Preesall Underground Gas Storage Facility, Lancashire

Review of the Proposed Drilling and Completion Programmes

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Document Approval & Distribution

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Report Distribution

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Summary

1. Halite Energy Group Limited (Halite) requested Baker Hughes to provide well design review for its proposed application to the Infrastructure Planning Commission (IPC) for a Development Consent Order (DCO) for an Underground Gas Storage Facility (UGS) at Preesall, Lancashire (the Project). The purpose of this report is to confirm the feasibility of the drilling aspects of the Project.

2. This report reviews seven critical elements of the Drilling and Completion Programmes, and contains the results of reviewing the existing design documents provided by Halite.
   1. Well Bore Placement and Surveying
   2. Directional Drilling and Coring
   3. Drilling Fluids
   4. Casing, Design & Installation
   5. Cementing and Pressure Testing
   6. Formation Evaluation
   7. Completion, Design & Installation

The scope of review commences from the point after the top hole casing has been cemented in the Mercia Mudstone, and assumes that the formations below are competent, treated or isolated in order to support the directional drilling work required and that the formations will remain stable to allow casing installation. Such assumptions can be verified by further investigations, perhaps including shallow boreholes.

The review identified four different well types required to complete the drilling programme:
   1. Vertical wells
   2. S-shaped wells
   3. Slant wells
   4. Extended reach slant wells

3. The objective of this review is to provide a technical assessment of the conceptual Drilling and Completion Programmes for a 600m horizontal step out well using industry standards and guidelines. As all the wells in this first phase of the Preesall development are similar in design but have less than 600m step out, the resultant findings can be considered for all well types required to complete this first phase of cavern construction.

4. A full examination and risk assessment of the design for the conceptual ‘600m Step Out’ well was completed and concluded that no significant risks remained after mitigation measures were put in place. Some key points are identified below:
   • While it is uncommon to start large bore wells at such high angles and then return to vertical, all of the key individual steps have been successfully performed elsewhere.
• Large diameter, near horizontal sections have been successfully drilled at angles of over 80° using rotary steerable technology. If it proves difficult to maintain the inclinations throughout a tangent section, a smaller pilot hole can be drilled, then enlarged.

• Casing has successfully been installed in large, high angle wells in many countries, demonstrating that 13 3/8” casing can be run in formations with low compressive strengths.

• The limited vertical depth in which to shape the well paths results in relatively high curvature for the 17 ½” sections of the wells, but these have been achieved. It is recommended that 12 ¼” pilot holes be drilled to achieve the doglegs required.

• Well Bore quality will be key. It is critical to minimise all forms of erosion and instability to accurately position the wells, install and cement casing. It is recommended that rotary steerable systems are used to drill all hole sections.

• It is recommended that the drilling sequence is tailored to allow valuable experience to be gathered, and that the less demanding wells be drilled first.

In summary, it is concluded that the existing conceptual programmes are suitable to successfully drill and complete all well types required for the cavern construction process using existing tools and techniques. Where necessary, recommendations have been made to reduce risk and to improve overall performance.
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Introduction

In July 2010, Baker Hughes Limited was contracted by Halite Energy Group Limited (Halite) to undertake a review of seven elements of the Well Bore construction phase of the proposed Preesall Underground Gas Storage (UGS) at Preesall, Lancashire (the Project). The review was to ascertain the technical feasibility of the following elements of the proposed Drilling and Completion Programmes:

1. Well Bore Placement and Surveying
2. Directional Drilling & Coring
3. Drilling Fluids
4. Casing Design and Installation
5. Cementing and Pressure Testing
6. Formation Evaluation
7. Completion Design and Installation

To undertake the review Baker Hughes utilised the expertise of its specialist divisions, managed by staff from its Integrated Operations Group.

1.1. Baker Hughes Limited

1.1.1 Baker Hughes is a Fortune 500 company headquartered in Houston Texas, serving the worldwide petroleum and continuous process industries. The company provides products and services for the drilling, evaluation, completion and production of oil and gas wells and is an industry leader in providing integrated services. Annual revenues are over $9 billion and about 50,000 people are employed in over 70 countries. In the UK, Baker Hughes Limited has played a leading role in assisting operators in the development of the North Sea oil and gas fields as well as many onshore projects.

