brown, soft claystone with some intercalated red bands and well sorted, very fine loose sand, sandstone & siltstone.		
			Pijnacker Zandsteen (submember)	Consists of fine to medium grained argillaceous and glauconitic sandstones, massively bedded up to a few metres thick with inter-bedded layers of thin silty claystone.		
				A succession of typically dark to light (brownish) grey, red and variegated clay- and siltstones, fine to medium grained sandstones and massive, thick-bedded, coarse grained sandstones. Coal & lignite beds.		
	Upper Germanic Trias RN	Keuper RNKP	Upper Keuper Claystone RNKP	Predominantly grey, silty claystones and marls with streaks of fine-grained sandstone.		Cavings
			Dolomitic Keuper RNKPD	A sequence of anhydritic, partly dolomitic or marly claystones, containing fine-grained sandstone intercalations. Grey to green colours are common, but some red claystones also occur.		
			Red Keuper Claystone RNKPR	Red, silty claystones or marlstones, which yield typical high gamma-ray readings. These rocks are strongly variegated displaying red, green, yellow and grey colours.		
		Muschelkalk RNMU	Lower Muschelkalk RNMUL	Alternation of mainly light-greenish/grey limestone or dolomite and marl beds.		
		Röt RNRO	Upper Röt Fringe Claystone RNRO	A red-brown, silty, sandy or anhydritic claystone. It may also contain some dolomitic stringers.		
			Röt Fringe Sandstone RNRO	Grey, cross-bedded, arkosic sandstones with intercalated claystone beds.		
			Lower Röt Fringe Claystone RNRO	Red-brown silty claystone, often with an anhydrite or anhydrite-cemented sandstone bed at its base.		
		Solling RNSO	Solling Claystone RNSOC	Red, green and locally grey claystones, which often show high gamma-ray readings in the basal part and some sand stringers.		
			Basal Solling Sandstone RNSOB	Light-coloured, massive or cross-bedded, and dolomite-cemented sandstone.		
	Lower Germanic Trias RB	Hardegsen RBMH		Several stacked alternations of off-white to pink sandstones and some red claystones.		Possible overpressure
		Detfurth RBMD	Lower Detfurth Sandstone RBMDL	A massive, light-coloured, arkosic sandstone.		
		Volpriehausen RBMV	Upper Volpriehausen Sandstone RBMVU	Light-brown sandstone, usually carbonate-cemented. The thin claystone beds have a greenish colour and show a rhythmic alternation of thin sandstone and claystone laminae.		
			Lower Volpriehausen Sandstone RBMVL	Pink to grey, (sub-)arkosic sandstone unit, frequently displaying a distinct, blocky character on the gamma-ray logs. The member contains reworked material of the underlying formation in its lower part, which in general is strongly cemented.		
		Lower Buntsandstein RBSH	Rogenstein RBSHR	A cyclical alternation of red-brown and green, in places grey, occasionally anhydritic claystones, siltstones and sandstones or calcareous oolite beds.		

Lithostratigraphic Column					Gas	Common Hazards
Era	Group	Formation	Member	Lithology		
Paleozoic	Zechstein ZE	Zechstein Upper Claystone ZEUC		The formation is composed of red-brown to pale brown, occasionally grey-green claystones with some anhydrite and/or carbonate stringers. In the upper part thin, well-cemented, sandy beds may occur.	No gas	Stuck pipe
		Zechstein 4 (Aller) ZEZ4	Z4 Pegmatite Anhydrite ZEZ4A			Hard formation
			Red Salt Clay ZEZ4R			Squeezing clay, stuck pipe
		Zechstein 3 (Leine) ZEZ3	Z3 Main Anhydrite* ZEZ3A	Generally developed as a relatively pure anhydrite body, but it can contain a large number of dolomitic or claystone intercalations. Thicknesses vary greatly.		Hard formation
			Z3 Carbonate ZEZ3C	'Plattendolomit'. A brownish, slightly argillaceous, dolomitic limestone or coarse-crystalline dolomite.	~3000 ppm	Overpressure
			Grey Salt Clay ZEZ3G	A grey claystone with a high gamma-ray response and corresponding low velocities on the sonic log.	~1600 ppm	Squeezing clay, stuck pipe
		Zechstein 2 (Stassfurt) ZEZ2	Z2 Basal Anhydrite ZEZ2A	A massive body of relatively pure anhydrite.		Hard formation
			Z2 Carbonate ZEZ2C	"Stinkschiefer", a thin, finely laminated, argillaceous, black and often bituminous limestone. It's charact. by an increasing amount of clay towards the top.	~3000 ppm	Overpressure
			Red-Brown Salt Clay ZEZ2R	A red to red-brown, finely laminatedbed with a high gamma-ray reading.		Squeezing clay
		Zechstein 1 (Werra) ZEZ1	Z1 Carbonate ZEZ1C			Hard formation
			Z1 Anhydrite ZEZ1W	A massive anhydrite body which attains a huge thickness in the sub-basins. Dolomite stringers occur frequently within the unit.		Overpressure
			Z1 Lower Claystone ZEZ1G	A grey to brown claystone or marl, in places dolomitic or anhydritic.		
			Coppershale ZEZ1K	A microlaminated, brownish-black bituminous shale with a thickness of 0,5 to 1 m. It is characterized on wire-line logs by high gamma-ray and low acoustic velocity readings.		
	Upper Rotliegend RO	Slochteren ROSL		Sequence of usually pink to pale red-brown, occasionally yellow or grey, sandstones with subordinate amounts of intercalated dark red, red-brown or green-grey silty claystones. Locally a conglomeratic base is present.	2000 ppm max.	Overpressure; Mudlosses, Differential sticking
	Limburg DC	Ruurlo DCCR		Succession of light to dark-grey or black, silty claystones, mudstones and shales containing a variable number of coal seams, and grey or buff, very fine- to fine-grained, fairly- to poorly-sorted, argillaceous or silty sandstone beds.		Mudlosses

APPENDIX 3 TYPICAL WELL BARRIER SCHEMATIC FOR THE GEOTHERMAL WELL LIFE

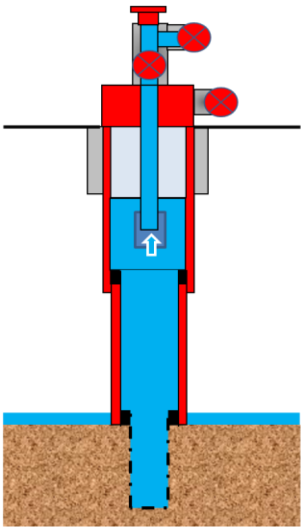
More details can be found in Figure 3. Possible failure modes of barriers.

The two well barrier schematics shown below are for the construction phase of the well and the short confirmation test done with the drilling rig still above the well

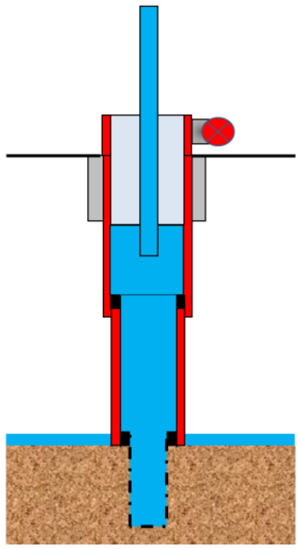


The two well barrier schematics shown below are for the production and intervention (workover) phase of the well.

Production

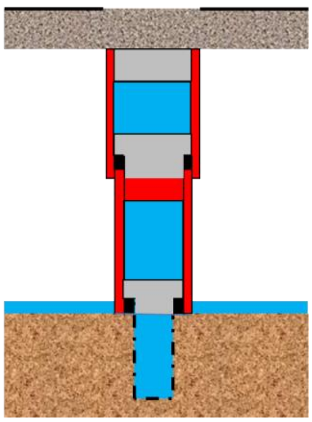


Intervention



Below the barrier schematic for the final abandonment phase of the well

Abandonment



APPENDIX 4 EXAMPLE CHECKLISTS FOR DIFFERENT WELL LIFE CYCLES

Well Construction to Operational Phase Checklist

Well location	
Permit No.	
Well Type	Geothermal Producer/Injector
Well Number	
TD (MD & TVD)	
Drilled by (company) / Rig	
Drilled on (Dates)	
Production method	ESP
Reservoir name	
Design Life	

Data	Well design elements relevant for well integrity performance	Selected element/value by original design	Actual result
General	Pore Pressure Gradient at Critical Points (S.G.) vs. TVD (m)		
	Fracture Pressure Gradient at Critical Points (S.G.) vs. TVD (m		
	Temperature Gradient at Critical Points (ºC/m) vs. TVD (m)		
Reservoir	Production or Injection Interval Name		
	Reservoir Temperature (ºC)		
	Reservoir Depth (m) AH TV		
	Reservoir Pressure (Bar)		
	GWR (m3/m3)		
	Bubble Point Pressure (Bar)		
	Zone Height (m) AH TV		
	Porosity (%)		
	Permeability (mD)		
	Formation water properties		
	pH		
	Chlorides (mg/l)		
	Total Dissolved Solids (mg/l)		
	Specific Gravity		
Injection water	Chlorides (mg/l)		
	Total Dissolved Solids (mg/l)		
	Specific Gravity		
Produced gas	Gas Gravity (Air = 1)		
	CO_2 content (%)		
	H_2S content (%)		
Designed	Wellhead Pressures (Bar)		

Water Production Conditions	Wellhead Temperatures (ºC)				
Designed Water Injection Conditions	Wellhead Injection Pressures (Bar)				
	Wellhead Injection Temperatures (ºC)				
Data Verification	Reservoir Engineering	Signature		Date	
	Petroleum Engineering	Signature		Date	
	Drilling Department	Signature		Date	

Well Handover document from Operational Phase to Workover/Well Intervention/Safe Operating Envelope

Validation date		**Well Schematic Attached**	
Well name		**Wellhead and Xmas tree rating, dimension, service trim**	
Well Type (Function)		Identify any leaking or failed barrier components	
Reservoir name		**Additional Notes:**	
		Any limitation on acceptable kill and completion fluids?	
Original Completion date		Any special monitoring requirements?	
Latest Completion date		Any other comments?	
Well design Life			
Operational Limits (enter value or NA)	**Min/Max**		
H2S (ppm in gas phase)			
CO2 (mol% in gas phase)			
O2 in Water Injection (ppb Oxygen equivalent)			
Maximum Injection Pressure (psi)			
GWR (scf/bbl)			
Reservoir Pressure (Bar)			
Reservoir Temperature (deg C)			
SITHP (Bar)			
Maximum design production rate (m3/hr)			
Maximum design injection rate (m3/hr)			
ESP design rate (m3/hr)			
Fluid Additives			
Corrosion inhibitor			

Scale inhibitor (continuous/intermittent)	
Bacteriocide/Biocide (continuous/intermittent)	
Oxygen Scavenger (Residual O2 concentration)	
H2S Scavenger (Residual H2S Concentration)	

Construction to Operations after Drilling / Workover or Intervention

Well location	
Permit No.	
Well Type	Geothermal Producer/Injector
Well Number	
TD (MD & TVD)	
Drilled by (company) / Rig	
Drilled on (Dates)	
Production method	ESP
Reservoir name	
Design Life	

Casing seat depths and Pressure test			
	Production Casing	**Liner**	**Comments**
Depth			
Formation Strength (Bar)			
Pressure test hold (pass or fail)			

Cement data					
	Cement Type	**Wt (S.G.)**	**Volume (m3)**	**Cement losses**	**Comments**
Intermediate Casing (if any)					
Production Casing					
Liner					

Cement and Corrosion logs data					
	Intermediate Casing (if any)	**Production Casing**	**Liner**	**Log results**	**Comments**

CBL/VDL/USI					
Corrosion / Cp logs Run					
Casing String Pressure test					
Intermediate Casing (Bar)	**Production Casing (Bar)**	**Liner (Bar)**			**Comments**
Casing Hanger seals test					
	Casing Head Housing (CHH) (Bar)	**Production Casing Hanger seal (Bar) (if any)**	**Liner Hanger seal (Bar)**		**Comments**
Xmas tree					
Size	**Type**	**Body tested to**	**Each valve tested to (Bar)**	**Xmas tree cavity tested to (Bar)**	**Comments**
Tubing Data					
Size drift (in)	Weight (lb/ft)	Grade			
Reservoir section					
Depth (MD/TVD) m					
Condition of recovered tubing					
Parted? Yes/No	Corrosion? Yes/No	Scaling? Yes/No			
Condition of recovered downhole pump					
Working? Yes/No	Corrosion? Yes/No	Scaling? Yes/No			
Losses in hole					
Which zone?	Volume (bbls)	Fluid type	Density		
Rig Released date					
Attached Documents					
Wellhead diagram	Pressure Test charts	Copy of cement bond logs	Copy of corrosion logs or CP logs	Other attachments	
Data Verification	Drilling Operations Name: Designation:		Signature:	Date:	
	Production Operations Name: Designation:		Signature:	Date:	

