DELIVERABLE D4.1

Legal & Regulatory Framework of Deep Drilling Technologies and Practices

WP4

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Publishable summary

D4.1 is a Legislative and Regulatory review of the deep drilling processes implemented in Europe. The deliverable considers the DeepU project technologies including the use of industrial scale lasers, the use of liquid cryogenic gas and the development of a new drill string to be adapted to existing deep borehole drilling technology to complete deep closed boreholes. Applicable legislation and regulations covering the field of geothermal boreholes, drilling equipment and drill sites and the completion requirements for geothermal system operators in Europe is considered to identify compliance of the new technology with existing regulated methodologies. The deliverable considers the licensing process of deep geothermal projects, the health and safety aspects related to site development, drilling operations completions and the environmental aspects associated with deep geothermal projects in an number of European jurisdiction as well as the two project virtual cases in Ireland and Italy, to identify the current regulatory challenges of the new technology that would allow it to gain compliance to the current deep drilling market. The outcomes of the deliverable are proposed in the context of the future development of the DeepU drilling technology in the future parts of the project that will provide the basis for recommendations to be implemented to allow the DeepU drilling method to achieve regulator acceptance and commercialisation.

Abbreviations

ALARP	‘as low as reasonably practicable’
ARPA	Agenzia Regionale per la Protezione dell’Ambiante (regional agencies for the environmental protection ARPA
Art.	Article
BOP	Blow Out Preventor
CA	Consortium Agreement
CIRM	Commissione per gli Idrocarburi e le Risorse Minerarie
CRU	Commission for Regulation of Utilities
D	Deliverable
DeepU	Deep U-tube heat exchanger breakthrough: combining laser and cryogenic gas for geothermal energy exploitation
EHS	Environmental Health and Safety
EIA	Environmental Impact Assessment
FMEA	Failure Mode and Effects Analysis
GSRO	Geoscience Regulatory Office
HAZID	Hazard Identification
HAS	Health and Safety Authority
HAS	Health & Safety Authority
ICB	Independent Competent Body
MAH	Major Accident Hazard
NPSC	non-production safety case
OHS	Occupational Health and Safety
PSF	Petroleum Safety Framework
SEA	Strategic Environmental Assessment
T	Task
WWSC	well work safety case

1 INTRODUCTION

The current legislative and regulatory regime for deep geothermal projects in Europe is varied amongst different jurisdictions. Many different legislative frameworks are adopted to permit and license deep geothermal resources in different EU Member States which generally adopt national mining, hydrocarbon or groundwater legislation to implement the licensing system.

As part of the permitting and regulatory process, regulations on both occupational and environmental health and safety are applied to deep geothermal and deep drilling projects alike. Whilst these differ slightly in terms of national implementation with specific rules set out at national, regional or municipal level, all are broadly aligned in the context of the implementation EU Directives.

The development of the DeepU laser and cryogenic gas drilling method, it is important to consider existing legislation and regulations that govern health and safety of drilling equipment and drill sites, the use of industrial scale lasers and the assessment of environmental impact as well the requirements for mitigation measures applicable in the development of deep drilling projects.

Consideration of the integration of the new multidisciplinary DeepU drilling method is given in the context of outlining the current regulatory frameworks applicable to deep geothermal projects in Europe and at two virtual case study sites in Italy and Ireland.

The regulatory review is focussed on understanding the current state-of-the-art in the context of applicable regulations in the design and implementation of deep drilling projects with an objective of identifying barrier to the potential future development of the DeepU technology, but also to highlight the opportunities that such a new drilling method may bring in the context of reduced environmental and health and safety conditions associated with the drilling and completion of deep geothermal wells compared to the existing drilling and completion methodologies used.

2 OBJECTIVES

The objectives of WP4 are to:

1. Establish the nature of the Regulatory and Legislative frameworks which the DeepU project and any associated underground storage may be subject to in relevant jurisdictions.
2. Undertake an Environmental Health and Safety risk assessment of the technology with a focus on the virtual case study sites and,
3. Provide recommendations on the development and deployment of DeepU technology considering the outcomes of objectives 1 & 2.

These objectives are be accomplished by three tasks:

- T4.1 Identifying project considerations related to Legislative, regulatory aspects and standards for gas flushing medium in deep drilling.
- T4.2 Complete an Environmental Health and Safety (EHS) comparison to conventional field drilling methods (shallow & deep).
- T4.3 Develop a deployment strategy that aligns with EHS and regulatory recommendations.

The purpose of this document is to report on the outcomes of Task 4.1.

3 METHODOLOGY

Several categories to investigate and understand how to integrate the novel technologies into an approved drilling operation were identified. These included drilling operations risk management, how standard drilling legislation and practises would fit with DeepU technologies, what the rig requirements would need to be to integrate the system, how necessary formation evaluation could be achieved and considerations of the full life cycle of the wellbore. Considering these categories, the starting point for Task 4.1 was to establish what the critical high-level questions to address were. These were identified as:

- What is potentially unique or novel about DeepU from the perspective of a regulator?
- What are fundamental EHS risk management principles that will frame how a regulator will views the technology?
- What are representative examples of existing regulatory processes and at what point in the process could there be a misfit of DeepU technologies and the requirements.
- What would be the requirements if the technology was deployed in Ireland today?
- What are the potential consequences for project delivery of real-world application that may need to be mitigated?

To address these questions a coherent and stepwise workflow was employed for Task 4.1 as follows.

1. Establish the critical elements of DeepU technologies that could present deployment challenges due to legislative, regulatory or standards requirements.
2. Develop a holistic picture of drilling legislation, regulations and standards from first principles to frame potential high-level challenges.
3. Conduct a review of existing relevant deep drilling legislation, regulations and standards to establish a degree of commonality or otherwise of requirements across different resource sectors and jurisdictions. The purpose of this is to map instances where regulatory expectations based on standard process may require a different approach for DeepU technologies.

4. Determine a real-world scenario of how DEEPU would fit with existing regulations by using the example of Ireland.
5. Summarise the key findings into deployment considerations and recommendations with respect to mitigating potential legislative or regulatory barriers.

4 TECHNOLOGY CONSIDERATIONS

Four distinct aspects of the DeepU technologies were identified as critical items to consider against existing legislation, regulations and standards. These were as follows:

- The use of an industrial scale laser in an uncontrolled and/or changing operational environment.
- The use of a cryogenic fluid as part of the drilling process and the subsequent use of gas to flush cuttings out of the wellbore
- The requirement to drill to depths of >4km in a U-tube configuration (steering, knowing where you are, intersecting another borehole) and maintain hole integrity over the life time of the project, especially in the case that there is no casing or external material applied to the wellbore wall (including how to abandon wells)
- The need to integrate the new technologies with established exploration and formation evaluation practise and critically with existing drilling equipment, practises and skill sets to ensure widespread deployment in a commercial manner.

From a project perspective initial analysis (Figure. 1) suggested each of these technologies may impact different aspects that would effective deployment and some multiple aspects.

Project Innovation		Technology Development	Environmental	Health & Safety	Operational
Gas Flush	Gas Type	√	√	√	
	Waste Type		√	√	
Drill String	Material	√		√	
	Rig Req/Ops	√		√	
Laser	Head Integration	√		√	
	Temp Management	√		√	
U-Tube	Vitrification		√	√	√
	Petrophysics		√	√	√
	Fluid/Steam		√	√	√
	Operation		√		√

Fig 1. Novel components of the project with respect to deep drilling

5 FUNDAMENTAL PRINCIPLES OF LEGISLATION, REGULATION & STANDARDS

The DeepU project technologies outlined in section 4 of the deliverable, highlight a combination of innovative methods drill and complete deep boreholes. The project is mainly focussed on the application of these in the context renewable energy (electricity and heat) production and the exploitation of deep geothermal resources in an innovative way. This section of the report is focussed on looking that the main legislative and regulatory principles that guide the implementation of deep drilling projects and highlights these principles in the context of the various technology components being integrated as part of the new DeepU drilling methodology.

Irrespective of the jurisdiction and the resource being extracted there are fundamental principles that govern the legislative, regulatory, and standards requirements for deep drilling. These are shown in Figure 2.

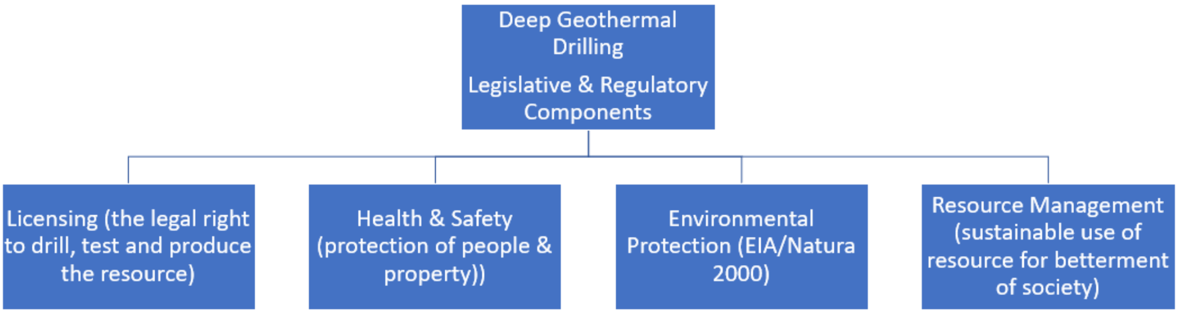

Fig 2. The fundamental components central to deep drilling legislation, regulation, and standards

5.1 LICENSING

The initial step in gaining approval to drill is establishing the legal right to explore for and extract the resource. In the case of geothermal this is the rights to the heat (and in some jurisdictions, depending on depth, the right to extract groundwater containing the heat). In most cases ownership of the resource is retained by the Government of the country or individual states or provinces within the country. Temporary extraction rights for fixed periods of time are awarded to, and maintained by, an operator or developer subject to meeting a series of criteria.

The types of processes by which rights are awarded and the criteria to maintain these will be outlined in this section. For geothermal and underground energy storage, responsibility for the governing legislation varies from jurisdiction to jurisdiction. Therefore, depending on the jurisdiction mining, petroleum, groundwater or more recently geothermal specific legislation could contain the relevant legal process for obtaining rights. Responsibility for the legislation can lie with different Government departments such as Energy, Environment, Business, Natural Resources etc. The primary goals of such legislation may be any combination of creating economic benefit of the citizens, promoting energy security, and meeting greenhouse gas emissions reduction targets. In addition to creating the legislation and awarding rights the parent department or legislative body may also have the role of administering the rights of the course of the project.

5.2 Health & Safety

Workplace or Occupational Health and Safety (OHS) legislation will be present in all jurisdictions. The fundamental goal of this legislation is to ensure the right of safe workplace for every individual. OHS legislation is by nature broad and will frequently cover everything from working conditions to workplace bullying. In some jurisdictions there may be sections of the legislation that are specific to resource extraction or deep drilling but in many cases specific safety requirements for drilling may exist in separate legislation or directives. The relevant OHS authority will have the right to conduct inspections of drilling site and issue enforcement notices that in some cases can require the shut-down of operations, in addition any serious workplace injury or fatality will be investigated by the relevant OHS authority along with the relevant law enforcement agency.

Due to the highly specialised and complex nature of deep drilling the assurance of safety will often be the responsibility of a separate authority. The focus of this authority, its governing legislation, and pursuant regulations will be centred on the following fundamental questions:

- What are the opportunities for the drilling operation to cause harm to people (both workers and the general public), property, and the environment?
- What measures are required in the design and execution of the operation to prevent such occurrences?
- What monitoring and verification processes need to be in place to ensure those measures are in place and functioning?
- What is the emergency response plan in the event of serious incident and how can it be verified?

A key aspect of drilling safety legislation that is additional to general OHS legislation is the focus on Process Safety Management. This is the reduction of risk at source through the application of sound design and engineering principles. Following appropriate standards for processes and equipment is a key element of this. It is critical to note that risk can rarely be entirely removed from a drilling operation. Drilling regulations therefore are often centred on the ALARP principle where risk is demonstrated to have been reduced to “As Low As Reasonably Practicable”. Given a residual risk will always remain in a drilling environment proof of existence of a safety management system is also viewed as a key pillar to drilling safety assurance. Safety practises for deep drilling have largely been informed by experiences from the Petroleum Sector. It has demonstrated from post-incident analysis of major accidents such the Deep Water Horizon that a focus on personal safety procedures alone is not enough to ensure safety. In addition, the demonstration of practises that reinforce a strong safety culture in the operation of a drilling site are also required along with a focus on process safety. Figure 3 summarises these key Health and Safety elements, some of which will be expanded upon in section 5.