1.1.2 Recently acquired by Baker Hughes, BJ Services specializes in pressure pumping, tubular running, cementing and coil tubing operations. BJ's state-of-the-art research facilities can assist in quantifying and developing the fluids required to provide life-long Well Bore security.

1.1.3 Gaffney Cline & Associates is Baker Hughes’ fully integrated subsurface and wells consultancy, operating worldwide on projects ranging from full field management services to single discipline studies. Underground gas storage capabilities range from screening of sites for potential gas storage systems, subsurface development design – concept to FEED, execution support – well design, programming & operations, reservoir & well monitoring – well operator support and gas storage into saline aquifer and depleted gas fields.

1.1.4 Baker Hughes Integrated Operations (BHIO) complements the services provided by the specialist divisions by providing project management for projects requiring an integrated approach. Project managers and coordinators manage the operations and client interface, whilst the local geomarket and product lines
retain responsibility for delivery of the services. Subcontractors are engaged as required to complete the range of specialist disciplines required for particular projects.

1.2. Project Background

1.2.1 Halite is developing a Natural Gas Storage Facility at Preesall, Lancashire consisting of three multiple, two double and two single wellhead locations to create 19 underground salt caverns by solution mining. It is proposed that the gas will be stored in caverns leached in the Preesall halite formation some 300-500m below sea level. As the formation lies under the Wyre Estuary some well trajectories are highly deviated, in most cases requiring the use of slanted boreholes from surface. Consent for the development has been declined by Lancashire County Council (LCC). Halite has subsequently sought technical support from Baker Hughes as part of a new application to the Infrastructure Planning Commission (IPC).

1.2.2 This report is a review of the subsurface design and is part of an overall project review process. The intention of this report is to provide technical support relating to the drilling and completion programmes.

1.3. The Scope of the Review

1.3.1 The scope of work is based on a review and audit of the current data, interpretations and results already developed by Halite (and its predecessor in promoting this scheme, Canatxx Gas Storage Limited (UGS)) and their consultants.

1.3.2 The objective of this review is to provide a technical assessment of the conceptual Drilling and Completion Programmes for a 600m step out well using industry standards and guidelines. As all of the wells in this phase of the Preesall development are similar in design but have less horizontal displacement than the 600m step out well, the resultant findings can be considered for all well types required to complete this phase.

1.3.3 The top-hole casing will be installed using different techniques, such as micro-tunnelling, hence the scope of the review commences after the top hole casing has been cemented in the Mercia Mudstone. It assumes that the formations below the top hole casing are competent to support the directional drilling work required and that the formations will remain stable or can be treated to allow the casing to be installed, and this can be confirmed by further site investigation. The report will however comment on the positional requirements, trajectories and other issues relating to the top hole that potentially impact on the well construction below the top hole casing shoes. The review also considers the surface layout and cellar positioning that may affect the elements under consideration.
Figure 1-1: Conceptual 600m Step Out Well
2.0 Review of the Proposed Drilling and Completion Programmes

A small core team of senior staff was assembled and led by an experienced Project Manager to conduct the review. For each element under consideration, a technical specialist reviewed the operations required to drill and complete the well and the measures to be taken to address potential risk. Where necessary the specialist has been able to call for support from the worldwide resources of Baker Hughes. The team of specialists then reviewed the overall drilling and completion operation. Each specialist is listed below for each element of the review:

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<th>Element</th>
<th>Specialist</th>
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<tbody>
<tr>
<td>Project Manager</td>
<td>Ian Lowrie</td>
</tr>
<tr>
<td>Well Bore Placement and Surveying</td>
<td>Matthew Sas</td>
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<td>Directional Drilling</td>
<td>Ronnie Pashley</td>
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<td>Adedokun Adenipekun</td>
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<td>Formation Evaluation (Logging &amp; Coring)</td>
<td>Geoff Page &amp; George Williamson</td>
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<td>Mike Haigh</td>
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<tr>
<td>Risk Assessment Co-ordinator</td>
<td>Sarah Grant</td>
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2.1. Documents Reviewed

For the purposes of this report we have reviewed the following documents:

- Halite Draft Drilling Programme, 2009
- Halite Draft Completion Programme, 2009
- Halite offset data for Armhill Well Bore, 2004
- Halite offset data for Burrows Marsh (No 1 Middle Deviated) Well Bore, 2008
- Halite offset data for Hay Nook Well Bore, 2009
- Halite Cavern and Surface Locations Drawings # K02060X00-15
- BHI Directional Drilling, Coring and Fluids data for Burrows Marsh Well Bore, 2008-2009
- Secretary of State’s Technical Assessor Report from Canabxx Gas Storage Public Inquiry, 2007
- Atkins Report Review of Geology and Geo-mechanics, 2009
- Mott MacDonald Geological Summary Report, November 2011
2.2. Development Well Types

2.2.1 To consider all of the wells required to complete the drilling phase, it was necessary to plan each well using the latest cavern and surface locations taken from Halite’s ‘Cavern Layout & Cavern Sizing’ drawings. All of the wells were designed using the same or a reduced rate of curvature (dogleg 5.57°/30m) as that used to plan the ‘600m step out well’. Once the exercise was complete, four categories of development wells were identified to complete the first phase of the Project:

MM amended Baker Hughes Drilling Report Figure 2.1

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Notes: 1 Cavern and Wellhead Locations and Identifiers taken from Halite Drawing: D-9000-031 Rev B
2 Well Types determined as detailed below:
3 Cavern Positions and Salt Formation Details taken from Geological Summary Report (Application Doc 9.2.2)

Table listed above has revised Well path data for all updated step out and Cavern top depths.

Figure 2-1: Four Well Categories

2.2.2 Vertical Wells, require 24” hole to be drilled from surface with 18 5/8” casing set in the Mercia Mudstone. A 17 ½” section to be drilled vertically and 13 3/8” casing set in the Preeasall Salts, 10m above the proposed cavern tops. 12 ¼” hole can then be drilled vertically to allow leaching operations. This well type can be drilled conventionally with a standard rig or any purpose designed rig in the vertical mode.
2.2.3 **S-Shaped Wells**, can achieve up to 100m horizontal displacement from surface. These wells require 24" hole to be drilled vertically from surface with 18 5/8" casing set in the Mercia Mudstone. A 17 ½" section to be directionally drilled and 13 3/8" casing set vertically in the Preesall Salts, 10m above the proposed cavern tops. 12 ¼" hole can then be drilled vertically to allow leaching operations. This well type can also be drilled conventionally with a standard or any purpose designed rig.

2.2.4 **Slant Wells**, can achieve between 100m and 250m horizontal displacement from surface. These wells require 24" hole to be drilled or conductor driven at an angle between 40° and 50° from surface to set 18 5/8" casing in the Mercia Mudstone. A 17 ½" section to be directionally drilled and 13 3/8" casing set vertically in the Preesall Salts, 10m above the proposed cavern tops. 12 ¼" hole can then be drilled vertically to allow leaching operations. In some instances the upper hole sizes may be increased to allow for an additional casing to be set prior to performing the drop to vertical. This well type will require a conventional or purpose built slant rig to operate at between 40° and 50°. Due to the near surface alluvial and glacial deposits it is anticipated that the top hole may have to be driven or casing drilled rather than conventionally drilled.

2.2.5 **Extended Reach Slant Wells**, can achieve between 250m and 650m horizontal displacement from surface. These wells require surface hole to be micro tunnelled at an angle between 65° and 80° from surface to position 28" or 18 5/8" casing in the Mercia Mudstone. Although not required in this first phase of drilling, an additional 24" tangent section may be required in longer reach wells to set a 18 5/8" casing prior to drilling the drop to vertical. A 17 ½" section can then be directionally drilled and 13 3/8" casing set vertically in the Preesall Salts, 10m above the proposed cavern tops. 12 ¼" hole can then be drilled vertically to allow leaching operations. Due to the near surface geological conditions, steerable micro-tunnelling operations will be used to position the top hole. A purpose designed slant rig to operate at between 67° and 80° will be required to drill the remaining sections.

2.2.6 The achievable horizontal displacement of all directional wells will to a large extent depend on the available vertical depth to the cavern to.
2.3. Methodology

To assess the technical feasibility of the Project, a review and audit of the current data was undertaken and the resultant technical assessment was applied to all well types required for the project.

2.3.1. Phases of Well Bore Construction

The Well Bore construction was divided into seven separate phases to allow examination of performance and risk during planned operations involving multiple operations. While health, safety and environment issues, surface requirements and the top hole section are not strictly included in the scope of this review, they can all impact on the successful outcome of the programme and are therefore considered.