APPENDIX 5 HAZARD IDENTIFICATION AND SCENARIO WORKSHEET (DRILLING)

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences									Consequences										
				People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk		People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Action	Who	By
1	Hydrocarbons																						
1.1	Shallow Gas	1.1.1	Gas release into the well bore and at the surface leading to potential fire ! with diverter installed (note: hydrocarbon RA / evaluation: possibility of encountering shallow gas)	4	3	4	4	4	4	B	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Shallow gas plan specific to operator and the drilling contractor. Good drilling practices (e.g. controlled ROP, curing losses, pump out of hole to prevent swabbing), Pilot hole, Gas sensors/detectors + alarm, Diverter equipment, Ex certified equipment + Crew competency (IWCF Certified) to operate equipment and identifying shallow gas influx, crew positions, training, evacuation plan, emergency response procedures. OEM spare parts policy of WC equipment, well control drills, PTW etc.	1	2	1	1	1	2	B	L			
		1.1.2	Gas release into the well bore and at the surface leading to potential fire ! <u>without</u> diverter installed (note: hydrocarbon RA / evaluation: <u>no</u> likelihood of encountering shallow gas)	4	3	4	4	4	4	B	M	Good well design and drilling practices (e.g. controlled ROP, curing losses, pump out of hole to prevent swabbing) Ex certified equipment + Crew competency (IWCF Certified) to identify and deal with shallow gas influx, crew positions, training, evacuation plan, emergency power shut down.	4	3	4	4	4	4	B	M	D1. Besides Independent Well Examination, consider obtaining a second opinion on hydrocarbon RA / evaluation		
		1.1.3	Contamination of shallow aquifers	1	3	1	3	4	4	B	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, I independent verification process. Proper interpretation of seismic information, pre drill hydrocarbon RA. Installation of conductor (cemented) over shallow aquifers. Crew competency and IWCF well control training, well control drills, PTW system and emergency response procedures.	1	1	1	1	1	1	B	L			
		1.1.4	Cratering ! gas migration to shallower formation leading to cratering/blowout	4	3	4	4	4	4	B	M	See 1.1. Options with and without diverter.	1	2	1	1	1	2	B	L			
1.2	Solution/dissolved gas	1.2.1	Circulated to well bore/Shakers and then leading to fire/explosion	4	2	3	4	4	4	B	M	Good well design, maintain hydrostatic overbalance, maintain mud properties, crew competency (IWCF certified), kick detection systems, mudlogging services, degasser equipment, gas detection systems, Ex certified equipment.	1	2	1	1	1	2	B	L			
		1.2.2	Test ! release of gas at surface and potential fire/explosion	4	2	3	4	4	4	B	M	Three phase (Water!Gas!Oil) separator, flare/vent (+ back! up ignition). ATEX Zones + Ex certified equipment. Gas sensors. Crew competency to operate equipment, crew & equipment positioning, training, evacuation plan, emergency power shut down.	1	2	1	1	1	2	B	L			
		1.2.3	Reduced hydrostatic head leading to self flowing well ! uncontrolled well leading to potential blowout	4	2	3	4	4	4	B	M	Good well design, maintain hydrostatic overbalance, maintain mud properties, crew competancy, kick detection systems, mudlogging services, degasser equipment, gas detection systems, Ex certified equipment.	1	2	1	1	1	2	B	L			
1.3	Liquid hydrocarbons in brine	1.3.1	Test ! Inadequate separation of hydrocarbons leading to fire/ environmental issues	3	3	3	3	2	3	A	L	Three phase (Water!Gas!Oil) separator, flare/vent (+ back! up ignition). ATEX Zones + Ex certified equipment. Gas sensors. Crew competency to operate equipment, crew & equipment positioning, training, evacuation plan, emergency power shut down.											

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences									Consequences										
				People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk		People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Action	Who	By
		1.3.2	Reduced hydrostatic head leading to self flowing well ! uncontrolled well leading to potential blowout	4	2	3	4	4	4	A	L	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Use of diverter or BOP system. Good drilling practices (e.g. controlled ROP, curing losses, pump out of hole to prevent swabbing) Ex certified equipment + Crew competency (IWCF Certified) to identify and deal with kick/influx, crew positions, training (kick drills), PTW, evacuation plan, emergency power shut down.	1	2	1	1	1	2	A	L			
1.4	Fuels for equipment	1.4.1	Poor maintenance/human error leading to leaks leading to fires/ environmental pollution	3	3	3	2	2	3	C	M	PM maintenance system based on industry standards and OEM instructions, (daily) inspections, crew training and competency, crew appraisal system, supervision, self verification, fuel storage standards, (fuel) hose management, emergency response procedures and training.	1	2	1	1	1	2	C	L			
1.5	Encountering unexpected HCs	1.5.1	Poor well planning leading to Kicks/Blowout	4	3	4	4	4	4	C	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Use of diverter and or/ BOP system. Good drilling practices (e.g. controlled ROP) well kill procedures and practices, case off well, operating instructions, preventive maintenance, spark arrestors, OEM spare parts policy of WC equipment, well control drills, PTW & LOTO system, emergency response procedures. Ex certified equipment + Crew competency (IWCF Certified) to identify and deal with kick/influx, crew positions, training (kick drills), evacuation plan, emergency power shut down.	1	2	1	1	1	2	C	L			
2	Other Flammable Materials																						
2.1	Pyrophoric materials		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A												
2.2	Drilling fluid additives	2.2.1	Incorrect storage/handling leading to spillage and/or fire and/or exposure to human, environment or asset	2	2	2	2	2	2	B	L	Defined storage location, good storage and handling procedures. Competency of crew, supervision, Safety Observation Program, correct and adequate PPE, fire fighting equipment, emergency response. Only additives in line with REACH regulation. Safety Data sheets. Liquid tight asphalt. Application of ATEX137 & PGS15. Gas & Fire sensors/detection.											
2.3	Oil Based muds	2.3.1	Incorrect storage/handling leading to spillage and/or fire and/or exposure to human, environment or asset	2	2	3	2	2	3	B	L	Ex certified equipment, crew competency, supervision, dedicated storage areas, operating instructions, PPE, fire fighting equipment, emergency response. Only chemicals in line with REACH regulation. Safety Data sheets. Liquid tight asphalt. Application of ATEX137 & PGS15. Gas & Fire sensors/detection.											

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences						Frequency	Risk		Consequences						Frequency	Risk	Action	Who	By
				People	Env't	Asset	Rep'n	Social	Severity				People	Env't	Asset	Rep'n	Social	Severity					
2.4	Industrial Gases used for welding etc	2.4.1	Incorrect storage/handling leading to spillage and/or fire and/or exposure to human, environment or asset	3	2	3	2	2	3	B	L	Good housekeeping. Gas bottle storage racks, good handling and storage procedures, equipment!on!site layout, competency of crew, awareness training, supervision, segregation of duties, Safety Observation Program, Self verification system, PPE, fire fighting equipment, emergency response. Only additives in line with REACH!regulation. Safety Data sheets. Liquid tight asphalt. Application of ATEX137 & PGS15 Gas & Fire sensors/detection											
3	Pressure Hazards																						
3.1	Water aquifer under pressure	3.1.1	Kick leading to asset damage/ personal injuries	3	2	2	3	3	3	B	L	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Interpretation of seismic data. Use of diverter and/ or BOP system. Good drilling practices. Crew competency (IWCF Certified) to identify and deal with kick/influx, crew positions, training (kick drills), evacuation plan, emergency power shut down. Preventive maintenance, Ex certified equipment, OEM spare parts policy of WC equipment, PTW system etc.											
		3.1.2	Test ! leak to the Formation/ Surface/ asset damage	3	2	2	3	3	3	C	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Certified and (pressure) tested high pressure equipment. Well supervision (IWCF certified). MAASP, Restricted (surface) test pressures.	1	1	1	1	1	1	C	L			
3.2	Liquid and gas hydrocarbons under pressure	3.2.1	Kick leading to asset damage/ personal injuries	3	2	2	3	3	3	B	L	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent well examination/verification process. Use of diverter/BOP system. Good drilling practices (e.g. controlled ROP, curing losses, pump out of hole to prevent swabbing). Ex certified equipment + Crew competency (IWCF Certified) to identify and deal with kick/influx, crew positions, training (kick drills), PTW & LOTO system, evacuation plan, emergency response procedures.											
3.3	Unexpected high pressure during drilling	3.3.1	Kick leading to asset damage/ personal injuries	3	2	2	3	3	3	C	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Use of diverter/BOP system. Good drilling practices (e.g. controlled ROP, curing losses, pump out of hole to prevent swabbing). Ex certified equipment + Crew competency (IWCF Certified) to identify and deal with kick/influx, crew positions, training (kick drills), PTW & LOTO system, evacuation plan, emergency response procedures.	2	1	2	1	1	2	C	L			

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
3.4	Drilling fluids under pressure	3.4.1	Potential leak from drilling equipment at surface leading to injury	3	2	2	3	3	3	C	M	Operating instructions, preventive maintenance system, regular inspections and recertification, Safety Observation Program, supervision, PTW and LOTO systems, regular pressure testing, minimum wall thickness requirements, HP hose management, temporary barrier, operating instructions, crew competency, PPE, emergency response procedures.	2	1	2	1	1	2	C	L			
		3.4.2	Potential leak into shallow formation	1	2	1	2	1	2	D	M	Good well design, hydrocarbon risk assessment, development of Risk Register, independent verification process, proper mud program, non!hazardous mud selection, monitoring of fluid loss, optimise mud properties.	2	1	2	1	1	2	C	L			
3.5	Test water injection	3.5.1	Potential leak from drilling equipment at surface	1	3	1	2	2	3	C	M	Certified and (pressure) tested high pressure equipment. Restricted (surface) test pressures. Good maintenance program and good housekeeping.	1	1	1	1	1	1	C	L			
		3.5.2	Potential leak into non target formation	1	2	2	1	1	3	B	L	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, independent verification process, proper mud program, non!hazardous mud selection, monitoring of fluid loss, optimise mud properties.											
3.6	Losses due to low pressure in formation	3.6.1	Poor well planning leading to loss of well bore	1	1	4	2	1	4	B	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process . BOP equipment. Good drilling practices, proper mud program, monitoring of fluid loss, well control procedures, total pit volume fluid management, optimised mud properties, loss of circulation management plan. Crew competency (IWCF Certified) to identify and deal with anomalies, training, kick drills.	1	1	2	1	1	2	B	L			
		3.6.2	Unexpected geology eg Faults, squeezing formation etc leading to losses or loss of well	1	1	4	2	1	4	C	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, Independent verification process. Use of diverter/BOP system. Good drilling practices (e.g. controlled ROP, proper mud program, monitoring of fluid loss, well control procedures, total pit volume fluid management, optimise mud properties). Crew competency (IWCF Certified) to identify and deal with anomalies, training (kick drills).	1	1	2	1	1	2	C	L			
4	Hazards associated with differences in height																						
4.1	Dropped loads	4.1.1	Failures/errors during equipment set up leading to injury/ asset damage	4	1	2	3	2	4	C	M	Design standards, certified lifting equipment, color coding, lifting standards, lifting training for crew, crew competency system, crew appraisal system, supervision, self verification, correct and adequate PPE, emergency response, DROPS zone and red zone management, tethered tool kit, temporary barrier policy, use of banksman, PTW system.	2	1	2	2	1	2	C	L			