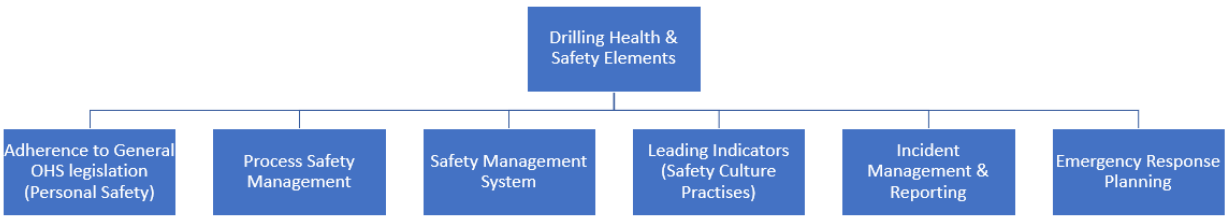

Fig. 3 Key Health & Safety elements with respect to Deep Drilling Legislation, Regulation & Standards

5.3 Environmental Protection

The principles of environmental protection are well enshrined in every EU member state through the adoption of relevant EU directives in this area. For deep drilling related to geothermal or underground energy storage projects the Strategic Environmental Assessment (SEA) Directive, the Environmental Impact Assessment (EIA) Directive and the Habitats Directive may all be relevant. SEAs are usually undertaken for public plans a sector level. For example, the proposed implementation of geothermal policy statement in Ireland has recently had a SEA conducted. SEAs will set the framework for the consent process for projects subject to the EIA directive. The Habitats Directive relates to Natura 2000 sites which are designated by EU countries as Special Areas of Conservation or Special Protection Areas (under the Birds Directive). Detailing the full scope and details of the EIA and Natura 2000 processes as they may relate to drilling is beyond the scope of WP4. The key point for deep drilling projects is that typical process for EIA and Natura 2000 is for a screening evaluation to be done to determine if the project requires a full Environmental Impact Assessment Report (EIAR) or Natura Impact Statement (NIS). With respect to deep drilling a decision by the Court of Justice of the European Union (CJEU) in 2015 can be interpreted as requiring Member States to demand an EIA if the drilling can be classified as "deep drilling" (>4150m) and, based on criteria such as size and location of the project, they are "likely to have significant effects on the environment." They also noted that the potential environmental impact must be assessed "jointly with other projects" in the same area. Similarly in some the cases the entirety of the project must be assessed at the time of application for a drilling project, for example with a geothermal project the impact of the above ground heat plant may also need assessed at the time of drilling if they are deemed to be one project. Depending on the jurisdiction and how the directives have been applied in that country the process may be lengthy and subject to unforeseen delays. This is highly important to take into consideration when planning deep drilling operations as frequently rig contracts must be entered into months or years in advance of planned project start and usually are for specific time windows. Appropriate description of the technologies involved, and accurate use of risk assessment is vital to navigating these processes efficiently.

The scope of WP4 in the DeepU project is focussed on how environmental protection at an operational level is regulated, which is very closely related to how Health and Safety is regulated. This is because the principles and practices that ensure the safety of people and property in a drilling operation are very similar to those required to protect the environment. For example, the unplanned release to surface of a toxic or hazardous substance from well can both harm human health and damage the environment. In the instance of environmental protection demonstrating Process Safety Management is often important. Figure 4 shows a general hierarchy of controls against environmental damage that should be in place to reduce risk for a complex deep drilling operation. To illustrate the concept the example of a diesel spill will be utilized. The most effective way to prevent a diesel spill on a drill site is to ELIMINATE or severely reduce the amount of diesel used by employing an electric drilling rig. However, a suitable electric drilling rig may not be available. In this case the risk of a diesel spill remains and must now be prevented. To PREVENT the spill barriers must be put in place. A barrier could be an object, an act or system that is in place to prevent the spill. Examples of these three barriers would be using an overfill protection system, ensuring an appropriately trained person supervises refuelling and having a written set of procedures for refuelling. Despite prevention measures leaks may still occur. Failure to follow proper maintenance procedures for example could lead to a leak in a fuel line. This could be a slow leak at a faulty seal or a rupture of a pressured line. In both cases having a process in place to DETECT the release as soon as possible will have a profound impact on the consequence. This could anything from a sensor on a fuel line to having a program of regular visual inspections on the drill site. In the case of the pressurised line a potential CONTROL that would minimise the impact would be an automated shutoff that prevents more fuel entering the line. For the case of the slow leak the control could be having n stationary equipment containing diesel placed on a bermed plastic barrier. The control in the fuel line example will not be sufficient to prevent a release onto the ground merely to lessen the volume. In this case there is a need to MITIGATE the impact of the hazard occurring. To be most effective this may involve ensuring appropriate clean-up equipment and appropriately trained personnel are on site, have a clear authority to act and a plan to follow. In an extreme and rare case, the release from the fuel line may lead to a catastrophic event where an ignition source is present. An explosion or small fire could disable a piece of critical safety equipment which in turn may instigate an event such as serious injury, fatality or ongoing release of toxic substance that will require the operator to RESPOND. The response will be managed through the activation of an Emergency Response Plan (ERP) which can either be managed from site or offsite depending on the whether the site remains safe. ERPs will cover everything from required engineering support to understand the situation to a defined communication plan to manage stakeholders.

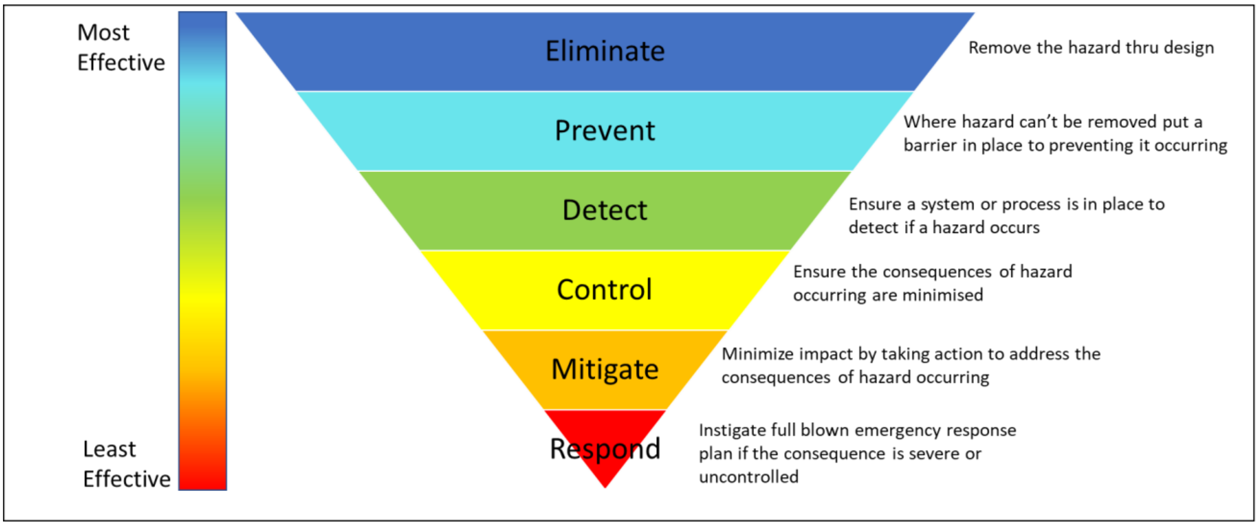

Figure 4. Hierarchy of Controls in Process Safety Management

As with Health and Safety legislation and regulation for deep drilling there may be multiple Government bodies or regulators who have legislative jurisdiction over the activities at a drill site. It is again important at the start of a project to map out the regulatory process in a jurisdiction and ensure that all reporting requirements and notification procedures are fully understood in addition to the approval process.

5.4 Resource Management

As noted in the licensing section governing principles of resource legislation will often relate to ensuring the resource is being utilized in a manner that benefit the country and its people. In most jurisdictions a government department, agency or independent body will have a legislative responsibility to maintain technical oversight on the resource being developed. Such an entity will review data from the developer to ensure license commitments are met and undertake independent resource assessments to ensure taxation or supports are set at appropriate levels. Key to fulfilling this responsibility is prescribing data gathering and reporting requirements in regulations or guidelines. This can include specifying at what interval drill cuttings are collected, how they are handled and how many sets are supplied to public bodies. The amount and type of geophysical logs can be prescribed along with requirements to core in certain circumstances. Pressure measurements, flow tests and formation fluid analysis are common engineering requirements.

6 LEGISLATION, REGULATORY & STANDARDS CONSIDERATIONS WITH RESPECT TO THE DEEPU TECHNOLOGIES

6.1 Overview – Purpose of Legislation, Regulation & Standards

The aim of drilling legislation and regulations in Europe is to ensure safe and responsible development of resources, while protecting the environment, people and property. There are various regulations and practices for drilling operations, which vary by country and specific circumstances. However, some common regulations include:

1. Environmental protection: Drilling operations must adhere to regulations to minimize the impact on the environment, such as restrictions on discharge of drilling muds and cuttings.
2. Health and safety: Operators must comply with regulations regarding the health and safety of workers and the public, including measures to prevent fires, spills, the release of toxic/hazardous materials and other accidents.
3. Permitting and licensing: Drilling operations require permits and licenses from government agencies, which may include review of environmental impact assessments and approval of well design and drilling plans.
4. Well design and construction: Drilling operations must adhere to standards for well design and construction, including casing and cementing programs, well control procedures, and blowout prevention measures.
5. Data reporting and management: Operators are required to submit regular reports on drilling activities, including information on wellbore conditions, drilling fluids, and other parameters.

6.2 Laser Device Regulations

Laser devices cover everything from basic laser pointers to laser welding machines are governed by safety standards in EN 60825 (2011/2014). The standards and regulations are transposed by national authorities in the different parts of the European Union through a set of local regulations and regulations that ensure compliance with the standard. Whilst the country specific regulations are not presented in this deliverable, this section reviews the main principles covered by the standard with the main risks associated with operational health and safety identified. EN 60825-1 [6] classifies laser products into different categories according to their hazard levels and application field. The hazard level of the lasers increases progressively. The purpose of setting up the classification system for the laser products is to identify and evaluate the hazard caused by different classes of laser products and take safety operation and protection methods accordingly.

Class 3B (industrial lasers, research lasers) and Class 4 (automated lasers, laser welding machines) as defined in the standard are characteristic to the DeepU drilling technology associated with the laser source, drill string and drilling head developed in the DeepU project. EN 60825-1 provides the general principle and reference standards for the evaluation of the laser product classification. Specifically, it refers to the following two standards for the measurement of laser classification method:

- IEC/TR 60825-13 – Measurements for Classification of Laser Products [7]

  - IEC 61508 – Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements [8]

EN ISO 11553 – Laser Processing Machines Safety Requirements describes hazards generated by laser processing machines and lays down safety requirements, protection measures, and labelling requirements. These requirements include mandating that a Quality Management System (QMS) should be proportionate to the risk class and the type of device that shall involve at least the following aspects:

- Strategy for regulatory compliance
- Strategy for safety, performance, and requirement compliance with applicable standards
- Supply chain and risk management in pre-sales and after-sales period
- Establishment of the post-market surveillance system

The Machinery Directive [9] concerns the safety and performance requirements for machinery and certain parts of machinery. This directive requires that laser equipment embedded in the machinery must be designed and constructed in a way to prevent accidental radiation, decrease effective radiation, or reflect, diffuse radiation so that the radiation does not pose health risks to the users. The following laser devices are under the coverage of the Machinery Directive:

- Levelling laser with orientation instruments for civil engineering applications
- Laser cutter engraving machines
- Show and projection laser machines
- Laser safety curtains
- Active laser safety walls

European Health and Safety regulation also place a specific focus on laser operator safety training requirement as outlined in standard EN60825. Several guidelines on the training requirement and operator safety associated with laser technologies are implemented across Europe. As an example, these include:

- Control of Artificial Optical Radiation at Work regulations [10]
- Minimum Requirements for the Education, Training, Examination and Qualification [10]

6.3 Overview – Well Approval Process

The specific requirements and timeline of a well approval process may vary depending on the location and scope of the drilling operation. The risk presented by the well may determine the complete nature of the process with wells falling into different categories depending on their complexity and risk profile

The approval process for drilling operations typically involves the following steps:

1. Planning and application: The operator submits a detailed drilling plan and application for a drilling permit to the relevant authorities, including information on well design, drilling fluids, and environmental protection measures.