- Phase 1, Health and Safety Executive (HSE)
- Phase 2, Surface Requirements
- Phase 3, Top Hole
- Phase 4, 24” Hole Section (not required in first phase of development)
- Phase 5, 17 ½” Hole Section
- Phase 6, 12 ¼” Hole Section
- Phase 7, Completions

2.3.2. Technical Risk Assessment

A key feature of a project Risk Assessment/Safety case is the requirement to demonstrate that all hazards with the potential to cause a significant accident have been identified, that risks have been evaluated and measures taken to reduce risks to people or assets so to render them ‘As Low As Reasonably Practicable’ (ALARP).

Quantitative risk analysis is a key ‘Method’ applied in safety management and risk control throughout concept, design, construction and operations of all oil industry activity in order to achieve safe operations and hazard control.

Risk analysis is a tool for identifying potential accidental events, quantifying the likelihood of these events and the consequence if they occur. A risk analysis usually involves a process to identify the hazards for the installation or operation and quantifying the probability of occurrence of each event. To this end, risk assessment exercises are performed to evaluate HSE, technical and financial risk.

This risk assessment only concerns itself with the technical feasibility of the conceptual designs.

2.3.3. Risk Identification through Peer and Team Reviews

To begin this process, all documentation was reviewed by each team specialist who then undertook a detailed high level risk identification
exercise, observing the events which may be encountered within the event envelope. Regardless of measurement model, the calculation of risk will always be subjective – hence, to ensure a multi disciplined and diverse approach, an amalgamation of the individual reports was consolidated for the consideration of the review team and other members of the BHI organization. These were then considered and appended in a review exercise with their respective peer groups.

2.3.4. Risk Mitigation through Peer and Team Reviews

A Risk Mitigation exercise was then undertaken, based directly on the Risk Identification findings, broken down by the same 7 phases, not only to suit mitigation efforts and focus, but also to assign the basic risk formulae to each element in order to best predict the outcome of each event. The basic formula used is:

\[ Risk = (Probability \text{ of Event occurring}) \times (Impact \text{ of Event occurring}) \]

2.3.5. Risk Assessment of Drilling and Completion Programmes

Finally, the review team, assisted by other specialists, conducted a Technical Risk Assessment exercise to fully assess the Risk and Mitigation methods. Any risk that could not be mitigated to an acceptable level was identified and the responsible persons for any such risk would then address those issues in their respective reviews.

All identified risks and their methods of mitigation were then considered for all well types.
3.0 Conclusions and Recommendations Overview

3.0.1 The seven specific reports together with the risk assessment make up the overall well design review process. These reports contain the results of reviewing the existing design documents as provided by Halite.

3.0.2 The review of the seven elements considered indicates that all of the main objectives of the drilling and completion programmes can be successfully achieved by the implementation of the considered programmes.

3.0.3 While it is uncommon to start large bore wells at such high angles and then return the wells to vertical, all of the key individual steps have been successfully performed in many locations throughout the world.

3.0.4 Large diameter near horizontal sections while not common, have with careful planning and execution been successfully drilled at angles of over 80°. This has been made possible by the advances in rotary steerable technology throughout the last ten years. If it proves difficult to maintain the high inclinations throughout the length of a tangent section, a smaller pilot hole can be drilled and subsequently enlarged by hole opening drilling technology. The use of pilot holes is common practice throughout the oil industry to directionally control well paths.

3.0.5 Casing has successfully been installed and cemented in large diameter 80° angle wells in many countries including Norway and Angola (Figure 3-1 and Figure 3-2). Although the wells have differing geometry, they serve to illustrate that 13 3/8” casing can be successfully run in soft and unconsolidated formations with low compressive strengths.

![Figure 3-1: 80° Well path, Norway](image)
The limited amount of vertical depth in which to shape the well paths results in relatively high rates of curvature (doglegs) for the 17 ½” sections of the wells, while not common these doglegs have been achieved in many other North Sea wells (Figure 3-3).

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3.0.7 To achieve these doglegs it is often necessary to drill smaller diameter pilot holes and then enlarge them to their required sizes. It is
recommended that 12 ¼" pilot holes be drilled to achieve the 5.57°/30m doglegs required for most of the Preesall wells.