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences									Consequences										
				People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk		People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Action	Who	By
4.2	Overhead equipment	4.2.1	Failures/errors leading to injury/ asset damage	4	1	2	3	2	4	C	M	Adequate DROPS philosophy, equipment design standards, regular DROPS and mast inspections, preventive maintenance system, supervision, self verification, Safety Observation Program. Good housekeeping.	2	1	1	2	1	2	C	L			
4.3	Working at height	4.3.1	Falls and trips leading to injuries	4	1	1	2	2	4	C	M	Fall protection, design standards, preventive maintenance system, use of a cherry picker, scaffold, ladder management, house keeping, PPE, emergency response. Good housekeeping.	2	1	1	2	1	2	C	L			
4.4	Crane activity	4.4.1	Failures/errors leading to injury/ asset damage	4	1	3	3	2	4	C	M	Equipment design standards, equipment and contractor selection, preventive maintenance system, supervision, self verification, Safety Observation Program, temporary barrier policy, red zone management, PTW, lift plans, use of Banks man, correct and adequate use of PPE, emergency response procedures.	2	1	1	2	1	2	C	L			
5	Dynamic situation hazards																						
5.1	Rotating equipment	5.1.1	Failures/errors leading to injury/ asset damage	3	1	2	2	2	3	B	L	Adequate design standards, warning signs, installation of protective covers, PTW and LOTO systems, restricted area management, crew competency system, crew appraisal system, Safety Observation Program, pre job RA, supervision, emergency response procedures.											
5.2	Unexpected breakdown	5.2.1	Failures/errors leading to injury/ asset damage	3	1	2	2	2	3	B	L	HAZOP and HAZID, equipment design, preventive maintenance system, back up power for safety critical and emergency equipment, fail safe design features, MoC procedures with RAs, correct use of PPE, emergency response procedures.											
5.3	Stored energy	5.3.1	Failures/errors leading to injury/ asset damage	3	1	2	2	2	3	B	L	Pre job RA, competency of crew, segregation of duties i.e. electrical and mechanical, PTW and LOTO systems, supervision, rig crew work instructions, correct use of PPE, emergency response procedures.											
5.4	Vehicle collision	5.4.1	Failures/errors leading to injury/ asset damage	3	1	3	2	2	3	B	L	Good housekeeping. Good site control and adherence to traffic laws.											
5.5	Aircraft impact	5.5.1	Failures/errors leading to injury/ asset damage	5	3	4	1	1	5	A	M	Permit regulations, flight routes, red top light in crown section, location lighting, emergency response procedures.	5	3	4	1	1	5	A	M	D2. Ensure drilling consent review considers proximity to airports/ flight paths.		
5.6	Concurrent activities	5.6.1	Failures/errors leading to injury/ asset damage	3	1	2	2	2	3	C	M	Job RA & planning, daily pre job meetings, concurrent ops meetings, PTW system and Supervision.	2	1	2	1	1	2	B	L			
5.7	Hazards posed by adjacent facilities	5.7.1	Failures/errors leading to injury/ asset damage	3	1	2	2	2	3	B	L	Fencing the site perimeter, pre job RA, effective communication lines, permits, local and country legislation. Good communication and awareness for stakeholders and neighbours.											
5.8	Accidents due to onsite transport (small footprint)	5.8.1	Failures/errors leading to injury/ asset damage	3	1	2	2	2	3	B	L	Adequate vehicle guidance, speed limits on site, supervision, awareness training, access control, flash lights, reverse alarms, horn, pipe clamp on forklift, transport standards, licensing of (forklift or truck) drivers, temporary barrier/ fencing, site rules. Good housekeeping.											
5.9	Stuck pipe	5.9.1	Differential sticking leading to potential loss of well/ asset damage/ operational downtime	1	1	5	1	1	5	E	H	Well planning, drilling mud optimisation, crew competency, BHA optimisation (use of right instruments), training for crew, Stuck Pipe procedure, good house keeping.	1	1	5	1	1	5	C	H	D3. Operator to have a valid LIH (Lost In Hole) insurance to cover this potential economic impact.		
5.10	Underground infrastructure	5.10.1	Unintentional damage to existing infrastructure during well site set up and Conductor piling	2	2	2	3	3	3	C	M	Permit regulations, "KLIC melding" (excavation report), PTW and LOTO systems, crew competency. Front end surveys and interpretation of data.	2	1	2	1	1	2	B	L			
6A	Natural Environmental hazards																						

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
6.1	Earthquake (natural)	6.1.1	Damage to drilling rig and well	2	2	3	1	2	3	B	L												
6.2	Landslides	6.2.1	Damage to drilling rig and well	2	2	3	1	2	3	B	L												
6.3	Flooding	6.3.1	Flooding of well area leading to downtime and damage to asset	1	2	3	1	1	3	C	M	Flooding action plan to ensure controlled shutdown of drilling operations to minimise damage.	1	2	3	1	1	3	C	M	D4. Operator to have valid insurance to cover potential economic impact of flooding during drilling operations.		
6.4	Temperature extremes	6.4.1	Leading to downtime, injury and damage to asset	2	1	2	1	1	2	C	L												
6.5	Ice/Snow loading	6.5.1	Leading to downtime, injury and damage to asset	2	1	2	1	1	2	B	L												
6.6	Lightning discharge	6.6.1	Leading to downtime, injuries and damage to asset	4	1	3	1	2	4	C	M	Grounding of equipment.	3	1	1	1	2	3	B	L			
6B	Induced Environmental hazards																						
6.7	Induced seismicity	6.7.1	Activating fault by drilling/well testing/planned stimulation leading to local seismic activities leading to building damages/public disturbances	2	2	2	4	4	4	B	M	Good well design, hydrocarbon risk assessment, development of Risk Register from the BOD and updating same through the whole well cycle, independent verification process, pre job RA, DWOPs, drilling permits. Installation of seismometers, Seismic Risk Action plan.	2	1	2	1	2	2	B	L			
6.8	Subsidence / uplift	6.8.1	Foundation errors leading to downtime, environmental leaks/pollution and asset damage	1	2	3	2	2	3	B	L	Proper drill site design covering the specific rig requirements, civil engineering calculations by specialists, site inspections prior to rig arrival, pre move meetings/Tool box talk.											
6.9	Surface Disturbances	6.9.1	Industrial activity leading to environmental impact	1	3	1	3	3	3	B	L	Drilling permit, pre job RA, emergency response, fluid containment on site I ditches and water collection tank, spill kits, competency of crew, crew awareness training, incident reporting and follow up.											
6.10	Contamination of surface water	6.10.1	Loss of containment leading to contamination of surface water	1	3	3	3	2	3	B	L												
6.11	Contamination of ground water	6.11.1	Loss of containment leading to contamination of surface water	1	3	3	3	3	3	B	L												
6.12	Impact on fauna/flora	6.12.1	Industrial activity leading to environmental impact	1	3	1	3	3	3	C	M	Good housekeeping.	1	2	1	2	2	2	B	L			
7	Hot surfaces																						
7.1	Process piping / well head	7.1.1	Direct contact leading to personal injury and/or asset damage	3	1	2	1	3	3	C	M	Design of equipment, warning signs, awareness training, local insulation, correct use of PPE, emergency response, first aid.	2	1	2	1	2	2	B	L			
8	Hot liquid																						
8.1	Loss of containment	8.1.1	Direct contact leading to personal injury and/or asset damage	3	1	2	1	3	3	C	M	Design of equipment, use of mud coolers, local insulation, correct use of PPE, emergency response, first aid.	2	1	2	1	2	2	B	L			
9	Electricity																						
9.1	Electrocution	9.1.1	Direct contact leading to personal injury, fatality	5	1	1	3	3	5	B	H	Grounding of equipment. Design of equipment, warning signs, awareness training, local insulation, PPE, emergency response, first aid.	3	1	1	3	3	3	B	L			
9.2	Electrostatic energy	9.2.1	Direct contact leading to personal injury and/or asset damage (ignition resulting in fire/explosion)	5	1	1	3	3	5	B	H	Grounding of equipment. Competency of crew, supervision, Safety Observation Program, correct use of PPE, fire fighting equipment, emergency response. Application of ATEX137 & PGS15. Gas & Fire sensors/detection.	3	1	1	3	3	3	B	L			
9.3	Loss of electrical supply	9.3.1	Leading to downtime, loss of well bore	1	2	4	2	1	4	B	M	Backup power system for critical equipment, preventive maintenance, regular inspections, competency of crew.	1	2	2	2	1	2	B	L			
10	Electromagnetic radiation																						
10.1	Instrumentation	10.1.1	Interference with nearby sensitive equipment leading to malfunction, damage to asset/neighbours' equipment	1	1	4	3	1	4	B	M	Pre job RA, pre move site visit, DWOPS, rig on location drawing, correct equipment design, local insulation or shielding, proper cable routing.	1	1	2	1	2	2	B	L			
11	Ionizing radiation																						

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences						Frequency	Risk		Consequences						Frequency	Risk	Action	Who	By
				People	Env't	Asset	Rep'n	Social	Severity				People	Env't	Asset	Rep'n	Social	Severity					
11.1	Logging equipment	11.1.1	Exposure of personnel to radiation leading to injury	3	3	3	3	2	3	B	L	Dedicated personnel for handling sources, operating procedures, competency of crew, awareness training, supervision, dedicated storage area, temporary barriers, signage, use of special storage and transport boxes, PTW, personnel detectors,correct use of PPE, emergency response procedures.											
11.2	Naturally occurring radioactive material (NORM) in drilling fluids/cuttings etc.	11.2.1	Test ! increase of LSA (Low Specific Activity) at the bends & in cavitating equipments leading to exposure/injury to personnel	3	3	3	3	2	3	D	M	Correct use of PPE, instructions and procedures, personal hygiene, radiation expert (min. level 5b) (stralingsdeskundige level 5b), LSA/NORM sensor/detectors.	2	2	2	3	2	3	B	L			
11.3	Radon		N/A																				
12	Asphyxiates																						
12.1	Confined spaces	12.1.1	Lack of oxygen in the presence of poisonous/explosive gases leading to personal injury/death	5	2	3	4	4	5	B	M	Equipment design, crew competency, confined space awareness training, operating instructions, PTW and LOTO systems, supervision, Safety Observation Program, multi warning gas detectors, manhole watchman, correct use of PPE, emergency response procedures, first aid.	2	2	1	2	2	2	B	L			
12.2	Excessive CO2	12.2.1	12.1	5	2	3	4	4	5	B	M	Equipment design, crew competency, confined space awareness training, operating instructions, PTW and LOTO systems, supervision, Safety Observation Program, multi warning gas detectors, manhole watchman, PPE, emergency response, first aid.	2	2	1	2	2	2	B	L			
12.3	Excessive N2		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A											
13	Toxic gas																						
13.1	Atmospheric emissions e.g. CO2, H2S	13.1.1	Gas coming out of Brine solution leading to respiratory issues/personal injury, metal cracking/corrosion leading to asset damage, downtime due to H2S management	5	1	4	4	4	5	C	H	Specific gas monitoring, careful geological well planning, mud logging, gas alarms, emergency response plans, crew competency, training, H2S fit for purpose equipment, maintenance programmes. Correct use of PPE.	2	1	2	3	2	3	B	L			
13.2	H2S exposure	13.2.1	13.1	5	1	4	4	4	5	C	H	Specific gas monitoring, careful geological well planning, mud logging, gas alarms, emergency response plans, crew competency, training, H2S fit for purpose equipment, maintenance programmes. Correct use of PPE.	2	1	2	3	2	3	B	L			
14	Toxic fluid																						
14.1	Brine	14.1.1	Corrosion leading to leaks on drilling equipment, spillage to environment/personal injury	2	3	3	3	2	3	C	M	Equipment design, regular inspections and preventive maintenance, wall thickness measurements, Only chemicals in line with REACH regulation. Safety Data sheets, Liquid tight asphalt. Application of ATEX137 & PGS15.	1	1	2	2	1	2	B	L			
14.2	Corrosion inhibitors		N/A ! See Operations Worksheet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A											
14.3	Scale inhibitors		N/A ! See Operations Worksheet	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A											
14.4	Mud additives	14.4.1	Direct contact leading to personal injury, LTIs, corrosion of equipment/ asset damage	3	3	3	3	2	3	C	M	Dedicated storage area, crew competency, awareness training, supervision, signage, temporary barriers, correct use of PPE, emergency response procedures, first aid. Only chemicals in line with REACH regulation. Safety Data sheets Liquid tight asphalt. Application of ATEX137 & PGS15.	1	1	2	2	1	2	B	L			
14.5	Discharge of chemicals	14.5.1	Direct contact leading to personal injury, corrosion of equipment/ asset damage	3	3	3	3	3	3	C	M	Dedicated storage area, crew competency, awareness training, supervision, signage, temporary barriers, PPE, emergency response, first aid. Only chemicals in line with REACH regulation. Safety Data sheets. Liquid tight asphalt. Application of ATEX137 & PGS15.	1	1	2	2	1	2	B	L			
14.6	Discharge of drilling effluents	14.6.1	Direct contact leading to personal injury, corrosion of equipment/ asset damage	3	3	3	3	3	3	C	M	Dedicated storage area, crew competency, awareness training, supervision, signage, temporary barriers, PPE, emergency response, first aid. Only chemicals in line with REACH regulation. Safety Data sheets. Liquid tight asphalt. Application of ATEX137 & PGS15.	1	1	2	2	1	2	B	L			