2. Environmental impact assessment: An environmental impact assessment is conducted to evaluate the potential impacts of the drilling operation on the environment, including air, water, and soil quality.

3. Technical review: The drilling plan and environmental impact assessment are reviewed by technical experts to ensure compliance with applicable regulations and standards.

4. Public consultation: The proposed drilling operation may be subject to public consultation, providing an opportunity for local residents and stakeholders to raise concerns or objections.
5. Permit decision: The relevant authorities will make a decision on the drilling permit, based on the results of the technical review, environmental impact assessment, and public consultation.
6. Monitoring and reporting: Once the drilling operation is underway, the operator is required to monitor and report on wellbore conditions, drilling fluids, and environmental impacts.

6.4 Licensing – Case Study Examples

A review of select jurisdictions other than of Ireland and Italy was carried out to identify the types of governing legislation, nature of the licencing system and application processes for geothermal projects. France, Germany, and The Netherlands were selected given active nature of the geothermal sector in those countries. A brief overview of salient point and diagram included that indicates competent authority and timeframes for applications.

6.4.1 France

In France geothermal licencing is issued under Mining Law which has been modified by decrees. There is not a single Regulatory Authority they aim to have the mining authority function as a single gateway for applications. The Licensing and Permit process involves Exploration license, Production licence and permits for component activities such as drilling. An Exploration License is valid for 5 years and can renewed twice, grants the holder sole right to apply for Production licence during the term. Production licenses are granted for 50 years and extendable by 25. Exploration and Production licence applications include technical financial & environmental components along with financial/work program commitments. Work permits required include technical, environmental, health & safety, and water resource impact information.

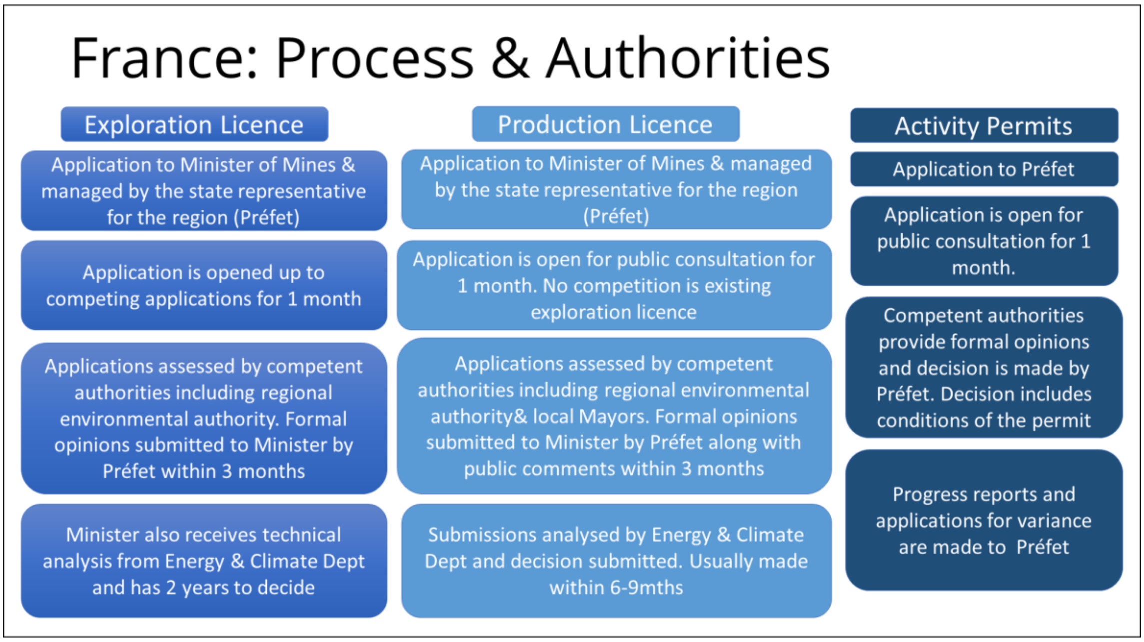

Figure 5. France – Overview of Well Licensing Process

6.4.2 Germany

In Germany the Licencing Authorities are the Federal & State Mining Authorities. There is a single Regulatory Authority the State Ministry of Economic Affairs. This is responsible for water protection and environmental protection related to mining licences which includes geothermal. The Licensing and Permit process is comprised of an Exploration license and Production licence phases. Both require approved operational plans. The Exploration License is valid for 5 years and can be extended by 3 years. The Production licenses are granted for up to 50 years and can also be extended. Exploration and Production licence applications include technical & financial capability details along with work program details and a projection of the geothermal use. Drilling plans are also required. The requires Operation plans include an overall business plan, prospecting plan, production plan, operational plan and short term seismic and drilling plans.

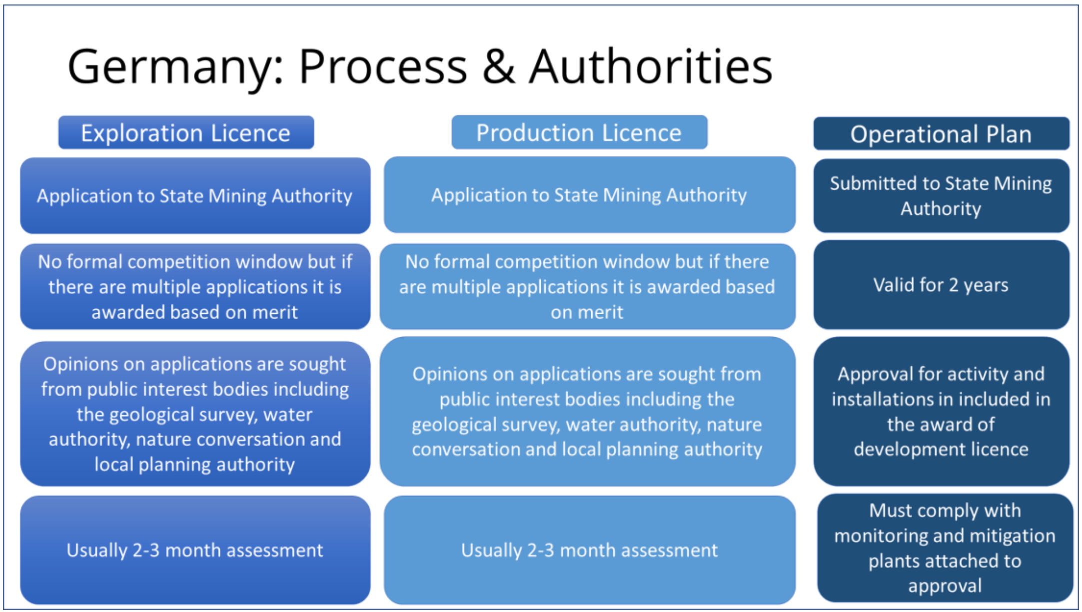

Figure 6. Germany – Overview of Well Licensing Process

6.4.3 The Netherlands

In The Netherlands the Licencing of geothermal is governed by Mining legislation. There is a single Regulatory Authority, the Minister of Economic Affairs however its functions are carried out in consultation with other departments. The Licensing and Permit Process consists of Exploration license and Production licence phases. The right to drill is granted under an exploration licence but a safety permit must be obtained. Production testing is also allowed under the exploration license. An Exploration License is valid for 3-6 years and can extended by 1-2 years and converted into Production licence by application. Production licenses are granted for 35 years. Exploration and Production licence applications must include technical, financial & environmental components along with details of proposed methods, safety procedures, risk assessments, expected outcomes, timeframe and potential inference with other operations. A detailed geological report is also required along with a proposed work program. For development licenses an estimate of resource is also required along with planned program of activities including production and cost forecasts.

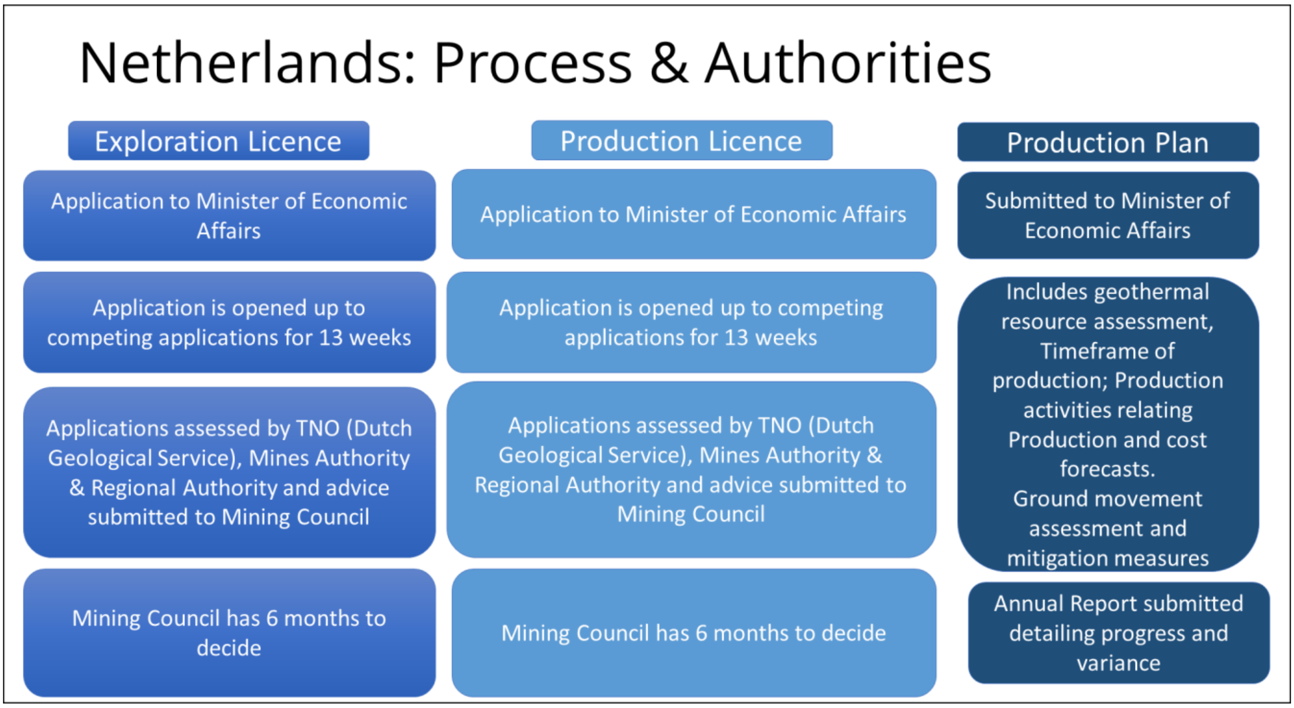

Figure 7. The Netherlands – Overview of Well Licensing Process

6.5 Summary

Figure 8 represents a summary diagram of what a typical licence process would look like based on the analysis of jurisdictions in Europe. As part of the application process for the licensing authority will typically assess the financial capability of the applicant along with ensuring appropriate operational, safety and environmental management systems are in place. Despite these elements being assessed at licence stage a critical point to note is that the issuance of a licence or production lease does not always automatically mean that permission is granted for drilling. Additional permits are required for specific activities that can take place in a licence stage. Drilling is one such activity.