3.0.8 Well Bore quality will be the key to successfully drilling and casing these hole sections, it is critical to minimise all forms of hole erosion and Well Bore instability to accurately position the wells, install casing and ensure a good cement bond between the casing and formations.

3.0.9 To ensure good Well Bore quality it is recommended that rotary steerable drilling systems are used to directionally drill all hole sections. These systems have a proven track record of delivering quality hole in relatively soft formations with a low compressive strength (UCS).

3.0.10 It is recommended that the sequence of drilling the wells is tailored to allow valuable offset information to be gathered, and that the less demanding wells be drilled first to gain experience of local conditions.

A summary of the individual sections is provided below.

3.1. Well Bore Placement and Surveying

3.1.1 The review concluded that the indicative cavern layout plans provided by Halite can all be achieved from their respective surface locations using the same or less demanding doglegs as that used to plan the base case 600m step out well (5.57°/30m).

3.1.2 The final positioning of the individual caverns will be influenced by the following.

- **Surface cellar layout**, this should be designed to simplify the well designs with regard to well profiles, surveying and well twinning. Spare slots should be available in the event a Well Bore is lost.

- **Positioning of top hole casings**, most of the slant and extended reach slant wells will require very accurate placement of these casings. The methods to install these casings should be developed on wells that have less demanding profiles.

- **Ability to accurately drill the desired profiles**, constant monitoring of directional data will be required whilst drilling all sections of the wells, any deviation from the planned trajectories could significantly impact on the final downhole location.

- **Surveying accuracy**, all survey instruments have accuracy limits which result in survey uncertainties in three dimensions. These tolerances depend on the survey instrument and the corrections applied to the measurement. As the wells are relatively shallow, utilisation of the most accurate survey tools and surveying techniques will result in the true bottom hole locations having very small surveying uncertainties.

- **Well twinning**, the requirement to twin the wells will increase the area of uncertainty around the cavern’s true downhole locations. Magnet ranging techniques will be used to position the second well of the twinned pair.
3.1.3 All of the above may limit the depth or diameter of the proposed caverns. It is recommended that a detailed study is conducted to accurately determine the optimum cavern layout with respect to the uncertainty of their downhole locations.

3.2. Directional Drilling and Coring

This review concludes that all well types can be successfully drilled to their required targets. The planned well profiles are achievable with existing technology based on currently available data. It is assumed that the Mercia Mudstone will remain stable and is competent to support the directional work required to accurately position the Well Bores. No Well Bore stability issues have been reported on any of the four vertical wells previously drilled at Preesall.

3.2.1 Pilot Holes and Hole Opening. From offset data, the near surface Mercia Mudstone is thought to be relatively soft and may not support directional drilling in full diameter hole. To directionally control the well paths, both the 24" and 17 ½" hole sections may require smaller diameter pilot holes to be drilled before enlarging the Well Bores to their required diameters. This report recommends 17 ½" and 12 ¼" pilot holes be drilled but all wells must be assessed on a well by well basis after gaining experience on less demanding wells.

3.2.2 24” Hole. This relatively short section was initially considered only to consolidate Well Bore integrity prior to commencing the directional drilling required to return the well path to vertical. However, if the top hole section can be extended or if the formation proves to be stable over a prolonged period of time, then this entire section can be omitted from the programme or drilled as full gauge hole. Again, this must be assessed on a well by well basis, depending on the length of the section and after gaining experience on less demanding wells.

3.2.3 Technical Casing. It is recommended that technical casing be installed prior to drilling pilot holes for both the 17 ½" and, if required, 24" sections. While these casings add an additional complexity to the Well Bore construction, they significantly improve hole cleaning, Well Bore centralisation and allow the pilot holes to be drilled with lower flow rates thus assisting directional control.

3.2.4 Directional Drilling Accuracy. A realistic target would be to directionally drill the more complex wells to within a 5m radius of their required downhole locations.

3.2.5 Drillstring and BHA Design. Rotary steerable drilling assemblies are recommended for all hole sections whilst drilling all slant wells. Motor assemblies can be considered for less demanding well types. Drillstring and BHA designs can be fine tuned after gaining experience on less demanding wells.
3.2.6 **Coring.** Current coring technology does not allow directional changes to take place whilst coring. Hence it will not be possible to perform a “full core” of the Mercia Mudstone or the top of the Preesall halites in almost all of the slant wells. Alternatively, rock samples can be acquired via Wireline conveyed coring devices in the high curvature slant wells. Additionally, a “full core” could be obtained of the Mercia Mudstone and Preesall halite interface by designing a fifth well type, namely a straight slant well, drilled and cored into the Mercia Mudstone Preesall halite interface.