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
14.7	Disposal e.g. of test water	14.7.1	Leading to Flora/fauna pollution leading to personal injury (from the heat)	2	3	1	3	2	3	C	M	Waste management procedures, containment of fluids on site, supervision, pre job RA, crew competency, emergency response procedures. Good house keeping.	1	1	2	2	1	2	B	L			
15	Toxic solid																						
15.1	Cement dust	15.1.1	Inhalation leading to personal injury, environmental pollution and reputational issue	3	3	2	3	3	3	C	M	Design of equipment, crew awareness, crew competency, supervision, correct use of PPE, emergency response procedures, first aid. Only chemicals in line with REACH regulation. Safety Data sheets. Liquid tight asphalt. Application of PGS15.	1	1	2	2	1	2	B	L			
15.2	Sodium hypochlorite I Drilling fluid additive	15.2.1	Ingestion/direct contact leading to personal injury	3	3	2	3	3	3	C	M	See 14.7.1	1	1	2	2	1	2	B	L			
15.3	Powdered mud additive	15.3.1	Ingestion/direct contact leading to personal injury	3	3	2	3	3	3	C	M	See 14.7.1	1	1	2	2	1	2	B	L			
15.4	Oil based muds	15.4.1	Ingestion/direct contact leading to personal injury	3	3	2	3	3	3	C	M	See 14.7.1	1	1	2	2	1	2	B	L			
15.5	Water based muds	15.5.1	Ingestion/direct contact leading to personal injury	3	3	2	3	3	3	C	M	See 14.7.1	1	1	2	2	1	2	B	L			
15.6	Cement slurries	15.6.1	Ingestion/direct contact leading to personal injury	3	3	2	3	3	3	C	M	See 14.7.1	1	1	2	2	1	2	B	L			
15.7	Disposal	15.7.1	Ingestion/direct contact leading to personal injury	3	3	2	3	3	3	C	M	See 14.7.1	1	1	2	2	1	2	B	L			
16	Corrosive substances																						
16.1	Brine	16.1.1	Damage to drilling equipment, asset, environment and/or injury to personnel	3	3	2	3	3	3	C	M	Equipment design, regular inspections, wall thickness measurements, preventive maintenance system, correct use of PPE, emergency response procedures, first aid. Only chemicals in line with REACHregulation. Safety Data sheets . Liquid tight asphalt. Application of PGS15.	1	1	2	2	1	2	B	L			
16.2	Well stimulation fluids (HF/HCL)	16.2.1	16.1	3	3	2	3	3	3	C	M	See 16.1.1	1	1	2	2	1	2	B	L			
16.3	Caustic soda I drilling fluid additive	16.3.1	16.1	3	3	2	3	3	3	C	M	See 16.1.1	1	1	2	2	1	2	B	L			
16.4	HF / other acids for stimulation	16.4.1	16.1	3	3	2	3	3	3	C	M	See 16.1.1	1	1	2	2	1	2	B	L			
17	Biological hazards																						
17.1	Water borne bacteria	17.1.1	SRB (sulphate reducing bacteria) accumlation in drilling muds leading to scale formation	1	1	2	1	1	2	C	L												
18	Ergonomic hazards																						
18.1	Manual handling	18.1.1	Personal injury, damage to assets	3	1	3	2	3	3	C	M	Crew awareness training, automation, manual handling procedures, Safety Observation Program, supervision, emergency response, first aid, correct use of PPE, certified equipment.	2	1	2	1	2	1	B	L			
18.2	Lighting	18.2.1	Personal injury, downtime	3	1	3	2	3	3	C	M	Pre job meetings, adverse weather procedures, proper grounding, crew awareness training, emergency response, first aid, correct use of PPE.	2	1	2	1	1	2	B	L			
18.3	Miscommunication	18.3.1	Personal injury, downtime, damage to asset/loss of asset, loss of well bore	3	1	3	2	3	3	D	M	Pre job meetings, handover meetings, written drilling instructions and reports, supervision, crew competency, correct use of PPE.	2	1	2	1	1	2	B	L			
18.4	Inadequate information	18.4.1	18.3	3	1	3	2	3	3	D	M	Pre job meetings, handover meetings, written drilling instructions and reports, supervision, crew competency.	2	1	2	1	1	2	B	L			
18.5	Stress	18.5.1	18.3	3	1	3	2	3	3	C	M	Crew composition, regular shift timing, optimised shift rotation time (on and off), regular breaks, medical tests, frequent rotation on the job, supervision.	2	1	2	1	1	2	B	L			
18.6	Lack of competency	18.6.1	18.3	3	1	3	2	3	3	C	M	Crew selection, competency program, appraisal system, supervision, Safety Observation Program.	2	1	2	1	1	2	B	L			
18.7	Vibration	18.7.1	18.3	3	1	3	2	3	3	C	M	Equipment design, correct use of PPE. Pre job meeting.	2	1	2	1	1	2	B	L			

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
18.8	Manning levels	18.8.1	18.3	3	1	3	2	3	3	C	M	Crew selection, competency program, appraisal system, supervision, Safety Observation Program.	2	1	2	1	1	2	B	L			
19	Security related hazards																						
19.1	Intruders	19.1.1	Personal injury, downtime, damage to asset, loss of well bore, reputation and social impact	2	1	3	3	2	3	A	L	Security RA, secured drill site and security control at the site entrance and around the site. Fencing around drill site, crew awareness, emergency response procedures.											
19.2	Sabotage	19.2.1	Personal injury, downtime, damage to asset, loss of well bore, reputation and social impact	2	1	3	3	2	3	A	L	Security RA, supervision, crew awareness, disciplinary procedures.											
19.3	Theft	19.3.1	Personal injury, downtime, damage to asset	1	1	3	3	1	3	B	L	Security RA, secured drill site and security control at the site entrance and around the site. Fencing around drill site, crew awareness, emergency response procedures.											
20	Use of natural resources																						
20.1	Water		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A											
20.2	Air		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A											
21	Noise/Light																						
21.1	Noise pollution	21.1.1	Rig noise leading to injury to personnel, reputation, social, downtime due to protests	2	2	1	3	3	3	E	H	Equipment selection, PPE, sound walls (Cocoon), drill site selection, communication strategy, crew competency or awareness, monitoring in nearby houses, careful planning/logistics.	2	2	1	2	2	2	E	M	D5. Ensure drilling consent review considers proximity to housing and potential noise impact.		
21.2	Local high noise levels		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A											
21.3	Light Pollution	21.3.1	High light leading to local complaints, reputation	1	2	1	3	3	3	D	M	Equipment selection, PR I communication with surrounding stakeholders, careful planning.	1	2	1	2	2	2	C	L			
21.4	Smell	21.4.1	leading to complaints	2	2	1	3	3	3	B	L	See 21.3.1											
22	Explosives																						
22.1	Perforation guns	22.1.1	Perforating operations leading to personnel injury, asset damage due to poor handling	4	1	3	3	3	4	B	M	Dedicated personel for handling sources, operating instructions, competency of crews, awareness training, supervision, dedicated storage area, temporary barriers, signage, use of special storage and transport boxes, PTW, personal detectors, correct use of PPE, emergency response procedures.	3	1	2	2	2	2	B	L			

APPENDIX 6 HAZARD IDENTIFICATION AND SCENARIO WORKSHEET (OPERATIONS)

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences						Frequency	Risk		Consequences						Frequency	Risk	Action	Who	By
				People	Env't	Asset	Rep'n	Social	Severity				People	Env't	Asset	Rep'n	Social	Severity					
1	Hydrocarbons																						
1.1	Shallow Gas	1.1.1	See Drilling worksheet																				
1.2	Gas separated from the Solution	1.2.1	Corrosion of upper tubulars leading to seal failure, loss of containment and potential release and fire at the surface	3	3	4	3	3	4	B	M	Design phase best available data is used for corrosion analysis and material selection. Data gathering by companies to know what the corrosion risks are. Logging data and sharing of inspection data of tubing and ESPs after withdrawal within companies. There are corrosion coupons at surface. Use of corrosion inhibitors and scale inhibitors (Supplier indicated selection). Monitoring P and T which may indicate casing leak. Workovers (re!tubing lining etc.) can be considered depending upon the location / source of leak. There are initiatives to develop knowledge sharing and technical steps like composite casing etc.	2	2	4	3	2	4	B	M	O1. In the basis of design (BOD) phase correct and detailed relevant data is needed for corrosion analysis and material selection. Life cycle costs (LCC) need to factored into material selection to get correct materials. A specific Risk Register should be produced during the BOD phase and updated as required thourghout the well lifecycle until the well is permenantly abandoned. O2. Comprehensive review of the whole system to optimise and minimise cost for best corrosion mitigation. O3. Data gathering and sharing to better understand the corrosion risks. O4. Logging data , sharing of inspection data of tubing and ESPs after retrieval O5. Correct testing and selection of corrosion inhibitors and compatibility with scale inhibitors based on individual well characteristics O6. Active monitoring of positive applied annular pressure (e.g. Nitrogen cushion). Monitoring to quickly detect leaks. Possibility to implement/trigger alarm and shutdown where feasible.		
		1.2.2	Gas Leakage through wellhead seals leading to release to environment and exposure of personnel	3	3	3	2	2	3	B	L	Routine wellhead seal leak testing.											
		1.2.3	Gas leakage through non!gas tight connections on casing	1	1	2	1	1	2	B	L	Monitoring Annuli pressures.											
1.3	Liquid hydrocarbons in brine	1.3.1	Leakage through wellhead seals. Potential fire in event of a leak	3	3	3	3	3	3	B	L	Routine wellhead seal leak testing.											
		1.3.2	Organic scales build up leading to diameter reduction, production or injection well performance loss. See 15.8 (Toxic solids, scale formation)																				
		1.3.3	Operating environment can impact the selection of the equipment incl rating etc.	1	1	1	1	1	1	D	L												
2	Other Flammable Materials																						
2.1	Pyrophoric materials	2.1.1	Some scales may be pyrophoric leading to risk of fires when equipment removed	3	2	3	3	3	3	B	L	NOGEPA guidelines being reconsidered for Geothermal and safety standard. Operators already trained on how to deal with this. There is a company established straalingsniveau3 , HSE docs all in place.											
3	Pressure Hazards																						
3.1	Brine at high pressure	3.1.1	Leakage of brine under hydrostatic pressure leading to release to environment and potential exposure of personnel	2	2	2	2	2	2	C	L												
		3.1.2	Casing burst or tubing collapse due to well fluid pressure and temperature	2	3	4	3	3	4	A	L												
		3.1.3	Leakage of injection well fluids through seals, etc.	2	2	2	2	2	2	C	L												
3.2	Non!hydrocarbon gas under pressure	3.2.1	Leakage of Nitrogen from nitrogen blanket in annulus	2	2	2	2	1	2	B	L												
3.3	Liquid and gas hydrocarbons under pressure	3.3.1	Leakage of fluids under hydrostatic pressure leading to release to environment See 1.2.2 (Hydrocarbons, gas leakage through well head seals)																				
		3.3.2	Casing burst or tubing collapse due to well fluid pressure and temperature See 3.1.2 (Pressure, casing burst)																				

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences						Frequency	Risk		Consequences						Frequency	Risk	Action	Who	By
				People	Env't	Asset	Rep'n	Social	Severity				People	Env't	Asset	Rep'n	Social	Severity					
		3.3.3	Cross flow from existing Oil & Gas wells in vicinity (whether abandoned or not) into "cemented" annulus leading to surface release and exposure of personnel	2	3	4	4	4	4	B	M	Drilling programme checks and predrill risk assessment include checks of local wells.	2	3	4	4	4	4	A	L			
3.4	Nitrogen blanket above brine level	3.4.1	Leak past seals See 3.2.1 (Pressure Hazards)																				
		3.4.2	Air ingress if N2 absent and seals leaking resulting in enhanced corrosion	1	1	3	2	1	3	B	L												
		3.4.3	Poor quality nitrogen leading to oxygen contamination and enhanced corrosion risks and leakage See 3.4.2. (air ingress)																				
4	Hazards associated with differences in height																						
4.1	Dropped loads	4.1.1	Changing of ESP etc. Losing the ESP downhole or dropped equipment during workover (causing need to fish and damaging the valuable equipment). Negligence of care of equipment (dropped wrench lost wire into well) resulting in work/fish. Stuck tools, corroded clamps, falling into the hole, causing complex operations and extra risks	2	1	2	3	2	3	C	M	Competent contractor used for workover activities.	2	1	2	2	2	2	B	L			
4.2	Overhead equipment	4.2.1	Dropping objects due to cranes working adjacent, hitting the wellhead	4	1	2	3	2	4	C	M	Competent contractor used for workover activities. Adequate DROPS philosophy, equipment design standards, preventive maintenance system, supervision, self verification, Safety Observation Program.	3	1	2	3	2	3	B	L			
4.3	Working at height	4.3.1	Falling into cellars causing personal accidents	4	1	1	3	3	4	B	M	Protection around well. HSE training of employees.	4	1	1	3	3	4	A	L			
		4.3.2	Access to wellheads not ergonomic/ difficult to access	2	1	1	1	1	2	B	M	HSE training of employees.	2	1	1	1	1	2	C	L			
5	Dynamic situation hazards																						
5.1	Rotating equipment	5.1.1	ESPs being out of balance could give rise to vibrations (in old equipment I now better). ESP failure (erosion, corrosion, seal failure, motor, pump, resulting in damage, item drop inhole and need for workover	1	1	4	2	2	4	B	M	Quality of equipment selected has improved.	1	1	4	2	2	4	A	L			
		5.1.2	Rotating jetting tools/ milling for clean the well (scale etc.) could lead to casing damage if not controlled properly	1	1	4	2	2	4	B	M	Competent contractor used for these operations.	1	1	4	2	2	4	A	L			
		5.1.3	Burn out of cable to ESP resulting in interference of electrical supply leading to enhanced corrosion risks	4	3	3	4	4	4	A	L	Grounding, current leakage detection.											
5.2	Stored energy	5.2.1	Water hammer effects on equipment at surface resulting in leak. See 1.2 (Hydrocarbons, gas leakage through seals)																				
5.3	Vehicle collision	5.3.1	Vehicle damages wellhead due to lack of manoeuvring room resulting in injury and leak of well fluids	3	3	3	2	2	3	B	L	Adherence to traffic laws.											
5.4	Aircraft impact	5.4.1	Helicopter or plane crashes on well site	4	3	4	1	1	4	A	L	Permit regulations, flight routes, emergency response.											
5.5	Concurrent activities	5.5.1	Drilling operations during production	3	1	2	2	2	3	B	L												
5.6	Hazards posed by adjacent facilities	5.6.1	Use of chemicals in adjacent works diffusing to site	2	3	3	2	2	3	B	L												