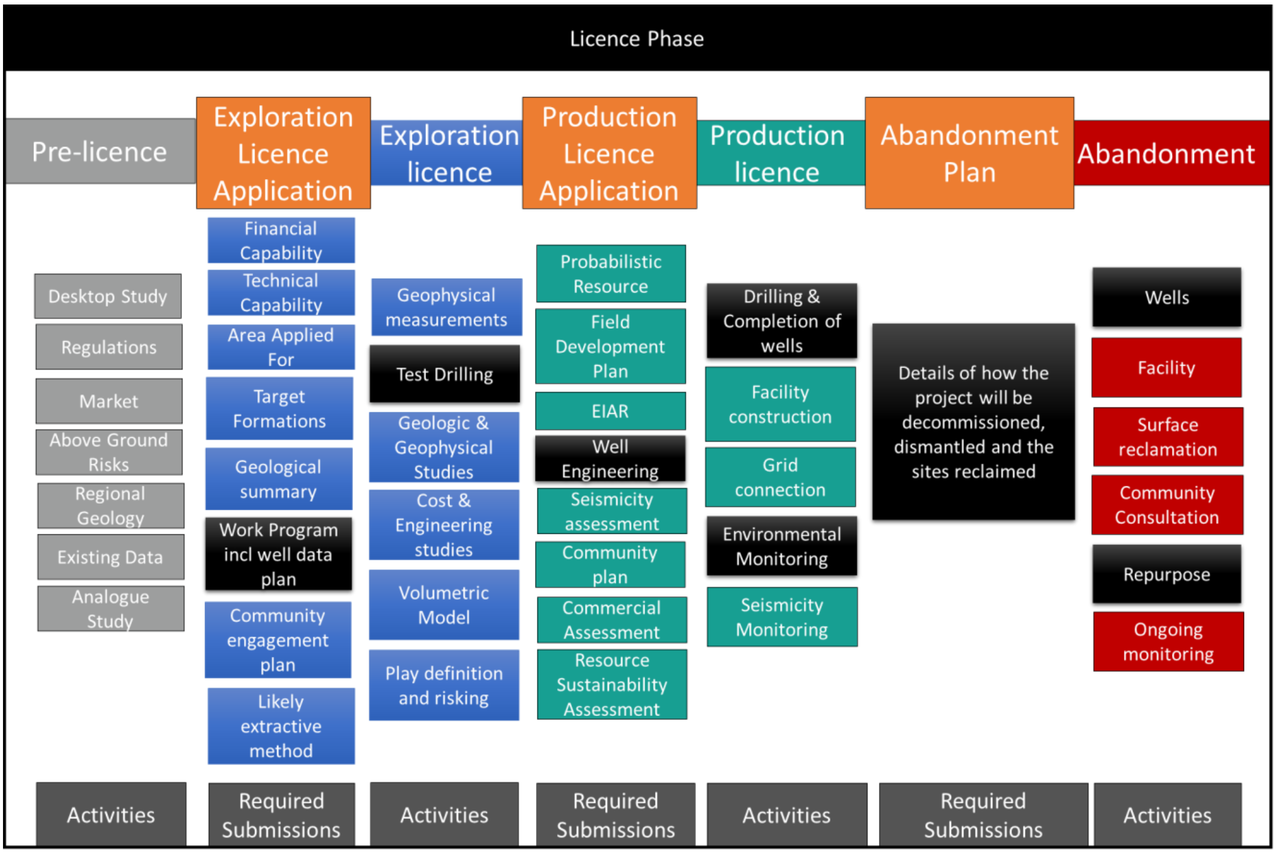

Fig 8. Composite example of typical geothermal licence stages and application requirements. Black boxes highlight topics directly related to DeepU technology however activities such as EIAR and Field Development Planning are related also.

The employment of the novel drilling technologies associated with the DeepU project should not create any exceptions with respect to being able to follow typical legislative processes. There are a number of considerations however. Details of drilling plans are often required at the licences stage even though separate permits are also required so it is important that novel techniques are familiarised as soon as possible.

Possible Issues: Exploration and Production are often distinct phases in legislation and may require certain demonstrations of progress to move forward. In the case of a deep U-tube system there is no exploration risk so the project may wish to progress to production lease immediately. In some jurisdictions an application to move from license to lease triggers a competitive process. Government supports for geothermal drilling may be tied to exploration and qualification for these may be based on assessment criteria rooted in more conventional or widespread technologies.

Mitigations: In most jurisdictions the period set for an exploration licence is a maximum period and the developer is free to apply for production lease at any stage of the licence thereby avoiding delays. In the absence of a distinct exploration drilling phase, it will be incumbent on the project team to build robust geologic, engineering and economic models to demonstrate to the regulator that planned heat recovery can be achieved. Such efforts would also form the basis of competing in open competitions for licences or leases and for making the case for financial supports. Early engagement with a range of licensing bodies during the project, especially once pilot results are available will help regulators understand how their processes need to be adapted. Despite the confidential nature of the technology once a field scale pilot is reached creating a program of site visits will be critical in achieving this last goal of regulator education.

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6.6 Health & Safety

As noted in the Licencing review a permit to drill must be received from the licencing authority before any drilling can commence. The licensing authority will not issue a drilling permit until several conditions are met. Based on the review of the permitting regulations for drilling these conditions can be summarised as follows

- Does the applicant have the legal right to the resource?
- Has the landowner given permission to allow access to the site?
- Has the applicant received permission from the relevant local planning authority or regulator to drill and any/all conditions imposed by that authority been met? Key issues may include:
    - Site location
    - Water management including run-off from site
    - Traffic volumes
    - On-site storage facilities
    - Noise
    - Groundwater
    - Induced seismicity
    - Waste Management
- Have appropriate permits or approvals been obtained from the Environmental Regulator? Overlap with planning permission is intended to be minimised but there may be additional requirements.
- Have all statutory consultations taken place? Statutory consultees can include:
    - Heritage organisations
    - Archaeological agencies
    - Forestry agencies
    - Depart of Transport
    - Department of Defence
    - Air traffic control/Civil Aviation Authorities
    - Agricultural and Fisheries organizations
    - Local authorities
    - Police
- Have all required notifications been issued?
    - Notifications usually must be issued at set timeframe from commencement of operations.
- Has the appropriate Health and Safety authority been notified of the operation and provided approvals for safety procedures and well design?
- Has a qualified independent well examiner verified the well design?

With respect Health and Safety authority approvals regarding safety procedures, well design and verification as typical application would be expected to contain the following items:

- The location of the borehole, both surface coordinates and the downhole coordinates where the geothermal resource will be penetrated and/or the bottom of the well. In addition the proposed depth of the borehole is required.

- A well schematic and associated report that contains the following:

  - the rationale by which the casing depths have been chosen including demonstration of isolation of freshwater aquifers;
  - the geological formations that will probably be penetrated by drilling;
  - a comparison of the casing depths of adjacent boreholes including mud weights used and stratigraphic column encountered;
  - the pore pressure that can be expected in the borehole and the fracture gradient pressure at the planned drilling mud pressures, and an assessment of where mud losses could occur, wellbore stability issues to be expected, or a hydrocarbon accumulation could be present;
  - A diagram of each casing section with details of the diameter; type of material, the weight per unit of length and the depth envisaged for each casing string and of the planned diameter of the borehole in the drilling trajectory to each of the depths
  - a report on all occurring kick situations of each casing string 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 kick situations
  - 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;
- Details on the type of the drilling rig to be used;
- Details of the methods for formation strength testing;
- Details of the drilling fluid to be used and the rationale for selection;
- List of chemicals to be used during drilling of the borehole, their quantities, and a description of the use of those chemicals showing that compliance is established with respect to relevant directives;
- A description of the well control installation to be used for each casing string detailing:
  - the type of every component of the installation, and
  - the maximum pressure that every component can withstand and that at which every component is tested;
  - the well control testing procedures;
  - A diagram of the intended completion of the borehole.

6.6.1 Health & Safety - Summary & Conclusions

There are several Health and Safety authority requirements that are likely to important with respect to deep drilling of geothermal wells using the DeepU technologies. These are:

i. Occupational Health and Safety legislation with respect to handling of cryogenic fluids and industrial lasers. Standards, safeguards and personal protective equipment that have not typically been part of drilling operations procedures will have to both adapted and subject to verification.
ii. The requirement for a risk-based, safety management system for well integrity, that ensures ensuring the safety of the well operations and environmental protection along with a suitable environmental management system that conforms to the principles set out in relevant standards.

The emphasis on well control equipment and procedures for well design and verification process.

There are likely to many exceptions created by DeepU technologies that will need to be addressed to satisfy the authorities that regulate Health and Safety of deep drilling operations.

Possible Issues: Typical OHS procedures drilling sites will not cover the handling of industrial lasers and cryogenic fluid. Given the powerful nature of the laser and potentially wide array of uses assurances will have to be established as to the security of laser at all times while on site.

Similarly, safety managements systems for drilling operations will not have included lasers and cryogenic fluid and the required interaction of these elements. The issue of well integrity for the lifespan of the well will have to addressed. Verification of well integrity typically centres on the design and standard of casing which in the case of DeepU will not be employed. It will have to demonstrated that necessary parts of the well are sealed for its lifetime and post abandonment and that any issues that occur can be remediated if wellbore integrity is compromised.

As noted much of the well design, engineering and verification process is around ensuring there is no unplanned release of fluid to surface in the form of a kick. The standard requirement in this regard is for there to be two barriers in place to prevent this. The first is the pressure exerted on the formation by the wellbore fluid and the second is placement of suitable well control equipment applied to the casing bowl which is typically comprised of a blowout preventer (BOP) system, a bleed of system and a kill system. Furthermore, many of operational requirements such as testing the strength of the formation with a leak of test are established based off the proposed casing design which has to take into account kick tolerance. An open hole system with potentially several thousand meters of uncased rock that is likely to underbalanced with to formation pressure will be notably different.

Additional operational safety issues included understanding and management of wellbore stability in the absence of a conventional drilling fluid. Any consequences that wellbore failure could have for the centralisation of the laser within the drill string could be serious. Off gassing of potential toxic substances into the nitrogen gas stream is another aspect that needs to be understood with respect to handling the return of gaseous nitrogen to surface.

Mitigations: Considerable resources and time will be required for writing new procedures and standards for DEEPU drilling operations (e.g. laser handling and liquid nitrogen handling) including additional confined space protocols with liquid nitrogen. Enhanced security measurements and protocols will have to be employed regarding laser security and special notification or reporting procedures with law enforcement agencies may be required.

Safety management systems will have to adapted to account for the new technology elements and also reassessed as whole to ensure no other components are materially affected by the introduction of these new elements.

Demonstration of ALARP with respect to well control will be critical, and this must begin with site selection by choosing demonstrations sites with demonstrably low risk of gas or pressured water/steam. A suitable kill fluid and deployment mechanism will likely also be needed.

Experimentation will be required with a wide range of sample lithologies to determine if off gassing occurs, what the nature of that gas could be and in what concentration would it occur in the flow stream. If it is found to be the case that toxic, hazardous or explosive gas is generated scenarios need to be investigated to determine if any set of circumstances could occur that would concentrate hazardous gas or material. For initial wells a managed pressure drilling system may need to be employed to allow for the capture and testing of the nitrogen stream leaving the well bore.

A comprehensive program of geomechanical modelling of the drilling process will be required to investigate wellbore stability and long-term integrity of the vitrified wellbore in a variety of rock types and tectonic settings.

Overall, it is recommended that early regulator engagement occur, and that piloting demonstration and site visits are used as part of this process.

6.6.2 Environmental Protection

Environmental protection with respect to deep geothermal drilling can be considered from two aspect with respect to legislation and regulation. This first is major environmental hazard prevention. In the context of drilling this will be inseparable from the health and safety regulations specific to well engineering and safety management systems. This is because the common risk element being managed is the prevention of unplanned releases of potentially toxic or hazardous material from the wellbore. The lead regulatory body for this aspect of environmental protection will therefore be the regulator responsible for drilling safety permits.

The second aspect is the standard environmental protection processes that any project or industry would be expected to follow. These elements are likely non-specific to drilling techniques and will deal with overall environmental impact of the activity (EIA/AA) as well as adherence to other environmental legislation such as ground water protection. A description of the requirements of EIA/AA processes are beyond the scope of D4.1 but based on reviewing requirements in jurisdictions can be summarised as follows. An aspects and impacts register is created (similar to FMEA for safety) and a determination made based of the nature of the activity and specifics of the site as to whether significant environmental impact could occur and what mitigations are required to prevent this. An example of some geothermal specific impacts are listed below.

- Effects on water quality and quantity (particularly groundwater) with indirect effects on water dependent habitats and species during exploration, development and operational activities.
- Water and thermal pollution from point or diffuse sources e.g. fluid injection and discharges to watercourses/groundwaters
- Impacts on groundwater quality and quantity, e.g. through dewatering, abstraction or groundwater rebound
- Fluids used to transfer heat can be toxic
- Potential for habitat loss and fragmentation during exploration and development activities
- Effects on sensitive habitats, e.g. peatlands,
- Potential for introduction of invasive species
- The potential for impacts on soil functions during exploration , development and operational activities due to encountering contamination
- Potential loss of the natural soil characteristics through extraction
- Hazardous dust emissions from drilling activities – impact to protected habitats and species
- Air, light, and noise emissions from drilling, excavation, installation, transport, construction and operation causing disturbance to protected species
- Vibrations or induced seismicity causing disturbance to protected species during exploration and development activities
- Loss/reduction of habitat area during construction / development activities.
- Disturbance from traffic to and from the site

This information is submitted to the relevant regulatory body called the Competent Authority (usually the local planning authority or the licencing authority) who will make determinations regarding EIA and Natura 2000 processes. Approval with respect to EIA/AA will often have conditions attached that need to be met in order to obtain overall drilling consent.