3.3. **Drilling Fluids**

It is concluded that the preliminary drilling fluid design is suitable for the wells with lower deviations. For wells with a more complex geometry, a higher density fluid is required to impart Well Bore stability and a higher level of lubricity is required to reduce torque and drag.

3.3.1 The geology at the location of the proposed wells, does not present any significant challenges from a drilling fluid standpoint. The main issue will be physical stability in the deviated wells.

3.3.2 Water based drilling fluids are the ideal choice for these wells due to environmental and logistical advantages.

3.3.3 While high flow rates would undoubtedly benefit hole cleaning, they would significantly impact on the directional performance of the BHAs. Hole cleaning will therefore have to be managed, a detailed plan for each well can be developed to monitor hole conditions and to provide for additional mechanical measures to ensure removal of solids from the annulus. This may be achieved by frequent tripping of the BHA, by the inclusion of small stabilisers (impellers) in the drill string or by other means. The important point is that this process can be developed on the less demanding wells to establish best practices for hole cleaning.

3.3.4 The preliminary drilling fluid design for the 24” hole section will require a density increase when drilling the extended reach slant well, s-shaped and intermediate step out slant well types to improve Well Bore stability. Fluid composition can remain the same with the addition of a weighting agent (Barite).

3.3.5 The preliminary drilling fluid design for the 17 ½” hole section is considered suitable for the less complex well types. Due to the high Dogleg severity in the extended reach slant well, s-shaped and intermediate step out slant well types, and the resultant torque and drag this will give rise to, a High Performance Water Based Fluid, Perflex, is recommended.

3.3.6 The preliminary drilling fluid design for the 12 ¼” hole section is considered suitable for the less complex well types. It is recommended that a liquid lubricant be added to the brine, in the deviated wells to increase the lubricity of the system.
3.3.7 ECD management will not present a challenge when drilling these wells. ECD whilst drilling will be well within the fracture gradient of the formations drilled.

3.4. Casing Design and Installation

Casing design and casing installation simulations have been carried out for the most demanding loading conditions for the proposed gas storage wells forming part of the Project. The proposed casing design for the 600m step out slant well has been reviewed and found to be acceptable, with the necessary recommendations on installation. The proposed casing design is therefore acceptable for the less demanding vertical, S-shaped and slant wells. No changes in casing design are proposed.

3.4.1 Torque and Drag analyses were carried out to predict the anticipated weights and torques during casing running.

3.4.2 It is concluded that the 18 5/8", 87.5 lbs/ft, K55, Big Omega and 13 3/8", 68 lbs/ft, L80, Vam Top casings satisfy the design factor requirements for burst, collapse, axial and tri-axial loadings. The connections meet the requirements of bending.

3.4.3 To minimise shock loading of the casings and avoid failure of casing connections, the casing running speed should be limited to between 1 ft/sec and 5 ft/sec.

3.4.4 As excessive casing wear may compromise well integrity, the casing design has documented allowable casing wear. It is important to ensure that necessary precautions are taken to minimise wear, particularly in the 13 3/8" casing.

3.4.5 Installation of the 18 5/8" and 13 3/8" casings for the slant wells will be quite challenging. The centralised casings will need to be pushed into the hole with up to 10 klbs of contingency push force.

3.4.6 Rotation of the casing while running and cementing is recommended. To aid casing rotation, reduction of Well Bore friction can be addressed using drilling fluid additives and/or friction reduction devices, such as roller type centralisers.

3.4.7 The proposed casing connections will maintain sealing integrity in Doglegs above 10°/30m. However, the connection has not gone through qualification testing for combined bending and rotation through such Doglegs. It is recommended that the manufacturers conduct integrity testing through such conditions.

3.4.8 Quality control of the casing manufacturing process at the Mills should be monitored and a full inspection of casings carried out prior to sending them to the well site.