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences						Frequency	Risk		Consequences						Frequency	Risk	Action	Who	By
				People	Env't	Asset	Rep'n	Social	Severity				People	Env't	Asset	Rep'n	Social	Severity					
5.7	Temperature changes	5.7.1	Temperature change during startup | well growth	1	1	2	1	1	2	C	L												
5.8	T & P changes, fluid flow	5.8.1	Geothermal stress around the wellbore leading to formation cracking and loss of integrity	1	1	4	4	4	4	A	L												
6A	Natural Environmental hazards																						
6.1	Earthquake (natural)	6.1.1	Well buckling or shearing leading to contamination of other formations, leak to surface and loss of well asset	1	1	1	1	1	1	B	L												
6.2	Landslides		N/A																				
6.3	Flooding	6.3.1	Flooding of well area leading to downtime and damage to asset	1	2	3	1	1	3	C	M		1	2	3	1	1	3	C	M	O7. Review economic risk associated with flooding.		
6.4	Ambient Temperature extremes	6.4.1	Well monitoring equipment damage if freezing. Potential for freezing, especially of chemical injection lines	1	2	3	2	2	3	C	M	Hot water flowing in production and reinjection lines prevents freezing of main surface piping. If ESP stops fluid level drops removing fluid and associated freezing risk from the wellhead. Heat tracing of vulnerable surface piping Ability to drain vulnerable surface piping.	1	2	2	2	2	2	C	L			
6.5	Ice/Snow loading	6.5.1	See 6.4 (Freezing)																				
6.6	Lightning discharge and storm	6.6.1	Potential equipment damage to ESPs, interruption of operations, minor injury (wells are earthed)	3	1	3	1	2	3	B	L												
6B	Induced Environmental hazards																						
6.7	Induced seismicity	6.7.1	Fluid extraction causing seismic impact leading to stress on the well and people notice it in the neighbourhood Exceeding reinjection MAASP (maximum allowable annulus surface pressure) may result in fracturing of the receiving formation. <u>Case Study</u>: The Basel event (2006: 3,4 magnitude) and Landau (2009); magnitude 2,5, switched off in 2014 after cracks in streets and ground movements.	1	1	4	4	4	4	B	M	State Supervisor engaged and applying O&G best practice. There are geographic criteria, depending on location may need specific measures. There are curently limits on injection pressures. There is subsidence monitoring in place where applicable. Seismic risk assessment is also required before drilling.	1	1	3	3	3	3	B	L	O8. Increased awareness is crucial in avoiding the most seismically active areas as the release of stresses at a tectonic fault is not controllable. There is current research from QCON together with IF technology to learn more about this quantitative risk methodology. The geothermal industry needs to maintain awareness of this. O9. The Basel 2006 and Landau 2009 events should be reviewed to ensure al available learning has been identified.		
6.8	Subsidence / Uplift	6.8.1	Thermal expansion of tubulars and wellhead growth (cement impact) <u>Case Study</u>: Staufen (2007) and also Böblingen (2009) !> swelling of a Triassic anhydrite formation (Gipskeuper)	1	1	4	1	1	4	C	M	Swellable formations are identified during well planning and isolated during drilling.	1	1	3	1	1	3	A	L			
		6.8.2	Compaction of the formations leading to noticeable ground movement at the surface	1	1	4	3	4	4	A	L												
		6.8.3	Uplift due to by brine migration into swellable formations causing impact on ground level. Fault activation leading to casing damage, shearing <u>Case Study</u>: Staufen (2007) and also Böblingen (2009) !> swelling of a Triassic anhydrite formation (Gipskeuper)	1	1	4	3	4	4	B	M	Swellable formations are identified during well planning and isolated during drilling.	1	1	3	1	1	3	A	L			
6.9	Surface Disturbances	6.9.1	See 6.8 (Subsidence/Uplift)																				
6.10	Hydrothermal eruptions	6.10.1	See 3.1.1, (Pressure, hydrostatic pressure brine)																				
6.11	Salt tectonics	6.11.1	Salt Squeezing leading to well collapse due to hydrostatic pressures on the salt moving plastically and squeezing the tubulars	1	1	4	1	1	4	B	M	Location of wells will be determined with knowledge of local geology.	1	1	4	1	1	4	A	L			

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
6.12	Leaching	6.12.1	Leaching out/dissolution of salt or formations by brine production / injection activity	1	2	3	2	2	3	B	L												
7	Hot surfaces																						
7.1	Process piping / well head	7.1.1	Burns to personnel touching wellsite. Expansion of flowlines exerting stresses on wells	2	1	1	1	1	2	C	L	Limited access Operator training and awareness PPE, emergency response, first aid.											
8	Hot liquid																						
8.1	Loss of containment	8.1.1	Thermal expansion of tubulars and wellhead growth (cement impact) leading to leak through cement	2	2	4	2	2	4	C	M	Drilling programme design ensures adequate cement bond. CBL carried out to confirm with remediation if problems identified	2	2	4	2	2	4	B	L			
9	Electricity																						
9.1	Electrocution	9.1.1	Health damage to personnel from faulty wiring	4	1	2	3	2	4	B	M	High voltage supply has to be correctly designed and installed.	4	1	2	3	2	4	A	L			
9.2	Electrostatic energy	9.2.1	Potential for electrostatic build up if failure to ground electrical circuits	4	1	2	3	2	4	B	M	All equipment grounded.	4	1	2	3	2	4	A	L			
9.3	Loss of electrical supply	9.3.1	Loss of production	1	1	2	1	1	2	C	L												
9.4	Stray current from ESP	9.4.1	Potential for enhanced internal corrosion and scale accumulation leading to loss of production	1	1	3	1	1	3	C	M	Monitoring of ESP electrical integrity	1	1	2	1	1	2	C	L			
10	Electromagnetic radiation																						
10.1	Instrumentation	10.1.1	Use of logging tools with EM radiation sources and especially if lost downhole	2	2	4	3	3	4	C	M	NOGEPA guidelines being reconsidered for Geothermal and safety standard. Operators already trained on awareness of the risks. There is a company established straalingsniveau3 , HSE docs all in place. Competent contractors used for well logging.	2	2	3	3	3	3	B	L			
11	Ionizing radiation																						
11.1	Logging equipment	11.1.1	Use of logging tools with ionizing radiation sources and especially if lost downhole	3	2	4	4	4	4	C	M	HSE guidance documentation all in place and fully implemented. Competent contractors used for well logging.	3	2	4	4	4	4	A	L			
11.2	Naturally occurring radioactive material (NORM)	11.2.1	Exposure of personnel to radiation coming from deposits (scale), contaminating equipment or disposal of fluids/solids/equipment issues	3	2	4	3	3	4	D	H	NOGEPA guidelines being reconsidered for Geothermal and safety standard. Operators already trained on how to deal with this. There is a company established straalingsniveau3 , HSE docs all in place.	1	2	2	2	2	2	B	L			
12	Asphyxiates																						
12.1	Confined spaces	12.1.1	Operator working in well cellars without H2S leak	1	1	1	1	1	1	E	L												
12.2	Excessive CO2	12.2.1	Operator working in well cellar when gas present could be asphyxiating	4	1	1	3	3	4	E	H	Operator competency, confined space awareness training, operating instructions, PTW and LOTO systems, supervision, Safety Observation Program, manhole watchman, PPE, emergency response, first aid.	4	1	1	3	3	4	A	L			
12.3	Excessive N2	12.3.1	Nitrogen blanket of annulus leakage. See 3.4.1 (nitrogen blanket above brine level)																				
13	Toxic gas																						
13.1	Atmospheric emissions e.g. CO2, H2S	13.1.1	Blow down exhaust could route to unexpected or inappropriate location	3	2	1	2	2	3	C	M	Operating Procedures exist for this operation.	3	2	1	2	2	3	B	L			
13.2	H2S exposure	13.2.1	Potential to accumulate in cellar as it is more dense than air. Any discharge is odious and toxic	4	1	1	3	3	4	C	M	Operator competency, confined space awareness training, operating instructions, PTW and LOTO systems, supervision, Safety Observation Program, manhole watchman, PPE, emergency response, first aid.	4	1	1	3	3	4	A	L			
14	Toxic fluid																						

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
14.1	Brine	14.1.1	Contamination of shallow aquifers can lead to souring of potable water Wall thickness loss of casing leading to leak Wall thickness loss of casing leading to buckling of casing Wall thickness loss of tubing leading to leak and potential rupture and loss of production Wall thickness loss of wellhead and Xmas tree leading to leak to surface Attack of sealing surfaces at wellhead etc. leading to leak to surface	1 1 1 1 2 2	3 2 2 1 2 2	4 4 5 3 3 2	4 3 3 1 2 2	3 2 2 1 2 2	4 4 5 3 3 2	B B B C B C	M	Design phase best available data is used for corrosion analysis and material selection. Data gathering by companies to know what the corrosion risks are. Logging data and sharing of inspection data of tubing and ESPs after withdrawal within companies. There are coupons at surface. Use of corrosion inhibitors and scale inhibitors (Supplier indicated selection). Monitoring P and T which may imply casing leak. Workovers (lining etc.) can be considered depending upon the location / source of leak. There are initiatives to develop knowledge sharing and technical steps like composite casing etc. Cathodic protection to mitigate external corrosion (use not widespread as internal corrosion risks are considered to dominate)	2	2	4	4	2	4	B	M	O1. In the basis of design (BOD) phase correct and detailed relevant data is needed for corrosion analysis and material selection. Life cycle costs (LCC) need to factored into material selection to get correct materials. A specific Risk Register should be produced during the BOD phase and updated as required thourghout the well lifecycle until the well is permenantly abandoned. O2. Comprehensive review of the whole system to optimise and minimise cost for best corrosion mitigation. O3. Data gathering and sharing to better understand the corrosion risks. O4. Logging data , sharing of inspection data of tubing and ESPs after retrieval O5. Correct testing and selection of corrosion inhibitors and compatibility with scale inhibitors based on individual well characteristics O6. Active monitoring of positive applied annular pressure (e.g. Nitrogen cushion). Monitoring to quickly detect leaks. Possibility to implement/trigger alarm and shutdown where feasible.		
14.2	Corrosion inhibitors	14.2.1	Can be aggressive to personnel if not properly contained. Corrosion if not dosed correctly. Incorrect chemical selection leading to corrosion and seal leaks. Overdosing can cause complications in topsides and can impact injectivity of reinjection well (e.g. by blocking receiving formation) Potential for long term contamination of receiving formation if selection/dosing poorly managed.	2	3	2	2	2	3	C	M	Operating procedure. Training, awareness. Monitoring of chemical dosing.	2	3	2	2	2	3	B	L	O10. Potential exists for improvements in dosing optimisation, control, chemical selection, testing and checking of compatibility with well components.		
14.3	Scale inhibitors	14.3.1	See 14.2 (corrosion inhibitors)																				
14.4	Discharge of chemicals	14.4.1	See 14.2 (corrosion inhibitors)																				
14.5	Discharge of chemicals	14.5.1	See 14.2 (corrosion inhibitors)																				
14.6	Disposal	14.6.1	ESP and tubing and etc. which may be contaminated, especially with NORM, could lead to personnel health and cost impacts See 11.2.1 (NORM impacts)																				
14.7	Produced gas	14.7.1	Corrosion of upper tubulars in gas cap above pump level leading to leak. See 1.2.1 (hydrocarbons)																				
14.8	External aggressive aquifers	14.8.1	External attack of casings leading to buckling and well collapse	1	1	4	3	3	4	B	M	Drilling programme design ensures adequate cement bond which protects casing from corrosion. CBL carried out to confirm with remediation if problems identified Cathodic protection to mitigate external corrosion (use not widespread as internal corrosion risks are considered to dominate)	1	1	4	3	3	4	A	L			
14.9	Produced and precipitating solids / heavy metals	14.9.1	Blockage of flow Erosion Damage to ESP	1	1	4	1	1	4	D	H	Scale inhibitor chemicals used to prevent build up. Scale treatment undertaken if it builds up.	1	1	3	1	1	3	C	M	O11. Potential for further optimisation of scale management and monitoring. O12. Need for modelling of water chemistry to predict issues.		
15	Toxic solid																						
15.1	Disposal of scales	15.1.1	See 14.6 and 11.2.1 (NORM impacts)																				