A second environmental permitting process is common to whereby an Environmental Regulator may specify additional requirements with respect to:

- air quality (e.g. dust from operations or traffic)
- discharge
- groundwater abstraction rates,
- use of radioactive sources, chemicals etc)?
- a site restoration plan.

Again, these must be met in order to obtain the consent to drill.

6.6.3 Environmental Protection - Summary & Conclusions

With respect to DeepU technologies any major exceptions to environmental regulations around deep drilling are not likely to be different to those identified for Health and Safety (e.g. well control etc). There does not at a high level appear to be anything with the technologies that would present environmental impact risks that would be more significant a standard deep drilling operation. In fact, the removal of drilling fluid potentially lowers environmental risk.

Potential Issues:

An aspects and impacts (or Risk and Receptor) analysis for any fluid that is not typical to drilling will need to be carried out.

Mitigation:

It would be considered good practise for EIA/AA assessments to do a desktop EIA/AA process for a jurisdiction and hire appropriate lawyers and consultants from that country to make a determination assessment (i.e. act in the role of a regulator) to highlight an issues before actual submission of screening reports.

6.6.4 Resource Management - Summary & Conclusions

In order to fulfil their requirement to steward resources in the public interest regulators and/or licencing authorities will require data and reports from drilling operations. In the predrilling permitting stage the following may be required:

- A summary of the basic well data (location etc) and a geological prognosis that lists major stratigraphic intervals likely to be encountered, the expected top and bottom of potential geothermal reservoirs and the total expected depth (TD) of the well.
- A summary of the geothermal play type including:
  - A seismic or structural depth map
  - A geoseismic section.
  - Geological rationale and objectives of drilling the well.
- Sampling/coring/logging and testing programme. This should include information on:
  - frequency of cuttings samples collection.
  - details of the coring programme and rationale if no coring is planned.
  - details of the side-wall coring.
  - details of the petrophysical measurements planned for the core.
  - details of the any of planned mud logging
- A description of the logging programme (open and cased hole) for each hole section including any intermediate survey points. should be included.
- Details of the mud type and proposed weight of mud for each interval to be drilled.

- An estimate pore pressure/fracture gradient profile for the well
- Details of any proposed well testing operations.

In many jurisdictions the frequency of cuttings sample interval will be specified and this may differ from what the operator intends to do. It also is often expected that exploration wells will be cored in the reservoir section and/or at the TD of the well. In addition, it is also often prescribed that exploration wells have some minimum logging program at intermediate casing points as well as over reservoir horizon(s). It is often possible to get exemptions from these requirements depending on the level of data already in the area and/or any safety concerns.

During the drilling operations daily reports on progress can be required and any modification to the pre-drill data gathering plans must be approved by the regulator. Post drilling all data must be made available to the appropriate agency responsible in the jurisdiction. This may include physical cuttings samples and core. Data is normally held confidential for some specified period before being released to the public. A final geological report summarising the data gathered and the finding of the well may be required within several months of the finish of the well.

The use of the technologies proposed for the DeepU project may create several exceptions to typical data requirements set out in legislations of guidelines.

Possible Issues:

One of the questions that may need to be resolved is how to standard geophysical logs (Gamma Ray, Density, Resistivity and Sonic) perform in a vitrified borehole. Is it more similar to cased hole logging or open hole logging in the choice of tool?

Any coring requirements will not be achievable with the laser drilling technology.

Drill cutting requirements will not be achievable with laser drilling technology.

Any well test requirements will not be achievable with vitrified wellbore without comprising the integrity of this.

Possible Mitigations:

Conduct a literature review around logging of vitrified wellbores and if required conduct lab based tests to investigate optimal logging techniques for vitrified wellbores (potentially with an industry partner).

Engage with regulators to seek mitigation on coring requirements. If such mitigation is not issued a wireline or conventional coring set up will need to be employed which would require a mud system.

Engage with regulators to seek mitigation on cuttings requirements. Demonstration of how geological information can be extracted from the analysis of the dust recovered.

It is unlikely that well tests will be specified however it remains an area to consider as to how the performance of a closed loop system is verified upon initial drilling. Robust models may be sufficient.

7 VIRTUAL CASE STUDY EXAMPLES

Extensive work has been carried out by a number of projects to outline the licensing and environmental requirement procedures applicable in the context of research and development of geothermal resources in Europe. Such projects have all identified complex legislative frameworks [12], weather associated with district heating [13] or power production [14] [15], the general result in barriers and slow development of deep geothermal resources. These barriers are often defined by the inclusion of geothermal resources in multiple different legislative contexts (generally associated with minerals and hydrocarbon legislation) and as such requiring consultation, permitting and authorisation by multiple authorities.

The permitting process is also requires the applicant or operator to undergo an Environmental Impact Assessment process which in many cases applies to both research and test drilling activities, as well as for drilling, completion and operation of a geothermal project (direct use or power production) in many European jurisdictions [15]. The EIA process is governed under the regulatory transposition of EU Directives 2014/52/EU and 2011/92/EU on the assessment of the effects of certain public and private projects on the environment [18] by individual Member States.

In all cases, the regulatory process requires the construction operation of a geothermal project to ensure that the drilling, well construction, testing and operation of the geothermal system are performed in compliance with applicable health and safety standards as well as any requirements for environmental protection.

Less mature geothermal markets, the legislative and regulatory conditions specific to the geothermal sector are less well defined or are under development. However, in all cases, regulations in relation to environmental health and safety for deep drilling operations are adopted from mineral, hydrocarbon or groundwater legislations.

This section of the deliverables covers an overview of regulatory and legislative aspects related to deep geothermal projects that are directly linked with the design, implementation and completion of deep drilling operations. These aspects are most critical to the development of the DeepU project technology and understanding potential compliance of key technology and operational aspects of the DeepU process will be critical to future development and commercialisation of the technology. Two virtual case study countries in Italy, where a mature deep geothermal sector is present and Ireland, where deep geothermal legislation and associated are being developed are considered in the sections below.

7.1 ITALY

7.1.1 Geothermal Legislation – Italy

Geothermal resources in Italy are defined by the national legislative decree D.Lgs. 22/2010 where the state delegates the management of geothermal resources for onshore activities to the Competent Region (and the provincial authorities of Trento and Bolzano) and the Ministry of Economic Development (MiSE) Ministry of Environment and Protection of Land and Sea (MATTM) Concession: Relevant regional administration (or MiSE in case of off-shore resources and pilot plants) respective regions for pilot projects. Specific regions where geothermal energy development is either under development or in production (Tuscany, Lazio, Lombardia, Trentino Alto Adige, Umbria, Emilia Romagna & Veneto) are, therefore, the competent authorities for the permitting, licensing and regulation of geothermal resources and associated development works.

7.1.2 Licensing & Activity Permits

Licensing and permitting activities related to deep geothermal projects are considered on the basis of 'local' (low enthalpy) or 'national' (high enthalpy) interest based on the type of resources and energy usage planned (electricity production vs thermal energy usage).

Resources deemed of 'national' interest are subject to licensing rounds and processed through the *'Commissione per gli Idrocarburi e le Risorse Minerarie'* (CIRM) who expresses opinion on the initial application process as well as imposing conditions on granted permits and licenses.

Geothermal resources as classified as in a number of different categories [16] based on usage, installed capacity and temperature of the resource:

- National Interest:
  - economically usable for the realisation of a geothermal project such as to ensure a total deliverable power of at least 20MWth, with a return temperature of 25 degrees centigrade;
- Local Interest:
  - economically usable for a geothermal project with a power of less than 20 MWth obtainable from a geothermal fluid with a return temperature of 25 degrees centigrade;
- Small local uses:
  - uses of geothermal hot water available at depths of less than 400 meters with an overall thermal power not exceeding 2MWth or less than 90ºC.

Whilst the specificities of the licensing process are slightly varied on the basis of the resource type, the application and the installed capacity of the system, these are not individually covered as part of the deliverable. However, the licensing process is broadly summarized in the steps that highlight the key parts of the licensing and environmental permitting requirements. These are summarised in figure 9 below.

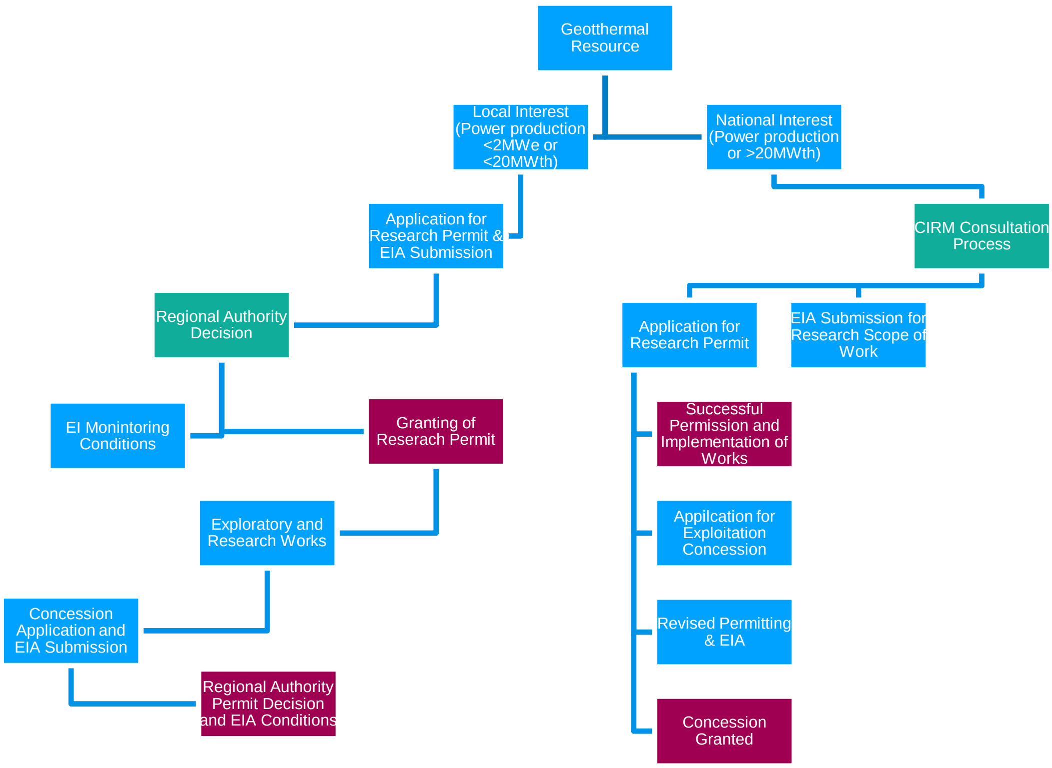

Fig 9. Simplified structure of the geothermal permitting process applicable to deep geothermal projects in Italy [16]

The licensing and permitting stage taken into consideration the guidelines with respect to environmental health and safety, protection of the environment in the context of the implementation of research activities associated with a project that include drilling and completion of both exploration and production wells. The requirements under these regulations is further highlighted in the sections below, where these are considered in a context specific to drilling operations, well completions and environmental monitoring compliance of deep boreholes.

7.1.3 Health and Safety and Well Control

Health & Safety for well drilling operations in Italy are governed by two specific legislative instruments. The first is Art. III of Legislative Decree 624/1996. The legislative decree is the implementation of Directive 92/91/EEC relating to the safety and health of workers in extractive industries for drilling and of directive 92/104/EEC relating to the safety and health of workers in open-cast or underground extractive industries. Art. III of the decree related to the implanting the minimum requirements aimed at improving the protection of the safety and health of workers in the extractive industries by drilling in above. The activities covered include:

- The production of mineral substances and subsoil energies, industrially usable, under any form or physical condition, implemented by drilling;
- Prospecting and research activities aimed at such production;
- The processing and storage of the extracted materials to make them suitable for market sale;
- Storage activities in the current reservoir by drilling.