3.4.9 The use of a reamer shoe is recommended for the 13 3/8" casing.
3.5. **Cementing and Pressure Testing**

It is concluded that all well types proposed can be successfully cemented and a long-term annular seal obtained, through application of the following elements.

3.5.1 Apply sound drilling practices to create in-gauge hole to the correct well profile. Control the drilling mud properties and use efficient well circulation, to ensure cuttings removal. Carry out wiper trips ahead of running casing to ensure the bore hole is smooth and cuttings free. Avoid leaving the hole open and static for extended periods of time, as this is detrimental to the quality of the bore hole generated.

3.5.2 Apply centralisers to limit casing eccentricity and promote fluid movement along the annulus. Model casing running forces expected when recommended centralisers are installed. Use solid or rigid centraliser units to obtain a known minimum casing stand-off. Casing movement (rotation and/or reciprocation) should be applied whenever possible.

3.5.3 Well and job specific modelling is required to ensure all “as drilled” details are accounted. The study focused on the ‘600m step out’ conceptual well but all wells will have specific challenges that need to be managed.

3.5.4 Use clean, well maintained cement mixing and pumping equipment. For optimum slurry quality, prepare all fluids in a batch mix tank ahead of pumping. Jobs that consist of significant volumes (200 bbls+) are impractical to mix ahead of pumping and should be prepared using accurate on-the-fly cement slurry mixing equipment, as detailed in the full report.

3.5.5 Prepare all cement slurries and spacers as per the programme and pump at the recommended rates to ensure correct annular velocity is achieved.

3.5.6 It is current accepted industry practice, in North America and the UK, to use salt saturated cement slurries for the full annular volume of the final casing string – the 13 3/8” in this case, regardless of the salinity of the formation against which it will set. Some cementing chemistry experts recommend matching the cement slurry and formation salinity, such that low salt formulations are applied against lower salt bearing rock. At the time of execution, industry practice and results will be assessed in conjunction with leading cement chemistry expert advice to formulate the final recommended cement programme.

3.5.7 Application of additional tools such as swellable packers, have been shown to support the assurance of the annular seal. Should the cement fracture, resulting in a leak path, fluid will only be able to flow as far the expanding element. Here they will cause the expanding (swelling) reaction of the elements and thus heal the fracture. Consideration regarding the use of these products is promoted within this project.
3.6. Formation Evaluation

3.6.1 It is concluded that Formation Evaluation data can be acquired in all proposed well types using one or more methodologies, including:

- Logging while Drilling, as part of the drilling process.
- Wireline via gravity, tractor, or pipe-conveyed (depending on well profile).
- Coring, drillstring or wireline rotary.
- Surface logging (Mud logging).

3.6.2 This will permit the identification of formation parameters including:

- Mineralogy/insolubles.
- Geological discontinuities, rock strength, fluid content and type.
- The identification of the base salt prior to drilling through it, in order to prevent this occurrence, via the use of Well Bore seismic.

3.6.3 Evaluation Instruments are available for:

- Identification of casing wear in order to confirm mechanical integrity after drilling deeper sections.
- Identification of Cement vertical and radial extent and bond in order to confirm zonal isolation. It is recommended that these are run in the 13 3/8" casing as a minimum.
- An acoustic bond log should be run to evaluate the cement strength and bonding of all 13 3/8" casings. As this seal is critical to the integrity of the caverns every effort should be made to ensure that this operation has been successful. This may require the logs to be conveyed via a Wireline Tractor or on Drill Pipe for the extended reach type wells.

3.7. Completion Design and Installation

It is concluded that the conceptual completion design configuration and component selection is suitable for the proposed duty and environmental conditions for the base case 600m step out well and for well types one, two and three (vertical, s-shaped and intermediate step out slant wells). The installation procedure for the completion system is considered to be suitable based on information supplied by TubeFuse Technologies Ltd and the completion programme supplied by Halite. The following provides a summary of our conclusions and recommendations regarding completions for all four well types.

3.7.1 Completion design and installation procedure is in-line with industry best practice.

3.7.2 Tubing stress analyses proved that predicted safety factors were greater than minimum design factors.
3.7.3 Welded connections are the preferred choice for production tubular coupling due to increased well integrity.

3.7.4 A double packer system enables pressure testing of the packer elements from below (i.e. cavern side).

3.7.5 L80 material is considered suitable as long as there is close monitoring of the gas stream composition.