Hazard Number	Hazard Description	Scenario		UNMITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	Safeguards / Mitigation	MITIGATED Consequences People	Env't	Asset	Rep'n	Social	Severity	Frequency	Risk	RECOMMENDATIONS Action	Who	By
15.2	Scale formation	15.2.1	Affects productivity/Injectivity and can have underdeposit corrosion that impacts capability to log well or undertake other interventions. Also results in need for more interventions	1	1	4	1	1	4	D	H	Scale inhibitor chemicals used to prevent build up. Scale treatment undertaken if builds up.	1	1	3	1	1	3	C	M	O11. Potential for further optimisation of scale management and monitoring. O12. Need for modelling of water chemistry to predict issues.		
16	Corrosive substances																						
16.1	Brine	16.1.1	See 14.1 (Toxic fluid, brine)																				
16.2	Well stimulation fluids and descaling	16.2.1	Aggressive to health if incorrectly selected, contained, managed. Potential damage to the well equipment if incorrect concentration and type. Potential impact on injectivity from damage in the wellbore or formation. See 14.2.1 (Toxic fluid, corrosion inhibitor)																				
16.3	CO2	16.3.1	Enhanced corrosion due to presence of CO2 See 14.1.1 (Toxic fluids)																				
16.4	H2S	16.4.1	Materials which require specialist selection not used resulting in cracking of well components	4	1	5	3	3	5	C	H	International standards exist for appropriate material selection. Recognised concern at well design.	1	1	1	1	1	1	B	L			
16.5	Chloride (Cl)	16.5.1	Chloride in shallow formations causing enhanced degradation of cement and reduced barrier integrity	2	1	3	1	1	3	C	M	International standards exist for appropriate material selection. Recognised concern at well design.	1	1	1	1	1	1	B	L			
17	Biological hazards																						
17.1	Water borne bacteria	17.1.1	Potential for microbially influenced corrosion	1	2	4	3	2	4	B	M	Biocide dosing.	1	1	3	2	2	3	B	L			
		17.1.2	Potential to increase the scaling risk (e.g. due to the action of sulphate reducing bacteris, SRB). See 15.2.1 (Toxic solids, scale formation)																				
18	Ergonomic hazards																						
18.1	Manual handling	18.1.1	Excessive loads and/or poor lifting technique leading to personal injury	3	1	1	1	1	3	C	M	Operator awareness training, manual handling procedures, Safety Observation Program, supervision, emergency response, first aid.	3	1	1	1	1	3	B	L			
18.2	Lighting	18.2.1	Inadequate lighting leading to personal injury, downtime	3	1	1	1	1	3	C	M	Adverse weather procedures, operator awareness training, emergency response, first aid.	3	1	1	1	1	3	B	L			
18.3	Miscommunication	18.3.1	Incorrectly installed equipment or operation procedure arising from lack of holistic management, org structure, interaction of disciplines leading to loss of well integrity . Incorrect tools, incorrect ops leads to unnecessary leaks (All these hazards considered to result in this common scenario)	1	3	4	3	2	4	D	H	There are Written Operational procedures for well operations and work instructions. There are HSE controls. DAGO have debrief (PDCA) and lessons learnt feedback. DAGO round field sharing information. There is SharePoint sharing of information related to QHSE system all can use.	1	2	3	2	2	3	C	M	O13. Need for improvements in ergonomics.		
18.4	Inadequate information	18.4.1		1	3	4	3	2	4	D	H	Preljob meeting prior to any jobs done for this industry. Competent people engaged. During development of geothermal there is more discussion between disciplines and 3rd party contractors.	1	2	3	2	2	3	B	L			
18.5	Stress	18.5.1		1	3	4	3	2	4	D	H	HSE procedures.	1	2	3	2	2	3	B	L			
18.6	Lack of competency	18.6.1		1	3	4	3	2	4	D	H	Self assessment; individual training; workshops; yearly audits.	1	2	3	2	2	3	B	L			
18.8	Manning levels	18.8.1		1	3	4	3	2	4	B	M	Access to manpower not bad given that the businesses are onshore and access to good contractors (O&G qualified) locally.	1	2	3	2	2	3	B	L			
18.9	Inadequate Organisation structure	18.9.1		1	3	4	3	2	4	B	M	There is one person responsible for operations and well integrity. They have contractor support as needed. There are clear roles and responsibilities. There is a reliance on 3rd parties relying on their stated competency. HSE documentation (Safety case, Veiligheids Gezondheid document) needed for any activity on the wells.	1	2	3	2	2	3	B	L			

Hazard Number	Hazard Description	Scenario		UNMITIGATED								Safeguards / Mitigation	MITIGATED								RECOMMENDATIONS		
				Consequences						Frequency	Risk		Consequences						Frequency	Risk	Action	Who	By
				People	Env't	Asset	Rep'n	Social	Severity				People	Env't	Asset	Rep'n	Social	Severity					
18.10	Improper work plan	18.10.1		1	3	4	3	2	4	B	M	Work cannot be started without the correct plan. These are checked by the State Authority but actual approval and confirmation is peer reviewed by competent person.	1	2	3	2	2	3	B	L			
18.11	insufficient budget	18.11.1		1	3	4	3	2	4	E	H	Budgetary decisions are centralised to typically one function who has to understand the impact on overall business and risks.	1	2	3	2	2	3	C	M			
18.12	Lack of safety culture	18.12.1	General increased likelihood of personal injury arising from lack of Safety culture/awareness	3	1	1	1	2	3	C	M	Education of employees (and contract staff) of HSE procedures.	2	1	1	1	2	2	C	L			
19	Security related hazards																						
19.1	Intruders	19.1.1	Access of public to site could lead to malicious damage.	1	3	3	2	2	3	B	L												
19.2	Sabotage	19.2.1	Malicious damage physically and/or software	1	3	3	2	2	3	B	L												
20	Use of natural resources																						
20.1	Water	20.1.1	Use of wrong chemicals in water is "polluting" once reinjected. Change in water chemistry by gas removal is altering overall water chemistry (when reinjected) resulting in subsurface environmental damage	1	3	1	3	3	3	C	M	Reinjection (disposal) of water is to designed location. Selection of chemicals according to international standards.	1	2	1	2	2	2	C	L			
21	Noise																						
21.1	Noise pollution	21.1.1	Complaints from neighbours in urban locations leading to shut downs or constraints on operation times	1	1	1	2	2	2	C	L												
21.2	Light pollution	12.2.1	Complaints from neighbours in urban locations leading to shut downs or constraints on operation times	1	1	1	2	2	2	C	L												

APPENDIX 7 RISK MATRIX FOR GEOTHERMAL OPERATIONS IN THE NETHERLANDS

Consequence						Increasing Probability				
Severity Rating	People	Environment	Assets	Reputation	Social	A	B	C	D	E
						10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
						Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
						Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	No/negligible health effect/injury	No effect	No damage	No impact	No impact					
2	Minor/Slight health effect/injury	Slight effect	Slight damage	Slight impact	Local impact		Manage for continuous improvement			
3	Major health effect/injury	Localised effect	Localized damage	Considerable impact	Regional impact			Incorporate risk reduction measures		
4	Permanent disability/up to 3 fatalities	Major effect	Major damage	National impact	National impact				Intolerable	
5	More than 3 fatalities	Massive effect	Extensive damage	International impact	International impact					

Summary Risk Matrix for Geothermal Operations in the Netherlands

Consequence			***Increasing Probability***				
Severity	***People***		***A***	***B***	***C***	***D***	***E***
			10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
			Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
			Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	None/negligible health effect/injury	No injury or damage to health. Not detrimental to individual employability or to the performance of present work. Agents which are not hazardous to health.					
2	Slight / Minor health effect / injury	Detrimental to the performance of present work, such as curtailment of activities or some days' absence to recover fully, maximum one week. Agents that have limited health effects which are reversible, e.g. irritants, many food poisoning bacteria.		**Manage for continuous improvement**			
3	Major health effect / injury	Leading to permanent partial disablement or unfitness for work or detrimental to performance of work over extended period, such as long term absence. Agents that are capable of irreversible damage without serious disability, e.g. noise, poorly designed manual handling tasks.			**Incorporate risk reduction measures**		
4	Permanent disability/up to 3 fatalities	Permanent disability or the possibility of multiple fatalities (maximum 3) in close succession due to the incident, e.g. explosion. Agents that are capable of irreversible damage with serious disability or death, e.g. corrosives, known human carcinogens.				**Intolerable**	
5	More than 3 fatalities	May include four (or more) fatalities in close succession due to the incident or four (or more) fatalities each at different points and / or with different activities. Agents with potential to cause multiple fatalities, e.g. chemicals with acute toxic effects (e.g. hydrogen sulphide, carbon monoxide), known human carcinogens.					

Supporting Risk Matrix for People related Consequences

Consequence			Increasing Probability				
Severity	Environment		A	B	C	D	E
			10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
			Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
			Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	Negligible effect	No environmental consequences / Local environmental risk; within the fence and within systems					
2	Minor effect	Contamination; damage sufficiently large to attack the environment; single exceedence of statutory or prescribed criteria; single complaint; no permanent effect on the environment		Manage for continuous improvement			
3	Localised effect	Limited loss of discharges of known toxicity; repeated exceedence of statutory or prescribed limit and beyond fence/neighbourhood			Incorporate risk reduction measures		
4	Major effect	Severe environmental damage; the company is required to take extensive measures to restore the contaminated environment to its original state. Extended exceedence of statutory or prescribed limit.					
5	Massive effect	Persistent severe environmental damage or nuisance extending over a large area. In terms of commercial or recreational use or nature conservancy, a major economic loss for the company. Constant high exceedence of statutory or prescribed limit.				Intolerable	

Supporting Risk Matrix for Environment related Consequences

Consequence			***Increasing Probability***				
Severity	***Assets***		***A***	***B***	***C***	***D***	***E***
			10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
			Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
			Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	Negligible damage	No damage to equipment; no financial consequences/ No disruption to the process, estimated costs of repair below EUR 1,000.					
2	Minor damage	Possible brief disruption to the process, isolation of equipment for repair, estimated costs of repair below EUR 10,000.		**Manage for continuous improvement**			
3	Localised damage	Plant partly down, process, can (possibly) be restarted, estimated costs of repair below EUR 100,000.			**Incorporate risk reduction measures**		
4	Major damage	Partial loss of plant, plant shut down for at most two weeks and / or estimated costs of repair below EUR 1.000,000.				**Intolerable**	
5	Extensive damage	Total loss of plant, extensive damage, and / or estimated costs of repair exceeds EUR 1,000,000.					

Supporting Risk Matrix for Asset related Consequences

Consequence			Increasing Probability				
Severity	*Reputation*		**A**	**B**	**C**	**D**	**E**
			10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
			Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
			Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	Negligible impact	No public awareness / Public awareness of the incident may exist; no public concern.					
2	Local impact	Some local public concern; slight local media and/or local political attention with potentially negative aspects for company operations.		**Manage for continuous improvement**			
3	Regional impact	Regional public concern. Extensive negative attention in local media; slight national media and/or local/regional political attention with possibly negative stance of local government and/or action groups. Negative impacts on similar companies operating in the region.			**Incorporate risk reduction measures**		
4	National impact	National public concern. Extensive negative attention in national media and/or regional national policies with potentially restrictive measures and/or impact on grant of licenses, mobilisation of action groups. Negative impacts on similar companies operating in the country.					**Intolerable**
5	International impact	International public attention. Extensive negative attention in international media and national/international policies with potentially severe impact on access to new areas, grants of licenses and/or tax legislation. Negative impacts on similar companies operating internationally.					

Supporting Risk Matrix for Reputation related Consequences

Severity	Consequence		Increasing Probability				
	Social		**A**	**B**	**C**	**D**	**E**
			10^{-6} to 10^{-4} occurrence / year	10^{-4} to 10^{-3} occurrence / year	10^{-3} to 10^{-1} occurrence / year	10^{-1} to 1 occurrence / year	> 1 occurrence / year
			Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely occurrence
			Never heard of in the Global industry	Heard of in the Global industry	Incident has occurred in DAGO	Happens several times per year in DAGO	Happens several times per year in DAGO
1	Negligible impact	Public awareness may exist; no public concern.					
2	Local impact	Some local public concern. Local conflict. Individual phone calls to complain or ask for information.		**Manage for continuous improvement**			
3	Regional impact	Regional public concern/ Regional conflict. Group/association complaints to local authorities.			**Incorporate risk reduction measures**		
4	National impact	National public concern / National conflict. Articles in newspapers. Violence/ Hostility to workers. Security issues.				**Intolerable**	
5	International impact	International public concern / International conflict. Strong opposition to the project/industry.					