The second legislative instrument which is relevant to geothermal resources exploration and development is Presidential Decree n. 128/1959, in which article 65 defines the *authorisation to drill and protection systems*. This defines that *'the holders of prospecting permits, exploration permits or cultivation concessions for liquid and gaseous hydrocarbons as well as for geothermal fluids or gases* *other than hydrocarbons, before starting any drilling exceeding 200 m deep are required to send the relative program to the competent supervisory authority for authorization to drill*' establishing the requirement for a geothermal company seeking to drill for exploratory or development purposes to secure a permit to drill. As part of the authorisation sought, the developer is to provide the following items:

7.1.3.1 Well Control

A detailed well risk assessment and drilling programme and safety plan that includes:

- safety and control plan that evaluates the possibility of the occurrence of blowouts during drilling and outlines the safety equipment planned for the prevention and mitigation of such risks,
- implementation of mud control measures, as well as emergency measures in case of blowout;
- details of BOP equipment and well head measures to allow for the well to be closed of in any operating conditions.
- detailed safety plan where the operator can demonstrate the partial use or non-use of the safety equipment only in cases of drilling intended for the development of resources where reservoir characteristics are already known and where such conditions can exclude the possibility of blowouts.
- an emergency plan to deal with formation fluid blowout indicating intervention methods, means to be involved, services and personnel to be used.
- safety measures in the event of anomalous behaviour of the well, with an indication of the personnel in charge of implementing the procedures.

In addition to the above requirements, the regulations also state that the safety equipment against free blowouts must consist of devices capable of closing the well in all operating conditions. In the context of drilling operations for hydrocarbons, provision must be made in particular for the assembly of a shearing jaw system with a double control device, as well as the relative operating methods. Such controls must be located along one of the escape routes or in another appropriate place established by the owner.

Each drilling rig must be equipped with such equipment, which must be installed after cementing from the anchoring pipeline. When manoeuvring the string of rods, the casing pipe, tools or other equipment, closing heads for the rods or for the manoeuvring pipes must be free on the casing plane.

Any electric line for operating the equipment against flare-ups must also be connected to the emergency electric system, where applicable.

7.1.3.2 Drilling Rig

- A table indicating the nominal capacity of the drilling tower must be included to the drilling plan and must clearly specify the applicable rig pull back at any time.
- A detailed health and safety plan document for the planned equipment and drilling operations.
- The fall arrest systems and types of protection from falls for workers operating on stairs, floors and structurally particular places of the drilling tower, which guarantee effective protection in all working conditions.
- Details of rig floor protection with fixed balustrades, except on the openings that overlook the pipe rack and in correspondence with the emergency slides, where removable protections must be affixed according to work requirements.

- The lift equipment to allow the operator descent in safe conditions from the bridge in the event of an emergency

7.1.3.3 Post drilling operations

The implementation of well safety verifications following the completion of deep borehole are also outlined under the safe regulatory and legislative conditions. Relevant to the implementation of the DeepU drilling technology, the following two key requirements are noted:

- safety equipment as well as post completion casing and cementing infrastructure is to be inspected and must be subjected to leak tests after their installation to demonstrate compliance and prevention of any gas or blowout risk;
- such equipment and permanent structures are to be subjected to periodic maintenance and revisions to verify its state of wear and tear with information on such testing submitted to the competent authority.

7.1.4 Environmental Protection

The licensing and permitting process for geothermal, mining and hydrocarbon boreholes (exploration or production) are subject to the Verification of EIA Subjectivity (VIA) and Environmental Impact Assessment as defined in Decree 152/2006 (and subsequent amendments, annex IV paragraph 2 letter b), that includes the research activities on dry land of the minerals, including geothermal resources. The decree defines such activities are subject to the "Verification of Subjectability to EIA". The process is government by both national legislation from the Ministry for Environment and by regional legislation through the regional government. Enforcement of the legislation is both carried out a national level (SNPA) and through regional agencies for the environmental protection (ARPA).

Whilst, the process is slightly different in the different cases, the process for geothermal fields is described in this section and generalised according to the provisions of applicable regional laws. At the regional level, the competent authority is the public administration with tasks of environmental protection, protection and enhancement identified according to the provisions of the regional laws or of the Autonomous Provinces.

The VIA is a verification procedure used to evaluate whether plans, programs or projects can have potential significant impacts on the environment and must be submitted to the relevant regional authority (ARPA) as part of the application for a research or exploration permit respectively. The applicant provides the competent authority a preliminary project proposal and environmental study for evaluation. Subject to a satisfactory opinion from the region, the competent Authority orders its exclusion from the Environmental Impact Assessment (VIA) procedure. The subjectability provision is published by the competent Authority, with a summary notice, in the Official Gazette of the Italian Republic and in the Official Bulletin of the Region or Autonomous Province, in full on the website of the competent Authority.

The Environmental Impact Assessment (EIA) is prepared in compliance with the results of the consultation phase with the competent Authority and the subjects responsible for environmental matters. The environmental impact study must contain at least the following information:

- characteristics, location and size of the project;
- description of the measures envisaged to avoid, reduce the relevant negative effects;
- identify and evaluate the main impacts of the project on the environment and cultural heritage, in all its phases;

- description of the alternatives considered, including the zero alternative, motivating the choices;
- description of monitoring measures.

The EIA process applicable to the development of geothermal projects in Italy is similar to that described in section 6.6 of this deliverable. It requires the applicant/operator to fulfil the requirements under the regulations to outline the project characteristics, the potential impacts and mitigation measures to be implemented as part of the project at both construction (site preparation, drilling and completion of all plant construction work) as well as the final operational phase of the plant. The EIA process is governed by the preliminary consultation and opinion of the authority which essentially acts as the screening process for the impacts assessment and likely mitigation measures required. All the requirements and specific sections relating to the project development phases are not outlined in detail in this deliverable.

As part of the country specific review, the following key items have been highlighted in the context of the development of deep geothermal projects and highlighted by previous work undertaken in the VIGOR [14] and GEOENVI [15] project as being most critical to the potential implementation of the DeepU technologies.

7.1.4.1 Aquifer Protection

The EIA process needs to clearly outline in the hydrology and hydrogeological sections, the potential impacts and associated mitigation measures to be implemented as part of the drilling and well construction operations on groundwater aquifers and surface waters. Specifically mitigation and monitoring measures are described in the GEOENVI project [15] as distinct for the two phases:

During drilling:

- Installation of groundwater monitoring boreholes in proximity to proposed development;
- Periodic monitoring of piezometric levels at wells;
- Spot control/monitoring of piezometric levels by regulating authority;
- Control of cementing procedure by regional agencies for the environmental protection ARPA

During operation (for Pilot Plants):

- Periodic monitoring of piezometric levels at wells.
- Spot control/monitoring of piezometric levels by authorised personnel (regional agencies for the environmental protection ARPA)

The frequency of monitoring at both stages of the project is aimed at demonstrating successful and safe completion of the project infrastructure with respect to the surrounding aquifers and the monitoring requirements and frequency are in general defined in the EIA by the regulatory authority.

7.1.4.2 Airborne Emissions

An analysis of covering the legal framework associated with fugitive emission to air from deep geothermal projects in various European jurisdictions demonstrates that national environmental and mining law covers most of the risk mitigation and reporting associated with emissions from geothermal fluids. The requirements under the project development phases are subdivided into measures required for implementation at the drilling and testing phase of a project (construction phase) and the long term geothermal plant operation (operational phase) [15].

The implementation of measures to mitigate against accidental fugitive emissions at the construction phase broadly require monitoring to be implemented during the drilling and testing phases. These include air quality monitoring to be undertaken:

- Before the beginning of plant construction.
- During drilling: only safety procedures for working personnel.
- During construction phase of drilling pad (spot monitoring).

The procedures specific to deep geothermal (and other deep drilling projects) in Italy include:

- mandatory gas monitoring during drilling within the drilling operation compound;
- gas monitoring during flow tests based on EIA conditions outside the drilling compound;
- use of BOP to stop the operation and mitigate accidental spills in exceedance of thresholds.

Studies from other EU legislative analyses also suggest that the use of degassers during drilling and flow tests can be imposed by regulatory authorities. However, based on the regulatory analysis undertaken as part of the GeoENVI project [17], fugitive emissions to air in the case of Italy and in particular the Tuscany region are specifically regulated in the case of the geothermal plant operation, with thresholds applied to certain gases, operating hours and abatement measures to be implemented. The construction and drilling phase requirements outlined above, are regulated on the basis of applying appropriate monitoring within the drilling compound in line with the operational health and safety measures outlined in section 7.1.3 above.

7.1.4.3 Liquid waste

Additional regulatory requirements are applicable in the case liquid waste produced during the course of geothermal project development from the construction and operational phases. No discharge in Italy is permissible to surface or underground water. The operator is required to demonstrate and apply as part of the construction management plan that is submitted to the regional authority how liquid waste will be reduced and in the case of drilling operations how this will be recycled. This is in particularly true with respect to any fluid or drilling mud as well as formation waters produced during the operations. An environmental management plan is required to demonstrate how any disposal requirements for liquid or solid waste will be undertaken through authorised treatment facilities only. The regulations also outline the operator reporting requirements of any dangerous waste substances to the relevant regional authorities.

This aspect of the regulation is relevant in the context of the DeepU technology as consideration will need to be given to the type of waste generated by the new laser and cryogenic gas technology. It would therefore be critical to demonstrate to the regulator that the production of dry waste and limited gas from the drilling process could generate a reduced environmental impact.

In the case of the operational phase of a geothermal plant, a regulatory requirement is applicable for the reinjection of liquid phase geothermal fluid to the original geological formations. Reinjection must be authorized by Regional Authorities. In the case of the DeepU completed boreholes, it is unclear at this point if the introduction of fluid to a sealed deep U-tube (with vitrified walls) would be similarly considered by the regulator in the context of current regulatory conditions.

7.1.4.4 Seismic Monitoring

Requirements associated with the development of geothermal projects are governed by the *'Guidelines For Monitoring Seismicity, Ground Deformation And Pore Pressure In Subsurface Industrial Activities*'. These include requirements for the implementation of monitoring systems to record any potential seismicity, ground deformation or pore pressure change as associated with any subsurface project including geothermal operations. Aside from long-term seismicity monitoring, these requirements include:

- bottom well measurements
- pore pressures in the reservoir, estimated from modelling & well measurements.

7.2 Ireland

This section provides an overview of drilling operations licensing and permitting processes implemented for deep drilling in the Republic of Ireland. The context of the review is framed based on the implementation of new licensing regulation for geothermal energy projects in Ireland. Ireland has not historically had a framework for drilling and completion of hydrocarbon boreholes onshore. The section, therefore, provides an overview of the proposed new process for upcoming dedicated geothermal legislation and regulation, which is underpinned by the same regulatory processes applicable for offshore deep drilling projects.

7.2.1 Licensing & Activity Permits

7.2.1.1 Licensing

To date Ireland has no geothermal specific legislation however progress has been made toward this by the publication in November 2022 of draft policy statement on “Geothermal Energy for a Circular Economy”. This document sets out the principles by which Ireland intends to legislate for geothermal as a resource and how it will be regulated. This policy statement has been informed by comparison to geothermal legislation in other European jurisdictions as well as Irelands existing legislation for the Petroleum and Mining sectors. In this regard it offers insights into how geothermal activities may be legislated in many locations. Even with the presence of strong and clear recommendations at an EU level from projects such as GEOENVI and bodies such as EGEC, it must be recognised that legislation and regulation will always have a component that is legacy to a specific countries' experiences with resource and groundwater management.

The Government authority responsible for geothermal in Ireland is the Department of Environment, Climate and Communications (DECC). Within DECC the Geoscience Policy Division (GSPD) is responsible for governing legislation and promotion of geothermal and the Geoscience Regulatory Division (GSRO) is the regulatory authority. Under the proposed legislation GSRO will be responsible for issuing and managing Geothermal Energy Exploration Licences (GEEL) and Geothermal Energy Capture Leases (GECL). This is similar to processes outlined in the licence section above. Figure 6 shows the architecture of the consents and permits process within licence or a lease.

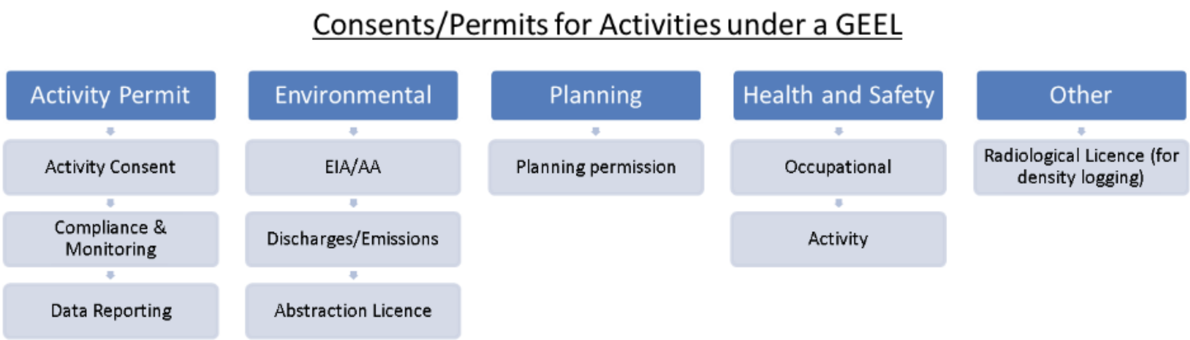

Fig 10. Overview of consents and permits required under proposed legislation for deep geothermal in Ireland [1]

The details of which agencies will be responsible for these consents and permits are not included in the draft policy. However, by reference to how the equivalent processes are managed for Petroleum activities, the following may be a reasonable estimation of how deep drilling consent would work for geothermal.