Supporting Risk Matrix for Social related Consequences

APPENDIX 8 HAZID WORKSHOP TEAM MEMBERS

Name	Organisation	Expertise	Role / Sub Team	email
Robert Magraw	BakerRisk	HSE and Risk Management	HAZID Facilitator (Project team)	rmagraw@bakerrisk.com
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Ad van Adrichem	Duijvestijn	Operator	Operations Sub Team	ad@duijvestijntomaten.nl
Erik Ham	DAGO	Well Engineer	Operations Sub Team	E.Ham@Agriporta7.nl
Martin van der Hout	DAGO	DAGO Secretary	Operations Sub Team	vanderhout@dago.nu
Robert te Gussinklo Ohmann	Groningen - warmtestad	Operator - Geologist	Operations Sub Team	r.gussinklo@spidron.co
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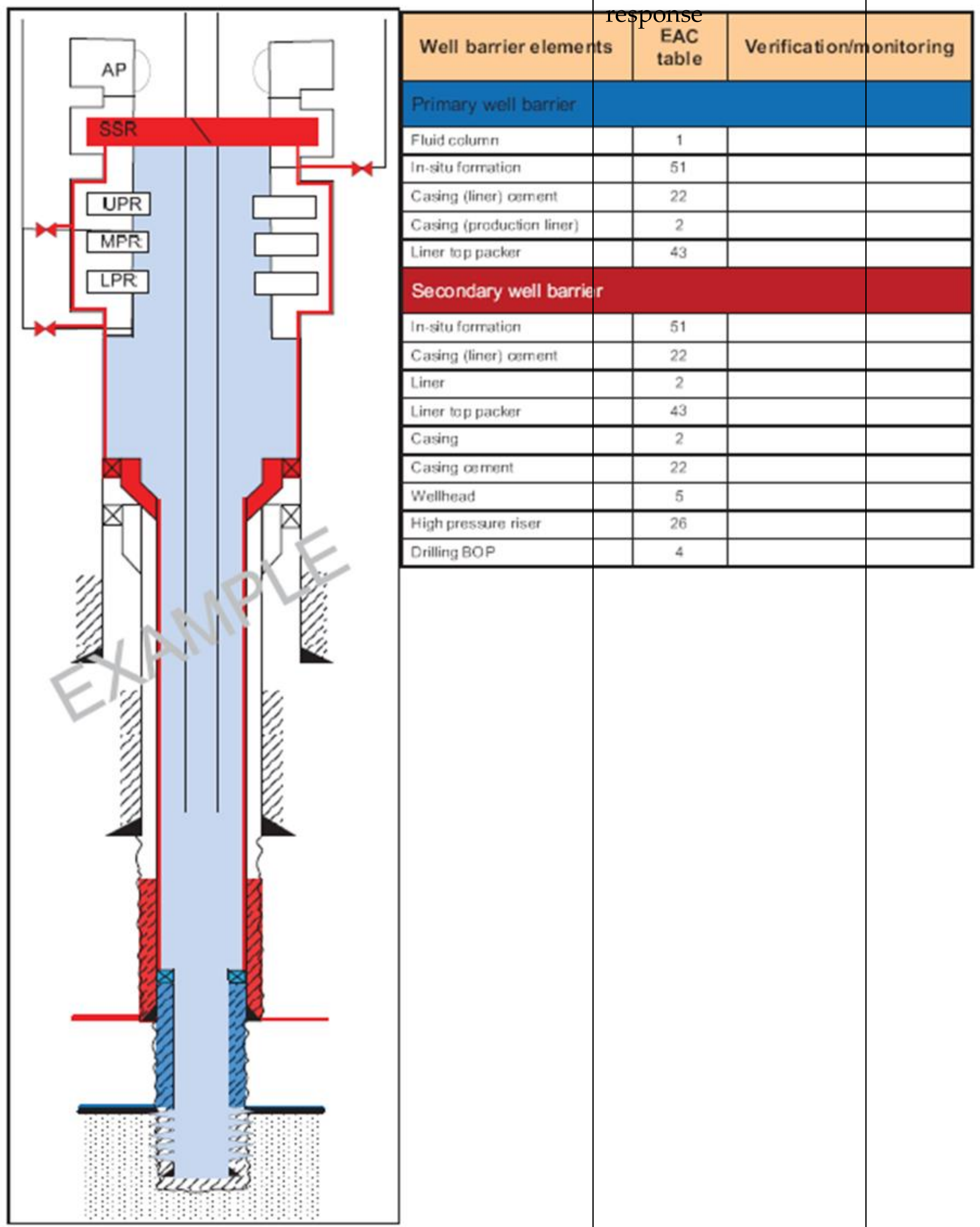
APPENDIX 9 EXTERNAL REVIEWER COMMENT WORKSHEET

Doc Number	N/A	Revision	0
Description	Geothermal Well Integrity Study	Date	21/10/2016

No.	Section/Page	External Reviewer's Comments	Study team's Response	External Reviewer's Comments	Project Manager's Response	Remarks
1	Executive summary This is outwith the ISO standard on which this study is based but considering the lesser risks envisagd for the low enthalpy onshore geothermal wells in the Netherlands, should be acceptable.	Reference to ISO with respect to two barriers is incorrect; ISO 16530 recognises free flowing and hydrostatic wells from a risk perspective. Remove reference.	The reference to ISO 16530 here is our opinion that using the Formation water as a primary barrier does not conform to the ISO standard as currently written and does not refer to free flowing and hydrostatic wells. Please also refer to comment 2 below.		Agree with team response	
2	Well Barrier Elements for the full well cycle were identified and performance standards established so far as is practicable. Well Integrity for low enthalpy wells in the Netherlands are currently managed on a two barrier philosophy using the well hydrostatic fluid column as the primary barrier and the well casing and wellhead the secondary barrier. During drilling, the same philosophy is adapted with drilling mud as the primary barrier and the casing plus wellhead and BOP as the secondary barrier this complies with the two barrier standard for Oil and Gas wells due to the likely presence of dissolved and shallow gas formations. Static inflow test of the Geothermal well	Change accordingly, drilling uses mud as primary barrier, hydrostatic wells use the___14 fluid columns as primary barrier, you have made the story to complex. This will affect whole document and barrier drawings but you can adapt same barrier philosophy as in drilling this means you do not need to exempt or deviate. Adding an extra casing string will add only extra barrier redundancy against failure of loss of the secondary barrier, no out flow will exit when this happens unless the well hydrostatic is over pressured in comparison with the aquifers and well fluids may flow in these aquifers if a leak would occur. This would have to be managed with corrosion logs and aquifer	Using the formation water as a primary barrier was considered thoroughly by the team and deemed not to comply with ISO 16530 nor the NORSOK D010 based on the performance standards written for the drilling fluid. We have on the other hand made up a PS that could be used to propose the formation water as a pressure containment barrier and with the external reviewers endorsement have updated the report to reflect that decision.	Reference of fluid column as barrier element Norsok D10 rev 4 Reference 1.12.1.2.Dago comment **Features** | **Acceptance criteria** | **See** **A. Description** | This is the fluid in the wellbore. | NORSOK D-001 **B. Function** | The purpose of the fluid column as a well barrier/WBE is to exert a hydrostatic pressure in the wellbore that will prevent well influx/inflow (kick) of formation fluid. **C. Design construction selection** | 1. The hydrostatic pressure shall at all times be equal to the estimated or measured pore/reservoir pressure, plus a defined safety margin (e.g. riser margin, trip margin). 2. Critical fluid properties and specifications shall be described prior to any operation. 3. The density shall be stable within specified tolerances under down hole conditions for a specified period of time when no circulation is performed. 4. The hydrostatic pressure should not exceed the formation fracture pressure in the open hole including a safety margin or as defined by the kick margin. 5. Changes in wellbore pressure caused by tripping (surge and swab) and circulation of fluid (ECD) should be estimated and included in the above safety margins. | ISO 10416 **D. Initial test and verification** | 1. Stable fluid level shall be verified. 2. Critical fluid properties, including density shall be within specifications.	Agree with team response	

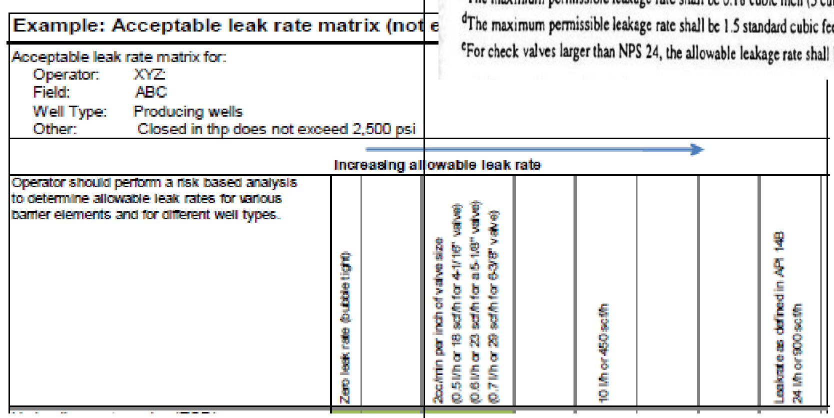
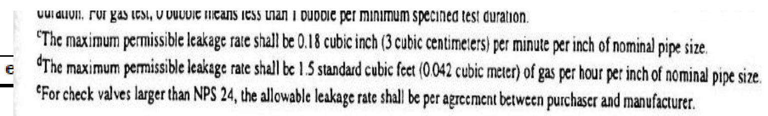
	may be conducted on regular intervals to confirm the adapted barrier philosophy.	sampling, finger printing against produced thermal fluids. With inflow testing of the wells to confirm risk.				
3	Executive summary and the use of thicker tubulars	This is incorrect, tubular connectors are often the same for different weights of tubulars, connector is 1 st to fail in most cases as this is the highest stress point , please remove reference.	Updated. This was a suggestion by a member of the client committee		Agree with team response	
4	The recommended actions to be taken are well within the capability of the Dutch geothermal operators that will require formal systemising of current practices to provide the necessary confidence in well integrity management.	Change from may to will (shall) statement this is in line with regulation, it is crucial that this is transparent is manage wells with a fluid barrier and a hardware barrier!	Updated		Agree with team response	
5	❖ Compliance by independent audit	Add compliance by audit, not having verified compliance to the proposed makes proposed guidance rather than a serious plan.	Updated		Agree with team response	
4	1.2 scope The well by well review based on the findings of this document shall be recommended and be implemented by 12 months after issue of the report	Add accordingly, if you do not include this there is no requirement to implement this.	Updated.		Agree with team response	
6	1.4 This casing string is cemented to the surface. The depth of the surface casing is determined by the formation strength at the shoe.	Change accordingly	Updated		Agree with team response	
7	1.5 The typical wells description	Change accordingly	Updated		Agree with team response	

	refers to current designs and do not include deeper, higher temperature potential wells with increased risk of outflow (subject of a future scope addition and addendum if needed).					
8	1.5 It was understood that future wells with radically different conditions may require further evaluation (outside of the present scope).	Adds no value only if you address the risk of increased outflow potential which is covered above	Updated above, so left it in		Agree with team response	
9	References ESP operating standards API 11S	This is missed also the fact that ESP shall be kept in balanced phase operating conditions to avoid stray or eddy currents and risk of associated corrosion , this need to be paced somewhere in the document.	Not updated. Didn't think this was required. There should be a manual for safe and efficient operation of the ESP based on individual well parameters…		Agree with team response	
10	2.4.1 conducted by an IADC accredited experienced drilling contractor	Change accordingly	Not updated. IADC not required in the Netherlands.		Agree with team response	
11	2.4.1 'Good well design' was identified as a safeguard for a number of scenarios.	Please change to The well design shall be competent to assure containment over the wells life cycle	Updated		Agree with team response	

12	3.1 However, all geothermal wells developed so far in the Netherlands are non-artesian (flow is aided by a submersible pump), thus in the exploitation phase the main concern is containment. Based on this the fluid column is considered as a barrier / barrier element conform Norsok D10 and ISO 104- 16	Add last sentence. See example of Norsok D10 revs 4 were by fluid column is specified as primary barrier!	Updated	 Figure 7.8.1 – Running open end completion string	Agree with team response	
13	3.2.1 Number of well barriers	This section can be deleted as single and dual barrier concept of a	Deleted and updated	I like to discuss how you can chance the barrier requirement to a barrier assurance statement using the	Agree with team response	