7.2.1.2 Activity Permitting

For petroleum activities GSRO are responsible for issuing activity permits. They will issue consent to drill (Activity Consent) once all other necessary permits, consultations, notifications, and environmental approvals are in place. Once drilling commences, they will manage compliance and monitoring through receiving daily reports and conducting site visits to ensure compliance with permits for the use and discharge of added chemicals. They also are likely to manage data reporting which is covered in the resource management section.

7.2.2 Health & Safety

The consent architecture for geothermal in figure 10 clearly shows the separation of Occupational Health and Safety and Activity Safety. In accordance with the Safety, Health and Welfare at Work Act, 2005 the agency responsible for Occupational Health and Safety in Ireland is the Health and Safety Authority (HSA). Standards for a safe working environment, transport of dangerous goods, personal protective equipment, hazardous material handling etc will be set and enforced by this agency. The use of Class 4 laser is governed by the "Guidance for Employers on the Control of Artificial Optical Radiation at Work Regulations 2010".

For the activity safety permit relating to deep geothermal drilling the appropriate authority is not indicated. For deep drilling related to Petroleum exploration and extraction the relevant authority is the Commission for Regulation of Utilities (CRU). The CRU has a comprehensive process for assessing and approving the safety of drilling operations governed by the Petroleum Safety Framework (PSF). While a considerable part of this framework is in place to manage the risk of an oil well blowout and resulting oil spill at sea, many of the parts of the framework could be applied to deep geothermal drilling. In particular the concept of a drilling permit being issued based on the approval of a safety case may transfer for complex, deep geothermal wells. The PSF requires a safety case for both the equipment and procedures of the drilling rig (non-production safety case, NPSC) and for the well engineering including safety management and emergency response procedures (well work safety case, WWSC). In the case where a facility is being put in place for production or energy storage a Production Safety Case is required. The requirements for the Safety Case are laid out in the Safety Case Guidelines shown in Figure 11 below.

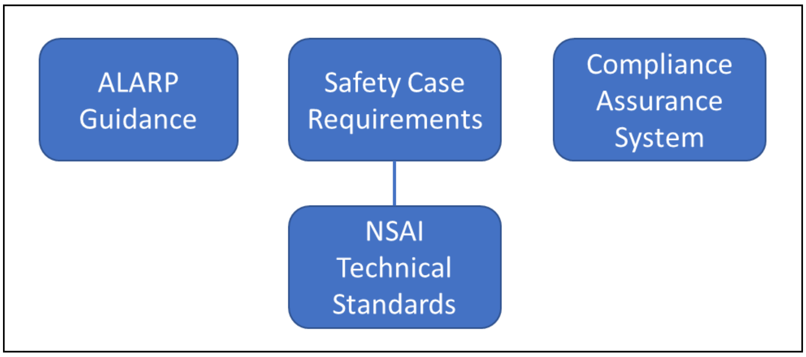

Fig. 11. Safety Case Guidelines issued by the Commission for Regulation of Utilities (CRU) in Ireland [2]

A brief overview of expectations on the operator for each of the guidelines is given below

7.2.2.1 ALARP

The concept of ALARP is illustrated in Figure 12. Below. The fundamental process of applying it is to begin with a hazard identification (HAZID) process, classify those hazards to determine if any are considered major accident (or environmental) hazards, identify risk reduction measures and ensure good practice is applied in managing these.

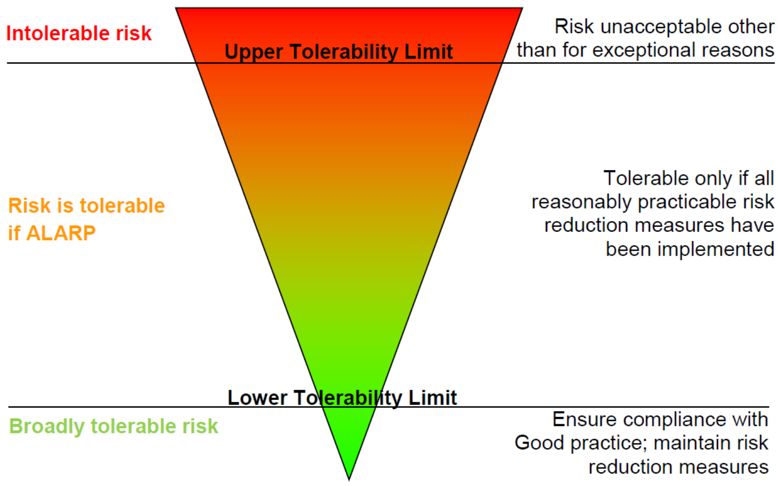

Figure 12. Diagram of the ALARP principle [3]

Good practise in this context is defined as "The recognised risk management practices and measures that are used by competent organisations to manage well-understood hazards arising from their activities." These could include standards, regulatory guidelines, professional guidelines or lesson learned from other operations or areas. Applying the hierarchy of process safety controls outline in Section 4 for example would be applying good practice. In the context of integrating DEEPU technologies into drilling operations the sets the importance of conducting a robust Failure Mode and Effects Analysis (FMEA) to determine if these technologies pose a Major Accident Hazard (MAH) risk beyond what is typical for deep drilling (or indeed remove MAH risk from the drilling process). An MAH is defined in Figure 13 below.

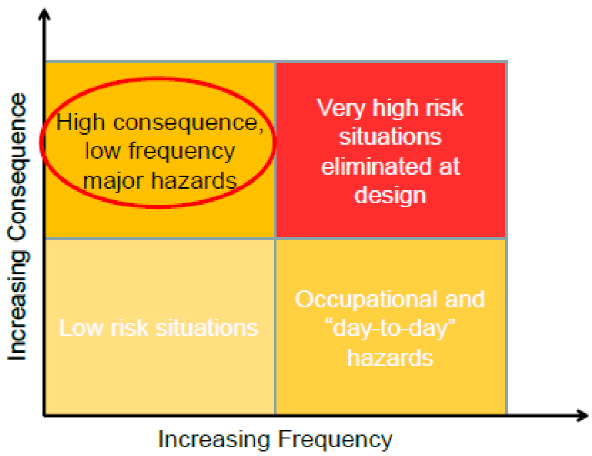

Figure 13. Identification of Major Accident (or Environmental) Hazards is central to Safety Case preparation in Irish regulations. [4]

In addition to identifying technology specific MAH's it will important to define what good practice is for industrial laser and cryogenic fluid use as these practices will sit outside drilling specific guidelines in most jurisdictions.

7.2.2.2 Safety Case Requirements

Well Work Safety Case Requirements require a document to be produced that will include the following elements

- A description of the project and all of the parties involved it including highlighting the designated licence holder.
- An assessment of the Rig Suitability for the Well Operations
- Details on additional equipment and non-well operations related to drilling

In the context of DeepU technologies it will be important to highlight rig suitability with respect to handling the laser and gas flushing elements including laser security. For non-well operations the area of focus is likely to be on trucking and handling of cryogenic fluid at site.

- Description of Well Operations including the well work activity, a description of the reservoir and well plan as well as details of plans to suspend or abandon the well

For DeepU technologies this require creating detailed description of how the system will work. With respect to suspension and abandonment there will be considerable work to do to describe how a vitrified wellbore will be abandoned and verified to be so.

- ALARP Demonstration (discussed above)
- Safety (and Environmental) Critical Elements, Performance Standards, Assurance and Verification
- Safety (and Environmental) Management System

With respect to the last two bullet points significant effort will be required to define and document the appropriate procedures, standards and safety management systems for DeepU technologies. In the technology maturation process it will be important to assign appropriate time and resources to this as it will be critical to assuring regulators of the safety of the operation.

7.2.2.3 Compliance & Assurance System

Verification of design, processes and safety management systems by the regulator and by an independent competent body (ICB) is central to the Irish Drilling Safety permitting process. For DeepU technologies this raises the issue of what constitutes a competent body when it comes to verifying a wholly new set of drilling techniques. In addition to early engagement with regulators to ensure they are appropriately educated on the process it is recommended that a well verification expert be engaged once safety processes are being written so that it is clear what verification steps will be required.

7.2.2.4 NSAI Technical Standards

Within the context of Safety Case these standards are Petroleum specific. How many of these are adopted for deep geothermal drilling is uncertain. However it will be important to discuss with regulators if standards specific to lasers and cryogenic fluid will be brought into the safety case standards.

7.2.2.5 Environmental Protection

Figure 14 shows the Environmental permitting and consent process is envisaged to have 3 parts. The EIA/AA procedures well established based the relevant EU directive and Case Law in Ireland. The process map for EIA/AA applications for deep Petroleum drilling is shown in Figure 10 below. The GSRO acts as the interface to operator and the public consultation and the competent authority who issues the decisions is the Environmental Assessment Unit (EAU) of the Department of Environment, Climate and Communications (DECC). In certain circumstances the planning authority could be responsible for administering the EIA/AA process in addition to issuing required planning permission for activities at the drilling site. Depending on the scale of the project this could be either the Local Authority such as city or county council (municipality) or the central planning authority An Bord Plenala.

The Environmental Protection Agency (EPA) is likely to relevant authority that issues permits for discharges and emissions as well as issuing groundwater abstraction licences. The Radiological Protection Institute which is under the umbrella of the EPA is responsible for issuing consents to use radioactive sources. Radon gas production may need to be managed in deep geothermal projects in Ireland and this institute will have a role in that along with the Geological Survey of Ireland.

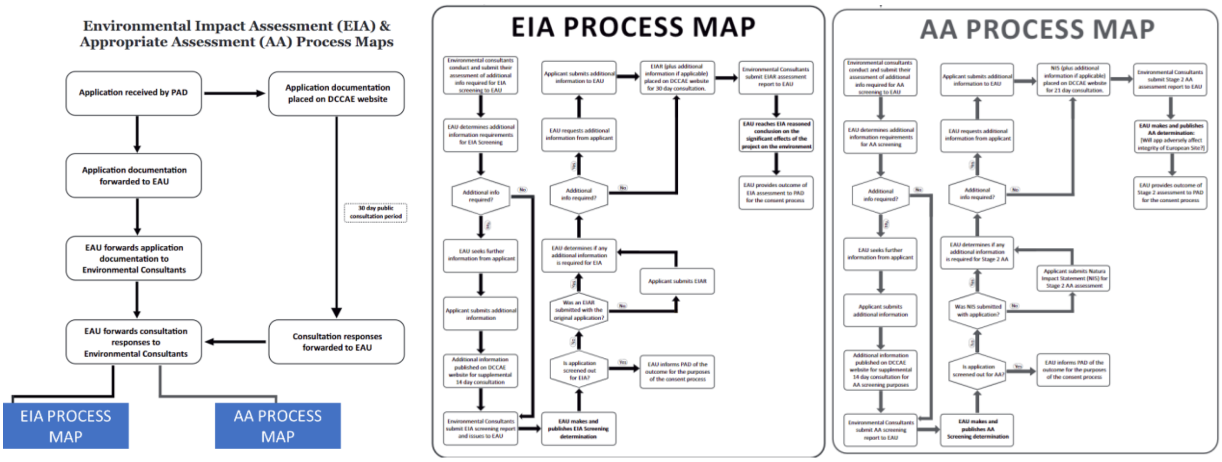

Fig 14. Process maps for EIA and AA screening for application submitted to GSRO (formerly PAD) and assessed by the competent authority, the Environmental Assessment Unit (EAU) of the Department of Environment, Climate and Communications (DECC). [5]

7.2.2.6 Resource Management

Resource management is not explicitly noted in the permit/consent architecture but GSRO, as the licensing authority and body responsible for data reporting, would be responsible for this. The GSRO fulfill this role for Petroleum and Mining activities so it is reasonable to assume requirements for data gathering and data reporting may be similar to those for deep petroleum drilling operations. These are set out in the two sections below and detailed in Appendix A

Data Gathering

The rules and procedures document for deep drilling in Ireland sets out requirements for well logging, coring, pressure & fluid testing and formation samples. Derogation from these requirements can be applied for in certain cases. The detailed requirements are set out in Appendix A.