Well barrier elements	EAC table	Verification/monitoring
Primary well barrier		
Fluid column	1	
In-situ formation	51	
Casing (liner) cement	22	
Casing (production liner)	2	
Liner top packer	43	
Secondary well barrier		
In-situ formation	51	
Casing (liner) cement	22	
Liner	2	
Liner top packer	43	
Casing	2	
Casing cement	22	
Wellhead	5	
High pressure riser	26	
Drilling BOP	4	

		well with no artesian flow is misunderstood reference above 1,12		fluid column as primary barrier in 1.13		
14	3.2.1.1 The generally accepted oilfield practice is to provide as minimum, two-barrier isolation between the reservoir and all outlets from the Xmas tree / Wellhead and other formations through which the wellbore passes. This practice is particularly important for non-routine well work or for valve repair work when the level of well isolation required must be clearly defined and carefully controlled. Whilst it is generally accepted that a two-barrier system provides for safe oil/gasfield operations, it is important to note that: ❖ The Operator may apply for an exemption to have just a single barrier in some wells or at some times in the well life. ❖ The advice to have 2 barriers for safety is based on the assumption that the oil/gas well can sustain natural flow to surface.	This statement is incorrect, all wellheads and xmass trees are single barrier by nature of design i.e. singe piece of steel , ring gasket or valve bonnet seal, only on tubing flow wells with a scsssv a dual barrier design is present , revisit section i.e. delete the referred text	Updated		Agree with team response	
15	<u>3.2.3</u> <u>Cementation of Casings / Monitoring of annulus</u> . Confirm Cement bond by CBL when wells is constructed and	What is the purpose of this section there is assurance measure or statement so why mentioned this. Otherwise recommend to confirm isolation by CBL when	The purpose of this section is to shed some light on the casing and cementing differences between Oil and gas wells and low enthalpy		Agree with team response	

	verify by CBL after 10 years operation	constructing the well and reconfirm every 10 years or sooner.	geothermal wells.			
16	Appendix 3 barrier diagrams are not conform Norsok d10 REV 4	adapt Norsok D10 rev 4 standard for barrier diagram , iso 16530 refers to this i.e. red diagram line g's from reservoir to BOP i.e. well head and back, fluid in well is blue to surface i.e. primary barrier .	Updated		Agree with team response	
17	Table 3 Leak rates table quotes 2 cc /inch diameter	This is wrong it is 3 cc per inch diameter per minute , a 7 "valve would be allowed to leak 21 cc / min this far too stringent for water wells or geothermal wells, I recommend to adapt the 400 cc/min rule for scsssc's for valves in general, see extract of API 598 were this originates from, ISO 16530-1 in ballot has been changed accordingly	2 cc/inch is a widely used acceptance leak rate and is quoted in ISO 16530-2, so is not wrong (please see below)  Example: Acceptable leak rate matrix (not e Acceptable leak rate matrix for: Operator: XYZ Field: ABC Well Type: Producing wells Other: Closed in thp does not exceed 2,500 psi Increasing allowable leak rate Operator should perform a risk based analysis to determine allowable leak rates for various barrier elements and for different well types. Zero leak rate (bubble tight) 2cc/min per inch of valve size (0.5 l/h or 18 scf/h for 4-1/16" valve) (0.6 l/h or 23 scf/h for a 5-1/8" valve) (0.7 l/h or 29 scf/h for 6-3/8" valve) 10 l/h or 450 scf/h Leakrate as defined in API 14B 24 l/h or 900 scf/h We think that 2cc/min is reasonable but have updated as per reviewers comments. DAGO/SSM can decide if 400 cc/min is ALARP.	Note shell adat 28 liters per 10 minutes for water well leak s based on fact that some one can plug a 2 inch hole with a wooden peg and a sledge hammer at this rate!  duration. For gas test, 0 bubble means less than 1 bubble per minimum specified test duration. [c]The maximum permissible leakage rate shall be 0.18 cubic inch (3 cubic centimeters) per minute per inch of nominal pipe size. [d]The maximum permissible leakage rate shall be 1.5 standard cubic feet (0.042 cubic meter) of gas per hour per inch of nominal pipe size. [e]For check valves larger than NPS 24, the allowable leakage rate shall be per agreement between purchaser and manufacturer.	Agree with team response	
18	Whole document ISO 16530-2 is referred to	We agreed in kick off to refer to ISO 16530-1 the lifecycle version that is in final ballot i.e. no changes expected just approval of changes of previous ballot. Please change references to	ISO 16530 was agreed to be the standard, we didn't specify ISO 16530-1. This version is not in the public domain yet, so we are not happy to make reference to it although we consulted it. Rather we stated in section 1.2 that *"At the kick off meeting, the ISO 16530 standard was proposed by*		Agree with team response	

			SSM and agreed by all present to be the basis for this Well Interity review. A draft has been issued for review of the ISO 16530 – 1, this was consulted and does not alter the approach taken in this study."			
19	3.4.1.1 MAASP missing Variation or changes to as build form basis of design should be recorded and effects on operating envelop. e.g. casing wear or tie back seal back up set, cement top not as per plan, etcetera's	MAASP is missing as operating limit should be provide by drilling for each conduit at handover please include in list of handover . Include box for changes from basis of design i.e. additional risk	Updated. We considered it originally but as there was no closed in annuli that could be monitored, we decided to leave it out.		Agree with team response	
20	1.15.2 Option of Y-bypass tool is missing that could allow logs to be run. Monitor cellar and nearby water wells, and compare fluid composition samples finger print to indicate f there is potential seepage or leakage from the well. Establish gradient and fluid column of Geothermal well versus aquifers to identify risk from out flow	Include Y tool as option for corrosion logging; note pulsed eddy current logging is available from Van Guard, Halliburton, Schlumberger & Baker that could be run through such a set up. . Include monitoring and sampling in list Included task to monitor gradients and changes over life cycle. Note near surface water regulator has most of this data available or can be obtained from Deltares, TNO through Dino Loket for free. https://www.dinoloket.nl/ Please include this information.	Updated Monitoring and sampling already included. Updated		Agree with team response	
21	3.4.3.2 Greasing	Make recommendation or high light that the appropriate grease must be selected, there are some good synthetic greases from Clare	No need to recommend any particular grease, the Original Equipment Manufacturer would advise on what type of		Agree with team response	

		that outperform most of the oil based greases. Note risk of wrong grease selection could on injector create plugging of formation, please address risk.	grease to use for maintenance and testing purposes. This is already stated in the report under general maintenance.			
22	3.4.3.2 valve maintenance	Cycle of 12 months is quite stringent; most water wells are serviced once in 24 months or 36 months. Yu could consider including a clause that if operator can demonstrate no failures over x period they are allowed to extend the maintenance period. O&G operators often use the failure frequency of the ESP as the basis for maintenance cycle i.e. service entire well head.	We think that 12 months is reasonable based on the lack of redundancies and is also practicable due to the small inventory of valves but have also added a clause for possible extension if no failures over X period. This is a risk based deferment of maintainance activities.		Agree with team response	
23	3.4.4 Should be inflow tested to ISO standards during well interventions.	There is no such standard as I recall, also when the well has no pressure how are you going to inflow test? IS allows testing of valve in opposite direction. Please include ISO 16530-1 reference	Reference to ISO standard was as per the adapted table from ISO 16530-2. Comment deleted and amended.	<u>Extract ISO 16530-1</u> <u>Direction of flow</u> A component should preferably be tested in the direction of flow. If this is impossible or impractical, a test of the component in the opposite flow direction should be performed. The test in the opposite flow direction can be of limited value in establishing the component's ability to seal in the direction of flow. Any component tested in the opposite direction of flow should have this documented.	Agree with team response	
24	✓ The maximum allowable leak rates for geothermal well components will be based on good industry practise. (see 3.4.5.1)	There is no 3.4.5.1 see reference to point 17 of list of comments with respect to leak rates.	Formatting got corrupted, report all properly formatted now and shows 3.4.5.1		Agree with team response	
25	3.4.5.1.1 There is an acceptance by many Oil and Gas operators that the API leak rates (API RP 14H) are unacceptably high and not applicable to many Xmas tree Good Oil and Gas Industry	Delete text as indicated and replace with: API 14 B and 6A VR recommend leak rate testing of 15 scf or 400 cc per minute for SCSSV's and ESD valves for hydrocarbon fluids. ISO 16530-1 refers to API 598 as 3	Text deleted and replaced with API 14B and API std 6AV2 recommend leak rate acceptance criteria of less than 400 cc/ minute for liquid or less than 15 scf / minute for		Agree with team response	

	practice for the field testing of valves and subsequent analysis suggests that serviceable life extends to leak rates of about 2 cubic centimetre (cm³) of liquid per minute per inch of valve bore with failure approaching beyond that point. valves.	cc per inch diameter per minute as acceptance criteria, a 7 valve would allow to leak 21 cc/ min that is quite stringent for a water well with low pressure delta, the 400 cc/ min is more acceptable norm for water Geothermal wells	gas. ISO 16530-1 refers to 2 cc per inch diameter per minute as acceptance criteria, a 7 valve would be allowed to leak 14 cc/ min which is quite stringent for a water well with low pressure delta, so the 400 cc/ min is more acceptable norm for water Geothermal wells.			
26	1.16 Use of corrosion coupons is missing this is most simple method to establish presence of corrosion	Please include corrosion coupons as monitoring for corrosion. Install corrosion coupons of same material as the casing and measure materials weight loss on set intervals	Was originally not included due to reasons stated below but included as advised. Corrosion coupons rarely reflect the actual corrosion rates of the casing because the fluid flow around the coupons and temperature is not the same as the casing. Any scaling on the coupons may also make interpretation difficult, so coupons not recommended. Inhibitor injection residuals and iron count of the water composition will be reliable indicators of *likelihood* of corrosion, and actual rates best determined from logging.		Agree with team response	
27	Weekly monitoring of bottom hole pressures and temperatures is only possible with real time monitoring and downhole instruments. Please change text accordingly	Note: The Producer and Injector casing bottom hole temperature and pressure (reservoir conditions), data may from initial drilling data/tests can and current fluid gradient can be used to extrapolate the formation productivity index. On	Updated		Agree with team response	

		opportunity base a static gradient survey could be run to confirm bottom hole pressures and temperatures if required.				
28	Figure 4. Well Barriers	Barrier diagram is wrong, as per Norsok D 10. Reference 1.12 above	Updated as per adoption of the fluid column as a barrier.		Agree with team response	
29	Chapter 4 Data management misses change management please include >	Changes or variation from basis of design and effects on operating limits Well handover Changes to well operating limits or varions , deviations during the operating period	Updated		Agree with team response	
30	Please include reference and crane option, huge cost saver initiative!! Delete below, long distance rod driven systems are highly prone to failure have shorter run lives then ESP's and you have absolute no need to make a tie back to liner this is based on your interpretation of barrier diagram stating the well is single barrier !! The major advantage of both pumps is the ability to put a tail pipe underneath the pump, which can then be stabbed into the PBR of the liner hanger. By doing so, a closed annulus can be created between the production tubing and the casing, which can be easily monitored. Furthermore, the produced fluid is no longer in contact with the casing, hence no associated corrosion or scaling.	Rod driven ESP that could be retrieved by Crane https://www.youtube.com/watch?v=5v8rj3Pyvds	The video has not been referenced as it adds no value to the report. All ESP change outs are already currently done with Cranes but has now been mentioned in the report. Not updated as we think this is an advantage.		Agree with team response	

	The initial costs for rod driven pumps are however higher but this might be offset by reduced operational cost over the lifetime of the system.					
31	Please change text accordingly wells that cannot flow are dual barrier wells as explained before	Well Barrier Elements for the full well cycle were identified and performance standards established so far as is practicable. Well Integrity for low enthalpy wells in the Netherlands are managed with a dual barrier philosophy based on hydrostatic fluid level as primary barrier as per NorsokD10 rev4. The associated gas is vented from the pump annulus like in any other O&G artificially lifted pump well. .The primary barrier (fluid level) needs to monitor against the gradient of Geothermal reservoir versus aquifer gradients / pressures to assure the potential risk of out flow in event of a leak is managed. Further the risk assessment should include the fluid composition and potential toxic ingredients to fully understand the consequences of a failed barrier (corroded casing). In event of capability of natural flow the fluid level cannot be regarded as a barrier a secondary barrier may be required in the from an extra casing, however this would have to be risk assessed based on the likelihood and consequence as explained in ISO 16530-2.	Updated The highlighted section is not correct. The annulus is not vented		Agree with team response	
32	Section 7 Audit is missing	Include audit as an element	Updated as 7.2.5 A well integrity audit is recommended to be carried		Agree with team response	

			out by an independent auditor and frequency can be proposed by DAGO.			
33	7.1 Please update text as you can not apply N2 pressure on a pumped annulus, by applying pressure on a pumped annulus you would lower the fluid level and the head on the pump there for pumped annuli are normally vented !	On closed annuli, active mmonitoring of positive may be applied annular pressure (for e.g. Nitrogen cushion) to quickly detect leaks and aannulus alarm and shutdown system to be set up with trigger pressures where possible is encouraged.	The statement is not correct. A N2-cushion is placed in the annulus as a kind of “demper”. That is why the annulus is closed. This is used in most of the geo-wells in NL.		Agree with team response	
34	Appendix 4 fluid additives	Please note that fluid additives like corrosion inhibitor are often toxic and as result make formation water toxic the risk of this should be described somewhere in the document as this is not specifically mentioned so far, reference	All chemicals are covered by requirements for their handling and is handled by HSE. This is captured under Action item O12 of the Operations HAZID. We don’t want to make statements in this report that is contradictory to the SHE framework applied by DAGO.	Reference Hazid point 14.9 need for modelling of water chemistry to predict issues	This is captured under Action item O12	