Data Reporting

For deep Petroleum drilling operations GSRO require extensive reporting during and after drilling operations. It is highly likely that these requirements will be applied to any deep onshore drilling operations in Ireland. The details of data required are included in Appendix A.

7.3 Summary - Ireland

The detailed review of potentially relevant legislation and regulations with respect to deep drilling and geothermal in Ireland was undertaken using the frameworks set out in Section 4. It was found that the general common areas of legislation and regulation outlined in Section 5 are largely present in Ireland. Most of the components of proposed geothermal licencing and consent system are straightforward and rely on existing legislation, guidelines, and authorities. The DeepU technologies should be treated no different to other deep geothermal projects in Ireland with respect to licencing, environmental protection, planning permission, and occupational health and safety. Data gathering and deep drilling safety permitting requirements for geothermal in Ireland are as yet unknown. However, if deep drilling regulation from the Petroleum sector are used as a template for these there are potential exceptions that will have to managed. The biggest uncertainty is which agency will be responsible for drilling safety permits (well engineering and rig requirements) and how much of PSF safety case process will be applied to geothermal. Verification of the safety of the novel technologies employed will be a critical regulatory hurdle to overcome and strategies will need to be developed to ensure this can be done to the satisfaction of a regulator.

With Ireland being in the process of developing deep geothermal specific legislation and regulations it represents an interesting jurisdiction to pilot the DeepU technology in. If regulator engagement were to happen early there could be potential to identify how DeepU technologies and the broader class of uncased deep borehole exchange geothermal wells could have specific wording attached to them in regulations.

At present there is no specific legislation on large scale underground energy storage in Ireland. With an increased interest in Hydrogen storage being applied to offshore wind generation and an increasing focus on district heating systems that may require thermal storage this may change.

8 CONCLUSIONS & RECOMMENDATIONS

An extensive review of Health, Safety and Environmental legislation related to deep drilling was undertaken to understand the current regulatory context in which DeepU novel technologies would be assessed. The findings have been detailed in the above sections and based on these the following recommendations are being made for the project.

Health & Safety

- A ROBUST Hazard Identification process (beginning with the FMEA (T4.2) is required and needs to include envisaging the worst outcomes from new technologies to determine if there are technology specific Major Accident Hazards
- Demonstration of wellbore integrity is critical for vitrified wellbore design.
- There will be a need to investigate potential wellbore stability issues, wellbore breakouts for example could cause eccentricity in the wellbore. This could impact the ability to centre the laser in the drill string. Geomechanical modelling to determine if thermal shock can induce failure or slip is also important.
- Definition of Laser technology operational health and safety as well as training requirements for operators will need to be developed as part of the DeepU technology project recommendations to demonstrate regulatory compliance where such lasers are planned for usage on a drilling platform. Consideration may be required to the control environments associated with the laser and the drill string during drilling operations.

- Extensive work will be required to adapt laser and fluid handling procedures to a drill site and appropriate time and resources will need to be allocated to this.
- Extensive work will be required to integrate new technologies into safety management systems for drilling and drilling equipment operation. Appropriate time and resources will need to be allocated to this.
- In accordance with process safety management principles, it is prudent to eliminate risks through design. For example, if there is risk from an eccentered laser damaging the drill string can the laser be moved to be part of a bottom hole assembly.
- Verification of the safety of the novel technologies employed by independent experts as well as regulators will be critical. Bringing an independent verification expert (well examiner) into later stages of the design process will be important.
- Pilot site selection will be critical to managing risk. It is imperative that due consideration and time is given to this process. It is recommended to build site selection criteria related to EHS factors and run peer reviewed process to choose the location.
- Early regulator engagement will be key.

Environmental

- An EIA/NIS may be required for deep drilling operations regardless of resource type and this will need to be factored into project schedules.

Resource Management

- As Ireland is in process of working out geothermal specific regulations it is an interesting location to pilot if suitable a site can be found. It may present an opportunity to have technology specific requirements written into legislative guidelines.

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Appendix A – Example of Data Reporting Requirements in Ireland

1 Data Gathering Requirements

Well Logging Requirements

- Unless otherwise agreed with DECC, all open-hole of 17½-inch diameter or less will be fully and comprehensively logged.
- For hole not logged, gamma ray shall be run through casing as a single run from the open hole section beneath the casing to the seabed.
- Each logging sonde run in open hole should carry three calibrated and marked maximum reading thermometers.
- As soon as digital LWD/MWD data have been downloaded, copies shall be sent to DECC by email, or via secure Internet website
- Immediately upon completion of a logging run, wireline log data shall be sent to DECC by email or via a secure Internet website (as agreed in advance with DECC).
- A VSP or well velocity survey will be run in all wells at TD, unless otherwise agreed with DECC.

Coring Requirements

Unless otherwise agreed with DECC, a core will be cut:

- where a drilling break of 3 metres with significant shows has been encountered, either at the top of any objective or at any other level in a well. Coring will continue from 3 metres into the drilling break until out of reservoir with shows.
- At the TD of the well
- Unless otherwise agreed with DECC, sidewall cores will be taken in all open-hole of 17½ inch diameter or less, for the purposes of lithological and/or palaeontological and/or geochemical analyses. Proposed sidewall coring programmes shall be submitted to DECC for approval.

Pressure & Fluid Testing

Unless otherwise agreed with DECC, wireline pressure/fluid sampling tools (e.g. RFT/MDT) will be run over all potential reservoir bearing intervals. Proposed pressure and sampling programmes shall be submitted to DECC for approval.

Formation Samples

All samples are archived with DECC, in order to facilitate future commercial / research inspection and analyses and are released only when the period of confidentiality has expired.

Unless otherwise agreed with DECC, the minimum sample requirements are as follows:

- Cuttings are to be collected at least every 10m from first returns to a level of 100m above the first prognosed objective and at least every 3m from 100m above the first prognosed objective to TD.

DECC is to be supplied with cuttings as follows: -

- Unwashed: 1kg in DECC approved plastic containers;
- Washed and dried: 100g in DECC approved plastic or paper containers.

All samples are to be clearly and permanently marked with well name and sample depth.

- A continuous longitudinal slice of all cores, comprising not less than one quarter of the core, is to be supplied in approved rigid containers, each one metre long (as specified in Appendix 3.4). All core pieces should be clearly marked to show right way up. Upon completion of use by the Operator, the remainder of the core shall be made available to DECC.
- Where practicable, at least one half of each sidewall core, to be supplied in approved glass containers.
- Representative samples of all clean, stabilised formation fluids recovered on any well test should be supplied in DECC-approved corrosion-resistant and non-reactive containers.
- All analytical preparations (slides, concentrates etc.) used for the purpose of palaeontological, geochemical, petrographical or other analyses should be lodged with DECC upon completion of use by the Operator.
- Samples and preparations should be clearly and permanently marked with well name and sample depth. The nature of the sample, test number, how and where the sample was acquired etc. should be indicated, as appropriate.

2 Data Reporting Requirements

Daily Drilling Report including:

- Date and reference time of the report.
- Well identification and name of Operator.
- Total number of days since spudding or commencement of work.
- Well depth (Measured and TVD in the case of a directional well) Depth drilled in last 24 hours.
- Short chronological description of activities during the preceding 24 hours, in particular a note of functional tests carried out on well control equipment (including BOPs).
- Operation at the reference time of the report and description of activities proposed for the next 24 hours.
- Inclination or deviation surveys; survey depth, inclination, azimuth and horizontal departure, and TVD.
- Mud properties.
- Notification of any significant accident.

Daily Geological Report including:

- Full lithological and stratigraphical description of cuttings and cores.
- Geological formation tops and any palaeontological results obtained.
- Details of logs run.
- Coring details.

Other reporting required when applicable:

- Report on running and cementing of casing.
- Details of leak-off tests performed.
- Perforating details.
- Formation testing. Step by step description of procedures and results, with time of occurrence, including field pressure readings from well tests.
- Stimulation operations.
- Abandonment procedures.
- Loss and recovery of circulation.
- Abnormal pressures encountered.

- Clean out and fishing details.

Daily Striplog

Each day while drilling is taking place, a copy of the Striplog/Mudlog relating to the previous 24-hour reporting period shall submitted including the following:

- Rate of penetration curve
- Lithological log
- Lithological descriptions
- Bit record
- Hot wire and chromatograph readings
- LWD data
- Directional data
- Well test intervals
- Cored intervals
- Perforations
- Casing and cementing details

Site Visits

To enable an Authorised Officer from the Department to be present if so decided, DECC shall be given a minimum of 24 hours notice where practicable (in the Daily Drilling and Geological Report or otherwise) in advance of the operations listed below:

- Spud in or commencement of work
- Coring
- Logging
- Perforating and Well Testing

Final Well Report set out in the following format:

Introduction

- Brief history of the authorisation (number, etc.).
- Well identification. Well number and well location (grid location and latitude and longitude co-ordinates (ETRS89); UTM); seismic line location. A location map at a suitable scale should be included.
- Depths, dates, status. TD driller; TD logger; elevation of rig datum (e.g. RT/KB/Drill Floor); Spud date; date TD reached; rig release date, well status.

Well Objectives and Results

- Prospect to be drilled, pre-drilling objectives, predicted depths.
- Summary of geology encountered, tops and thicknesses of formations and stages; departure from prognosis. Sidewall cores and cores taken. Logs run. Test results.

Well Results

- Lithology and stratigraphy in detail including detailed well site sample descriptions, sidewall core descriptions and core descriptions. Criteria for picking tops of lithological units and formations should be discussed.
- Evaluation of structural results, geological and geophysical. Where detected, gaps in section (fault/unconformity) should be noted and a comparison of formation tops and structural dips with pre-drilling seismic interpretation should be made.

- Evaluation of potential reservoirs including results of detailed log analyses, noting all petrophysical constants used.
- Complete descriptions and copies of the results of all laboratory analyses shall be submitted with the Final Well Report.
- The Well Results section should be accompanied by copies of log analyses (CPI's) and results from all associated well reports, in-house or from service companies or consultants, in particular those relating to lithological, petrophysical, palaeontological and geochemical studies and analysis of formation fluids, testing, etc; also a Composite Log (to include lithological summary and brief descriptions; sonic/gamma-ray/resistivity logs; and details of casings, cores, sidewall cores, shows, porosity, dips; stratigraphical and palaeo environmental determinations); also a Striplog with penetration rates, lithology, shows etc. The temperature data should also be included.

Drilling History

- General:- Drilling contractor; dates; depths; location of well and status. Details of site investigations, reports on bottom conditions etc., and drilling unit positioning surveys.
- Operational - Details of drilling unit, workboats, and helicopters. Daily well history, both engineering and geological. Bit record; drilling unit time analysis including penetration curve. Drilling fluids, casing and cementing details. Drilling problems.
- Logging – (Attention should be drawn to any discrepancy between driller's and logger's depths):
  - Log Type: Electrical, Acoustic, Nuclear etc.: date, intervals, depths, scales, logging problems (tool failures or hole conditions).
  - Deviation: complete record and plot of inclination and/or directional surveys (depths as TVD as well as measured and TVD depth to be given in the case of deviated wells).
  - Temperature: recorded bottom hole temperatures and corrected formation temperatures with details of how corrections were made.
  - Velocity: seismic calibration log, time/depth listing, synthetic seismogram displays. VSP report where appropriate.
- Testing - description of all tests attempted, including details of perforations and results (pressures, flow rates, nature of fluids etc.). 31
- Stimulation - details of fracturing, acidizing or other well stimulation operations.
- Completion or Plugging - description, with diagram. In particular, details of tubing, strings, packers, subsurface chokes, nipples and safety valves. Specifications and diagrams of wellhead and all subsurface installations.

It is unclear are present whether these specific requirements will be applied to deep geothermal drilling projects but given similar requirements are in place in other jurisdictions it would be prudent to plan for a similar set of requirements.

Operator's Conclusions

The Operator's conclusions should include modifications to the original understanding of the prospect and analysis of future possibilities. The conclusions should be comprehensive and incorporate the data and conclusions from contractor studies. If all relevant data is not available at time of preparation of the Final Well Report then a Post-Mortem Report should be submitted as soon as possible thereafter with all new data appended. This should include any seismic re-interpretation carried out after drilling.

It is unclear are present whether these specific requirements will be applied to deep geothermal drilling projects but given similar requirements are in place in other jurisdictions it would be prudent to plan for a similar set of requirements.